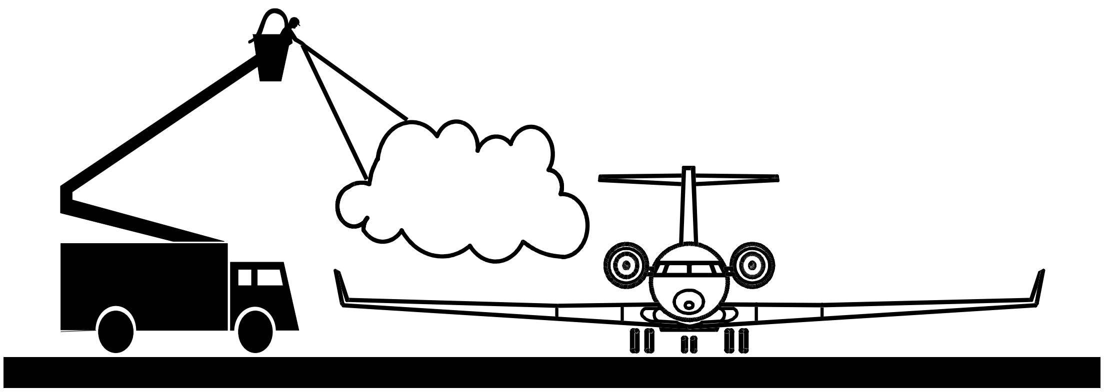
TP 13315E

Aircraft Deicing Fluid Freeze Point Buffer Requirements

Deicing Only and First Step of Two-Step Deicing



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by

APS AVIATION INC.

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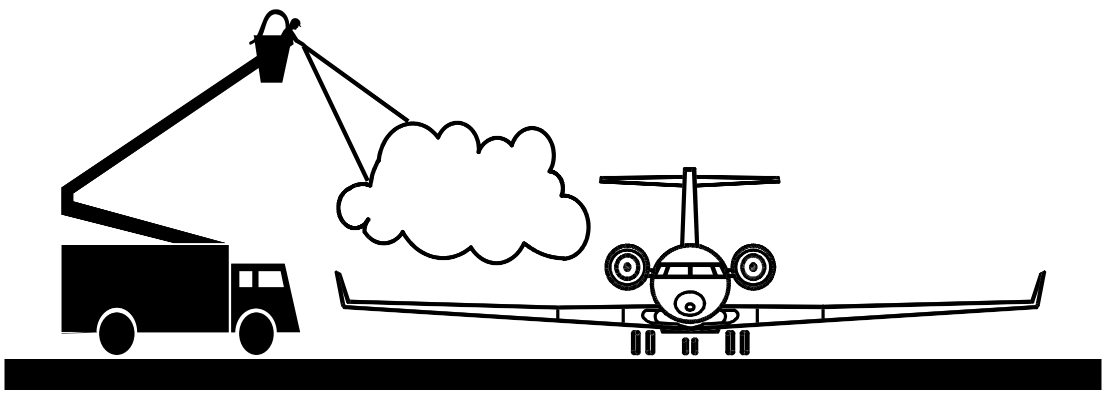

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Un sommaire français se trouve avant la table des matières.

PREFACE

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

- To develop holdover time tables for new Type IV fluids and to validate *fluid-specific* tables and SAE tables;

- To determine the influence of fluid type, precipitation, and wind on location and time to fluid failure initiation, and also failure progression on the Canadair Regional Jet and on high-wing turboprop commuter aircraft;

- To establish experimental data sufficient to support development of a *deicing only* table to serve as an industry guideline, and to evaluate freeze point temperature limits for fluids used as the first step of a two-step deicing operation;

- To establish 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 rotation speeds;

- To document the appearance of fluid failure and the characteristics of the fluid at time of failure, through conduct of a series of tests on standard flat plates; and

- To determine the feasibility of examining the condition of aircraft wings prior to takeoff through use of ice contamination sensor systems.

The research activities of the program conducted on behalf of Transport Canada during the 1997-98 winter season are documented in six separate reports. The titles of these reports are as follows:

- TP 13318E Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1997-98 Winter;

- TP 13314E Research on Aircraft Deicing Operations for the 1997-98 Winter;

- TP 13315E Aircraft Deicing Fluid Freeze Point Buffer Requirements: *Deicing Only* and First Step of Two-Step Deicing;

- TP 13316E Contaminated Aircraft Takeoff Test for the 1997-98 Winter;

- TP 13317E Characteristics of Aircraft Anti-Icing Fluids Subjected to Precipitation; and
- TP 13489E Deicing with a Mobile Infrared System.

This report, TP 13315E addresses the following objective:

- To establish experimental data sufficient to support development of a *deicing only* table to serve as an industry guideline, and to evaluate freeze point temperature limits for fluids used as the first step of a two-step deicing operation.

This objective was met by conducting tests on different fluids at various concentrations at National Research Council Canada's Climatic Engineering Facility at Ottawa, as well as tests on operational aircraft at Montreal International Airport (Dorval).

Research has been funded by the Civil Aviation Group, Transport Canada, with support from the U.S. Federal Aviation Administration and US Airways Inc. This research program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Transportation Development Centre, the U.S. Federal Aviation Administration, US Airways Inc., National Research Council Canada, Atmospheric Environment Services, Transport Canada, and the fluid manufacturers for their contributions to and assistance with the program. Special thanks are extended to US Airways Inc., Air Canada, National Research Council Canada, Canadian Airlines International, Inter-Canadien, AéroMag 2000, Aéroport de Montreal, RVSI, Cox and Company Inc., KnightHawk, and Shell Aviation for provision of personnel and facilities, and for their co-operation on the test program. Union Carbide, Octagon, SPCA, Kilfrost, Clariant, and Inland Technologies Inc. are thanked for provision of fluids for testing. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data leading to the preparation of this document.

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16. Abstract

In the performance of aircraft ground deicing operations, operational efficiencies and potential damage to the environment are influenced by the amounts of glycol applied to the aircraft. Defining operational guidelines that may allow reduced concentrations of fluid while protecting achieved levels of safety, offers an approach to controlling these issues.

The spread between ambient temperature and the freeze point temperature of the fluid is referred to as the fluid freeze point buffer. In this study, deicing fluid freeze point buffers were examined for two operational conditions. The first condition concerns situations when active precipitation has ceased, and the only requirement is to remove contamination without the need for ongoing anti-icing protection. Currently there are no guidelines specific to this condition, and by default, the guideline developed for ongoing precipitation conditions, requiring a fluid freeze point buffer of no less than -10°C, applies. This study examined the results of applying fluid with various buffer values, including fluid mixes having freeze points above ambient temperature. Various fluids at different strengths were examined in conditions of different ambient temperatures, and different wind speeds. The final fluid condition (frozen or not frozen) and the increase in fluid concentration as a result of evaporation following application on the test surface are documented.

The second condition concerns the standard two-step deicing procedure, wherein an initial heated fluid is applied to clean the surface, followed by application of a second fluid, which provides anti-icing protection. Current guidelines require that the freeze point of the first-step (deicing) fluid not be more than 3°C above outside air temperature. This study evaluates the duration until freezing occurs following application of the first-step fluid, which provides time for application of the second (anti-icing) fluid. Various fluids at different strengths were examined in conditions of different ambient temperatures, types and rates of precipitation, and wind speeds. The time available after spray until onset of freezing is reported, as well as the rate of dilution of the first-step fluid and the relationship over time of fluid freeze point temperature and surface temperature.

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Les rapports sur les recherches effectuées au cours des hivers précédents pour le compte de Transports Canada sont disponibles au Centre de développement des transports (CDT). Six rapports, dont le présent, ont été produits dans le cadre des recherches menées pendant l'hiver 1997-1998. Leur objet est précisé dans l'avant-propos.

16. Résumé

Lors des opérations de dégivrage des aéronefs au sol, l'efficacité opérationnelle et les dommages causés à l'environnement sont liés à la quantité de glycol appliqué sur l'aéronef. Des lignes directrices opérationnelles qui permettraient de réduire la teneur en glycol des liquides utilisés, sans toutefois compromettre les niveaux de sécurité actuels, sont un moyen d'agir sur ces facteurs.

On appelle «valeur tampon du point de congélation» l'écart entre la température ambiante et le point de congélation du liquide. La présente étude s'est penchée sur les valeurs tampons du point de congélation des liquides de dégivrage dans deux conditions d'exploitation. La première concerne les situations où toute précipitation a cessé : il faut enlever les contaminants mais il n'est pas nécessaire d'assurer une protection antigivrage. À l'heure actuelle, il n'existe pas de ligne directrice spécifique pour une telle situation. On applique donc, par défaut, la ligne directrice applicable aux cas de précipitations continues, laquelle exige que le point de congélation du liquide soit d'au moins 10 degrés Celsius inférieur à la température ambiante. Les chercheurs ont examiné les résultats de l'application de liquides associés à différentes valeurs tampons, y compris de préparations qui gèlent à une température supérieure à la température ambiante. L'étude a porté sur divers liquides, plus ou moins dilués, appliqués à différentes températures ambiantes, alors que le vent soufflait à différentes vitesses. L'état final du liquide (gelé ou non gelé) et l'augmentation de sa concentration par évaporation d'eau après la pulvérisation, sont documentés.

La deuxième condition a trait à la procédure de dégivrage standard en deux étapes, selon laquelle dans un premier temps, on pulvérise un liquide chauffé pour nettoyer la surface, après quoi on applique un deuxième liquide, qui assure une protection antigivrage. Les lignes directrices en vigueur exigent que le point de congélation du liquide utilisé pour la première étape (dégivrage) soit d'au plus 3 degrés Celsius supérieur à la température de l'air extérieur. La présente étude mesure le délai entre l'application du premier liquide et le moment où il gèle, soit le temps dont on dispose pour appliquer le deuxième liquide (antigivrage). Encore une fois, divers liquides, plus ou moins dilués, ont été étudiés sous diverses températures ambiantes, taux de précipitation et vitesses du vent. On consignait le temps écoulé entre la pulvérisation et l'amorce du givrage, ainsi que le taux de dilution du premier liquide appliqué et la relation, dans le temps, du point de congélation du liquide à la température de la surface.

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EXECUTIVE SUMMARY

At the request of the Transportation Development Centre of Transport Canada, APS Aviation Inc. undertook a research program to examine fluid freeze point buffer requirements for two specific operational conditions. The fluid freeze point buffer is defined as the difference between the ambient temperature and the freeze point temperature of the fluid. The buffer value can be positive or negative, depending on the relative values of the two temperatures.

The first of these conditions concerns situations in which active precipitation has ceased, and the sole requirement is to remove contamination from the aircraft. Protection against ongoing precipitation is not required. The objective of this first study was to generate experimental data to support development of a *deicing only* table intended to serve as an industry guideline.

The second condition concerns aspects of the standard two-step deicing procedure, wherein an initial fluid is applied to clean the surface, and a second fluid is oversprayed to provide a period of ongoing anti-icing protection (commonly known as holdover time). The objective of this second study was to evaluate freeze point temperature limits for the first-step fluids.

Until very recently, the ability to provide adequate protection to aircraft critical surfaces following deicing until takeoff has been a major challenge. Recent development of new fluids designed to provide long periods of protection during ongoing precipitation has lessened the need for the intensive focus on ongoing protection. This study addresses two other considerations of deicing operations: operational efficiencies and potential damage to the environment. Both of these factors are influenced by the amounts of glycol used in deicing. Increased control and optimization of operational efficiency can result in improved operational guidelines that allow use of fluid at reduced concentrations without jeopardizing current safety levels.

In the one-step procedure where the fluid is intended to serve both a deicing and an anti-icing role, the fluid freeze point must always be at least 10°C (18°F) below outside air temperature. In conditions when precipitation has ceased and anti-icing protection is no longer required, a buffer of this magnitude may be overly conservative, and field operations will use a more concentrated fluid than is truly necessary. Transport Canada report TP 13129E, *Examination of the Role of Fluid Freeze Point Buffers,* indicated that the concentration of deicing fluid after spray application increased measurably as a result of water evaporation, and suggested that an inherent buffer may result. This study examines this rise in fluid concentration and quantifies its contribution to protection against freezing.

A two-step deicing procedure uses two fluids applied in sequence. The first fluid performs a deicing function, cleaning the aircraft surfaces of any frost, ice, snow, or slush contaminants, and is applied at elevated temperatures not less than 60°C (140°F). The second (anti-icing) fluid is then applied as an overspray, and must be applied before the first-step fluid freezes, typically within three minutes. If the second fluid is a Type II or Type IV fluid, it is normally applied unheated. Current guidelines require that the freeze point of the first-step (deicing) fluid not be more than 3°C above outside air temperature. This limitation may be more severe than necessary, and a limitation based on scientific data could provide equivalent levels of safety, while enabling operators to achieve economies in fluid consumption due to reduced fluid concentrations.

Data to support these studies were generated in tests conducted on flat plates in National Research Council Canada's Climatic Engineering Facility in Ottawa and in tests on operational aircraft conducted at Montreal International Airport (Dorval). In all of these tests, fluids of various types were mixed to different levels of concentration, resulting in different freeze point buffers. Fluids were applied to test surfaces under a range of ambient temperatures and wind speeds.

In the *deicing only* tests, the final fluid condition was observed to identify whether it remained unfrozen on the test surface. Using duplicate surfaces, fluid concentration was measured progressively to determine the influence of evaporation. Surface temperature was measured on an ongoing basis with thermistor probes installed directly on the test surfaces.

In the first-step fluid tests, conditions included artificial precipitation, either as light freezing rain or freezing drizzle. Test surfaces were observed to determine how long they remained unfrozen. Surface temperature was measured on an ongoing basis with thermistor probes. Dilution of fluid due to absorption of precipitation was measured on duplicate test surfaces.

RESULTS AND CONCLUSIONS

Deicing Only Tests

The final test surface condition varied according to the value of the initial freeze point buffer:

- Test fluids with zero degree buffers and those mixed to positive values of freeze point buffer always resulted in unfrozen fluid, regardless of wind speed;

- From a zero degree buffer to a negative 3°C buffer, tests generally concluded with the plate condition either fluid covered, bare, or with ice on the drip line at the lower edge of the plate (the surface of the plate being non-frozen); and

- Freezing in some fashion generally resulted in cases where the initial negative buffer was beyond -3°C, with the type of freezing condition increasing in severity with the magnitude of the negative buffer. Cases where the negative buffer was beyond -10°C always resulted in ice formation on the surface.

Wind was shown to have a major influence on icing severity. Ice formations increased with higher winds. However, a small amount of wind appeared to have a beneficial effect, reducing the severity of icing.

Fluid strength improved (freeze point dropped) during test runs as a result of water evaporating from the thin film of fluid on the test surface. Plots of fluid freeze point profile versus surface temperature profile illustrate the relationship between the two factors, as well as the way in which wind influences the onset of freezing.

In some instances, the increase in fluid strength was remarkable, with freeze points dropping by an increment as large as -20°C beyond the initial value. Fluids having a very low glycol content to begin with (those with initial freeze points just below 0°C) appeared unable to support large increases in fluid strength.

The most consistent results were produced from Type I fluids. Ethylene and propylene glycol-based fluids produced similar results. Recycled spent deicing fluids, reconstituted from ethylene or propylene glycol-based fluids, exhibited a level of performance equivalent to commercial Type I fluids. Diluted Type IV fluids did not perform as well as Type I fluids, developing ice in the form of slush in less severe conditions. A limited number of tests conducted on Type II fluids demonstrated performance levels equivalent to Type I fluids.

While the study considered appearance of ice in any form to constitute a failure, in many cases ice appeared only on the drip line at the lower edge of the plate, with the remainder of the plate surface completely free of ice. This test condition would correspond to the operational condition of a wing being clear of ice on the surface and leading edge, but having a bead of ice at the trailing edge. When ice did form on the test surface following Type I application, it was extremely thin, estimated at less than 0.0025 mm (0.0001 in.) in thickness.

First-Step Tests

The study presents new data that provide an improved understanding of the influence of ambient temperature, wind and rate of fluid dilution on the time interval from fluid application to onset of freezing.

In calm wind conditions, all fluids tested delivered an interval prior to initiation of freezing of at least three minutes, including tests conducted at the lowest temperature (-14°C).

Dilution of applied fluids occurs very rapidly. At the upper limit of precipitation rates defining light freezing rain (25 g/dm^2/h), the applied fluid film quickly becomes pure water:

- ADF at -7°C initial freeze point, in 4 to 5 minutes, and
- XL54 at -43°C initial freeze point, in 7 to 8 minutes.

At the lower precipitation rate of 12 g/dm^2/h, (the boundary defining light freezing drizzle/light freezing rain), XL54 fluid is diluted to a concentration having a -10°C freeze point in about three minutes.

In precipitation conditions, the major contributor to the period of protection is the surface temperature, which is elevated above ambient temperature levels through heat transfer from the applied heated fluid.

Wind exerts a major influence on the time interval available prior to freezing. Test data indicate a 50 percent reduction in the time for freezing to initiate for tests conducted in a 10 km/h wind, as compared to tests in calm wind conditions.

SOMMAIRE

À la demande du Centre de développement des transports de Transports Canada, APS Aviation Inc. a entrepris un programme de recherche visant à examiner les exigences relatives aux valeurs tampons du point de congélation des liquides, pour deux conditions d'exploitation précises. On appelle «valeur tampon du point de congélation» l'écart entre la température ambiante et le point de congélation du liquide. Cette valeur est dite positive lorsque le point de congélation du liquide est inférieur à la température ambiante, et négative dans le cas inverse.

La première condition d'exploitation (dégivrage simple) est celle où la précipitation a cessé : il suffit alors d'enlever les contaminants. Il n'y a pas lieu de protéger les surfaces contre une précipitation continue. Le but de cette première étude était de produire des données expérimentales en vue de l'élaboration d'un tableau pour la procédure dégivrage simple, qui doit servir de ligne directrice à l'industrie.

La deuxième condition d'exploitation a trait à la procédure de dégivrage standard en deux étapes, selon laquelle dans un premier temps, on pulvérise un liquide pour nettoyer la surface, après quoi on applique un deuxième liquide, par-dessus le premier, pour protéger les surfaces contre une nouvelle contamination (pendant une certaine période désignée «durée d'efficacité»). Le but de cette deuxième étude était de déterminer les valeurs tampons du point de congélation des liquides utilisés à la première étape.

Jusqu'à tout récemment, il était difficile d'assurer une protection adéquate des surfaces critiques d'un aéronef pendant la période suivant le dégivrage jusqu'au décollage. Mais le développement récent de nouveaux liquides conçus pour assurer une protection de longue durée pendant des précipitations continues a solutionné le problème de la protection prolongée. C'est ainsi que les chercheurs ont été amenés à explorer deux autres préoccupations reliées aux opérations de dégivrage : l'efficacité opérationnelle et les dommages éventuels à l'environnement. La quantité de glycol utilisée influe sur ces deux facteurs. Un contrôle accru et une optimisation de l'efficacité opérationnelle peuvent engendrer de meilleures lignes directrices opérationnelles, qui permettront d'utiliser des liquides moins concentrés, sans que la sécurité soit mise en péril.

Dans la procédure de dégivrage simple, qui utilise le même liquide comme agent de dégivrage et d'antigivrage, le point de congélation du liquide doit toujours être d'au moins 10 degrés Celsius (18 degrés Fahrenheit) inférieur à la température de l'air extérieur. Lorsque les précipitations ont cessé et que la protection antigivrage n'est plus nécessaire, une telle valeur tampon risque d'être exagérément prudente et d'entraîner, sur le terrain, l'utilisation d'un

liquide plus concentré que nécessaire. Le rapport TP 13129E de Transports Canada, *Examination of the Role of Fluid Freeze Point Buffers,* a révélé que la concentration du liquide de dégivrage après sa pulvérisation augmentait sensiblement par suite de l'évaporation d'eau : le liquide présenterait donc une valeur tampon inhérente. La présente étude examine l'augmentation de la concentration du liquide et quantifie la contribution de ce facteur à la protection contre le gel.

Une procédure de dégivrage en deux étapes fait appel à deux liquides, appliqués un après l'autre. Le premier réalise une fonction de dégivrage, nettoyant les surfaces de l'aéronef de toute contamination (givre, glace, neige, neige fondante), et est appliqué à des températures élevées, d'au moins 60 °C (140 °F). Le deuxième liquide (d'antigivrage) est appliqué par-dessus le premier. Il doit être appliqué avant que le premier liquide gèle, habituellement dans les trois minutes. Si ce deuxième liquide est un liquide de type II ou de type IV, il est habituellement appliqué non chauffé. Les lignes directrices en vigueur exigent que le point de congélation du premier liquide (de dégivrage) soit d'au plus 3 degrés Celsius supérieur à la température de l'air extérieur. Il se peut que cette exigence soit exagérément restrictive et qu'une limite fondée sur des données scientifiques procure des niveaux de sécurité équivalents tout en permettant aux préposés de consommer moins de liquide, grâce à des concentrations plus faibles.

Les données de ces deux études proviennent d'essais menés sur des plaques planes à l'Installation de génie climatique du Conseil national de recherches du Canada à Ottawa, et d'essais sur des aéronefs en vraie grandeur menés à l'Aéroport international de Montréal (Dorval). Dans tous ces essais, des liquides de différents types ont été mélangés avec de l'eau pour donner différentes concentrations correspondant à différentes valeurs tampons du point de congélation. Les liquides ont été appliqués sur des surfaces d'essai dans une gamme de températures ambiantes et de vitesses du vent.

Aux essais de *dégivrage simple*, on observait l'état final du liquide, à savoir s'il était toujours en phase liquide sur la surface d'essai. Des doubles de la surface avaient été préparés, ce qui permettait de mesurer la concentration du liquide à différents intervalles, et de déterminer ainsi l'effet de l'évaporation. La température de la surface était mesurée en continu par des sondes à thermistor installées directement sur celle-ci.

Aux essais du liquide utilisé pour la première étape d'une procédure en deux étapes, les conditions comprenaient des précipitations artificielles de pluie verglaçante légère ou de bruine verglaçante. On observait les surfaces d'essai pour déterminer pendant combien de temps elles demeuraient sans givre. La température de la surface était mesurée en continu par des sondes à thermistor. On mesurait la dilution du liquide par absorption des précipitations sur des doubles des surfaces d'essai.

RÉSULTATS ET CONCLUSIONS

Essais de *dégivrage simple*

L'état final de la surface d'essai variait en fonction de la valeur tampon initiale du point de congélation :

- les liquides associés à des valeurs tampons nulles et les liquides mélangés de façon à présenter des valeurs tampons positives n'étaient jamais gelés, quelle que soit la vitesse du vent;
- pour une valeur tampon nulle jusqu'à une valeur négative de 3 degrés Celsius, à la fin de l'essai, la plaque était généralement soit couverte de liquide, soit nue, soit contaminée de givre le long de son bord inférieur (mais la surface de la plaque n'était pas gelée);
- une valeur tampon négative initiale de plus de 3 degrés Celsius entraînait généralement le gel du liquide, sous une forme ou une autre; le gel était d'autant plus marqué que la valeur tampon négative était importante. Dans les cas où la valeur tampon négative dépassait 10 degrés Celsius, on observait immanquablement de la glace sur la surface.

Le vent s'est révélé avoir une influence déterminante sur le givrage. Plus les vents étaient forts, plus se formait du givre. Toutefois, un vent faible semblait avoir un effet bénéfique, atténuant l'intensité du givrage.

Au cours des essais, la concentration du liquide s'améliorait (le point de congélation s'abaissait) par suite de l'évaporation de l'eau contenue dans la mince pellicule de liquide sur la surface. Des courbes du point de congélation du liquide en fonction de la température de la surface illustrent la relation entre les deux facteurs, de même que l'effet du vent sur l'amorce du givrage.

Dans certains cas, l'augmentation de la concentration du liquide était remarquable, le point de congélation s'abaissant de pas moins de 20 degrés Celsius par rapport à sa valeur initiale. Il n'a pas été possible d'obtenir une forte augmentation de la concentration des liquides qui au départ avaient une très faible teneur en glycol (ceux dont le point de congélation initial était tout juste sous 0 °C).

C'est avec les liquides de type I que les résultats les plus cohérents ont été obtenus. Les liquides à base d'éthylène et de propylène glycol ont donné des résultats semblables. Les liquides de dégivrage recyclés, reconstitués à partir de liquides à base d'éthylène ou de propylène glycol, ont affiché un niveau de performance équivalent à celui des liquides de type I vendus dans le commerce. Les liquides de type IV dilués n'étaient pas aussi efficaces que les liquides de type I : dans des conditions clémentes, ils se transformaient en neige fondante. Quelques essais réalisés sur des liquides de type II ont révélé des niveaux de performance équivalents à ceux des liquides de type I.

L'apparition de givre, sous quelque forme que ce soit, était considérée comme une perte d'efficacité du liquide. Mais souvent, le givre apparaissait uniquement le long du bord inférieur de la plaque, le reste de celle-ci demeurant complètement propre. En situation réelle, cet état de fait correspondrait à une aile dont la surface et le bord d'attaque seraient exempts de tout givre, mais dont le bord de fuite serait contaminé par un cordon de givre. Par ailleurs, lorsque du givre se formait après l'application d'un liquide de type I, celui-ci était extrêmement mince, soit d'une épaisseur évaluée à moins de 0,0025 mm (0,0001 po).

Essais de *dégivrage en tant que première étape d'une procédure en deux étapes*

L'étude a généré de nouvelles données qui aident à comprendre l'influence de la température ambiante, du vent et du taux de dilution du liquide sur le délai entre l'application du liquide et l'amorce du givrage.

Par vent calme, le délai jusqu'à l'amorce du givrage a été d'au moins trois minutes pour tous les liquides mis à l'essai, même lors des essais à basse température (-14 °C).

La dilution des liquides après leur application est très rapide. À la limite supérieure des taux de précipitation définissant une pluie légère verglaçante (25 g/dm^2/h), la pellicule de liquide devient rapidement de l'eau pure :

- en 4 à 5 minutes dans le cas du liquide ADF dont le point de congélation initial est de -7 °C;
- en 7 à 8 minutes dans le cas du liquide XL54 dont le point de congélation initial est de -43 °C.

À la limite inférieure de 12 g/dm^2/h (limite définissant la bruine légère verglaçante/pluie légère verglaçante), le liquide XL54 est dilué à une concentration donnant un point de congélation de -10 °C après trois minutes environ.

Sous des précipitations, le facteur qui influe le plus sur la durée de la période de protection est la température de la surface, qui se réchauffe au-delà de la température ambiante, par le transfert de la chaleur du liquide chauffé.

Le vent exerce une influence majeure sur la période de protection contre le givrage. Les données d'essai révèlent en effet qu'un vent de 10 km/h mène à une réduction de moitié du temps avant givrage, par rapport à un vent calme.

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GLOSSARY

APS	APS Aviation Inc.
FAA	Federal Aviation Administration (U.S.)
READAC	Remote Environmental Automatic Data Acquisition Concept
RVSI	Robotic Vision System Inc.
SAE	Society of Automotive Engineers
C/FIMS	Contaminant/Fluid Integrity Monitoring System
TDC	Transportation Development Centre (Canada)
NRC	National Research Council Canada
CEF	Climatic Engineering Facility
OAT	Outside Air Temperature
COX	Cox & Company, Inc.

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1. INTRODUCTION

At the request of the Transportation Development Centre (TDC) of Transport Canada, APS Aviation undertook a research program to examine fluid freeze point buffer requirements for two specific operational conditions.

The first of these conditions applies to situations when active precipitation has ceased, and the sole requirement is to remove contamination from the aircraft, resulting in clean critical surfaces. Protection against ongoing precipitation is not required.

The objective of this segment of the study was to generate experimental data to support development of a *deicing only* table to serve as an industry guideline. This program was initiated by the U.S. Federal Aviation Administration (FAA) and supported by the FAA and TDC.

The second condition concerns the standard two-step deicing procedure, wherein an application of a first-step fluid is used to deice the surface, and a second-step fluid is oversprayed to provide a period of ongoing anti-icing protection (commonly known as holdover time).

The objective of this segment of the study was to evaluate freeze point temperature limits for fluids used in the first step in such a procedure. This program was initiated by US Airways Inc. and supported by US Airways Inc. and TDC.

Appendix A presents the work statement for this project.

1.1 Background

The principal industry document that addresses aircraft deicing is the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) ARP4737, *Aircraft Deicing/Anti-icing Methods with Fluids*. Relevant excerpts of this document are included in Appendix B. This publication documents guidelines for the methods and procedures used in aircraft deicing and anti-icing ground operations, and specifies temperature limits for fluids used in the process.

The primary focus of ARP4737 is on those operating conditions requiring the use of an anti-icing fluid treatment to provide a period of protection against ice or snow contamination during ongoing precipitation. Until very recently, the ability to provide adequate protection to aircraft critical surfaces during winter storms for the time interval following deicing until takeoff has been a major challenge. Recent developments in anti-icing fluid technology, resulting in the production of new fluids designed to provide long periods of protection during ongoing precipitation, have lessened the need for an exclusive focus on anti-icing protection.

This study addresses two other consequences of deicing operations:
- Operational efficiencies, and
- Potential damage to the environment.

Both of these factors are governed by the amounts of glycol applied to the aircraft. Controlling of the level of concentration of glycol in the applied fluid mixture offers a means to control both these factors while still respecting safety needs. Required levels of glycol concentration, as measured by fluid freeze point, are examined for two different operating conditions.

A previous review of fluid strength requirements for various operating conditions can be found in Transport Canada report, TP 13129E (1). The conclusions listed in that report state that, in certain situations, there is an opportunity to reduce fluid strength from those levels currently recommended.

1.2 *Deicing Only* Conditions

The condition under which anti-icing protection is not needed (as an example, morning start-up following the end of an overnight snowfall) and when the only requirement is to deice the aircraft, is not specifically addressed in SAE ARP4737. As a result, the only published guidelines for deicing procedures are those that have been documented for use in conjunction with treatments intended to provide anti-icing protection. This approach may result in procedural constraints that are unnecessarily severe for those instances when *deicing only* is required.

The sole temperature related limits in SAE ARP4737 for SAE Type I deicing fluid application are those that are provided in paragraphs 3.4.1 and 6.3.1.1.1, and in Figure 1 of Appendix B (*Guidelines for the Application of SAE Type I Fluid Mixtures as a Function of Outside Air Temperature*). Here, Type I deicing fluid is used either alone to serve as a combined deicing/anti-icing function in a one-step procedure, or as a first-step (deicing) fluid followed by an anti-icing fluid overspray in a two-step procedure.

In the one-step procedure where the fluid is intended to serve both a deicing and an anti-icing role, the freeze point of the fluid must be maintained at least 10°C (18°F) below outside air temperature. The difference between the outside air temperature and the fluid freeze point is referred to as the fluid temperature buffer, or fluid freeze point buffer. In conditions when precipitation is no longer occurring, a buffer of this magnitude may be more conservative than necessary. In consequence, airline procedures for *deicing only* conditions will use a more concentrated fluid than is truly necessary, resulting in less than optimum levels of cost effectiveness.

A preliminary study considering changes in fluid concentration following application of a heated fluid to test surfaces was reported in Transport Canada report TP 13131E (2). That study showed that the glycol concentration within the thin film remaining on the treated surface following the application of a heated deicing fluid increased measurably due to evaporation of water, and concluded that an inherent buffer may result.

Publication of a *deicing only* table would complement existing procedures, and would provide airline operators with needed support and encouragement to institute more cost-effective and environmentally responsible procedures. This table would identify limits for fluid concentrations (identified as fluid freeze points) appropriate to the condition.

The primary objective of this study was to develop data that would support the proposal for a *deicing only* table. Such a table would provide guidelines for the application of deicing fluids during conditions of no precipitation.

1.3 First-Step Fluid in a Two-Step Deicing Operation

A two-step deicing procedure uses two fluids applied sequentially. Each fluid performs a distinct function. The first fluid performs a deicing function, cleaning the aircraft surfaces of any frost, ice, snow, or slush contaminants. This first-step fluid is applied at elevated temperatures of not less than 60°C (140°F). The second-step fluid is then applied as an overspray, and must be applied before the first-step fluid freezes. ARP4737 states that the time available for an overspray before the first-step fluid freezes is typically within three minutes. The second fluid provides anti-icing protection against the formation of frost or ice, or the accumulation of snow (or slush) on the clean surfaces. This anti-icing fluid is normally applied unheated.

Current guidelines require that the freeze point of the first-step (deicing) fluid not be more than 3°C above outside air temperature. Certain operators feel that this limitation is more severe than necessary, and that a limitation based on scientific data would provide equivalent levels of safety while enabling operators to achieve economies through reductions to first-step fluid concentration.

In the past, some operators have operated successfully using heated water to temperatures as low as -7°C, in other words, applying a first-step fluid having a freeze point temperature 7°C above outside air temperature. Freedom to continue this practice was terminated by industry adoption of ARP4737 in 1992, which included the 3°C limit in response to voiced concerns of particular carriers.

This subject was investigated in a previous study and the findings are presented in Transport Canada report TP 12653E (3). That study reports the results of the use of hot water as a deicing (first-step) fluid and concluded that hot water deicing is feasible at outside air temperatures below -3°C, depending on other factors such as wind and operator disciplines. Wind was shown to have a major negative impact on the period of protection that exists before freezing of the water treatment occurs.

The primary objective of this study was to generate experimental data and to make recommendations on operational limitations to first-step fluid at freeze point temperatures.

Data to support these studies were generated in tests conducted on flat plates at the National Research Council Canada (NRC) Climatic Engineering Facility (CEF) in Ottawa. In addition, a preliminary series of tests on potential test surfaces, and tests on operational aircraft, were conducted at Montreal International Airport (Dorval).

2. METHODOLOGY

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

2.1 Test Sites

A series of laboratory experiments designed to generate required data was conducted at NRC's CEF in Ottawa. Experiments in the *deicing only* study and in the first-step fluid study were carried out at the same time, using separate chambers within the CEF. Simultaneous testing enabled staffing efficiencies associated with fluid preparation activities.

For the *deicing only* study, the CEF enabled conduct of experiments under the controlled conditions of ambient temperature, wind velocity, and a variety of fluids diluted to several freeze point temperatures. The capability to generate different types of precipitation was not required for these tests.

For the first-step fluid study, the facility enabled conduct of experiments under conditions of controlled freezing precipitation and several stable ambient temperatures. An assortment of fluids mixed to several freeze point temperatures was employed in the study. Supplemental experiments were conducted with the additional variable of wind at several controlled speeds.

In addition, a preliminary series of tests on potential test surfaces, and tests on operational aircraft, was conducted at Montreal International Airport (Dorval). The purpose of these tests was to determine the most suitable test surface for use in the laboratory experiments.

2.2 Description of Test Procedures

2.2.1 Preliminary Tests at the APS Test Site

The objective of these tests, and of the tests on operational aircraft, was to determine the most suitable test surface for the experiments at NRC's CEF, that is, which surface best represents the actual wing for the conditions being evaluated.

Candidate surfaces examined as potential test surfaces included:

- Cold-soak boxes (heat sinks) 7.5 cm deep;
- Aluminum honeycomb core plate;
- Standard aluminum test flat plate 3.2 mm (1/8 in.) thick; and
- Thin flat aluminum plate 1.6 mm (1/16 in.) thick.

The cold-soak box was originally designed to simulate the heat sink effect on the main structural area of the wing over the fuel tank. The material used in the aluminum honeycomb core plate was taken from stock intended for fabrication of McDonnell Douglas DC-9 spoiler panels.

Observations were made during this series of tests relating to:

- Area of the surface left bare and dry;
- Final strength of fluid left on surface at various locations;
- Temperature profiles of surfaces after application of heated fluid; and
- Elapsed times from the point of fluid application to the onset of freezing (at least 5 minutes).

An SAE Type I fluid diluted to a number of selected concentrations was used to provide different fluid freeze point buffers.

The main elements of the test procedure were as follows:

- Conduct tests inside a non-heated test trailer to eliminate the influence of wind;
- Position test surfaces at the standard 10° slope;
- Set ambient temperature to -5°C or lower;
- Mix fluid strength to -3 and +3°C buffer;
- Fill cold-soak boxes to 25% capacity so that the upper surface is not wetted. This represents the typical condition of aircraft following overnight parking;
- Heat test fluids to 60°C; and
- Apply fixed quantity (0.5 L) of fluid to test surfaces.

2.2.2 Tests on Operational Aircraft

Tests were conducted on operational aircraft to allow comparison of results on candidate test surfaces to those on aircraft wings. Over-nighting McDonnell Douglas DC-9 aircraft were made available on two occasions by US Airways, sponsors of the first-step fluid project.

These tests were conducted at the central deicing facility at Montreal International Airport (Dorval). AéroMag 2000 Inc. participated in the tests and performed the actual spray operation.

The four candidate test surfaces were mounted on a flat plate stand situated near the wing under test, and facing into the wind. The aircraft was parked facing into the wind.

Test fluids used were hot water and an SAE Type I fluid diluted to provide different levels of fluid freeze point buffer. The actual fluid freeze points were decided on the basis of expected outside air temperature.

The spray truck was emptied, and the tank and plumbing systems were well flushed during the day prior to the test session. The initial fluid tested was heated water. Following tests with hot water, SAE Type I deicing fluid was mixed to the desired concentration directly in the spray truck by adding calculated quantities of full strength fluid to the fluid remaining in the truck tanks. The resultant fluid concentration was tested with a hand-held Brix-scale refractometer to ensure that the required fluid freeze point was achieved.

Test fluids were applied to the wing following the operator's standard spraying procedures. At the same time, fluid (taken from the deicing truck) was applied to each test surface positioned on the test stand. The method of fluid application to each test surface was standardized through using a fluid applicator designed for these experiments.

Test surfaces were monitored for freezing. The time and location of any occurrences of freezing were recorded. Patterns of freezing were sketched on wing and plate data forms. A Robotic Vision Systems Inc. (RVSI) ice contamination sensor was used during one overnight test session to provide a supplementary indication of ice formation.

Final fluid concentration values for fluid samples from various points on the wing were recorded. During the second test, fluid concentration was sampled periodically at selected locations near thermistor installation points to enable development of a fluid strength profile.

Temperatures were measured on an ongoing basis using thermistor probes installed on each test surface and at several locations on the wing. Measurement locations on the wing were selected to provide temperature information for known or suspected critical areas. These included the cold corner (the wing area over the fuel tank that is first wetted by fuel), control surfaces that demonstrated fastest cooling and earliest freezing during the hot water tests conducted in 1995, and points on the upper and lower surfaces of the leading edge.

The general test plan for tests on operational aircraft is shown in Table 2.1.

The experimental program for the aircraft tests is included as Appendix C.

2.2.3 Tests at National Research Council Canada's Climatic Engineering Facility

Conducting the *deicing only* and first-step tests during the same period resulted in the need to organize three teams. Two of these teams were responsible for conducting the actual tests, while the third was a support team responsible for the preparation and management of fluids for testing.

TABLE 2.1

TEST PLAN FOR AIRCRAFT TESTS

DEICING ONLY TABLE / FIRST-STEP FLUID LIMITS

WINTER 1997-98

Occasion	OAT (°C)	Run	Test[1] Fluid	Fluid Freeze Point (°C)	Fluid Freeze Buffer (°C)
1	-8 to -12	1	H_2O	0	-8 to -12
1	-8 to -12	2	7%	-2	-6 to -10
1	-8 to -12	3	16%	-6	-2 to -6
2	-2 to -5	4	H_2O	0	-2 to -5
2	-2 to -5	5	5%	-1.5	-0.5 to -3
2	-2 to -5	6[2]	12%	-4	-1

[1] Percentage UCAR ADF

[2] This run to be performed only if OAT is at low end (-5°C) of range.

2.2.3.1 Fluid Management

The process of managing and preparing the supply of heated fluids for testing deserves discussion. Several fluid types and a variety of concentrations were tested to provide a range of fluid temperature buffers at each ambient temperature under test. The test sequence required the ability to prepare a large number of different fluid examples. The complexity of managing this large inventory was compounded by the fact that *deicing only* and first-step fluid experiments were run during the same period, in adjacent chambers of NRC's CEF. Each set of experiments imposed its own specific test fluid requirements.

The fluid management team was responsible for a defined cycle of activities in preparation for each test:

- Accurate and timely selection of fluid samples for upcoming tests;
- Heating those samples to the required temperature;
- Accurately measuring quantities of heated fluids into vacuum containers to protect concentration and temperature prior to application;
- Delivering test samples to the test team;
- Pouring test samples on plates under test team supervision; and
- Cleaning fluid applicators and vacuum containers to prepare for the next series of tests.

This support role required detailed pre-planning of procedures and equipment, and good co-ordination between test members. The specialized equipment selected or developed to perform these experiments is described in Subsection 2.4.

2.2.3.2 Deicing Only Study

Experiments performed to acquire data in support of the development of a *deicing only* table involved applying heated deicing fluids to test plates under a range of outside air temperature and wind conditions. Hot water and SAE Type I, Type II and Type IV fluids were tested, including both ethylene and propylene glycol-based fluids. Fluids were mixed to various concentrations to provide a range of freeze point buffers for each outside air temperature condition tested. The initial test plan is presented in Table 2.2.

TABLE 2.2

TEST PLAN FOR DEVELOPMENT OF *DEICING ONLY* TABLE

NATIONAL RESEARCH COUNCIL CANADA - CLIMATIC ENGINEERING FACILITY

OAT		**FLUID FREEZE POINT (°C)**								**WIND (km/h)**				**REMARKS**
		0	**-1.5**	**-3**	**-8**	**-14**	**-22**	**-30**	**-43**					
°C	**°F**	**FLUID FREEZE POINT BUFFER**								**0**	**5**	**10**	**20**	
+1	34	1	2.5	4						√	√	√	√	Contingent on results at -1°C
-1	29	-1	0.5	2						√	√	√	√	
-5	23	-5	-3.5	-2	3					√	√	√	√	
-10	14	-10	-8.5	-7	-2	4				√	√	√	√	
-18	0	-18	-16.5	-15	-10	-4	4			√	√	√	√	
-35	-31	-35					-13	-5	8	√	√			

Note: Supplemental tests examined fluids with freeze point equal to outside air temperature, and 3°C higher than outside air temperature, as well as higher wind at -35°C

The desired fluid type and mix was heated to a standard temperature of 60°C. This temperature was selected to represent the lower temperature limit of deicing fluid at the nozzle of the deicing vehicle.

The quantity of fluid applied on the test surface was predetermined to be 0.5 L. This quantity was selected to represent an amount of fluid typically sprayed on an aircraft wing during a light snow condition.

Ambient temperatures were varied to provide a cross section of typical operating conditions. Temperatures selected for testing were -1, -5, -10, -18 and -35°C (29, 23, 14, 0, and -31°F). The extreme cold temperature in this range was selected to examine fluid performance when used to remove frost in very cold temperatures.

A range of wind speeds (calm, 5, 10 and 20 km/h) were generated at each temperature setting using large electric fans. These fans were mounted on a wheeled base, allowing repositioning to produce different wind speeds at the test stand. Winds were measured at various points across the stand using hand-held anemometers. In addition, a wind gauge was fixed to the test stand to provide wind speeds on a continuous basis. The plate stand was positioned with the lower plate edge into the wind.

The duration of each test was limited to 20 minutes following fluid application, based on the expectation that any significant changes will have occurred within that time period. Test observers determined whether the plate had dried off completely or whether fluid remained on the plate, and whether it was frozen or liquid. At test end, a plate with no evidence of freezing was considered to be a success.

The fluid concentration of each test fluid was measured and recorded at time of pouring. Any fluid remaining on the test plate at test end, either as a wet or frozen film on the surface of the plate or as a bead of fluid at the plate drip line, was tested for fluid concentration.

Intermediate values of Brix were not measured to avoid disturbing the progress of fluid evaporation on the plate. As fluids very quickly assumed a very thin layer, a relatively large area of the plate surface was disturbed when collecting enough fluid for a valid Brix sample.

A number of separate runs were conducted specifically to determine the progressive nature of the strength of the fluid as it evaporated from the plate surface.

The area of the plate left bare versus that covered with fluid, as well as any area covered with frozen fluid was sketched on a data form. An RVSI ice detection sensor was installed to scan all test plates on a continuous basis to provide supplementary documentation of areas of plates covered with frozen fluid.

The temperature of the test plates was measured on a continuous basis using thermistor probes installed on the plate surface, and logged to enable development of test surface temperature profiles. Thermistor probes were mounted at the 22.5 cm (9 in.) line on the plate. A separate thermistor probe measured air temperature at the plate stand, and the data channel for that probe was used to measure the temperature of a reference fluid container at time of pouring.

Relative humidity was measured by use of a Vaisala relative humidity meter designed to operate in very cold temperatures.

The experimental program for these tests is included as Appendix D.

2.2.3.3 First-Step Fluid Study

First-step fluid experiments involved applying heated deicing fluids at appropriate concentrations to test plates under a range of outside air temperatures in light freezing rain conditions. Fluid samples of hot water, and hot, diluted SAE Type I, Type II and Type IV fluids were tested, including both ethylene and propylene glycol-based fluids. Fluids were mixed to various concentrations to provide a range of freeze point buffers for each outside air temperature condition tested. The initial test plan (Table 2.3) describes the scope of tests.

The desired fluid type and mix was heated to a standard temperature of 60°C. This temperature was selected to represent the lower temperature limit of deicing fluid at the nozzle of the deicing vehicle.

The quantity of fluid applied on the test surface was predetermined to be 0.5 L. This quantity was selected to represent an amount

TABLE 2.3

FIRST STEP FLUID TESTS

GENERAL TEST PLAN

OAT (°C)	Rate (g/dm²/h)	FLUID FREEZE POINTS					
-3	25	0					
-8	25	0	-3 (1)	-6 (1)			
-14	25	0	-3	-6 (1)	-11		
-25	12.7	0	-3		-11	-17	-22

Precipitation Type: Light Freezing Rain

Heated Fluids: Water

Type I (Including both ethylene and propylene glycol-based)

Type II (Including both ethylene and propylene glycol-based)

Type IV (Including both ethylene and propylene glycol-based)

(1) Type I ethylene will be tested at all cells showing freeze point values.

Other fluids will be tested in cells indicated by (1).

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of fluid typically sprayed on an aircraft wing during a light snow condition.

Ambient temperatures initially selected for testing were -3, -8, -14, and -25°C (27, 18, 7, and -13°F). Testing at -25°C was not conducted due to freeze up of the spray equipment. A supplemental series of tests involving wind were conducted at -10°C (14°F).

The rate of precipitation tested was 25 g/dm²/h, the upper precipitation rate limit for light freezing rain. The series of supplemental tests involved two rates, 25 and 12.7 g/dm²/h. Precipitation rates were measured following standard fluid holdover test procedures, which consisted of the timed collection and weighing of precipitation in plate pans. Calibration of droplet size was performed using a dye-stain technique employed by staff at NRC's CEF.

A series of supplemental tests to evaluate the impact of wind were conducted at several wind velocities (calm, 10 and 20 km/h). Winds were generated as in the tests for *deicing only*, using large electric fans positioned to produce different wind speeds at the test stand. Winds were measured at various points across the stand using hand-held anemometers.

This test was the first time that deicing tests were conducted in the laboratory facility under the combined conditions of controlled wind and rain. Because the sprinkler system was installed in the smaller chamber of the CEF, it was necessary to open the door between the chambers to allow the fans to be positioned at the required distance to generate the specified wind speeds.

The key issue examined by the first-step fluid tests was whether an adequate time prior to re-freezing is made available to the operator to allow overspray of the second-step fluid. Following fluid application, the test plates were observed to determine the time at which freezing first took place. Tests were allowed to proceed until freezing occurred.

Several tests were conducted specifically to monitor how the fluid concentration varied as it underwent dilution from ongoing precipitation. These tests were conducted on plates dedicated to this purpose to avoid disturbances to the plate surfaces used to determine time intervals until onset of freezing.

The temperature of the test plates was measured on a continuous basis using thermistor probes installed on the plate surface, and logged to enable the recording of test surface temperature profiles.

The experimental program for these tests is included as Appendix E.

2.3 Data Forms

2.3.1 Preliminary Tests at the APS Test Site and Tests on Aircraft

During preliminary tests, data were recorded using Heated Fluid Test Forms, shown in Figure 2.1.

The principal information recorded on these forms was:

- Surface area left wetted;
- Strength of fluid remaining on surface;
- Temperature profile of surface;
- Safe period of non-freezing following fluid application; and
- Time for test surface to recover to ambient temperature following initial fluid application.

These same forms were used during aircraft tests for recording results from simultaneous tests on flat plates.

Three data forms were used during aircraft tests:

- General Form (once per session) (Figure 2.2);
- General Form (every test) (Figure 2.3); and
- Icing Location Form for Aircraft Wing (Figure 2.4).

The icing location form for wing tests served a function similar to the plate form for plate tests.

2.3.2 Deicing Only

A single data form was used for these experiments (Figure 2.5). The data form served the dual purpose of test fluid order form for the next test run and of recording test data during test.

FIGURE 2.1

HEATED FLUID TEST FORM

REMEMBER TO SYNCHRONIZE TIME WITH AES - USE REAL TIME V

LOCATION:	DATE:	TEST # :	TIME OF FLUID APPLICATION:

AIR TEMPERATURE: ____ °C **SURFACE TYPE:** STD. PLATE / THICK PLATE / 7.5 CM BOX

FLUID TEMP.: 60°C

PLATE ANGLE: 10° **FLUID:** WATER / XL54 WITH +3°C BUFFER / XL54 WITH -3°C BUFFER

WIND SPEED ________ km/h

FLUID QUANTITY: 0.5 L

THERMISTOR #'s: ________

BRIX BEFORE POURING: ______ **TEMP. BEFORE POURING:** ______ °C

BRIX OF FLUID LEFT ON PLATE:

Time: ____________ Brix ____________

Time: ____________ Brix ____________

Time: ____________ Brix ____________

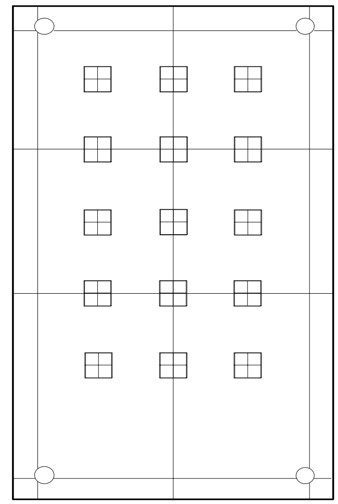
SKIN TEMPERATURES (9" LINE)

TIME: ________	TEMP. ____ °C	TIME: ________	TEMP. ______ °C
TIME: ________	TEMP. ____ °C	TIME: ________	TEMP. ______ °C
TIME: ________	TEMP. ____ °C	TIME: ________	TEMP. ______ °C
TIME: ________	TEMP. ____ °C	TIME: ________	TEMP. ______ °C
TIME: ________	TEMP. ____ °C	TIME: ________	TEMP. ______ °C
TIME: ________	TEMP. ____ °C	TIME: ________	TEMP. ______ °C

	PRINT	SIGN
OBSERVATIONS BY :		
HAND WRITTTEN BY :		
TEST SITE LEADER :		

TIME ____________ **SKIN T.** ____ °C

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100%

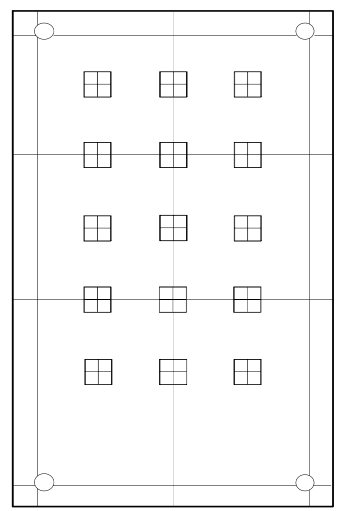


TIME **SKIN T.**

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95

TIME ____________ **SKIN T.** ____ °C

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100%



TIME **SKIN T.**

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95

FIGURE 2.2

GENERAL FORM (ONCE PER SESSION)

(TO BE FILLED IN BY OVERALL COORDINATOR)

AIRPORT: YUL YYZ YOW

AIRCRAFT TYPE: DC-9 F100 B-737 RJ

EXACT PAD LOCATION OF TEST: ______________________

AIRLINE: ______________________

DATE: ______________________

FIN #: ______________________

APPROX. AIR TEMPERATURE: ________ °C

FUEL LOAD IN WING: ______________________ **LB / KG**

R/H: ________ %

TYPE I FLUID APPLICATION	***TYPE IV FLUID APPLICATION***
TYPE I FLUID TEMP: ________ °C	**TYPE IV FLUID TEMP:** ________ °C
Type I Truck #: ________	**Type IV Truck #:** ________
Type I Fluid Nozzle Type: ________	**Type IV Fluid Nozzle Type:** ________

Thermistor Probes Mounting Locations

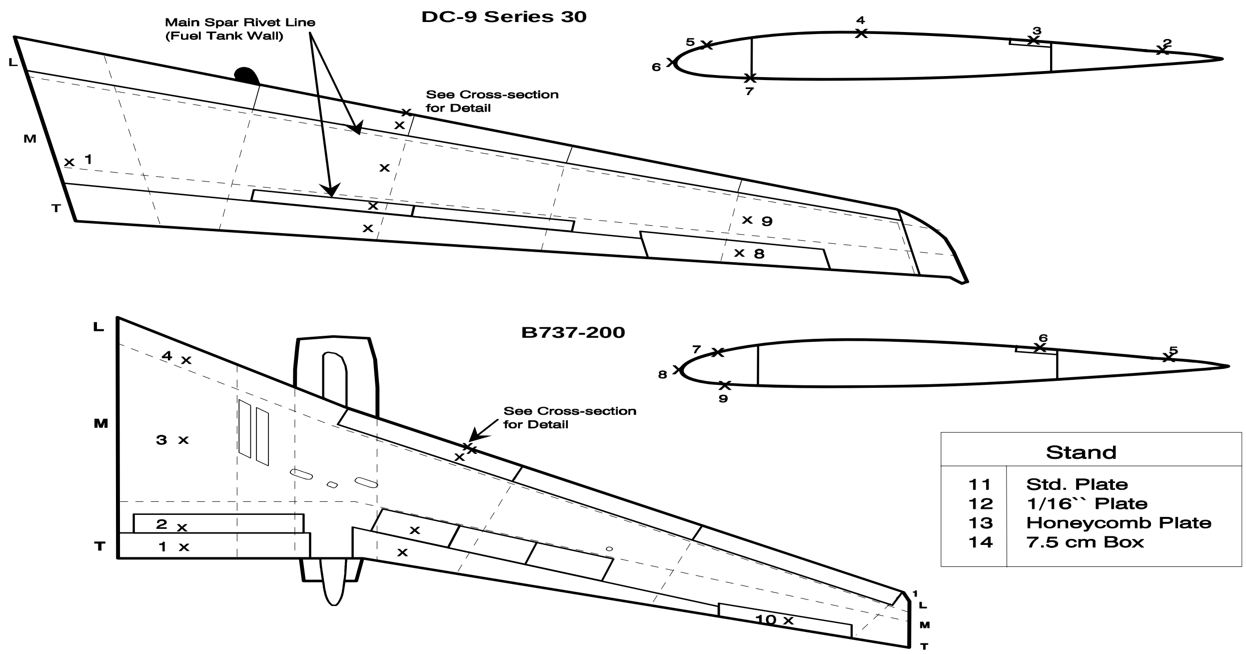


FIGURE 2.3

GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY PLATE/WING COORDINATOR)

AIRCRAFT TYPE: DC-9 F100 B-737 RJ

DATE: ____________________

RUN #: ____________________

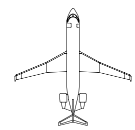
WING: PORT (A) STARBOARD (B)

WIND SPEED: __________ km/h

DIRECTION OF AIRCRAFT: __________ DEGREES

WIND DIRECTION: __________ Degrees

DRAW DIRECTION OF WIND WRT WING:



OAT: __________ °C

R/H: __________ %

1st FLUID APPLICATION

Actual Start Time: ____________________

Actual End Time: ____________________

Amount of Fluid Sprayed: ____________________ **L / gal**

Type of Fluid: ____________________ %

Fluid Temperature: ____________________ °C

End of Test Time: ____________________ (hr:min:ss)

COMMENTS: ____________________

MEASUREMENTS BY: ____________________

HAND WRITTEN BY: ____________________

FIGURE 2.4

ICING LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME VERSION 4.0 Winter 97/98

DATE: **RUN NUMBER:**

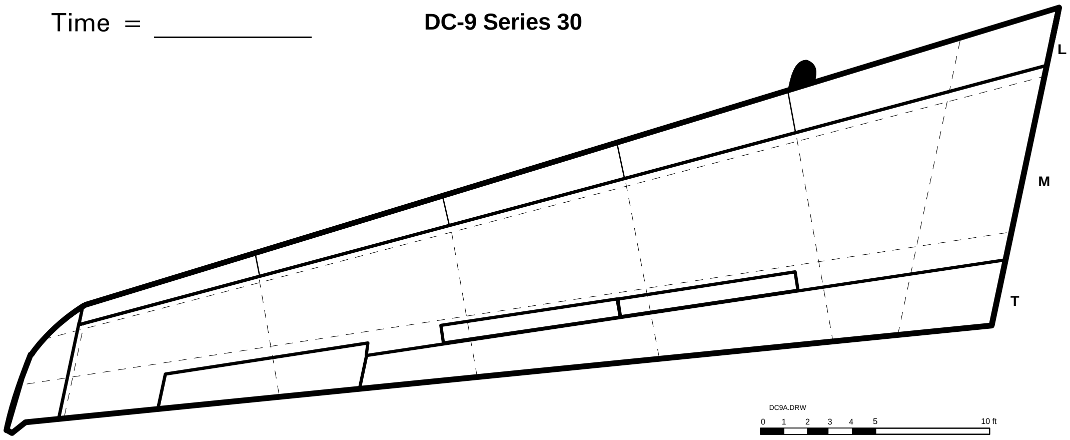
FAILURES CALLED BY: ____________ **COMMENTS:** ____________

HANDWRITTEN BY: ____________

ASSISTED BY: ____________

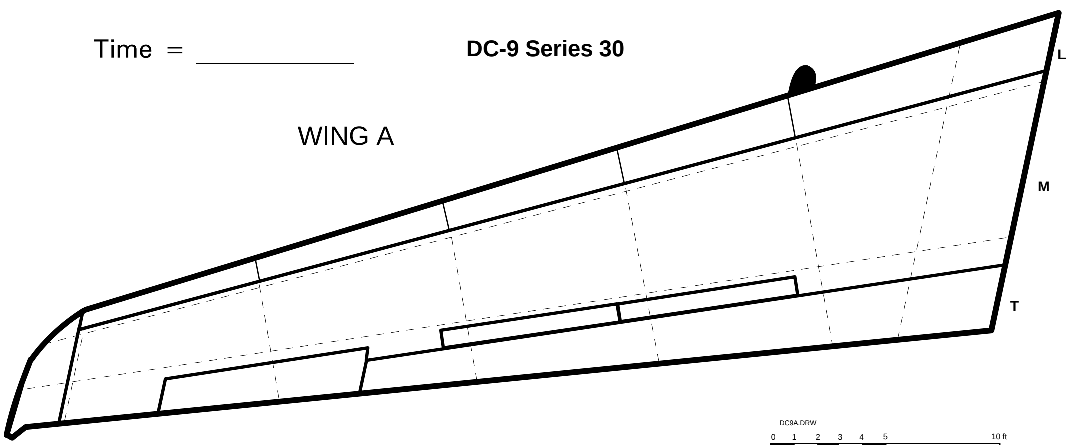
DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

Time = __________ **DC-9 Series 30**



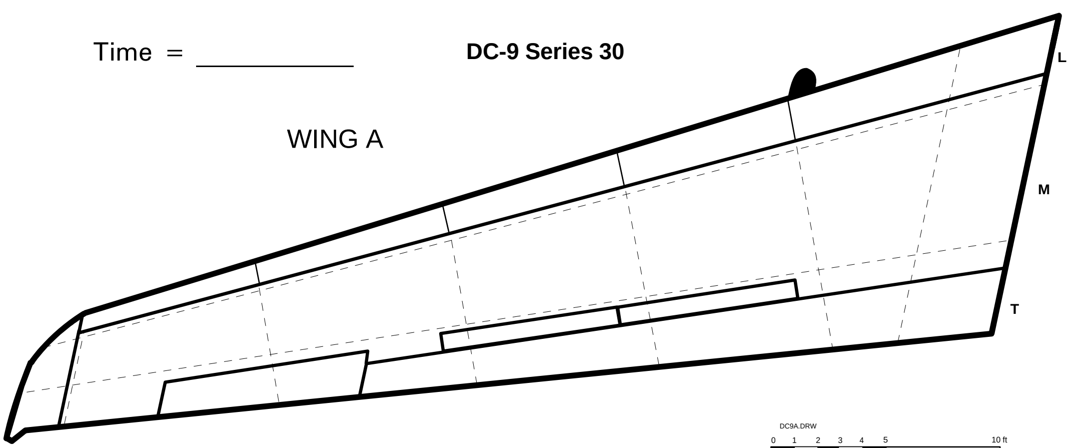
Time = __________ **DC-9 Series 30**

WING A



Time = __________ **DC-9 Series 30**

WING A



cm1380/report/buffer/DC9_WA.DRW

FIGURE 2.5

DATA FORM FOR *DEICING ONLY* TABLE TESTS

REMEMBER TO SYNCHRONIZE TIME VERSION 1.0 1997/98

LOCATION: CEF (Ottawa) **DATE:** **RUN NUMBER:** **STAND # :** **AMBIENT TEMPERATURE:** **°C**

Fluid Application Time: ______ ______ ______

Fluid Temperature: ______ ______ ______

Fluid Brix: ______ ______ ______

Relative Humidity

Start: ______ %

End: ______ %

FLUID NAME

Plate 1 Plate 2 Plate 3

WIND SPEED:

Start: ______ km/h

End: ______ km/h

WIND SPEED:

Start: ______ km/h

End: ______ km/h

End Time ______ ______ ______

% Dry : 5/25/50/75/95/100 5/25/50/75/95/100 5/25/50/75/95/100

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

Fluid Application Time: ______ ______ ______

Fluid Temperature: ______ ______ ______

Fluid Brix: ______ ______ ______

FLUID NAME

Plate 4 Plate 5 Plate 6

WIND SPEED:

Start: ______ km/h

End: ______ km/h

WIND SPEED:

Start: ______ km/h

End: ______ km/h

End Time ______ ______ ______

% Dry : 5/25/50/75/95/100 5/25/50/75/95/100 5/25/50/75/95/100

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

Indicate location of Brix values and fluid thickness on plate diagrams

COMMENTS: ______

HAND WRITTTEN BY : ______ **LEADER:** ______

The form was initiated by the test team captain who recorded the run number, fluid types, and concentrations required for the next test run. The form was then passed to the fluid management team as a fluids order form.

The fluid manager prepared the required fluids, and recorded the final temperature and Brix value for each of the test fluids on the data form. The data form was then returned along with the set of prepared test fluids to the test team.

At beginning and end of each test, the test team captain recorded the wind speed measured at the four corners of the plate test stand and recorded these values at the corresponding locations on the data form schematic. Relative humidity was also recorded on the form.

Fluid application time was recorded as the absolute time that the fluid sample was poured into the applicator.

At test end, the percent of plate area left dry was estimated, and the observed pattern of the wetted area (or iced area) of the plate was sketched. Brix values and fluid thickness were measured at points where fluid existed on the plate. Sampled points were noted on the plate form.

The same data form was used to record ongoing Brix values for a series of supplemental tests that were conducted to develop Brix profiles of the fluids on the test plate surfaces as a function of time. These tests were run separately to avoid disturbing fluid surfaces and plate temperatures during the main tests.

2.3.3 First-Step Fluid Tests

The single data form used for these tests is shown in Figure 2.6. The significant data recorded on these sheets were ambient temperature, fluid type, initial fluid temperature, initial Brix value, time of fluid application and time at which freezing first appeared.

In later tests, wind speed was recorded.

Precipitation rates were measured and recorded using standard precipitation rate forms (Figure 2.7).

FIGURE 2.6

DATA FORM FOR FIRST STEP FLUID TESTS (LIGHT FREEZING RAIN)

REMEMBER TO SYNCHRONIZE TIME VERSION 1.0 VERSION 1.0 1997/98

LOCATION: CEF (Ottawa) **DATE:** **RUN NUMBER:** **AMBIENT TEMPERATURE: °C** **STAND # :**

Fluid Application Time: ________ ________ ________

Fluid Temperature: ________ ________ ________

Fluid Brix: ________ ________ ________

FLUID NAME

Plate 8	Plate 9	Plate 10

Time to 1st Freezing: ________ ________ ________

Time to Failure (6" Line): ________ ________ ________

Time to complete Failure (15" Line): ________ ________ ________

Fluid Application Time: ________ ________ ________

Fluid Temperature: ________ ________ ________

Fluid Brix: ________ ________ ________

FLUID NAME

Plate 11	Plate 12	Plate 13

Time to 1st Freezing: ________ ________ ________

Time to Failure (6" Line): ________ ________ ________

Time to complete Failure (15" Line): ________ ________ ________

COMMENTS: ________

HAND WRITTTEN BY : ________ **LEADER:** ________

FIGURE 2.7

PRECIPITATION RATE MEASUREMENT AT CEF IN OTTAWA

Date: ____________________

Start Time: ____________________ am/pm

Run # : ____________________

Precip Type: ____________________ (FZD, FZR, FZF, S)

Pan Location:

U	UU	V	VV	W	WW
XX	**X**	**YY**	**Y**	**ZZ**	**Z**

Collection Pan:

Pan/ Cup #	Area of Pan (dm^2)	Location		Weight of Pan (g) Before	After	Collection Time (min) Start	End
		U	=				
		UU	=				
		V	=				
		VV	=				
		W	=				
		WW	=				
		XX	=				
		X	=				
		YY	=				
		Y	=				
		ZZ	=				
		Z	=				

Comments: ____

Handwritten by: ____________________

Measured by: ____________________

Precipitation Rate = Δg/area (dm^2)/h

2.4 Equipment

2.4.1 Preliminary Tests at APS Test Site and Tests on Aircraft

Standard flat plate test apparatus as used in fluid holdover time tests were employed in these experiments. During the second aircraft test session, a flat plate designed for this purpose was mounted directly on the aircraft wing.

Prior to aircraft tests, thermistor probes and a data logger system were installed to record ongoing test plate and wing surface temperatures. Locations for probe installation were selected to generate data for wing surfaces that in past tests have demonstrated different rates of cooling. During the Hot Water Deicing Tests (3) it was observed that, after being heated through application of hot water, flight control surfaces cooled much faster than the main wing surface. This behaviour is illustrated in Figure 2.8, developed from those tests, which charts temperature profile curves for different wing surfaces.

Fluid applicators and thermos containers for heated test fluids as described in tests at NRC's CEF (Section 2.4.2) were used.

A mobile generator with light mast was rented for each test occasion to illuminate test surfaces. This unit proved to be quite satisfactory, being fast and simple to set up, and providing good lighting over the entire wing surface.

Photo 2.1 shows the general setup for aircraft tests, with the mast light in the left foreground. Photo 2.2 shows a typical spray application from the deicing vehicle, with simultaneous tests in process on the flat plate stand ahead of the wing. Photo 2.3 shows a typical installation of thermistor probes on the wing surface. Photo 2.4 shows the four candidate test surfaces positioned on the test stand, and installed thermistor probes.

A complete list of equipment used in tests on aircraft is included in the test procedure (Appendix C).

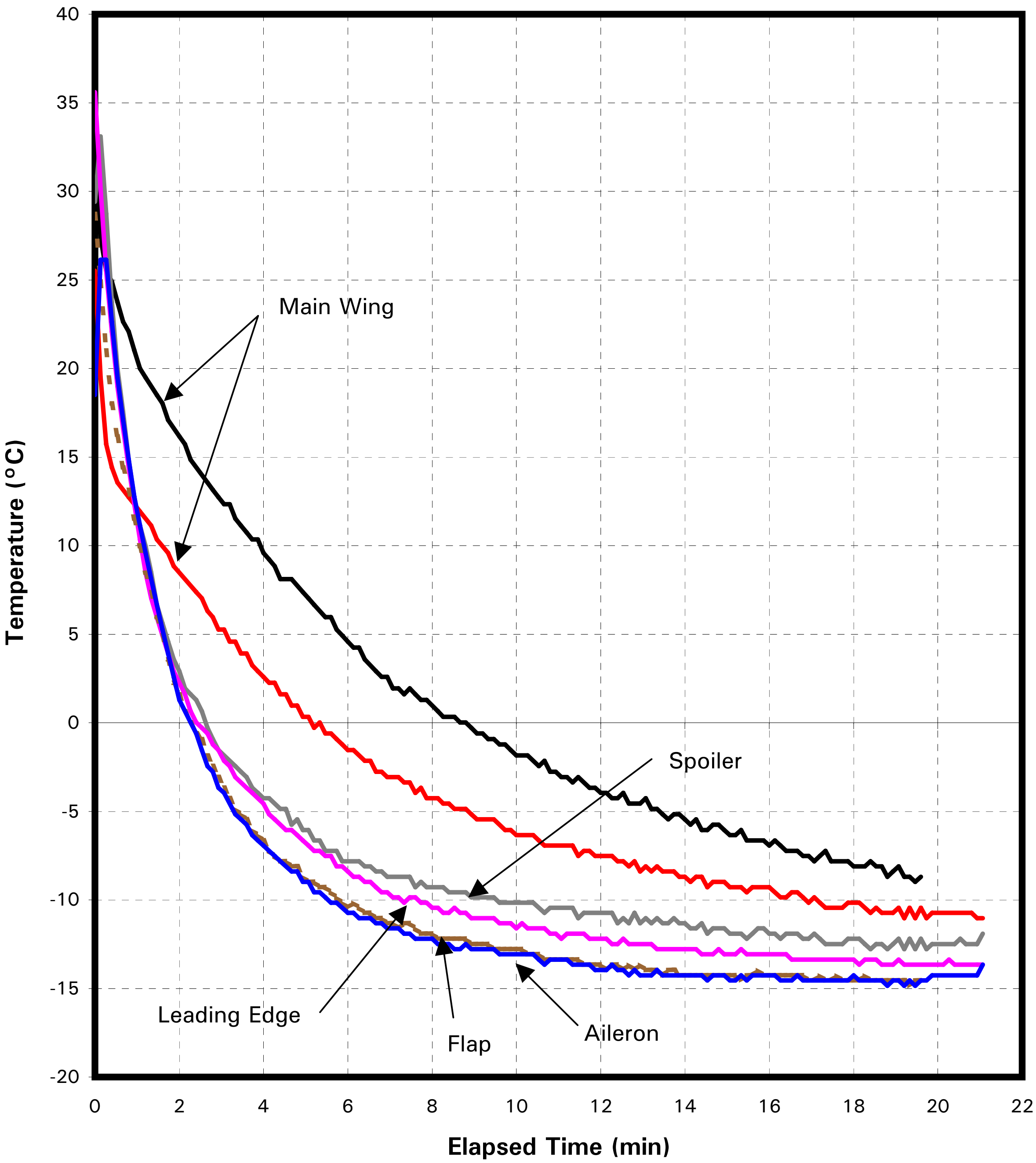
FIGURE 2.8

VARIATION IN COOLING RATE FOR VARIOUS WING SURFACES

HOT WATER SKIN TEMPERATURE TEST AT YUL

April 05, 1995, Run # 3, Port Side

OAT = -13°C, Wind = 52 km/h



cm1380/report/buffer/Figure 2.8
At: Chart1

2.4.2 Tests at NRC's CEF

2.4.2.1 Preparation of Fluids for Tests

All required fluid samples were mixed at the APS test site prior to departing for NRC's CEF, and maintained in well-marked containers ready for preparation for testing (Photo 2.5). Hand-held Brix-scale refractometers were used to measure fluid concentrations.

During the test runs, each test team captain provided the fluid manager with a data form specifying fluids required for the next test run. Fluid samples were then heated in covered aluminum cooking pots on hot plates. Each pot lid was fitted with a thermometer that extended into the fluid contents, allowing close monitoring of fluid temperatures in order to avoid overheating. When the desired temperature was reached, 0.5 L of the fluid sample was measured out and poured into a thermos container. The sample temperature and the Brix value were then measured and recorded on the data sheet. Each thermos was labelled to indicate fluid type and concentration. Photo 2.6 shows the setup for this procedure, with heating pots on the hot plate range, and thermos containers placed in the custom designed tray for carrying to the test chamber.

Thermos containers (maximum of six) and data sheets for individual test sessions were then temporarily stored in a heated area until the test team was ready to commence the next test. A seventh thermos container fitted with a thermistor probe served as a temperature reference container to indicate whether cooling had occurred during the wait. This thermos was filled with the standard volume (0.5 L) of one of the heated test fluids. At the time the fluids were poured, the temperature of this probe was displayed to ensure fluid temperatures were at the required level, and logged for future reference. This procedure proved satisfactory in providing fluids at the desired temperatures without affecting fluid concentrations due to evaporation while awaiting the start of the actual test.

The experiments involved comparison of the performance of different fluids. Therefore, it was important that the fluids be applied in the same manner for every test. Accordingly, a device for applying fluid to test plates was designed and fabricated. The device, pictured in Photos 2.7 and 2.8, served this purpose satisfactorily. A member of the support team was responsible for washing and drying applicators between fluid applications to avoid any possibility of fluid residue affecting subsequent tests. A hair dryer was used to provide a completely dry unit. The applicators were transported in a tray, and kept on standby in a warm area for the next set of tests to avoid chilling fluid samples during pouring.

Although the fluid preparation facility had the capacity to heat 12 fluid samples (enough for the two simultaneous tests under way), some test delays were encountered while awaiting test fluids. Separate fluid management teams (one supporting each test team) would have avoided such delays. This approach is recommended for any future similar tests.

2.4.2.2 Deicing Only Tests

Photo 2.9 shows the general test setup for these tests. Standard flat plate test equipment as used in fluid holdover time tests was employed for these experiments. The flat plates were refinished prior to testing to ensure that the nature of the surface was common to all test runs. It had been noted in preliminary tests that the standard marking pattern applied for holdover tests caused some damming of thin fluid films and thereby interfered with the process of evaporation. Consequently, the plates were marked only with dots to assist sketching the final patterns of wetting onto the data forms.

Thermistor probes were installed on each plate and a logger system recorded ongoing test plate surface temperature as the heated fluid was poured, and the plate subsequently cooled to ambient temperature.

Electric fans mounted on castors were used to provide specified wind speeds (Photo 2.10). These fans provided a satisfactory quality of wind after initial test and error adjustments of distance and orientation relative to the test stand.

Winds were measured with a hand-held anemometer. The standard procedure required wind speeds to be measured at several points across the test stand as part of each test (Photo 2.11). In addition, a larger anemometer was fixed to a central location on the plate stand and digital readouts were cabled to a personal computer to record ongoing wind speed.

Relative humidity in the extreme cold laboratory temperatures was measured by use of a cold temperature relative humidity probe cabled to a sensor readout located in the adjacent heated office area.

Samples for fluid concentration tests were lifted off the test surfaces using strips of clear acetate plastic to scrape together a small amount of fluid sufficient for testing with the Brixometer. Photos 2.12 to 2.15 depict the process of collecting a fluid sample from the plate surface and measuring its strength with the Brixometer.

2.4.2.3 First-Step Fluid Tests

Standard flat plates with installed thermistor probes and plate stands as described for the *deicing only* tests were used.

Light freezing rain precipitation was provided by a scanning sprinkler system (Photo 2.16). This system produced constant and uniform distribution over the entire stand area, and a satisfactory distribution of droplet size. The scanner cycle, however, produced a spray pattern that was repeated every 24 seconds. This meant that any one test plate was subjected to a periodically repeating exposure to rainfall every 24 seconds. Failure times were influenced somewhat by the intermittent nature of exposure, as fluids tended to fail in the period while under active spray. The sprayer scan cycle time was subsequently reduced through modifications to the software that controls the spray pattern.

Photo 2.17 shows the general test setup with plates installed on a flat plate stand positioned in the sprayer pattern.

Preliminary tests to assess the influence of wind on time elapsed before the appearance of freezing utilized two types of small fans as pictured in Photos 2.17 and 2.18. These fans did not provide fully satisfactory wind quality. Subsequent tests to evaluate wind effects were conducted using the same large fans used in the *deicing only* tests. In order to position the fans at a distance great enough to generate low-speed winds over the plate stand, it was necessary to use both chambers of the CEF (with the dividing door opened). This setup proved successful for winds of 10 and 20 km/h, but winds of 5 km/h were disturbed by the door frame and resulted in inconsistent wind speeds. As a result, tests could not be conducted at 5 km/h. Future tests requiring the combination of rain precipitation and wind should consider relocation of the scanning sprinkler unit to the large chamber.

A complete list of equipment used in tests at NRC's CEF is included in the test procedures (Appendices D and E).

2.5 Fluids

Fluids used during preliminary and aircraft tests were limited to SAE Type I fluids (Union Carbide ADF), mixed to different concentrations.

Laboratory tests for both *deicing only* and first-step fluid studies employed Union Carbide ADF as the base fluid, with representation from other SAE Type I, Type II, and Type IV fluids for comparison of results. Both ethylene and propylene glycol-based fluids were tested. Included in the test fluid inventory were recycled fluids supplied by Inland Technologies. These fluids had been recovered from deicing operations and reconstituted using Inland's own recycling process.

Fluids tested included:

	Brand	**Symbol**
Water		H20
Type I	UCAR ADF	UI
	UCAR XL54	XL54
	Octagon Octaflo	0I
Type II	Octagon 40 below	0 II
	Hoechst II	H II
	Kilfrost II	K II
Type IV	UCAR ULTRA IV	UIV
	Octagon MaxFlight	0IV
Recycled Fluids (Inland Technologies)		
	Ethylene glycol-based	T 0 E
	Propylene glycol-based	T 0 P

Dilutions are indicated as in the following example:

UI (–6) indicates UCAR Type I ADF fluid diluted to a freeze point of -6°C.

2.6 Personnel and Participation

AéroMag 2000 operated the deicing vehicles and performed the spray operations during aircraft deicing tests.

NRC's CEF staff provided technical support during laboratory tests at that facility.

US Airways provided over-nighting aircraft for tests.

RVSI participated at both aircraft and laboratory tests by providing an ice contamination sensor and supporting staff.

Representatives from US Airways, the FAA and Transport Canada's TDCparticipated as observers at various tests.

APS Aviation designed, co-ordinated and conducted the tests. Data were gathered and analysed by APS Aviation.

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Photo 2.1
Aircraft Tests – General Setup

Photo 2.2
Spray Application from Deicing Vehicle and Position of Flat Plate Test Stand

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Photo 2.3
Typical Installation of Thermistor Probes on Wing and Flat Plate Mounted on Wing

Photo 2.4
Typical Installation of Thermistor Probes on Cold-Soaked Boxes

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Photo 2.5
Containers of Various Fluids at Desired Concentration

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Photo 2.6
Apparatus for Heating Fluids and Transporting Fluids to Test Stand

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Photo 2.7
Applying Fluid to Test Plate

Photo 2.8
Fluid Spreader

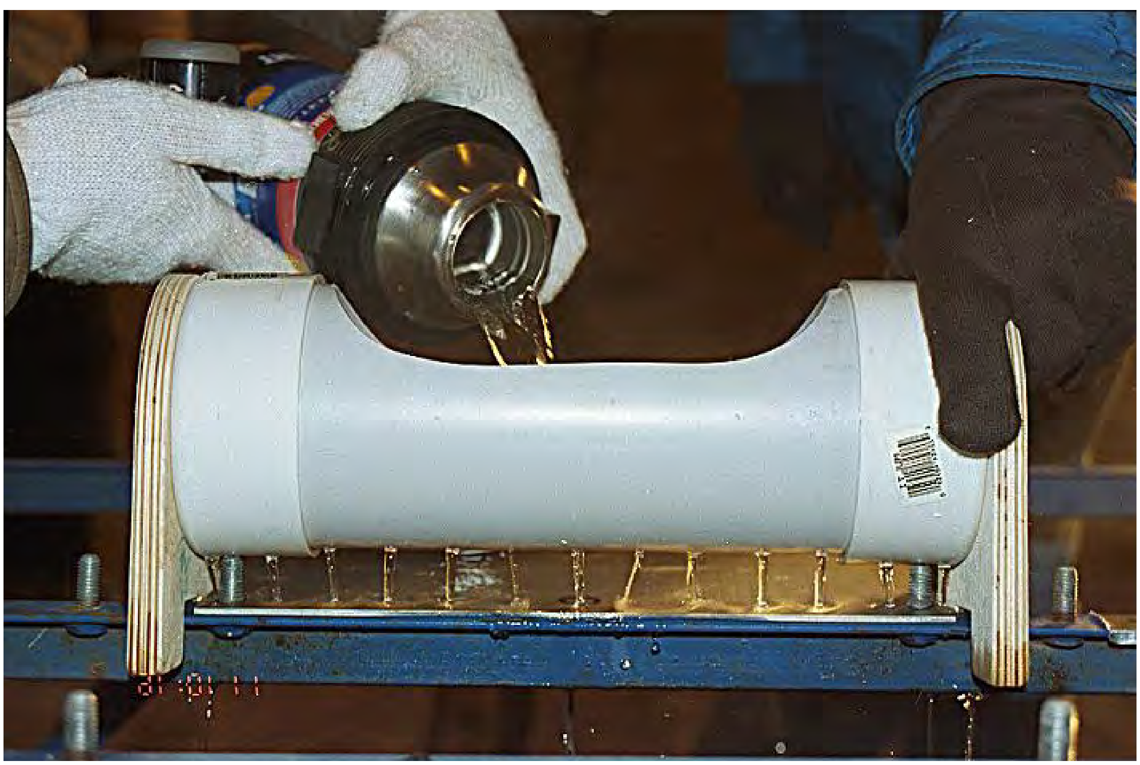

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Photo 2.9
NRC Cold Chamber Test Setup - Deicing Only Tests
Plate Test Stand, RVSI and Spar/Cox Ice Sensors

Photo 2.10
Fans Used to Generate Winds

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Photo 2.11
Measuring Wind Speed with Hand-held Anemometer and Vaisala RH Meter

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Photo 2.12
Collecting Fluid Sample for Testing Concentration

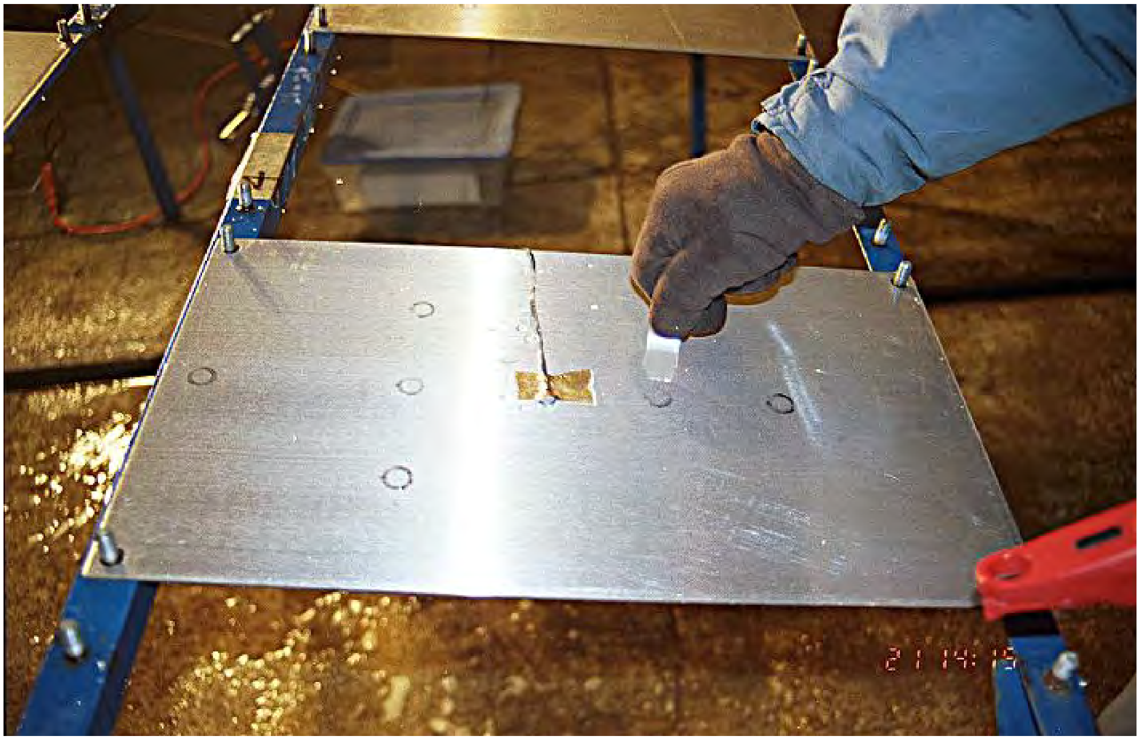

Photo 2.13
Close-up of Fluid Sampling

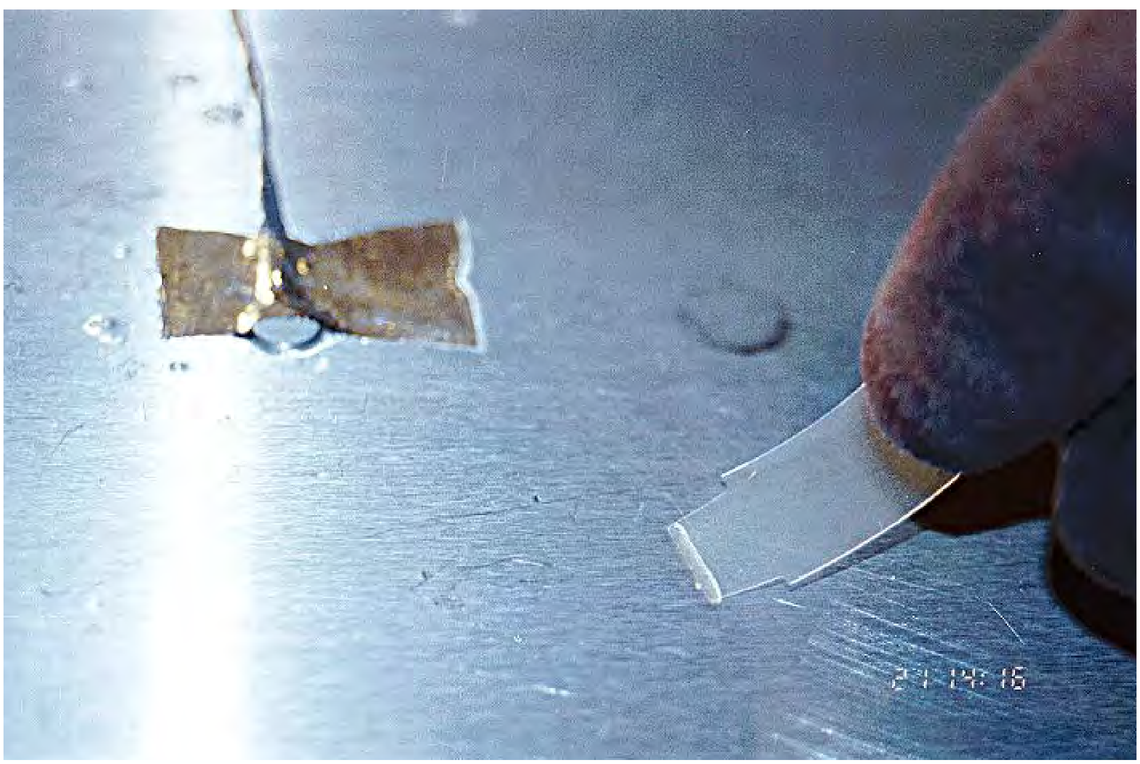

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Photo 2.14
Fluid Sample Being Placed on Brixometer

Photo 2.15
Reading Brix Value

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Photo 2.16
Overhead Sprayer to Produce Light Freezing Rain

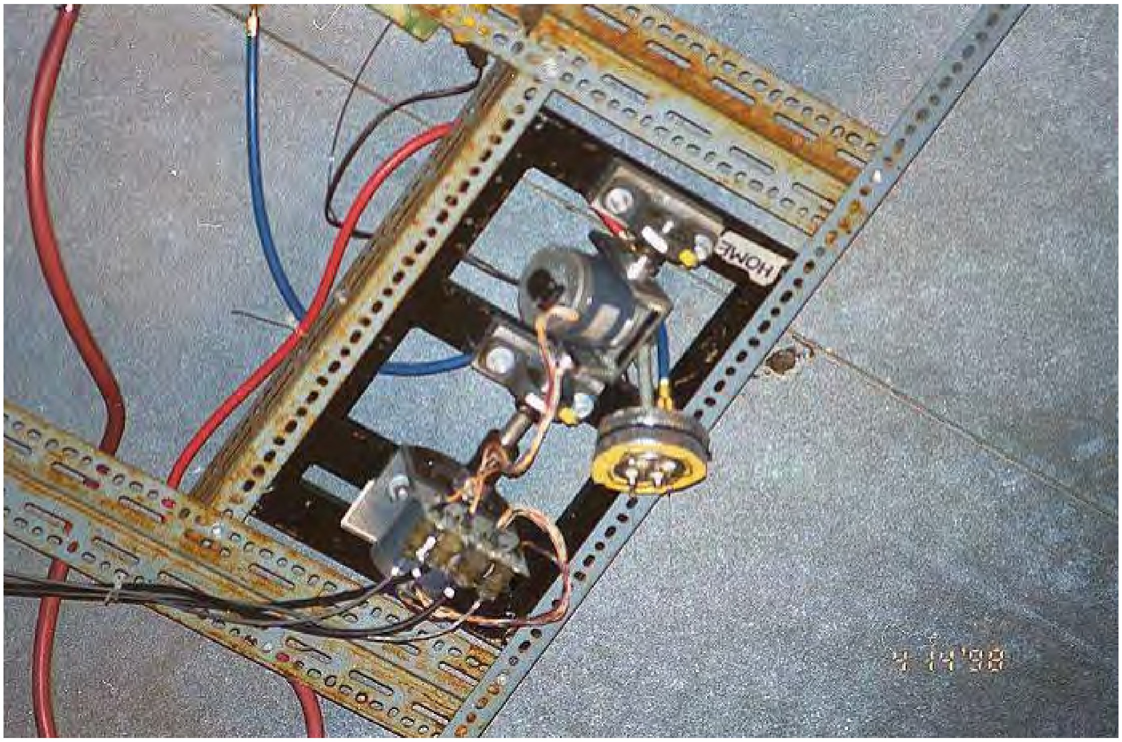

Photo 2.17
Test Setup – First-Step Fluid Tests under Freezing Rain Test Stand

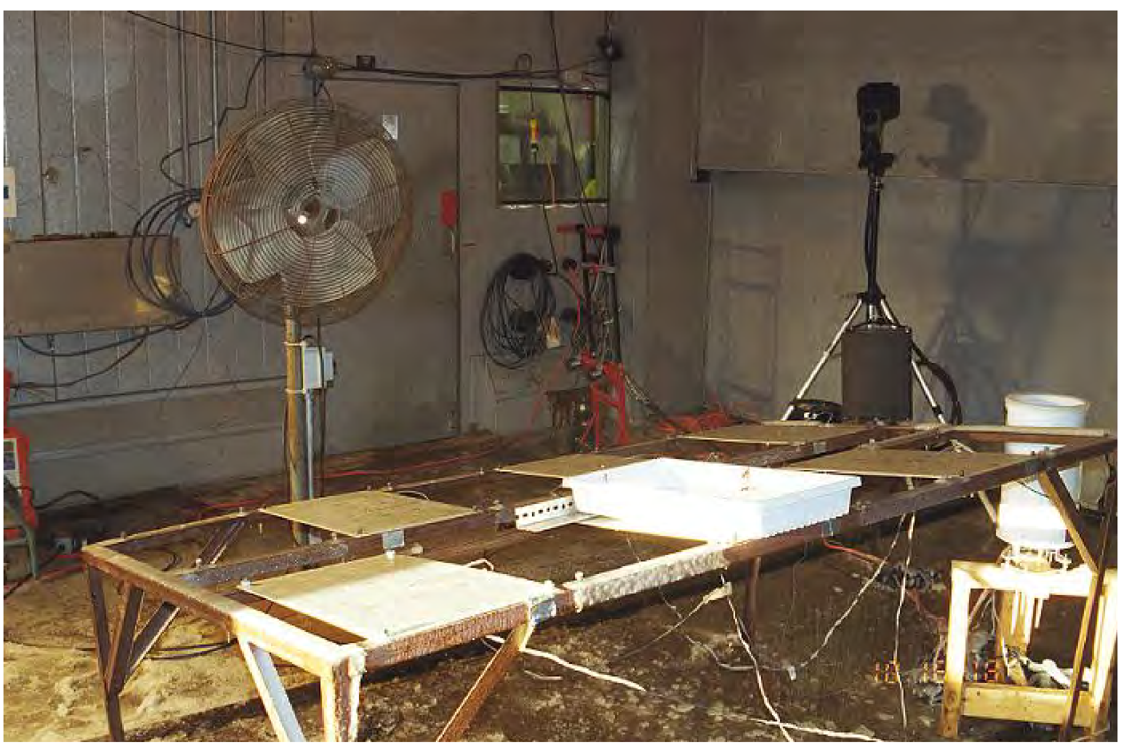

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Photo 2.18
Smaller Fan Used for Wind - Initial Evaluation of Wind Effect

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3. DESCRIPTION AND PROCESSING OF DATA

3.1 Preliminary Tests

Two sessions of preliminary tests were conducted: on December 8, 1997, and on January 15, 1998.

These sessions examined four potential test surfaces:
- Cold-soak boxes (heat sinks) 7.5 cm deep (filled to 25 percent capacity);
- Aluminum honeycomb core plate;
- Standard aluminum test flat plate 3.2 mm (1/8 in.); and
- Thin aluminum flat plate 1.6 mm (1/16 in.).

Fluid samples prepared for these tests were heated to 60°C. A 0.5 L volume of the heated fluid was applied to each test surface. The test fluids included water, and Union Carbide ADF mixed to two fluid freeze point buffer values: 3°C above and 3°C below the outside air temperature.

Conditions for the December 8 tests were:
- Outdoors;
- Calm wind, clear sky; and
- Outside air temperature: -6 to -8°C.

Conditions for the January 15 tests were:
- Inside cold-soak test trailer;
- No wind; and
- Outside air temperature: -8°C.

A typical completed data sheet is shown in Figure 3.1. Results from these tests were compared on the basis of final condition of plate surface.

FIGURE 3.1

HOT FLUID TEST FORM

REMEMBER TO SYNCHRONIZE TIME WITH AES - USE REAL TIME

LOCATION: Dorval **DATE:** Jan. 15, 1998 **TEST # :** **TIME OF FLUID APPLICATION:** 0:49

AIR TEMPERATURE: -8 °C

SURFACE TYPE: STD. PLATE / THICK PLATE / 7.5 CM BOX / Honeycomb

FLUID TEMP.: 60°C

PLATE ANGLE: 10°

FLUID: WATER / XL54 WITH +3°C BUFFER / XL54 WITH -3°C BUFFER

WIND SPEED 0 km/h

FLUID QUANTITY: 0.5 L

THERMISTOR #'s: ________

BRIX BEFORE POURING: 10 **TEMP. BEFORE POURING:** -8 °C

BRIX OF FLUID LEFT ON PLATE:

Time	Brix
0:57	11
1:02	13
1:06	15

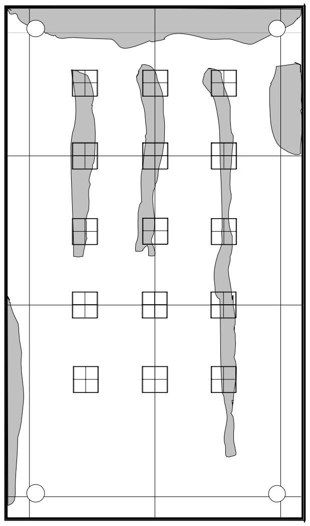
SKIN TEMPERATURES (9" LINE)

TIME:	TEMP. (°C)	TIME:	TEMP. (°C)
0:49	34	0:58	-2
0:50	16	1:01	-3
0:51	12	1:04	-5
0:52	8	1:06	-6
0:54	3	1:08	-6
0:56	-1		

	PRINT	SIGN
OBSERVATIONS BY :		
HAND WRITTTEN BY :		
TEST SITE LEADER :		

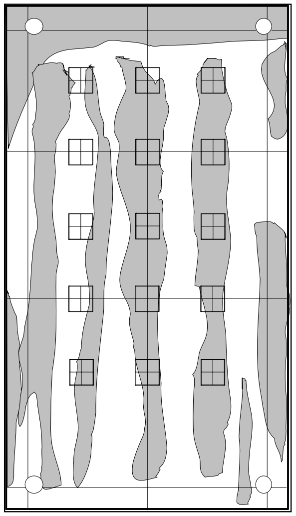
TIME 0:54 **SKIN T.** ____ °C **TIME** 0:59 **SK**

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100% **% Dry:** 0-5 / 5-25 / 25-50 / 50-



TIME 1:04 **SKIN T.** ____ °C **TIME** **SK**

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100% **% Dry:** 0-5 / 5-25 / 25-50 / 50-



File:g:\cm1380\report\buffer\JAN15_HW
At: Data Form Printed: 2/20/2007

3.2 Aircraft Tests

Two overnight test sessions were conducted on McDonnell Douglas DC-9 aircraft.

The first test session included simultaneous tests on test surfaces mounted on a flat plate stand. These were the same surfaces reported in the discussion of preliminary tests. During the second aircraft test session, a flat plate was mounted directly on the aircraft wing, with a view to subjecting the plate to the same spray application as the wing (Photo 2.3).

A typical completed data form, showing locations of freezing on the wing is shown in Figure 3.2.

Temperature profiles were logged for all plate surfaces, and at several selected points on the wing. A typical temperature profile is discussed in Section 4.

At test end, fluid concentrations were measured on all test surfaces. An example of the distribution of fluid strength over a wing surface is given in Figure 3.3. During the second test, fluid concentration profiles were developed for different locations on the wing and on the flat plate mounted on the wing.

FIGURE 3.2
WING ICING LOCATION; JANUARY 22, 1998 - RUN 5

REMEMBER TO SYNCHRONIZE TIME | VERSION 4.0 | Winter 97/98

DATE: Jan. 22, 1998 **RUN NUMBER:** 5

FAILURES CALLED BY: ____________

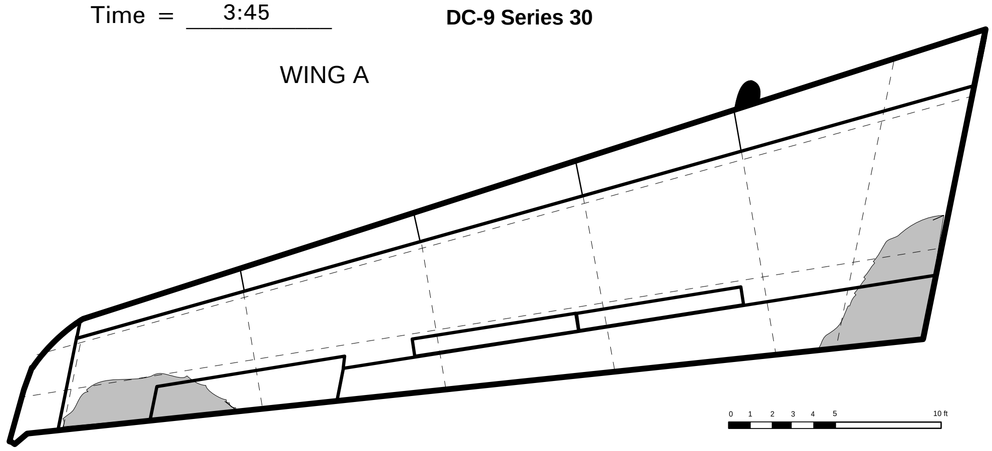
HANDWRITTEN BY: ____________

ASSISTED BY: ____________

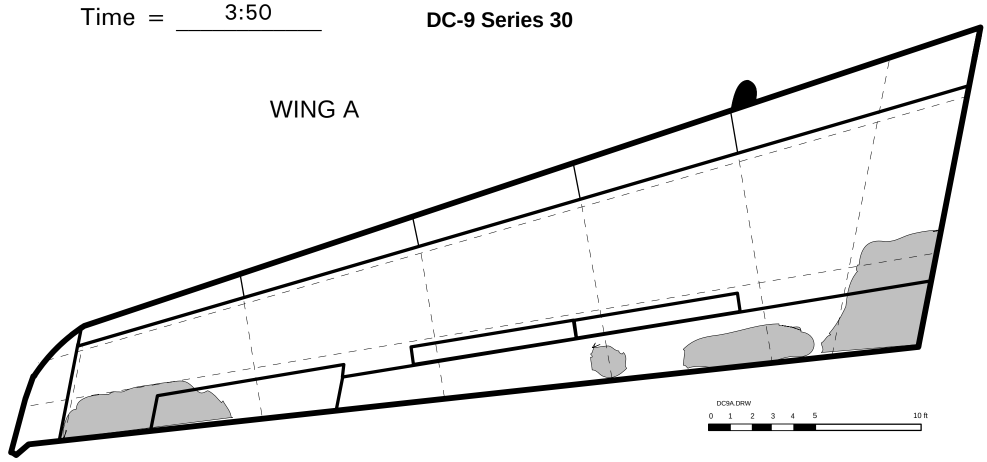
COMMENTS: Fluid Application Time: 3:25
Fluid: UCAR ADF (-12ºC) - 160 Litres at 75ºC
OAT = -16ºC, Wind: 5 kt headwind

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

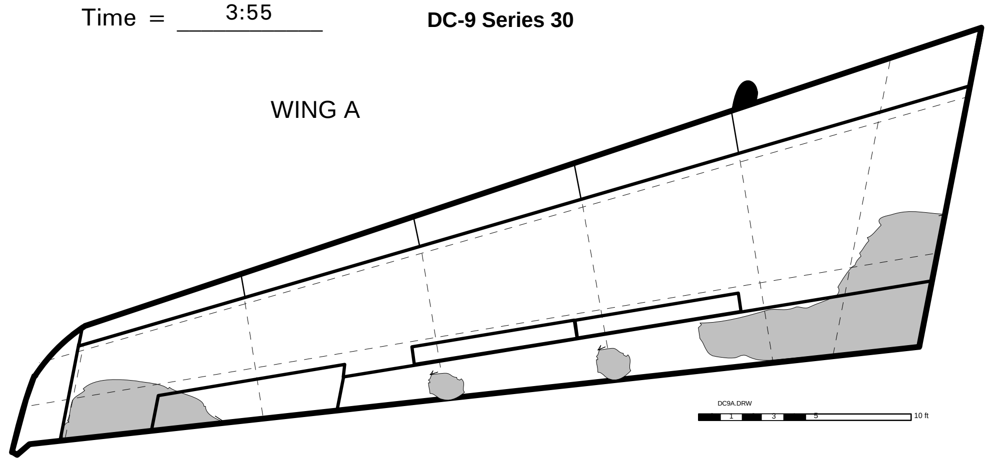
Time = 3:45 **DC-9 Series 30**



Time = 3:50 **DC-9 Series 30**



Time = 3:55 **DC-9 Series 30**



cm1380/report/buffer/2-J22_R5.CH4

FIGURE 3.3

AIRCRAFT TESTS; JANUARY 22, 1998 - RUN 5

VERSION 4.0 Winter 97/98

DATE:	JAN. 22, 1998	RUN NUMBER:	5	OAT = -16°C

FAILURES CALLED BY:

HANDWRITTEN BY:

ASSISTED BY:

COMMENTS: Initial Fluid Freeze Point Temperature = -12°C (Wing and Plate)

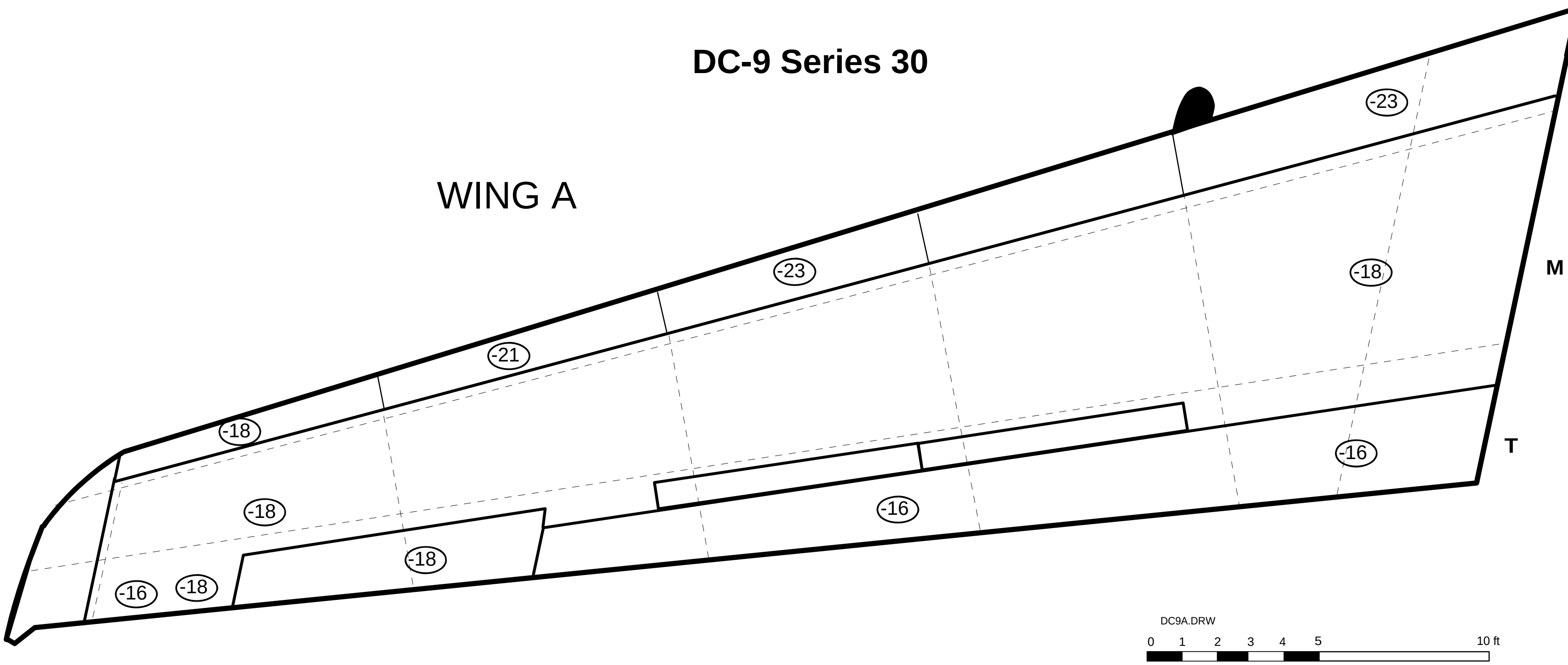
Wing Time to First Icing = 20 minutes

Fluid Final Freeze Point Temperature (°C) shown on Wing Plan eg (-23)

Standard Plate

Time to First Icing = 15 minutes

Final Fluid Freeze Point = -16°C



cm1380/report/buffer/JAN22_DO.DRW

3.3 *Deicing Only* Tests at the NRC's CEF

The initial test session was conducted during the week of February 9 to 13, 1998, during which 150 individual tests were executed. On the basis of results from these tests, two further test sessions were conducted (on March 30 and 31, and on April 20 and 21, 1998) to generate additional data. These sessions were dedicated to testing fluid mixes having freeze points at 3°C below outside air temperatures, at outside air temperatures, and at various wind speeds.

A complete log of tests and results is shown in Table 3.1. The logged values for the column entitled *Condition of Plate at End* demand explanation. The key attribute being examined in the study was whether the plate remained uncontaminated (either dry and bare, or fluid covered) or whether ice in some form appeared on the plate surface or at the drip line along the bottom edge. The description of the final plate condition was logged in accordance with the following legend. In the case of more than one condition appearing, only the most severe was logged. The level of severity is in descending order from Ice to Bare.

I	Ice	(any ice appearing on the plate surface)
S	Slush	(ice appearing in the form of slush)
D	Drip ice	(ice appearing only on the lower edge of the plate)
F	Fluid	(no ice, surface wetted by fluid)
B	Bare	(surface dried to bare condition)

In addition to the logged information, progressive Brix values were recorded over time for certain tests to demonstrate the increase in fluid concentration due to the evaporation of water. These data were then graphed as fluid freeze point temperature profiles, and are shown in Section 4.

The range of conditions over which tests were conducted is shown graphically in Figure 3.4. In this chart, the diamonds represent test points. The range of outside air temperature is given on the vertical scale, and values for initial fluid freeze point are given on the horizontal scale.

The diagonal lines indicate ranges of fluid freeze point buffer values, both negative and positive. A test point at the intersection of the horizontal line representing -10°C outside air temperature and the vertical line representing an initial fluid freeze point of -10°C would have a buffer value of zero, and the diagonal zero degree buffer line passes through this

TABLE 3.1

DEICING ONLY - WINTER 1997-98

Test no.	Form no.	Date	Run no.	Plate #	Time of application (Local)	End time (Local)	Fluid name	Fluid freeze temp.	Fluid type	OAT (°C)	Relative Humidity Start (%)	Relative Humidity End (%)	Wind Avg. (km/h)	Initial fluid temp. (°C)	Initial fluid Brix	Condition of plate at end	Brix @ 5 min drip	End Condition Brix - Location 1	Brix - Location 2	Brix - Location 3	Brix - Location Avg 2,3	Brix - Location Drip	Thickness - Location 1	Thickness - Location 2	Thickness - Location 3	Thickness - Location Drip	Comments
1	2	Feb-09-98	1	1	15:40:00	16:10:00	Water	0.0		-1	68.4	66.1	0.0	60	0.0	DI						0.0					
2	2	Feb-09-98	1	2	15:41:00	16:11:00	UCAR ADF	-3.0	1	-1	68.4	66.1	0.0	60	5.5	F						9.0					
3	2	Feb-09-98	1	3	15:41:30	16:12:00	Octagon	-1.5	1	-1	68.4	66.1	0.0	60	5.0	F						18.0					
4	2	Feb-09-98	1	4	15:42:00	16:12:00	T O P	-1.5	0	-1	68.4	66.1	0.0	60	5.5	F						9.0					
5	2	Feb-09-98	1	5	15:42:30	16:13:00	UCAR ADF	-2.0	1	-1	68.4	66.1	0.0	60	3.5	F						6.0					
6	2	Feb-09-98	1	6	15:43:00	16:14:00	T O E	-3.0	0	-1	68.4	66.1	0.0	60	5.0	F						9.0					
7	3	Feb-09-98	2	1	12:00:00	12:30:00	Water	0.0		-1	56.0	57.0	4.4	65	0.0	B											
8	3	Feb-09-98	2	2	12:01:00	12:31:00	UCAR ADF	-3.0	1	-1	56.0	57.0	4.4	65	5.0	F						13.0					
9	3	Feb-09-98	2	3	12:02:00	12:32:00	Octagon	-1.5	1	-1	56.0	57.0	4.4	65	5.0	F											
10	3	Feb-09-98	2	4	12:02:30	12:32:00	T O P	-1.5	0	-1	56.0	57.0	4.4	65	5.0	F						10.0					
11	3	Feb-09-98	2	5	12:03:00	12:33:00	UCAR ADF	-2.0	1	-1	56.0	57.0	4.4	65	3.0	F						6.0					
12	3	Feb-09-98	2	6	12:04:00	12:34:00	T O E	-3.0	0	-1	56.0	57.0	4.4	65	5.0	F						11.0					
13	4	Feb-09-98	3	1	13:05:00	13:21:00	Water	0.0		-1	58.3	62.0	10.3	59	0.0	B											
14	4	Feb-09-98	3	2	13:05:30	13:23:00	UCAR ADF	-3.0	1	-1	58.3	62.0	10.3	60	5.0	F				23.0	23.0	10.0					
15	4	Feb-09-98	3	3	13:06:00		Octagon	-1.5	1	-1	58.3	62.0	10.3	60	5.0	F				23.0	23.0	17.0					
16	4	Feb-09-98	3	4	13:07:00	13:29:00	T O P	-1.5	0	-1	58.3	62.0	10.3	59	5.5	F						15.0					
17	4	Feb-09-98	3	5	13:07:30	13:31:00	UCAR ADF	-2.0	1	-1	58.3	62.0	10.3	60	3.0	F						11.0					
18	4	Feb-09-98	3	6	13:08:00	13:35:00	T O E	-3.0	0	-1	58.3	62.0	10.3	60	5.0	F				9.0	9.0	11.0					
19	5	Feb-09-98	4	1	14:48:30	15:20:00	Water	0.0		-1	63.3	63.3	19.5	60	0.0	I											
20	5	Feb-09-98	4	2	14:49:00	15:20:00	UCAR ADF	-3.0	1	-1	63.3	63.3	19.5	60	5.0	F				24.0	24.0	15.0					
21	5	Feb-09-98	4	3	14:49:30	15:20:00	Octagon	-1.5	1	-1	63.3	63.3	19.5	60	5.0	F						22.0					
22	5	Feb-09-98	4	4	14:50:00	15:20:00	T O P	-1.5	0	-1	63.3	63.3	19.5	60	5.5	F				12.0	12.0	27.0					
23	5	Feb-09-98	4	5	14:50:30	15:21:00	UCAR ADF	-2.0	1	-1	63.3	63.3	19.5	60	3.5	F				8.0	8.0	13.0					
24	5	Feb-09-98	4	6	14:51:00	15:21:00	T O E	-3.0	0	-1	63.3	63.3	19.5	60	5.0	F				36.0	36.0	14.0					
25	6	Feb-10-98	5	1	9:12:00		Water	0.0		-5	63.2	62.5	0.0	60	0.0	I											
26	6	Feb-10-98	5	2	9:12:30		UCAR ADF	-3.0	1	-5	63.2	62.5	0.0	60	5.0	DI						7.0					
27	6	Feb-10-98	5	3	9:13:00		Octagon	-1.5	1	-5	63.2	62.5	0.0	60	5.0	DI		24.0		7.0	7.0	12.0					
28	6	Feb-10-98	5	4	9:13:30		T O P	-1.5	0	-5	63.2	62.5	0.0	60	5.5	DI						7.0					
29	6	Feb-10-98	5	5	9:14:00		UCAR ADF	-2.0	1	-5	63.2	62.5	0.0	60	3.0	DI						5.0					
30	6	Feb-10-98	5	6	9:14:30		T O E	-3.0	0	-5	63.2	62.5	0.0	60	5.0	DI						9.0					
31	7	Feb-10-98	6	1	10:12:00		Octagon	-4.5	1	-5	62.2	62.2	0.0	60	12.5	F		44.0	37.0		37.0	21.0					
32	7	Feb-10-98	6	2	10:12:30		ULTRA IV	-3.0	4	-5	62.2	62.2	0.0	60	5.0	DI		17.0				7.0					
33	7	Feb-10-98	6	3	10:13:00		Octagon IV	-1.5	4	-5	62.2	62.2	0.0	60	5.0	DI						10.0					
34	7	Feb-10-98	6	4	10:13:30		T O P	-4.5	0	-5	62.2	62.2	0.0	60	12.0	F				42.0	42.0	17.0					
35	7	Feb-10-98	6	5	10:14:00		UCAR ADF	-8.0	1	-5	62.2	62.2	0.0	60	12.5	F				38.0	38.0	18.0					
36	7	Feb-10-98	6	6	10:14:30		T O E	-8.0	0	-5	62.2	62.2	0.0	60	12.5	F				39.0	39.0	21.0					
37	8	Feb-10-98	7	1	15:36:30		Water	0.0		-5	62.9	62.1	5.3	60	0.0	DI						0.0					
38	8	Feb-10-98	7	2	15:37:00		UCAR ADF	-3.0	1	-5	62.9	62.1	5.3	60	5.0	DI						8.0					
39	8	Feb-10-98	7	3	15:37:30		Octagon	-1.5	1	-5	62.9	62.1	5.3	60	5.0	DI						0.0					
40	8	Feb-10-98	7	4	15:38:00		T O P	-1.5	0	-5	62.9	62.1	5.3	60	5.5	DI				28.0	28.0	10.0					
41	8	Feb-10-98	7	5	15:38:30		UCAR ADF	-2.0	1	-5	62.9	62.1	5.3	60	3.0	DI											
42	8	Feb-10-98	7	6	15:39:00		T O E	-3.0	0	-5	62.9	62.1	5.3	60	5.5	DI				30.0	30.0	14.0					
43	9	Feb-10-98	8	1	16:25:00	16:55:00	Octagon	-4.5	1	-5	63.3	62.8	5.6	60	12.0	F			34.0	26.0	30.0	21.0					
44	9	Feb-10-98	8	2	16:26:00	16:56:00	ULTRA IV	-3.0	4	-5	63.3	62.8	5.6	60	5.0	DI			20.0	14.0	17.0	7.0					
45	9	Feb-10-98	8	3	16:26:30	16:56:00	Octagon IV	-1.5	4	-5	63.3	62.8	5.6	60	5.0	DI				14.0	14.0	9.0					
46	9	Feb-10-98	8	4	16:27:00	16:57:00	T O P	-4.5	0	-5	63.3	62.8	5.6	60	13.0	F			43.0	37.0	40.0	20.0					
47	9	Feb-10-98	8	5	16:27:30	16:58:00	UCAR ADF	-8.0	1	-5	63.3	62.8	5.6	60	12.0	F			39.0	27.0	33.0	20.0					

TABLE 3.1

DEICING ONLY - WINTER 1997-98

Test no.	Form no.	Date	Run no.	Plate #	Time of application (Local)	End time (Local)	Fluid name	Fluid freeze temp.	Fluid type	OAT (°C)	Relative Humidity Start (%)	Relative Humidity End (%)	Wind Avg. (km/h)	Initial fluid temp. (°C)	Initial fluid Brix	Condition of plate at end	Brix @ 5 min drip	End Condition Brix - Location 1	Brix - Location 2	Brix - Location 3	Brix - Location Avg 2,3	Brix - Location Drip	Thickness - Location 1	Thickness - Location 2	Thickness - Location 3	Thickness - Location Drip	Comments
48	9	Feb-10-98	8	6	16:28:00	16:58:00	T 0 E	-8.0	0	-5	63.3	62.8	5.6	60	12.0	F			39.0	36.0	37.5	25.0					
49	10	Feb-10-98	9,10	1	14:20:00		Water	0.0		-5	63.8	63.6	9.6	60	0.0	DI											
50	10	Feb-10-98	9,10	2	14:21:00		UCAR ADF	-3.0	1	-5	63.8	63.6	9.6	60	5.5	DI			35.0	22.0	28.5	10.0					
51	10	Feb-10-98	9,10	3	14:21:00		Octagon	-1.5	1	-5	63.8	63.6	9.6	60	5.0	DI				35.0	35.0	13.0					
52	10	Feb-10-98	9,10	4	14:22:00		Octagon IV	-1.5	4	-5	63.8	63.6	9.6	60	5.5	DI			23.0	16.0	19.5	9.0					
53	10	Feb-10-98	9,10	5	14:22:30		UCAR ADF	-2.0	1	-5	63.8	63.6	9.6	60	3.0	DI						10.0					
54	10	Feb-10-98	9,10	6	14:23:00		ULTRA IV	-3.0	4	-5	63.8	63.6	9.6	60	5.0	DI			28.0	18.0	23.0	9.0					
55	11	Feb-10-98	11	1	11:19:00	11:49:00	Water	0.0		-5	66.5	65.0	20.1	60	0.0	I											
56	11	Feb-10-98	11	2	11:20:00	11:50:00	UCAR ADF	-3.0	1	-5	66.5	65.0	20.1	60	5.5	DI			28.0	17.0	22.5	9.0					
57	11	Feb-10-98	11	3	11:23:00	11:53:00	Octagon	-1.5	1	-5	66.5	65.0	20.1	60	5.0	DI			45.0		45.0	12.0					
58	11	Feb-10-98	11	4	11:21:00	11:51:00	T 0 P	-1.5	0	-5	66.5	65.0	20.1	60	5.0	DI				27.0	27.0	10.0					
59	11	Feb-10-98	11	5	11:21:30	11:52:00	UCAR ADF	-2.0	1	-5	66.5	65.0	20.1	60	3.0	I						6.0					
60	11	Feb-10-98	11	6	11:22:00	11:52:00	T 0 E	-3.0	0	-5	66.5	65.0	20.1	60	5.0	DI				37.0	37.0	10.0					
61	12	Feb-10-98	12	1	13:06:00		Octagon	-4.5	1	-5	65.6	65.1	20.1	60	12.5	F		42.0	37.0	30.0	33.5	24.0					
62	12	Feb-10-98	12	2	13:06:30		ULTRA IV	-3.0	4	-5	65.6	65.1	20.1	60	5.5	DI		31.0	20.0	13.0	16.5	9.0					
63	12	Feb-10-98	12	3	13:07:00		Octagon IV	-1.5	4	-5	65.6	65.1	20.1	60	5.0	DI			36.0	21.0	28.5	8.0					
64	12	Feb-10-98	12	4	13:07:30		T 0 P	-4.5	0	-5	65.6	65.1	20.1	60	13.0	F				31.0	31.0	25.0					
65	12	Feb-10-98	12	5	13:08:00		UCAR ADF	-8.0	1	-5	65.6	65.1	20.1	60	13.0	F			33.0	30.0	31.5	26.0					
66	12	Feb-10-98	12	6	13:08:30		T 0 E	-8.0	0	-5	65.6	65.1	20.1	60	13.0	F				32.0	32.0	26.0					
67	13	Feb-11-98	13	1	8:30:00	9:00:00	Water	0.0		-10	62.0	62.0	0.0	60	0.0	DI											
68	13	Feb-11-98	13	2	8:30:30	9:01:00	UCAR ADF	-3.0	1	-10	62.0	62.0	0.0	60	5.0	DI				26.0	26.0	9.0					
69	13	Feb-11-98	13	3	8:31:00	9:01:00	Octagon	-1.5	1	-10	62.0	62.0	0.0	60	5.0	DI				23.0	23.0	9.0					
70	13	Feb-11-98	13	4	8:31:30	9:02:00	T 0 P	-1.5	0	-10	62.0	62.0	0.0	60	5.5	DI				31.0	31.0						
71	13	Feb-11-98	13	5	8:32:00	9:02:00	UCAR ADF	-2.0	1	-10	62.0	62.0	0.0	60	3.0	DI				16.0	16.0	6.0					
72	13	Feb-11-98	13	6	8:32:30	9:03:00	T 0 E	-3.0	0	-10	62.0	62.0	0.0	60	5.0	DI				36.0	36.0	13.0					
73	14	Feb-11-98	14	1	10:15:00	10:45:00	ULTRA IV	-3.0	4	-10	63.4	63.4	0.0	60	5.0	I			10.0	9.0	9.5	8.0					
74	14	Feb-11-98	14	2	10:15:30	10:46:00	UCAR ADF	-14.0	1	-10	63.4	63.4	0.0	60	18.0	F			43.0	40.0	41.5	25.0					
75	14	Feb-11-98	14	3	10:16:00	10:46:00	Octagon	-4.5	1	-10	63.4	63.4	0.0	60	12.5	F			48.0	41.0	44.5	27.0					
76	14	Feb-11-98	14	4	10:16:30	10:46:00	T 0 P	-4.5	0	-10	63.4	63.4	0.0	60	13.0	F			47.0	36.0	41.5	26.0					
77	14	Feb-11-98	14	5	10:17:00	10:47:00	UCAR ADF	-8.0	1	-10	63.4	63.4	0.0	60	12.5	F			41.0	29.0	35.0	18.0					
78	14	Feb-11-98	14	6	10:17:30	10:48:00	T 0 E	-8.0	0	-10	63.4	63.4	0.0	60	13.0	F			41.0	37.0	39.0	28.0					
79	15	Feb-11-98	15	1	11:17:00	11:47:00	Water	0.0		-10	62.8	63.8	5.4	60	0.0	I											
80	15	Feb-11-98	15	2	11:17:30	11:47:00	UCAR ADF	-3.0	1	-10	62.8	63.8	5.4	60	5.0	DI				28.0	28.0	10.0					
81	15	Feb-11-98	15	3	11:18:00	11:48:00	Octagon	-1.5	1	-10	62.8	63.8	5.4	60	5.0	I				11.0	11.0	12.0					
82	15	Feb-11-98	15	4	11:18:30	11:49:00	T 0 P	-1.5	0	-10	62.8	63.8	5.4	60	5.0	I				15.0	15.0	9.0					
83	15	Feb-11-98	15	5	11:19:00	11:49:00	UCAR ADF	-2.0	1	-10	62.8	63.8	5.4	60	3.0	I				12.0	12.0	8.0					
84	15	Feb-11-98	15	6	11:19:30	11:50:00	T 0 E	-3.0	0	-10	62.8	63.8	5.4	60	5.0	I			37.0	26.0	31.5	10.0					
85	16	Feb-11-98	16	1	13:01:30	13:32:00	ULTRA IV	-3.0	4	-10	63.0	62.5	5.1	60	5.0	I			9.0	8.0	8.5	7.0					
86	16	Feb-11-98	16	2	13:02:00	13:32:00	UCAR ADF	-14.0	1	-10	63.0	62.5	5.1	60	18.0	F			39.0	37.0	38.0	25.0					
87	16	Feb-11-98	16	3	13:02:30	13:33:00	Octagon	-4.5	1	-10	63.0	62.5	5.1	60	12.0	DI			41.0	30.0	35.5	23.0					
88	16	Feb-11-98	16	4	13:03:00	13:33:00	T 0 P	-4.5	0	-10	63.0	62.5	5.1	60	12.0	DI			30.0	28.0	29.0	8.0					
89	16	Feb-11-98	16	5	13:03:30	13:34:00	UCAR ADF	-8.0	1	-10	63.0	62.5	5.1	60	12.0	F			38.0	32.0	35.0	25.0					
90	16	Feb-11-98	16	6	13:04:00	13:34:00	T 0 E	-8.0	0	-10	63.0	62.5	5.1	60	12.0	F			37.0	32.0	34.5	25.0					
91	17	Feb-11-98	17, 18	1	14:05:00	14:35:00	Water	0.0		-10	63.1	64.0	10.3	60	0.0	I											
92	17	Feb-11-98	17, 18	2	14:06:00	14:36:00	UCAR ADF	-8.0	1	-10	63.1	64.0	10.3	60	12.0	F			37.0	32.0	34.5	22.0					
93	17	Feb-11-98	17, 18	3	14:06:30		Octagon	-4.5	1	-10	63.1	64.0	10.3	60	12.0	DI			36.0	26.0	31.0	22.0					
94	17	Feb-11-98	17, 18	4	14:07:00		Octagon IV	-3.0	4	-10	63.1	64.0	10.3	60	9.0	I			16.0	14.0	15.0						

cm1380\report\buffer\98DEO_LG
6/8/2006

TABLE 3.1

DEICING ONLY - WINTER 1997-98

Test no.	Form no.	Date	Run no.	Plate #	Time of application (Local)	End time (Local)	Fluid name	Fluid freeze temp.	Fluid type	OAT (°C)	Relative Humidity Start (%)	Relative Humidity End (%)	Wind Avg. (km/h)	Initial fluid temp. (°C)	Initial fluid Brix	Condition of plate at end	Brix @ 5 min drip	End Condition: Brix - Location 1	Brix - Location 2	Brix - Location 3	Brix - Location Avg 2,3	Brix - Location Drip	Thickness - Location 1	Thickness - Location 2	Thickness - Location 3	Thickness - Location Drip	Comments
95	17	Feb-11-98	17, 18	5	14:07:30		UCAR ADF	-2.0	1	-10	63.1	64.0	10.3	60	3.0	I			15.0	9.0	12.0	6.0					
96	17	Feb-11-98	17, 18	6	14:08:00		ULTRA IV	-3.0	4	-10	63.1	64.0	10.3	60	5.0	I			16.0		16.0	9.0					
97	18	Feb-11-98	19	1	15:02:00	15:32:00	Water	0.0		-10	65.8	64.1	19.8	60	0.0	I											
98	18	Feb-11-98	19	2	15:04:00	15:34:00	UCAR ADF	-3.0	1	-10	65.8	64.1	19.8	60	5.0	I				10.0	10.0	8.0					
99	18	Feb-11-98	19	3	15:03:00	15:33:00	Octagon	-1.5	1	-10	65.8	64.1	19.8	60	5.0	I				32.0	32.0	12.0					
100	18	Feb-11-98	19	4	15:03:30	15:34:00	T 0 P	-1.5	0	-10	65.8	64.1	19.8	60	5.0	I			40.0	16.0	28.0	10.0					
101	18	Feb-11-98	19	5	15:05:00	15:35:00	UCAR ADF	-2.0	1	-10	65.8	64.1	19.8	60	3.0	I				9.0	9.0	5.0					
102	18	Feb-11-98	19	6	15:05:30	15:36:00	T 0 E	-3.0	0	-10	65.8	64.1	19.8	60	5.0	I			22.0	11.0	16.5						
103	19	Feb-11-98	20	1	16:05:00	16:35:00	ULTRA IV	-3.0	4	-10	65.1	64.0	20.3	60	5.0	I			9.0	8.0	8.5	8.0					
104	19	Feb-11-98	20	2	16:05:30	16:36:00	UCAR ADF	-14.0	1	-10	65.1	64.0	20.3	60	18.0	F			38.0	31.0	34.5	28.0					
105	19	Feb-11-98	20	3	16:06:00	16:36:00	Octagon	-1.5	1	-10	65.1	64.0	20.3	60	5.0	I			32.0	11.0	21.5	7.0					
106	19	Feb-11-98	20	4	16:06:00	16:36:00	T 0 P	-1.5	0	-10	65.1	64.0	20.3	60	5.5	I			42.0	15.0	28.5	11.0					
107	19	Feb-11-98	20	5	16:07:00	16:37:00	UCAR ADF	-2.0	1	-10	65.1	64.0	20.3	60	3.0	I			21.0	8.0	14.5	5.0					
108	19	Feb-11-98	20	6	16:07:30	16:38:00	T 0 E	-3.0	0	-10	65.1	64.0	20.3	60	5.5	I			33.0	24.0	28.5	11.0					
109	20	Feb-12-98	21	1	8:58:30		Water	0.0		-18	72.3	72.8	0.0	60	0.0	I											
110	20	Feb-12-98	21	2	8:59:00		UCAR ADF	-3.0	1	-18	72.3	72.8	0.0	60	5.0	I				15.0	15.0	7.0					
111	20	Feb-12-98	21	3	8:59:30		Octagon	-1.5	1	-18	72.3	72.8	0.0	60	5.0	I				9.0	9.0	7.0					
112	20	Feb-12-98	21	4	9:00:00		T 0 P	-1.5	0	-18	72.3	72.8	0.0	60	5.5	I				12.0	12.0	9.0					
113	20	Feb-12-98	21	5	9:02:00		UCAR ADF	-2.0	1	-18	72.3	72.8	0.0	60	3.0	I				5.0	5.0	5.0					
114	20	Feb-12-98	21	6	9:02:30		T 0 E	-3.0	0	-18	72.3	72.8	0.0	60	5.0	I				11.0	11.0	10.0					
115	21	Feb-12-98	22	1	9:57:00	10:27:00	UCAR ADF	-8.0	1	-18	69.0	69.2	0.0	60	12.0	I			17.0	17.0	17.0	16.0					
116	21	Feb-12-98	22	2	9:58:00	10:28:00	UCAR ADF	-14.0	1	-18	69.0	69.2	0.0	60	18.0	DI			37.0	29.0	33.0	24.0					
117	21	Feb-12-98	22	3	9:58:00	10:28:00	ULTRA IV	-15.0	4	-18	69.0	69.2	0.0	60	18.5	I			20.0	20.0	20.0	20.0					
118	21	Feb-12-98	22	4	9:59:00	10:29:00	T 0 P	-4.5	0	-18	69.0	69.2	0.0	60	13.0	I			37.0	23.0	30.0	21.0					
119	21	Feb-12-98	22	5	9:59:00	10:29:00	UCAR ADF	-22.0	1	-18	69.0	69.2	0.0	60	23.5	F			38.0	34.0	36.0	29.0					
120	21	Feb-12-98	22	6	10:00:00	10:30:00	T 0 E	-8.0	0	-18	69.0	69.2	0.0	60	12.0	I			38.0	21.0	29.5	17.0					
121	22	Feb-12-98	24	1	14:39:00		UCAR ADF	-8.0	1	-18	64.0	64.7	5.1	60	12.0	I			38.0	18.0	28.0	17.0					
122	22	Feb-12-98	24	2	14:40:00		UCAR ADF	-14.0	1	-18	64.0	64.7	5.1	60	17.8	F			39.0	32.0	35.5	23.0					
123	22	Feb-12-98	24	3	14:40:00		Octagon	-4.5	1	-18	64.0	64.7	5.1	60	11.8	I			23.0	23.0	23.0	19.0					
124	22	Feb-12-98	24	4	14:40:30		T 0 P	-4.5	0	-18	64.0	64.7	5.1	60	13.3	I			23.0	19.0	21.0	19.0					
125	22	Feb-12-98	24	5	14:41:00		UCAR ADF	-22.0	1	-18	64.0	64.7	5.1	60	23.5	F											
126	22	Feb-12-98	24	6	14:41:30		T 0 E	-8.0	0	-18	64.0	64.7	5.1	60	12.5	I			34.0	21.0	27.5	17.0					
127	23	Feb-12-98	26	1	13:12:00	13:42:00	Octagon IV	-8.0	4	-18	65.0	66.0	9.5	60	17.8	I			20.0	21.0	20.5	23.0					
128	23	Feb-12-98	26	2	13:12:00	13:42:00	UCAR ADF	-14.0	1	-18	65.0	66.0	9.5	60	18.0	F			40.0	29.0	34.5	26.0					
129	23	Feb-12-98	26	3	13:13:00	13:43:00	Octagon	-4.5	1	-18	65.0	66.0	9.5	60	12.3	I			29.0	22.0	25.5	19.0					
130	23	Feb-12-98	26	4	13:13:00	13:43:00	ULTRA IV	-15.0	4	-18	65.0	66.0	9.5	60	17.3	I			22.0	23.0	22.5	24.0					
131	23	Feb-12-98	26	5	13:14:00	13:44:00	UCAR ADF	-22.0	1	-18	65.0	66.0	9.5	60	23.5	F			40.0	32.0	36.0	29.0					
132	23	Feb-12-98	26	6	13:14:00	13:45:00	UCAR ADF	-8.0	1	-18	65.0	66.0	9.5	60	11.8	I			29.0	19.0	24.0	18.0					
133	24	Feb-12-98	28	1	11:31:30		ULTRA IV	-15.0	4	-18	67.1	66.5	20.1	60	18.5	I			20.0	20.0	20.0	21.0					
134	24	Feb-12-98	28	2	11:32:00		UCAR ADF	-14.0	1	-18	67.1	66.5	20.1	60	18.0	I			32.0	26.0	29.0	24.0					
135	24	Feb-12-98	28	3	11:33:00		Octagon	-4.5	1	-18	67.1	66.5	20.1	60	12.5	I			22.0	20.0	21.0	21.0					
136	24	Feb-12-98	28	4	11:33:00		T 0 P	-4.5	0	-18	67.1	66.5	20.1	60	12.0	I			25.0	22.0	23.5						
137	24	Feb-12-98	28	5	11:33:30		UCAR ADF	-8.0	1	-18	67.1	66.5	20.1	60	12.0	I			22.0	20.0	21.0	19.0					
138	24	Feb-12-98	28	6	11:34:00		T 0 E	-8.0	0	-18	67.1	66.5	20.1	60	12.5	I			24.0	19.0	21.5	16.0					
139	25	Feb-13-98	29	1	9:43:00	10:13:00	Water	0.0		-35	65.8	63.9	0.0	60	0.0	I											
140	25	Feb-13-98	29	2	9:43:00	10:14:00	Octagon	-27.0	1	-35	65.8	63.9	0.0	60	32.5	I			37.0	37.0	37.0	38.0					
141	25	Feb-13-98	29	3	9:44:00	10:15:00	UCAR ADF	-22.0	1	-35	65.8	63.9	0.0	60	23.8	I			32.0	27.0	29.5	27.0					

TABLE 3.1

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Test no.	Form no.	Date	Run no.	Plate #	Time of application (Local)	End time (Local)	Fluid name	Fluid freeze temp.	Fluid type	OAT (°C)	Relative Humidity Start (%)	Relative Humidity End (%)	Wind Avg. (km/h)	Initial fluid temp. (°C)	Initial fluid Brix	Condition of plate at end	Brix @ 5 min drip	End Condition Brix - Location 1	Brix - Location 2	Brix - Location 3	Brix - Location Avg 2,3	Brix - Location Drip	Thickness - Location 1	Thickness - Location 2	Thickness - Location 3	Thickness - Location Drip	Comments
142	25	Feb-13-98	29	4	9:44:00	10:15:00	Octagon	-20.0	1	-35	65.8	63.9	0.0	60	27.5	I			33.0	33.0	33.0	35.0					
143	25	Feb-13-98	29	5	9:45:00	10:15:00	UCAR ADF	-43.0	1	-35	65.8	63.9	0.0	60	33.0	F			39.0	37.0	38.0	37.0					
144	25	Feb-13-98	29	6	9:45:30	10:16:00	UCAR ADF	-30.0	1	-35	65.8	63.9	0.0	60	28.5	I			37.0	34.0	35.5						
145	26	Feb-13-98	30	1	11:40:30		Water	0.0		-35	58.5	58.3	4.8	60	0.0	I											
146	26	Feb-13-98	30	2	11:41:00		Octagon	-27.0	1	-35	58.5	58.3	4.8	60	33.5	I			38.0	35.0	36.5	36.0					
147	26	Feb-13-98	30	3	11:41:30		UCAR ADF	-22.0	1	-35	58.5	58.3	4.8	60	24.0	I			32.0	27.0	29.5	26.0					
148	26	Feb-13-98	30	4	11:42:00		Octagon	-20.0	1	-35	58.5	58.3	4.8	60	28.0	I			34.0	32.0	33.0	33.0					
149	26	Feb-13-98	30	5	11:42:30		UCAR ADF	-43.0	1	-35	58.5	58.3	4.8	60	32.5	F			38.0	37.0	37.5	30.0					
150	26	Feb-13-98	30	6	11:43:00		UCAR ADF	-30.0	1	-35	65.8	64.1	4.8	60	28.0	I			39.0	34.0	36.5	34.0					
151	27	Mar-30-98	1	1	12:29:00		UCAR ADF	-2.0	1	-5			0.0	62	3.0	I	5.0			14.5	14.5	6.5			<1	Ice	
152	27	Mar-30-98	1	2	12:30:00		Octagon	-1.5	1	-5			0.0	60	5.0	DI	6.5			18.0	18.0	8.5			<2	Ice	
153	27	Mar-30-98	1	3	12:30:30		Kilfrost	-1.5	2	-5			0.0	60	5.3	DI	6.5					9.5			<3	Ice	
154	27	Mar-30-98	1	4	12:31:00		ULTRA IV	-2.0	4	-5			0.0	59	3.3	I	5.0		15.5	7.5	11.5	7.0		<1	Ice	Ice	
155	28	Mar-30-98	2	1	14:04:00		UCAR ADF	-2.0	1	-5			20.0	62	3.0	I	5.3		17.0	5.5	11.3	3.5		<1	Ice	Ice	
156	28	Mar-30-98	2	2	14:04:00		Octagon	-1.5	1	-5			20.0	58	5.3	I	5.0		15.5	10.0	12.8	8.0		2.0	Ice	Ice	
157	28	Mar-30-98	2	3	14:04:00		Kilfrost	-1.5	2	-5			20.0	58	5.3	I	6.3		17.0	9.5	13.3	8.0		2.0	Ice	Ice	
158	28	Mar-30-98	2	4	14:05:00		ULTRA IV	-2.0	4	-5			20.0	60	3.5	I	5.0		10.0	9.0	9.5	8.0		Ice	Ice	Ice	
159	29	Mar-30-98	3	1	15:31:30		UCAR ADF	-2.0	1	-5			10.5	60	3.3	I	4.0			7.0	7.0	6.0		<1	Ice	Ice	
160	29	Mar-30-98	3	2	15:32:00		Octagon	-1.5	1	-5			10.5	60	5.3	I	6.0			10.0	10.0	7.5		<1	Ice	Ice	
161	29	Mar-30-98	3	3	15:32:30		Kilfrost	-1.5	2	-5			10.5	60	5.5	I	6.5			15.0	15.0	9.0		<1	<1	Ice	
162	29	Mar-30-98	3	4	15:33:00		ULTRA IV	-2.0	4	-5			10.5	61	3.3	I	3.5		13.0	7.0	10.0	6.0		<1	Ice	Ice	
163	30	Mar-30-98	3	1	17:03:30		UCAR ADF	-2.0	1	-5			4.9	59	3.3	I	5.0			11.5	11.5	6.5			<1	Ice	
164	30	Mar-30-98	3	2	17:04:00		Octagon	-1.5	1	-5			4.9	58	5.0	I	5.0			15.5	15.5	7.0			<1	Ice	
165	30	Mar-30-98	3	3	17:04:00		Kilfrost	-1.5	2	-5			4.9	60	5.3	DI	7.0			19.5	19.5	8.0			<1	Ice	
166	30	Mar-30-98	3	4	17:05:00		ULTRA IV	-2.0	4	-5			4.9	58	3.5	I	4.0		15.0	7.0	11.0	5.0		<1	Ice	Ice	
167	31	Mar-31-98	1	1	8:58:30		UCAR ADF	-32.0	1	-35	59.9	60.2	10.3	61	29.0	S	30.0	36.0	34.0	32.0	33.0	33.0	1.5	2.2	2.2	30.0	
168	31	Mar-31-98	1	2	8:59:00		Octagon	-27.0	1	-35	59.9	60.2	10.3	60	32.0	S	34.0	41.0	38.0	38.0	38.0	38.5	2.2	2.2	6.0	30.0	
169	31	Mar-31-98	1	3	8:59:30		Kilfrost	-27.0	2	-35	59.9	60.2	10.3	62	33.0	S	35.0	38.0	37.5	37.5	37.5	37.0	6.6	14.2	16.0	35.0	
170	31	Mar-31-98	1	4	9:00:00		ULTRA IV	-32.0	4	-35	59.9	60.2	10.3	30	29.5	F	33.0	33.0	33.0	32.5	32.8	32.5	48.0	48.0	48.0	80.0	
171	32	Mar-31-98	2	1	11:13:00		UCAR ADF	-30.0	1	-33	62.1	62.0	19.5	28	28.0	S	30.0	36.0	32.3	32.0	32.1	32.3	2.2	2.2	2.2	16.0	
172	32	Mar-31-98	2	2	11:13:30		Octagon	-27.0	1	-33	62.1	62.0	19.5	32	32.0	S	34.0	39.0	37.5	37.0	37.3	37.5	2.6	2.6	2.6	20.2	
173	32	Mar-31-98	2	3	11:14:00		Kilfrost	-27.0	2	-33	62.1	62.0	19.5	32	32.0	S	35.0	38.0	37.5	37.5	37.5	37.5	7.7	16.6	16.6	48.0	
174	32	Mar-31-98	2	4	11:14:30		ULTRA IV	-30.0	4	-33	62.1	62.0	19.5	28	28.0	S	31.0	33.3	33.3	33.3	33.3	33.3	30.0	35.0	48.0	48.0	
175	33	Mar-31-98		1	14:45:00		UCAR ADF	-22.0	1	-25	65.4		19.5	60	23.8	S	27.0	35.0	31.0	29.5	30.3	27.5	2.6	2.6	2.6	48.0	Lost thermistor data, repeat April 03
176	33	Mar-31-98		2	14:45:00		Octagon	-20.0	1	-25	65.4		19.5	61	28.3	S	31.0	37.0	35.5	34.5	35.0	32.5	2.6	2.6	2.6	40.0	Lost thermistor data, repeat April 03
177	33	Mar-31-98		3	14:46:00		Kilfrost	-21.0	2	-25	65.4		19.5	61	28.5	S	32.0	34.0	33.5	34.0	33.8	34.5	20.2	20.2	20.2	25.0	Lost thermistor data, repeat April 03
178	33	Mar-31-98		4	14:46:00		ULTRA IV	-22.0	4	-25	65.4		19.5	61	24.0	S	27.0	30.0	29.5	29.5	29.5	28.5	30.0	29.5	29.5	28.5	Lost thermistor data, repeat April 03
179	34	Mar-31-98		1	16:17:30		UCAR ADF	-22.0	1	-25	66.9	67.1	10.3	61	23.5	F	27.0	37.0	37.5	32.0	34.8	35.0	2.2	2.2	2.2	40.0	Lost thermistor data, repeat April 03
180	34	Mar-31-98		2	16:18:00		Octagon	-20.0	1	-25	66.9	67.1	10.3	60	27.8	S	31.0	42.0	35.0	34.5	34.8	34.0	1.5	2.2	2.8	48.0	Lost thermistor data, repeat April 03
181	34	Mar-31-98		3	16:18:00		Kilfrost	-21.0	2	-25	66.9	67.1	10.3	61	28.0	F	31.5	34.0	33.5	33.5	33.5	33.5	20.2	20.2	20.2	48.0	Lost thermistor data, repeat April 03
182	34	Mar-31-98		4	16:19:00		ULTRA IV	-22.0	4	-25	66.9	67.1	10.3	60	23.8	S	27.0	29.5	29.5	29.5	29.5	29.5	40.0	40.0	48.0	48.0	Lost thermistor data, repeat April 03
183	35	Apr-20-98		1	12:18:00		UCAR ADF	-34.0	1	-34	56.0	57.7	0.0	61	29.5	F											
184	35	Apr-20-98		3	11:52:00		Octagon	-34.0	1	-34	56.0	57.7	0.0	60	35.0	F											
185	36	Apr-20-98		1	13:16:30		UCAR ADF	-34.0	1	-34	57.7	60.2	20.0	61	29.5	F											
186	36	Apr-20-98		3	13:34:00		Octagon	-34.0	1	-34	57.7	60.2	20.0	60	35.0	F											
187	37	Apr-20-98		1	14:07:00		UCAR ADF	-34.0	1	-34	62.5	67.2	10.0	61	29.5	F											
188	37	Apr-20-98		3	14:23:00		Octagon	-34.0	1	-34	62.5	67.2	10.0	60	35.0	F											

TABLE 3.1

DEICING ONLY - WINTER 1997-98

Test no.	Form no.	Date	Run no.	Plate #	Time of application (Local)	End time (Local)	Fluid name	Fluid freeze temp.	Fluid type	OAT (°C)	Relative Humidity Start (%)	Relative Humidity End (%)	Wind Avg. (km/h)	Initial fluid temp. (°C)	Initial fluid Brix	Condition of plate at end	Brix @ 5 min drip	End Condition Brix - Location 1	2	3	Avg 2,3	Drip	Thickness - Location 1	2	3	Drip	Comments
189	38	Apr-20-98		1	15:27:00		UCAR ADF	-25.0	1	-25	69.3	68.5	10.0	60	25.5	F											
190	38	Apr-20-98		3	15:12:00		Octagon	-25.0	1	-25	69.3	68.5	10.0	59	31.5	F											
191	39	Apr-20-98		1	16:13:00		UCAR ADF	-25.0	1	-25	65.2	64.6	20.0	60	25.5	F											
192	39	Apr-20-98		3	16:26:30		Octagon	-25.0	1	-25	65.2	64.6	20.0	61	31.5	F											
193	40	Apr-20-98		1	17:15:00		UCAR ADF	-25.0	1	-25	64.7	64.4	0.0	60	25.5	F											
194	40	Apr-20-98		3	17:23:00		Octagon	-25.0	1	-25	64.7	64.4	0.0	60	31.5	F											
195	41	Apr-21-98		1	8:48:00		UCAR ADF	-15.0	1	-15	67.7	65.6	0.0	71	18.5	F											
196	41	Apr-21-98		3	8:37:30		Octagon	-15.0	1	-15	67.7	65.6	0.0	61	24.0	F											
197	42	Apr-21-98		1	9:20:30		UCAR ADF	-15.0	1	-15	65.6	66.8	20.0	61	18.5	F											
198	42	Apr-21-98		3	9:32:30		Octagon	-15.0	1	-15	65.6	66.8	20.0	66	24.0	F											
199	43	Apr-21-98		1	10:14:00		UCAR ADF	-15.0	1	-15	67.3	66.6	10.0	61	19.0	F											
200	43	Apr-21-98		3	10:35:00		Octagon	-15.0	1	-15	67.3	66.6	10.0	61	24.0	F											
201	44	Apr-21-98		1	11:17:00		UCAR ADF	-15.0	1	-15	66.6	68.2	5.0	60	19.0	F											
202	44	Apr-21-98		3	11:39:00		Octagon	-15.0	1	-15	66.6	68.2	5.0	60	24.0	F											
203	45	Apr-21-98		1	12:53:30		UCAR ADF	-5.0	1	-5			5.0	60	8.5	F											
204	45	Apr-21-98		3	13:02:00		Octagon	-5.0	1	-5			5.0	60	14.0	F											
205	46	Apr-21-98		1	13:39:00		UCAR ADF	-5.0	1	-5	73.5	72.3	10.0	61	8.5	F											
206	46	Apr-21-98		3	14:03:00		Octagon	-5.0	1	-5	73.5	72.3	10.0	60	13.8	F											
207	47	Apr-21-98		1	14:44:00		UCAR ADF	-5.0	1	-5	69.3	69.8	20.0	60	8.5	F											
208	47	Apr-21-98		3	14:54:00		Octagon	-5.0	1	-5	69.3	69.8	20.0	60	13.8	F											
209	48	Apr-21-98		1	15:19:12		UCAR ADF	-5.0	1	-5	72.9	72.6	0.0	60	8.5	F											
210	48	Apr-21-98		3	15:23:00		Octagon	-5.0	1	-5	72.9	72.6	0.0	61	13.8	F											

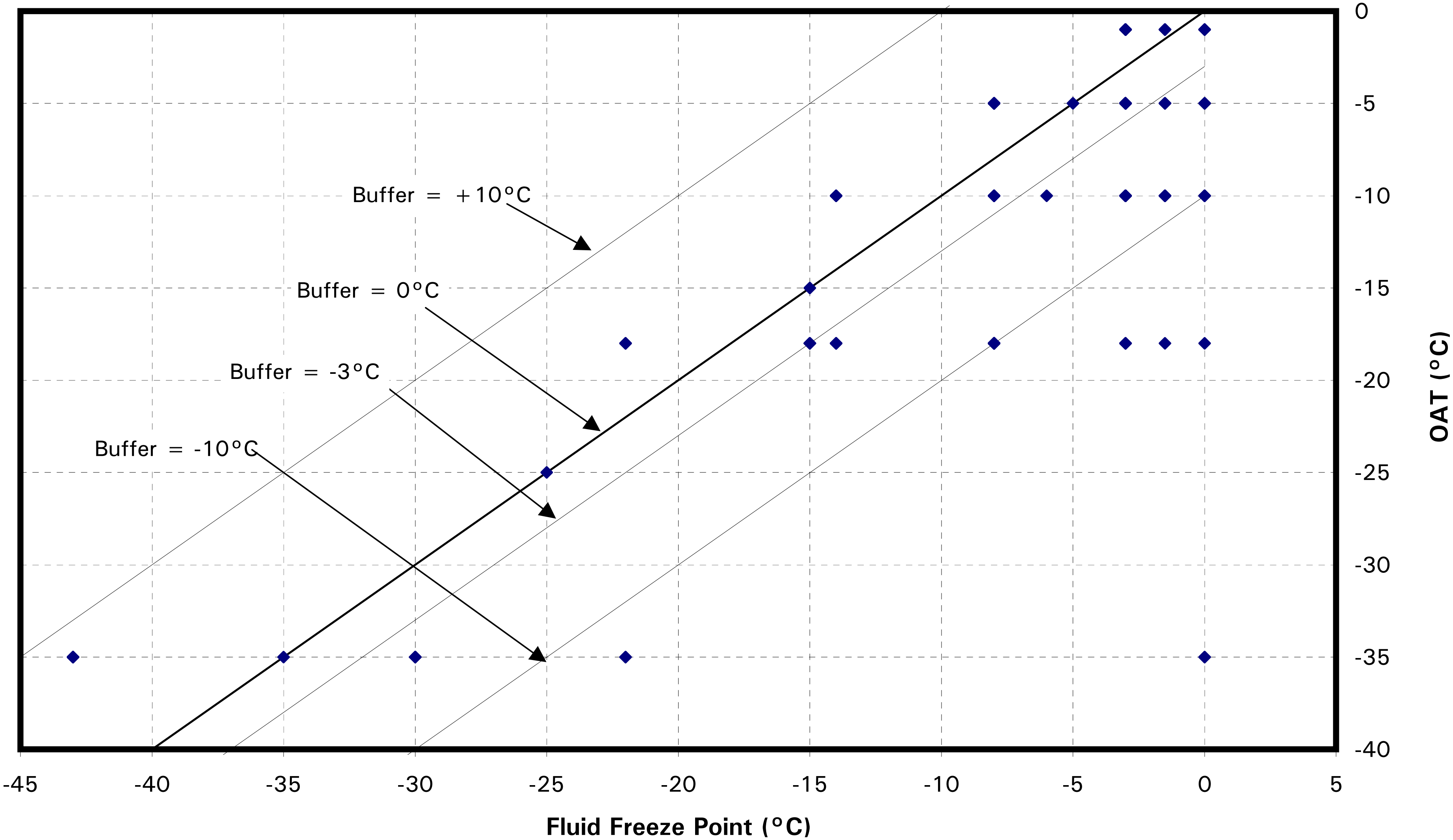
point. A test point at the intersection of the horizontal line representing -10°C outside air temperature and the vertical line representing an initial fluid freeze point of -7°C would have a negative buffer value of -3°C, and the diagonal -3°C line passes through this point.

Test data were sorted and graphically presented in several arrangements as described in Section 4, to aid in understanding results and reaching conclusions.

FIGURE 3.4

DEICING ONLY TESTS

FLUID TEST RANGE



cm1380\report\buffer\DE_TESTS
At: Range
2/20/2007

3.4 First-Step Fluid Tests at NRC's CEF

The principal test session was conducted from February 9 to February 11, 1998, concurrent with the initial tests for the *deicing only* study. A further test was conducted on April 1, 1998, to investigate the influence of wind on test fluid behaviour.

A log of the tests conducted, along with test results, is given in Table 3.2. The range of conditions over which tests were performed is shown graphically in Figure 3.5. As described for the *deicing only* study, the diamonds represent test points, with values of outside air temperature on the vertical scale, and values for initial fluid freeze point on the horizontal scale. The points identified with a large X represent test conditions for supplemental tests. These supplemental tests were performed to assess the impact of wind on test fluid freezing profiles. Note that tests planned at the outside air temperature of -25°C were not conducted due to refrigeration limitations in the smaller chamber of the facility, where freezing rain-type precipitation tests are normally conducted. As well, stable wind speeds of 5 km/h were not able to be produced, and no data are reported for that test condition.

The test data, including the test fluid concentration profiles, were processed and are presented in several graphical formats to aid in reaching conclusions on test results. These are presented and discussed in Chapter 4.

TABLE 3.2

FIRST STEP FLUID FAILURE - WINTER 1997-98

Test no.	Form no.	Date	Run no.	Plate #	Thermistor #	Time of application (Local)	Time to 1st freezing (Local)	Time to failure (6") (Local)	Time to complete failure (15") (Local)	Fluid name	Fluid freeze temp.	Fluid type	OAT (°C)	Wind (kph)	Fluid temp. (°C)	Fluid Brix	Time to 1st freezing (min)	Time to failure (6") (min)	Time to complete failure (15") (min)	AVG PAN	Comments
1	1	Feb-09-98	1	8	8	15:24:56	15:35:34	15:36:28	15:36:28	H_2O	0		-3	0	59	0.0	10.6	11.5	11.5	24.2	
2	1	Feb-09-98	1	9	9	15:30:59	15:39:32	15:40:44	15:43:30	H_2O	0		-3	0	59	0.0	8.6	9.8	12.5	23.8	
3	2	Feb-10-98	2	8	8	10:21:00	10:26:37	10:27:01	10:27:09	H_2O	0		-8	0	60	0.0	5.6	6.0	6.2	24.3	
4	2	Feb-10-98	2	9	9	10:22:40	10:27:47	10:28:22	10:28:36	Ultra IV	-3	4	-8	0	60	5.0	5.1	5.7	5.9	23.9	
5	2	Feb-10-98	2	10	10	10:24:22	10:28:30	10:29:40	10:29:40	Octagon MaxFlight	-1	4	-8	0	60	5.0	4.1	5.3	5.3	25.1	
6	2	Feb-10-98	2	11	11	10:25:26	10:32:00	10:32:40	10:33:33	UCAR ADF	-3	1	-8	0	60	5.0	6.6	7.2	8.1	24.7	
7	2	Feb-10-98	2	12	12	10:26:20	10:32:14	10:32:50	10:33:50	Octagon	-1	1	-8	0	60	5.0	5.9	6.5	7.5	23.5	
8	2	Feb-10-98	2	13	13	10:27:20	10:33:23	10:33:55	10:34:26	Octagon 40 Below	-1	2	-8	0	60	5.5	6.1	6.6	7.1	26.2	
9	3	Feb-10-98	2a	8	8	13:27:25	13:33:00	13:33:35	13:34:24	H_2O	0		-8	0	60	0.0	5.6	6.2	7.0	24.3	
10	3	Feb-10-98	2a	9	9	13:28:13	13:33:11	13:34:30	13:35:12	Ultra IV	-3	4	-8	0	60	5.5	5.0	6.3	7.0	23.9	
11	3	Feb-10-98	2a	10	10	13:28:55	13:34:00	13:35:00	13:35:30	Octagon MaxFlight	-1	4	-8	0	60	5.0	5.1	6.1	6.6	25.1	
12	3	Feb-10-98	2a	11	11	13:29:35	13:35:11	13:35:40	13:36:15	UCAR ADF	-3	1	-8	0	60	5.0	5.6	6.1	6.7	24.7	
13	3	Feb-10-98	2a	12	12	13:30:08	13:35:15	13:35:50	13:36:20	Octagon	-1	1	-8	0	60	5.0	5.1	5.7	6.2	23.5	
14	3	Feb-10-98	2a	13	13	13:30:43	13:36:00	13:36:30	13:37:00	Octagon 40 Below	-1	2	-8	0	60	5.0	5.3	5.8	6.3	26.2	
15	4	Feb-10-98	3	9	9	11:37:15	11:43:15	11:43:50	11:45:12	Ultra IV	-6	4	-8	0	60	9.8	6.0	6.6	8.0	23.9	
16	4	Feb-10-98	3	10	10	11:38:31	11:43:40	11:44:10	11:44:57	Octagon MaxFlight	-3	4	-8	0	60	10.0	5.2	5.7	6.4	25.1	
17	4	Feb-10-98	3	11	11	11:39:59	11:45:12	11:46:07	11:46:50	UCAR ADF	-6	1	-8	0	60	9.5	5.2	6.1	6.9	24.7	
18	4	Feb-10-98	3	12	12	11:41:35	11:47:13	11:47:50	11:48:13	Octagon	-3	1	-8	0	60	9.5	5.6	6.3	6.6	23.5	
19	4	Feb-10-98	3	13	13	11:43:00	11:48:40	11:49:07	11:49:50	Octagon 40 Below	-3	2	-8	0	60	9.9	5.7	6.1	6.8	26.2	
20	5	Feb-10-98	3a	9	9	14:45:25	14:51:26	14:51:42	14:52:44	Ultra IV	-6	4	-8	0	60	9.5	6.0	6.3	7.3	23.9	
21	5	Feb-10-98	3a	10	10	14:46:58	14:51:30	14:53:16	14:53:34	Octagon MaxFlight	-3	4	-8	0	60	10.0	4.5	6.3	6.6	25.5	
22	5	Feb-10-98	3a	11	11	14:47:53	14:53:54	14:54:34	14:54:55	UCAR ADF	-6	1	-8	0	60	9.5	6.0	6.7	7.0	22.5	
23	5	Feb-10-98	3a	12	12	14:48:45	14:54:00	14:54:36	14:54:57	Octagon	-3	1	-8	0	60	10.0	5.3	5.9	6.2	22.5	
24	5	Feb-10-98	3a	13	13	14:49:30	14:55:15	14:56:52	14:56:50	Octagon 40 Below	-3	2	-8	0	60	10.0	5.8	7.4	7.3	23.9	
25	6	Feb-10-98	4	9	9	12:28:38	12:30:34	12:34:40	12:35:35	Type 0 Ethylene	-3	0	-8	0	60	5.5	1.9	6.0	7.0	23.9	
26	6	Feb-10-98	4	10	10	12:29:35	12:35:16	12:35:30	12:36:12	Hoechst	-1	2	-8	0	60	5.0	5.7	5.9	6.6	25.1	
27	6	Feb-10-98	4	11	11	12:30:20	12:36:22	12:36:41	12:37:03	Type 0 Ethylene	-3	0	-8	0	60	5.5	6.0	6.4	6.7	24.7	
28	6	Feb-10-98	4	12	12	12:31:12	12:37:00	12:37:40	12:39:00	Type 0 Propylene	-1	0	-8	0	60	5.5	5.8	6.5	7.8	23.5	
29	6	Feb-10-98	4	13	13	12:32:00	12:37:58	12:38:27	12:39:30	Type 0 Propylene	-1	0	-8	0	60	5.5	6.0	6.5	7.5	26.2	
30	7	Feb-10-98	4a	9	9	15:14:59	15:20:24	15:21:11	15:22:11	Type 0 Ethylene	-3	0	-8	0	60	5.0	5.4	6.2	7.2	23.9	
31	7	Feb-10-98	4a	10	10	15:15:30	15:20:58	15:21:35	15:22:45	Hoechst	-1	2	-8	0	60	5.5	5.5	6.1	7.3	25.5	
32	7	Feb-10-98	4a	11	11	15:16:00	15:21:47	15:22:33	15:21:00	Type 0 Ethylene	-3	0	-8	0	60	5.0	5.8	6.6	5.0	22.5	
33	7	Feb-10-98	4a	12	12	15:17:00	15:22:22	15:23:50	15:24:30	Type 0 Propylene	-1	0	-8	0	60	5.0	5.4	6.8	7.5	22.5	
34	7	Feb-10-98	4a	13	13	15:17:35	15:23:35	15:24:24	15:25:00	Type 0 Propylene	-1	0	-8	0	60	5.0	6.0	6.8	7.4	23.9	
35	8	Feb-11-98	5	8	8	10:37:40	10:41:17	10:41:50	10:42:53	H_2O	0		-14	0	60	0.0	3.6	4.2	5.2	26.4	
36	8	Feb-11-98	5	9	9	10:38:15	10:41:30	10:41:50	10:42:42	UCAR ADF	-6	1	-14	0	60	9.0	3.3	3.6	4.5	27.0	
37	8	Feb-11-98	5	10	10	10:38:40	10:41:39	10:42:31	10:43:35	Octagon MaxFlight	-3	4	-14	0	60	10.0	3.0	3.9	4.9	27.0	
38	8	Feb-11-98	5	11	11	10:39:15	10:43:00	10:43:30	10:43:40	UCAR ADF	-3	1	-14	0	60	5.0	3.8	4.3	4.4	24.3	
39	8	Feb-11-98	5	12	12	10:39:40	10:42:58	10:43:50	10:44:00	Octagon	-3	1	-14	0	60	13.0	3.3	4.2	4.3	25.5	
40	8	Feb-11-98	5	13	13	10:40:10	10:43:30	10:44:28	10:44:30	Octagon 40 Below	-3	2	-14	0	60	10.0	3.3	4.3	4.3	25.7	
42	9	Feb-11-98	5a	9	9	13:21:38	13:24:11	13:25:21	13:26:30	UCAR ADF	-6	1	-14	0	60	9.0	2.6	3.7	4.9	27.0	
43	9	Feb-11-98	5a	10	10	13:22:30	13:25:30	13:26:28	13:27:05	Octagon MaxFlight	-3	4	-14	0	60	9.5	3.0	4.0	4.6	27.0	
44	11	Feb-11-98	5a	11	11	13:23:12	13:26:00	13:27:00	13:28:18	UCAR ADF	-3	1	-14	0	60	5.0	2.8	3.8	5.1	24.3	

TABLE 3.2

FIRST STEP FLUID FAILURE - WINTER 1997-98

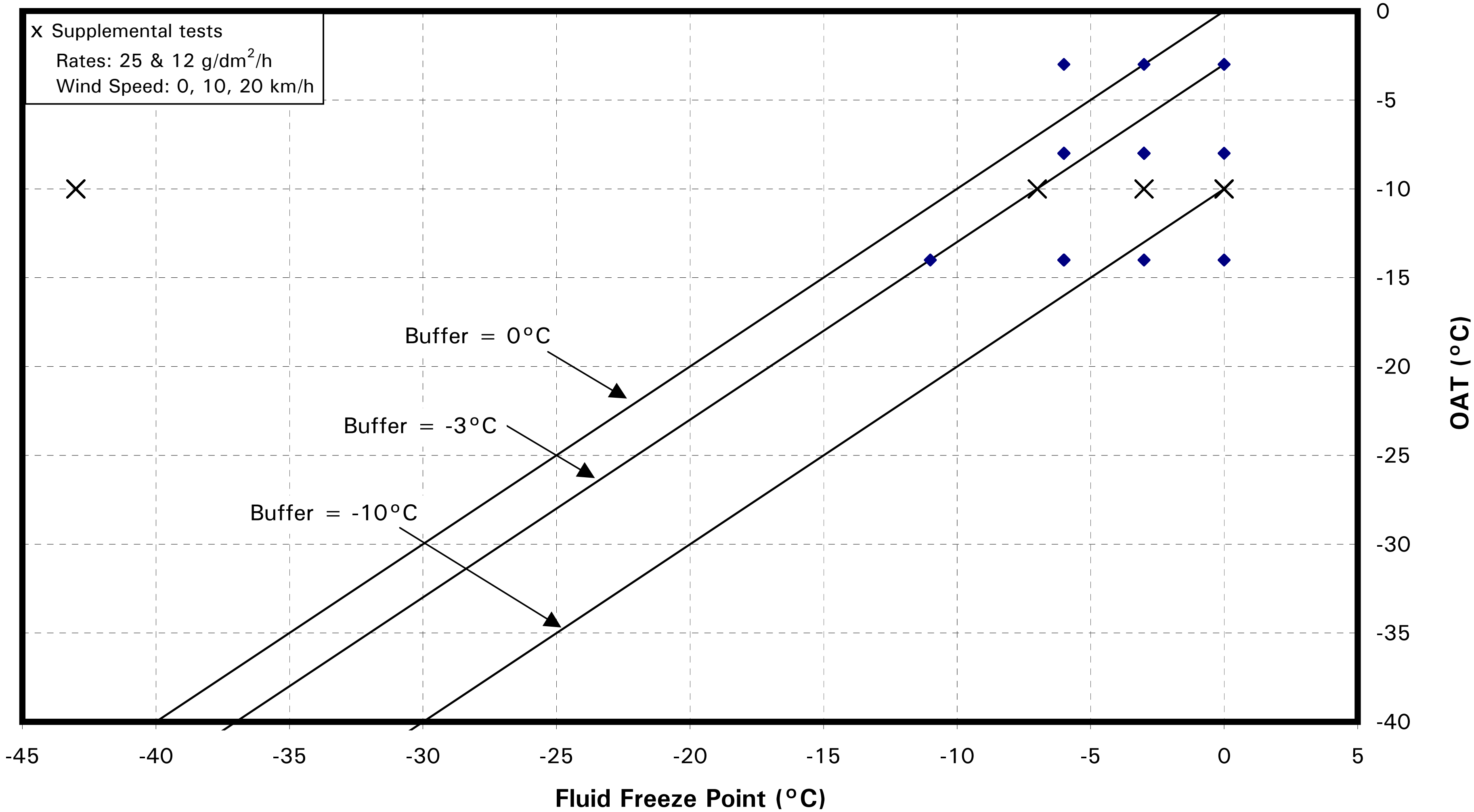
Test no.	Form no.	Date	Run no.	Plate #	Thermistor #	Time of application (Local)	Time to 1st freezing (Local)	Time to failure (6") (Local)	Time to complete failure (15") (Local)	Fluid name	Fluid freeze temp.	Fluid type	OAT (°C)	Wind (kph)	Fluid temp. (°C)	Fluid Brix	Time to 1st freezing (min)	Time to failure (6") (min)	Time to complete failure (15") (min)	AVG PAN	Comments
45	9	Feb-11-98	5a	12	12	13:23:47	13:26:05	13:27:22	13:27:50	Octagon	-3	1	-14	0	60	9.5	2.3	3.6	4.1	25.5	
46	9	Feb-11-98	5a	13	13	13:24:05	13:27:20	13:28:12	13:28:40	Octagon 40 Below	-3	2	-14	0	60	9.5	3.3	4.1	4.6	25.7	
47	10	Feb-11-98	6	9	9	11:36:55	11:41:00	11:42:00	11:42:30	Ultra IV	-6	4	-14	0	60	10.0	4.1	5.1	5.6	27.0	
48	10	Feb-11-98	6	10	10	11:37:25	11:41:45	11:42:20	11:42:47	Hoechst	-3	2	-14	0	60	9.5	4.3	4.9	5.4	27.0	
49	10	Feb-11-98	6	11	11	11:38:50	11:42:04	11:42:55	11:43:20	UCAR ADF	-11	1	-14	0	60	16.0	3.2	4.1	4.5	24.3	
50	10	Feb-11-98	6	12	12	11:39:15	11:42:50	11:43:40	11:44:00	Type 0 Propylene	-3	0	-14	0	60	9.5	3.6	4.4	4.8	25.5	
51	11	Feb-11-98	6a	9	9	12:30:10	12:34:12	12:34:55	12:35:30	Ultra IV	-6	4	-14	0	60	10.0	4.0	4.8	5.3	27.0	
52	11	Feb-11-98	6a	10	10	12:30:45	12:35:10	12:35:35	12:36:20	Hoechst	-3	2	-14	0	60	9.5	4.4	4.8	5.6	27.0	
53	11	Feb-11-98	6a	11	11	12:31:30	12:34:30	12:35:12	12:36:13	UCAR ADF	-11	1	-14	0	60	16.5	3.0	3.7	4.7	24.3	
54	11	Feb-11-98	6a	12	12	12:31:55	12:35:00	12:35:40	12:36:44	Type 0 Propylene	-3	0	-14	0	60	10.0	3.1	3.8	4.8	25.5	
55	11	Feb-11-98	6a	13	13	12:32:25	12:35:50	12:36:45	12:37:45	Type 0 Ethylene	-6	0	-14	0	60	9.0	3.4	4.3	5.3	25.7	
56	S4	Feb-10-98		9	9	17:17:35	17:19:08	17:20:11	17:20:55	UCAR ADF	-6	1	-8	10	60	5.0	1.6	2.6	3.3	23.9	Special Test with Wind
57	S1	Feb-10-98		9	9	16:09:35	16:12:44	16:13:32	16:14:15	UCAR ADF	-3	1	-8	6	60	5.5	3.2	4.0	4.7	23.9	Special Test with Wind
58	S2	Feb-10-98		9	9	16:40:15	16:43:25	16:44:00	16:44:32	UCAR ADF	-3	1	-8	6	60	5.5	3.2	3.8	4.3	23.9	Special Test with Wind
59	S3	Feb-10-98		9	9	16:49:16	16:50:30	16:50:59	16:52:20	UCAR ADF	-3	1	-8	10	60	5.5	1.2	1.7	3.1	23.9	Special Test with Wind
60	S4	Feb-09-98				15:50:45		16:02:55		XL54	std	1	-3		53		N/F	12.2	N/F		Special Test - FLUID DILUTION
61	S5	Feb-09-98				16:04:04		16:12:38		UCAR ADF	-6	1	-3		57			8.6			Special Test - FLUID DILUTION
62	S6	Feb-09-98				16:18:00		16:26:31		UCAR ADF	-3	1	-3		59		N/F	8.5	N/F		Special Test - FLUID DILUTION
63	1	Apr-01-98	1	1	1	11:07:30	11:09:00	11:09:00	11:11:30	H2O			-10	20	61	0.0	1.5	1.5	4.0	24.2	Wind Effect
64	1	Apr-01-98	1	7	4	11:08:20	11:09:00	11:10:00	11:11:30	UCAR ADF	-3	1	-10	20	61	4.8	0.7	1.7	3.2	27.6	Wind Effect
65	1	Apr-01-98	1	8	5	11:09:00	11:11:00	11:11:30	11:12:00	UCAR ADF	-7	1	-10	20	61	11.3	2.0	2.5	3.0	27.4	Wind Effect
66	1	Apr-01-98	1	12	6	11:09:10	11:12:30	11:13:40	11:16:00	XL54	std	1	-10	20	61	34.0	3.3	4.5	6.8	24.3	Wind Effect
67	2	Apr-01-98	2	1	1	13:09:30	13:13:30	13:15:00	13:15:50	H2O			-10	0	61		4.0	5.5	6.3	23.9	Wind Effect
68	2	Apr-01-98	2	4	4	13:10:00	13:13:30	13:14:40	13:16:00	UCAR ADF	-3	1	-10	0	60	4.3	3.5	4.7	6.0	24.0	Wind Effect
69	2	Apr-01-98	2	5	5	13:10:30	13:14:30	13:15:45	13:16:45	UCAR ADF	-7	1	-10	0	61	12.0	4.0	5.3	6.3	22.7	Wind Effect
70	2	Apr-01-98	2	9	6	13:11:00	13:15:40	13:16:20	13:16:35	XL54	std	1	-10	0	61	33.0	4.7	5.3	5.6	24.9	Wind Effect
71	3	Apr-01-98	3	1	1	15:17:30	15:21:30	15:22:20		H2O			-10	0	60		4.0	4.8	N/F	12.5	Wind Effect
72	3	Apr-01-98	3	2	2	15:18:00	15:21:45	15:22:50	15:24:00	UCAR ADF	-3	1	-10	0	61	4.3	3.8	4.8	6.0	12.0	Wind Effect
73	3	Apr-01-98	3	3	3	15:18:30	15:23:00	15:23:45	15:24:30	UCAR ADF	-7	1	-10	0	60	11.0	4.5	5.3	6.0	13.0	Wind Effect
74	3	Apr-01-98	3	9	6	15:19:00	15:24:45	15:25:30	15:26:00	XL54	std	1	-10	0	60	33.5	5.8	6.5	7.0	13.0	Wind Effect
75	4	Apr-01-98	4	1	1	16:48:30	16:50:00	16:50:15	16:51:45	H2O			-10	20	60		1.5	1.8	3.3	13.6	Wind Effect
76	4	Apr-01-98	4	3	3	16:49:00	16:50:40	16:51:30	16:52:30	UCAR ADF	-3	1	-10	20	61	4.3	1.7	2.5	3.5	13.5	Wind Effect
77	4	Apr-01-98	4	7	4	16:49:00	16:51:00	16:52:00	16:53:00	UCAR ADF	-7	1	-10	20	61	11.0	2.0	3.0	4.0	13.1	Wind Effect
78	4	Apr-01-98	4	8	5	16:49:30	16:53:20	16:57:00	16:58:30	XL54	std	1	-10	20	61	33.5	3.8	7.5	9.0	11.8	Wind Effect
79	5	Apr-01-98	5	1	1	17:36:00	17:38:15	17:39:00	17:40:45	H2O			-10	10	61		2.3	3.0	4.8	13.3	Wind Effect
80	5	Apr-01-98	5	3	3	17:36:30	17:38:30	17:39:30	17:40:45	UCAR ADF	-3	1	-10	10	60	5.0	2.0	3.0	4.3	13.9	Wind Effect
81	5	Apr-01-98	5	7	4	17:36:45	17:39:20	17:40:30	17:41:15	UCAR ADF	-7	1	-10	10	60	11.3	2.6	3.8	4.5	12.0	Wind Effect
82	5	Apr-01-98	5	10	6	17:37:00	17:41:45	17:42:30	17:43:45	XL54	std	1	-10	10	60	33.8	4.8	5.5	6.8	12.0	Wind Effect
83	6	Apr-01-98	4	2	2	18:11:00	18:13:15	18:14:15	18:15:30	H2O			-10	10	60	0.0	2.3	3.3	4.5	23.7	Wind Effect
84	6	Apr-01-98	4	3	3	18:11:30	18:13:30	18:14:30	18:15:45	UCAR ADF	-3	1	-10	10	61	5.0	2.0	3.0	4.3	24.4	Wind Effect
85	6	Apr-01-98	4	9	5	18:11:45	18:14:45	18:15:30	18:16:00	UCAR ADF	-7	1	-10	10	60	11.0	3.0	3.8	4.3	24.6	Wind Effect
86	6	Apr-01-98	4	10	6	18:12:00	18:16:00	18:16:45	18:17:15	XL54	std	1	-10	10	61	34.0	4.0	4.8	5.3	26.8	Wind Effect

FIGURE 3.5

FIRST STEP FLUID TESTS

FLUID TEST RANGE

Light Freezing Rain: 25 g/dm²/h



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4. DATA ANALYSIS AND OBSERVATIONS

4.1 Preliminary Tests

The purpose of these tests was to assess the relative suitability of several types of test surfaces that were proposed as candidates for the full laboratory series of tests.

The preliminary tests were conducted in a manner similar to that intended for the *deicing only* tests, where the key characteristic observed was the final condition of the plate surface.

The final plate conditions, as recorded by sketches on each data sheet, were compared to determine whether types of candidate surfaces influenced results. Based on this criterion, there was no apparent justification for selecting one candidate surface over any other, and the selection decision was deferred until more information was gained during aircraft tests.

4.2 Aircraft Tests

The test conditions for the two overnight test sessions conducted on McDonnell Douglas DC-9 aircraft are shown in Table 4.1. Tests indicated for each fluid were conducted in duplicate, resulting in a total of six runs on January 21/22, 1998, and two runs on March 17/18, 1998. In addition, during the latter session, three supplemental runs were conducted to measure fluid strength profiles over a 20-minute period at points on the wing surface.

Tests were conducted on the port wing, which in each session had an amount of fuel remaining on board from the inbound flight sufficient to wet the fuel tank *cold corner* / wing surface interface (Figure 4.1). A thermistor was installed in this area during the March test session to track local temperature. The *cold corner* surface was not cold-soaked; at the beginning of the test session the temperature was -6°C, dropping to -7°C by the end of the test session.

TABLE 4.1
SCOPE OF AIRCRAFT TESTS

- US Airways DC-9 (over-nighting)
- Central Deicing Facility, Dorval Airport

	Jan 21/22, 1998	**March 17/18, 1998**
OAT	-12 to 16°C	-8°C
Wind	Headwind 9 km/h	Calm wind
Fluids	Water	UCAR ADF -4°C FP
	UCAR ADF -3°C FP	
	UCAR ADF -12°C FP	
Fluid Temp.	75°C	80°C

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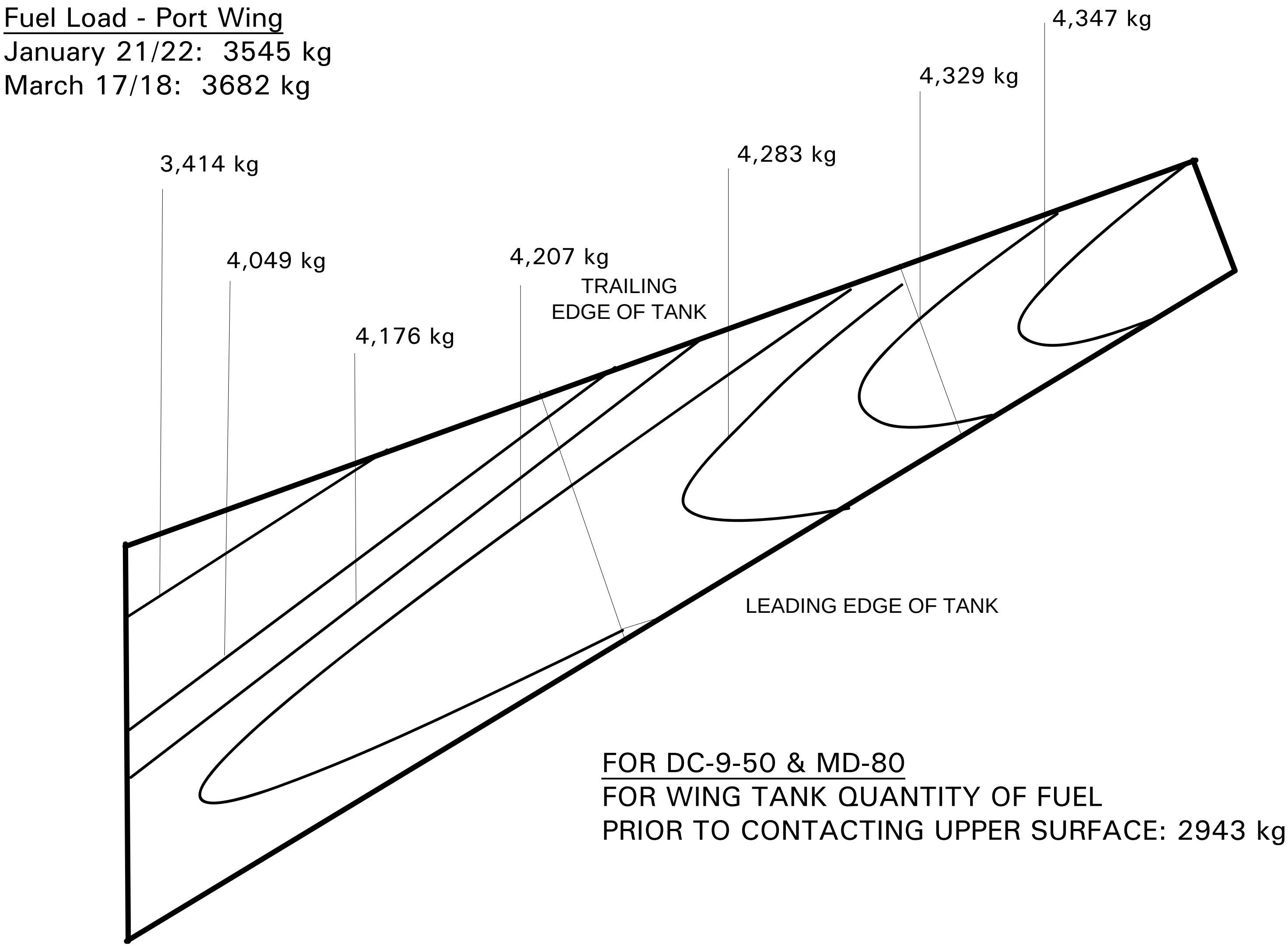
FIGURE 4.1

AREA OF WING SURFACE WETTED BY VARIOUS AMOUNTS OF FUEL

MAIN (WING) TANK DC-9-50 & MD-80



SOURCE: McDONNELL DOUGLAS

h:\cm1380\report\buffer\tank_wng.drw

4.2.1 Wing Condition at Test End

Figures 4.2 to 4.5 present sketches of distribution of frozen fluid over the wing surface at test end. The test conditions are indicated on each figure.

4.2.1.1 January 22, 1998; Run 1

Figure 4.2 is a representation of the results of an application of hot water. The outside air temperature was -13°C, meaning that the fluid freeze point buffer had a negative value of 13°C. Freezing started very quickly, initiating at the outer wing trailing edge. After five minutes, freezing had progressed over the entire wing, with the exception of the upper surface on the main wing.

All of the candidate test surfaces were tested simultaneously, and also experienced ice formation. The standard plate was the first to freeze.

4.2.1.2 January 22, 1998; Run 3

Figures 4.3(a) and 4.3(b) show the results from the application of a dilute Type I fluid having a freeze point of -3°C (negative buffer of 12°C). Freezing started at about three minutes, at the outer wing and along the trailing edge. At test end, the entire trailing edge control panels were covered with frozen fluid (Photo 4.1). The wing near the fuselage had been given only a light spray, and the fluid here was frozen. The outer 2/3 of the leading edge was bare and dry. A line of drip ice formed along the bottom rear edge of the leading edge slat (Photo 4.2). This ice was quite slushy and came away at the touch.

Ice formed on all the candidate test panels during simultaneous tests.

FIGURE 4.2
WING ICING LOCATION; JANUARY 22, 1998 - RUN1

REMEMBER TO SYNCHRONIZE TIME VERSION 4.0 Winter 97/98

DATE: Jan. 22, 1998	RUN NUMBER: 1

FAILURES CALLED BY: ____________________

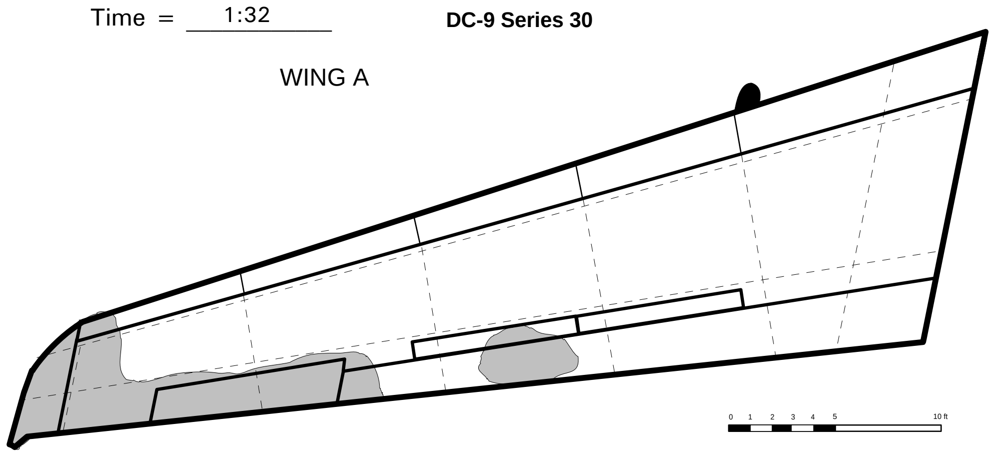
HANDWRITTEN BY: ____________________

ASSISTED BY: ____________________

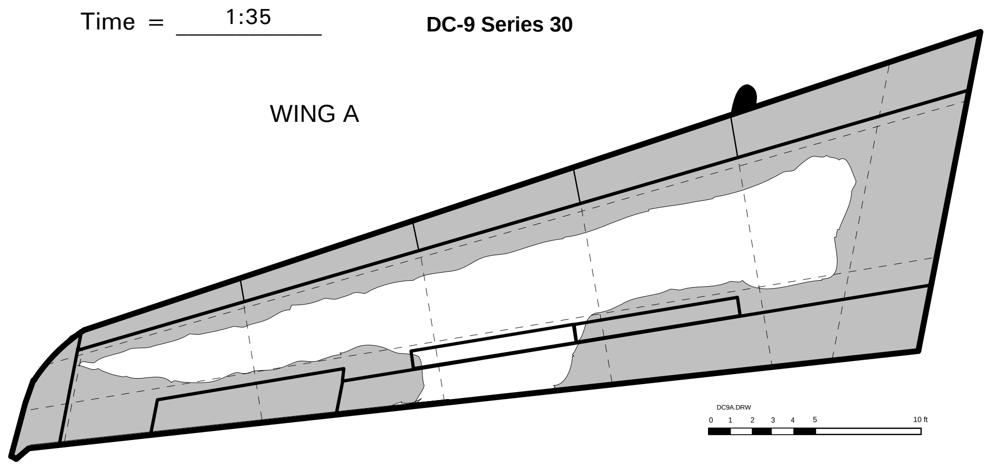
COMMENTS: Fluid Application Time: 1:30
Fluid: Water at 60ºC - 158 Litres at 60ºC
OAT = -13ºC, Wind: 5 kt headwind

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

Time = 1:32



Time = 1:35



Time = 1:39

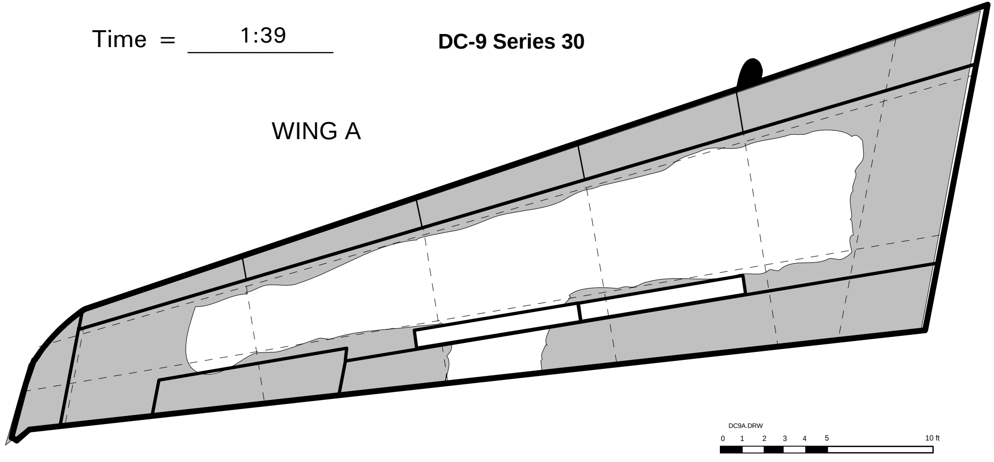


FIGURE 4.3a

WING ICING LOCATION; JANUARY 22, 1998 - RUN 3

REMEMBER TO SYNCHRONIZE TIME VERSION 4.0 Winter 97/98

DATE: Jan. 22, 1998 RUN NUMBER: 3

FAILURES CALLED BY: ____________

HANDWRITTEN BY: ____________

ASSISTED BY: ____________

COMMENTS: Fluid Application Time: 2:27

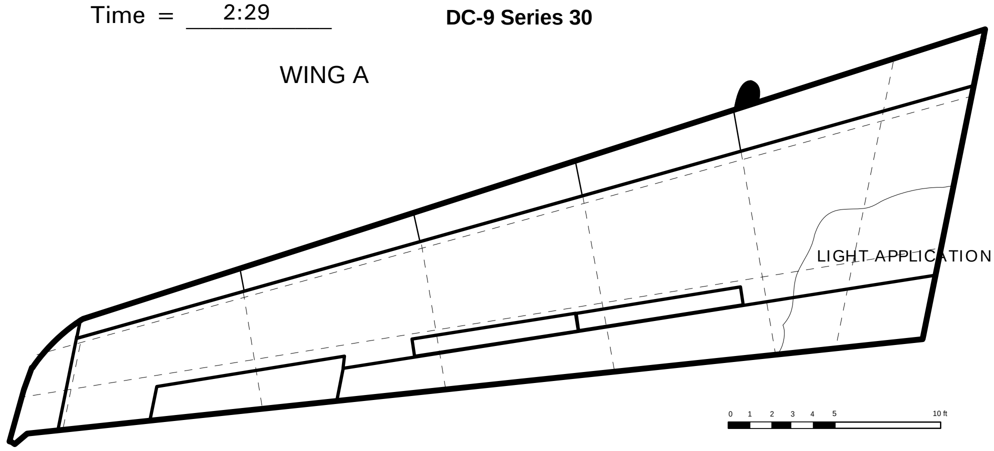
Fluid: UCAR ADF (-5°C) - 155 Litres at 76°C

OAT = -15°C, Wind: 5 kt headwind

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

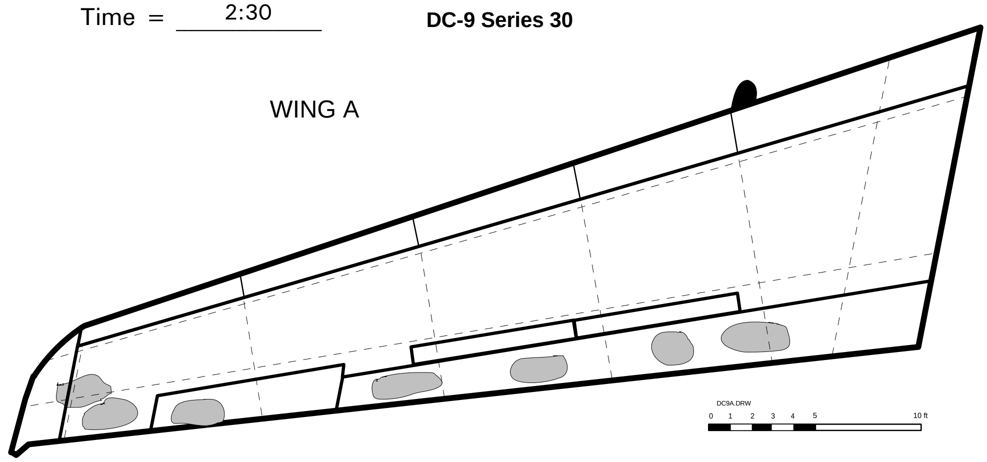
Time = 2:29 **DC-9 Series 30**

WING A



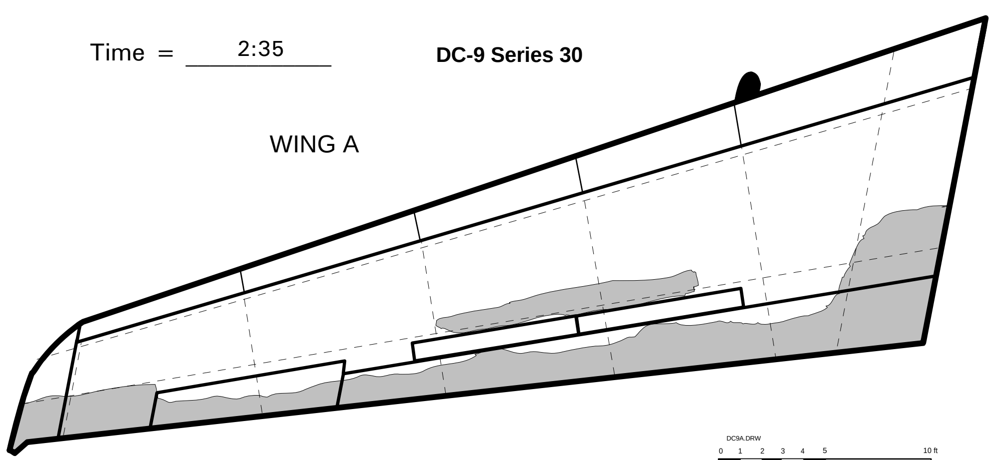
Time = 2:30 **DC-9 Series 30**

WING A



Time = 2:35 **DC-9 Series 30**

WING A



cm1380/report/buffer/JAN22R3A.CH4

FIGURE 4.3b
WING ICING LOCATION; JANUARY 22, 1998 - RUN 3

REMEMBER TO SYNCHRONIZE TIME — VERSION 4.0 — Winter 97/98

DATE: Jan. 22, 1998 RUN NUMBER: 3

FAILURES CALLED BY: ____________

HANDWRITTEN BY: ____________

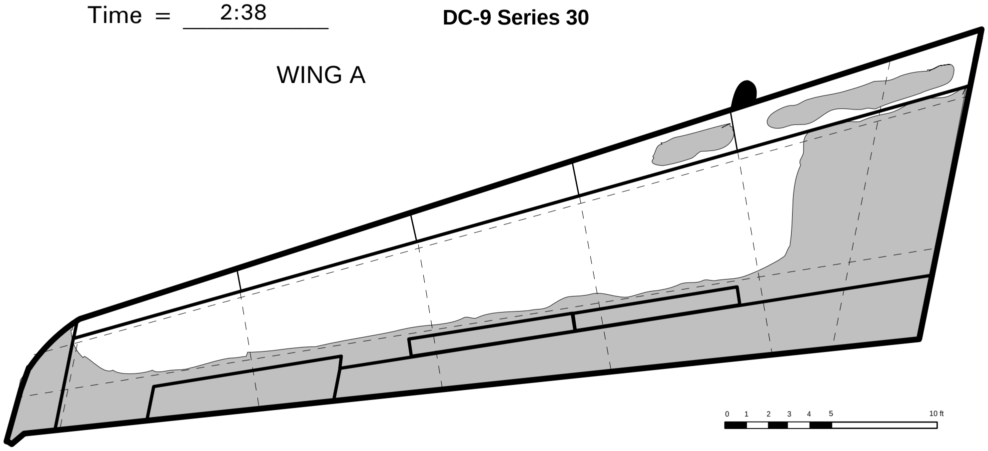
ASSISTED BY: ____________

COMMENTS: Fluid Application Time: 2:27
Fluid: UCAR ADF (-5°C) - 155 Litres at 76°C
OAT = -15°C, Wind: 5 kt headwind

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

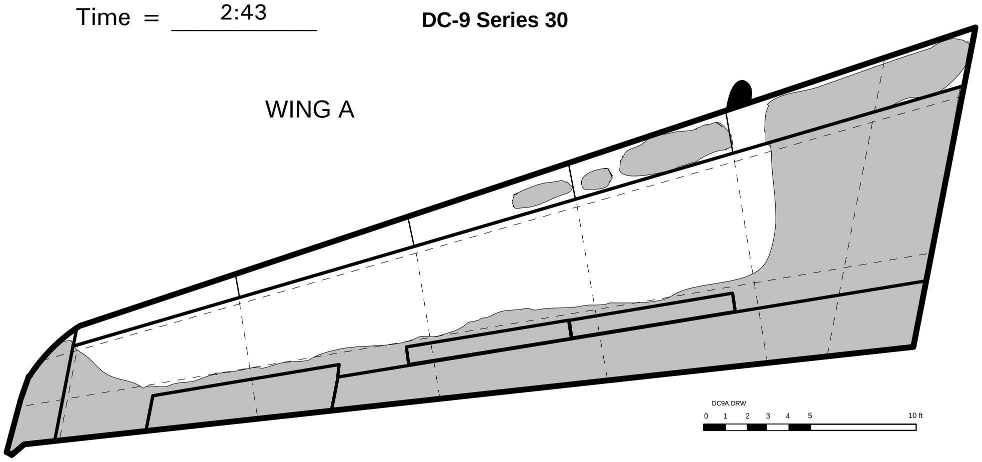
Time = 2:38 **DC-9 Series 30**

WING A



Time = 2:43 **DC-9 Series 30**

WING A



Time = 2:48 **DC-9 Series 30**

WING A

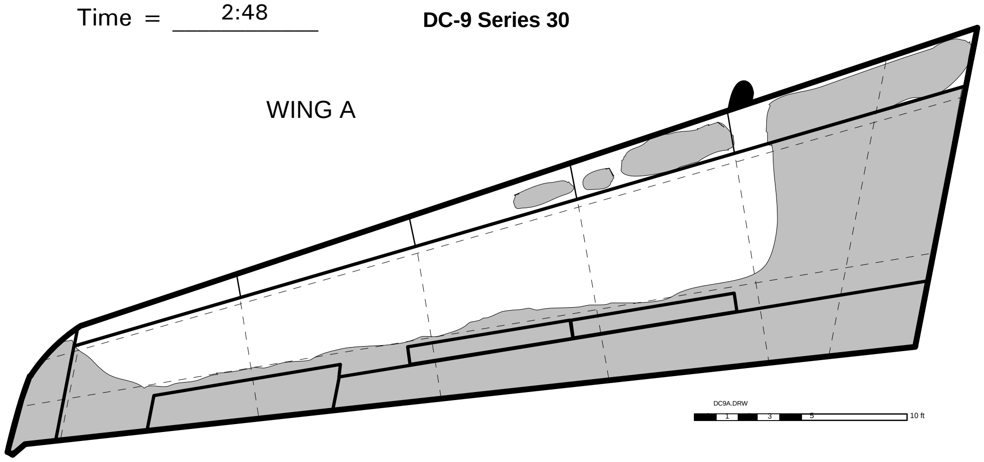


FIGURE 4.4
WING ICING LOCATION; JANUARY 22, 1998 - RUN 5

REMEMBER TO SYNCHRONIZE TIME | VERSION 4.0 | Winter 97/98

DATE: Jan. 22, 1998 **RUN NUMBER:** 5

FAILURES CALLED BY: ____________________

HANDWRITTEN BY: ____________________

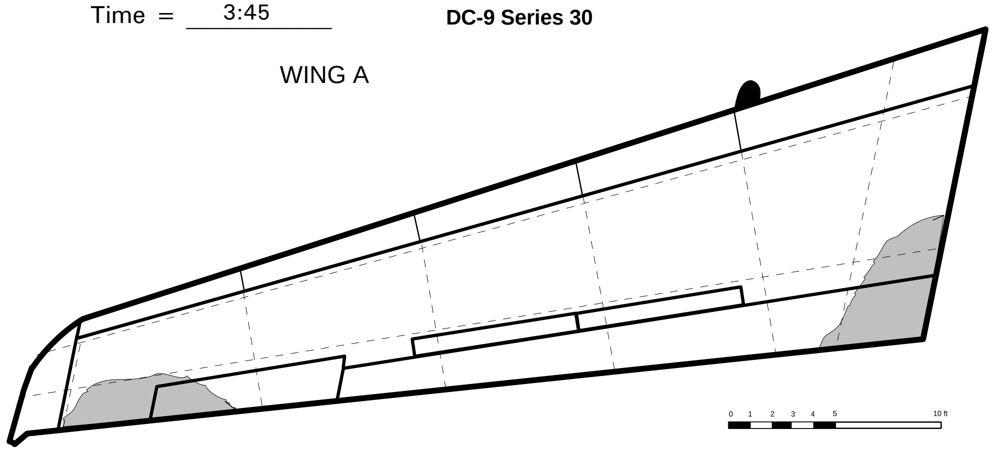
ASSISTED BY: ____________________

COMMENTS: Fluid Application Time: 3:25
Fluid: UCAR ADF (-12°C) - 160 Litres at 75°C
OAT = -16°C, Wind: 5 kt headwind

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

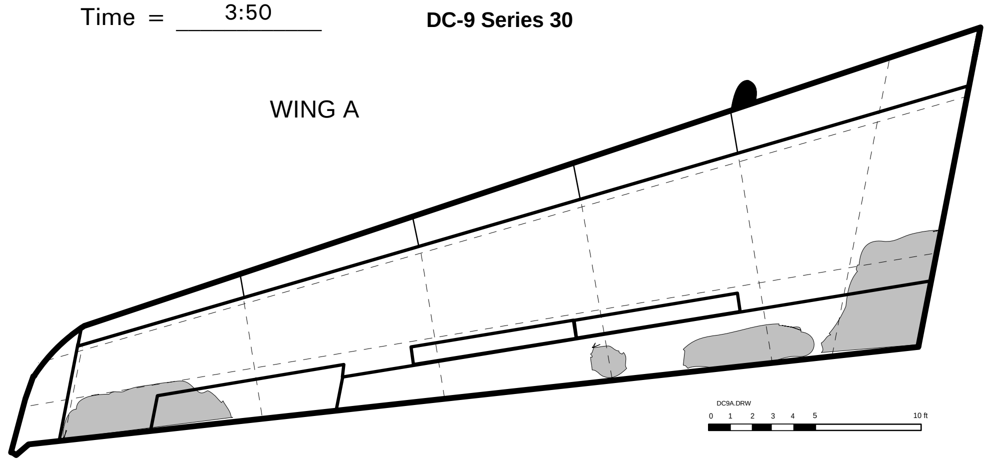
Time = 3:45 **DC-9 Series 30**

WING A



Time = 3:50 **DC-9 Series 30**

WING A



Time = 3:55 **DC-9 Series 30**

WING A

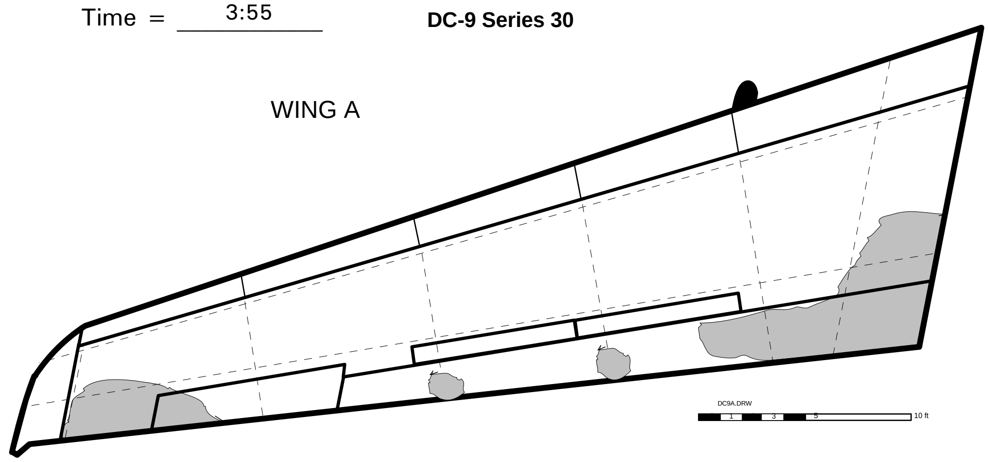


FIGURE 4.5 (a)
WING ICING LOCATION; MARCH 18, 1998 - RUN 1

REMEMBER TO SYNCHRONIZE TIME | VERSION 4.0 | Winter 97/98

DATE: March 18, 1998 **RUN NUMBER:** 1

FAILURES CALLED BY: ____________

COMMENTS: Fluid Application Time: 1:24

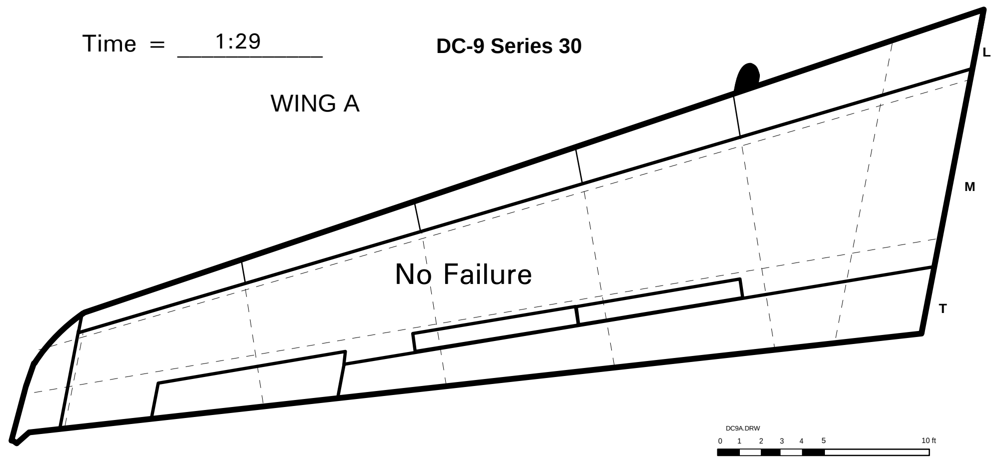
HANDWRITTEN BY: ____________

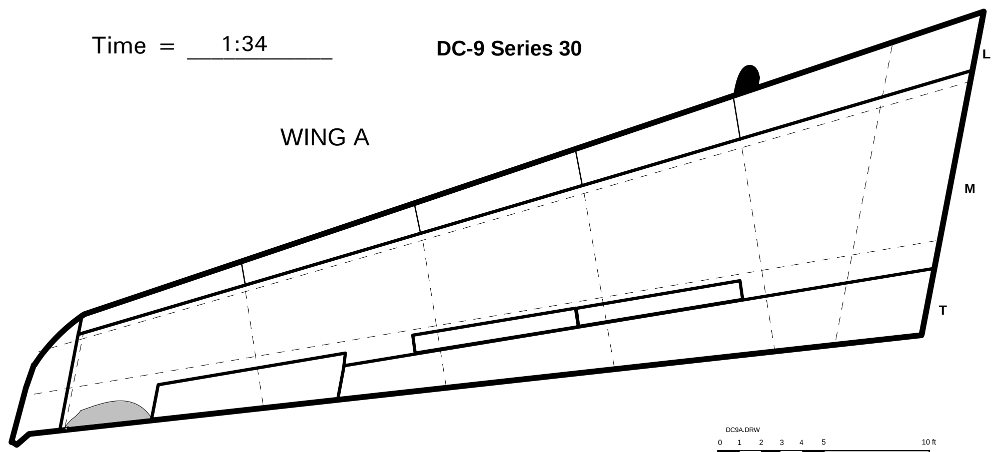
Fluid: UCAR ADF (-4°C) - 71 Litres at 80°C

ASSISTED BY: ____________

OAT = -8°C, Wind Calm

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE





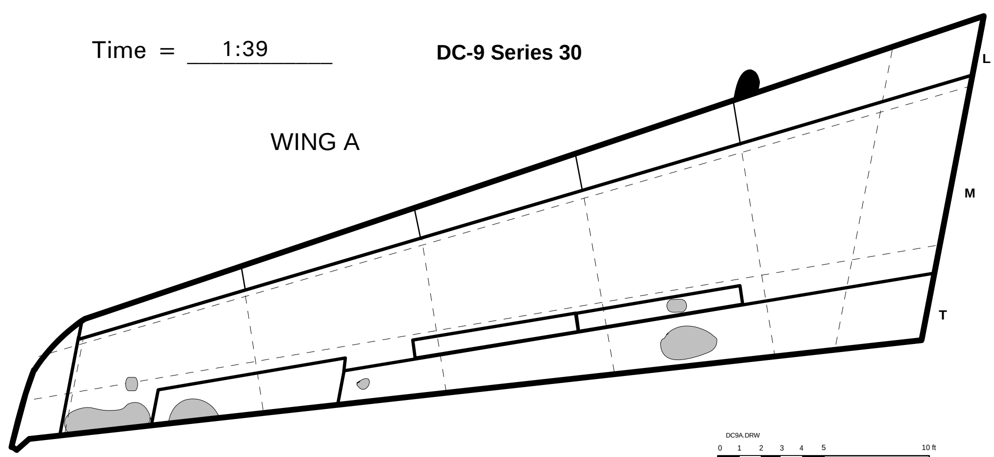


FIGURE 4.5 (b)
WING ICING LOCATION; MARCH 18, 1998 - RUN 1

REMEMBER TO SYNCHRONIZE TIME | VERSION 4.0 | Winter 97/98

DATE: March 18, 1998 **RUN NUMBER:** 1

FAILURES CALLED BY: ____________

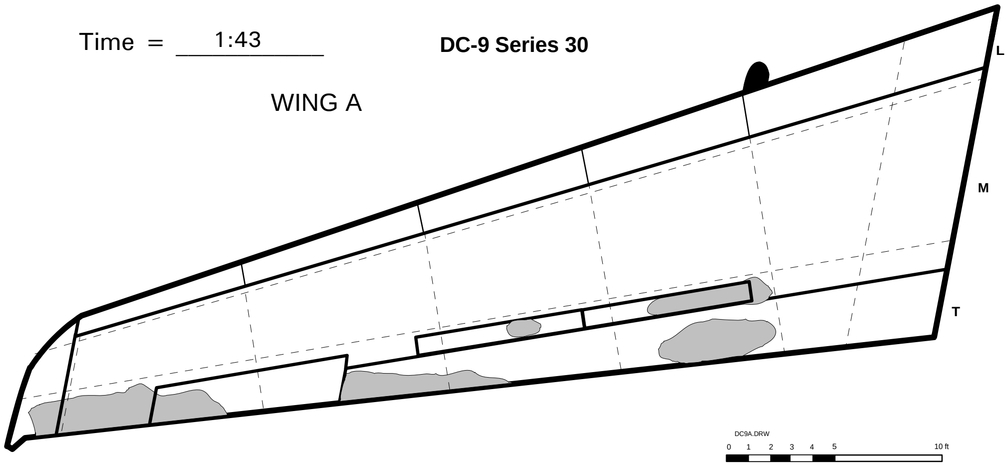
HANDWRITTEN BY: ____________

ASSISTED BY: ____________

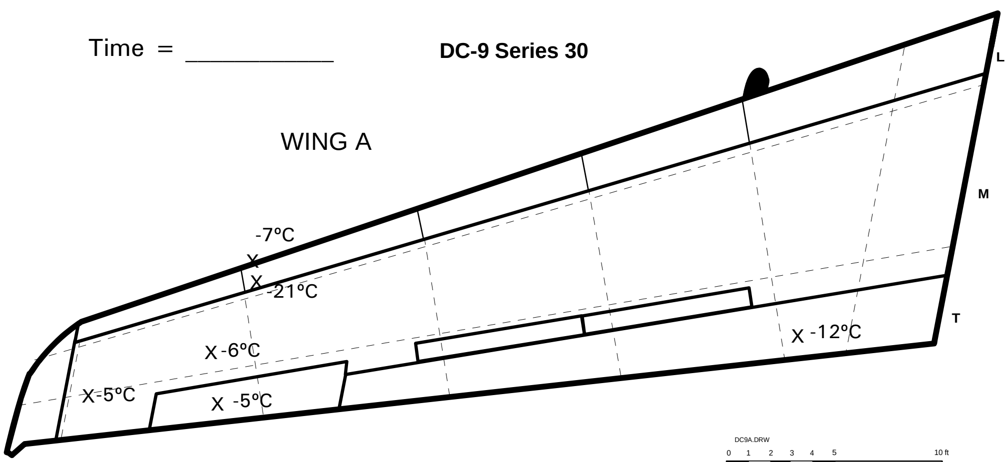
COMMENTS: Fluid Application Time: 1:24
Fluid: UCAR ADF (-4°C) - 71 Litres at 80°C
OAT = -8°C, Wind Calm

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

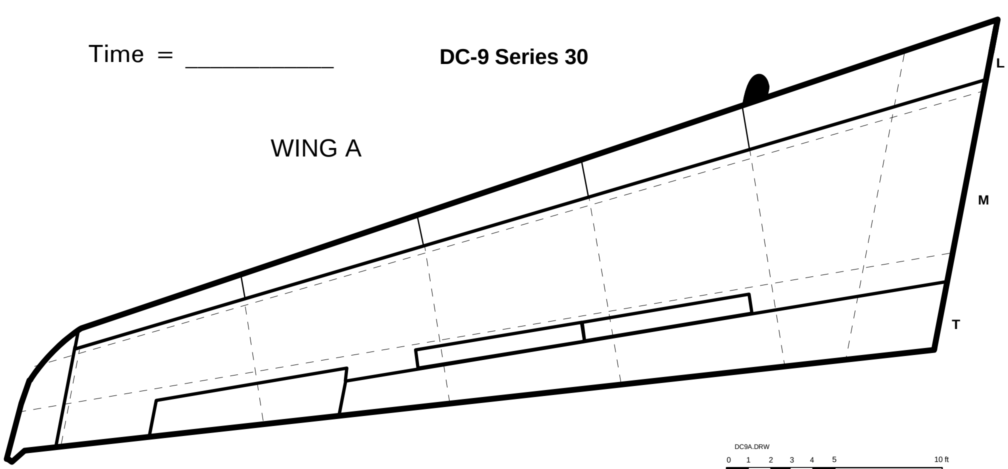
Time = 1:43



Time = ____________



Time = ____________



4.2.1.3 January 22, 1998; Run 5

Figure 4.4 shows the results from the application of Type I fluid diluted to a freeze point of -12°C (negative buffer of 4°C). At this fluid concentration, freezing began much later, about 20 minutes following fluid application. First freezing occurred at the same location as previous tests (see Photo 4.3): on the outer wing just beyond the aileron. At test end, freezing was limited to spots along the trailing edge control panels, and the rear inner wing beside the fuselage. Again, a line of slushy drip ice formed along the bottom rear edge of the leading edge slat.

Of the candidate test surfaces, the standard plate and the thin plate performed similarly, with ice forming along the lower edge of the plate. The remainder of the plate was covered with unfrozen fluid, and a few dry spots developed by the time the end of test was called. Freezing on the standard plate began 15 minutes following fluid application. Ice had formed along the lower edge of the honeycomb panel, with the remainder of the surface divided between dry and fluid-covered regions. The cold-soak box exhibited no ice formation and the surface was divided between dry and fluid-covered regions.

4.2.1.4 March 18, 1998; Run 1

Figures 4.5(a) and 4.5(b) represent results from the second test session, at a warmer outside air temperature and calm wind. The test fluid was a dilute Type I mixed to a freeze point of -4°C (negative buffer of 4°C). Freezing initiated at about 10 minutes following fluid application, at the same location as noted in previous tests. At test end, freezing existed at several spot locations along the trailing edge flight control panels.

4.2.2 Variation of Fluid Strength

Figures 4.6 to 4.8 present the final values of fluid strength (concentration) in terms of fluid freeze point, measured at the designated points on the wing surface.

4.2.2.1 January 21, 1998 Run 3

Figure 4.6 (outside air temperature = -16°C) shows a drop in fluid freeze point from the initial value of -3°C to -8°C and to -17°C. The locations on the wing where these values occurred correspond well to freezing patterns that developed on the wing. For example, the very low fluid freeze point located on the wing leading edge remained unfrozen.

4.2.2.2 January 22, 1998; Run 5

Figure 4.7 (outside air temperature = -16°C) shows a drop in fluid freeze point from the initial value of -12°C to a range varying from -16°C to -23°C. Locations where fluid freeze points of -16°C and above were measured experienced freezing; other locations remained unfrozen.

4.2.2.3 March 18, 1998; Run 1

Figure 4.8 (outside air temperature = -8°C) shows a drop in fluid freeze point from the initial value of -4°C to a range varying from -5°C to -21°C. The more subtle increase in fluid strength noted here (when compared to that of Run 5, January 22) may be due to the smaller quantity of fluid applied: 71 L versus 160 L.

Figure 4.9 charts the time profiles for the surface temperature and for the fluid freeze point temperature at one point on the wing leading edge. The fluid freeze point profile drops progressively to a value of -12°C from the initial value of -4°C, while the surface temperature drops from its peak, reached at the time of fluid application, to ambient. At any point along these curves, the value of fluid freeze point is less than the corresponding surface temperature, and freezing would not be expected to occur. Measurement of the fluid freeze point profile was conducted during the March 18 session, and involved spraying only a specific area of interest on the wing.

Figure 4.10 charts the time profiles for the surface temperature and for the fluid freeze point temperature at one point on the wing outboard trailing edge. In this case, the fluid freeze point value dropped only slightly, from -4°C to -5°C. As the fluid freeze point line intersects the surface temperature line, freezing would be expected to occur (as was the case).

FIGURE 4.6

AIRCRAFT TESTS; JANUARY 22, 1998 - RUN 3

VERSION 4.0 Winter 97/98

DATE: JAN. 22, 1998	RUN NUMBER: 3	OAT = -16°C

FAILURES CALLED BY:

HANDWRITTEN BY:

ASSISTED BY:

COMMENTS: Initial Fluid Freeze Point Temperature = -3°C (Wing and Plate)

Wing Time to First Icing = 3 minutes

Fluid Wing Final Freeze Point Temperature (°C) shown on Wing Plan.

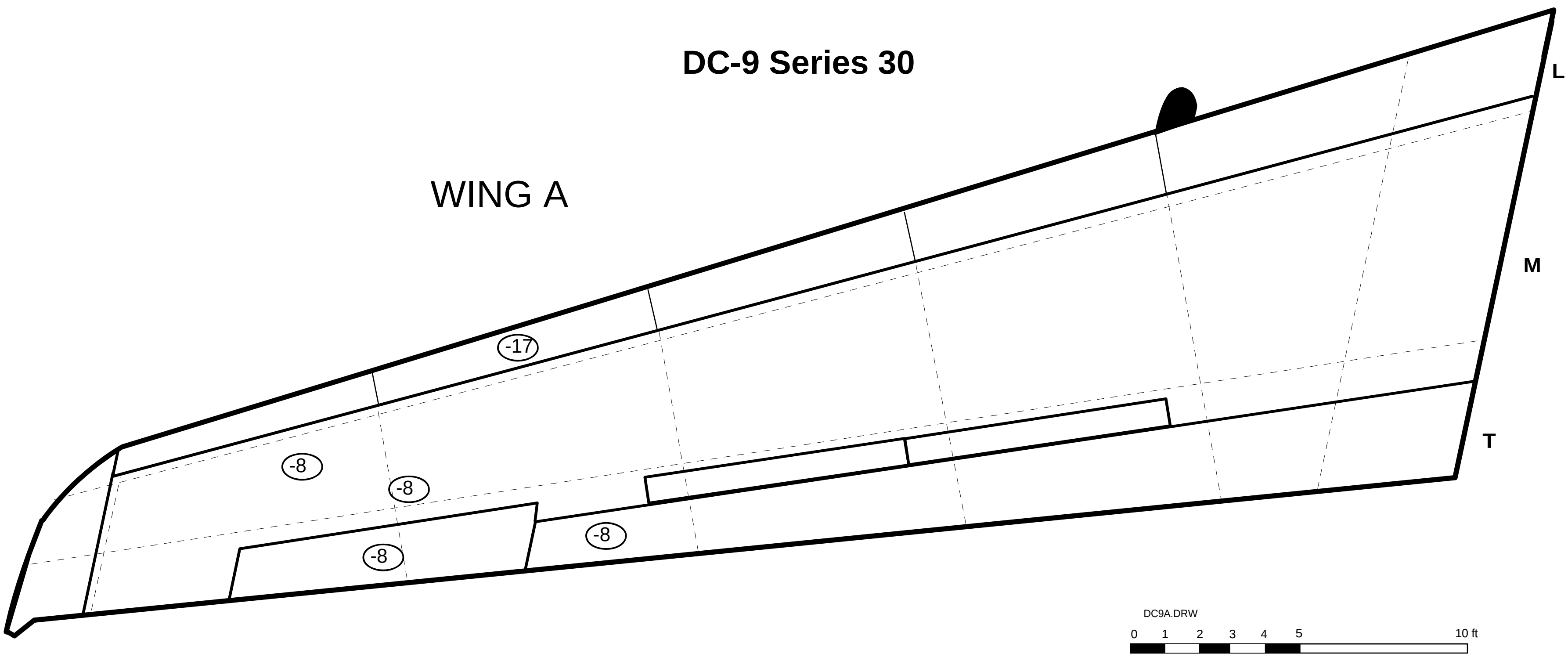
Standard Plate

Time to First Icing = 3 minutes

Final Fluid Freeze Point = -4°C

DC-9 Series 30

WING A



cm1380/report/buffer/JAN22_R3.DRW

FIGURE 4.7

AIRCRAFT TESTS; JANUARY 22, 1998 - RUN 5

VERSION 4.0 Winter 97/98

DATE: JAN. 22, 1998	RUN NUMBER: 5	OAT = -16°C

FAILURES CALLED BY:

HANDWRITTEN BY:

ASSISTED BY:

COMMENTS: Initial Fluid Freeze Point Temperature = -12°C (Wing and Plate)

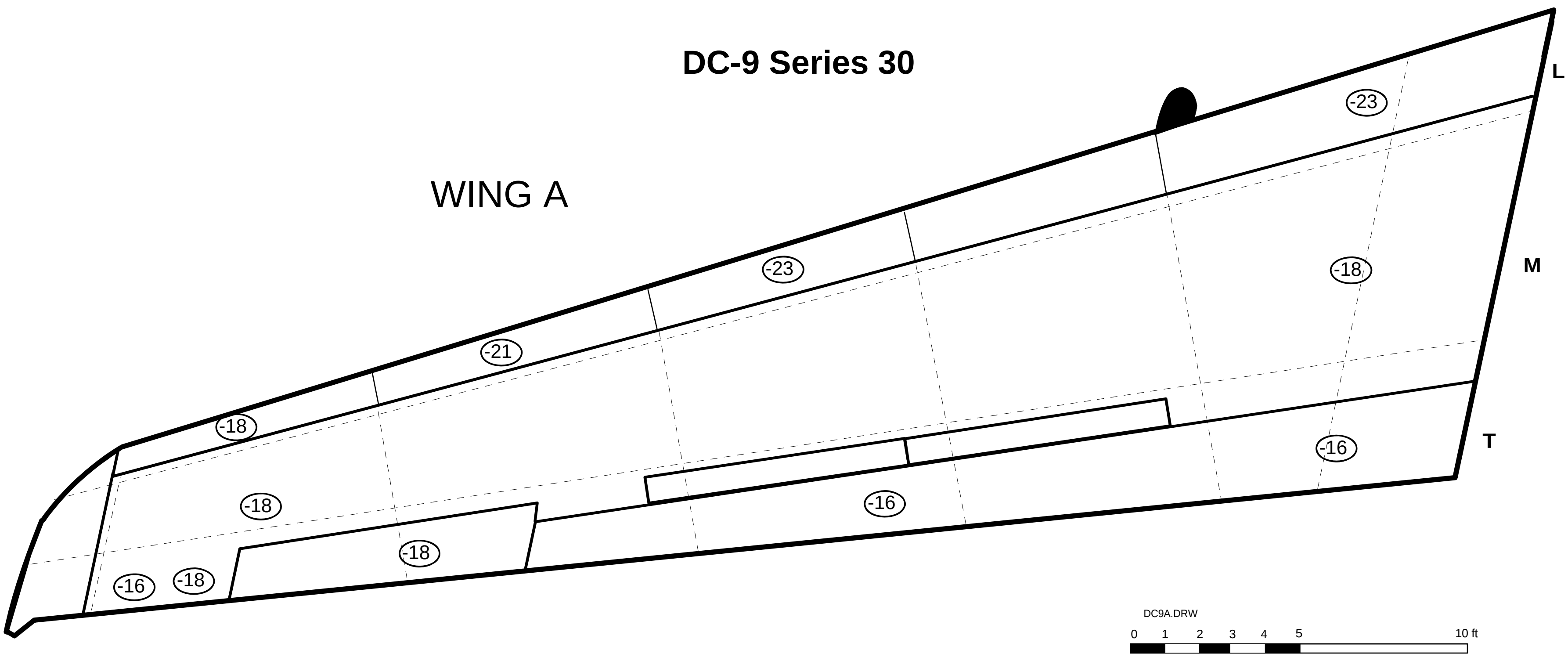
Wing Time to First Icing = 20 minutes

Fluid Final Freeze Point Temperature (°C) shown on Wing Plan

Standard Plate

Time to First Icing = 15 minutes

Final Fluid Freeze Point = -16°C



cm1380/report/buffer/JN22_R5.DRW

FIGURE 4.8

AIRCRAFT TESTS; MARCH 18, 1998 - RUN 1

VERSION 4.0 Winter 97/98

DATE: March 18, 1998 **RUN NUMBER:** 1 OAT = -10°C

FAILURES CALLED BY:

HANDWRITTEN BY:

ASSISTED BY:

COMMENTS: Initial Fluid Freeze Point Temperature = -4°C (Wing and Plate)

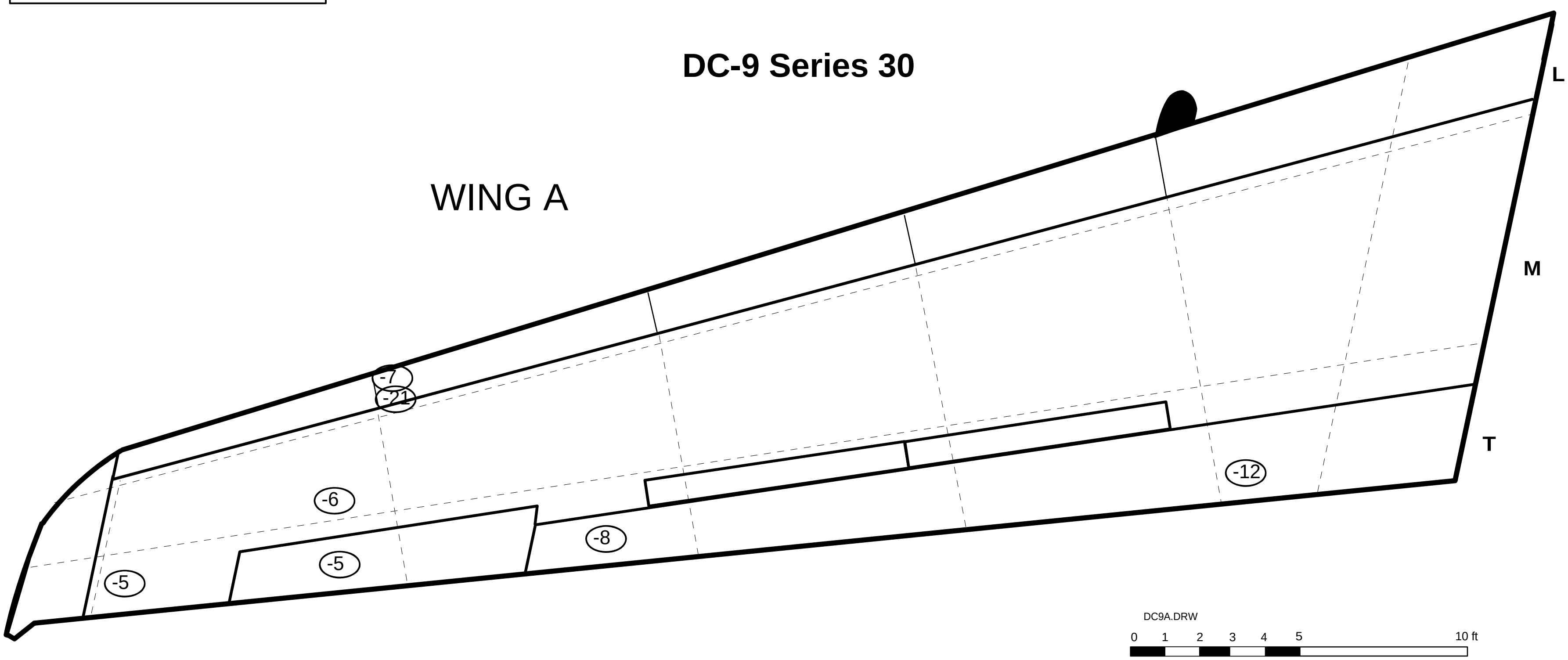
Wing Time to First Icing = 10 minutes

Fluid Final Freeze Point Temperature (°C) shown on Wing Plan

Standard Plate

Time to First Icing = 10 minutes

Final Fluid Freeze Point = -9°C



cm1380/report/buffer/MAR18_R1.DRW

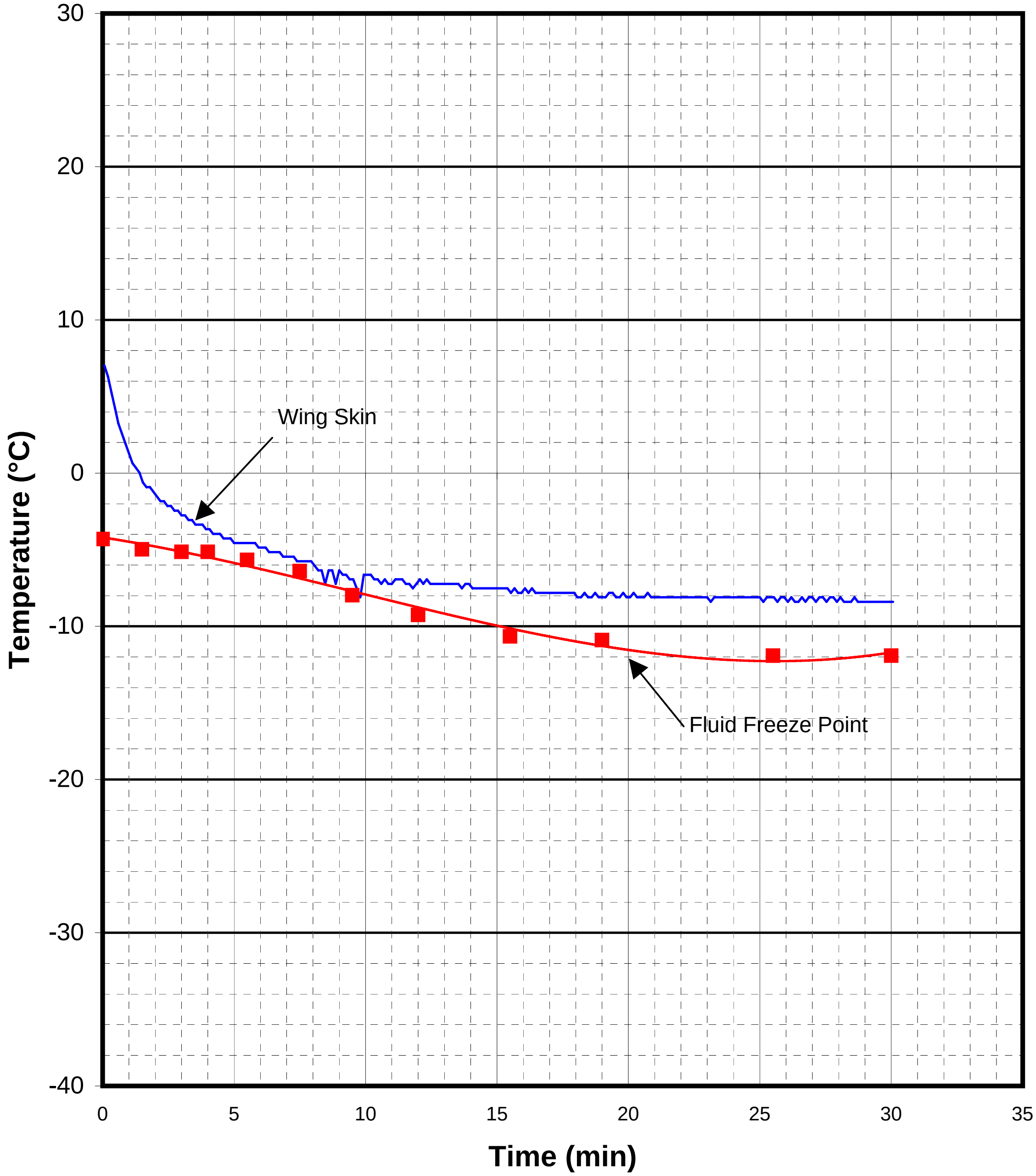
FIGURE 4.9

Fluid Freeze Point and Wing Temperature Profiles - Leading Edge

UCAR ADF (-4°C)

March 18, 1998, Run 2 - YUL

OAT = -8°C



File:g:\cm1380\report\buffer\M18_THM3
2/21/2007

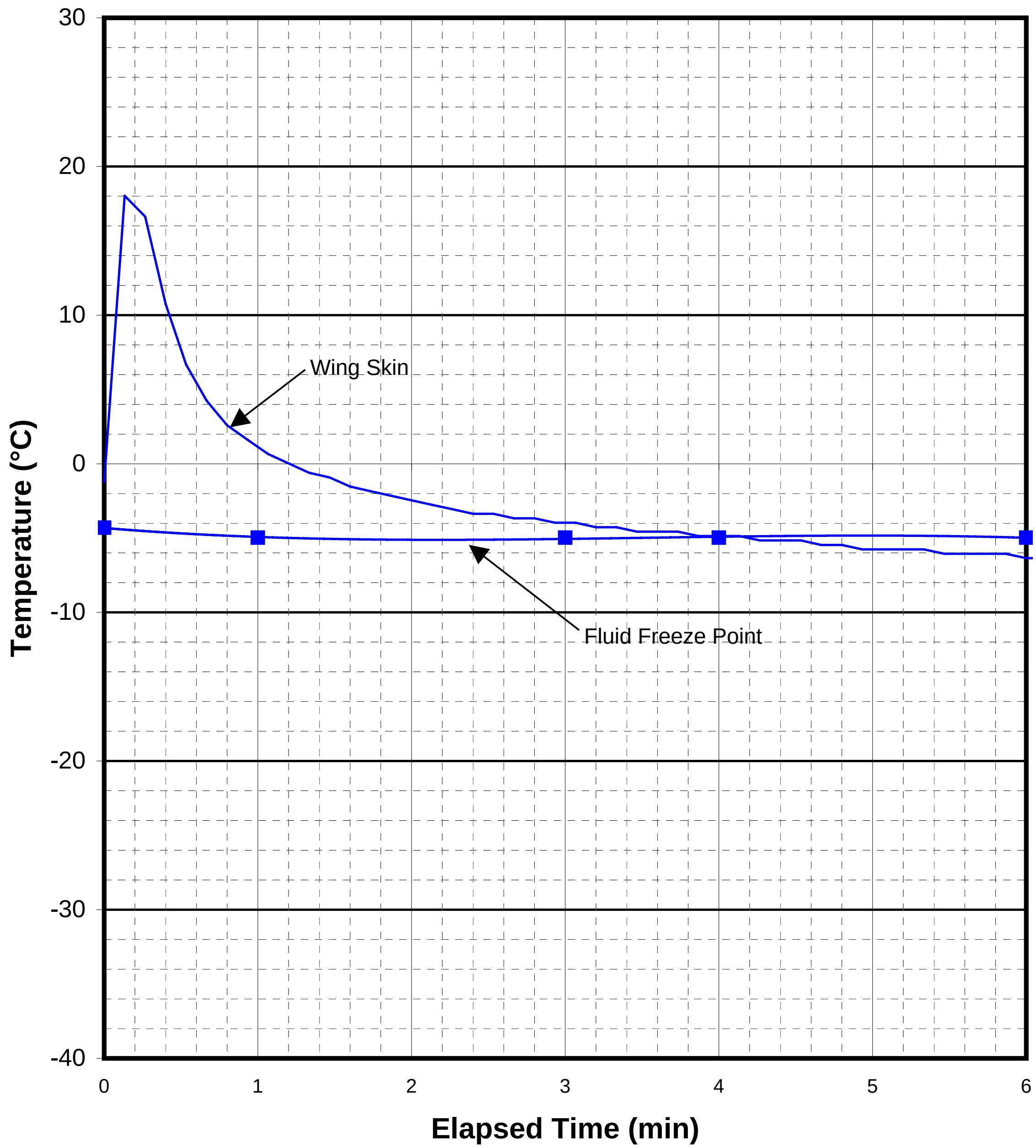
FIGURE 4.10

Fluid Freeze Point and Wing Temperature Profiles - Trailing Edge

UCAR ADF (-4°C)

March 18, 1998, Run 2 - YUL

OAT = -8°C



File:g:\cm1380\report\buffer\M18_THM7
At: Temp&frzp
2/21/2007

4.2.3 Comparison of Candidate Test Surfaces

Figure 4.11 plots surface temperature profiles for the four candidate surfaces as well as two points of interest on the wing surface. The profiles indicate that the top surface of the wing is the slowest to cool. This would support observations that this area was the last to freeze, and in many cases, experienced no freezing. This is followed by a group of surfaces that includes the wing aileron, the cold-soak box and the standard plate, with the standard plate being the fastest within this group. The thin plate and the honeycomb core plate were the fastest surfaces to cool.

Most of the test runs examining the four candidate surfaces showed that they produced very similar final fluid conditions. However, during January 22, 1998; Run 5, while the standard and thin flat plates produced ice formation results similar to that observed at the most critical location on the wing, the cold-soak box did not produce ice in any form. The honeycomb core panel produced ice, but not in more severe form than the standard plate. The standard plate was the first to freeze among the candidate surfaces, and froze 10 minutes before first freezing occurred on the wing. The final fluid freeze point measured on the plate surface was 16°C, the same value as the lowest strength fluid on the wing.

This was a significant test as the fluid freeze point buffer was in the particular range of interest for laboratory tests.

Continuing to regard the final condition of the surface as the key criterion for test surface selection, the Run 5 results indicated that the standard plate would provide a conservative representation of the wing. Accordingly, it was decided to employ the standard flat plate as the test surface during planned laboratory tests.

4.3 Deicing Only Study

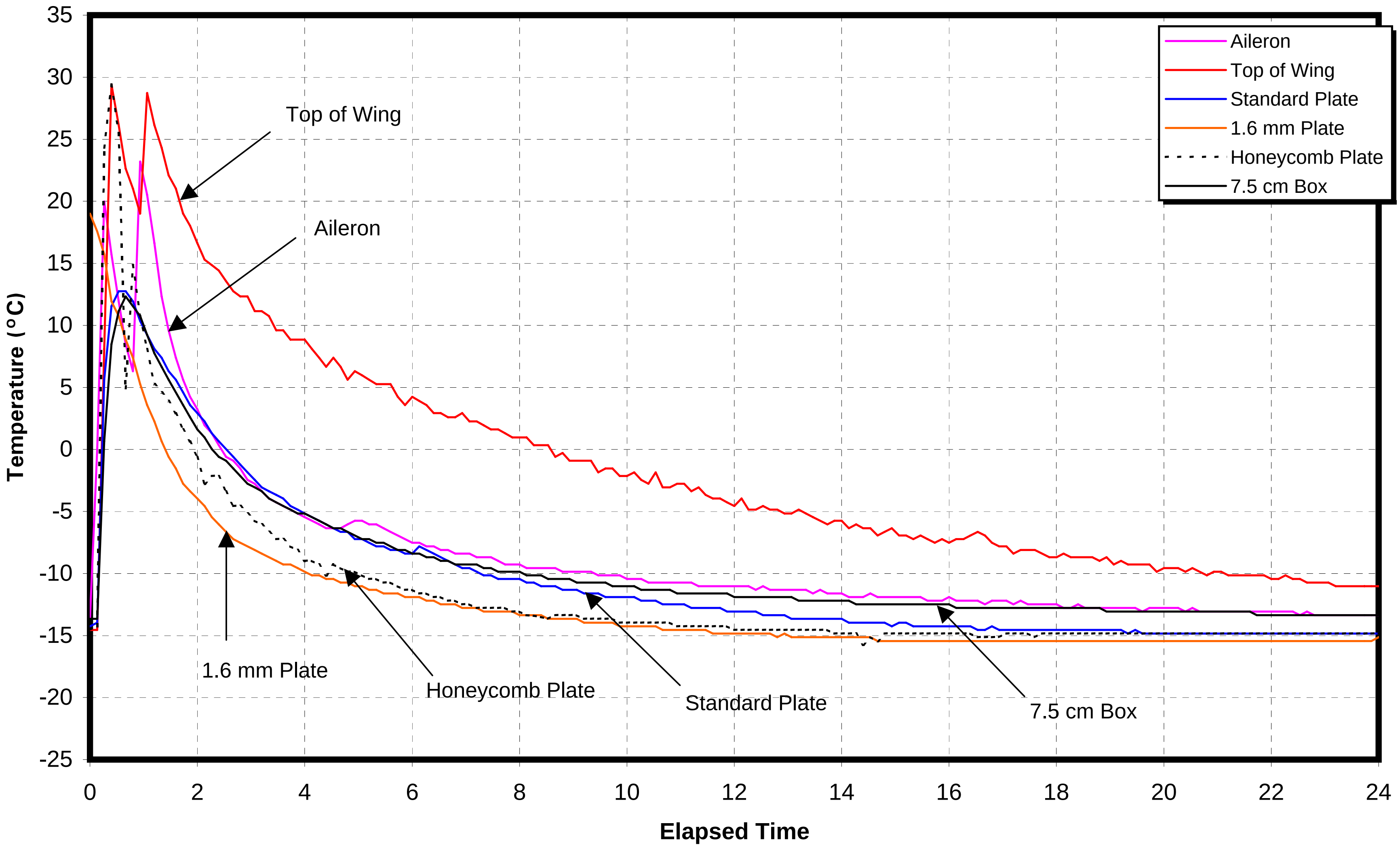
The principal goal of the data analysis was to examine and compare the results produced by various fluids and fluid strengths under different test conditions, and to identify those fluid/condition combinations that produced a successful result. Here, success is considered to be a plate condition completely free of ice in any form. Further analysis was performed to examine the influence of test variables, both in isolation and collectively.

FIGURE 4.11

AIRCRAFT SURFACE TEMPERATURE PROFILES

January 22, 1998 - Run 3

OAT = -15°C, Initial Fluid Freeze Point = -3°C



4.3.1 Plate Condition at Test End

4.3.1.1 Plots of Final Plate Condition

The test data were organized to provide a graphical representation of the plate condition at test end (after 20 minutes). Figures 4.12 to 4.23 present these data for the different wind speeds tested in a format similar to that used to describe the range of conditions for the tests considered in Section 3. Test results are plotted separately for different levels of wind speed.

In Figure 4.12, the diamonds represent the specific outside air temperature and initial fluid freeze points for the tests performed. The fluids tested were water and Union Carbide ADF (at various freeze points). The horizontal scale corresponds to the initial fluid freeze point range and the vertical scale represents the outside air temperature. Wind speed is indicated at the top of the figure. The final condition of the plate surface is indicated by a single letter according to the legend in the upper left corner. Where more than one condition was present, only the most severe was indicated (with level of severity decreasing from Ice to Bare). Ranges of fluid freeze point buffer values are indicated by the diagonal lines.

In Figure 4.13, results of several other fluid types are presented. Symbols representing each fluid are shown in the lower right corner.

Figures 4.12 to 4.23 facilitate an examination of the distribution of type of final plate condition relative to value of freeze point buffer.

Test points on the zero degree buffer line and to the left of it (positive values of freeze point buffer) were always indicated with the symbol F, signifying that only unfrozen fluid remained on the test surface in this buffer range. This held true regardless of wind speed.

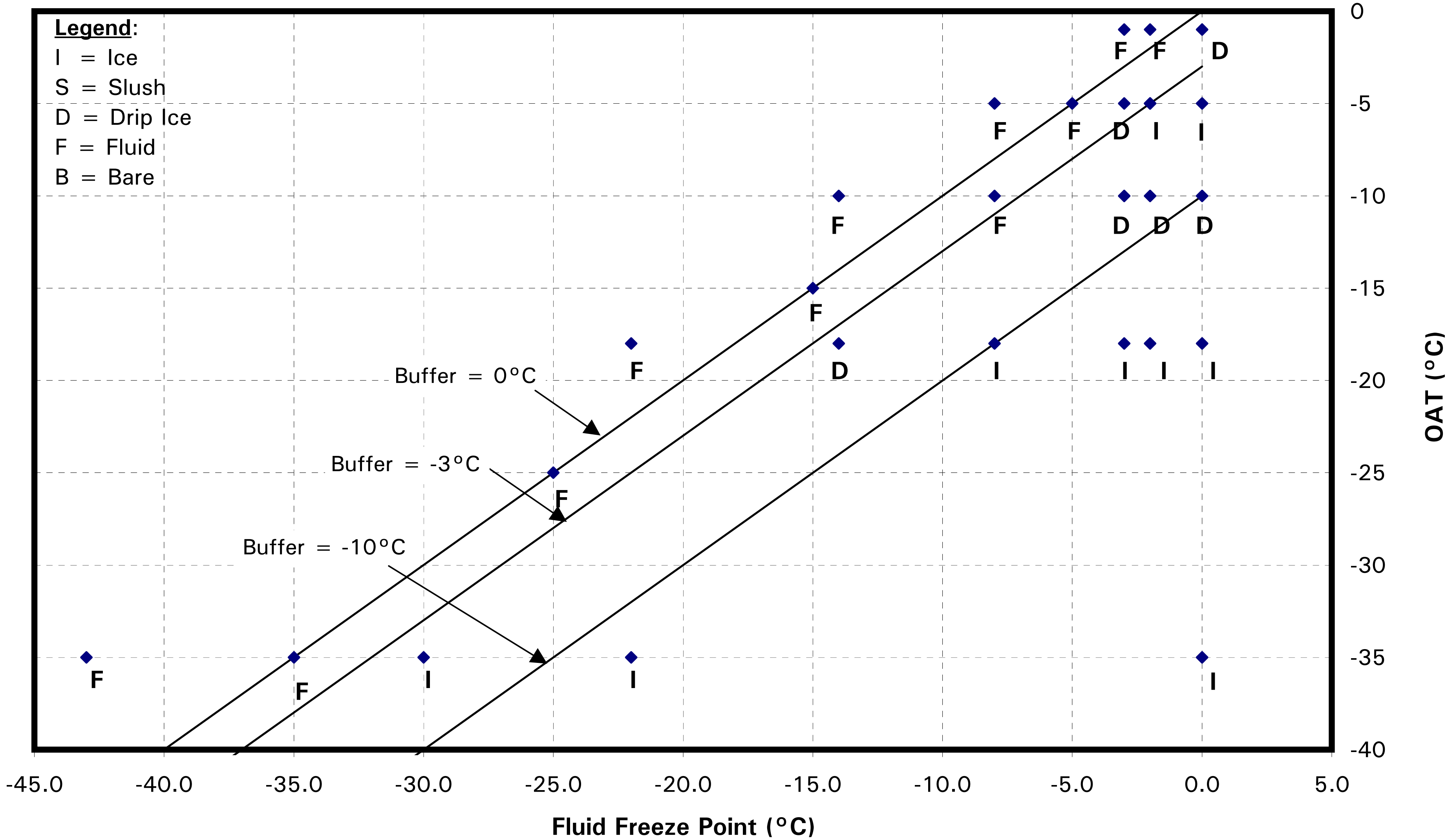
Test points in the range from the zero degree buffer to the -3°C buffer line generally concluded with the plate condition being either fluid covered, bare, or with ice on the drip line (the surface of the plate being non-frozen).

Freezing in some fashion generally started to appear at the -3°C buffer line, with the type of freezing condition increasing in severity

FIGURE 4.12

DEICING ONLY TESTS, UCAR ADF AND WATER, WIND = 0 km/h

PLATE CONDITION AT TEST END (20 min)

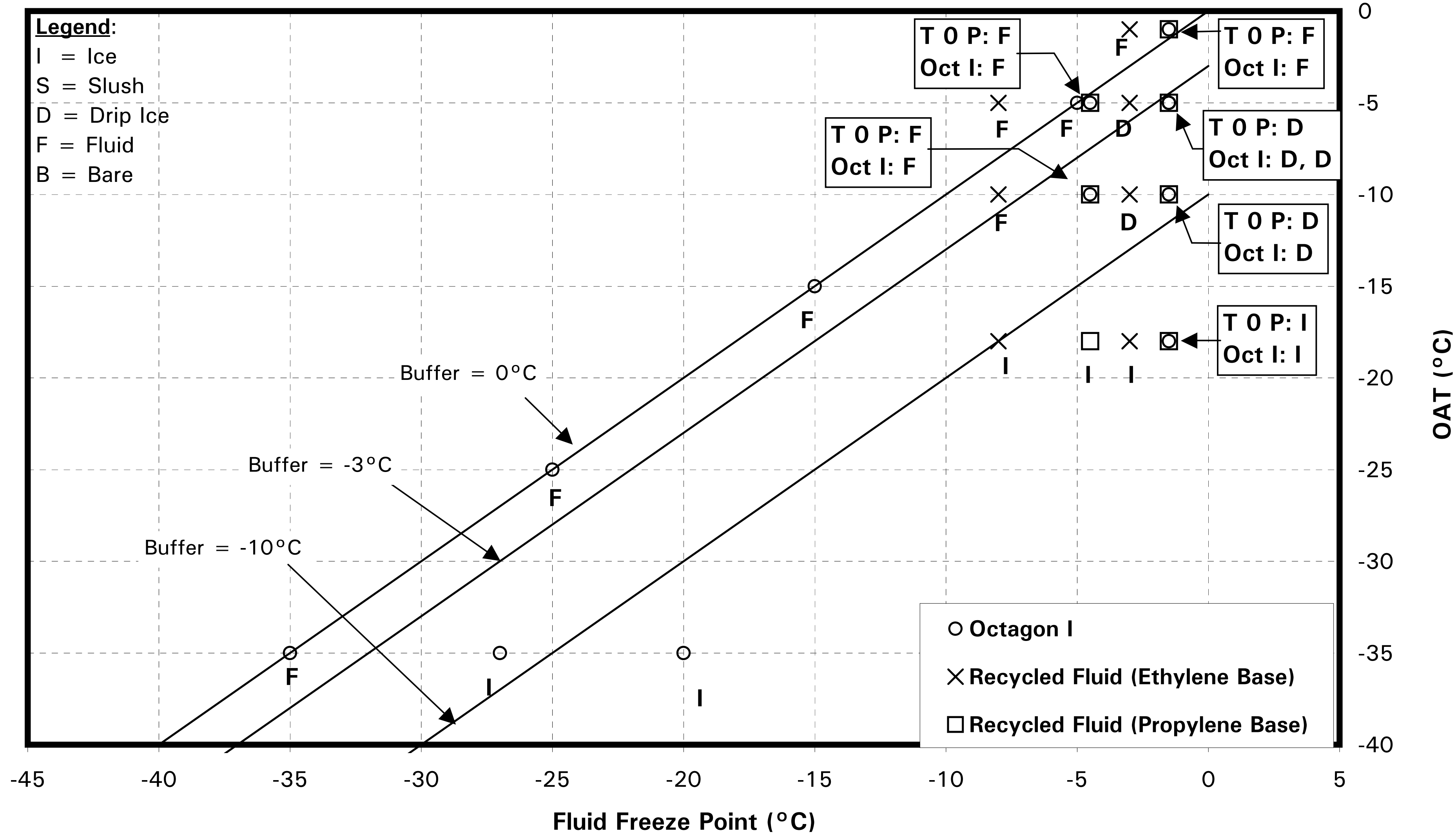


cm1380\report\buffer\ADF_0KPH
2/21/2007

FIGURE 4.13

DEICING ONLY TESTS, OCTAGON TYPE I AND RECYCLED FLUIDS, WIND = 0 km/h

PLATE CONDITION AT TEST END

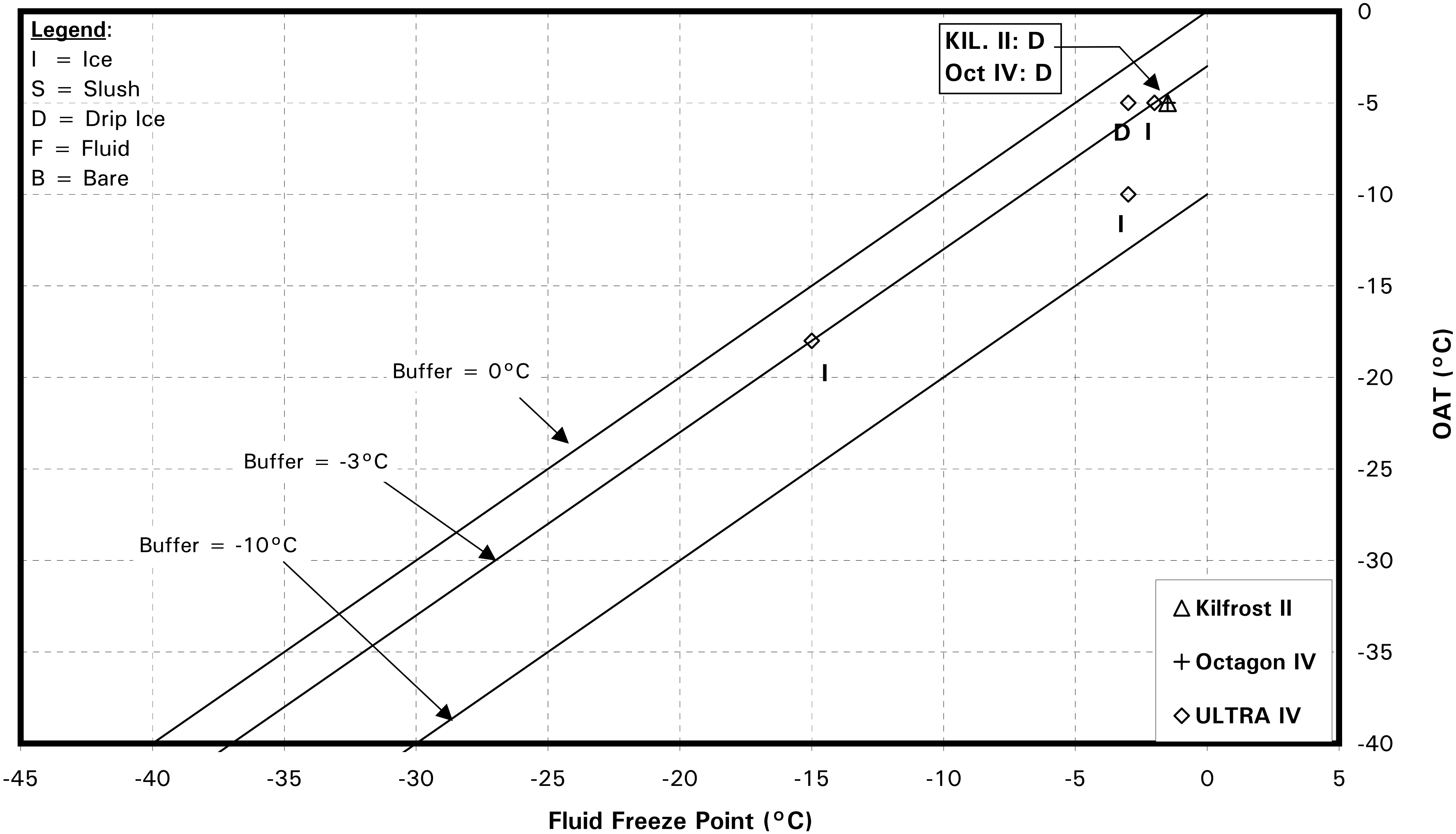


cm1380\report\buffer\ALL_0KPH
At: T0,1
2/21/2007

FIGURE 4.14

DEICING ONLY TESTS, TYPE II AND IV FLUIDS, WIND = 0 km/h

PLATE CONDITION AT TEST END

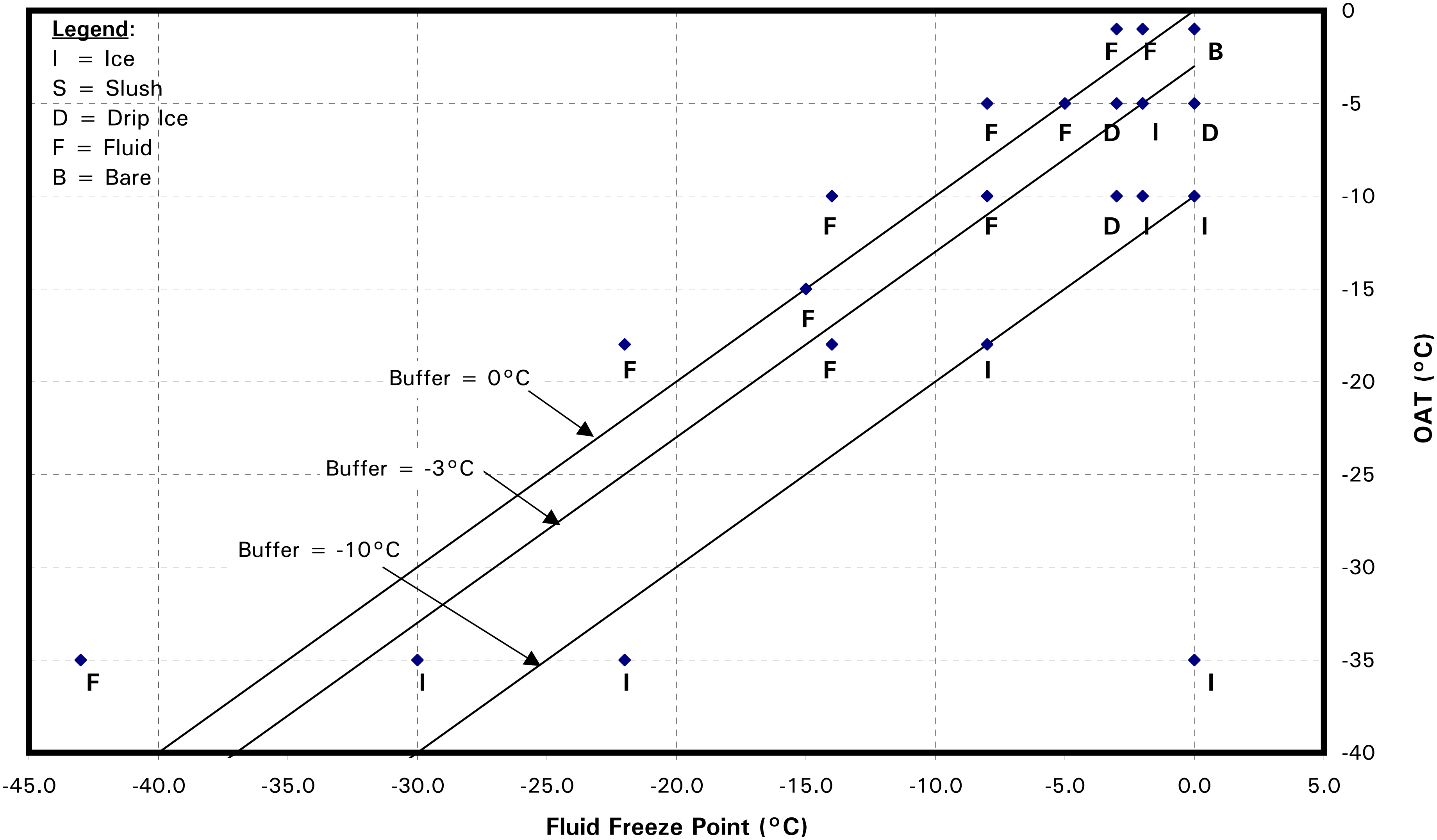


cm1380\report\buffer\ALL_0KPH
At: T4
2/21/2007

FIGURE 4.15

DEICING ONLY TESTS, UCAR ADF AND WATER, WIND = 5 km/h

PLATE CONDITION AT TEST END (20 min)

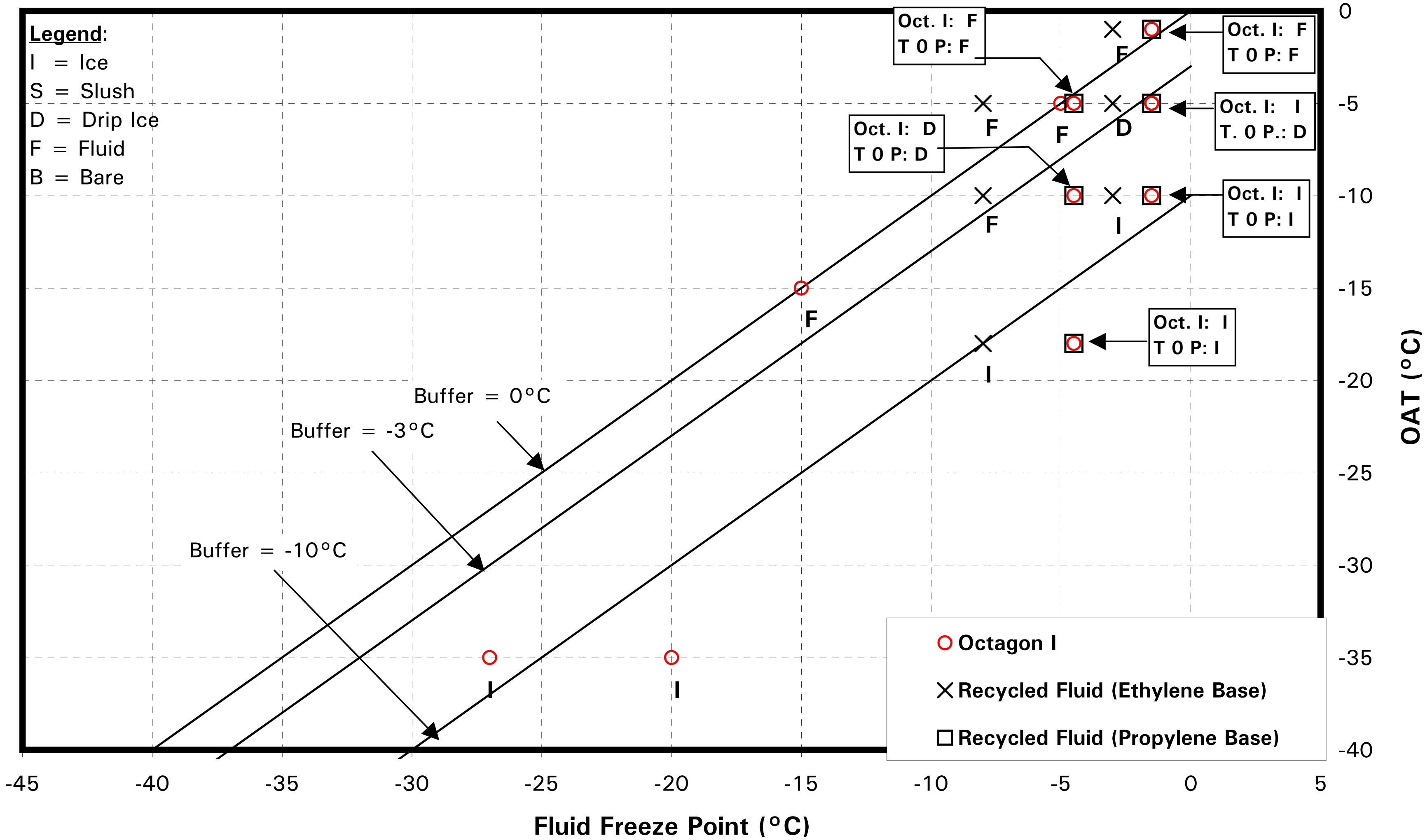


cm1380\report\buffer\\ADF_5KPH
2/21/2007

FIGURE 4.16

DEICING ONLY TESTS, OCTAGON TYPE I AND RECYCLED FLUIDS, WIND = 5 km/h

PLATE CONDITION AT TEST END

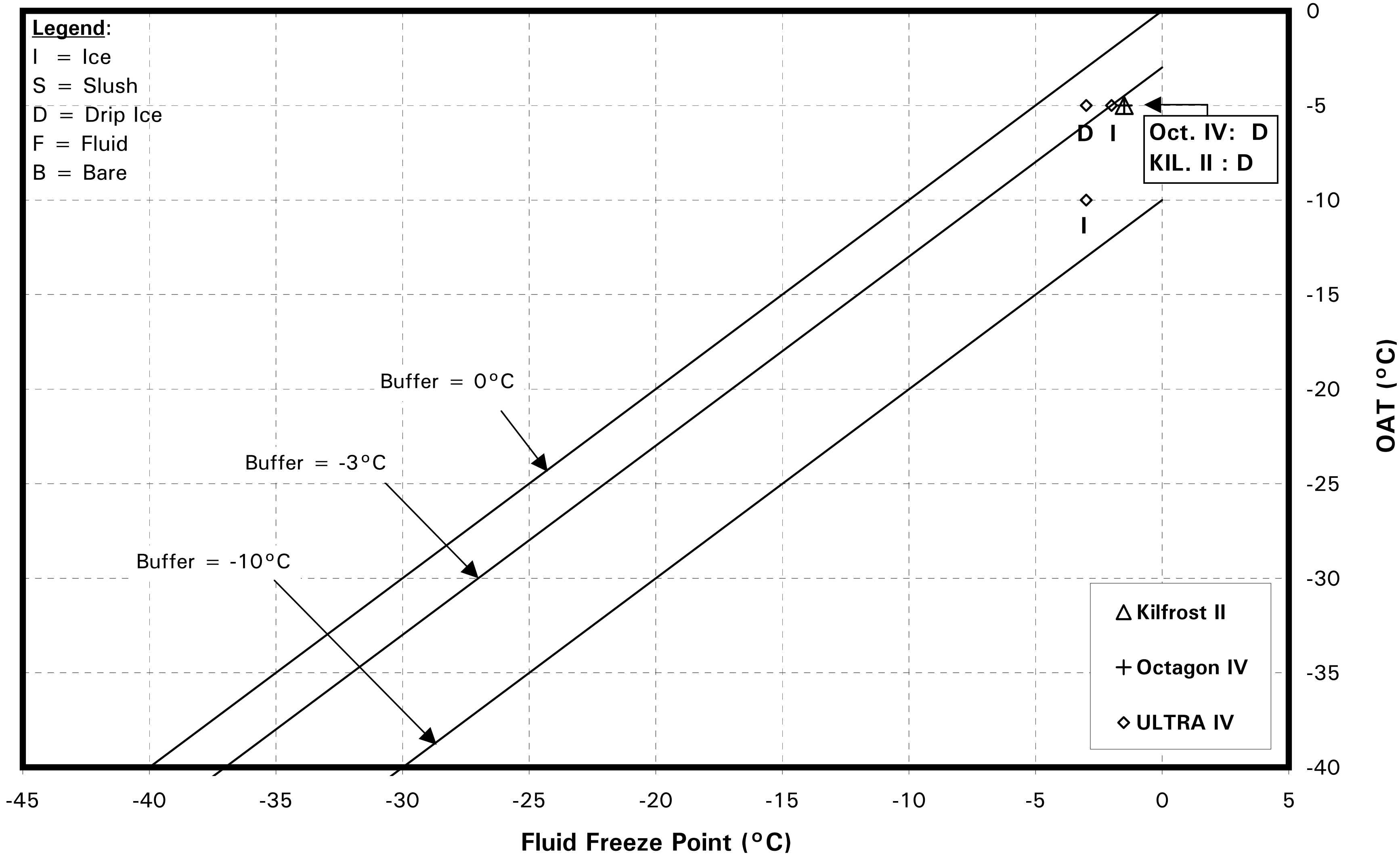


cm1380\report\buffer\ALL_5KPH
At: T0,1
2/21/2007

FIGURE 4.17

DEICING ONLY TESTS, TYPE II AND IV FLUIDS, WIND = 5 km/h

PLATE CONDITION AT TEST END

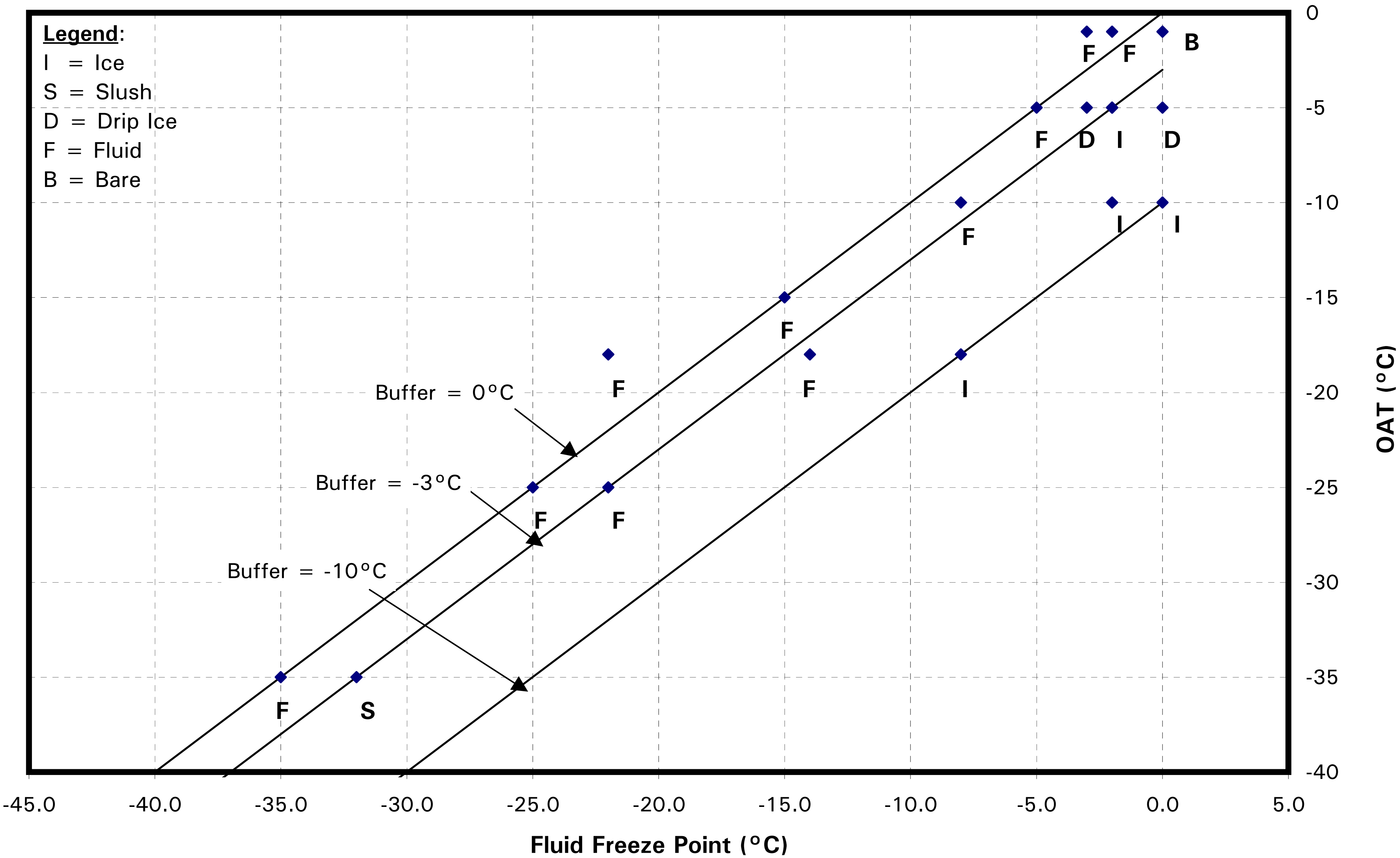


cm1380\report\buffer\ALL_5KPH
At: T4
2/21/2007

FIGURE 4.18

DEICING ONLY TESTS, UCAR ADF AND WATER, WIND = 10 km/h

PLATE CONDITION AT TEST END

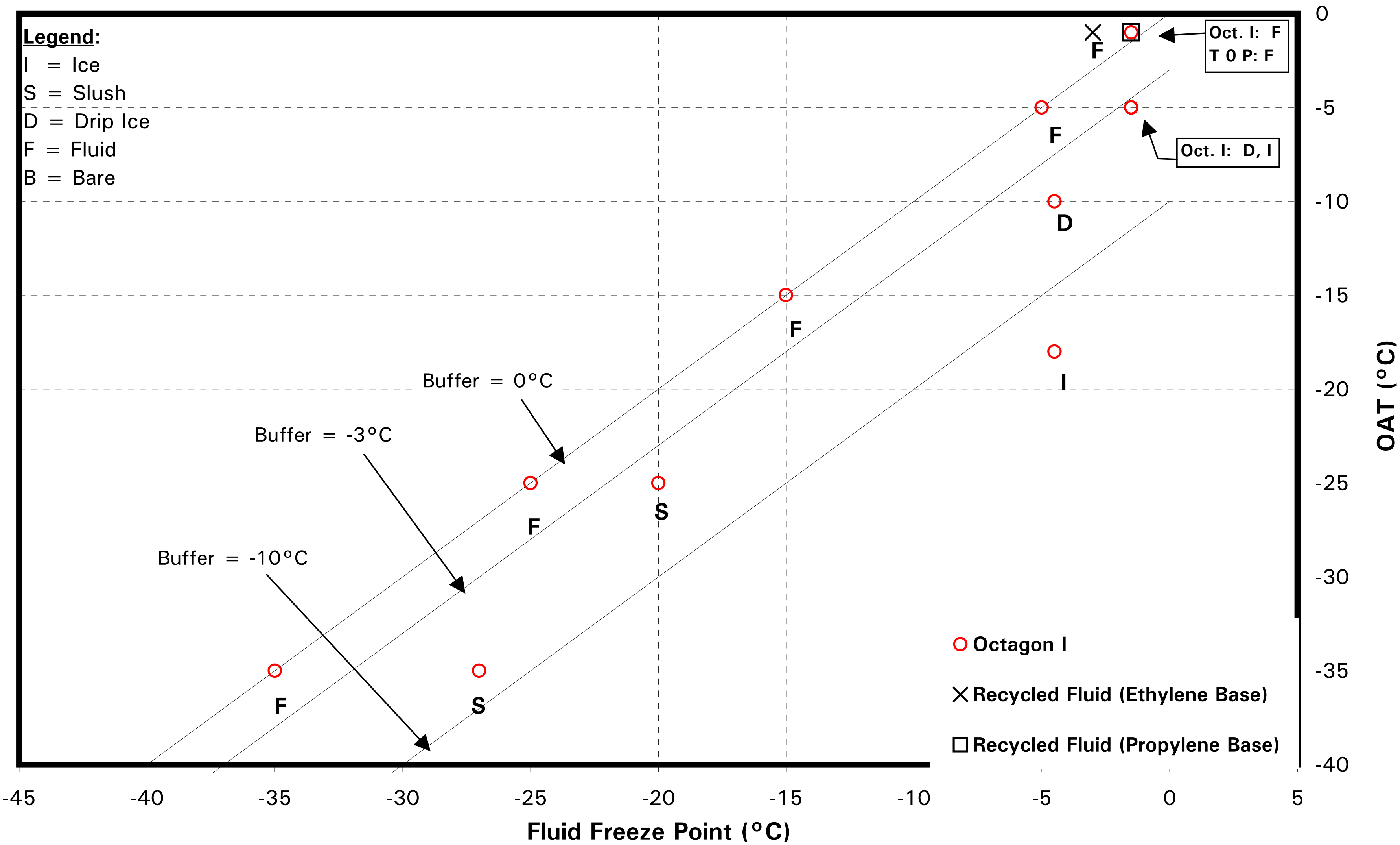


cm1380\report\buffer\ADF_10KH
2/21/2007

FIGURE 4.19

DEICING ONLY TESTS, OCTAGON TYPE I AND RECYCLED FLUIDS, WIND = 10 km/h

PLATE CONDITION AT TEST END

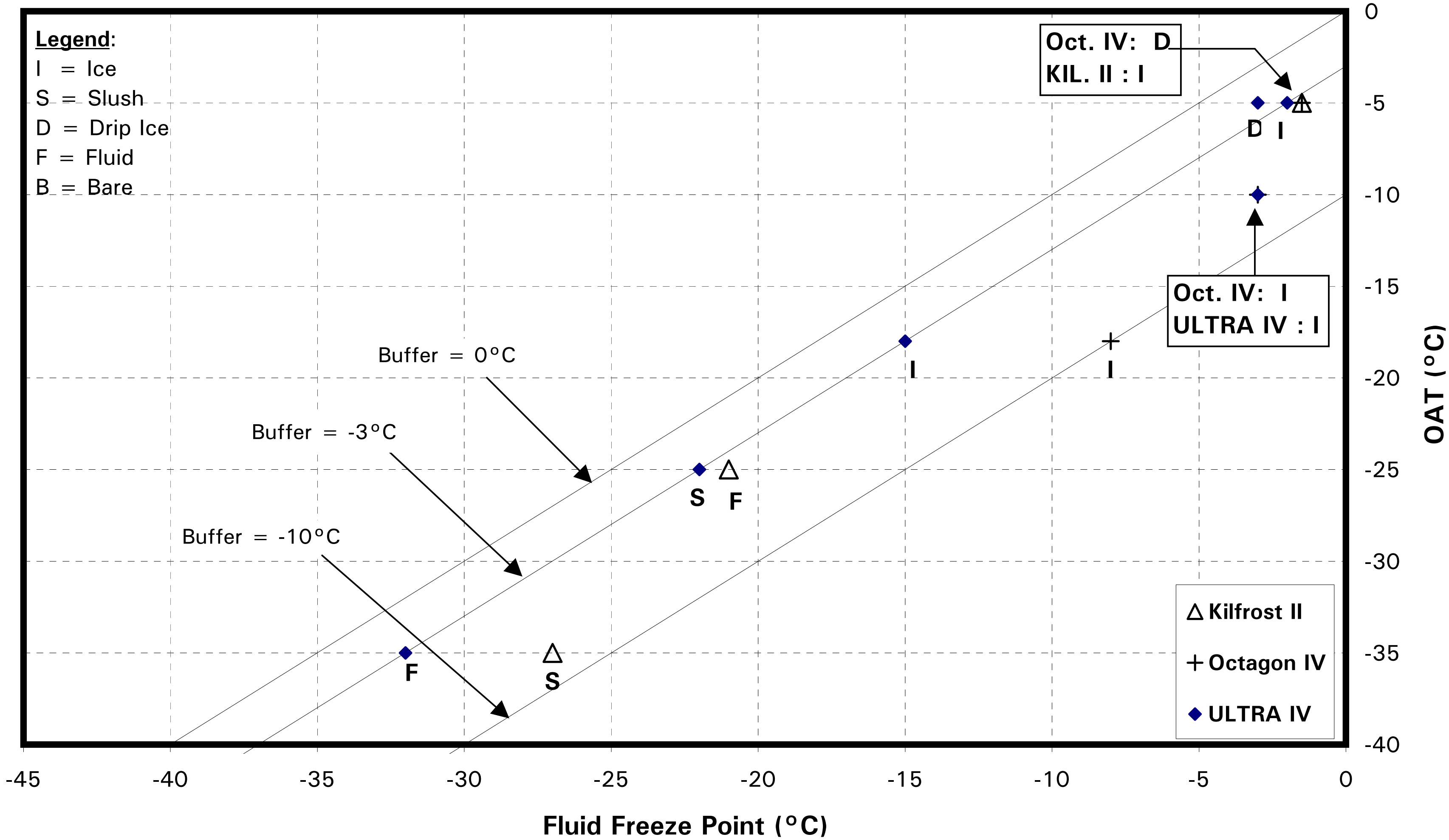


cm1380\report\buffer\ALL_10KH
At: T0,1
2/21/2007

FIGURE 4.20

DEICING ONLY TESTS, TYPE II AND IV FLUIDS, WIND = 10 km/h

PLATE CONDITION AT TEST END



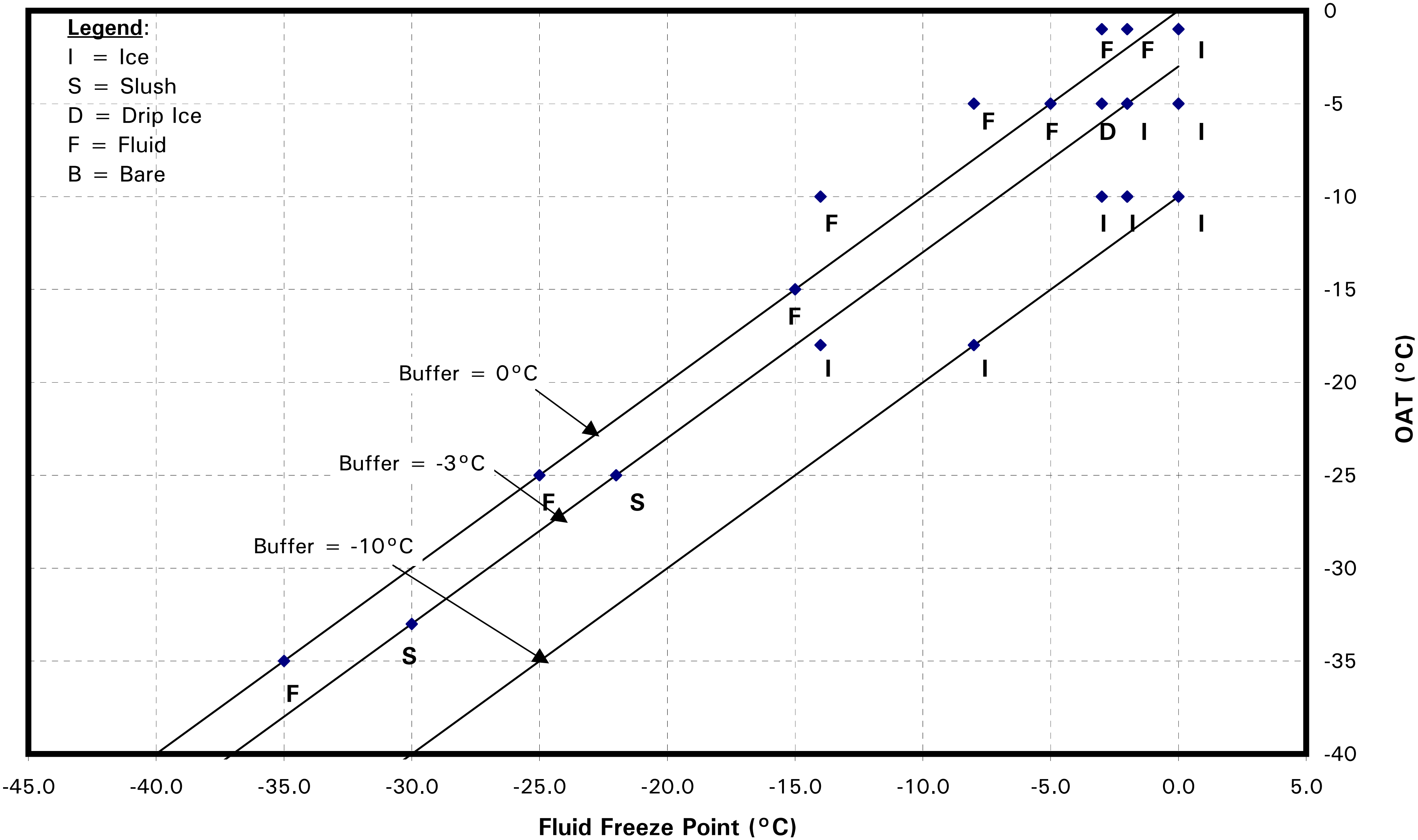
cm1380\report\buffer\ALL_10KH
At: T4
2/21/2007

FIGURE 4.21

DEICING ONLY TESTS

PLATE CONDITION AT TEST END (20 min)

UCAR ADF and Water, Wind = 20 km/h

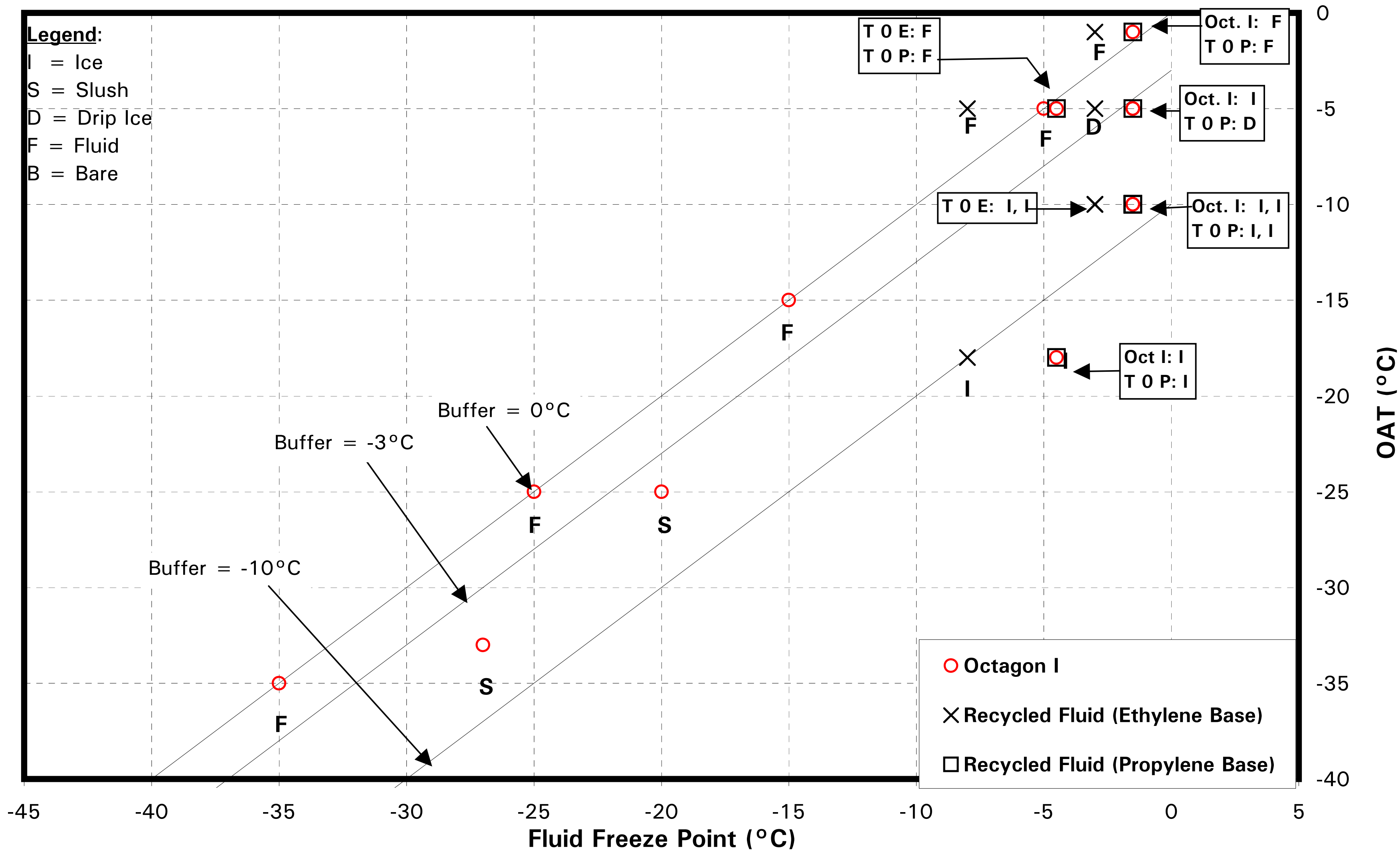


cm1380\report\buffer\ADF_20KH
At: 20 KPH
2/21/2007

FIGURE 4.22

DEICING ONLY TESTS, OCTAGON TYPE I AND RECYCLED FLUIDS, WIND = 20 km/h

PLATE CONDITION AT TEST END

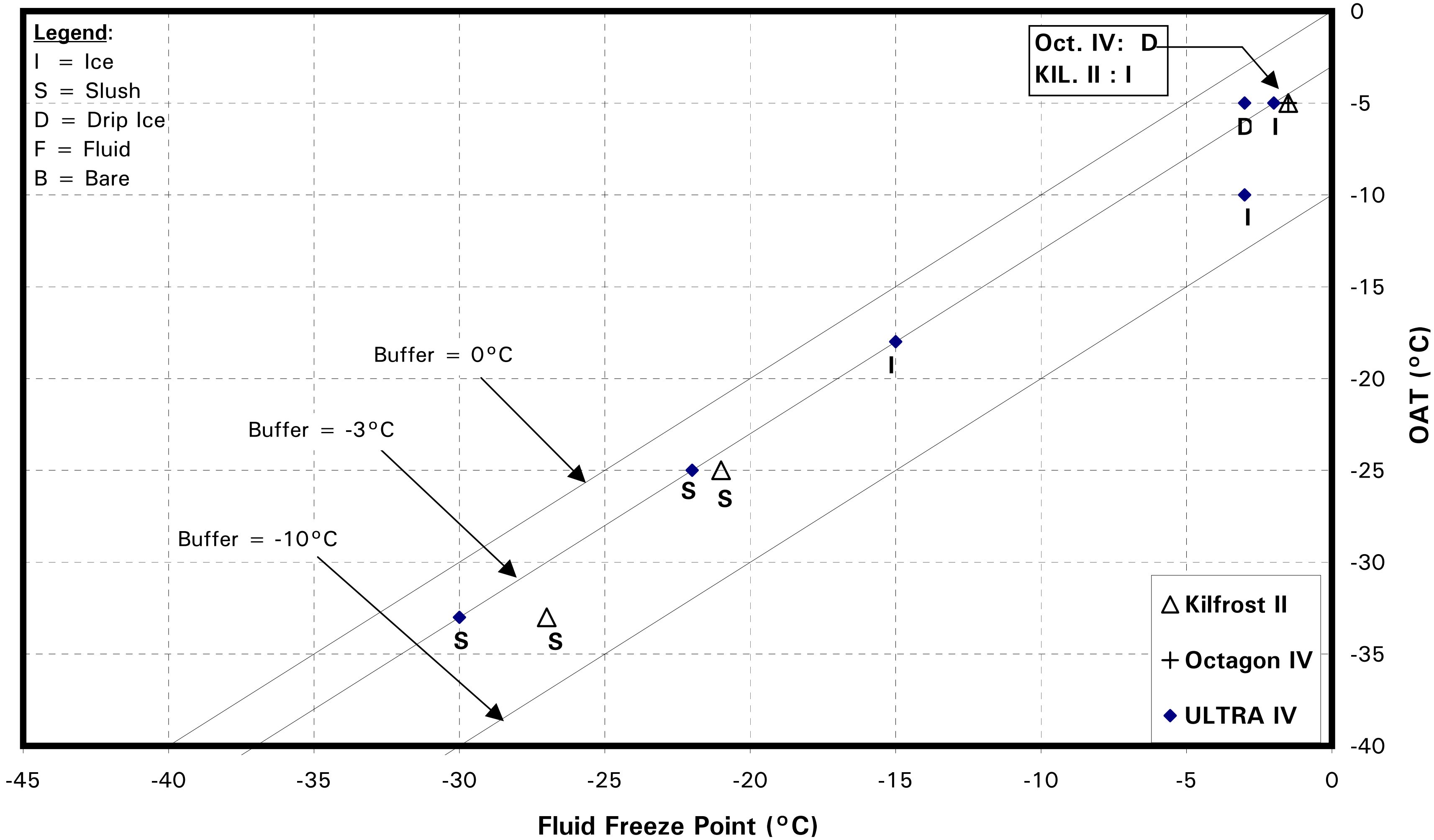


cm1380/report/buffer/ALL_20KH
At: T0,1
2/21/2007

FIGURE 4.23

DEICING ONLY TESTS, TYPE II AND IV FLUIDS, WIND = 20 km/h

PLATE CONDITION AT TEST END



cm1380/report/buffer/ALL_20KH
At: T4
2/21/2007

as the negative buffer grows larger. Cases where the negative buffer was larger than 10°C always resulted in ice formation on the surface.

An analysis of the results obtained for the fluid used in the majority of tests, Union Carbide ADF, demonstrated that fluids mixed to fixed buffer values perform somewhat better at colder as opposed to milder values of OATS (near to 0°C). Reference to Figure 4.18, (outside air temperature = -5°C, wind = 10 km/h), shows that Union Carbide ADF with a negative 3°C buffer (freeze point = -2°C) resulted in ice formation, as it did at all other wind speeds tested. However, at outside air temperatures of -18°C and -25°C, with the same or a more severe negative buffer, the final condition was fluid (no ice present). The explanation for this may be that the very small amount of glycol present in the initial fluid mix at mild temperatures (5 percent concentration by volume at a freeze point of -2°C) has a limited capacity for attaining a higher fluid concentration through evaporation. Glycol concentrations rise due to evaporation because water is the more volatile component in the fluid mix. Water evaporates more readily than glycol, so the composition of the remaining fluid is enriched in glycol.

Following through the charts for different wind speeds for the baseline fluid, Union Carbide ADF, it is noted that high wind speeds (20 km/h) result in more severe icing conditions for certain data point conditions, with cases where final plate condition was fluid and drip ice at lower wind speeds, becoming ice over the plate surface when exposed to the higher wind speed. A further perspective is discussed in Section 4.3.4, where fluid strength profiles are examined for different wind speeds.

4.3.1.2 Summary of Final Plate Condition

Final plate conditions are presented in an alternative format in Tables 4.2 to 4.10. Here the results are given in tabular form, sorted by outside air temperature, fluid type, fluid freeze point and wind speed. The check marks indicate the type of final condition, following the same hierarchy of severity as previously described. This presentation enables a quick comparison of results for different wind speeds, and for different fluid strengths.

In Table 4.2 (outside air temperature = -1°C), all glycol-based test fluids were mixed to a positive buffer value, and all resulted in unfrozen surfaces. Water (a negative buffer value of 1°C) gave the following results as a function of wind speed:

TABLE 4.2

PLATE CONDITION; OAT = -1°C

Fluid	UCAR ADF								Octagon I				Recycled Propylene				Recycled Ethylene				Water			
Freeze Pt.	-2				-3				-1.5				-1.5				-3							
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																						✓	✓	
Fluid	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓				
Drip Line																					✓			
Slush																								
Ice																								✓

TABLE 4.3

PLATE CONDITION; OAT = -5°C

Fluid	ULTRA IV								UCAR ADF																Recycled Propylene							
Freeze Pt.	-2				-3				-2				-3				-5				-8				-1.5				-4.5			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																																
Fluid																	✓	✓	✓	✓	✓	✓	✓	✓					✓	✓		✓
Drip Line					✓	✓	✓	✓					✓	✓	✓	✓									✓	✓		✓				
Slush																																
Ice	✓	✓	✓	✓					✓	✓	✓	✓																				

Fluid	Recycled Ethylene								KILFROST II				Octagon MaxFlight				Octagon 1												Water			
Freeze Pt.	-3				-8				-1.5				-3				-1.5				-4.5				-5							
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																																
Fluid					✓	✓		✓													✓	✓		✓	✓	✓	✓	✓				
Drip Line	✓	✓		✓					✓	✓			✓	✓	✓	✓	✓													✓	✓	
Slush																																
Ice											✓	✓						✓	✓	✓									✓			✓

TABLE 4.4

PLATE CONDITION; OAT = -10°C

Fluid	ULTRA IV				UCAR ADF																Recycled Propylene							
Freeze Pt.	-3				-2				-3				-8				-14				-1.5				-4.5			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																												
Fluid													✓	✓	✓		✓	✓		✓					✓			
Drip Line					✓				✓	✓											✓					✓		
Slush																												
Ice	✓	✓	✓	✓		✓	✓	✓				✓										✓		✓				

Fluid	Recycled Ethylene								Octagon MaxFlight				OCTAGON I								Water			
Freeze Pt.	-3				-8				-3				-1.5				-4.5							
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																								
Fluid					✓	✓											✓							
Drip Line	✓												✓					✓	✓		✓			
Slush																								
Ice		✓		✓							✓			✓		✓						✓	✓	✓

TABLE 4.5

PLATE CONDITION; OAT = -15°C

Fluid	UCAR ADF				Octagon 1			
Freeze Pt.	-15				-15			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare								
Fluid	✓	✓	✓	✓	✓	✓	✓	✓
Drip Line								
Slush								
Ice								

TABLE 4.6

PLATE CONDITION; OAT = -18°C

Fluid	ULTRA IV				UCAR ADF																								Recycled Propylene							
Freeze Pt.	-15				-2				-3				-8				-14				-22								-1.5				-4.5			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h					Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																																				
Fluid																		✓	✓		✓	✓	✓													
Drip Line																	✓																			
Slush																																				
Ice	✓		✓	✓	✓				✓				✓	✓	✓	✓				✓									✓				✓	✓		✓

Fluid	Recycled Ethylene								Octagon MaxFlight				Octagon 1								Water			
Freeze Pt.	-3				-8				-8				-1.5				-4.5							
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																								
Fluid																								
Drip Line																								
Slush																								
Ice	✓				✓	✓		✓			✓		✓					✓	✓	✓	✓			

TABLE 4.7

PLATE CONDITION; OAT = -25°C

Fluid	ULTRA IV				UCAR ADF				UCAR ADF			OCTAGON I				OCTAGON I			KILFROST II			
Freeze Pt.	-22				-22				-25			-20				-25			-21			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																						
Fluid							✓		✓	✓	✓					✓	✓	✓			✓	
Drip Line																						
Slush			✓	✓				✓						✓	✓							✓
Ice																						

TABLE 4.8

PLATE CONDITION; OAT = -33°C

Fluid	ULTRA IV				UCAR ADF				Octagon 1				KILFROST II			
Freeze Pt.	-30				-30				-27				-27			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																
Fluid																
Drip Line																
Slush				✓				✓				✓				✓
Ice																

TABLE 4.9

PLATE CONDITION; OAT = -34°C

Fluid	UCAR ADF			Octagon 1		
Freeze Pt.	-34			-34		
Wind	Calm	10 km/h	20 km/h	Calm	10 km/h	20 km/h
Bare						
Fluid	✓	✓	✓	✓	✓	✓
Drip Line						
Slush						
Ice						

TABLE 4.10

PLATE CONDITION; OAT = -35°C

Fluid	ULTRA IV				UCAR ADF															
Freeze Pt.	-32				-22				-30				-32				-43			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																				
Fluid			✓														✓	✓		
Drip Line																				
Slush															✓					
Ice					✓	✓			✓	✓										

Fluid	OCTAGON I								KILFROST II				WATER			
Freeze Pt.	-20				-27				-27				-22			
Wind	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h	Calm	5 km/h	10 km/h	20 km/h
Bare																
Fluid																
Drip Line																
Slush							✓				✓					
Ice	✓	✓			✓	✓							✓	✓		

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- Under calm conditions, ice formed at the lower edge (drip line) with the surface of the plate left bare and dry;

- At wind speeds of 5 and 10 km/h, no drip ice was formed and the complete plate was left bare and dry. The bead of water that accumulated at the drip line (and subsequently froze in tests conducted with no wind) was dispersed; and

- At 20 km/h, freezing occurred on the plate surface before complete evaporation could take place. The resultant film was very thin, estimated at less than 0.0025 mm (0.0001 in.). This estimate of thickness was based on detection limits of the RVSI contamination sensor system, which, at its standard settings, was unable to detect the ice film.

Table 4.3 (outside air temperature = -5°C) reports results for a number of fluids and fluid mixes. The fluid used in the majority of tests (Union Carbide ADF) was tested at four different buffer values and the following observations were made:

- At zero degree buffer and +3°C buffer, the surface remained wetted with unfrozen fluid under all wind conditions;

- At a negative 2°C buffer, drip line ice formed, with the remainder of the surface left in a non-frozen condition at all wind speeds;

- At a -3°C buffer, ice formed on the plate surface at all wind speeds. This was discussed in Subsection 4.3.1.1, where it was conjectured that the very small amounts of glycol present in the initial fluid mix were insufficient to support large gains in fluid concentration through the process of evaporation; and

- As before, this film of ice was very thin, in the order of less than 0.0025 mm (0.0001 in.). During some tests, similar films of very thin ice formed during the test run, only to disappear before test end (sublimation), leaving a dry bare surface.

  Other fluids tested at the same buffer values behaved similarly, including recycled fluids recovered from spent fluid during deicing operations. Water displayed a final plate condition pattern based on wind speeds similar to that observed and discussed at -1°C outside air temperature, where mild winds offered improved results over calm conditions, but high winds gave a deteriorated result.

Table 4.4 (outside air temperature = -10°C) includes results for larger values of negative buffers in the order of -7°C and more. These buffers generally produced only drip ice at lower wind speeds, and ice on the surface at higher wind speeds. The exception to this was the Ultra IV (Type IV) fluid, which did not perform as well, producing ice on the surface at all wind speeds. Union Carbide ADF with a -2°C buffer value produced a safe surface, wet and unfrozen.

Table 4.5 (outside air temperature = -15°C) reports on a test conducted specifically to test fluids at zero degree buffer. Final plate condition was non-frozen fluid at all wind speeds.

Table 4.6 (outside air temperature = -18°C) reports on further increases in negative buffer values in the order of -10 to -15°C. These tests resulted in ice on the test surface. Ultra IV tested at a -3°C produced ice on the surface at all wind speeds, whereas Union Carbide ADF, at a -4°C buffer, produced ice on the surface only at the high wind speed (20 km/h), and produced a non-frozen wet surface at wind speeds of 5 and 10 km/h.

In Table 4.7 (outside air temperature = -25°C), Union Carbide ADF at a zero degree buffer produced a non-frozen wet surface, but at a -3°C buffer and at high wind, produced ice on the surface. Octagon Type I performed similarly. Ultra IV at a -3°C buffer produced slush at the two wind speeds tested (10 and 20 km/h).

The remaining tables report results for tests conducted at colder outside air temperature values (-33°C to -35°C). For Union Carbide ADF and Octagon Type I, fluids mixed to a zero degree buffer produced a non-frozen surface at all wind speeds. Fluids with larger values of negative buffers, including -3°C, experienced icing in some form.

4.3.2 Effect of Ambient Air Temperature on Surface Temperature Profile

The temperature of the test surface was logged continuously during the course of tests, by means of a thermistor probe mounted on the plate surface at the 22.5 cm (9 in.) line.

These profiles were charted to indicate the degree of heat rise at the time of fluid application, and to show the rate of cooling over time. These charts enable an examination of the influence of outside air temperature and wind speed on plate temperature profile.

Figure 4.24 presents a comparison of plate temperature profiles for different values of outside air temperature under constant wind. This case is based on a single fluid mix (Union Carbide ADF at a freeze point of -3°C) and a wind speed of 5 km/h. Outside air temperature values examined are -1°C, -5°C and -10°C.

The temperature profile curves show that there is no significant difference in initial temperature rise, all rising to a temperature increment of about 35°C above outside air temperature. Further, each of the three curves returns to the initial outside air temperature value at about the same time, in about 18 minutes. The shape of the curves are similar.

The time taken for plate temperature to fall to 0°C differs considerably for each outside air temperature case, varying from 3.5 minutes for outside air temperature = -10°C, to 12 minutes for outside air temperature = -1°C. This would indicate that a heated water application should not freeze within 3.5 minutes following application for these test cases.

4.3.3 Effect of Wind Speed on Surface Temperature Profile

Figure 4.25 provides a comparison of plate temperature profiles when exposed to different wind speeds.

This chart is based on a single fluid mix (Union Carbide ADF at a freeze point of -3°C) and outside air temperature = -5°C. Wind speeds are calm, 5, 10 and 20 km/h.

These curves show a difference in temperature rise with the greatest rise seen for calm conditions, and the least for the highest (20 km/h) wind speed. The profile curves are similar in shape. However, the curves for experiments conducted in high winds have a steeper slope than those carried out in calm and low wind conditions. The time required for plate temperatures to cool to the outside air temperature (and to 0°C) is dependent on wind speed:

FIGURE 4.24

EFFECT OF OAT ON SURFACE TEMPERATURE PROFILE

UCAR ADF (-3) - Wind = 5 km/h

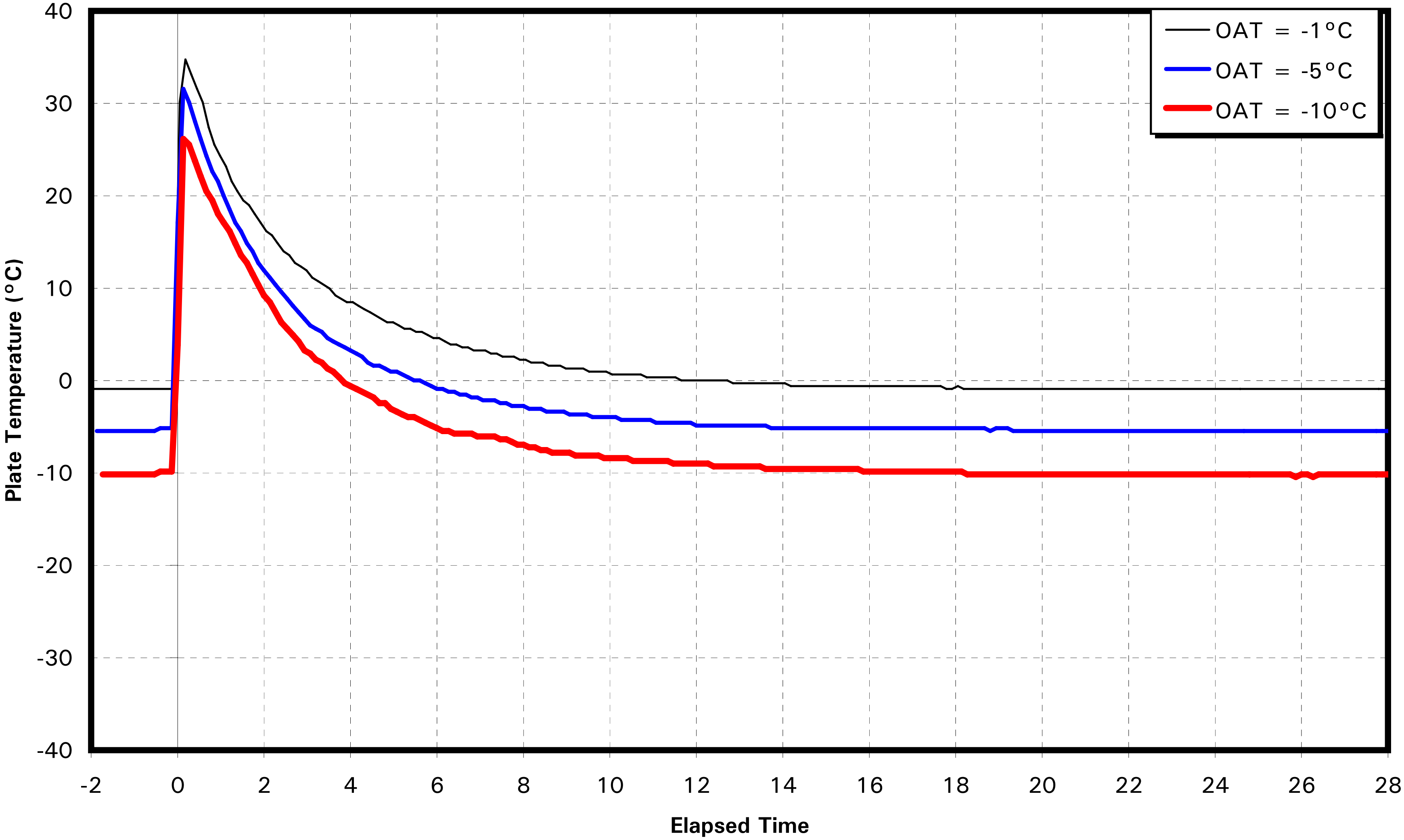
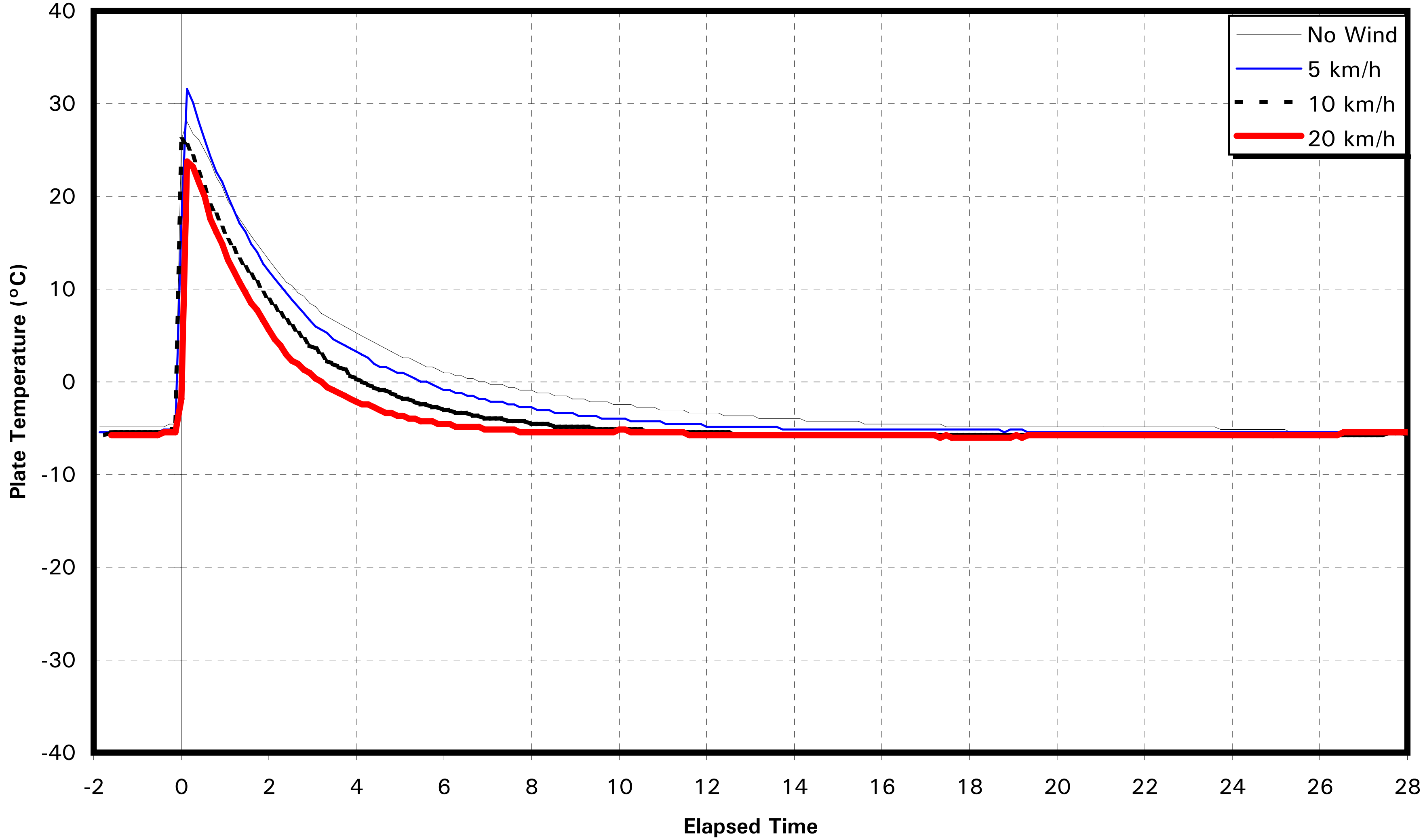


FIGURE 4.25

EFFECT OF WIND ON SURFACE TEMPERATURE PROFILE

UCAR ADF (-3) - OAT = -5°C



cm1380\report\buffer\Figure 4.25
5/1/2007

WIND SPEED (km/h)	TIME TO REACH OAT (minutes)	TIME TO REACH 0°C (minutes)
calm	25	7
5	18	5
10	12	4
20	8	3

The combined effects of the outside air temperature and the wind speed can be seen in Figure 4.26, based on test points for water and dilute Union Carbide ADF solutions. In this chart, the time interval for the plate temperature to fall to 0°C following heated fluid application is plotted versus outside air temperature for different wind speeds. Exponential regression lines drawn for different wind speeds illustrate the influence of outside air temperature and wind.

4.3.4 Fluid Strength Profile Versus Plate Temperature Profile

Dedicated test runs were performed to allow the measurement of changes in fluid strength as a result of evaporation over a 20-minute period following fluid application. These tests were performed on duplicate plates to avoid disturbing the plate temperatures and fluid profiles of the primary test plates, which were used to determine final plate condition.

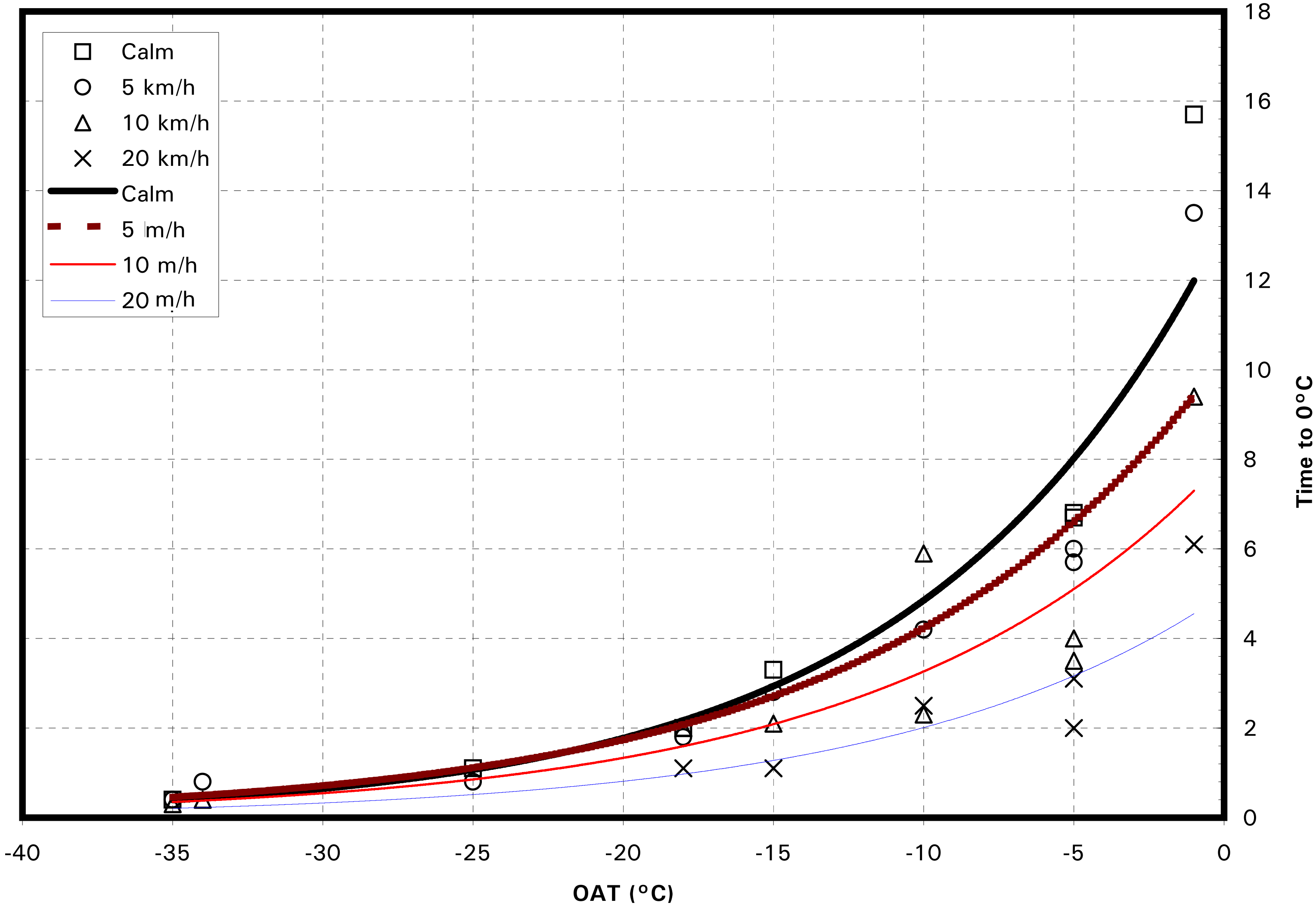
Figures 4.27 to 4.31 present typical profiles for fluid freeze point values measured over the course of tests, along with concurrent plate temperature profiles. Initial fluid freeze point and outside air temperature are indicated in the chart title; wind speed legends are indicated in the legend box. A complete set of similar curves for all fluid strength profile tests conducted is presented in Appendix E.

In Figure 4.27, for each wind speed, the fluid freeze point temperature is tracked as it descends during the test run. The fluid freeze point value can be related to plate temperature at any time, with the difference in temperatures being an indication of proximity to freezing. If the two profiles do not cross, then freezing would not be expected to occur. The temperature differential at any point in time represents the actual freeze point buffer in effect at that moment.

FIGURE 4.26

INFLUENCE OF OAT AND WIND ON PLATE COOLING RATE

DEICING ONLY TESTS



cm1380/report/buffer/Figure 4.26
At: 97-98
5/1/2007

FIGURE 4.27

Fluid Freeze Point and Surface Temperature Profile, U1 (-5), OAT = -5°C

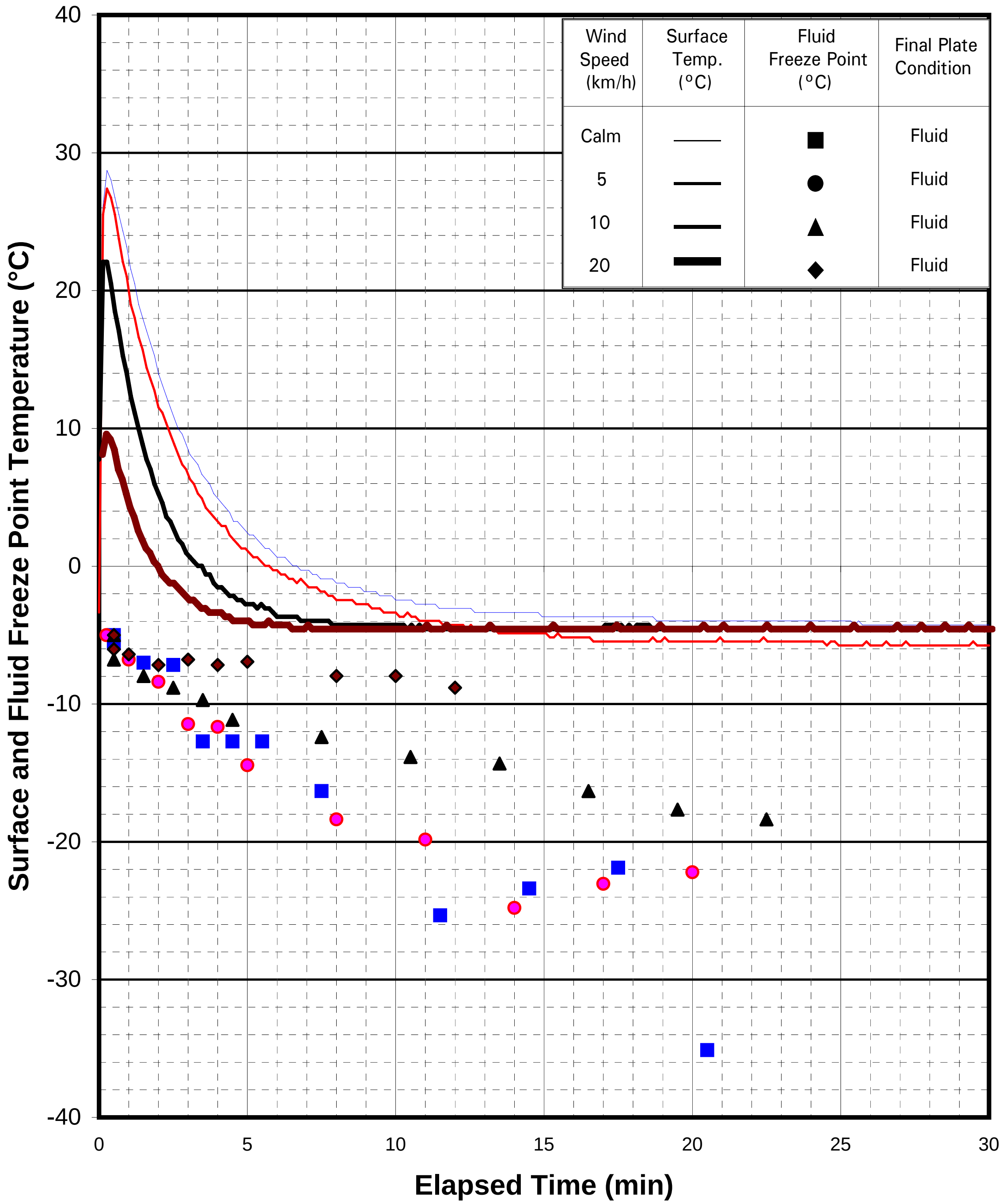


FIGURE 4.28

Fluid Freeze Point and Surface Temperature Profile, U1 (-2), OAT = -5°C

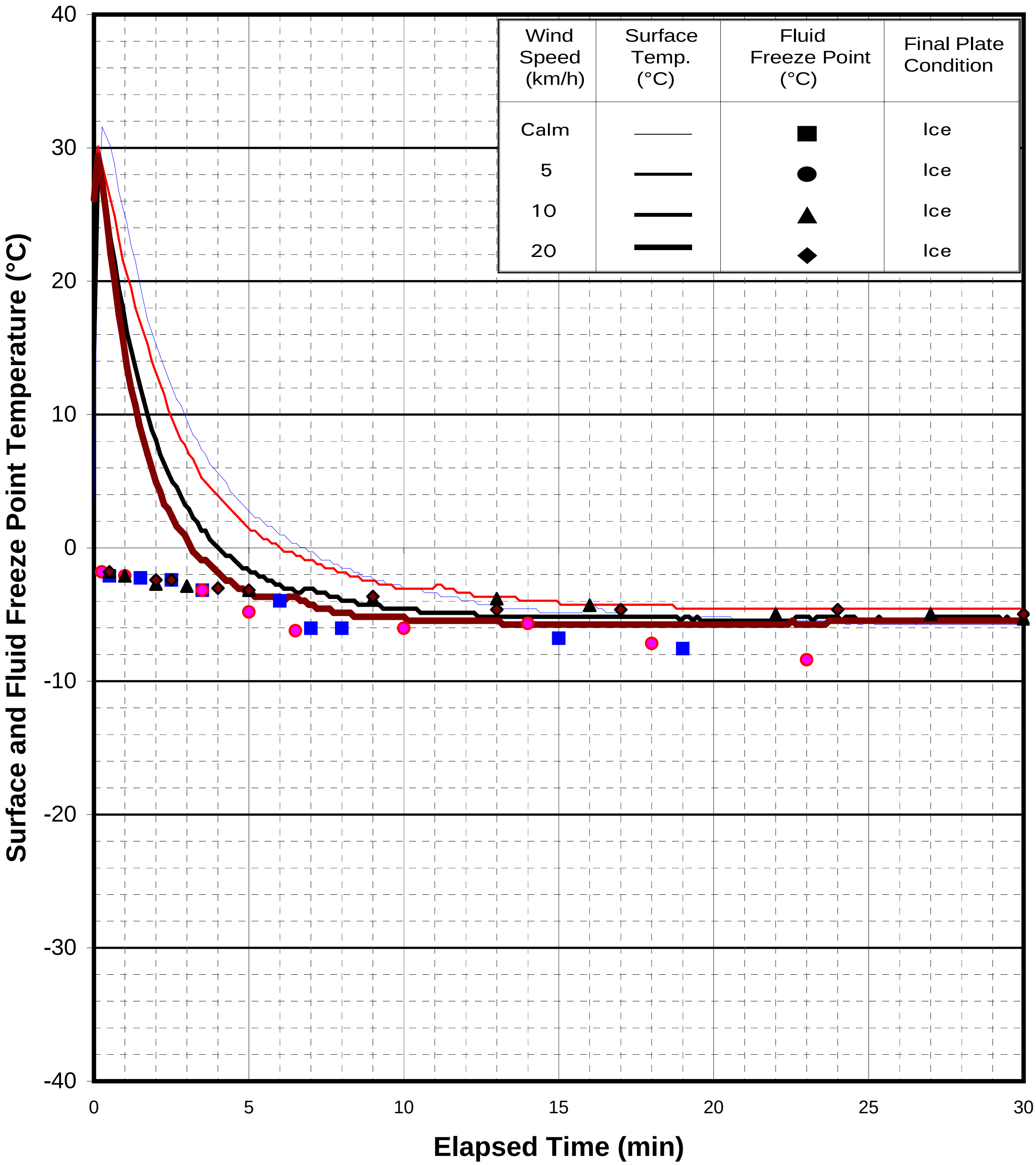


FIGURE 4.29

Fluid Freeze Point and Surface Temperature Profile, U1 (-8), OAT = -10°C

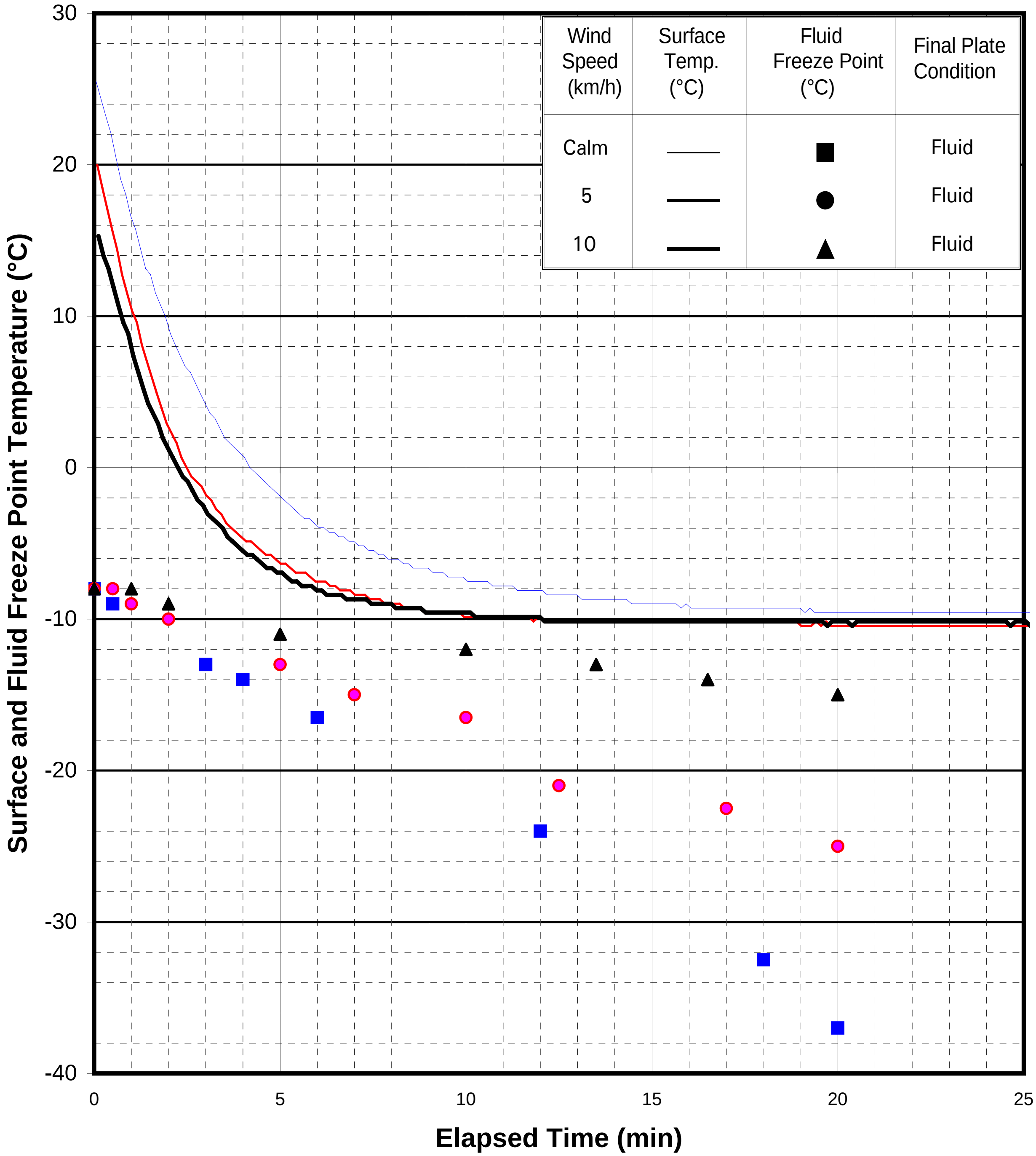
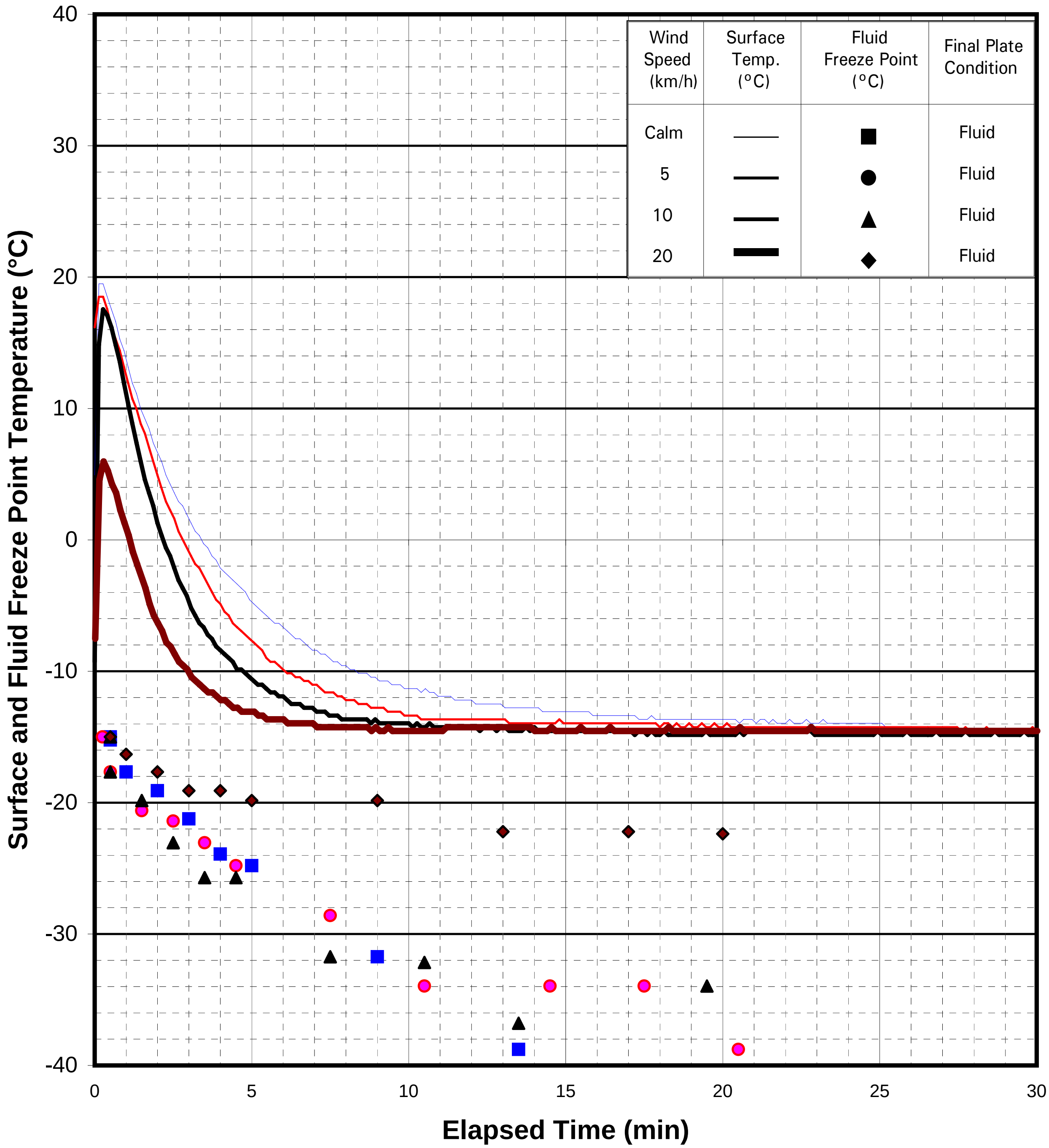


FIGURE 4.30

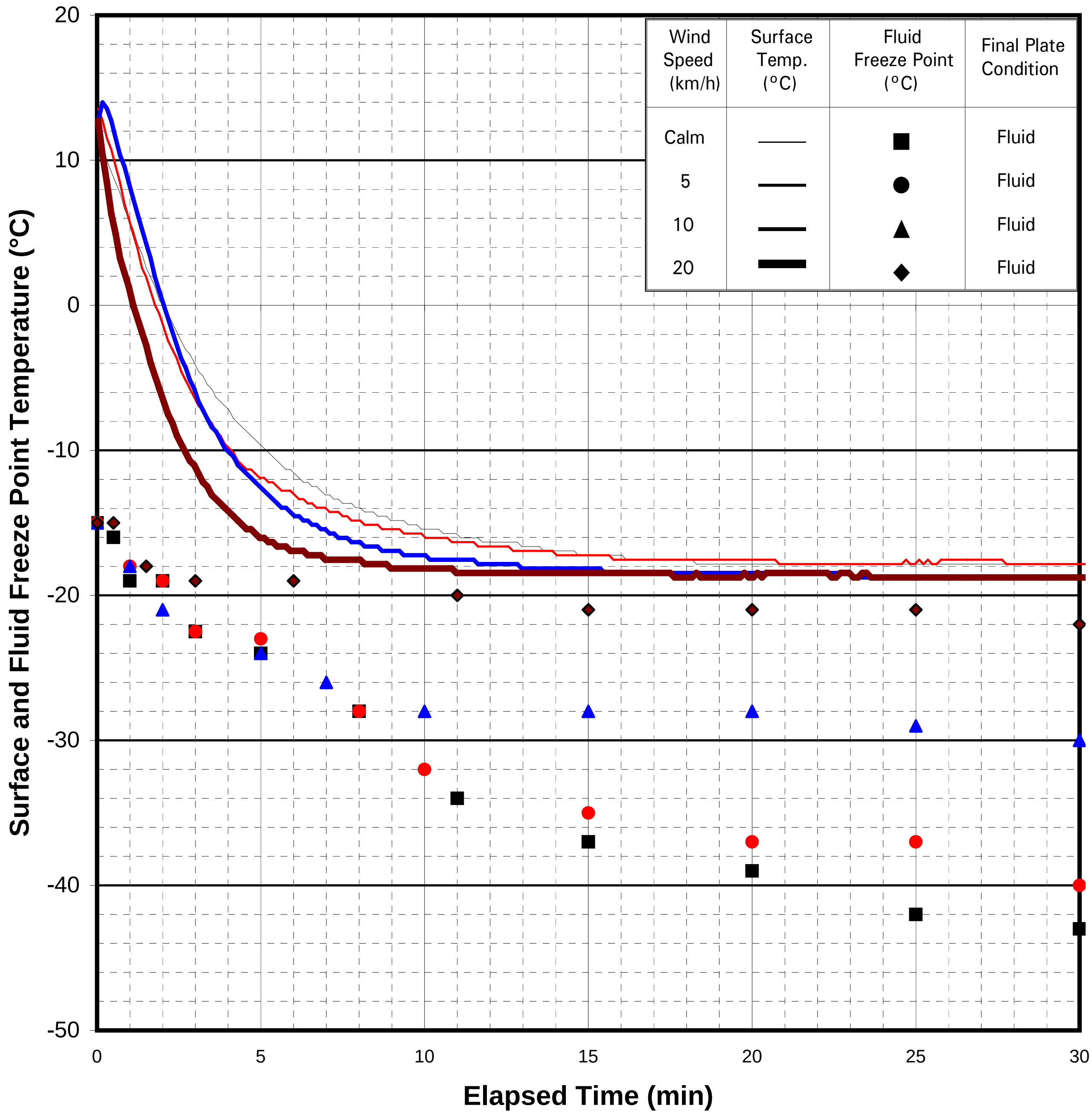
Fluid Freeze Point and Surface Temperature Profile, U1 (-15), OAT = -15°C



cm1380\report\buffer\Figure 4.30
5/1/2007

FIGURE 4.31

Fluid Freeze Point and Surface Temperature Profile, U1 (-14), OAT = -18°C



File:g:\cm1380\report\buffer\Figure 4.31
5/1/2007

Fluid freeze point profiles are different for each wind speed, with profiles during calm and lower winds showing a larger drop (improvement in protection) than when exposed to high speed winds. This is somewhat counter-intuitive, as evaporation would be expected to increase with increased wind speed. The explanation appears to lie with the plate temperature, which falls more rapidly in high wind conditions, as illustrated here in the plate temperature profiles. The influence of wind on evaporation appears to be offset by the more rapid fall in plate temperature. It may also be that the higher winds are causing the glycol in the fluid mix to evaporate more rapidly, thereby maintaining a partial balance of water and glycol.

Figure 4.28 presents results where the fluid has been mixed to a -3°C buffer (outside air temperature = -5°C; fluid freeze point = -2°C). Here the profile is much flatter than in the previous chart, and fluid freeze point profiles for 10 and 20 km/h cross over the corresponding plate temperature profile lines. Freezing would be expected to occur, which is confirmed by reference to the final plate condition charts. Ice was also reported for low wind speeds (calm and 5 km/h); here freezing occurred on the plate near the lower edge further down than the location where fluid samples for Brix values were being lifted.

As mentioned in the discussion on final plate condition, it appears that the amount of improvement in fluid freeze point is less notable in cases where the initial glycol content was very low to begin with.

Figure 4.29 presents results for a fluid having a -2°C buffer at an outside air temperature -10°C. For the three wind speeds reported at this condition, none of the freeze point curves cross over the plate temperature curves, and freezing would not be expected to occur. Reference to the final condition charts confirms that ice did not appear on these plates.

Figure 4.30 presents results for an outside air temperature of -15°C and fluid with a freeze point of -15°C (zero buffer). Significant improvement in fluid freeze point is seen in the first few minutes following application. No freezing occurred, either on the plate surface or on the drip line.

Figure 4.31 reflects an outside air temperature of -1°C and fluid with a freeze point of -14°C (-4°C buffer). Throughout the run, a large spread is maintained between the fluid freeze point and plate temperature curves for wind speeds of calm, 5 and 10 km/h. No ice appeared on the surfaces of these plates, although drip ice did appear in the calm condition. At 20 km/h, ice appeared on the lower part of the plate below the location where samples were taken for Brix measurement.

4.3.5 General Observations

The degree of severity of icing conditions on plate surfaces is deserving of comment. In many cases, the only ice to appear was at the drip line (the lower edge of the plate). When drip ice forms on a small surface such as the size of the plate under test, it may appear to be more serious than justified. In fact, in this test the plate bottom edge is equivalent to the trailing edge of an aircraft wing, or the rear edge of a surface such as the underside of the leading edge slat. In an operational mode, formation of a bead of ice at the trailing edge of a wing, while the remainder of the wing surface remains completely clear of ice, has questionable significance.

In the case of dilute Type I fluids, the final plate condition assessed as ice on the surface, generally consisted of a very thin film of ice, estimated by the RVSI sensor to be less than 0.0025 mm (0.0001 in.) thick. Photos 4.4 and 4.5 offer examples. In some cases, the film was seen to appear in a manner typical of flash freezing, rapidly spreading over the plate area, only to subsequently disappear completely, leaving a completely bare and dry surface. The effect on wing aerodynamics of an ice film of such thickness is debatable.

In contrast to Type I fluids, dilute Type IV fluids tended to freeze as thick layers of slush (Photos 4.6 and 4.7).

The series of images shown in Photos 4.8 to 4.13 are results from the RVSI contamination sensor. In this series, ice can be seen forming over Plate 6 treated with a Union Carbide ADF mixed to a -10°C buffer. Ice can also be seen forming on Plate 4, treated with a Type IV fluid mixed to a -3°C buffer. Plate 2, treated with a Union Carbide ADF mixed to a -4°C buffer, does not show any ice formation.

4.4 First-Step Fluid Study

Assessment of the interval following fluid application until freezing first started to appear on the test surface was the primary issue of these tests, and the data were analysed from that perspective. Other aspects, such as influence of test variables, were examined to assist in explanation of the main results.

4.4.1 Duration of Safe Period Following Spray Application

Figures 4.32 to 4.37 present the interval until first appearance of freezing, and until plate failure, for each of the ambient temperature test conditions under calm winds.

In Figure 4.32, the bars represent time for the fluid (water in this case) to first start to freeze. The test conditions are reported in the chart title; type and rate of precipitation (light freezing rain at 25 g/dm²/h), outside air temperature (-3°C), and wind speed (calm). The two tests reported showed times to freeze of about 8.5 and 10.5 minutes.

Figure 4.33 reports time to reach plate failure for the same test runs. Plate failure is defined in holdover tests as the point when 1/3 of the plate has failed. For the two tests reported, time to reach that point was about 9.5 and 11.5 minutes. In both tests, about one minute passed from the time of initiation of freezing until plate failure.

Figure 4.34 presents results at an outside air temperature of -8°C with the same wind and precipitation conditions as discussed previously. A number of fluids at various strengths were tested at this condition, as reported in the legend. With the exception of Octagon Type IV fluid, all fluids and strengths tested produced times to initiation of freezing in a range from 5 to 6 minutes. Octagon Type IV fluid times ranged from 4 to 5 minutes. The short reported time for one test (recycled ethylene glycol-based fluid at a -3°C freezing point) is an aberration, perhaps due to observer error. Time to plate failure for this case was normal.

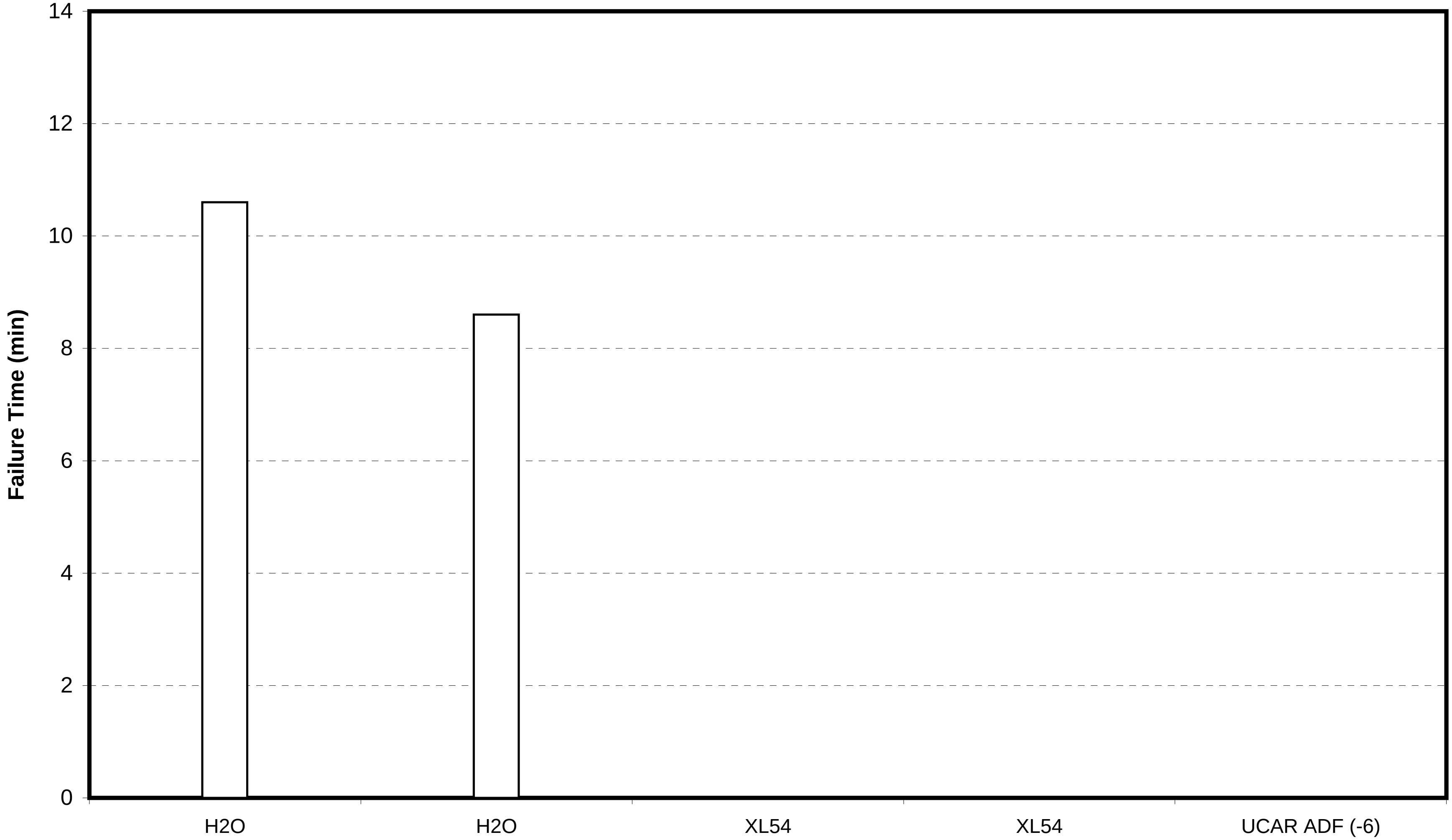
Figure 4.35 presents time to plate failure for the same test. As previously, a time interval of about a one minute passed from freezing initiation to plate failure. Again, all fluids tested, including water, performed similarly.

It should be noted that this test run included fluids recycled from spent fluid recovered from actual deicing operations. These fluids included both ethylene and propylene glycol-based fluids, and both types delivered safe periods of protection (time interval prior to freezing), equivalent to present commercially available Type I fluid brands.

FIGURE 4.32

FIRST STEP, FIRST APPEARANCE OF ICE, OAT = -3°C, WIND CALM

LIGHT FREEZING RAIN (25 g/dm²/h)

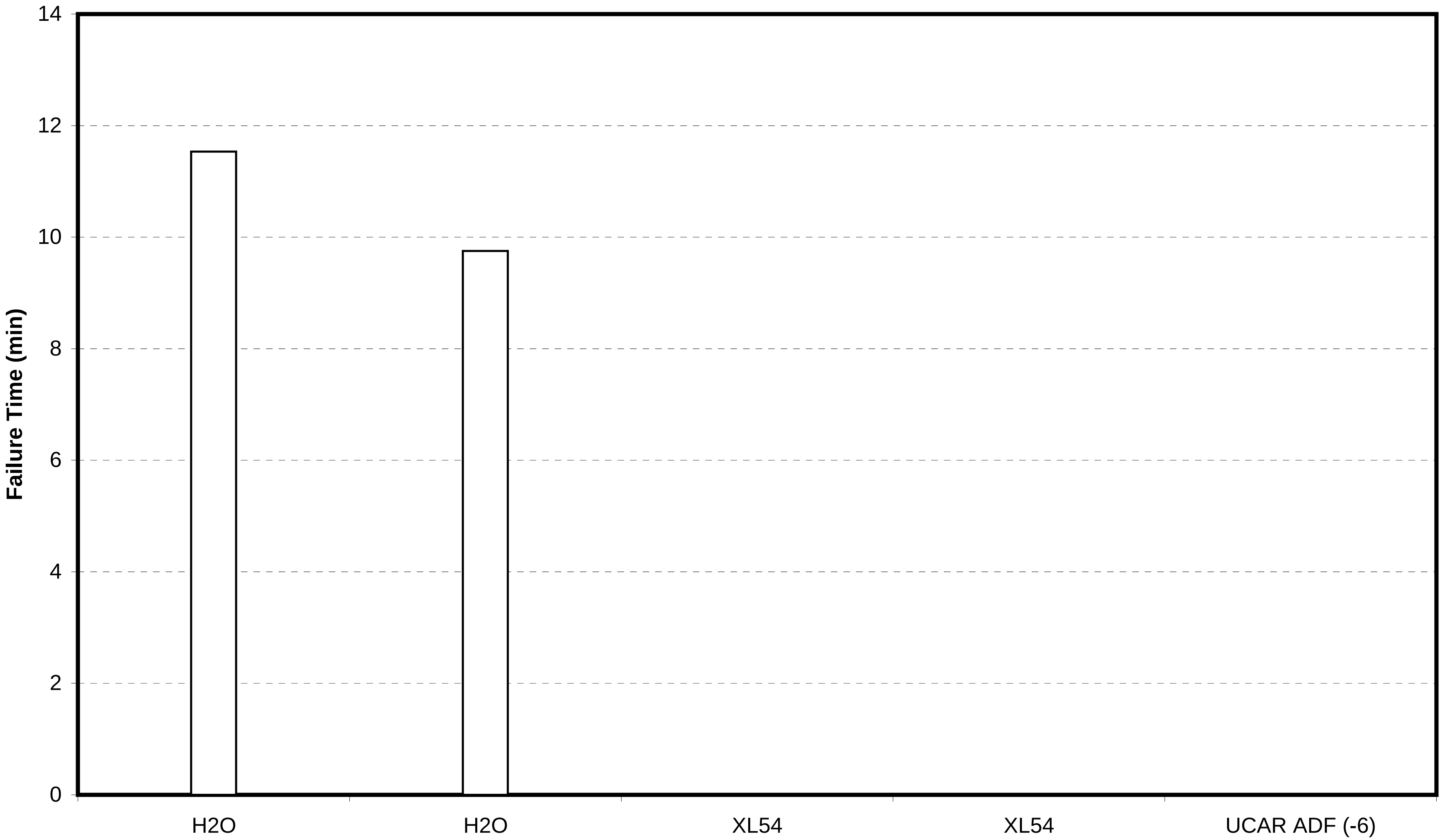


cm1380\report\buffer\FSP_1SF
At: -3
2/22/2007

FIGURE 4.33

FIRST STEP, PLATE FAILURE, OAT = -3°C, WIND CALM

LIGHT FREEZING RAIN (25 g/dm²/h)

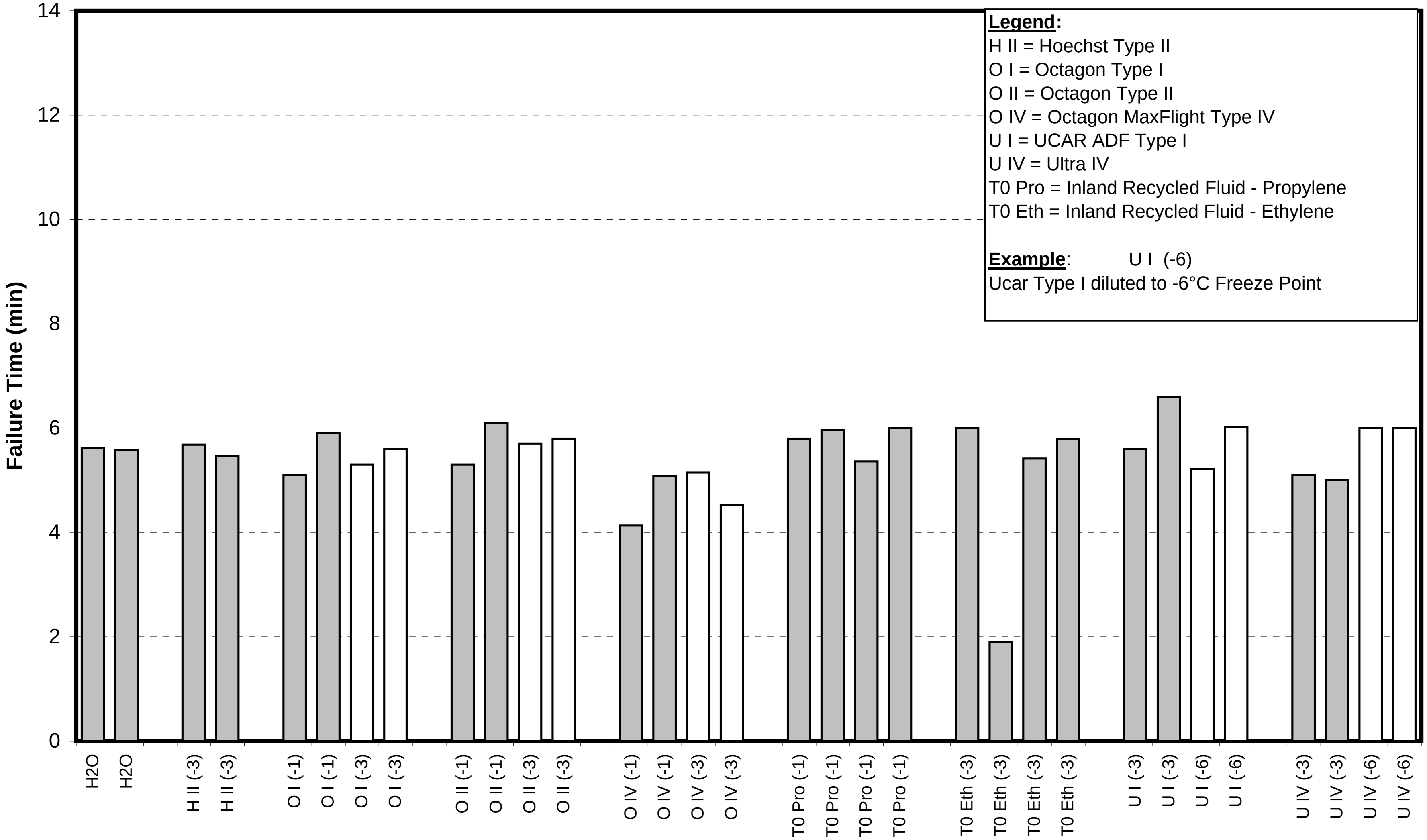


cm1380\report\buffer\BARS_11
At: -3
2/22/2007

FIGURE 4.34

FIRST STEP, FIRST APPEARANCE OF ICE, OAT = -8°C, WIND CALM

LIGHT FREEZING RAIN (25 g/dm²/h)

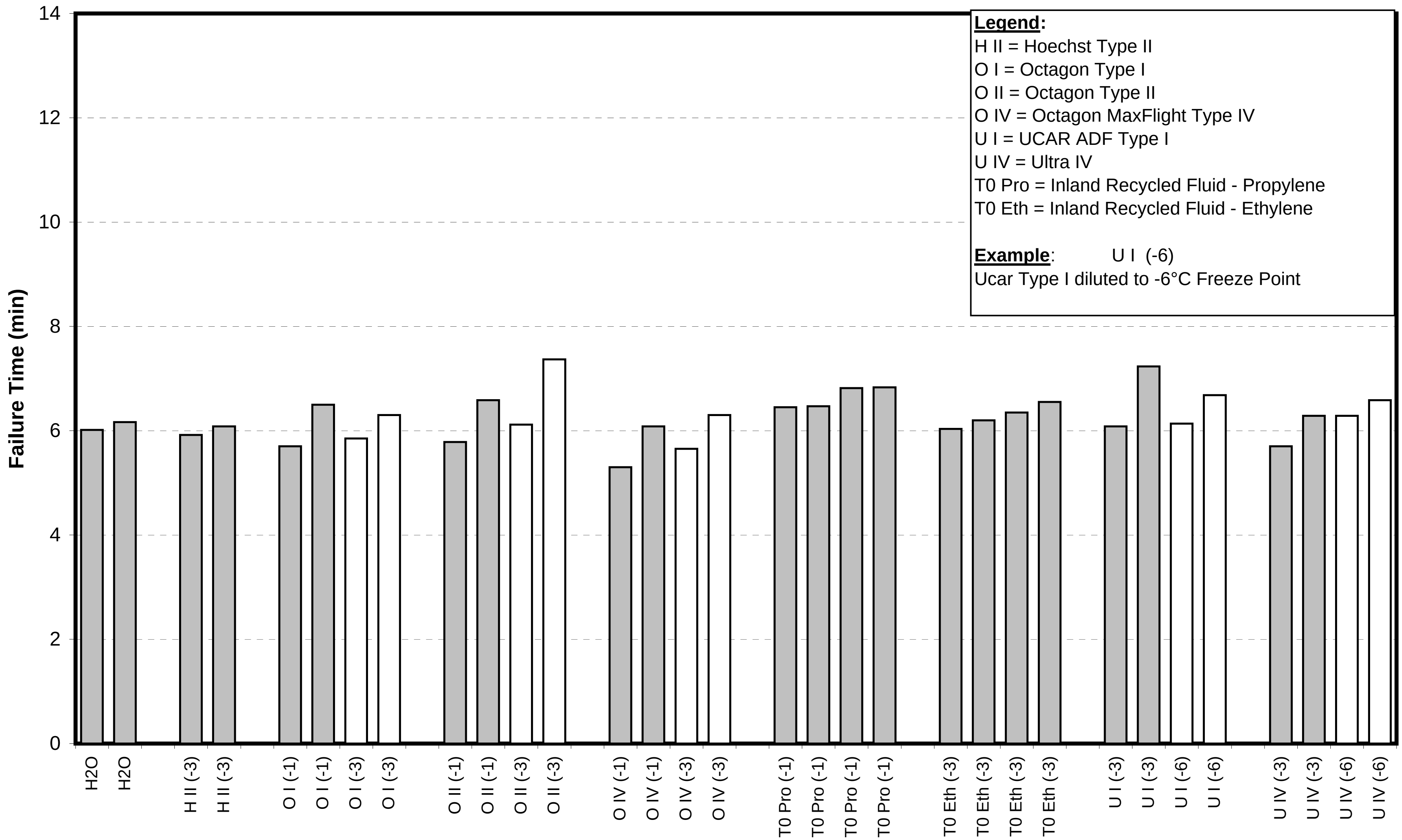


cm1380\report\buffer\FSP_1SF
At: -8
2/22/2007

FIGURE 4.35

FIRST STEP, PLATE FAILURE, OAT = -8°C, WIND CALM

LIGHT FREEZING RAIN (25 g/dm²/h)

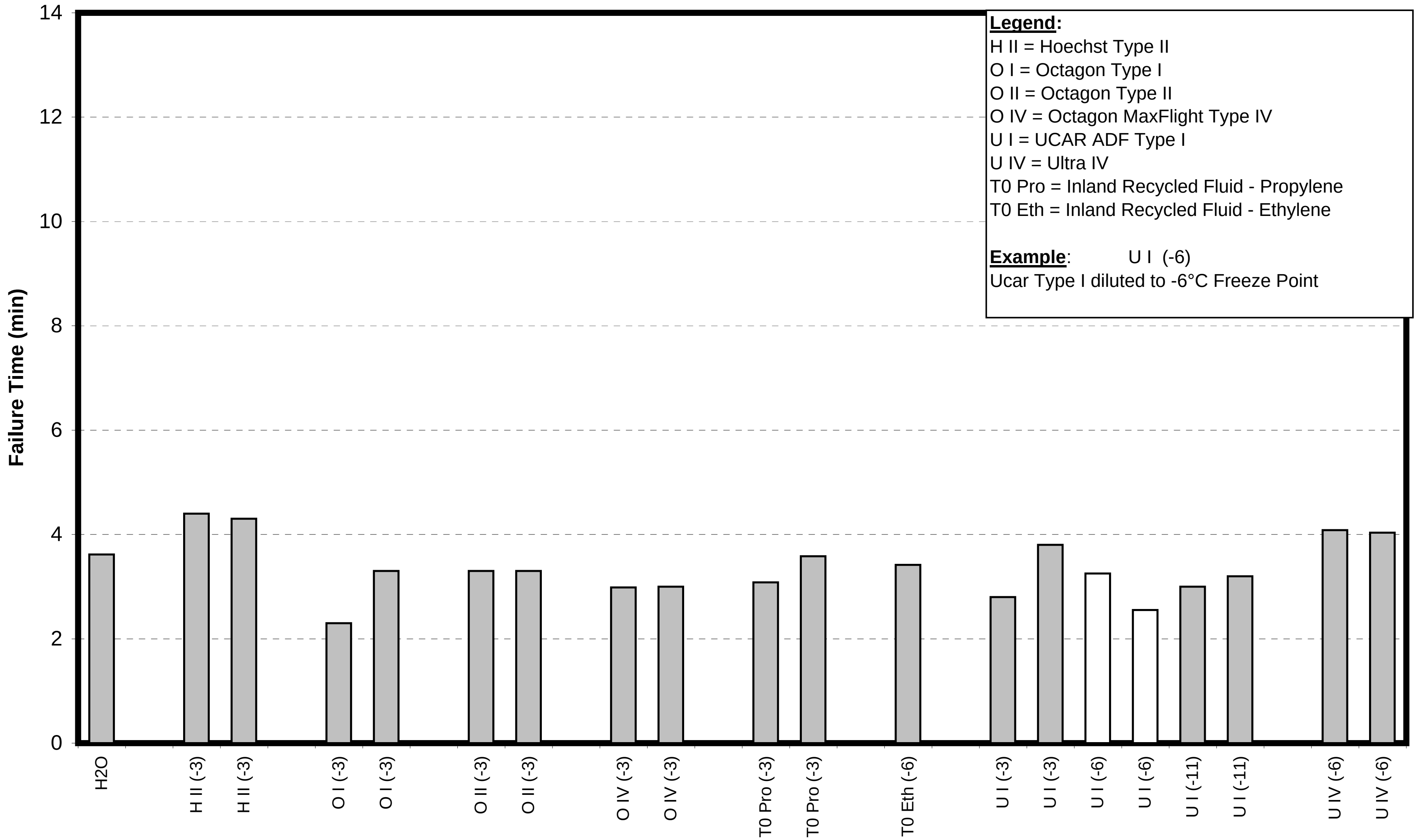


cm1380\report\buffer\BARS_11
At: -8
2/22/2007

FIGURE 4.36

FIRST STEP, FIRST APPEARANCE OF ICE, OAT = -14°C, WIND CALM

LIGHT FREEZING RAIN (25 g/dm²/h)

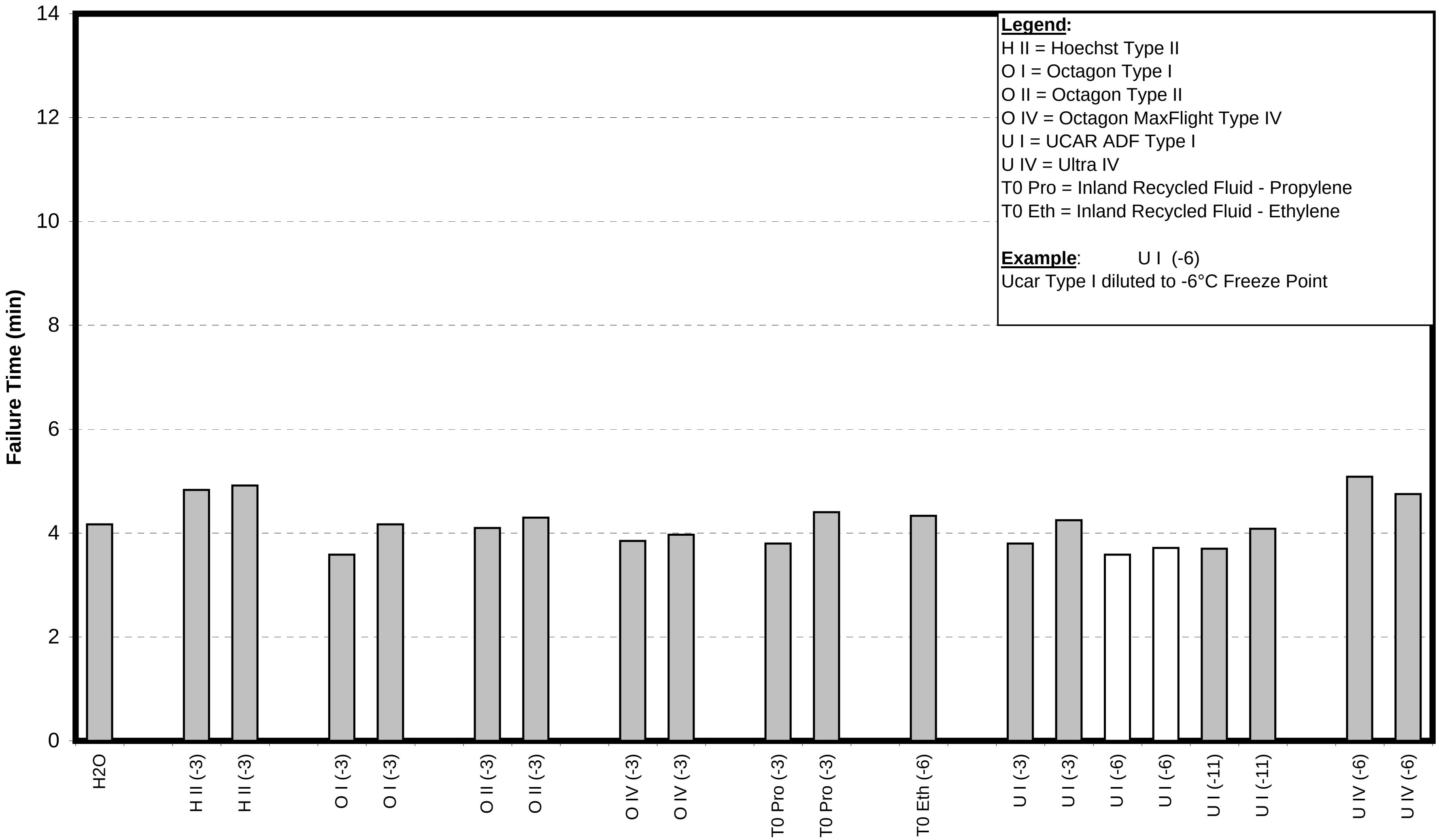


cm1380\report\buffer\FSP_1SF
At: -14
2/22/2007

FIGURE 4.37

FIRST STEP, PLATE FAILURE, OAT = -14°C, WIND CALM

LIGHT FREEZING RAIN (25 g/dm²/h)



cm1380\report\buffer\BARS_11
At: -14
2/22/2007

Figure 4.36 reports results for an outside air temperature of -14°C. Here the time intervals from fluid application to initiation of freezing are scattered about the 3-minute level. The only difference in results from the different fluids tested appears to be a slightly stronger performance from Hoechst (Clariant) Type II mixed to -3°C freeze point, and from Union Carbide Type IV mixed to -6°C freeze point, which delivered safe periods of 4 minutes. Times from other fluids, including water and recycled fluids, ranged from 2.5 to 3.5 minutes.

Figure 4.37 reports plate failure times for the foregoing tests. Again, the time from initiation of freezing until plate failure occurred was about one minute.

Figure 4.38 summarizes the results from the three test conditions, plotting the average time interval values delivered by the variety of fluids tested at each ambient temperature condition. The trend line drawn through these points shows consistency of results.

4.4.2 Influence of Wind

A previous study on the use of hot water for deicing (3) identified that performance was greatly influenced by wind speed. A preliminary attempt to evaluate the influence of wind was performed while the chamber ambient air temperature was controlled at -8°C. The rate of precipitation of 25 g/dm^2/h was maintained.

Wind for these tests was produced by use of small fans as described in Section 2. Although the quality of wind produced by these fans was not ideal, it was adequate to provide some indication of wind effect.

Figure 4.39 presents the time until first appearance of ice experienced at three wind speeds based on a Type I fluid mixed to a -3°C freeze point (a -5°C buffer):

- The results from calm wind are shown in Figure 4.34;

- Winds at 6 km/h produced a time interval until initial freezing of about 3 minutes, or about one half of that resulting from calm conditions; and

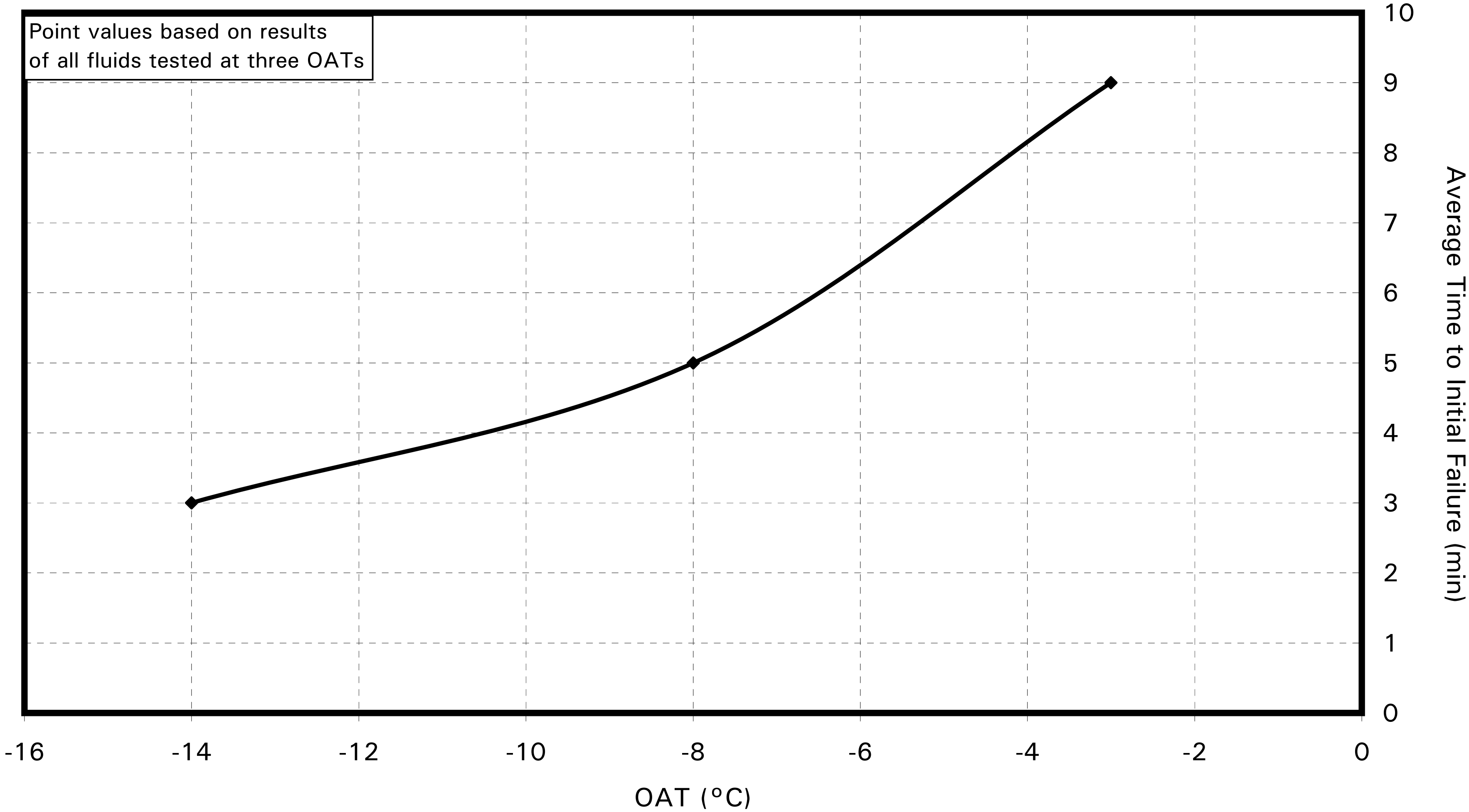
- A wind speed of 10 km/h further reduced the interval until initial freezing to about 1 minute.

FIGURE 4.38

EFFECT OF OAT ON TIME TO FIRST FREEZE

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

Wind Calm

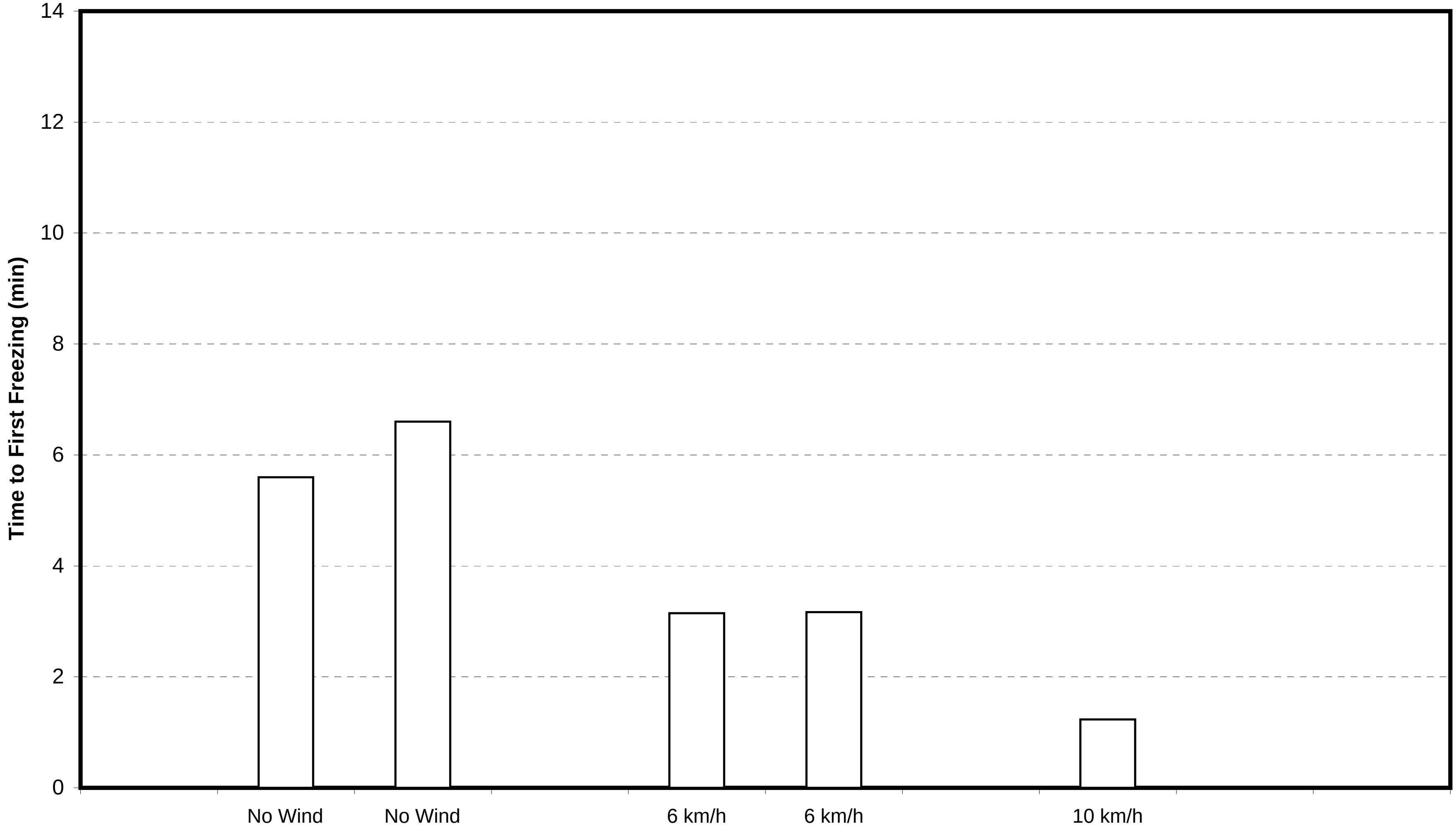


cm1380/report/buffer/EFFC_OAT
At: Effect (2)
2/22/2007

FIGURE 4.39

INFLUENCE OF WIND ON TIME TO FIRST FREEZE, LIGHT FREEZING RAIN, OAT = -8°C

UCAR ADF (-3°C); OAT = -8°C



cm1380\report\buffer\BARS_11
At: -8°C - WIND - 1st Frz.
2/22/2007

The time interval from the initiation of freezing until plate failure at each wind speed (Figure 4.40) was similar to the time intervals recorded for the appearance of initial freezing after fluid application.

These results justified further effort to better understand the impact of wind, and a short series of tests was conducted using the large fans (used in the *deicing only* study) to produce a controlled wind. The plan for these supplemental tests is shown in Table 4.11. Problems were encountered when attempting to produce winds at 5 km/h, which prevented the conduct of tests at that wind speed.

Figure 4.41 presents the interval to initiation of freezing following fluid application for several fluids at wind speeds of calm, 10 and 20 km/h. Fluids tested in these tests included water, dilute Type I and (standard full strength) Type I, as shown in the legend. The ambient air temperature was -10°C and precipitation was light freezing rain at 25 g/dm^2/h.

In calm winds, water and the two dilute fluids performed at about the same level, producing an interval of about four minutes before onset of freezing. Standard (full strength) XL54 performed slightly better, producing an interval of about 4.5 minutes. The meagreness of improvement in performance provided by full strength fluid is caused by its rapid rate of dilution under test precipitation conditions. This is examined further in Section 5.

All fluid samples showed a reduced time interval until freezing initiated when wind was increased to 10 km/h and a further reduction when wind was increased to 20 km/h. The reduction for full strength fluid (standard Type I) was slightly less than those for water and dilute fluids.

Fluid mixed to a freeze point of -7°C performed slightly better than water at higher wind speeds, while fluid with an initial freeze point of -3°C performed worse than water at all wind speeds.

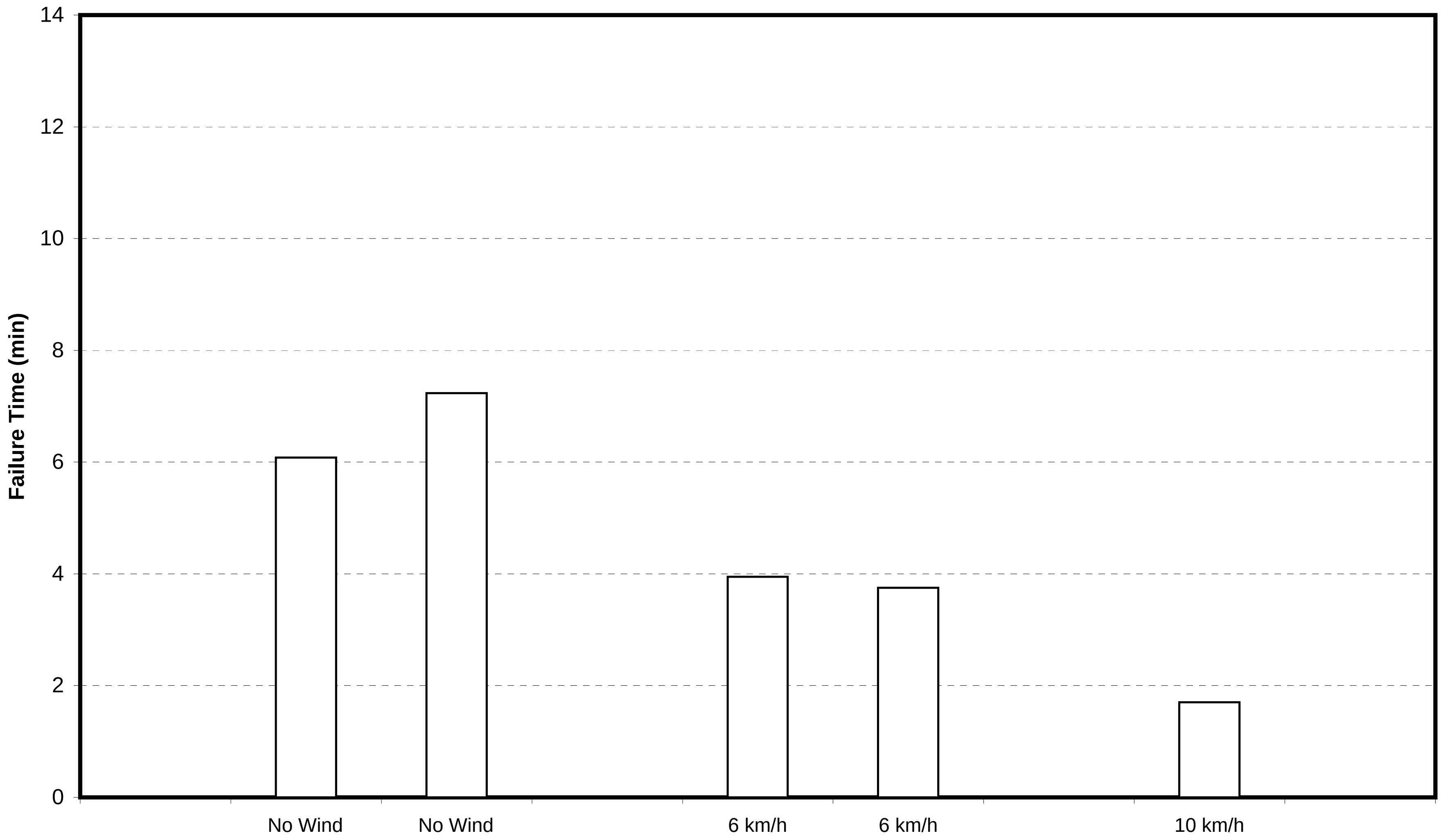
The corresponding time intervals for the lower precipitation rate of 12 g/dm^2/h are shown in Figure 4.42. Times for water are not affected by the change in precipitation rate, as dilution is not a factor for this fluid.

The average time interval for water and dilute fluids (4 minutes) at calm winds is, along with previous test results, plotted in Figure 4.43. These results provide further confirmation of the trend established previously, and shown in Figure 4.38.

FIGURE 4.40

INFLUENCE OF WIND ON TIME TO PLATE FAILURE, LIGHT FREEZING RAIN, OAT = -8°C

UCAR ADF (-3°C); OAT = -8°C



cm1380\report\buffer\BARS_11
At: -8°C - WIND
2/22/2007

TABLE 4.11
FIRST STEP FLUID TESTS

Further Tests at the National Research Council Canada Climatic Engineering Facility

Objectives:

a) Quantify impact of wind on time to freeze for different fluid strengths; and

b) Measure dilution curves for different fluid strengths at two different precipitation rates.

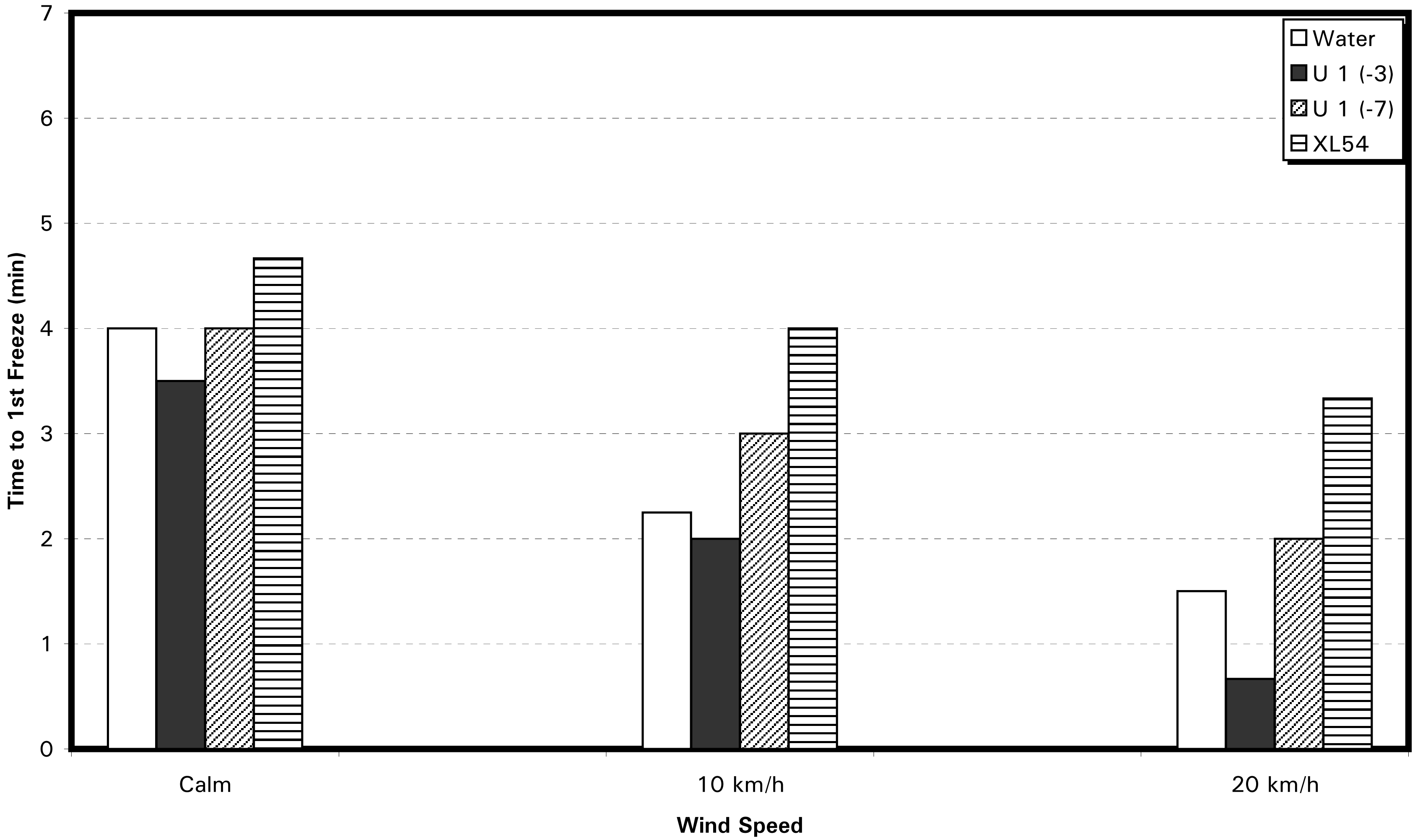
Conditions: Rates: (freezing rain) - 25 g/dm²/h
(freezing drizzle) - 12 g/dm²/h

OAT: -10ºC

Fluid	Wind Speed			
	Calm	5 km/h	10 km/h	20 km/h
Water	x	x	x	x
ADF -3ºC	x	x	x	x
ADF -7ºC	x	x	x	x
XL54	x	x	x	x

FIGURE 4.41

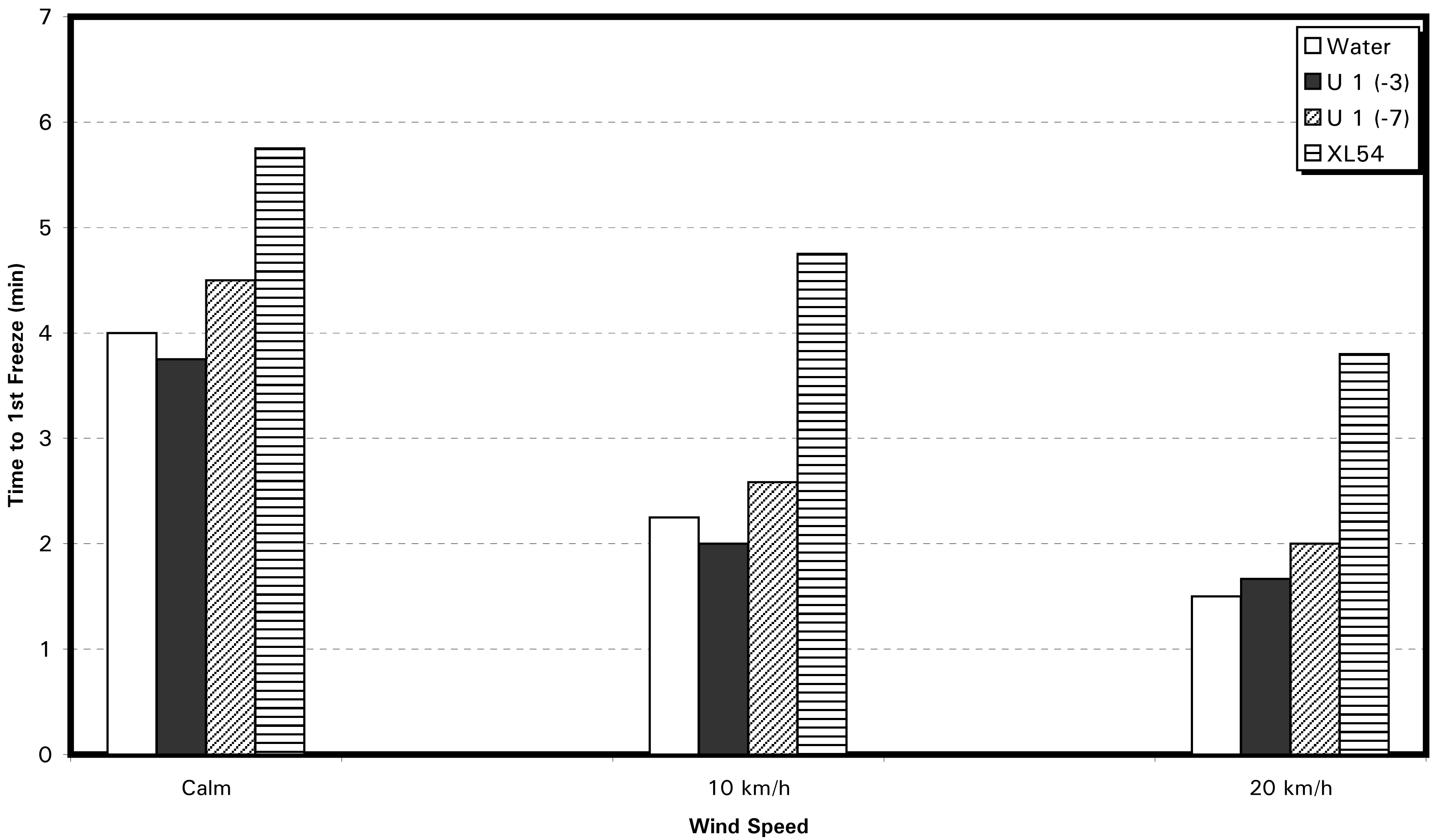
INFLUENCE OF WIND ON TIME TO FIRST FREEZE, LIGHT FREEZING RAIN, OAT = -10°C



cm1380/report/buffer/WND_-10C
At: Rain
2/22/2007

FIGURE 4.42

INFLUENCE OF WIND ON TIME TO FIRST FREEZE, FREEZING DRIZZLE, OAT = -10°C

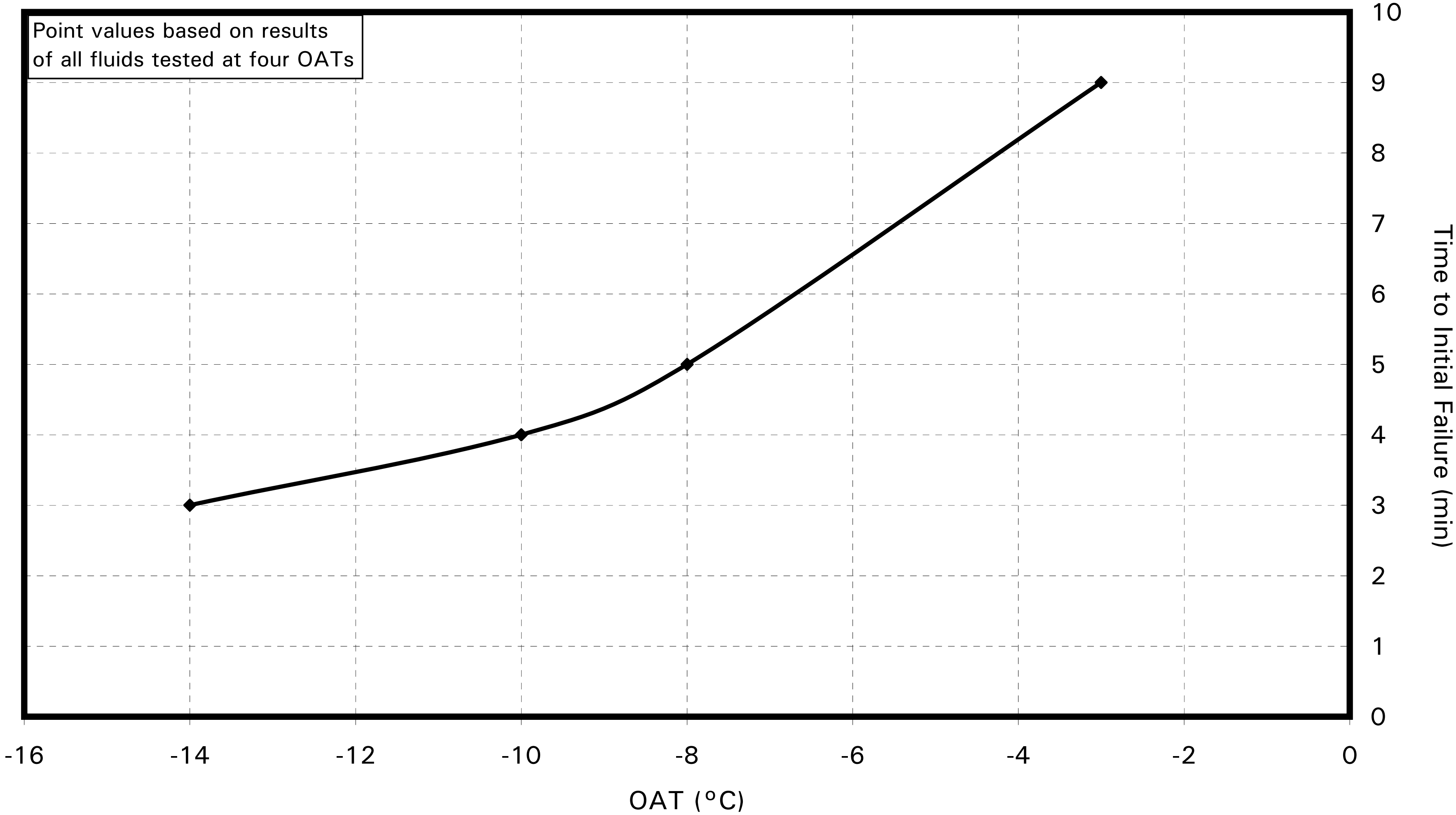


cm1380/report/buffer/WND_-10C
At: Drizzle
2/22/2007

FIGURE 4.43

EFFECT OF OAT ON TIME TO FIRST FREEZE - COMBINED RESULTS

LIGHT FREEZING RAIN (25 g/dm^2/h), Wind Calm



cm1380/report/buffer/EFFC_OAT
At: Effect
2/22/2007

4.4.3 Dilution of Fluid Strength

In the initial series of tests, special runs were devised to measure fluid strength on a progressive basis in order to document the rate of dilution under test conditions. As rate of dilution was seen to have a significant influence on results, the procedure was repeated during the second set of tests to provide additional data. Figure 4.44 shows results from both test sessions. At outside air temperature of -3°C and at a rate of precipitation of 25 g/dm^2/h, full strength Type I fluid was diluted and ultimately washed off the plate. There was no detectable glycol in the fluid on the plate in about seven minutes. An initial mix with freeze point of -6°C, diluted to pure water in about four minutes. A comparison of rates of dilution for different precipitation rates, 12 versus 25 g/dm^2/h, is shown in the bottom chart.

The very high rates of dilution start to provide an explanation of those observed test results where water provided an interval prior to initial freezing similar to or greater than that of diluted glycol deicing fluids. As discussed in the *deicing only* study, the relationship of fluid freeze point temperature and plate temperature is a dynamic one, and freezing is expected to occur only when the two values became equal. In contrast to the *deicing only* study, where the fluid freeze point progressively decreased due to evaporation, in these (first-step) fluid tests the freeze point increased rapidly due to dilution. In those instances when the fluid is completely replaced by pure water prior to the initiation of freezing, the fluid mix provides an interval prior to freezing similar to that which would have been provided by an initial application of pure water.

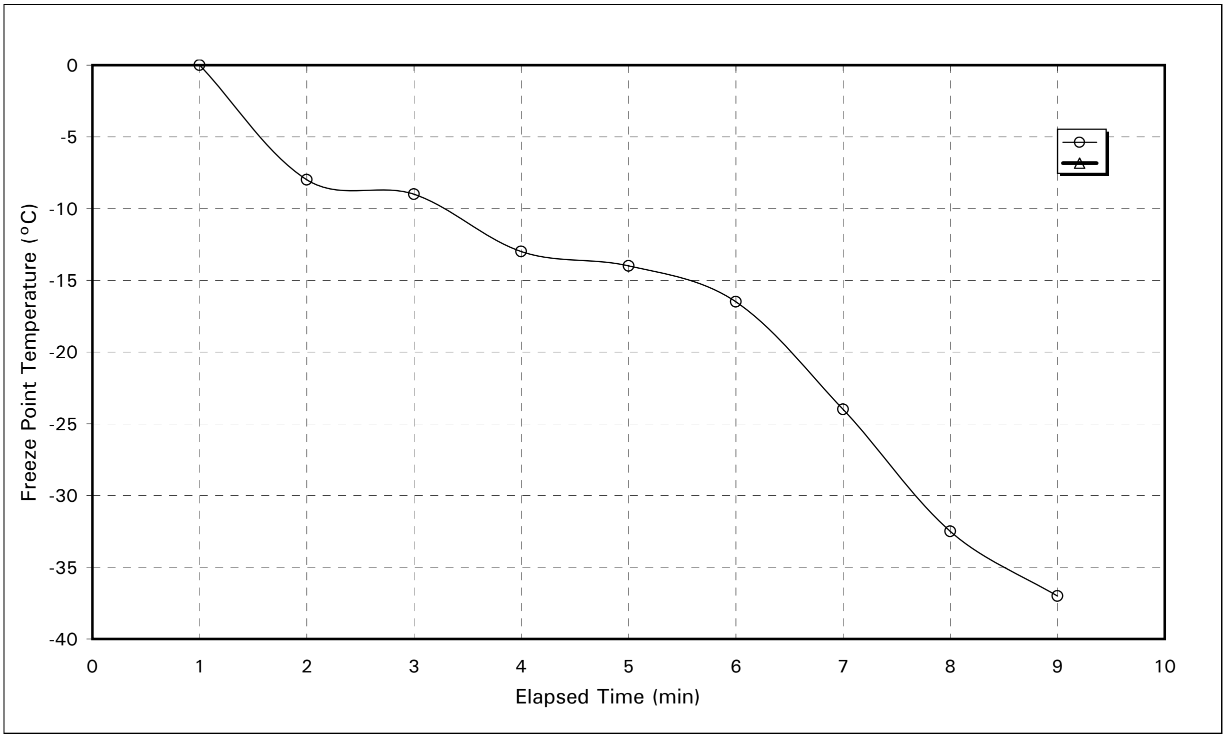
4.4.4 Fluid Freeze Point / Plate Temperature Profiles

At any point in time, the instantaneous value of the fluid freeze point and the test surface temperature are the parameters that most directly influence the state of the fluid. To examine the relationship between these two parameters, a set of graphs was developed from the data gathered during the test series that examined the impact of wind on the freezing of fluids. These graphs are presented in Figures 4.45 to 4.52.

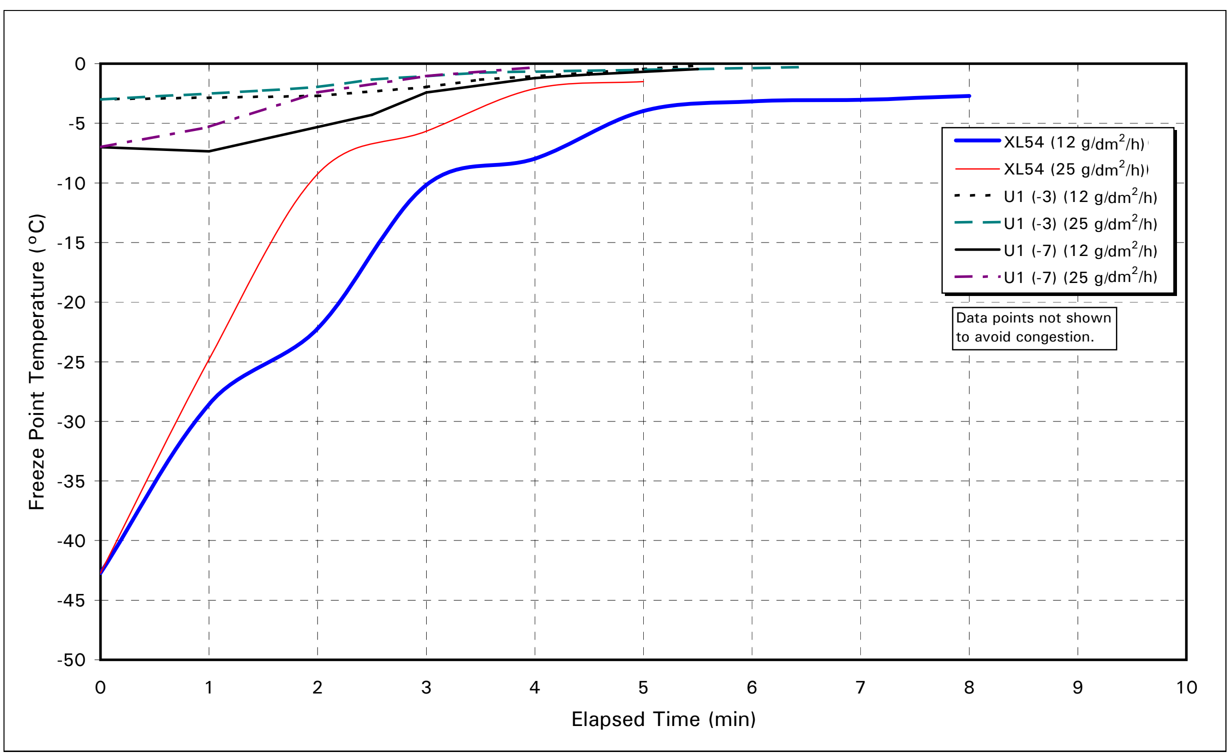
FIGURE 4.44

FREEZE POINT DILUTION CURVES

LIGHT FREEZING RAIN (25 g/dm²/h)
OAT = -3°C, WIND CALM



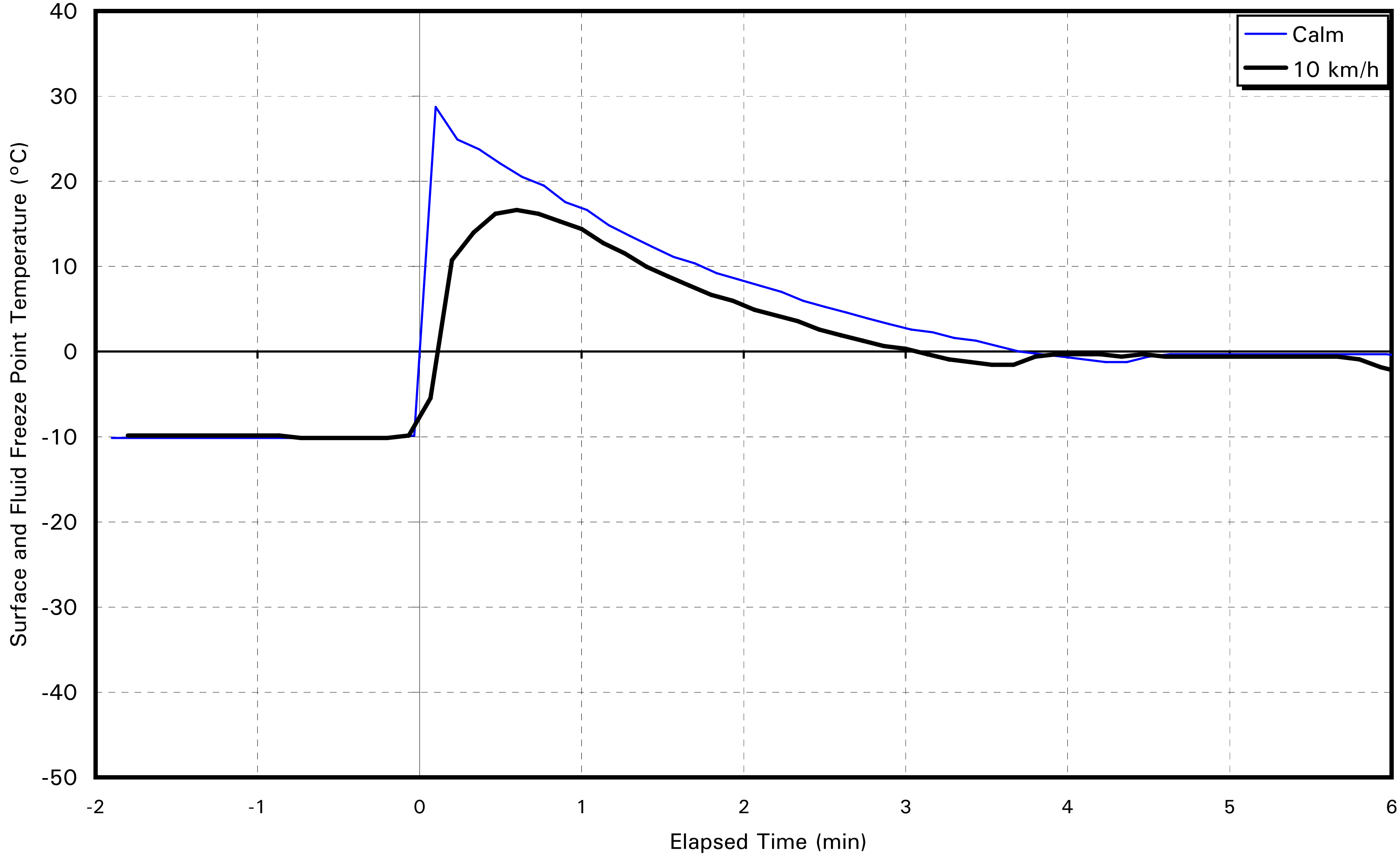
LIGHT FREEZING RAIN
OAT = -10°C, WIND CALM



cm1380/report/buffer/Figure 4.44
5/1/2007

FIGURE 4.45

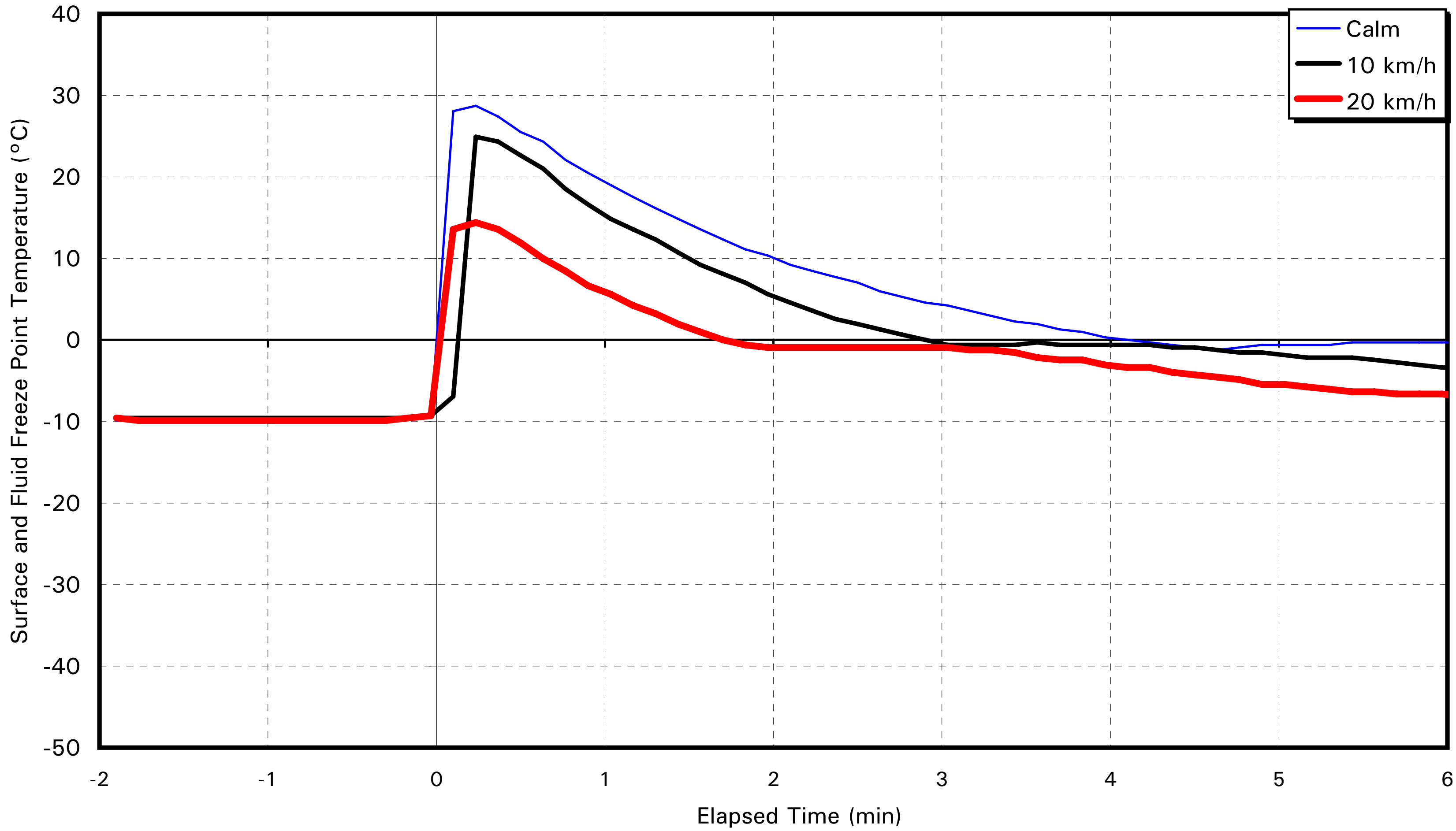
WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, WATER, FREEZING DRIZZLE (12 g/dm²/h), OAT = -10°C



cm1380/report/buffer/WATER-10
At: 12g
2/22/2007

FIGURE 4.46

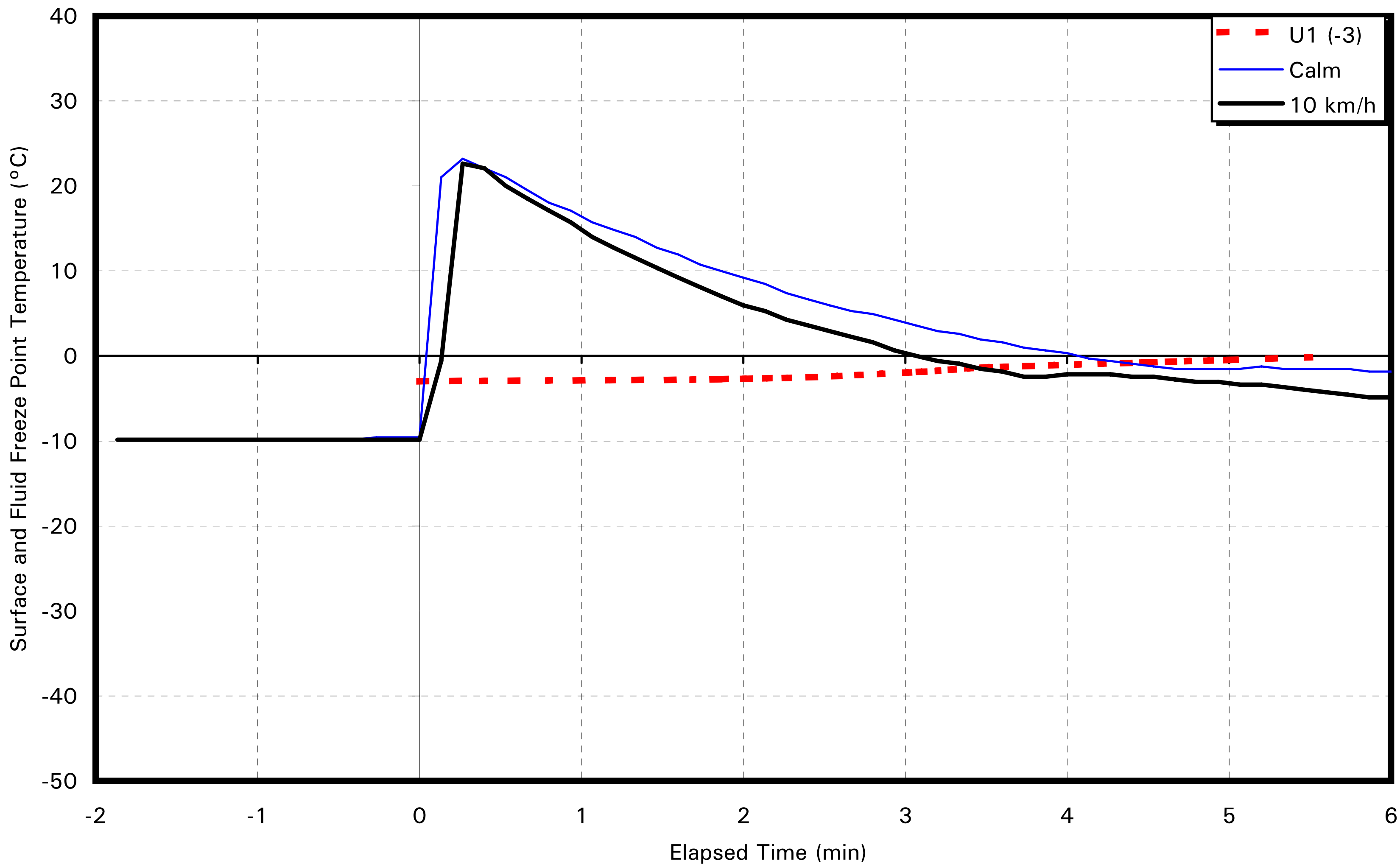
WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, WATER, LIGHT FREEZING RAIN (25 g/dm²/h), OAT = -10°C



cm1380/report/buffer/WATER-10
At: 25g
2/22/2007

FIGURE 4.47

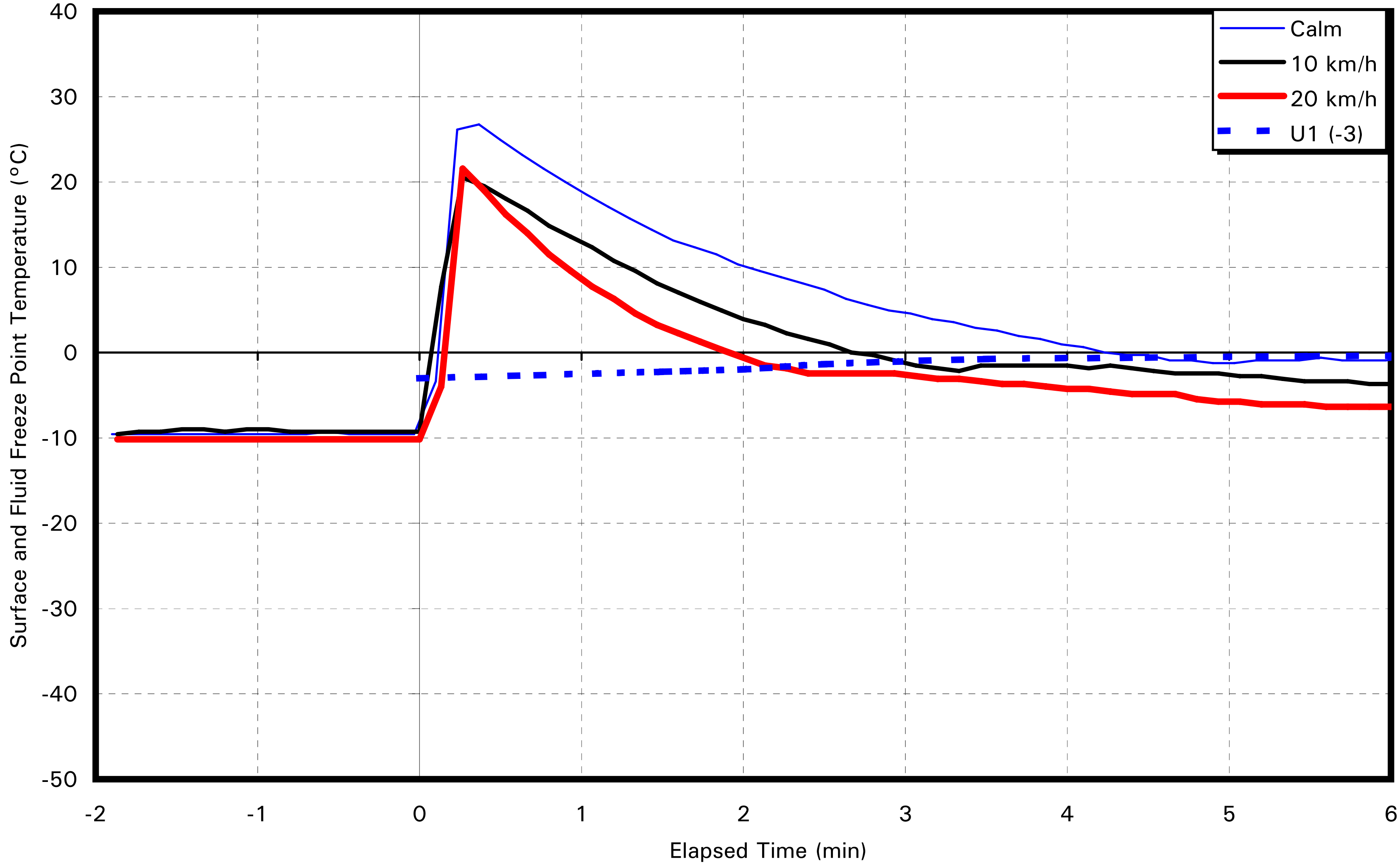
WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, U1 (-3), FREEZING DRIZZLE (12 g/dm²/h), OAT = -10°C



cm1380\report\buffer\ADF3_-10
At: 12 g
2/22/2007

FIGURE 4.48

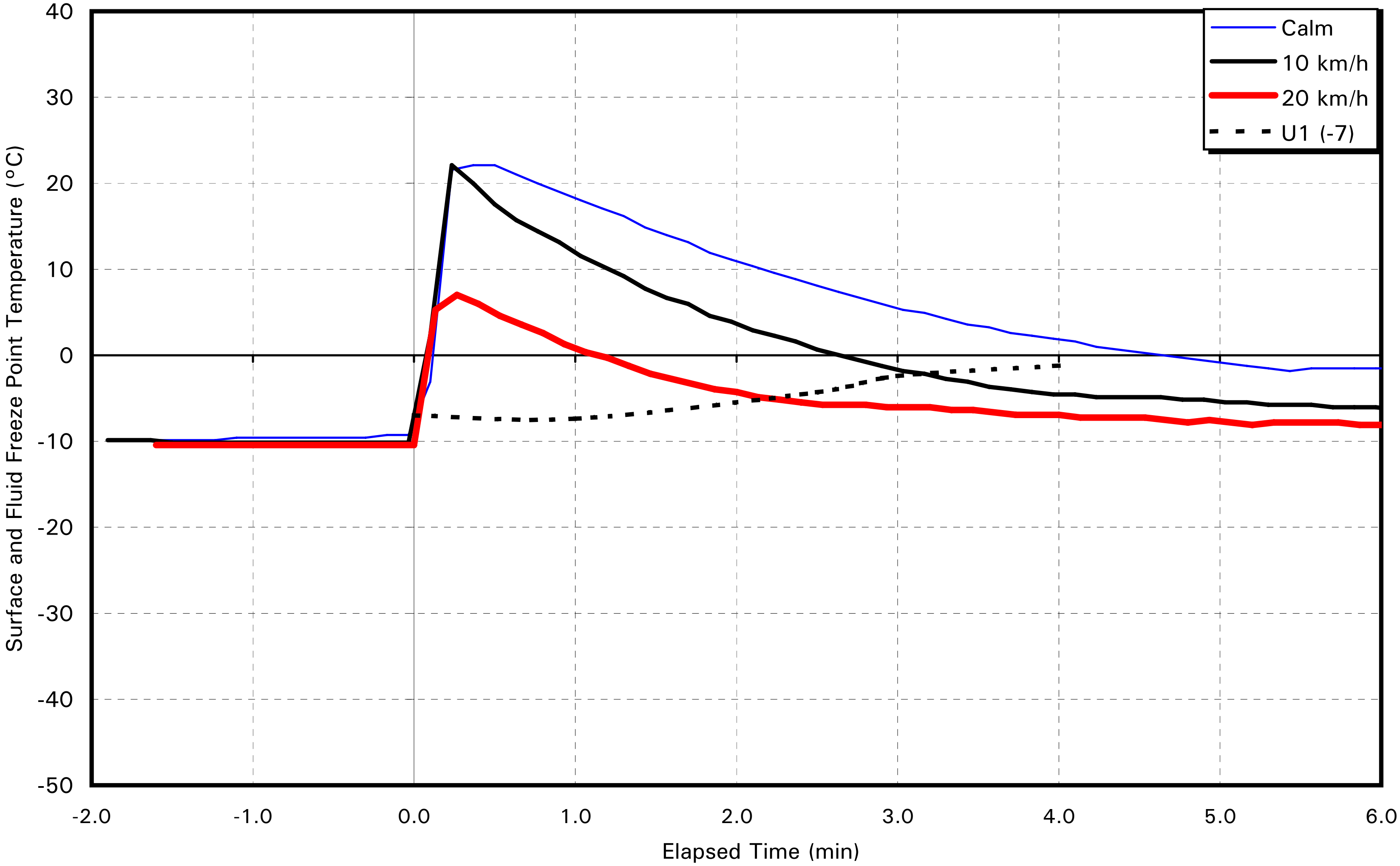
WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, U1 (-3), LIGHT FREEZING RAIN (25 g/dm²/h), OAT = -10°C



cm1380\report\buffer\ADF3_-10
At: 25g
2/22/2007

FIGURE 4.49

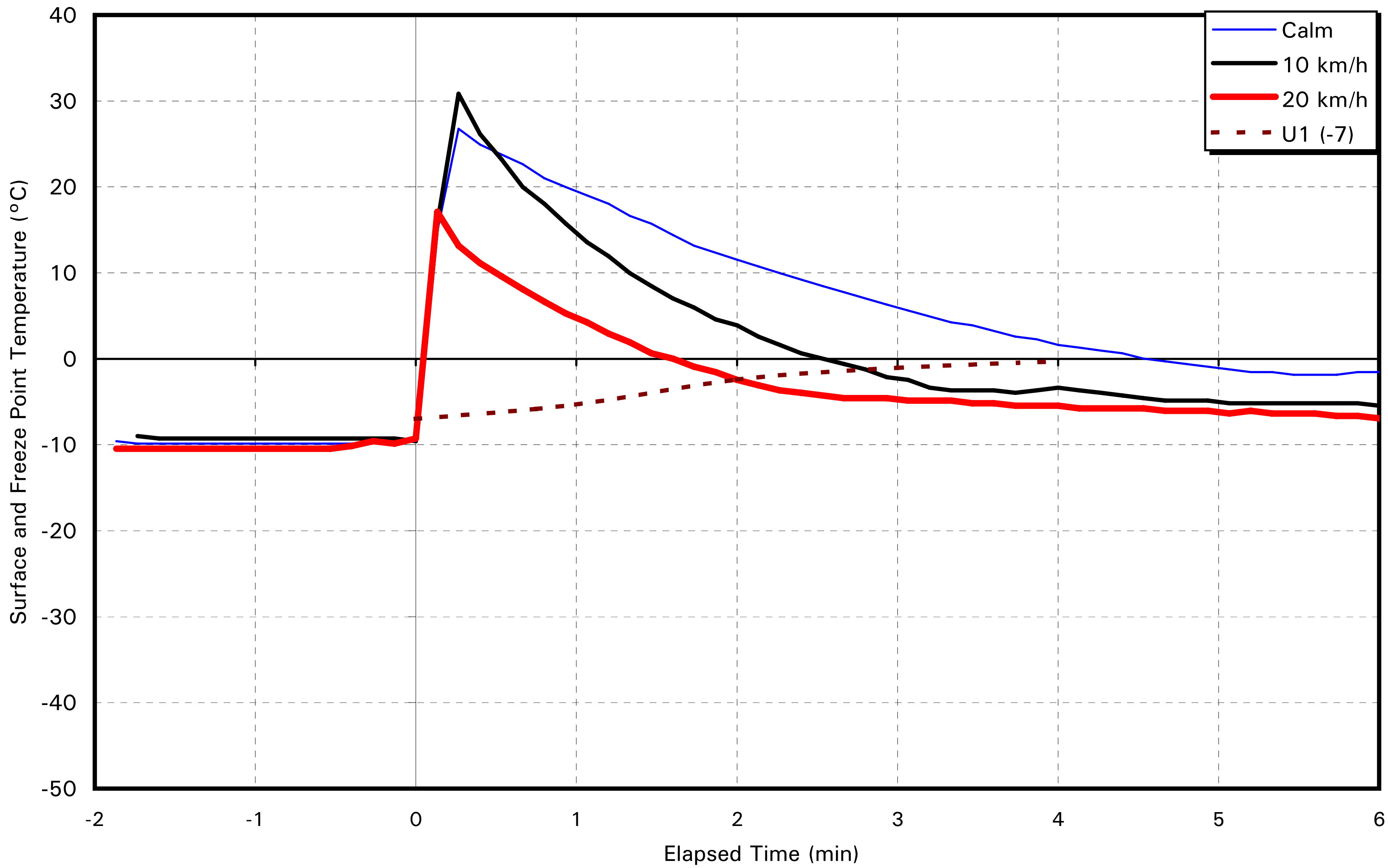
WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, U1 (-7), FREEZING DRIZZLE (12 g/dm²/h), OAT = -10°C



cm1380\report\buffer\ADF7_-10
At: 12g
2/22/2007

FIGURE 4.50

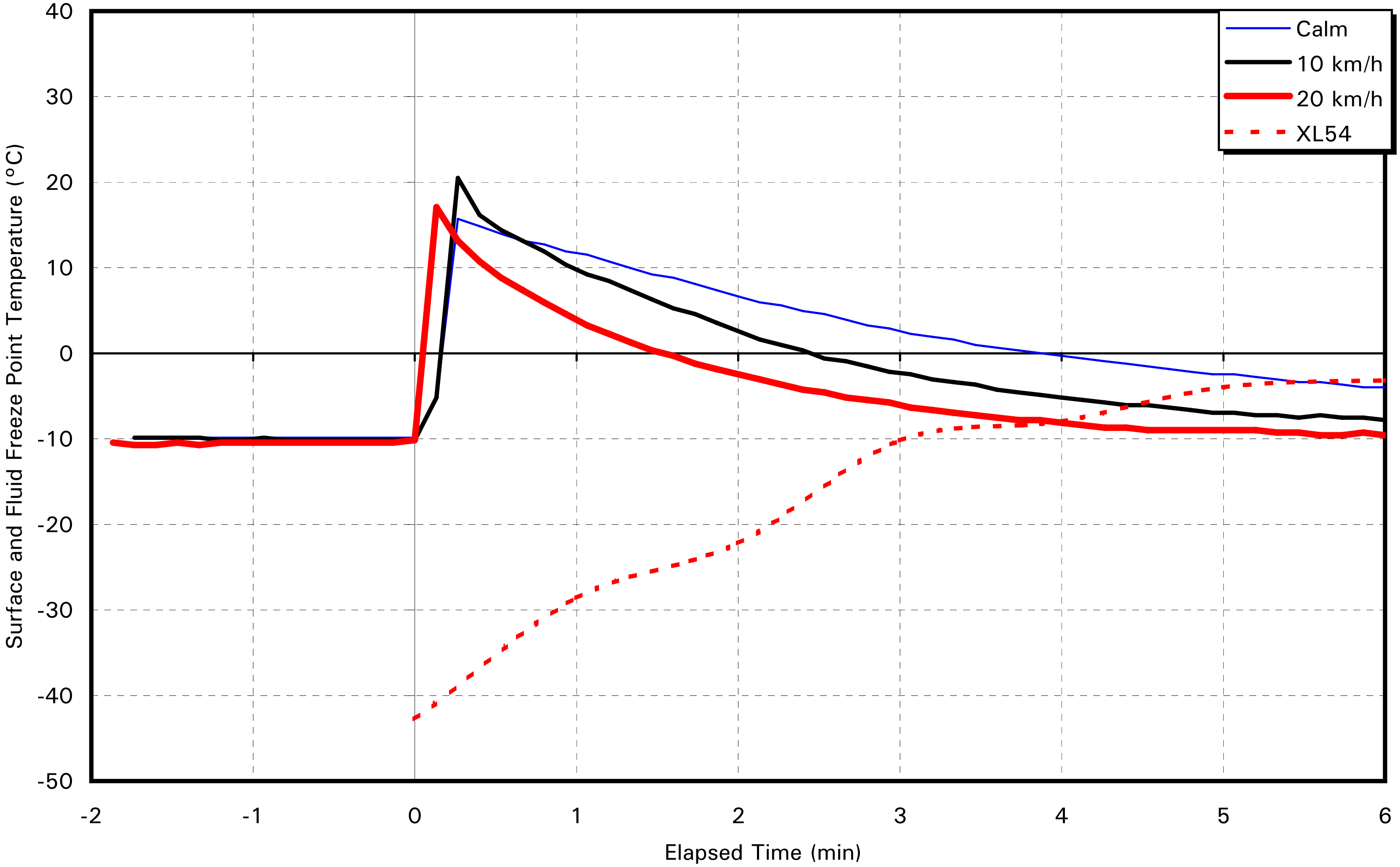
WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, U1 (-7), LIGHT FREEZING RAIN (25 g/dm²/h), OAT = -10°C



cm1380\report\buffer\Figure 4.50
At: 25g
5/1/2007

FIGURE 4.51

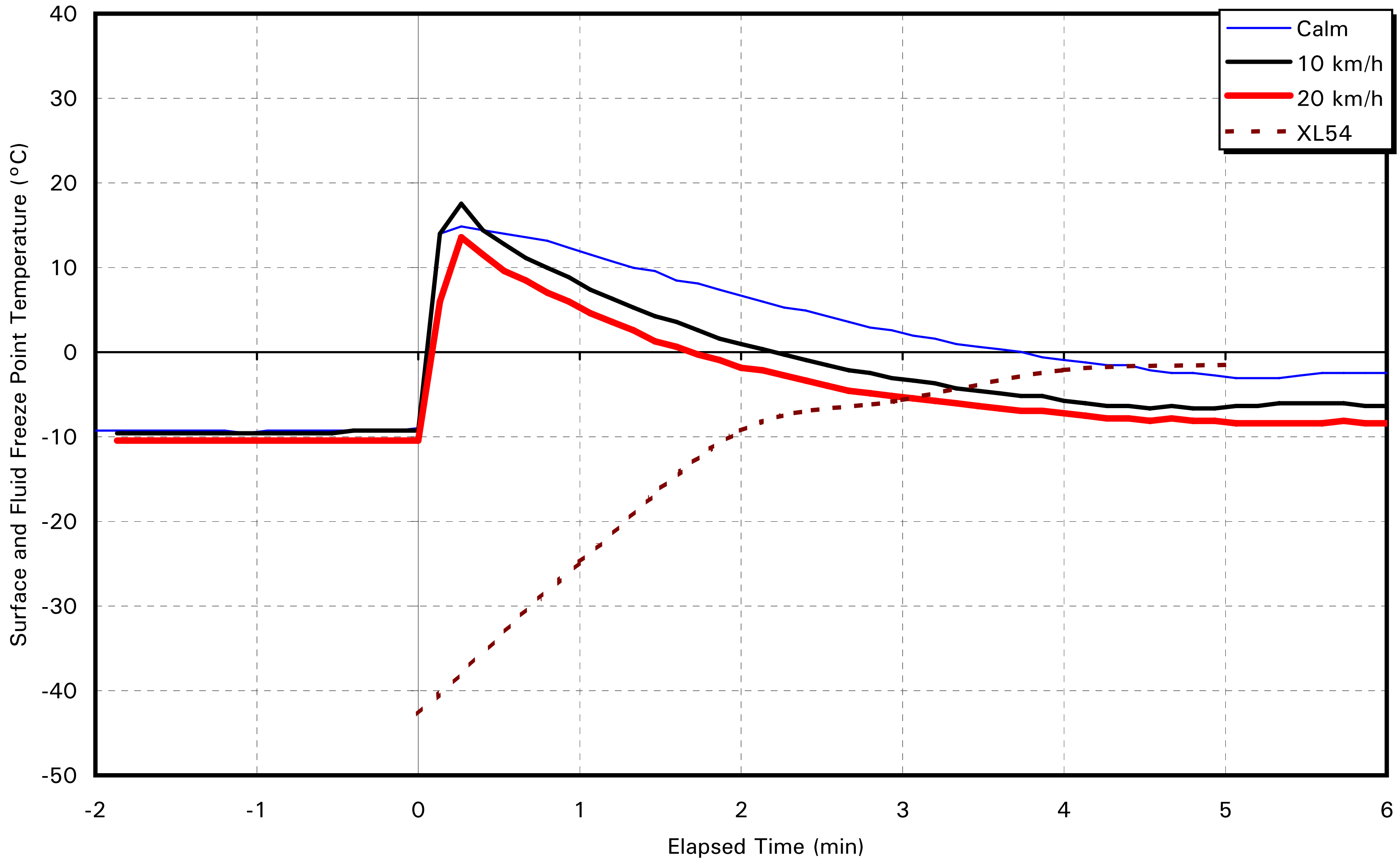
WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, XL54, FREEZING DRIZZLE (12 g/dm²/h), OAT = -10°C



cm1380\report\buffer\XL54-10C
At: 12 g
2/22/2007

FIGURE 4.52

WIND INFLUENCE ON FLUID FREEZE POINT VERSUS SURFACE TEMPERATURE, XL54, LIGHT FREEZING RAIN (25 g/dm²/h), OAT = -10°C



cm1380\report\buffer\Figure 4.52
At: 25 g
5/1/2007

Figures 4.45 and 4.46 were plotted to examine the plate temperature profiles in the case of water, at different wind speeds and at different precipitation rates. In these cases, the fluid freeze point is always zero, and freezing would be expected to occur when the plate temperature falls to zero after being heated by the fluid application. The times noted for the initiation of freezing (Figure 4.41) confirm this expectation, with some error due to plate temperature being measured at a single location, partway up the plate. Freezing generally initiated at one of the plate edges, with a small delay before freezing at the actual measurement location.

These graphs illustrate the influence of wind speed on the cooling rate of the plate surface. Comparison of results attained from the two precipitation rates does not indicate any difference in the cooling rate due to the rate of precipitation. In the case of water, where dilution is not a factor and freeze point of the fluid is constant, changes in the time interval until freezing were influenced solely by wind speed.

In Figures 4.47 and 4.48, the data were plotted from tests that used fluids mixed to an initial freeze point of -3°C, with the same outside air temperature, precipitation and wind conditions as seen in the case of water. In these charts, the fluid strength is seen to progressively decrease (freeze point rises), as reported in Figure 4.44. At the point where the fluid freeze point profile intersects the plate temperature profile, the fluid still has a slight glycol content remaining. As in the case of water, the rate of precipitation has no measurable influence on the rate of cooling.

In Figures 4.49 and 4.50, the data were plotted from tests that used fluids mixed to an initial freeze point of -7°C, again with the same outside air temperature, precipitation and wind conditions as the previous set of figures. These cases are notable, as the fluid freeze point corresponds to the limit prescribed in SAE ARP4737, excerpts of which are contained in Appendix B of this report.

The dynamics of the relationship between fluid strength and plate temperature can be seen more clearly in these three sets of figures. At a wind speed of 20 km/h and a precipitation rate of 25 g/dm^2/h (Figure 4.50), the surface temperature profile is very similar to that experienced for water (Figure 4.46), with temperature dropping to 0°C in the same time (about 1.5 minutes). However, because the fluid freeze point is still depressed below zero due to a small amount of glycol remaining, the plate temperature profile intersects with the fluid freeze point a little later than for water (at about two minutes).

At the lower precipitation rate of 12 g/dm^2/h (Figure 4.49), the fluid dilutes somewhat less rapidly (freeze point rises somewhat more slowly), giving slightly longer time intervals prior to freezing for winds of 10 and 20 km/h. In the case of calm winds, the surface temperature profile intersected with the fluid freeze point profile only after the fluid had completely diluted to water. In other words, in calm conditions and at the precipitation rates tested, water provided a time interval prior to freezing equivalent to fluid mixed to a freeze point of -7°C. At higher wind speeds, the fluid provided a slightly longer interval prior to freezing than did water, but both liquids exhibited a shorter time interval before the onset of freezing when compared to lower wind speed tests.

Figures 4.51 and 4.52 supply an explanation for the relatively small improvement in time interval prior to freezing provided by full strength (standard Type I) fluid. At both test rates of precipitation, fluid freeze points, which started at -43°C, climbed very rapidly, reaching freeze points of -10°C and less in about three minutes. In the precipitation conditions tested, the substantial initial glycol content in the full strength fluid provided only a modest improvement over other test fluids in the time interval available prior to freezing. This gives an idea of how short the interval of protection is after first-step fluid application, and how quickly a low to moderate rainfall can dilute and ultimately wash a fluid clean from aircraft flight surfaces.

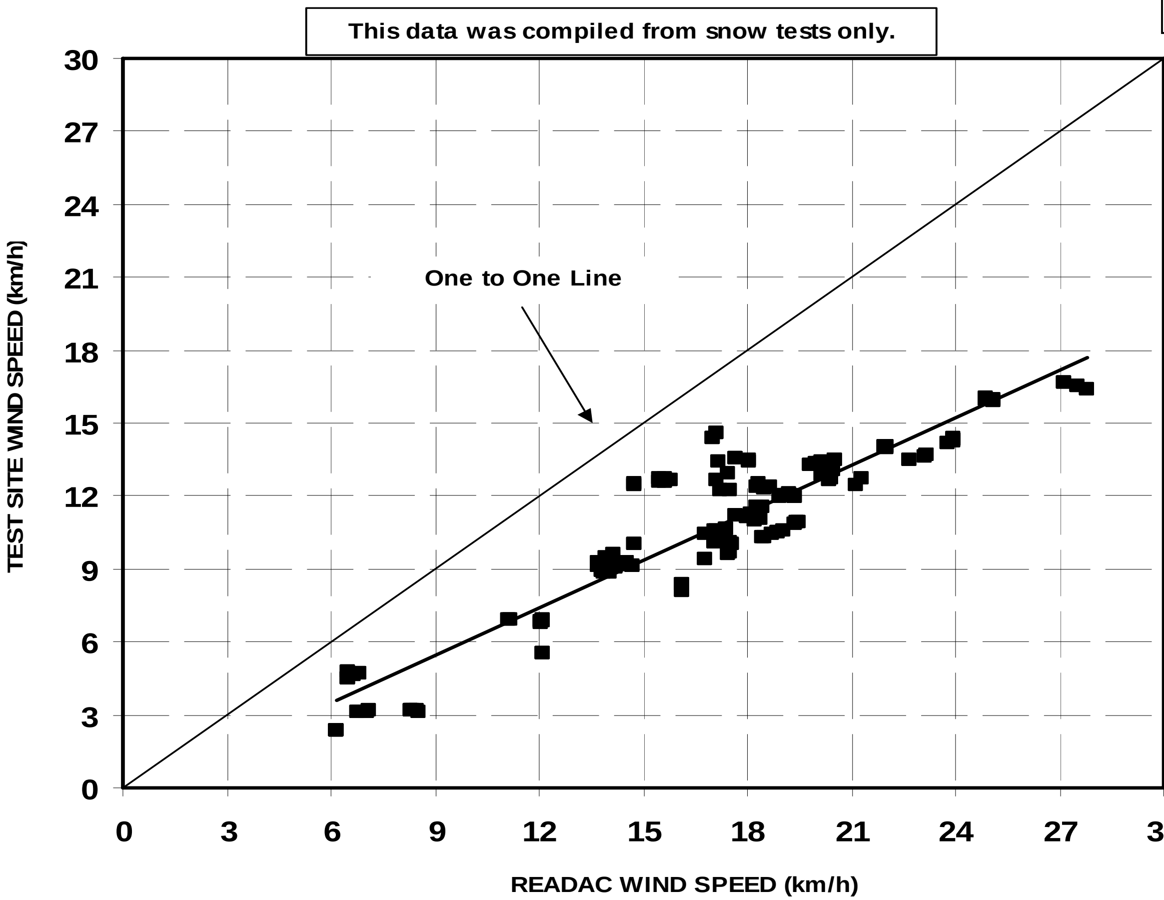
4.5 Reconciliation of Wind Speed Measured at Test Surface

In both the *deicing only* and the first-step fluid tests, wind speed was measured at the test stand height. In real operations, wind is measured by the weather service using an instrument that is mounted some height above ground level. This is to escape the region where measurements will result in a shear profile of wind speeds, with the lowest speeds occurring at ground level. In Canada, READAC wind data are gathered with instrumentation mounted at a height of 10 m above ground level.

A correlation of wind speeds measured at plate stand level, with winds measured by the meteorological service was reported in a previous study, Transport Canada report TP 12654E (4). Figure 4.53 from that study shows the relationship, and concludes that a reading of 10 km/h at the plate stand would be equivalent to a reported wind speed of 16 km/h (9 kts).

FIGURE 4.53
COMPARISON OF WIND SPEED DATA
APS DATA vs. READAC DATA
1994-95

HEIGHT ABOVE GROUND	
• READAC Instrument	10 m
• APS Instrument	2 m



$y = 0.65x - 0.43$
$R^2 = 0.88$

- 10 km/h at APS instrument
- ≈ 16 km/h READAC

Cm1380/rpt/buffer/FIG_4-53.PPT

In other words, test data gathered at winds of 10 km/h is representative of expected experience with reported winds of 16 km/h.

4.6 Completeness of Test Data

Discussions of test results have identified concerns as to whether the scope of tests was sufficiently broad to justify changes to current SAE ARP4737 guidelines.

Selection of the standard flat aluminum plate used for holdover time tests to serve as the test surface for the study was based on field experiments in which flat plate tests were conducted in tandem with tests on the McDonnell Douglas DC-9 aircraft. While many aircraft of this generation are still in service, newer generation aircraft make use of a variety of composite materials on wing and tail surfaces. There is a concern that these surfaces might not produce test results similar to those observed on aluminum surfaces; that is, fluids on composite surfaces may not demonstrate equivalent variations in concentration compared to when they are applied to aircraft aluminum surfaces.

The temperature and quantity of fluid applied may also be questioned. The test quantity of 0.5 L per test panel was based on a typical spray amount for a light snow condition, factored from wing surface area to the area of a test plate. However, different operators might use different quantities of fluid, and different conditions (such as frost) would likely require less fluid. The aircraft tests present an opportunity to compare the results of the application of different quantities of fluids to the same aircraft wing. Compare Run 5 from January 21 to Run 1 from March 17:

	Jan 21, Run 5	**Mar 17, Run 1**
Outside air temperature (0°C)	-16	-8
Wind	9 km/h	Calm
Initial Fluid freeze point (°C)	-12	-4
Fluid quantity (litres)	160	71
Comparison of final condition		Less severe icing
Comparison of final fluid strength		Smaller increase in strength

This comparison supports the concern that the extent of the increase in fluid strength can be influenced by the amount of fluid applied. Although a less severe icing condition prevailed in the March 17 test, both tests used fluids mixed to concentrations affording -4°C buffers.

From the data acquired during hot water tests (3), the impact of fluid quantity was examined. Figure 4.54 compares lag times (interval from fluid application until initial fluid freezing) for different surfaces and wind speeds when fluid quantity is varied. It was found that doubling the amount of fluid from 0.5 to 1.0 L resulted in a notable increase in lag time for the thicker plates (C/FIMS 6.4 mm thick), but little or no increase for thin plates (1.2 mm thick). The standard plate (3.2 mm thick) experienced a measurable increase in lag time with the greater amount of fluid.

In field operations, the temperature of the fluid can drop significantly during spraying. Temperature drops are dependent on the distance from the spray nozzle to the target surface. The study made some allowance for this by using a fluid temperature of 60°C, which represents the lowest recommended temperature range. It is possible, during actual deicing operations, that fluids can be delivered to the wing surface at temperatures below 60°C.

FIGURE 4.54

EFFECT OF WIND SPEED, VOLUME POURED AND PLATE THICKNESS ON LAG TIME TO FREEZE POINT

Tests Conducted @ National Research Council Canada Climatic Engineering Facility
APRIL 12, 1995

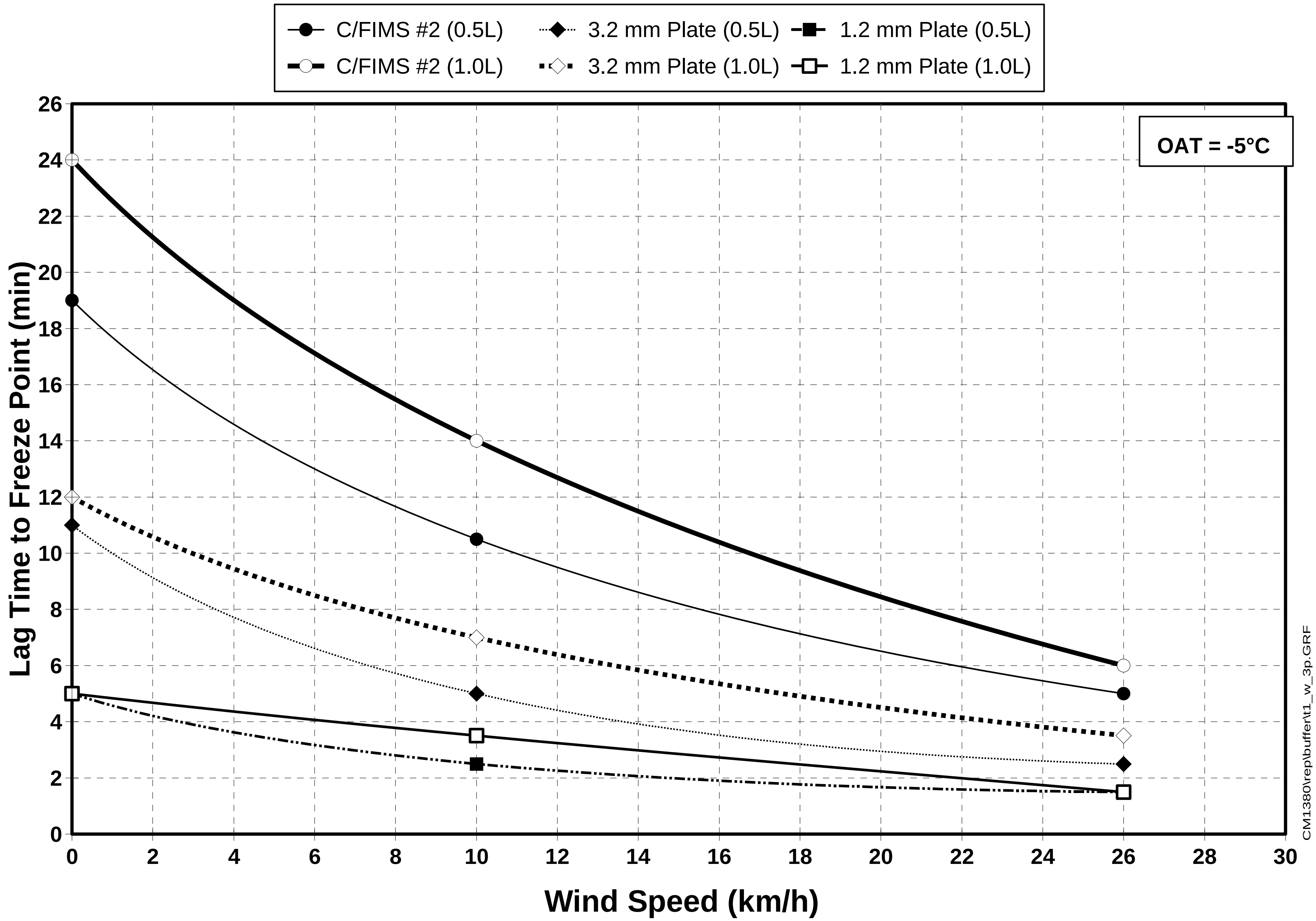


Photo 4.1
Freezing on Flight Control Panels

Photo 4.2
Drip Ice at Rear of Leading Edge Slat

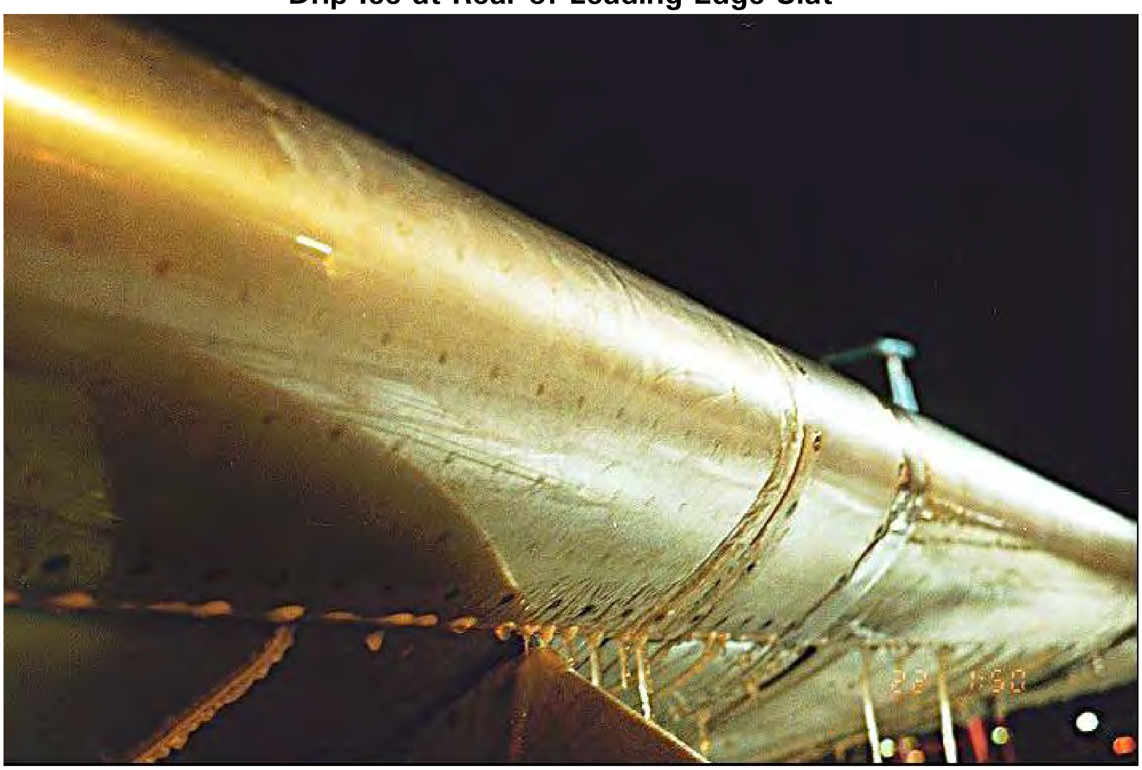


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Photo 4.3
Freezing of Thin Film Outboard of Aileron

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Photo 4.4
Typical Flash Freezing of Thin Film (Type I)

Photo 4.5
Second View of Flash Freezing (Type I)

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Photo 4.6

Slush Type of Failure - Type II Fluid (Propylene Base)

OAT = -35°C; Fluid FP = -27°C; Wind = 10 km/h

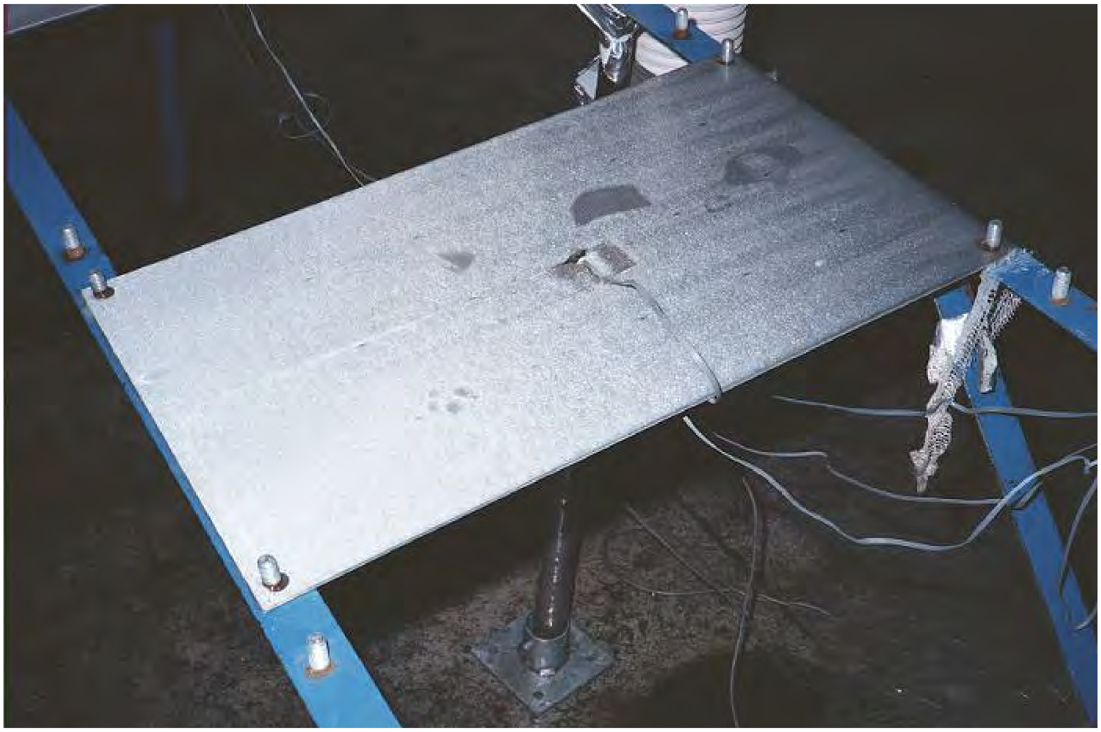

Photo 4.7

Slush Type of Failure - Type IV Fluid (Ethylene Base)

OAT = -35°C; Fluid FP = -32°C; Wind = 10 km/h

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Progressive Appearance of Icing on Plates
OAT: -18°C, Wind: 10 km/h

Plate 2 (centre, top row)	**UCAR ADF**	**FP -14°C**	**Pour Time**	**13:12**
Plate 4 (left, bottom row)	**UCAR Type IV**	**FP -15°C**	**Pour Time**	**13:13**
Plate 6 (right, bottom row)	**UCAR ADF**	**FP -8°C**	**Pour Time**	**13:14**

Photo 4.8

Following Application

Photo 4.9

Ice Appears on Plate 6

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Photo 4.10

Ice on Plates 4 and 6

Photo 4.11

No Ice on Plate 2

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Photo 4.12

No Ice on Plate 2

Photo 4.13

No Ice on Plate 2

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5. CONCLUSIONS

5.1 Deicing Only

The key objective of this study was to determine the final condition of the test surface after it had been treated with heated fluids of various strengths, under various ambient conditions. Several other perspectives were analyzed to provide a more complete understanding of observed results.

5.1.1 Final Surface Condition as a Function of Freeze Point Buffer

The final condition of the test surface at 20 minutes following fluid application could be differentiated by the value of the initial freeze point buffer:

- Test points generated using fluids with either zero degree buffers, or those using fluids with positive values of freeze point buffers always resulted in final plate conditions whereupon only unfrozen fluid remained. This held true regardless of wind speed;
- Test points generated using fluids with concentrations in the range from a zero degree buffer to a -3°C buffer generally concluded with the plate condition being either fluid covered or bare, or with ice on the drip line (the surface of the plate being non-frozen); and
- Freezing in some fashion (on the plate surface) generally resulted from tests in which the initial negative buffer was beyond -3°C, with the type of freezing condition increasing in severity with the magnitude of the negative buffer. Cases where the negative buffer was beyond -10°C always resulted in ice formation on the surface.

Examining the performance of the deicing fluid used in the majority of tests (Union Carbide ADF), it appears that fluids mixed to specific buffer values relative to outside air temperature perform somewhat better at colder temperatures than at mild temperatures just below 0°C.

5.1.2 Influence of Wind on Final Surface Condition

Tests using fluids with a zero degree buffer, and those using fluids with positive values of freeze point buffers always resulted in unfrozen fluid on the surface, regardless of wind speed.

At buffer levels where the surface condition started to show freezing, the type of freezing was generally more severe with high winds (20 km/h). A condition of unfrozen fluid on the test surface and drip line ice only (at lower winds) was transformed at higher winds to a condition with sheet ice on the surface.

A small amount of wind appeared to help, with instances where drip line ice occurred during calm winds, changing to a "fluid-covered with no ice" condition at winds of 5 km/h.

5.1.3 Improvement in Fluid Strength

Fluid strength improved (freeze point dropped) during test runs on Type I fluid as a result of water evaporating from the thin film of fluid on the test surface. Plots of fluid freeze point profile versus surface temperature profile illustrate the relationship between the two factors. The difference in values at any point in time reflects the true freeze point buffer at that time and explains the observed results where fluids having initial freeze points above ambient temperature did not experience freezing during the test run.

The plots also illustrate the mechanisms by which wind influences final fluid condition. The effect of more rapid cooling due to higher wind speeds causes a steeper surface temperature profile, with the surface temperature quickly approaching the freeze point value of the fluid. Simultaneously, the rate of improvement to fluid freeze point is lessened, with the fluid freeze point value following a much flatter profile. The two curves close rapidly; if and when they intersect, freezing results.

In some instances the increase in fluid strength was remarkable, with freeze points dropping by an increment as large as -20°C beyond the initial value. Fluids having a very low glycol content to begin with (those with initial freeze points just below 0°C) appeared not to have the capacity to support large increases in fluid strength.

5.1.4 Results from Different Fluids

The most consistent results were produced from Type I fluids of the different brands and strengths tested. Ethylene and propylene glycol-based fluids produced similar results. Recycled, spent fluids, reconstituted from either ethylene or propylene glycol-based spent deicing fluids, exhibited equivalent performance when compared to commercial Type I fluid brands.

Type IV fluids did not perform as well as Type I fluids. They developed ice in the form of slush and did so in conditions less severe than those limiting Type I fluid behaviour.

A limited number of tests conducted on diluted Type II fluids demonstrated performance equivalent to Type I fluids.

5.1.5 Severity of Icing Conditions

While the study considered the appearance of any type of ice to constitute a failure, in many cases ice appeared only on the drip line at the lower edge of the plate, with the remainder of the plate surface being completely free of ice. This test condition would correspond to the operational condition of a wing being clear of ice on the surface and leading edge, but having a bead of ice at the trailing edge.

The thickness of ice film resultant from Type I fluids was generally extremely small, estimated at less than 0.0025 mm (0.0001 in.).

5.1.6 Basis for Construction of a *Deicing Only* Table

Tests using Type I fluids indicated that a safe surface, clear of any type of ice, was produced in all cases when the initial fluid freeze point was equal to or lower than outside air temperature. This result was independent of wind. Tests with -3°C buffers showed scattered results – sometimes with ice starting to appear in some form at this condition. Wind exerts a definite influence at this condition, increasing the severity of any ice that does appear.

A reasonable approach, which has the added benefit of allowing the influence of wind to be ignored, would be to base *deicing only* tables on SAE Type I fluids, with freeze point limits matching the lowest outside air temperature value expected to occur during the deicing session. In other words, if a low of -8°C is forecast to occur during the upcoming deicing period, then the freeze point limit to which the *deicing only* fluid can be mixed should be no higher than -8°C.

5.2 First-Step Fluid

5.2.1 General Conclusions

A number of conclusions can be drawn from the data analysis:

- In calm wind conditions, all fluids tested delivered an interval prior to initiation of freezing of at least three minutes, at the lowest test temperature of -14°C;

- Wind exerts a major influence on the time interval available prior to freezing;

- Wind exerts its influence by causing more rapid cooling of the protected surface;

- Dilution of applied fluids occurs very rapidly. At the upper range of light freezing rain (25 g/dm^2/h), the applied fluid film is quickly replaced by rainwater:

    - ADF at −7°C freeze point: 4 to 5 minutes, and
    - XL54 (−43°C freeze point): 7 to 8 minutes;

  At the lower precipitation rate of 12 g/dm^2/h, (the boundary defining freezing drizzle/light freezing rain), XL54 fluid still dilutes to a -10°C freeze point in about three minutes; and

- In precipitation conditions, the major contributor to the period of protection is the temperature of the surface, elevated above ambient through heat transfer from the applied heated fluid.

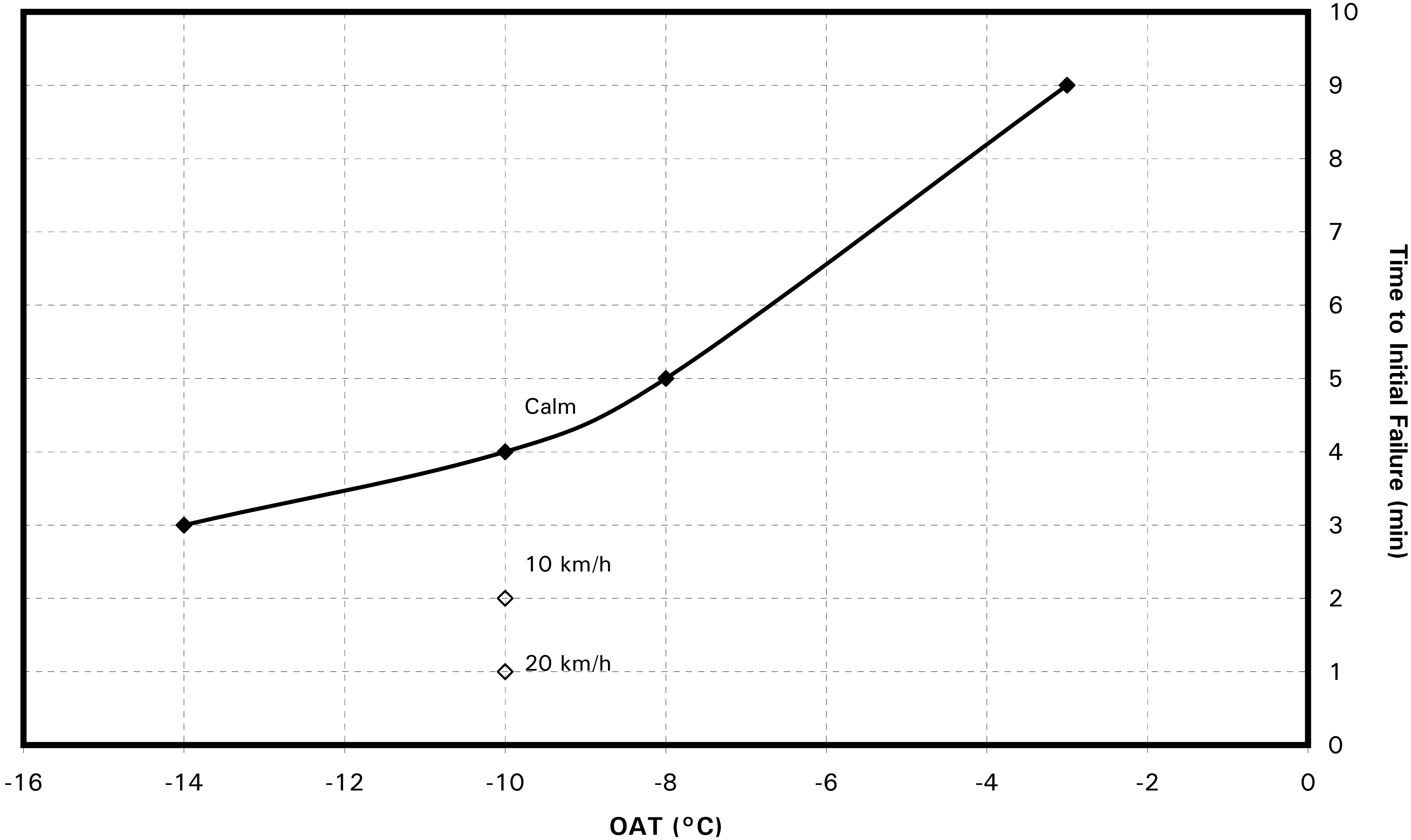
5.2.2 Definition of Freeze Point Limits

In addressing the objective of the study to evaluate fluid freeze point limits for first-step fluids, new data have been established that provide an improved understanding of the influence of wind and rate of dilution of fluids on the prime consideration: the interval from time of fluid application until time start of freezing. The principal results can be expressed in a single chart as shown in Figure 5.1, which presents time intervals prior to freezing for different outside air temperatures and wind speeds. These data represent average results from the variety of dilute Type I fluids and water tested at each condition.

FIGURE 5.1

TIME TO INITIAL FAILURE

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



cm1380/report/buffer/EFFC_OAT
At: 1
2/22/2007

The chart illustrates the important influence that wind speed exerts on results, but also highlights the limits of the scope of data.

In considering a basis for recommending freeze point limits for first-step fluids, a reasonable approach would be to provide the operator with a safe period of at least three minutes before the first-step fluid freezes, during which time the overspray of anti-icing fluid would be applied. The results of tests conducted at 10 and 20 km/h wind speeds do not satisfy this goal. In Figure 5.2, it is suggested that a line drawn parallel to the trend line through the 10 km/h data point would intersect the three minute time (to initial failure) line at about an outside air temperature of -8°C. The assumption of parallel lines is believed to be sufficiently valid for the small temperature difference involved (from -10 to -8°C). Accepting this assumption, it could then be stated that application of any of the fluid mixes tested would be expected to deliver a 3-minute safe period prior to freezing in conditions of outside air temperature of -8°C and warmer, and winds of 10 km/h or less.

Based on the scope of data collected, no conclusions can be reached for conditions of colder temperatures or higher wind speeds.

5.3 Adequacy of Experimental Data

Use of only the McDonnell Douglas DC-9 aircraft in field tests limited the opportunity to evaluate results on new types of composite surfaces, to determine whether they produce similar results.

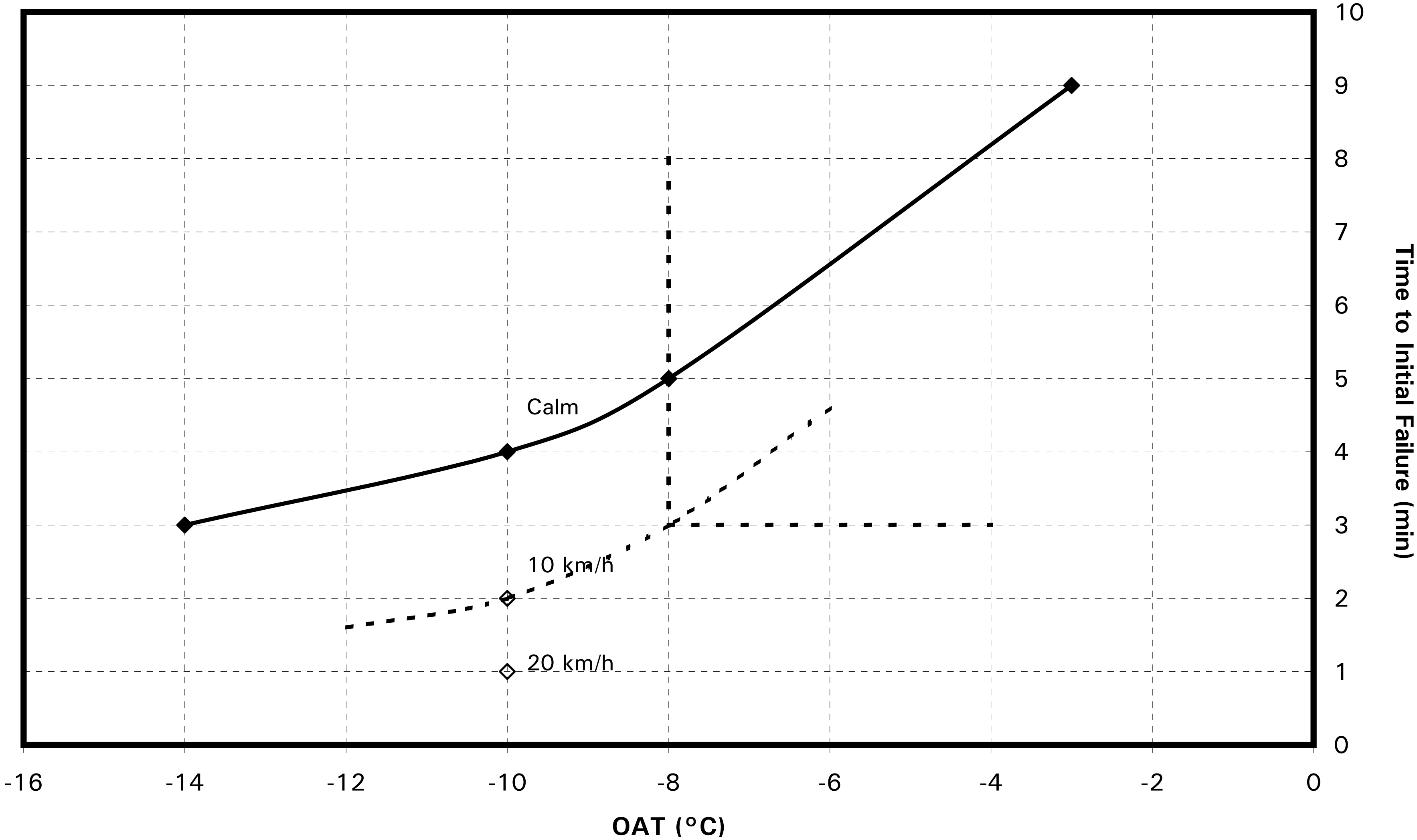
The quantity of fluid applied can affect results, particularly in those areas where skin thickness is greater. These areas tend not to be the critical areas; the flight control panels at the rear of the wing are generally more critical and have thinner skin panels.

Application of a lower temperature fluid would be expected to influence results negatively. Testing with a range of fluid temperatures typical of low values that might be experienced in field operations could be of value.

FIGURE 5.2

TIME TO INITIAL FAILURE

LIGHT FREEZING RAIN (25 g/dm²/h)



cm1380/report/buffer/EFFC_OAT
At: 2
2/22/2007

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6. RECOMMENDATIONS

6.1 Deicing Only

The data produced in this series of tests indicates that, for dilute Type I fluids (both ethylene and propylene glycol-based), an improvement in fluid strength can be expected due to evaporation following fluid application. As well, the data indicates that the test surfaces did not experience freezing when the applied fluid was mixed to a freeze point equal to the outside air temperature, regardless of wind speed.

The positive nature of findings to date provides encouragement to do whatever is necessary to bring this project to a conclusion, leading to publication of a *Deicing Only* table.

Discussions resulting from several presentations of this study's findings have questioned whether all variables that might potentially influence results have been fully examined, and have proposed further tests to evaluate these.

It is recommended that:

1. Supplementary tests be defined and conducted to investigate voiced concerns.

2. Definition of any future testing be distributed to interested individuals in the industry for their comments prior to the initiation of tests.

The nature of any ice that appeared during tests conducted on Type I fluids was typically limited to either a very thin film of ice on the test plate or wing surface, or drip ice located at the draining edge of the plate or wing surface. Results from the RVSI sensor indicated that surface ice was less than 0.0025 mm (0.0001 in.) thick. Drip ice was generally slushy in nature with no adherence, and was not located in areas where wing aerodynamics would be influenced. The concern that reduced buffers may result in freezing of the applied fluid should be examined from the perspective of evaluating the safety risk resulting from any such freezing.

It is recommended that:

3. Frozen contamination typical of that observed during these tests be evaluated from a flight safety perspective.

6.2 First-Step Fluid

An operational concern expressed by airline representatives is related to practical limitations imposed by spray equipment commonly in use. Current deicing vehicles are generally equipped with a maximum of two tanks, and vehicle inventories do not allow for spare vehicles to be held out of service with different fluid mixes, awaiting a change in conditions. Although some vehicles are capable of mixing fluids to desired concentrations, this capability is not yet widespread. These and other constraints lead the operator to prefer a procedure wherein vehicles are loaded with a fluid having a freeze point buffer that is adequate both for first-step fluids during storms and for *deicing only* conditions following storms.

A further concern raised during discussions relates to some operators past successful practice of application of first-step fluids having negative buffers as large as 7°C. At the time when these practices were followed, Type IV fluids had not yet been developed, and the subsequent application of anti-icing fluid consisted of an application of a heated Type I fluid. Any freezing that may have occurred between application of the two fluids was thereby corrected by the heated second-step fluid. In current practice, the second-step fluid may well consist of a cold Type IV fluid, which will not necessarily correct any refreezing of the first-step fluid.

It is recommended that:

4. Establishment of a guideline for the freeze point buffer for first-step fluids be considered in conjunction with the guideline for *deicing only* conditions.

These tests illustrated that anti-icing protection provided by the application of Type I fluid is mainly related to the heat transferred from the fluid to the wing surface. Even under moderate levels of precipitation, fluid concentration is diluted within a matter of minutes and the fluid freeze point temperature rapidly approaches that of outside air. High wind conditions were shown to cause rapid cooling. Past tests to determine holdover times for Type I fluids have been conducted with fluid temperatures in the order of 20°C, well below truck fluid temperatures. Conservative holdover time guidelines would be expected to result for calm wind conditions. The use of test fluid at a lower temperature would tend to compensate for wind conditions.

It is recommended that:

5. Current procedures for Type I holdover time testing adequately compensate for the influence of wind on the rate of surface cooling and thereby on holdover time.

This series of tests marked the first time that wind and precipitation were combined as controlled variables in a laboratory experiment. While the laboratory setup to produce this combination proved adequate for this test, it is capable of being significantly improved.

It is recommended that:

6. Management at NRC's CEF be approached to examine ways to produce an improved quality of combined wind and precipitation conditions for future tests.

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REFERENCES

1 Dawson, P, D'Avirro, J., *Examination of the Role of Fluid Freeze Point Buffers*, APS Aviation Inc., Montreal, November 1997, Transportation Development Centre, TP 13129E, 44.

2 D'Avirro, J., Peters, A., Hanna, M., Dawson, P., Chaput, M., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1996-97 Winter*, APS Aviation Inc., Montreal, November 1997, Transportation Development Centre, TP 13131E, 232.

3 Dawson, P., D'Avirro, J., *Hot Water De/icing Trials for the 1994-1995 Winter*, APS Aviation Inc., Montreal, December 1995, Transportation Development Centre, TP 12653E, 48.

4 Boutanios, Z., D'Avirro, J., *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1994-1995 Winter*, APS Aviation Inc., Montreal, December 1995, Transportation Development Centre, TP 12654E, 180.

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APPENDIX A

TERMS OF REFERENCE – WORK STATEMENT

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 97/98
(Short Title: Winter Tests 97/98)
(Revised December 1997)

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 was set up. Together with many other regulatory activities an intensive DCIP research program of field testing of deicing and anti-icing fluids was initiated with guidance from the international air transport sector through the 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 (DCIP research representing the bulk of the testing).

The times given in HOT Tables were originally established by 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 Transport Canada, Transportation Development Centre (TDC), which has taken over the functions of the DCIP, has been to determine the performance of fluids on standard flat plates in order to substantiate the times, or if warranted, to recommend changes.

DCIP 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 $gm/dm^2/hr$ 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 and with hot air for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 96/97 winter.

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 hold-over 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 new Holdover Time Tables
  (a) for Type IV and Type III fluids
  (b) for de-icing operations only, i.e. without precipitation;

4.2 Establish limits for the use of negative buffered deicing fluids for the first step of two step anti-icing procedures

4.3 Determine the influence of fluid type, precipitation and wind on location of fluid failure initiation, time to fluid failure initiation, pattern of fluid failure progression, and visibility of failed fluid on a sample high wing turbo-propeller and a low wing turbojet commuter aircraft.

4.4 Assess the practicality of using a vehicle mounted remote area contamination detection sensor for pre-flight (end of runway) checks.

4.5 Collect data on taxi times from start of de-icing or anti-icing, as applicable, to start of the take-off roll under winter precipitation conditions at sample airports.

5. DETAILED STATEMENT OF WORK

5.1 Planning and Preparation

5.1.1 Scope of Work

The work shall be executed as eleven separate sub-projects:

1) Planning and Preparation.
2) Holdover Time Testing and Evaluation of de/anti-icing fluids.
3) 'Negative Buffer' De-icing Fluids
4) Development of a Low Glycol 'De-icing only' Fluid Table.
5) Aircraft Full Scale Tests.
6) Documentation of Pilot field of View, and Wing Visibility
7) Documentation of the Appearance of Failed Fluids.
8) Potential use of Remote Sensors for End-of-Runway inspection.
9) Taxi Times under conditions of Precipitation.
10) Support for Review of Alternative Technologies.
11) Provision of Support Services.

5.1.2 Program management

The work shall be broken down into the distinct areas of activity consistent with the project objectives.

A detailed work plan, activity schedule, cash flow projection, project management control and documentation procedure shall be developed for each of the seven sub-projects, and delivered to the TDC project officer for approval within one week of the pertinent start date.

5.1.3 Coordination

Prepare, plan, and coordinate with personnel from TDC, airlines, airport authorities, fluid manufacturers, Instrumentation suppliers, and the National Research Council of Canada (NRC) with respect to site requirements and test procedures; training of test personnel; conduct of dry-run(s) and tests.

5.1.4 Safety of Personnel and Aircraft

Planning shall include precautions to ensure safety of personnel, and safety (freedom from damage) of aircraft.

A safety officer shall be nominated to prepare an appropriate plan, and monitor its implementation.

Conduct of tests shall respect recognized safety standards and applicable sections of Federal and Provincial labour codes. Where exceptions are taken due to the nature of the work, e.g. emplacement of power and instrumentation cables in the work area, test personnel shall be made aware of potential hazards.

Within the work area, comprising the de-icing pad and access ways, test personnel shall co-ordinate their movements and be made aware of all other operations taking place. Movement of airline equipment - aircraft, tow trucks, de-icing trucks, shall have precedence over test personnel activities.
Care shall be taken to ensure that mobile equipment, such as inspection platforms, lighting stands etc. are not in contact with aircraft surfaces. Potential contact points for such equipment shall be padded.
Movements of visitors and personnel not directly involved in tests at any given time shall be tightly controlled, with safety as the governing criteria.
Obtain 'Airport owners and operators premises and products liability insurance' to indemnify and hold harmless the airport and the operators against any claim arising.

5.1.5 Tests at National Research Council, Climatic Engineering Facility
Arrangements will be made by Transport Canada for use of the National Research Council, Climatic Engineering Facility (NRC, CEF) for conduct of certain tests.
Coordinate with NRC for use of the Test facility, including setting of dates for tests, environmental conditions to be simulated, and equipment and test materials to be supplied by the respective agencies.

5.1.6 Supply and Condition of De/Anti-icing Fluids
Fluids will be made available by TDC at no cost to the contractor.
The contractor shall make arrangements for fluids delivery and on-site storage.

For dedicated flat plate tests, the contractor shall ensure that Type IV fluids are pre-sheared prior to delivery, and are representative of the manufacturer's marketed product. Where the only samples available for the conduct of tests are those with the manufacturer's lowest level of viscosity, this shall be duly recorded.
Where exceptions are taken to this requirement these shall be noted, and every effort shall be made to obtain samples which comply with the requirements.
Where flat plate testing necessitates application of fluids sheared consistent with normal truck application, and such fluids are not available, the contractor shall bring the problem to the attention of the scientific authority for appropriate action. This may require subjecting the fluids to shearing by other means.

5.2 Holdover Time Testing and Evaluation of de/anti-icing fluids

5.2.1 Site preparation.
Set up experimental sites and install sensors as inspection aids to provide consistent plate failure conditions under field and laboratory conditions.

5.2.2 Flat Plate Tests for New Type IV fluids
Conduct flat plate tests under conditions of natural snow and freezing drizzle precipitation to record the holdover times, and to develop individual Holdover Time Tables based on samples of new and previously qualified 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. Tests shall be anticipated for at least four different manufacturer's fluids and shall be conducted in the field and the laboratory.

5.2.3 Validation of "Fluid-Specific" and SAE Tables
Conduct flat plate tests to validate "fluid-specific" and SAE tables that currently lack sufficient supporting data. For the "freezing fog" condition the current upper holdover time shall be revised as necessary.

5.2.4 Evaluation of Snow Weather Data
Evaluate snow weather data (precipitation rate/temperature data) from previous winters to ascertain the suitability of the data ranges used to date for evaluation of HOT limits.
Obtain data from Environment Canada for four sites in Quebec: Rouyn, Mingan (Sept Isles), Pointe-au-père (Mont Joli), and Ancienne Lorette (Québec City), in addition to Dorval (Montreal).

5.2.5 Analysis of Current Type I and Type II Holdover Time Tables
Conduct an analysis of current Type I and II fluid holdover time data to determine their concurrence with values determined from the data ranges established in task 5.2.4 above. This evaluation will be conducted for all fluid dilutions and precipitation conditions. Develop appropriate regression equations.

5.2.6 Evaluation of the SPAR Aerospace Ice Detection Camera
TDC will arrange for provision of a SPAR Aerospace (Also referred to as a "SPAR/Cox") camera, with software modifications appropriate for data collection and evaluation.
Install the Camera at the Dorval "Field" test site for use in standard flat plate tests.
Calibrate camera output to characterize fluid 'failure' consistent with visual and other instrumented failure 'calls'. Compare camera observations during conduct of flat plate tests with visual observations of fluid behaviour under conditions of precipitation, and similar observations by other sensing devices.

5.2.7 Supplementary Tests

Conduct supplementary tests in the NRC Climatic Engineering Facility to:

- Measure film thickness of 'new' fluids (fluids made available by TDC, but not previously tested) on flat plates.
- Observe the effects of fluids on ice-phobic materials on standard (aluminum) plates.
- Determine the effect on holdover time of spraying versus pouring of Type IV fluids.
- Determine the effect on holdover time of applying heated versus cold Type IV fluids for standard flat plate tests.

5.2.8 Compatibility with De-icing Fluids

Holdover time tests shall in general be conducted with fluid applied directly to clean plates. Additional tests shall be conducted to determine compatibility of the Type IV fluid samples with a proposed new category, "Type 0" fluid, derived from reclaimed spent fluid.

5.2.9 Measurements and instrumentation

In addition to measurements and records of environmental conditions pertinent to the tests, measurements may be made during the conduct of the tests to obtain histories at selected locations on the plates of fluid thickness, refractive index, and viscosity through to the end of the tests.

SPAR/Cox and RVSI remote sensors should also be used to record the initiation and progression of fluid failure.

5.2.10 Location of Tests

Planning shall be based on conduct of outdoor (field) tests at Dorval Airport, Montreal, and indoor laboratory tests in the NRC Climatic Engineering Facility, Ottawa. Anticipate 20 days occupancy in the laboratory.

Consideration shall be given to conduct field tests at alternate sites where desirable test conditions may occur more frequently.

5.3 'Negative Buffer' De-icing Fluids

(Note: The guidelines for holdover times given in the SAE Tables call for the freezing points of fluid mixtures to be at least 10°C (18°F) for Type I, and 7°C (13°F) for Type II below the ambient air temperature).

Conduct tests to determine the limits of the use of hot water, and reduced glycol content de-icing fluids under conditions of precipitation.

Focus of activity shall be conduct of tests in the laboratory (NRC Environmental Test Facility) under controlled conditions. Availability of aircraft and procurement of laboratory services will be by TDC.

All other services and facilities shall be provided by the contractor.

5.3.1 Aircraft Tests

- Conduct two test sessions with a selected aircraft at Dorval Airport, Montreal to establish a 'reference' case for comparison with laboratory results. Choice of aircraft shall be determined in cooperation with US Airways and TDC. Test records shall include relative humidity at the time of test, and the fuel load of the aircraft to be tested.
- Test shall be conducted under conditions without precipitation, at zero or low wind velocity, and with low level of insolation - i.e. overcast or night-time. Plan for conduct of tests at two temperature ranges.
- Tests shall be conducted with hot water heated and applied in accordance with the first step of SAE ARP4737, latest edition, Two-Step de-icing/anti-icing procedure.
- Tests shall be conducted for two dilutions of an ethylene-glycol based Type I fluid, to be selected in coordination with TDC.
- Condition of fluid as applied, duration of application, and quantity of fluid applied shall be recorded.

  Temperature histories on the wing surfaces at selected locations shall be recorded starting prior to fluid application and terminating after fluid freezing. Locations shall include 'over fuel tank' and low thermal inertia surfaces such as control surfaces.
- Simultaneous tests shall be conducted adjacent to the aircraft using standard 1/8" (1.2mm) thick 'SAE' flat plates, increased thermal capacity 1/4" (6mm) plates, and 'Cold-Soak' boxes developed for laboratory simulation of cold-soaked wing. Boxes of appropriate depth shall be provided, as necessary, to ensure that the observed range of fluid behaviour on the wing can be adequately simulated in the laboratory.

5.3.2 Laboratory Tests

- Schedule a test session of one-week nominal duration in the NRC Environmental Test Facility in coordination with TDC. Notify TDC of the anticipated start date with minimum of two weeks notice.
- Anticipate tests using Type I ethylene glycol, and Type I propylene glycol de-icing fluids, and at least one Type IV fluid, heated and applied in accordance with the first step of SAE ARP4737, latest edition, Two-Step de-icing/anti-icing procedure.
- Conduct a matrix of tests using standard 1/8" (1.2mm) thick 'SAE' flat plates, increased thermal capacity 1/4" (6mm) plates, and 'Cold-Soak' boxes developed for laboratory simulation of cold-soaked wing, based on:

  A range of selected temperatures (e.g. -3°C, -7°C, -14C, -25°C,).

  A range of appropriate precipitation rates, based on simulated Freezing Rain.

  A range of selected buffers, i.e. fluid dilutions.

Relative humidity at time of test shall be recorded.
Effects of wind are not to be considered.

- Record all test conditions, and time to fluid failure.
- Prepare recommendations for use of 'Negative Buffer' fluids based on ambient temperature, an appropriate, conservative delay (e.g. 3 minutes) before application of Anti-icing fluid, and limitations which might be imposed by wind conditions.

5.4 Development of a Low Glycol 'De-icing only' Fluid Table

Conduct tests to develop a 'De-icing Only' table for removal of ice, slush, snow or frost, in the absence of precipitation when the fluid is applied in accordance with SAE ARP 4737, latest revision. It is anticipated that the table would give values of minimum acceptable de-icing fluid glycol content, with appropriate buffer, as a function of a set of ambient temperature ranges.

Focus of activity shall be conduct of tests in the laboratory (NRC Environmental Test Facility) under controlled conditions. Procurement of laboratory services will be by TDC.

5.4.1 Laboratory Tests

- Schedule a test session of one-week nominal duration in the NRC Environmental Test Facility in coordination with TDC. Notify TDC of the anticipated start date with minimum of two weeks notice.
- Anticipate tests using water; a proposed new category "Type '0'" fluid based on recycled spent fluid; and Type I ethylene glycol, and Type I propylene glycol diluted to provide a range of 'low-glycol' heated de-icing fluids.
- Conduct a matrix of tests using standard 1/8" (1.2mm) thick 'SAE' flat plates, increased thermal capacity 1/4" (6mm) plates, and 'Cold-Soak' boxes developed for laboratory simulation of cold-soaked wing, based on:
  - A range of five or more selected temperatures.
  - A range of simulated wind velocities, representative of those encountered in operational service.
  - A range of selected buffers, i.e. fluid dilutions.
- Record the relative humidity.
- Record all test conditions including history of test surface temperature, and time to fluid failure.
- Develop a draft 'De-Icing, only,Table'
- Prepare a presentation to the SAE G-12 HoldOver Time Subcommittee.

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 assess a pilot's field of view during adverse conditions of winter precipitation for selected aircraft;
- to assess whether Representative Surfaces can be used to provide a reliable first indication of anti-icing fluid failure;
- to explore the potential application of point detection sensors to warn the Pilot in Command (P.I.C.) of an 'unsafe to take-off condition';
- to obtain failed fluid contamination distributions and profiles which can serve as inputs to a theoretical program designed to assess the effects of such contamination on possible aircraft take-off performance; and
- to compare the performance of de/anti-icing fluids on aircraft surfaces with the performance of de/anti-icing fluids on flat plates.

5.5.2 Test Locations

Conduct tests at the Central De-icing Facility, Dorval International Airport, Montreal using aircraft made available by airlines.

Contingency plans shall be made to conduct tests at alternative sites: Ottawa, Uplands Airport; Quebec City, Ancienne Lorette Airport.

Tests shall be performed at the new central de-icing facility. Coordinate with the facility operator for application and clean-up of fluids.

5.5.3 Facilities to be Provided

Provide all necessary equipment and facilities for conduct of the tests. Negotiate provision of ancillary equipment and services where possible with the pertinent airlines. Notify TDC of such arrangements. Equipment shall include lighting fixtures as necessary, observation platforms, vehicles, storage facilities, office facilities and personnel rest accommodation. Additional facilities and test equipment, if required, may be requested subject to agreement by all parties involved.

5.5.4 Test Plans

Prepare Test Plans for full-scale aircraft tests to include the following:

a) A detailed statement of work for each of the participants;

b) A specific test plan, for review by all parties, which will include as a minimum:

- Test procedures including Schedule and sequence of activities;
- Detailed list of responsibilities;
- Complete equipment list;
- List of data, measurements and observations to be recorded; and

c) A list of test activities including:
- Visual and Instrumented Data Logging;
- Monitoring and recording environmental conditions, including:
  - Air temperature,
  - Wing surface temperature at selected locations,
  - Wind velocity and direction, and
  - Precipitation type and rate;
- Record of aircraft and plate orientation to the wind; and
- Use of instrumentation to determine the condition of the fluid.

d) Data to be acquired from the tests including:
- Identification of fluid failure criteria;
- Location and time of first point of fluid failure on the wing, and of subsequent failure progression;
- Correlation of fluid failure time to environmental conditions;
- Correlation of fluid failure times on flat plates and aircraft; and
- Behaviour of fluid on the "representative" surface.

Plans shall include concurrent comparison tests of fluids on flat plates with the aircraft tests.
Present plans for review and approval by the TDC project officer.
Present the approved program to the airline and de-icing facility operator involved prior to the start of field tests.

5.5.5 Test Scheduling
Schedule tests on the basis of forecast freezing precipitation.
Notify the airline and de-icing facility operator in advance of the desired test set-up, including aircraft orientation with respect to the forecast wind direction, sequence of fluid applications, and any additional services requested.
Confirm that the de-icing equipment used for the tests is equipped with a nozzle suitable for the application of the pertinent fluids. Application of fluids will be by de-icing facility operator personnel.

5.5.6 Personnel and facility preparation
Recruit and train local personnel who will conduct test work.
Secure necessary approvals and passes for personnel and vehicle access for operation on airport airside property.
Provide all equipment and all other instrumentation necessary for conduct of tests and recording of data.
Arrange (with the cooperation of TDC) for deicing equipment and aircraft to be made available for the tests .
Arrange for the provision of fluids for spraying an aircraft.
Arrange for spray application during the initial tests to be observed by the fluid manufacturer's representative for endorsement, if possible.

5.5.7 Aircraft, De-Icing Pads and Crews

Planning shall be based on the following aircraft and facilities:

Aircraft	Airline	Test Locn.	De-Icing Pad	De-Icing Crew
Canadair RJ	Air Canada	Dorval	Central	Aeromag 2000
DHC-8	Air alliance	Dorval	Central	Aeromag 2000

5.5.8 Dry Runs

Conduct a 'dry run' for test team personnel to ensure familiarity with their requested roles. Dry runs shall be scheduled as early in the winter season as can reasonably be achieved and shall be scheduled at the participating airline's convenience. Operations shall include Type I and Type IV fluid applications and re-orientation of the aircraft.

5.5.9 Full-Scale Tests

Conduct up to 8 full all-night test sessions.

Note: In general, aircraft will be made available for testing outside regular service hours, i.e. available between 23:00 hrs. and 06:00 hrs. Subject to weather conditions additional test sessions may be requested.

Tests shall be conducted under a selection of the following conditions:

Aircraft orientations:	Headwind, Crosswind, Tailwind
Precipitation:	Snow, Freezing drizzle (If possible)
Fluids:	Type I, Type IV 'Ultra' and Octagon.
Engine Operations:	Anticipate dry run & full scale tests with engines running for Turbo-prop aircraft.

The following matrix of tests is anticipated:

Aircraft	No. of Tests	A/C Orient's*	Comments
Canadair RJ	4	T, C, H	Dry Run required
DHC-8	3	T, C, H	Engines running
Total Tests	7 + 1 dry run		

T = Tail Wind, C = Cross- Wind, H = Head Wind

5.5.10 Priority of Tests

Initial planning for tests shall be based on the matrix of tests covered by items 5.5.7 and 5.5.9, above.

Plans shall be made such that the number of tests with each aircraft and sequence of tests can be easily revised.

5.5.11 Aircraft Orientation and Fluid Application:

Tests shall be conducted in the following sequence: Tail to wind, Cross wind, Head wind.

Type IV tests shall be conducted with UCAR ULTRA, except as otherwise indicated.
For tests with Tail to wind and Nose to wind, Type I fluid shall be applied to the port wing, and Type I fluid followed by Type IV fluid shall be applied to the starboard wing in a standard 2-step application procedure. Tests with Type I fluid, only, shall be repeated without change in aircraft orientation until failure of the Type IV fluid.
For cross-wind tests both wings shall be treated with Type I only and observations of fluid behaviour shall be to failure of the fluid on both wings.
Under conditions of light precipitation when the expected time to failure of the Type IV fluid is judged to be be 'excessive' the Type IV test shall be aborted, and the aircraft re-orientaion shall proceed for further Type I tests.
Under conditions of heavy precipitation when the expected time to failure of the Type IV fluid is judged to be be 'short', Type IV test(s) shall also be conducted in a cross-wind, with the same fluid application to both wings.
A maximum of three (3) Type I tests and one Type (IV) test are contemplated for each orientation, on a given test night.

5.5.12 Tests with a Canadair RJ
Tests with a Canadair RJ shall include sessions with a local area of the wing having fluid thinly applied. Thickness distribution and history shall be monitored, and observations made to determine whether local fluid failure occurs, and in such an event whether the failure propagates prematurely.
Tests shall also be conducted during a single test session with UCAR ULTRA and with OCTAGON fluids to compare their behaviours.

5.5.13 Tests with Turbo-prop aircraft
True functional tests with Turbo-prop aircraft require that the engines should be running.
Gather available information applicable to the ground operations of these aircraft in regular service. Based on observation and the observations of others, assess the influence of propeller 'wash' on fluid flow-back patterns, and on precipitation behaviour, particularly under cross wind conditions.
Particular consideration shall be given to safety. In the event of conflict between access for data gathering to obtain required test results and safety considerations, safety shall govern.

5.5.14 Test Measurements
Make the following measurements during conduct of each test:
Contaminated thickness histories at points on wings, selected in cooperation with TDC.
Contamination histories at points on wings to be selected in cooperation with TDC.

Location and time of first failure of fluids on wings -
Concurrent measurement of time to failure of fluids on flat plates; plates to be mounted on standard frames and on aircraft wings at agreed locations.
Pattern and history of fluid failure Progression.
Wing temperature distributions.
Amount of fluid applied in each test run, and fluid temperature
Meteorological conditions.

5.5.15 'Clean' Fluid Thickness Measurements

In the event that there is no precipitation at the time of the dry run, or during full scale tests, advantage 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 uniformity of fluid application.

5.5.16 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 observervations.

5.5.17 Remote sensor records

Record the progression of fluid failure on the wing using RVSI and/or SPAR remote contamination detection sensors.

5.5.18 Videotape Records

Make videotape records of tests. Advise with respect to professional video tape coverage for at least two overnight test sessions.

5.5.19 Return of equipment

Return any equipment obtained from airlines for use during the tests to its original condition at the end of the test program.

5.5.20 Assembly and analysis of results

Assemble and analyze all results.

5.5.21 Flat plate tests

Conduct standard flat plate tests concurrently with the aircraft tests.

5.6 Documentation of Pilot field of View, and Wing Visibility

5.6.1 Aircraft Types

Document the area of the wing that is visible to the PIC from inside the cockpit and from inside the cabin for as many aircraft types in service in Canada as can reasonably be checked. Aircraft types shall include at least DC-9, B-767, Canadair RJ, DHC-8 and Bae-146.

5.6.2 Lighting Conditions
Area of visibility shall be recorded under conditions of 'normal' daylight, and at night under conditions of precipitation with on-board lighting, only.

5.6.3 Documentation
Provide sketches, illustrations and photographic records of the visible area(s) of the wing.

5.7 Documentation of the Appearance of Failed Fluids

5.7.1 Tests
Conduct flat plate tests in the NRC CEF laboratory, and in the field designed to address the following issues:
What is the appearance of a failed fluid.
How does the appearance of a Type I fluid failure differ from a Type IV fluid failure.
How does the appearance of failure under conditions of freezing drizzle differ from failure in freezing rain, and in snow.
Under what conditions do de/anti-icing fluids "Flash freeze".
Are there differences in failure appearance between ethylene-, and propylene-glycol fluids when exposed to freezing drizzle.
Do strong winds significantly affect failure appearance.

5.7.2 Records
For each test record the following information with appropriate instrumentation:

Fluid thickness history at selected locations.
Viscosity at selected locations.
Refractive Index history at selected locations.
Video camera appearance of flat plate at time of fluid failure.
Video camera appearance of 'cross-hair' detail at time of fluid failure.
RVSI and/or SPAR/COX remote sensor record of fluid failure.
C/FIMS point sensor record of fluid failure.

and record the description of the visual appearance of fluid failure

5.7.3 Documentation
For each test provide the following documentation:

Record of purpose of test, and test conditions.
Photographic record of initiation and progression of failure.
Output 'traces' for each of the three sensors as a function of time.
Fluid freeze point temperature history and Fluid viscosity history.
Fluid thickness history.
A subjective determination of failed fluid adherence, together with

criteria used.

5.8 Potential use of Remote Sensors for End-of-Runway inspection

5.8.1 Preparation

Purpose of the task is to determine the problems and possible solutions with respect to operation of remote sensors for to supplement the PIC's visual pre-takeoff contamination inspection.

Arrange for installation of a SPAR/COX remote sensor to be installed on a mobile vehicle.

Arrange with pertinent agencies having jurisdiction for the sensor and vehicle to be operated on a trial basis suitable for conduct of pre-takoff inspection of aircraft at, or close to, the end of runway immediately prior to start of the take-off roll.

Anticipated duration of the test period will be approximately two weeks and shall encompass at least two periods of freezing precipitation.

5.8.2 implementation

Anticipated problems include:

accessibility of the vehicle to the end of runway,
liasion with the tower
communication between vehicle, tower, and aircraft,
responsibility for communication of sensor observations to the PIC,
qualifications required for the vehicle/sensor operator.

Problems encountered should be reported and recommendations for solutions made.

5.8.3 Sensor Outputs

Sensor electronic outputs shall be recorded for analysis at the end of the winter season. During conduct of the task the sensor operator shall NOT report the sensor observations of the condition of the aircraft critical surfaces.

5.9 Taxi Times under conditions of Precipitation

Record and report taxi times from start of hold-over time to start of take-off roll (Nominal time of conduct of the pre-takeoff inspection) under conditions of winter precipitation to assess actual taxi times experienced and the impact of conditions of precipitation on ground operations.

Record and report taxi times under daylight conditions in the absence of precipitation, for aircraft requiring de-icing only, in order to provide reference times for sample runway use.

5.9.1 Locations

Collect data for operations at Montreal, Dorval Airport, and at Toronto, Lester B. Pearson Airport, and supply any additional relevant data as may be readily available.

5.10 Support for Review of Alternative Technologies
Provide support services for the evaluation of an infra-red heating device to be demonstrated by Infra-Red Technologies Inc. as a low cost and zero environmental impact alternative technology for aircraft de-icing.

5.11 Provision of Support Services
Provide support services to assist with conduct of tests, collection/reduction of data and presentation of findings, all in areas associated with other tasks of this work statement. These services shall include assistance with TDC project "Contaminated Aircraft Take-off Tests".

5.12 Presentations of test program results

5.12.1 Preliminary Findings
Prepare and present preliminary findings of test programs involving field tests with aircraft to representatives of Transport Canada and the Airlines involved at end of the test season, but no later than May 30 1997.

5.12.2 Presentation of findings to the SAE
Participate at the SAE meeting to be held in Vienna in May1998, and present the results of the work conducted during the winter season 1997/98.

5.13 Reporting
Reporting shall be in accordance with section 10 "Reporting", below. Separate final reports shall be issued for each area of activity consistent with the project objectives.

APPENDIX B

EXCERPTS OF SAE ARP4737

AIRCRAFT DEICING/ANTI-ICING METHODS WITH FLUIDS

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
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AEROSPACE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard

SAE ARP4737 REV. C

Issued 1992-10
Revised Proposed Draft 1998-03-27

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 ensure that no one attempts to dispatch or operate an aircraft with frozen deposits adhering to any aircraft component critical to safe flight.

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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3.3.2 Anti-icing fluids are:

a. SAE Type I fluid (see previous caution)
b. Mixtures of water and SAE Type I fluid
c. Concentrates or mixtures of SAE Type II fluid and water
d. Concentrates or mixtures of SAE Type III fluid and water
e. Concentrates or mixtures of SAE Type IV fluid and water

SAE Type II, III, and IV fluids for anti-icing are normally applied unheated on clean aircraft surfaces but may be applied heated. SAE Type I fluid may be used unheated or heated after the aircraft has been deiced (reference Figure A1 and AMS 1424).

3.3.3 Fluid terms are:

a. Newtonian fluids are defined as fluids whose viscosities are shear independent and time independent. The shear rate of a Newtonian fluid is directly proportional to the shear stress. The fluid will begin to move immediately upon application of a stress; it has no yield stress to overcome before flow begins.

   NOTE: SAE Type I fluids are considered Newtonian.

b. Non-Newtonian fluids are defined as fluids whose viscosities are shear and time dependent and whose shear rate is not directly proportional to its shear stress. The fluid will not begin to move immediately upon application of a stress, it has a yield stress to overcome before flow begins.

   NOTE: SAE Type II, III, or IV fluids containing thickeners demonstrate a pseudoplastic behavior which is defined as a decrease in viscosity with an increase in shear rate.

3.4 Methods/Procedures:

3.4.1 Deicing is a procedure by which frost, ice, slush, or snow is removed from the aircraft in order to provide clean surfaces.

3.4.2 Anti-icing is a procedure, which provides protection against the formation of frost or ice and accumulation of snow or slush on clean surfaces of the aircraft for a limited period of time (holdover time).

3.4.3 Deicing/anti-icing is a combination of the two procedures described previously. It can be performed in one or two steps.

3.4.3.1 One step deicing/anti-icing is carried out with an anti-icing fluid. The fluid used to deice the aircraft remains on aircraft surfaces to provide limited anti-icing capability.

6.3 Limits/Precautions:

6.3.1 Fluid Related Limits:

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). This is due to adverse aerodynamic effects of propylene glycol and diethylene glycol based fluids and the freeze point characteristics of ethylene glycol and diethylene glycol based fluid.

6.3.1.1 Temperature Limits (see appropriate figures): When performing two step deicing/anti-icing, the FP of the fluid used for the first step shall not be more than 3 °C (5 °F) above ambient temperature (refer to 6.3.3.2).

6.3.1.1.1 SAE Type I Fluids: The FP of the SAE Type I fluid mixture used for either one step deicing/anti-icing or as a second step in the two step operation shall be at least 10 °C (18 °F) below the ambient temperature.

6.3.1.1.2 SAE Type II and IV fluids used as deicing/anti-icing agents may have a lower temperature application limit of -25 °C (-13 °F). The application limit may be lower, provided a 7 °C (13 °F) buffer is maintained between the FP of the concentrated fluid and OAT. In no case shall this temperature be lower than the lowest operational use temperature as defined by the aerodynamic acceptance test.

6.3.1.2 Application Limits (see applicable figures): Under no circumstances shall an aircraft that has been anti-iced receive a further coating of anti-icing fluid directly on top of the contaminated film. Should it be necessary for an aircraft to be reprotected prior to the next flight, the external surfaces shall first be deiced with a hot deicing fluid mix before a further application of anti-icing fluid.

6.3.2 Aircraft Related Limits: The application of deicing/anti-icing fluid shall be in accordance with the requirements of the airframe/engine manufacturers.

6.3.3 Procedure Precautions:

6.3.3.1 One Step Deicing/Anti-icing: It is performed with an anti-icing fluid (see 3.2.2). The correct fluid concentration is chosen with regard to desired holdover time, dictated by OAT and weather conditions.

CAUTION: Wing skin temperature may differ and in some cases may be lower than OAT. A stronger mix can be used under the latter conditions

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)

<table>
<tr><th rowspan="2">Outside Air Temperature OAT</th><th rowspan="2">One-Step Procedure see 6.3.3.1 Deicing/Anti-icing</th><th colspan="2">Two-Step Procedure see 6.3.3.2</th></tr>
<tr><th>First Step: Deicing</th><th>Second Step: Anti-icing[1]</th></tr>
<tr><td>-3 °C (27 °F) and above</td><td>50/50 Heated[2] Type II/IV</td><td>Water heated to 60 °C (140 °F) minimum at the nozzle or a heated mix of Type I, II or IV with water.</td><td>50/50 Type II/IV</td></tr>
<tr><td>Below -3 °C (27 °F) to -14 °C (7 °F)</td><td>75/25 Heated[2] Type II/IV</td><td rowspan="2">Heated suitable mix of Type I, II or IV with FP not more than 3 °C (5 °F) above actual OAT.</td><td>75/25 Type II/IV</td></tr>
<tr><td>Below -14° C (7° F) to -25 °C (-13 °F)</td><td>100/0 Heated[2] Type II/IV</td><td>100/0 Type II/IV</td></tr>
<tr><td>Below -25 °C (-13 °F)</td><td colspan="3">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).</td></tr>
</table>

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)

concentrations in % V/V

Outside air temperature OAT	One-step procedure see para. 6.3.3.1 Deicing/anti-icing	Two-step Procedure see para. 6.3.3.2	
		First step: Deicing	Second step Anti-icing 1)
-3° C (27° F) and above	100/0 Heated[2] Type III	Water heated to 60°C (140°F) minimum at the nozzle or a heated mix of Type I or III with water	100/0 Type III
Below -3° C (27° F) to -14° C (7° F)	100/0 Heated[2] Type III	Heated suitable mix of Type I or III with FP not more than 3 °C (5 °F) above actual OAT.	100/0 Type III
Below -14° C (7° F)	SAE Type III fluid may be used below -14° C (-7° 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 III 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 manufacturers recommendations

Caution: Wing skin temperatures may differ and in some cases may be lower than OAT.

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. This is particularly true when using a Type I fluid mixture for the first step(deicing)

1) To be applied before first step fluid freezes, typically within 3 minutes
2) Clean aircraft may be anti-iced with cold fluid.

FIGURE 6 - Guidelines for the Application of SAE Type III Fluid Mixtures as a Function of Outside Air Temperature (OAT)

APPENDIX C

EXPERIMENTAL PROGRAM

AIRCRAFT TESTS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE

AND DETERMINATION OF FIRST-STEP FLUID TEMPERATURE LIMITS

CM1380.001

EXPERIMENTAL PROGRAM
AIRCRAFT TRIALS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE AND DETERMINATION OF FIRST STEP FLUID TEMPERATURE LIMITS

Winter 1997-98

APS AVIATION INC.

January 21, 1998
Version 1.1

EXPERIMENTAL PROGRAM
AIRCRAFT TRIALS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE AND DETERMINATION OF FIRST STEP FLUID TEMPERATURE LIMITS

Winter 1997-98

APS will conduct a series of tests on flat plates and\or cold-soaked boxes at the National Research Council Climatic Engineering Facility, and on aircraft at Montreal International Airport (Dorval).

This document provides the detailed procedures and equipment required for the conduct of the aircraft trial portion of this project.

1. OBJECTIVES

This project addresses two principal objectives:

i) To establish data sufficient to develop a *Deicing Only* table.

This table will provide guidelines similar to the current table in SAE ARP4737, but will apply only to those conditions when a holdover time is not required. Removal of snow following termination of a snow storm would be a typical case when this proposed table would be applied.

The process of developing this table will include investigation of the requirement for fluid freeze point buffers in conditions when a holdover time is not required.

ii) To determine the limits for negative freeze point buffers for fluids used as the first step fluid in a two-step deicing procedure.

Current guidelines in SAE ARP4737 state that the freeze point of the first step fluid shall be not more than 3°C above outside air temperature.

These tests will determine whether application of heated fluids having freeze points higher than 3°C above outside air temperature will provide an interval of five minutes or more before freezing when applied during a condition of freezing precipitation.

The purpose of the aircraft trials is to confirm that results of detailed tests conducted on wing substitutes are faithful predictors of results on wing surfaces.

2. TEST REQUIREMENTS

2.1 Aircraft Tests at Dorval Airport

Trials will be conducted on aircraft on two occasions with the objective of confirming that results of tests conducted on flat plates or cold-soaked boxes are representative of results of tests on aircraft wings.

Tests in dry conditions and at two temperature ranges are planned: between -2° to -5°C and between -8° to -12°C. Calm winds are desired. A limited number of fluid concentrations will be selected to provide fluid freeze points above the existing ambient air temperature. Trials will also examine results of application of heated water. Attachment C-I presents a detailed plan for this series of tests.

Aircraft availability and towing will be coordinated with US Airways and their local ground handler. Aircraft spraying will be coordinated with AéroMag 2000.

The product of each test will be the documentation of the final condition of the surface with respect to area wetted versus dry, and the condition of any fluid remaining. The Spar/Cox camera will be employed in these trials to supplement observers comments and diagrams of results. Data collected will include progressive tracking of temperature profiles at various points on the wing surface as measured by installed thermistors.

Simultaneous tests will be conducted on flat plates and cold-soaked boxes.

Complete photo and video records of conduct of tests and results will be maintained.

3. EQUIPMENT

Test equipment is listed in Attachment C-II.

4. PERSONNEL

A description of the responsibilities and duties of each member of the test team is provided in Attachment C-III.

5. SUMMARY OF PROCEDURE

The trial will be initiated by APS Aviation based on forecast weather conditions, and confirmation of availability of aircraft and aircraft towing and deicing ground crews.

The aircraft will be placed at the deicing centre by US Airways ground handler. APS will mount thermistor probes on all test surfaces (wings and flat plates and/or cold-soaked boxes) at pre-defined locations.

AéroMag 2000 will prepare to spray heated fluids as specified.

Test fluid will be sprayed on the wing according to standard procedures. Fluid from the deicing vehicle will be poured on the test surfaces on the stand.

Temperature profiles will be recorded with the thermistor loggers. Test surfaces will be monitored for freezing, and time and location of any occurrences will be recorded. Appearance of all test surfaces will be recorded after 5, 10 and 20 minutes and when wing cools to ambient temperature, noting areas bare and dry, and areas covered with fluid, and whether liquid or frozen. An ice contamination sensor will be used throughout to record fluid distribution on the wing and to identify areas with frozen fluid.

Samples of remaining fluid will be taken from test surfaces to determine fluid concentration and freeze point.

A record will be maintained of all test parameters, including ambient conditions and fluid sprayed.

A complete photo and video record will be maintained.

A detailed test procedure is contained in Attachment C-IV.

6. DATA FORMS

Data form are listed below:

- Figure C-2 General Form (Once per Session);
- Figure C-3 General Form (Every Test);
- Figure C-4a Icing Location Form DC-9;
- Figure C-4b Icing Location Form Boeing 737;
- Figure C-5a Brix Location Form DC-9;
- Figure C-5b Brix Location Form Boeing 737; and
- Figure C-6 Flat Plate Data Form.

7. PROPOSED NOTICE PROCEDURE

i)	Potential for testing	24 to 48 hours prior
ii)	Day of testing - Monitoring throughout day	by 1600 hrs
iii)	Day of testing - Confirm or cancel	by 2000 hrs
iv)	Proceed to APS test site	2100 hrs
v)	Preparation/briefing	2200 - 2300 hrs

Potential participants to be alerted:

- US Airways;
- AéroMag 2000;
- US Airways ground handler;
- Transportation Development Centre;
- The Federal Aviation Administration;
- Aéroports de Montréal;
- Spar/Cox; and
- RVSI

ATTACHMENT C-I

TEST PLAN FOR AIRCRAFT TRIALS

DEICING ONLY TABLE / FIRST STEP FLUID LIMITS

WINTER 1997-98

Occasion	OAT (°C)	Run	Test[1] Fluid	Fluid Freeze Point (°C)	Fluid Freeze Buffer (°C)
1	-8 to -12	1	H_2O	0	-8 to -12
1	-8 to -12	2	7%	-2	-3 to -7
1	-8 to -12	3	16%	-6	-2 to -6
2	-2 to -5	4	H_2O	0	-2 to -5
2	-2 to -5	5	5%	-1.5	-0.5 to -3
2	-2 to -5	6[2]	12%	-4	-1

[1] Percentage UCAR ADF

[2] This run to be performed only if OAT is at low end (-5°C) of range.

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6/12/2006

ATTACHMENT C-II

DEICING ONLY AIRCRAFT TRIALS

TEST EQUIPMENT CHECKLIST

TASK
Logistics for Every Test
Passes x 2 / Escort x 2
Rent Van / Rent Lights
Call Personnel
Advise Airlines (Personnel, A/C Orientation, Equip)
Monitor Forecast
Call potential participants
Test Equipment
Stand x 1 Blue detached ones: - with 1/8" standard plate; - with 1/16" plate; - with honeycomb core plate; and - with 7.5 cm box, 25% filled.
SPAR Camera Kit
Tape Recorder with Mic.(voice) x 2
Video Cameras X 2 + 10 batteries + 2 chargers
Laptop computer
Thermistor Probe and Logger Kit
Data Forms for plates and general
Aircraft Wing Forms
Compass x 1
Video cassettes / films
Clipboards
Space pens and pencils
Paper Towels
Rubber squeegees x 2
Plastic Refills for Fluids and funnels
Electrical Extension Chords
Tools
Stop watches
Pylons
Laser Pointers x 3
Storage bins for small equipment
Temperature Probe x 2
VHF radios
Brixometer x 2
Glass Thermometer
Flash lights x 4
Protective clothing
Tie wraps
Tags (Labels) for Fluid designation on stand
Scrapers x 2
Whistle x 2
Rolling Stairs x 6
Tape measure x 4 (2 small, 2 large)
RH Meter
Wind Gauge
Mast lights
Duct Tape
Test procedure x 10
Photo Camera
Step ladders (platforms) x 4 (2 x 6', 2 x 4')
Fire extinguisher for trailer
Table and Chairs
Lighting x 1 double yellow poles
Fuel for generator
Marker for wing
Space heater (Perabolic)
Non-slip step-ladder for truck
Solvent for wing
OTHER TEST EQUIPMENT (1)
UCAR ADF Fluids for wings (UCAR)
Spray vehicle for XL54 x1 (A/L)
Test Aircraft (A/L)
Storage Facilities
Airline Personnel

(1) To be provided by others

ATTACHMENT C-III
Development of *Deicing Only* Table
RESPONSIBILITIES/DUTIES OF TEST PERSONNEL

Refer to Figure C-1 for position of equipment and personnel relative to the aircraft. Also refer to the test procedure (Attachment C-IV) for more detailed tester requirements.

Video 1 (V1)
- Video and photograph general test site;
- Video and photograph setup, including lighting, probe installation on wings, etc;
- Video application of all fluids on wing and plates;
- Assist in deployment of lighting;
- Ensure videotape of plates indicates plate number;
- Ensure areas of wing are identifiable for precise location;
- Pictures to be well lit;
- Knowledge of test procedures; and
- Video and photograph results of tests, showing where fluid remains on surfaces and where frozen.

RVSI (S1)
- Responsible for setting up generator and lights;
- Rent truck for Spar or RVSI sensor installation;
- Install Spar system on truck;
- Position truck and Spar/Cox camera at test site to allow viewing of the entire wing and the flat plate test stand without need to reposition;
- Monitor test surfaces with Spar/Cox camera (or RVSI), ensuring ongoing operation and iMage capture of all tests; and
- Retrieve tape from camera following test.

Wing Observer (W1)
- Responsible for setting up wing for test;
- Map out aircraft with pylons and plan view of aircraft;
- Located on rolling stair during test;
- Make observations of ice formation on wing surfaces;
- Record time and location for initial freezing;
- Draw contours showing ice formation at specified times and at end of test; and
- Draw contour showing fluid remaining on surface at end of test.

Brix Sampler (B1)
- Responsible for installing thermistor probes on aircraft and plate surfaces; complete cable linkage to loggers and laptop PC in cube van; check integrity;
- Responsible for down loading data from temperature loggers following test;
- Located on rolling stair during test;

- Assist wing observer in identifying ice formation for observer documentation;
- Communicate initial failure to all;
- Measure Brix values of fluid remaining on wing at end of test. Record time, location and Brix value. Sampled locations to include drip line and any wetted areas of the wing; and
- Assist plate observer to apply fluids.

Plate Observer (P1)
- Responsible for setting up cube van with laptop PC, table, heater for PC;
- Responsible for setting up flat plate stand;
- Located by test stand during tests;
- Make observations and record ice formation on test surfaces;
- Measure Brix values of fluid remaining on plate at end of test. Record time, location and Brix value. Sampled locations to include drip line and any wetted areas of the plate; and
- Knowledge of procedures for test stands.

Plate Observer (P2)
- Assist in application of fluids; and
- Record data as directed by P1.

Wing Coordinator (WC)
- Take sample of fluid from truck nozzle immediately following each spray operation; record Brix value and fluid temperature;
- Prepare all data forms in advance;
- Complete general data form for each test;
- Ensure failure calls are consistent;
- Communicate initial failure to all;
- Assist wing and plate observers as required;
- Assist overall coordinator as required; and
- Communicate critical times to wing observers.

Overall Coordinator (T6)
- Team coordinator;
- Responsible for area and people;
- Monitor operation of thermistor system during tests;
- Knowledge of test procedures and calling end conditions;
- To aid any personnel;
- Coordinate actions of APS team and as required airline personnel;
- Responsible for weather condition observations and forecast, advise tester team;
- Call personnel to conduct tests;
- Ensure that there are no objects on the ground which may cause FOD at end of session;
- Ensure test site is safe, functional and operational at all times;

- Supervise site personnel during the conduct of tests;
- Review data forms upon completion of test for completeness and correctness (sign);
- Ensure aircraft positioned appropriately;
- Monitor weather forecasts during test period;
- Ensure fluids are available and verify fluids being used for test are correct;
- Ensure electronic data is being collected for all tests;
- Ensure proper documentation of tapes, diskettes, cassettes;
- Verify test procedure is correct (e.g. stand into wind);
- Ensure all materials are available (pens, paper, batteries, etc.);
- Ensure all equipment is on;
- Ensure aircraft is not damaged; and
- Complete general data form at beginning of night.

ATTACHMENT C-IV
TEST PROCEDURE

1. PRETEST SET-UP

Prepare cold-soaked boxes and flat plates and install thermistor probes.

Maintain cold-soaked boxes at expected test ambient temperature.

Monitor weather forecasts seeking an outside air temperature of -8 to -12°C, or -2 to -5°C, with no precipitation and calm or little wind.

When suitable weather is out looked, discuss with US Airways and AéroMag 2000 to decide and prepare for tests. Advise AéroMag 2000 of fluid requirements for tests.

Advise all involved.

APS will rent truck for ice sensor unit, cube van, lights and generator.

APS will install ice sensor unit on truck in advance of test.

AéroMag 2000 will prepare to spray fluids as required for the test. The nature of preparation will depend on truck capabilities and will be discussed and decided at an initial meeting with AéroMag 2000.

US Airways ground handler will tow aircraft to deicing centre.

Prior to test, APS team:

i) Assembles and briefs. Prepare and distribute data forms;

ii) Synchronize all timepieces including cameras and PC/logger;

iii) Confirm functioning of camera and video recorder;

iv) Move to deicing centre with equipment;

v) Set up test stand with support equipment;

vi) Set up lights and generator; confirm adequate lighting on aircraft wing surface;

vii) Position stairs at aircraft wings;

viii) Install thermistor probes on wings, and ensure operation of probes and loggers. Photograph and videotape the precise location of each probe including reference points on the wing;

ix) Set up ice sensor and confirm operation. Confirm that adequate view of wing and plate stand is being provided if camera is in fixed location;

x) Set up van. Install Laptop PC. Install portable heater to maintain satisfactory temperature for PC operation;

xi) Prepare fluid sampling equipment;

xii) Record general test data including fuel load in aircraft wings and ambient conditions;

xiii) Establish communication between team members and coordinator; and

xiv) Ensure spray personnel are familiar with procedures.

2. INITIALIZATION OF TEST

i) Record wing skin temperature prior to start. Allow time for the wing to regain ambient temperature following previous test;

ii) Record all data from deicing vehicle (fluid temperature, concentration, nozzle type, truck serial number); and

iii) Take sample of truck fluid sufficient to conduct tests on surfaces at the stand. Measure the temperature of the fluid at the nozzle while the sample is being taken. Test concentration of the fluid to ensure that it is prepared to specified concentration.

3. EXECUTION OF FLUID TEST

i) Spray test fluid on wing, using AéroMag 2000 vehicle. Amount sprayed to be typical of removing light covering of snow, about 150 to 175 litres. Record amount of fluid sprayed;

ii) In continuous operation, spray fluid on test surfaces on flat plate stand following wing spray;

iii) Visually monitor test surfaces for freezing and note time and location if freezing occurs;

iv) Record area of wing bare and dry versus covered with fluid after 5, 10 and 20 minutes, and when wing regains ambient temperature. Inspect any wing cavities and underwing for ice, and record;

v) Monitor wing and flat plate stand with ice sensor throughout test;

vi) Record temperature profile of test surfaces with thermistor probes and loggers. Monitor logging with PC to ensure ongoing data capture;

vii) Measure Brix values of any fluid (liquid or frozen) remaining on test surfaces at end of test. Take two samples of fluid in individual wetted areas on the wing and flight control surfaces, and at least three from drip lines. Include drip line under leading edge. Record on data form location where samples were taken; and

viii) Acquire complete photo and video record of conduct of test and of appearance of test surfaces.

4. END OF TEST

Coordinator will advise end of test. This will normally occur when the wing temperature has regained ambient temperature, or when all test surfaces are confirmed to be bare and dry.

FIGURE C-1

POSITION OF EQUIPMENT AND PERSONNEL

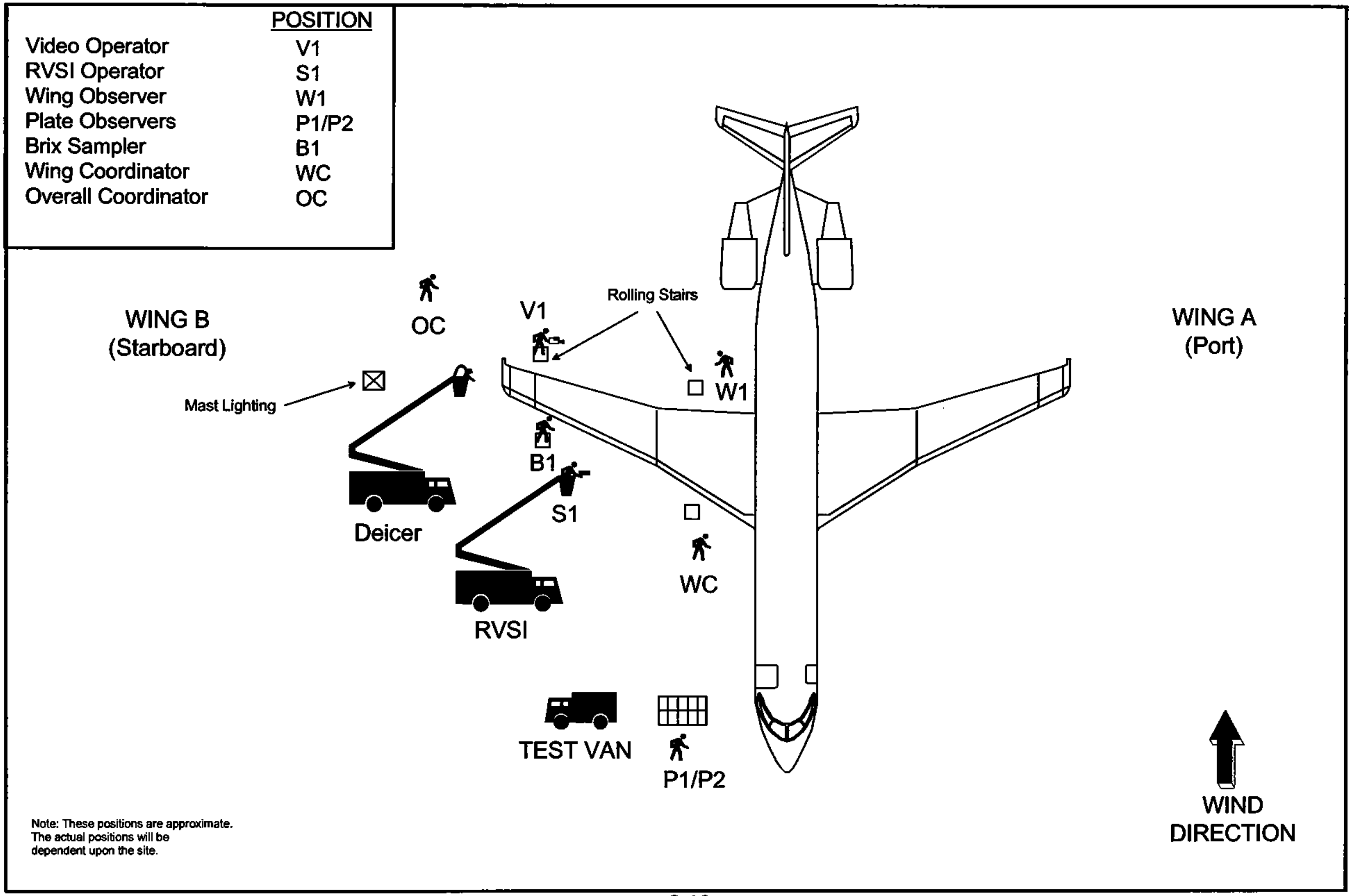

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FIGURE C-2

GENERAL FORM (ONCE PER SESSION)

(TO BE FILLED IN BY OVERALL COORDINATOR)

AIRPORT: YUL YYZ YOW

EXACT PAD LOCATION OF TEST: ______________________________

DATE: ______________________

APPROX. AIR TEMPERATURE: ________ °C

R/H: ________ %

AIRCRAFT TYPE: DC-9 F100 B-737 RJ

AIRLINE: ____________________

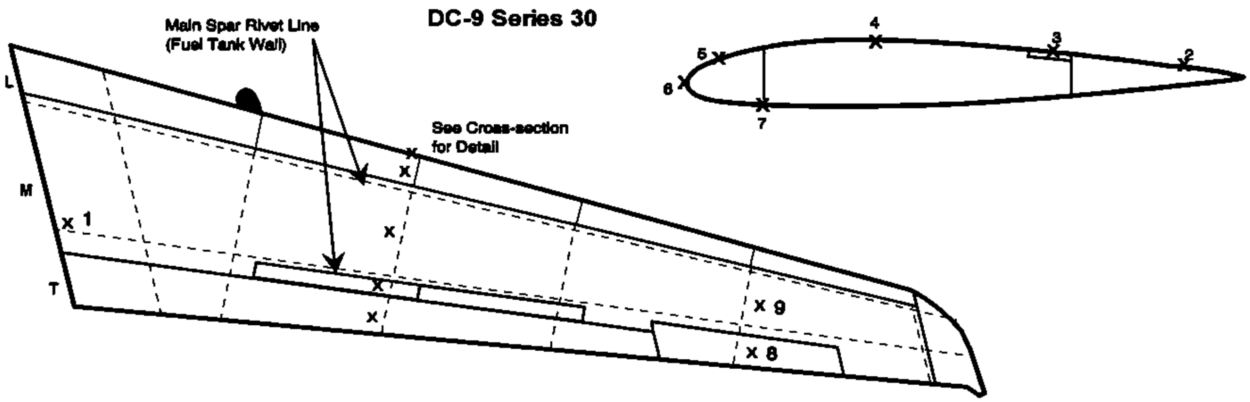
FIN #: ____________________

FUEL LOAD IN WING: ____________________ **LB / KG**

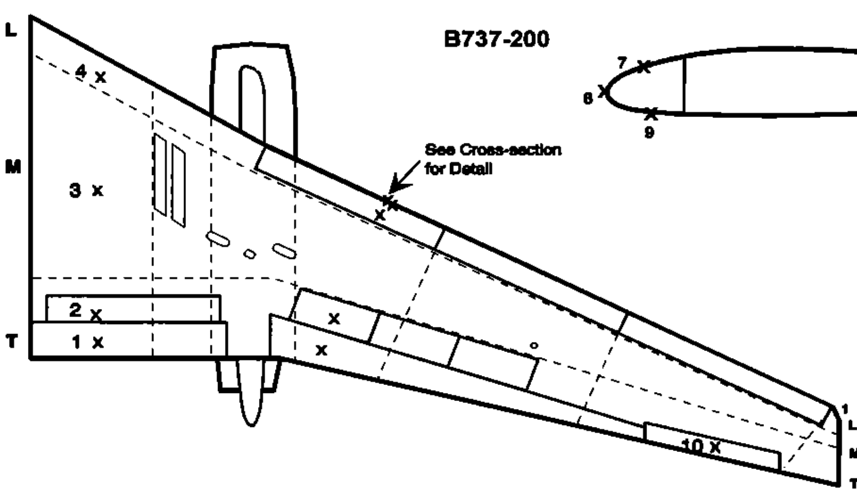
TYPE I FLUID APPLICATION	***TYPE IV FLUID APPLICATION***
TYPE I FLUID TEMP: ________ °C	**TYPE IV FLUID TEMP:** ________ °C
Type I Truck #: ________	**Type IV Truck #:** ________
Type I Fluid Nozzle Type: ________	**Type IV Fluid Nozzle Type:** ________

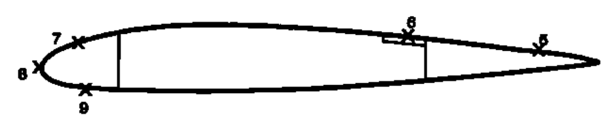
Thermistor Probes Mounting Locations

DC-9 Series 30



B737-200





Stand	
11	Std. Plate
12	**1.6 mm Plate**
13	Honeycomb Plate
14	7.5 cm Box

COMMENTS: ______________________________

MEASUREMENTS BY: ____________________

HAND WRITTEN BY: ____________________

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At: GFORM 1
6/12/2006

FIGURE C-3

GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY PLATE/WING COORDINATOR)

AIRCRAFT TYPE: DC-9 F100 B-737 RJ

DATE: ____________________

RUN #: ______________

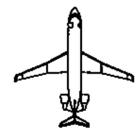
WING: PORT (A) STARBOARD (B)

WIND SPEED: ________ km/h

DIRECTION OF AIRCRAFT: ________ DEGREES

WIND DIRECTION: ________ Degrees

DRAW DIRECTION OF WIND WRT WING:



OAT: ________ °C

R/H: ________ %

1st FLUID APPLICATION

Actual Start Time: ______________

Actual End Time: ____________________

Amount of Fluid Sprayed: ______________ **L / gal**

Type of Fluid: ______________ **%**

Fluid Temperature: ______________ **°C**

End of Test Time: ______________ (hr:min:ss)

COMMENTS: ____

____

____

____

____

____

____

____

____

MEASUREMENTS BY: ____________________

HAND WRITTEN BY: ____________________

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At: GFORM 2
6/12/2006

FIGURE C-4a
ICING LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME VERSION 4.0 Winter 97/98

DATE:	RUN NUMBER:

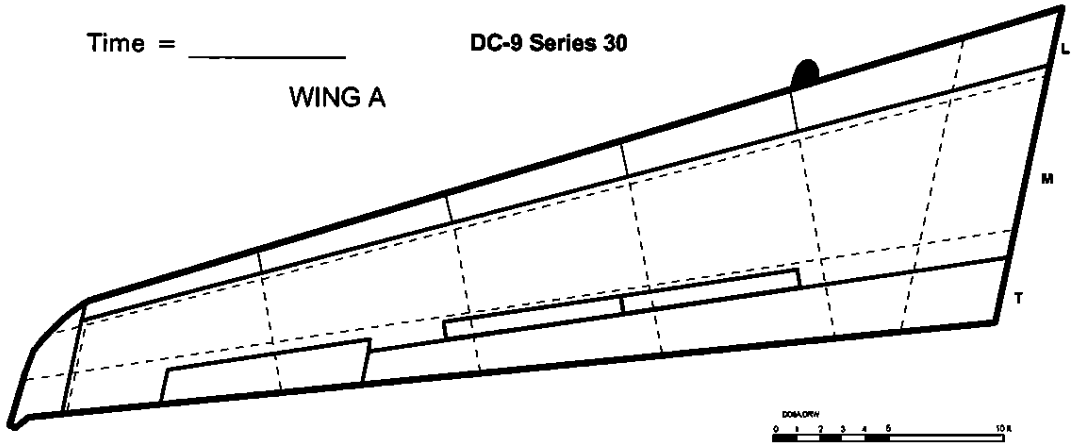
FAILURES CALLED BY: ____________ COMMENTS: ____________

HANDWRITTEN BY: ____________ ____________

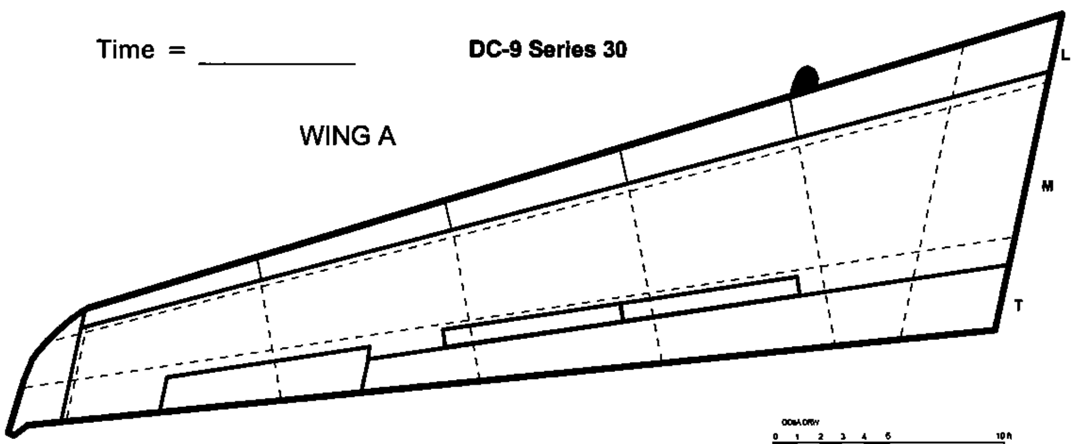
ASSISTED BY: ____________ ____________

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE

Time = __________



Time = __________



Time = __________

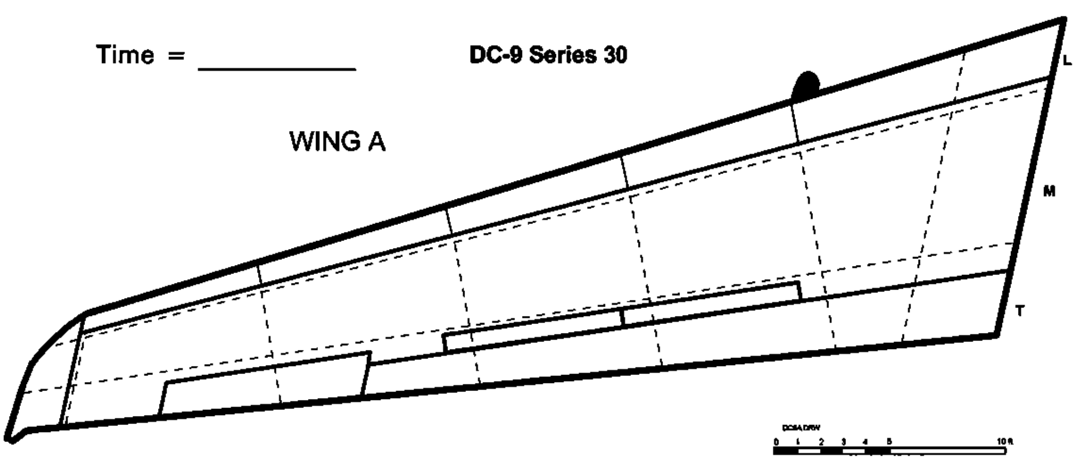


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FIGURE C-4a
ICING LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME VERSION 4.0 Winter 97/98

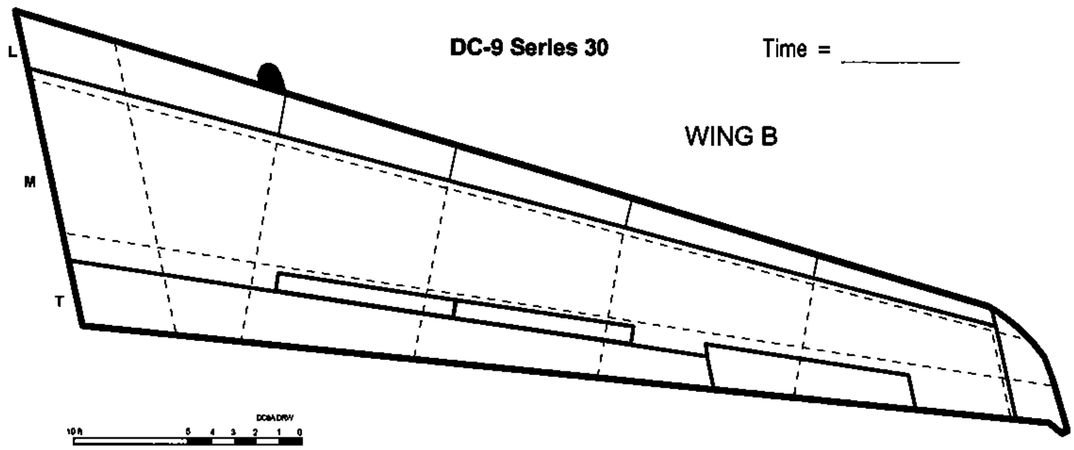
DATE:	RUN NUMBER:

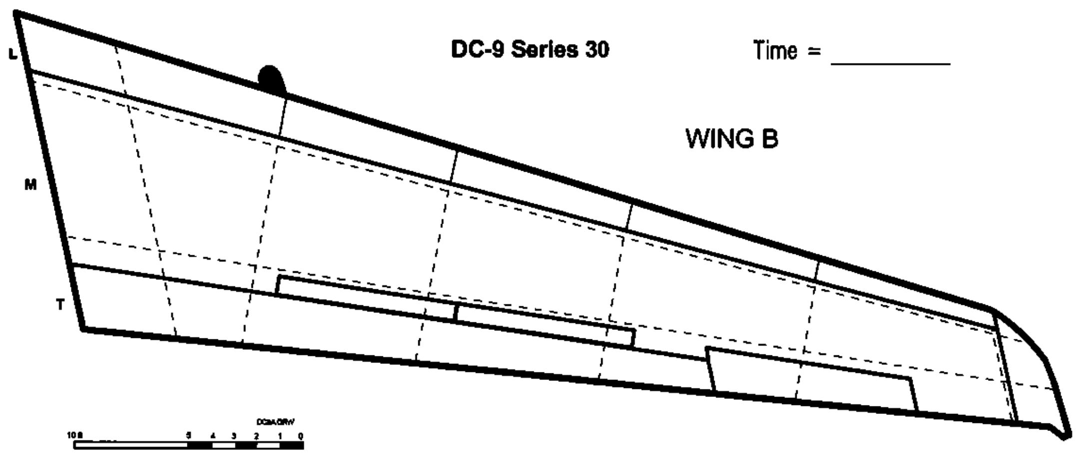
FAILURES CALLED BY: ____________ COMMENTS: ______________________________

HANDWRITTEN BY: ____________ ______________________________

ASSISTED BY: ____________ ______________________________

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE





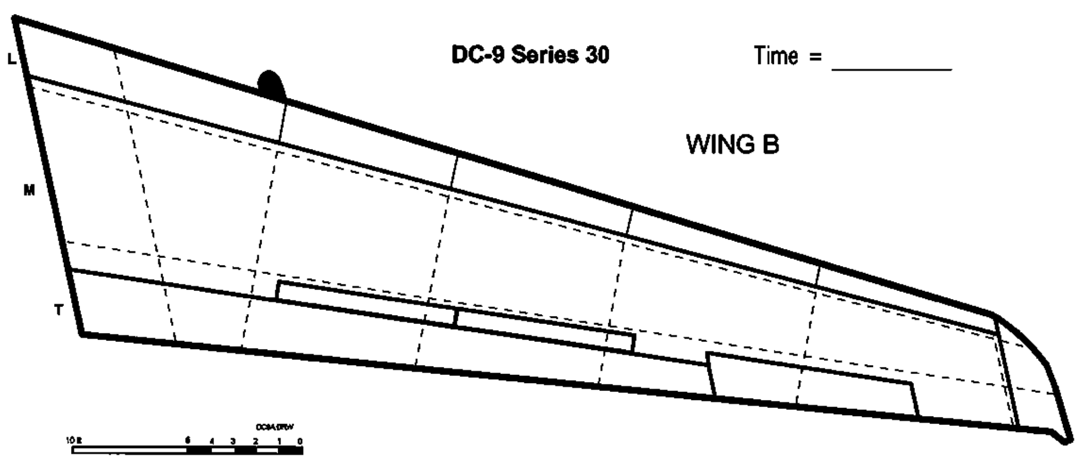


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FIGURE C-4b
ICING LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME VERSION 4.0 Winter 97/98

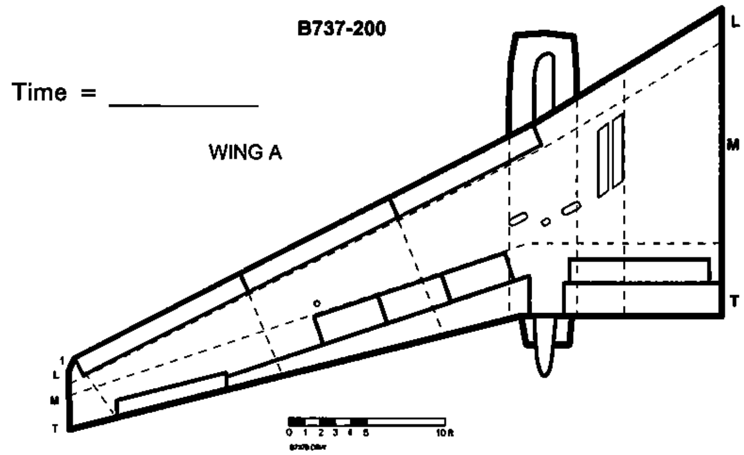
DATE: RUN NUMBER:

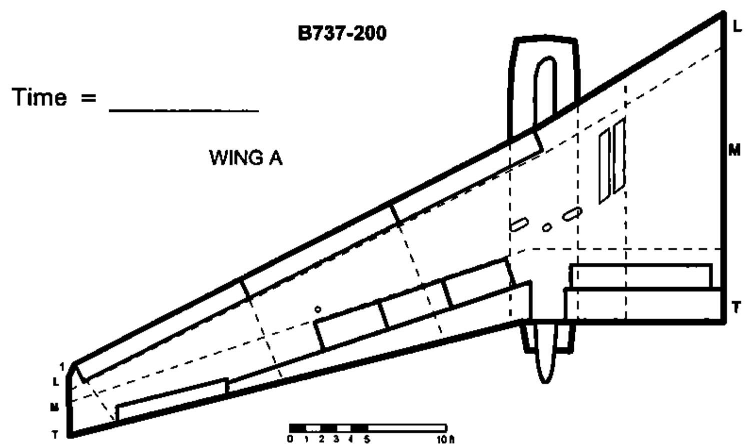
FAILURES CALLED BY: ____________ COMMENTS: ____________

HANDWRITTEN BY: ____________ ____________

ASSISTED BY: ____________ ____________

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE





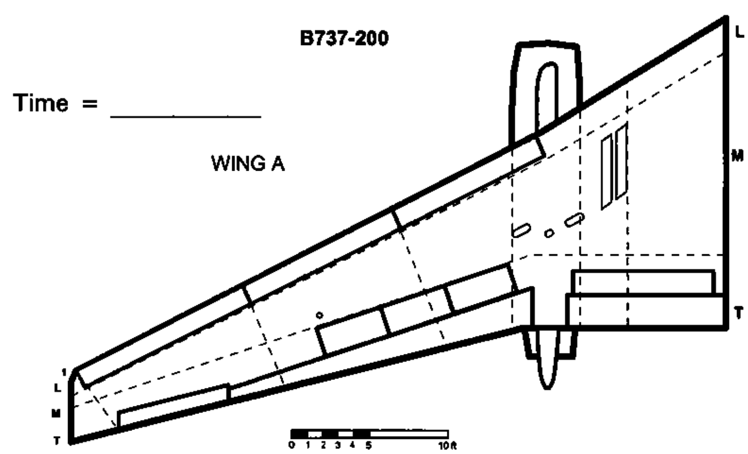


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FIGURE C-4b
ICING LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME VERSION 4.0 Winter 97/98

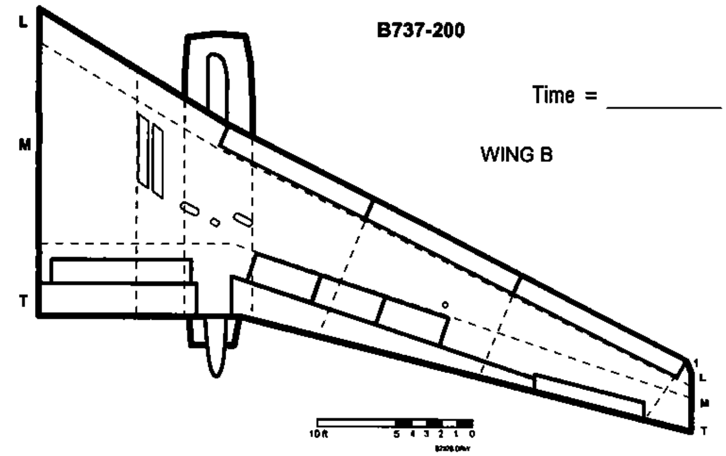
DATE:	RUN NUMBER:

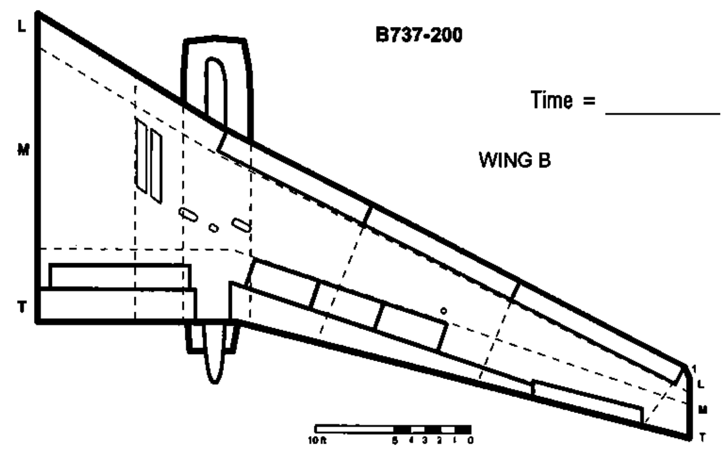
FAILURES CALLED BY: __________ COMMENTS: ____________________

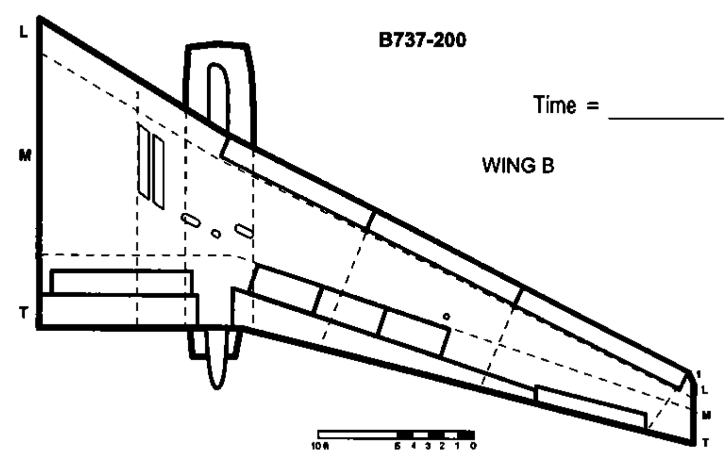
HANDWRITTEN BY: __________ ____________________

ASSISTED BY: __________ ____________________

DRAW FAILURE CONTOURS (hr:min) ACCORDING TO THE PROCEDURE







cm1380/procedur/ds_only/B737_WB.DRW

FIGURE C-5a
BRIX LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME

VERSION 4.0 Winter 97/98

DATE:	**RUN NUMBER:**

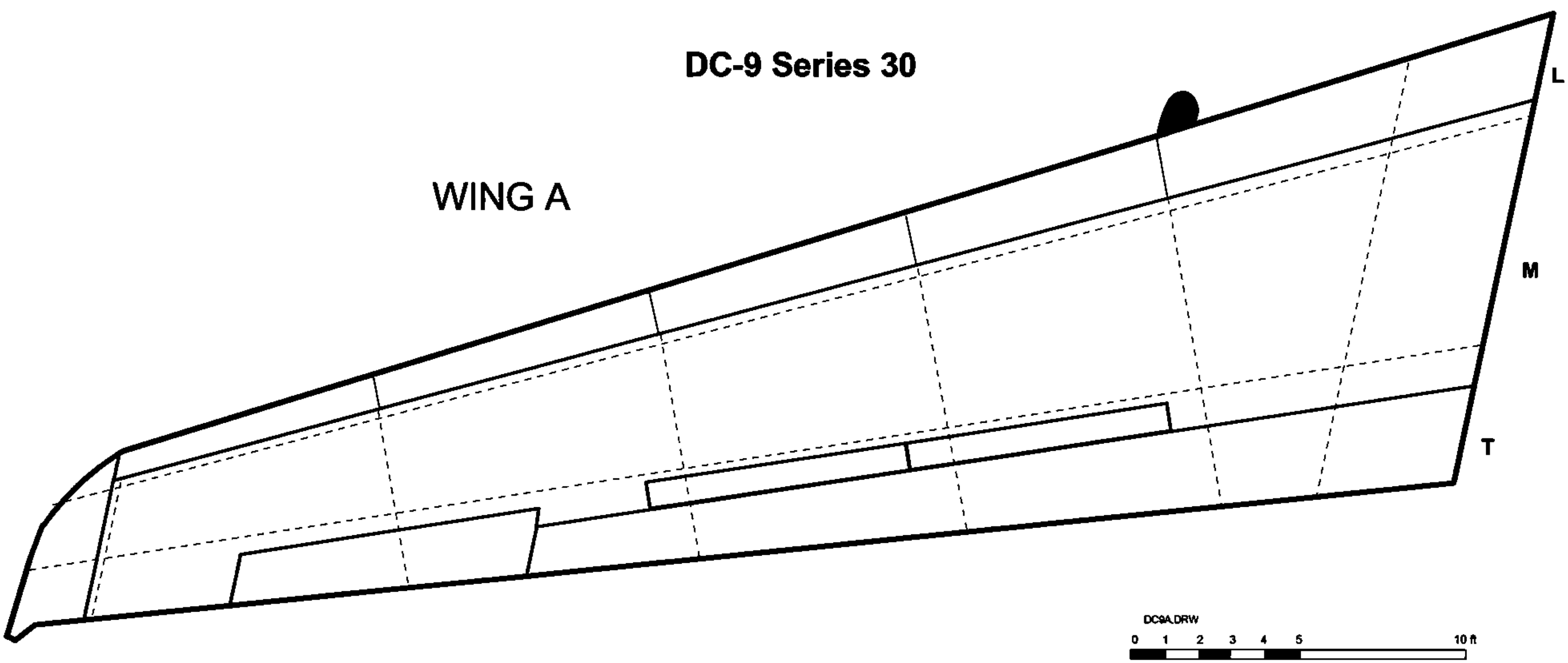
FAILURES CALLED BY: ____________________

HANDWRITTEN BY: ____________________

ASSISTED BY: ____________________

COMMENTS: ____________________

Record Brix Values



cm1380/procedur/de_only/BDC9_WA.DRW

FIGURE C-5a
BRIX LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME

VERSION 4.0 Winter 97/98

DATE: **RUN NUMBER:**

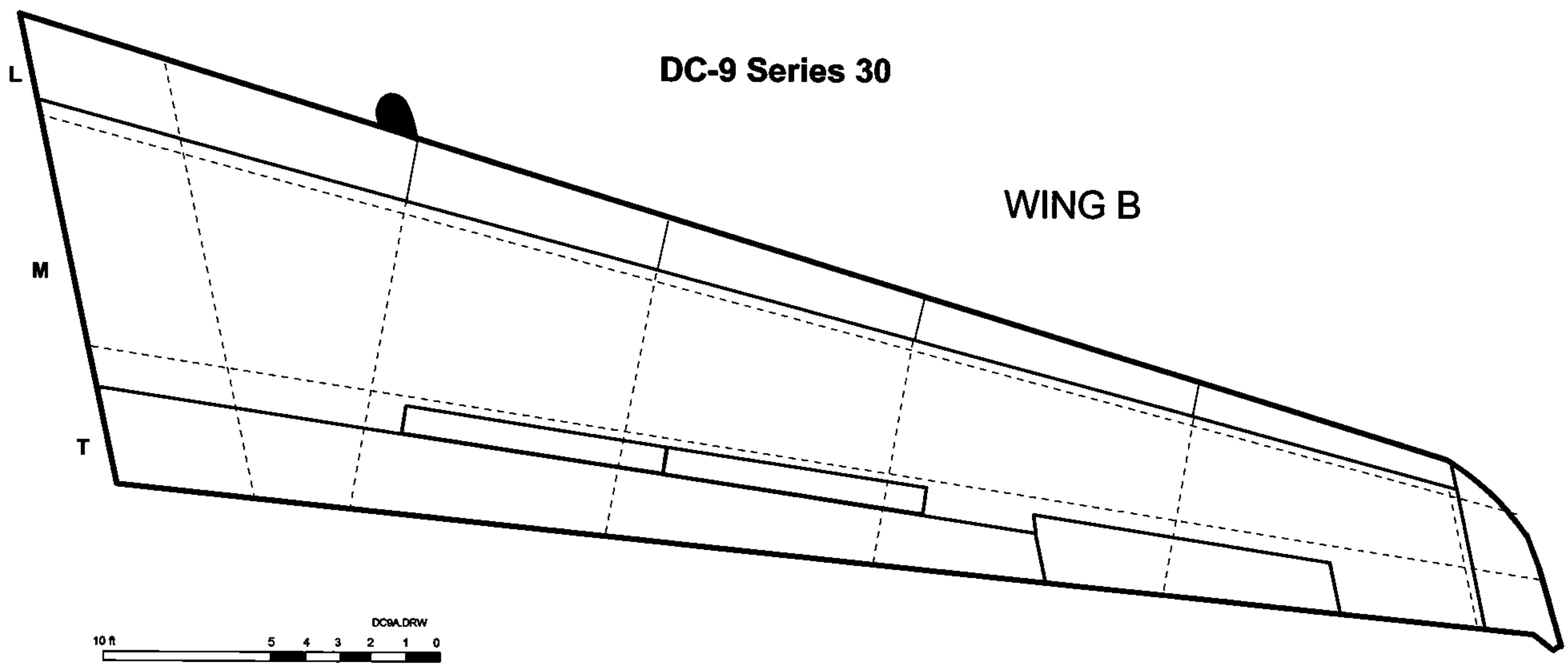
FAILURES CALLED BY: ____________

HANDWRITTEN BY: ____________

ASSISTED BY: ____________

COMMENTS: ____________

Record Brix Values



cm1380/procedur/de_only/BDC9_WB.DRW

FIGURE C-5b

BRIX LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME

VERSION 4.0 Winter 97/98

DATE:	**RUN NUMBER:**

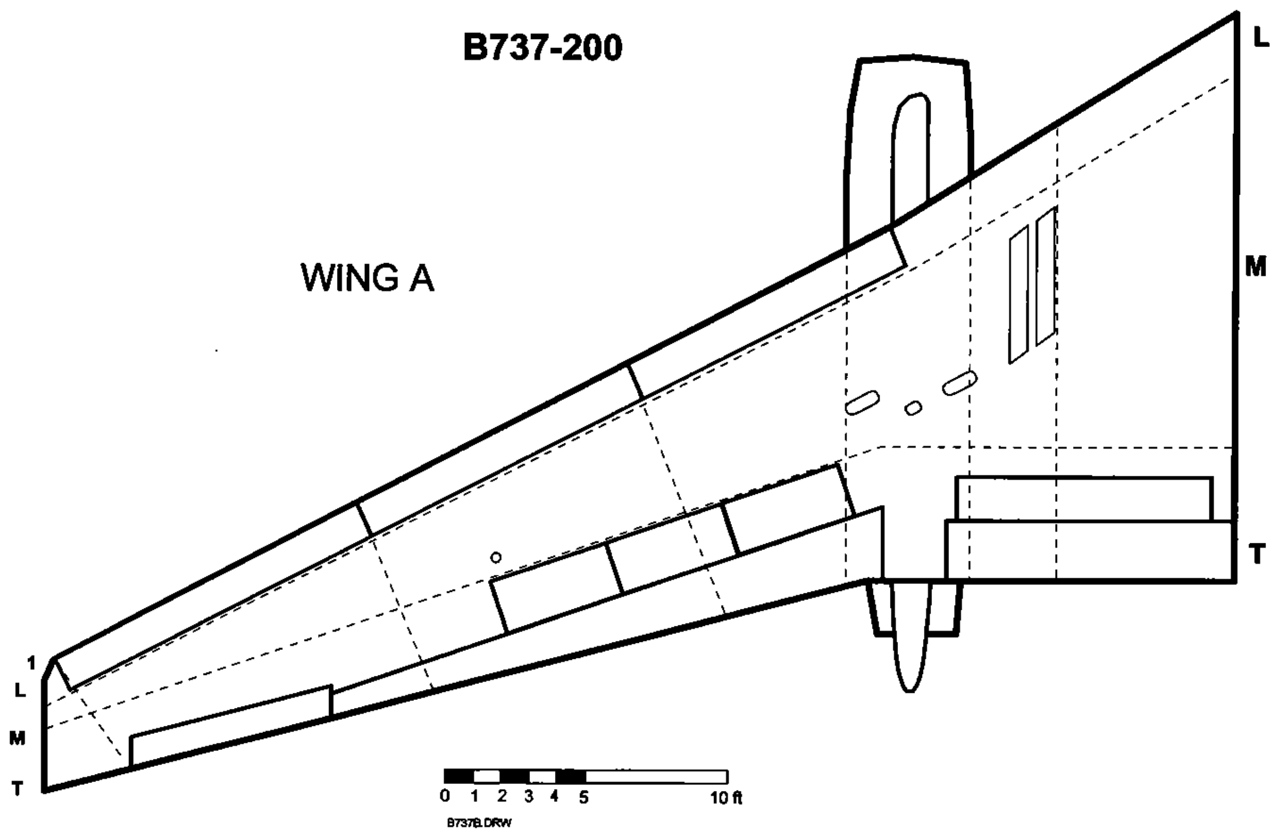
FAILURES CALLED BY: ____________________

HANDWRITTEN BY: ____________________

ASSISTED BY: ____________________

COMMENTS: ____

Record Brix Values



cm1380/procedur/de_only/BB737_WA.DRW

FIGURE C-5b

BRIX LOCATION FORM FOR AIRCRAFT WING

REMEMBER TO SYNCHRONIZE TIME

VERSION 4.0 Winter 97/98

DATE: RUN NUMBER:

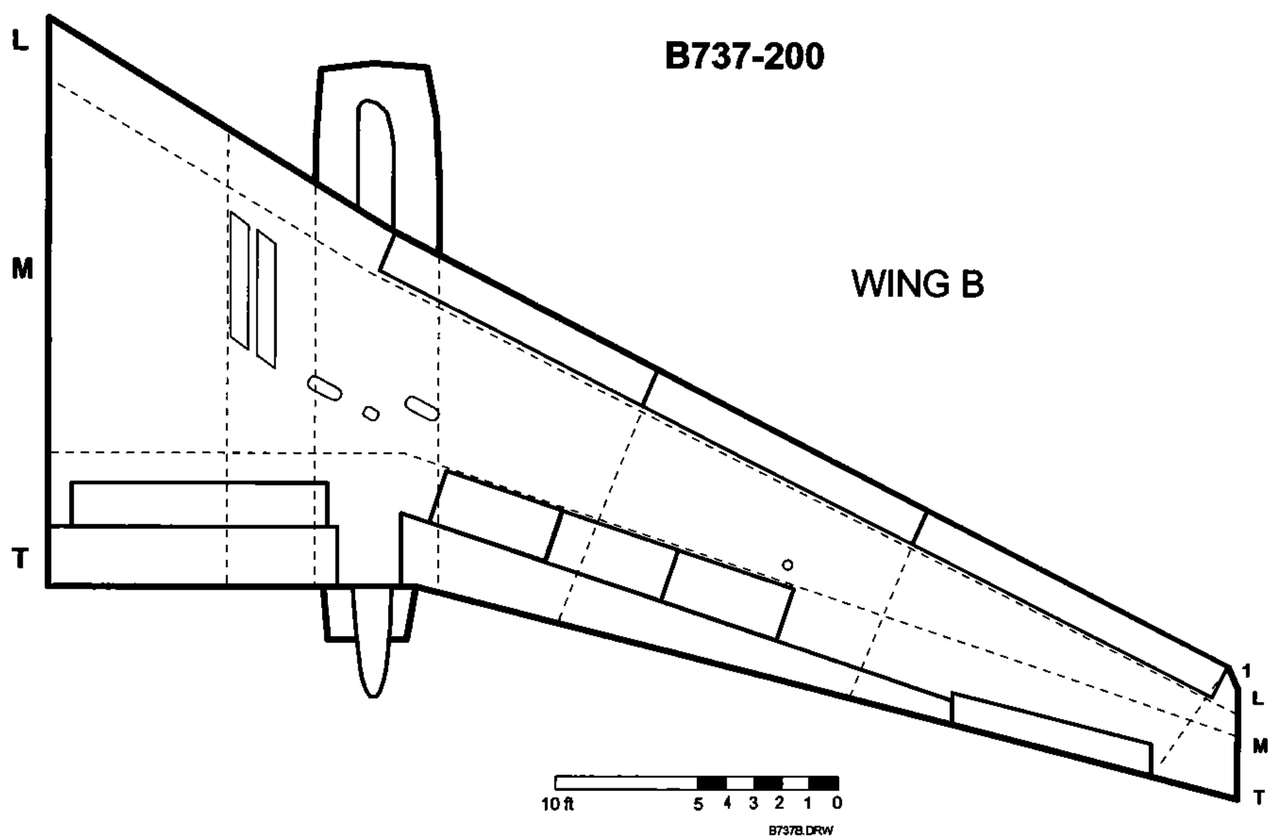
FAILURES CALLED BY: ____________________

HANDWRITTEN BY: ____________________

ASSISTED BY: ____________________

COMMENTS: ____________________

Record Brix Values



cm1380/procedur/de_only/BB737_WB.DRW

FIGURE C-6

HOT FLUID TEST FORM - AIRCRAFT TRIALS

REMEMBER TO SYNCHRONIZE TIME - USE REAL TIME

VERSION 2.0

LOCATION: **DATE:** **RUN # :** **TIME OF FLUID APPLICATION:**

SURFACE TYPE:
- STD. PLATE 1/8" ☐
- THICK PLATE 1/16" ☐
- 7.5 CM BOX ☐
- HONEYCOMB PANEL ☐

PLATE ANGLE: 10°

FLUID QUANTITY: 0.5 L

THERMISTOR #'s: ______

BRIX BEFORE POURING: _____ **TEMP. BEFORE POURING:** ______ °C

BRIX OF FLUID LEFT ON PLATE:

Time: __________ Brix __________

Time: __________ Brix __________

Time: __________ Brix __________

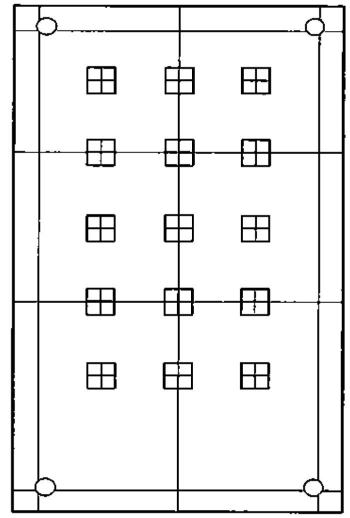
SKIN TEMPERATURES (9" LINE)

TIME:	________	TEMP.	____°C	TIME:	________	TEMP.	______°C
TIME:	________	TEMP.	____°C	TIME:	________	TEMP.	______°C
TIME:	________	TEMP.	____°C	TIME:	________	TEMP.	______°C
TIME:	________	TEMP.	____°C	TIME:	________	TEMP.	______°C
TIME:	________	TEMP.	____°C	TIME:	________	TEMP.	______°C
TIME:	________	TEMP.	____°C	TIME:	________	TEMP.	______°C

	PRINT	SIGN
OBSERVATIONS BY :	____________	____________
HAND WRITTTEN BY :	____________	____________
TEST SITE LEADER :	____________	____________

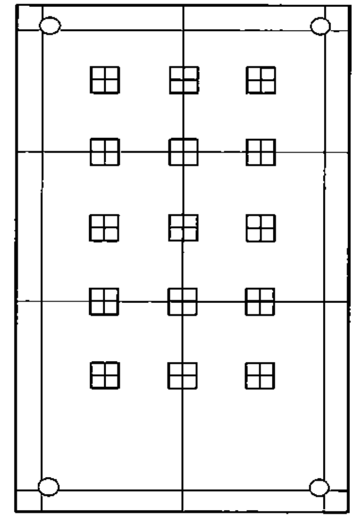
TIME __________ SKIN T. ____ °C

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100%



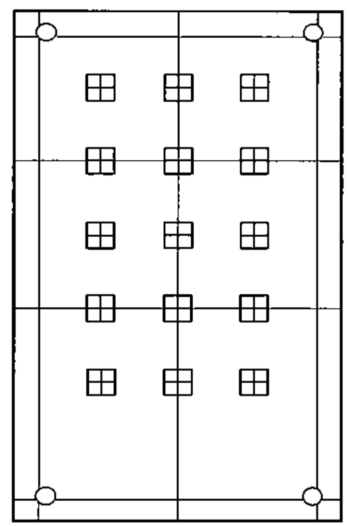
TIME __________ SKIN T. ____ °C

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100%



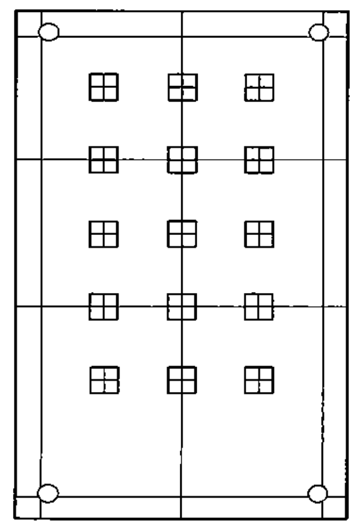
TIME __________ SKIN T. ____ °C

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100%



TIME __________ SKIN T. ____ °C

% Dry: 0-5 / 5-25 / 25-50 / 50-75 / 75-95 / 95-100%



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At: Data Form 6/12/2006

APPENDIX D

EXPERIMENTAL PROGRAM
LABORATORY TESTS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE
Winter 1997-98

CM1380.001

EXPERIMENTAL PROGRAM
LABORATORY TRIALS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE

Winter 1997/98

APS AVIATION INC.

February 25, 1998
Version 2.1

EXPERIMENTAL PROGRAM
LABORATORY TRIALS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE
Winter 1997/98

APS will conduct a series of tests on flat plates and\or cold-soaked boxes at the National Research Council Climatic Engineering Facility, and on aircraft at Montreal International Airport (Dorval). This document provides the detailed procedures and equipment required for the conduct of tests at the National Research Council Climatic Engineering Facility. The experimental program for aircraft testing is contained in a separate document.

1. OBJECTIVES

This project addresses the following objective:

i) To establish data sufficient to develop a *Deicing Only* Table.

This table will provide guidelines similar to the current table in SAE ARP4737, but will apply only to conditions of no precipitation. Removal of snow following termination of a snow storm would be a typical case when this proposed table would be applied.

The process of developing this table will include investigation of the requirement for fluid freeze point buffers in conditions of no precipitation.

2. TEST REQUIREMENTS

2.1 Test Surface for Full Trials

APS will conduct a preliminary series of tests on flat plates and cold-soaked boxes to determine the most suitable test surface for full trials at the National Research Council Climatic Engineering Facility. The test plan for these preliminary trials is in a separate document.

2.2 Tests at the National Research Council Climatic Engineering Facility

Tests at the National Research Council Climatic Engineering Facility will be scheduled over a one week period. Test variables will include air temperature and wind speeds. The fluid concentrations to be tested are selected to provide data points at several values of positive and negative freeze point buffers for each ambient temperature tested. Hot water, SAE Type I fluid (both ethylene and propylene based) and a recycled fluid (both ethylene and propylene based) will be tested progressively at a variety of concentrations and at increasingly critical temperature conditions until test results indicate that further testing serves no purpose. Tests are to be conducted in dry non-precipitation conditions with wind at a controlled velocity. Attachment D-I presents a detailed plan for this series of tests.

The outcome of each test will be documentation of Brix values on the test surface during the test run and at test end, and a description of any fluid remaining at test end. The size of the area left bare and dry, and the area still covered with fluid and any iced areas will be recorded by sketches, still photography and video footage, and by Spar/Cox and/or RVSI camera images. The condition of any fluid remaining on the test surface will be examined to determine refractive index at various locations within the wetted area, and state (whether liquid or frozen).

Data collected will include progressive tracking of plate surface temperature as measured by installed thermistors.

Preliminary tests will be conducted at the APS test site at Dorval airport to examine the comparative merits of using cold-soaked boxes and flat plates.

Clean test surfaces without markings will be used to avoid the damming effect of line markings and their consequent interference with fluid runoff and evaporation.

3. EQUIPMENT AND FLUIDS

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

Fluids will be applied heated.

SAE Type I fluids will be tested. The principal Type I fluid will be UCAR XL54 supplemented by sufficient tests using a propylene based Type I fluid to provide confidence that results are not dependent on fluid type. A limited number of tests will be conducted on Type IV fluids where they can be accommodated in test runs.

A recycled fluid proposed as a new Type 0 will be also be tested.

4. PERSONNEL

A team of five personnel is required to conduct tests at the National Research Council Climatic Engineering Facility. Duties of each team member is shown in Attachment D-III.

5. TEST PLAN

A test matrix of fluid types and concentrations, ambient temperatures and wind speeds is shown in Figure D-1.

A detailed test plan is provided in Attachment D-V.

6. DATA FORMS

The following data form is required:

- Attachment D-IV Data form for *Deicing Only* Table Trials.

FIGURE D-1

TEST PLAN FOR DEVELOPMENT OF *DEICING ONLY* TABLE

NATIONAL RESEARCH COUNCIL - CLIMATIC ENGINEERING FACILITY

OAT		FLUID FREEZE POINT (°C)								WIND (km/h)				REMARKS
		0	-1.5	-3	-8	-14	-22	-30	-43					
°C	°F	FLUID FREEZE POINT BUFFER								0	5	10*	20	
+1	34	1	2.5	4						√	√	√	√	Contingent on results at -1°C
-1	29	-1	0.5	2						√	√	√	√	
-5	23	-5	-3.5	-2	3					√	√	√	√	
-10	14	-10	-8.5	-7	-2	4				√	√	√	√	
-18	0	-18	-16.5	-15	-10	-4	4			√	√	√	√	
-35	-31	-35					-13	-5	8	√	√			

<u>**Note:**</u> Past tests have showed that low concentrate fluids (2%, water) evaporated more readily than higher concentrates (10%, XL54), and consequently are proposed for testing at very low temperatures conditional on results experienced as tests progress.

* Trials at wind speed of 10 km/h will be conducted only if time allows during each test session.

Fluid to be Tested:

- H_2O
- UCAR ADF at all indicated cells.
- Octaflo at -3° and -8° freeze point temperature, and other freeze points where the test plan allows.
- Inland Recycled Fluid (Ethylene and Propylene based) at -3° and -8° freeze point temperature.
- Type IV (Ethylene and Propylene) will be tested on a limited basis.

ATTACHMENT D-I
DEVELOP *DEICING ONLY* TABLE
DETAIL TEST PROCEDURE

Tests at the National Research Council Climatic Engineering Facility

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 but mark gradations on edge of plates.

Prepare fluid mixes in advance.

Prepare equipment for transport to the National Research Council.

2. PRE TEST SET-UP AT SITE

Establish initial temperature in chamber.

Set up equipment for test support, including fluid heating equipment.

Install thermistor system and confirm operation of thermistors and temperature loggers.

3. PROCEDURES

Wind rates will be measured at several locations across the test stand before and after each run. Winds will be established through use of the large floor fans located at the National Research Council Climatic Engineering Facility. Initial investigation indicates that a 5 km/h wind speed can be established by locating the fans about 18 m from the test stand, and 20 km/h wind speed with the fans about 12 m from the stand. The use of two fans may provide a more standard flow over the width of the stand.

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

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

Fluids are to be heated to 60°C at time of pouring. Temperature and Brix values of fluids are to be measured at time of pouring. Fluids are to be applied using fluid spreaders designed for the purpose.

Trials will run until 30 minutes has past, or will terminate earlier if the plate surface is dry or is iced.

At test end, a final sketch of the pattern of surface wetting will be made, indicating any areas covered with frozen fluid. An estimate of percentage of area dry and bare will be recorded.

Thickness of fluid will be measured and recorded on the data sheet at the location measured.

Plate temperatures will be monitored throughout by means of mounted thermistors and loggers.

Brix values will be measured after five minutes at the 15 cm (6 in.), 30 cm (12 in.) and drip line.

At test end, Brix values will be measured for any fluid remaining on the surface. Location of Brix measurements are to include any area of the surface that is wetted, as well as the drip line.

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

The Spar/Cox and/or RVSI fluid contamination sensor camera will be used to supplement visual observations of fluid condition on test surfaces.

ATTACHMENT D-II

NATIONAL RESEARCH COUNCIL COLD CHAMBER TESTS

DEICING ONLY

TEST EQUIPMENT CHECKLIST

TASK	***NRC Cold Chamber***	
	Resp.	**Status**
Logistics for Every Test		
Rent Van/Car		
Call Site Personnel		
Test Equipment		
Special Stand x 1		
Still Photo Camera		
Video Camera X 1 (Surf & Snow) + Access		
Plates (wing nuts) X 6 (Standard)		
Data Forms for plates		
Reports + Tables		
Video Tapes		
Fluid spreaders		
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 x 20		
Tape for Thernistors		
Refractometer x 4		
Tie wraps		
Tags (Labels) for plate designation on stand		
2.0 Litre Containers		
Fan x 2		
Fluids: - UCAR ADF		
- Octagon Type I		
- Clariant Type II		
Thickness gauge		
1/2 litre thermos containers		
Wind gauge		
Vaisala RH Meter		
Cloths		
Heat guns X 2		
Isopropyl alcohol		
Tub for spreaders		
Plate for windshield		
New scrapers		
Special plates: - painted surfaces (aluminium) x 2		
- aluminium honey comb core		
- carbon fiber		
- kevlar		
- FAA supplied surface		
Cold soak boxes (7.5 cm) x 6		
Fluid collection system for stand		
Wet/dry vacuum		
Non-slip mats for beside stand		
Absorbent matting for floor		
Garden sprayer		
Snow shaker		
Scale (for weighing sprayer)		
Nitrogen bath		
Nitrogen supply		

ATTACHMENT D-III
PERSONNEL ASSIGNMENT

Overall Coordinator

- Assists team leaders of the *Deicing Only* trials and of the First Step Fluid trials as required; and
- Discusses and approves any changes to test procedures as determined necessary from test results or circumstances.

Team Leader

- Coordinates team member activities;
- Ensures experiments conducted in accordance with procedures;
- Advises Climatic Engineering Facility 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 and records fluid temperature and Brix at time of fluid application; and
- With plate observer, measures and records Brix values and thickness of any fluid remaining on test surfaces at end of test.

Fluids Manager

- 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 pouring accurate quantities of fluids when directed by team leader; and
- Ensures fluid temperature and Brix is measured at time of fluid application.

Plate Observer 1

- Responsible to monitor condition of plate surfaces and to alert other team members of change in condition;
- Record area of plate that is dry or wetted and area covered by ice at test end by sketching patterns and noting percentages; and
- Completes data form including record of fluid condition at time of application.

Photographer

- Responsible to photograph and videotape test setup, conduct of tests, and results on test surfaces;
- Ensure that final results of each test surface are captured on videotape and on still photographs;
- Responsible for setting up and ongoing operation of the Spar/Cox sensor. Ensure all test surfaces are included in image capture. Ensure that final results of each test surface are captured by sensor camera; and
- Assists team as directed by team leader.

ATTACHMENT D-IV

DATA FORM FOR *DEICING ONLY* TABLE TRIALS

REMEMBER TO SYNCHRONIZE TIME | VERSION 1.0 | 1997/98

LOCATION: CEF (Ottawa) | **DATE:** | **RUN NUMBER:** | **STAND # :** | **AMBIENT TEMPERATURE:** °C

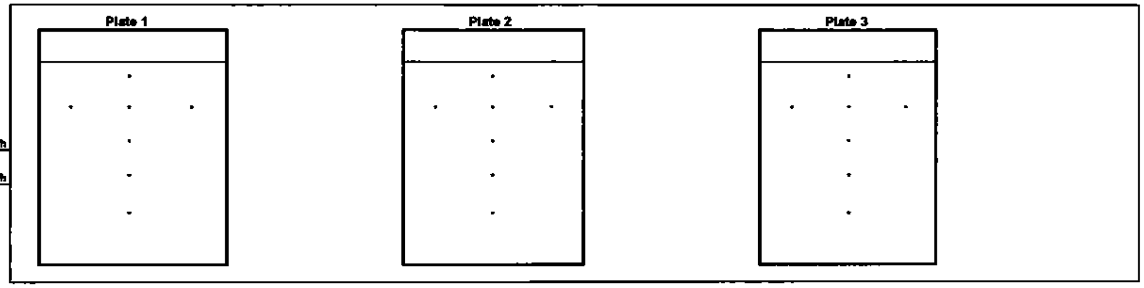
Fluid Application Time:	______	______	______	**Relative Humidity**
Fluid Temperature:	______	______	______	**Start:** ______ %
Fluid Brix:	______	______	______	**End:** ______ %

FLUID NAME

WIND SPEED:

Start: ______ km/h

End: ______ km/h



WIND SPEED:

Start: ______ km/h

End: ______ km/h

End Time ______ ______ ______

% Dry : 5/25/50/75/95/100 | 5/25/50/75/95/100 | 5/25/50/75/95/100

Plate 1

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

Plate 2

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

Plate 3

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

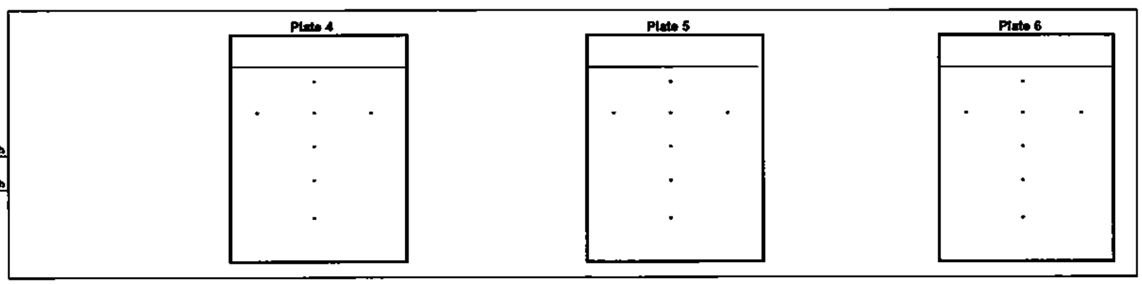
Fluid Application Time:	______	______	______
Fluid Temperature:	______	______	______
Fluid Brix:	______	______	______

FLUID NAME

WIND SPEED:

Start: ______ km/h

End: ______ km/h



WIND SPEED:

Start: ______ km/h

End: ______ km/h

End Time ______ ______ ______

% Dry : 5/25/50/75/95/100 | 5/25/50/75/95/100 | 5/25/50/75/95/100

Plate 4

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

Plate 5

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

Plate 6

5 Minutes	
Loc.	Brix
6"	
12"	
Drip	

Loc.	Thick.	Brix
1		
2		
3		
4		

Indicate location of Brix values and fluid thickness on plate diagrams

COMMENTS: ______________________________

HAND WRITTEN BY : ______________ **LEADER:** ______________

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ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 1
Temperature : -1 °C Wind: 0 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 2
Temperature : -1 °C Wind: 5 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Legend

U = UCAR Type I (Ethylene)
O = Octagon Type I (Propylene)
TOE = Type 0 (Recycled Fluid - Ethylene)
TOP = Type 0 (Recycled Fluid - Propylene)
U IV = UCAR Type IV (Ethylene)
O IV = Octagon Type IV (Propylene)

Fluid freeze points are indicated in brackets (ex. U (-1.5) = UCAR at -1.5° freeze point temperature)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 3
Temperature : -1°C Wind: 10 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 4
Temperature : -1°C Wind: 20 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 5
Temperature : -5°C   Wind: 0 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 6
Temperature : -5°C   Wind: 0 km/h

		U IV (-3)		O IV (-3)	
	TOP (-8) O (-8)		U (-8)		TOE (-8)

File:h:\cm1380\procedur\de_only\NRC_PLAN
At: -5C
6/12/2006

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 7
Temperature : -5°C Wind: 5 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 8
Temperature : -5°C Wind: 5 km/h

		U IV (-3)		O IV (-3)	
	TOP (-8) O (-8)		U (-8)		TOE (-8)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 9
Temperature : -5°C Wind: 10 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 10
Temperature : -5°C Wind: 10 km/h

		U IV (-3)		O IV (-3)	
	TOP (-8) O (-8)		U (-8)		TOE (-8)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 11
Temperature : -5°C Wind: 20 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 12
Temperature : -5°C Wind: 20 km/h

		U IV (-3)		O IV (-3)	
	TOP (-8) O (-8)		U (-8)		TOE (-8)

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At: -5C
6/12/2006

ATTACHMENT D-V

CEF DETAILED TEST PLAN

DEICING ONLY TABLE

Run # : 13
Temperature : -10°C Wind: 0 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 14
Temperature : -10°C Wind: 0 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-8)		TOE (-8) U IV (-3)

File:h:\cm1380\procedur\de_only\NRC_PLAN
At: -10C
6/12/2006

ATTACHMENT D-V

CEF DETAILED TEST PLAN

DEICING ONLY TABLE

Run # : 15

Temperature : -10°C Wind: 5 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 16

Temperature : -10°C Wind: 5 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-8)		TOE (-8) U IV (-3)

File:h:\cm1380\procedur\de_only\NRC_PLAN
At: -10C
6/12/2006

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 17
Temperature : -10°C Wind: 10 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 18
Temperature : -10°C Wind: 10 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-8)		TOE (-8) U IV (-3)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 19
Temperature : -10°C Wind: 20 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 20
Temperature : -10°C Wind: 20 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-8)		TOE (-8) U IV (-3)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 21
Temperature : -18°C   Wind: 0 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 22
Temperature : -18°C   Wind: 0 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-22)		TOE (-8) U (-8)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 23
Temperature : -18°C Wind: 5 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 24
Temperature : -18°C Wind: 5 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-22)		TOE (-8) U (-8)

ATTACHMENT D-V

CEF DETAILED TEST PLAN

DEICING ONLY TABLE

Run # : 25
Temperature : -18°C Wind: 10 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 26
Temperature : -18°C Wind: 10 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-22)		TOE (-8) U (-8)

File:h:\cm1380\procedur\de_only\NRC_PLAN
At: -18C
6/12/2006

ATTACHMENT D-V

CEF DETAILED TEST PLAN

DEICING ONLY TABLE

Run # : 27
Temperature : -18°C   Wind: 20 km/h

H_2O		U (-3)		O (-3)	
	TOP (-3)		U (-1.5)		TOE (-3)

Run # : 28
Temperature : -18°C   Wind: 20 km/h

		U (-14)		O (-8)	
	TOP (-8)		U (-22)		TOE (-8) U (-8)

ATTACHMENT D-V
CEF DETAILED TEST PLAN
DEICING ONLY TABLE

Run # : 29
Temperature : -35°C Wind: 0 km/h

H_2O		U (-1.5)		U(-22)	
			U (-43)		U(-30)

Run # : 30
Temperature : -35°C Wind: 5 km/h

H_2O		U (-1.5)		U(-22)	
			U (-43)		U(-30)

APPENDIX E

EXPERIMENTAL PROGRAM
LABORATORY TESTS TO DETERMINE
FIRST-STEP FLUID TEMPERATURE LIMITS

Winter 1997-98

CM1380.001

EXPERIMENTAL PROGRAM
LABORATORY TRIALS TO DETERMINE
FIRST STEP FLUID TEMPERATURE LIMITS

Winter 1997/98

APS AVIATION INC. APS

February 5, 1998
Version 2.0

EXPERIMENTAL PROGRAM
LABORATORY TRIALS TO DETERMINE
FIRST STEP FLUID TEMPERATURE LIMITS
Winter 1997/98

APS will conduct a series of tests on flat plates and\or cold-soaked boxes at the National Research Council Climatic Engineering Facility, and on aircraft at Montreal International Airport (Dorval). This document provides the detailed procedures and equipment required for the conduct of tests at the National Research Council Climatic Engineering Facility. The experimental program for aircraft testing is contained in a separate document.

1. OBJECTIVES

This project addresses the following objectives:

- To determine the limits for negative freeze point buffers for fluids used as the first step fluid in a two-step deicing procedure; and
- Current guidelines in SAE ARP4737 state that the freeze point of the first step fluid shall be not more than 3°C above outside air temperature. These tests will determine whether application of heated fluids having freeze points greater than 3°C above outside air temperature will provide an interval of five minutes or more before freezing when applied during a condition of freezing precipitation.

2. TEST REQUIREMENTS

APS will conduct a preliminary series of tests on flat plates and cold-soaked boxes to determine the most suitable test surface for full trials at the National Research Council Climatic Engineering Facility.

2.1 Tests at the National Research Council Climatic Engineering Facility

Tests at the National Research Council Climatic Engineering Facility will be scheduled over a one week period. Test variables will include air temperature, freezing precipitation (light freezing rain) and heated fluids of various types at different concentrations, as well as hot water. The fluid concentrations to be tested will be selected to provide data points at several values of negative freeze point buffers for each ambient temperature tested. Hot water will be tested at all temperature conditions. Wind conditions will not be tested due to physical limitations of the test chamber equipment.

The influence of wind will be examined in the *Deicing Only* trials, and extrapolated to results of these tests. An attempt will be made to evaluate accuracy of these extrapolations by a later test combining wind and precipitation on a single test plate.

The outcome of each test will be the documentation of the elapsed time until the fluid freezes. The goal is to identify fluid concentrations that will provide an elapsed time of at least five minutes. Tests will be allowed to run to complete failure, to provide data points for analysis.

Data collected will include progressive tracking of plate surface temperature as measured by installed thermistors. Conduct and results of the tests will be recorded by still photography and video footage, and by Spar/Cox camera images.

Attachment E-I provides a detailed test procedure.

3. EQUIPMENT AND FLUIDS

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

For the First Step Fluid Buffer tests, test fluids will include SAE Types I, II, and IV with representation of both ethylene and propylene based fluids.

4. TEST PLAN

A test matrix of fluid types and concentrations, ambient temperatures and wind speeds is shown in Figure E-1.

A detailed test plan is provided in Attachment E-VII.

5. PERSONNEL

A team of four personnel is required to conduct tests at the National Research Council Climatic Engineering Facility. Duties of each team member is shown in Attachment E-III.

FIGURE E-1

FIRST STEP FLUID TRIALS

GENERAL TEST PLAN

OAT (°C)	Rate ($g/dm^2/h$)	FLUID FREEZE POINTS					
-3	25	0					
-8	25	0	-3(1)	-6(1)			
-14	25	0	-3	-6(1)	-11		
-25	12.7	0	-3		-11	-17	-22

Precipitation Type: Light Freezing Rain

Heated Fluids: Water

Type I (Including representation of both ethylene and propylene based)

Type II (Including representation of both ethylene and propylene based)

Type IV (Including representation of both ethylene and propylene based)

(1) Type I ethylene will be tested at all cells showing freeze point values.

Other fluids will be tested in cells indicated by (1).

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At: Plan
6/12/2006

6. DATA FORMS

The following data forms are required:

- Attachment E-IV — Data form for First Step Fluid Trials;
- Attachment E-V — Precipitation Rate Measurement at the National Research Council Climatic Engineering Facility; and
- Attachment E-VI — Continuous Precipitation Rate Measurement

ATTACHMENT E-I
DETERMINE FIRST STEP FLUID TEMPERATURE LIMITS
TEST PROCEDURE

Tests at the National Research Council Climatic Engineering Facility.

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 but mark gradations on edge of plates.

Prepare fluid mixes in advance

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 produced by new spray unit;
- Set up equipment for test support, including fluid heating equipment; and
- Install thermistor system and confirm operation of thermistors and temperature loggers.

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 60°C at time of pouring. Temperature and Brix values of fluids are to be measured at time of pouring. Fluids are to be applied using fluid spreaders designed for the purpose.

Tests will be run until complete plate failure, and times recorded.

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

The Spar/Cox and/or RVSI fluid contamination sensor camera will be used to supplement visual observations of fluid condition on test surfaces.

Temperature of test surfaces will be allowed to return to ambient laboratory temperature prior to proceeding with the next test.

ATTACHMENT E-II

NATIONAL RESEARCH COUNCIL COLD CHAMBER TESTS

FIRST STEP FLUID

TEST EQUIPMENT CHECKLIST

TASK	***NRC Cold Chamber***	
	Resp.	**Status**
Logistics for Every Test		
Make Hotel reservations		
Rent Van/Car		
Call Site Personnel		
Call RVSI Personnel		
Call Spar/Cox Personnel		
Test Equipment		
Stand x 1		
Still Photo Camera		
Tape Recorder with Mic.(voice)		
Weigh Scale		
Stand Video Camera		
Pole for Video Camera		
Video Camera X 1 (Surf & Snow) + Access		
Plates (wing nuts) X 12+12*		
Data Forms		
Precipitation rate Data Forms		
Reports + Tables		
Cake Pans x 12		
Video Tapes		
Type I Fluids		
Type II Fluids, Type IV 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		
Putty for Thermistors		
Protective clothing		
Refractometer		
Tie wraps		
Tags (Labels) for Fluid designation on stand		
2.0 Litre Containers		
Fluid heating apparatus		
Thermos containers		
Wet/dry shop vaccum		

* Type of plate TBD

ATTACHMENT E-III
PERSONNEL ASSIGNMENT

Team Leader

- Coordinates team member activities;
- Ensures experiments conducted in accordance with procedures;
- Advises Climatic Engineering Facility 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 calibration of sprinkler system;
- Directs measurement of precipitation rates; and
- Assists in fluid application by positioning fluid spreader for fluid application, and measuring fluid temperature and Brix at time of fluid application.

Fluids Manager

- 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 pouring accurate quantities of fluids when directed by team leader; and
- Ensures fluid temperature and Brix is measured at time of fluid application.

Plate Observer 1

- Responsible to monitor condition of plate surfaces for fluid freezing, and to alert other team members of change in condition;
- Record condition of fluid on test plate at specified times. Note time and location of any freezing and percentage of surface affected; and
- Complete data form including record of fluid condition at time of application.

Photographer

- Responsible to photograph and videotape test setup, conduct of tests, and results on test surfaces;
- Ensure that final results of each test surface are captured on videotape and on still photographs; and
- Coordinate use of Spar/Cox and/or RVSI sensor with team conducting deicing only experiment. Specific tests having significant results as decided by the team leader or overall coordinator will be scanned and documented.

ATTACHMENT E-IV

DATA FORM FOR FIRST STEP FLUID TRIALS (LIGHT FREEZING RAIN)

REMEMBER TO SYNCHRONIZE TIME VERSION 1.0 VERSION 1.0 1997/98

LOCATION: CEF (Ottawa) DATE: RUN NUMBER: AMBIENT TEMPERATURE: °C STAND # :

Fluid Application Time: ______ ______ ______

Fluid Temperature: ______ ______ ______

Fluid Brix: ______ ______ ______

FLUID NAME

Plate 8 Plate 9 Plate 10

Time to 1st Freezing: ______ ______ ______

Time to Failure (6" Line): ______ ______ ______

Time to complete Failure (15" Line): ______ ______ ______

Fluid Application Time: ______ ______ ______

Fluid Temperature: ______ ______ ______

Fluid Brix: ______ ______ ______

FLUID NAME

Plate 11 Plate 12 Plate 13

Time to 1st Freezing: ______ ______ ______

Time to Failure (6" Line): ______ ______ ______

Time to complete Failure (15" Line): ______ ______ ______

COMMENTS:

HAND WRITTTEN BY : ______ LEADER: ______

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ATTACHMENT E-V

PRECIPITATION RATE MEASUREMENT AT CEF IN OTTAWA

Date: ____________________

Start Time: ____________________ am/pm

Run # : ____________________

Precip Type: ____________________ (FZD, FZR, FZF, S)

Pan Location:

U	UU	V	VV	W	WW
XX	X	YY	Y	ZZ	Z

Collection Pan:

Pan/ Cup #	Area of Pan (dm²)	Location		Weight of Pan (g) Before	Weight of Pan (g) After	Collection Time (min) Start	Collection Time (min) End
		U	=				
		UU	=				
		V	=				
		VV	=				
		W	=				
		WW	=				
		XX	=				
		X	=				
		YY	=				
		Y	=				
		ZZ	=				
		Z	=				

Comments: ____________________

Handwritten by: ____________________

Measured by: ____________________

ATTACHMENT E-VI

CONTINUOUS PRECIPITATION RATE MEASUREMENT @ CEF IN OTTAWA

Date: ______________________

Start Time: ______________________ am/pm

Run # : ______________________

Stand: ______________________

Precip Type: ______________________ (FZD, FZR, FZF, S, CS)

Pan Location:

U	UU	V	VV	W	WW
XX	X	YY	Y	ZZ	Z

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							
1							
2							
1							
2							

Comments: ____

____

____

____

Handwritten by: ______________________

Measured by: ______________________

Precipitation Rate = Δg/area (dm²)/h

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6/12/2000

ATTACHMENT E-VII
CEF DETAILED TEST PLAN
FIRST STEP FLUID TRIALS

Run # : 1
Temperature : -3°C

Rate: 25 g/dm²/h

H_2O		H_2O			**RATE**
RATE					

Legend

U I = UCAR Type I (Ethylene)
U IV = UCAR Type IV (Ethylene)
O I = Octagon Type I (Propylene)
O II = Octagon Type II (Propylene)
O IV = Octagon Type IV (Propylene)
H II = Hoechst Type II (Propylene)
TOE = Type 0 (Recycled Fluid - Ethylene)
TOP = Type 0 (Recycled Fluid - Propylene)

Fluid freeze points are indicated in brackets (ex. U I (-3) = UCAR Type I at -3° freeze point temperatu

ATTACHMENT E-VII

CEF DETAILED TEST PLAN

FIRST STEP FLUID TRIALS

Run # : 2 Rate: 25 g/dm^2/h
Temperature : -8°C

H_2O		U IV (-3)		O IV (-3)	**RATE**
RATE	U I (-3)		O I (-3)		O II (-3)

Run # : 3 Rate: 25 g/dm^2/h
Temperature : -8°C

		U IV (-6)		O IV (-6)	**RATE**
RATE	U I (-6)		O I (-6)		O II (-6)

Run # : 4 Rate: 25 g/dm^2/h
Temperature : -8°C

		TOE (-3)		H II (-3)	**RATE**
RATE	TOE (-3)		TOP (-3)		TOP (-3)

ATTACHMENT E-VII
CEF DETAILED TEST PLAN
FIRST STEP FLUID TRIALS

Run # : 5 Rate: 25 g/dm^2/h
Temperature : -14°C

H_2O		U I (-6)		O IV (-6)	**RATE**
RATE	U I (-3)		O I (-6)		O II (-6)

Run # : 6 Rate: 25 g/dm^2/h
Temperature : -14°C

		U IV (-6)		H II (-6)	**RATE**
RATE	U I (-11) TOE (-6)		TOP (-6)		

ATTACHMENT E-VII
CEF DETAILED TEST PLAN
FIRST STEP FLUID TRIALS

Run # : 7
Temperature : -25°C

Rate: 12.7 $g/dm^2/h$

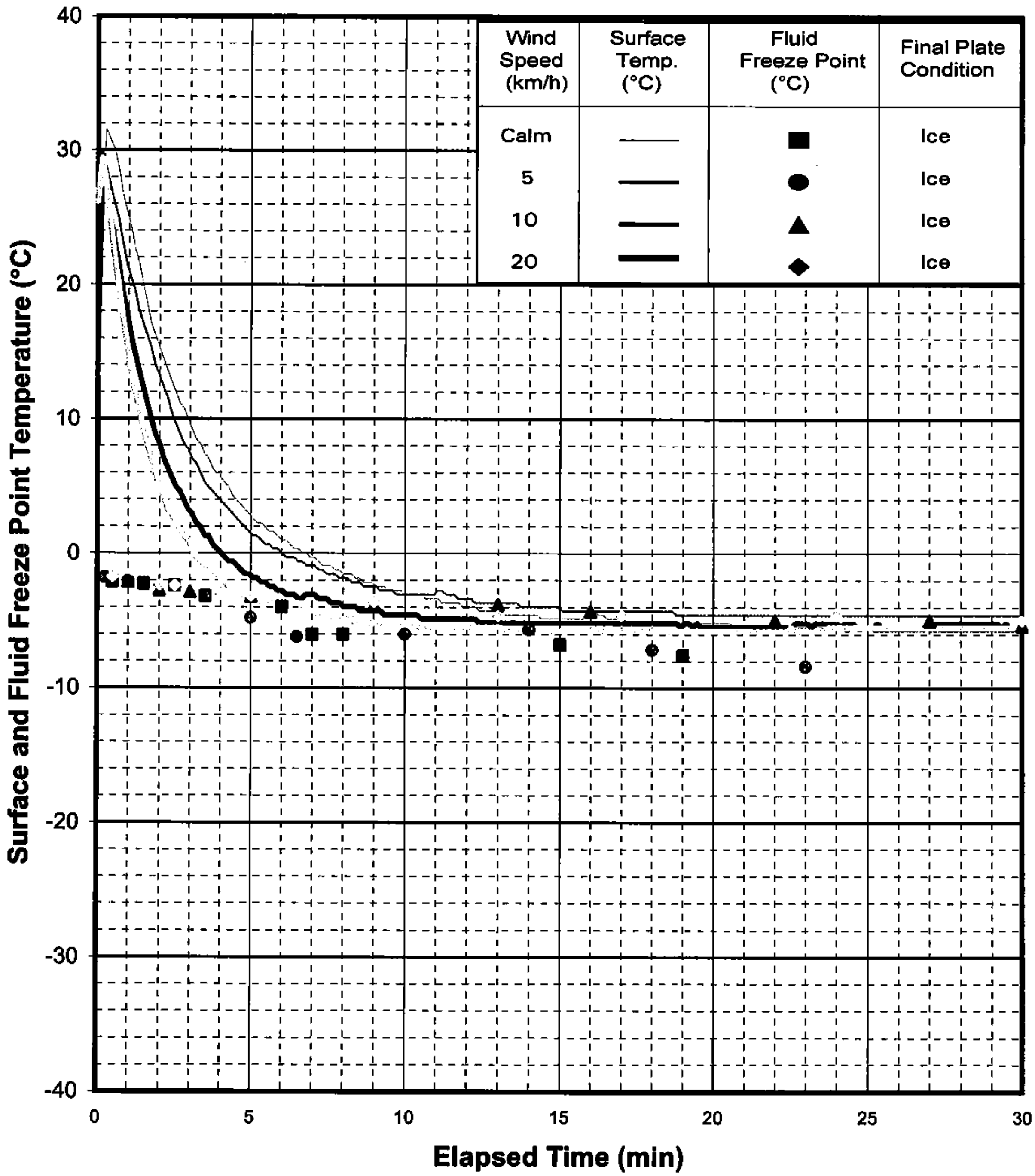
H_2O		U I (-3) U I (-17)		O I (-3)	**RATE**
RATE	U I (-11) U I (-22)				

File:h:\cm1380\procedur\firststp\NRC_FSTP
At: -25
6/12/2006

APPENDIX F

FLUID STRENGTH PROFILES - *DEICING ONLY* TESTS

Fluid Freeze Point and Surface Temperature Profile, U1 (-2), OAT = -5°C



cm1380\analysis\de_only\UCAR-5
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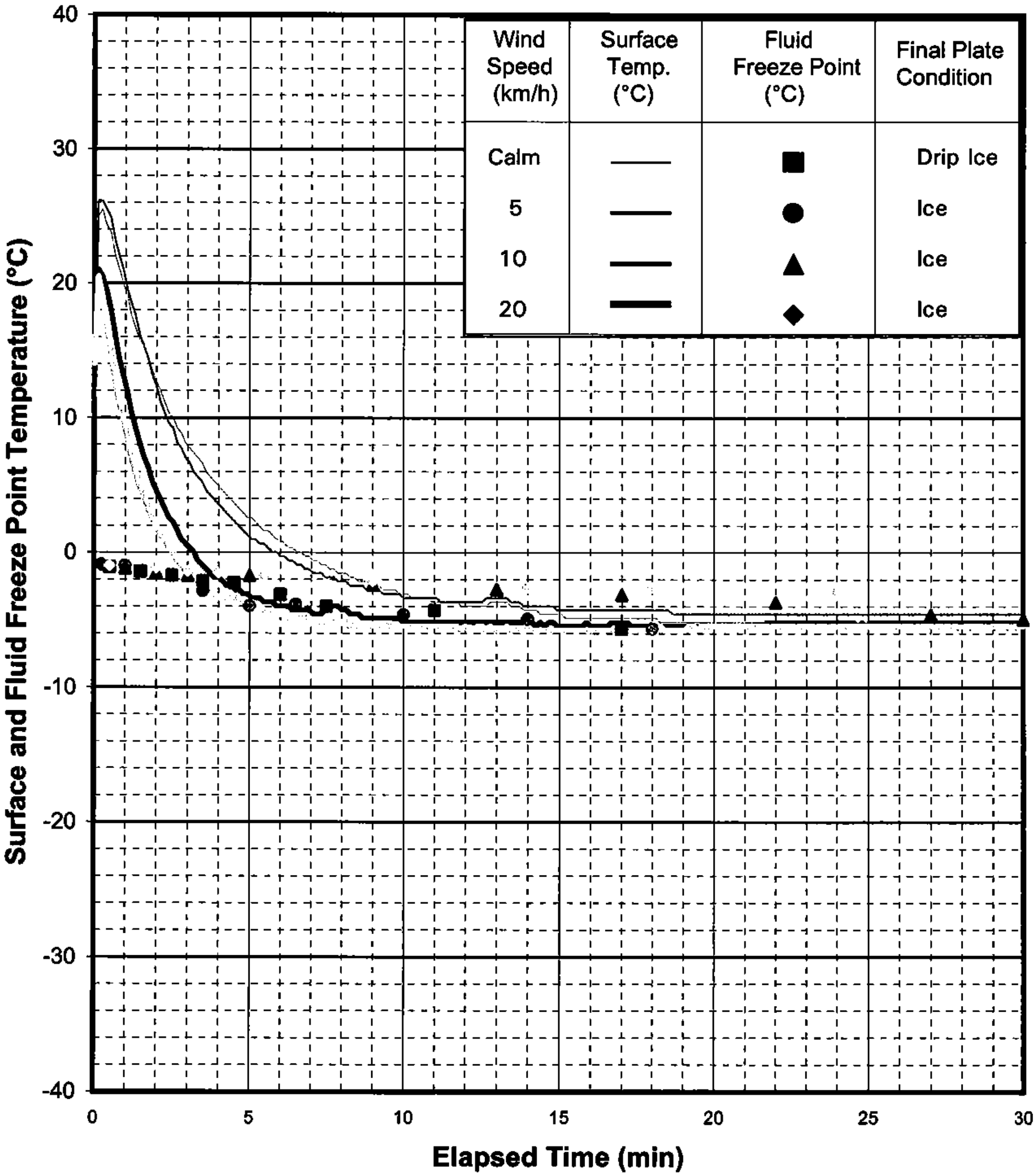
Fluid Freeze Point and Surface Temperature Profile, O1 (-1.5), OAT = -5°C



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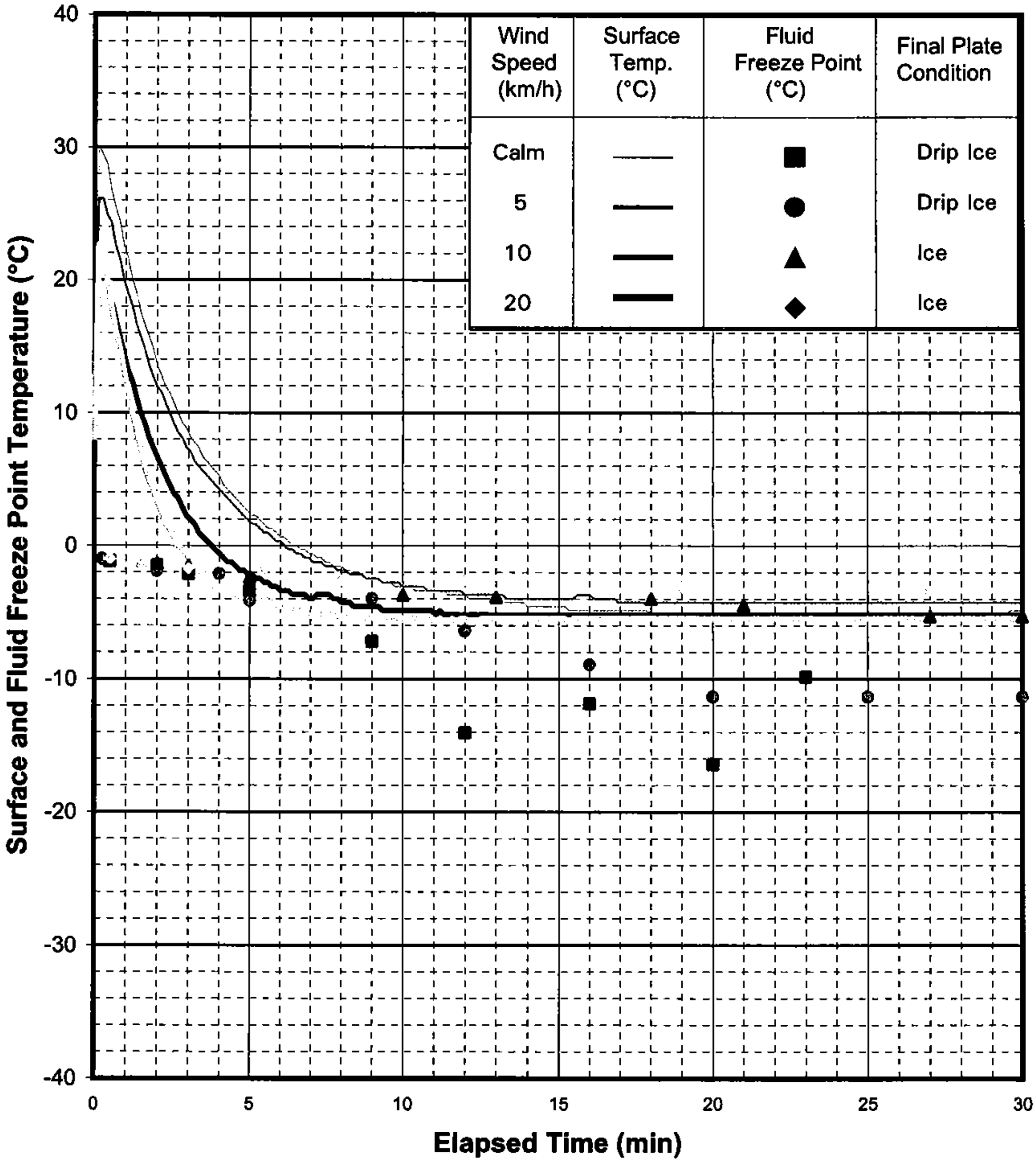
Fluid Freeze Point and Surface Temperature Profile, K II (-1.5), OAT = -5°C



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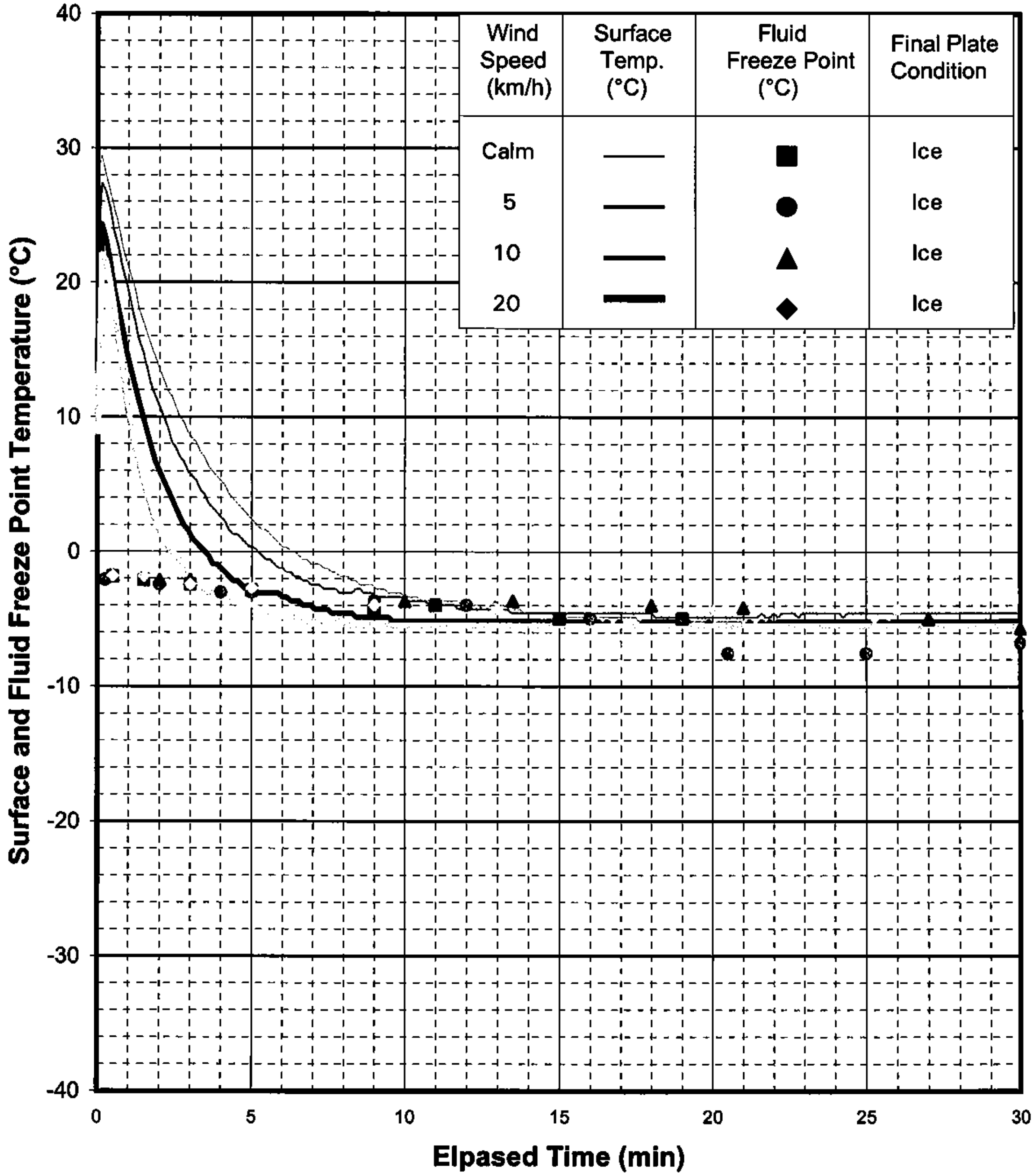
Fluid Freeze Point and Surface Temperature Profile, U IV (-2), OAT = -5°C



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At: -5°C
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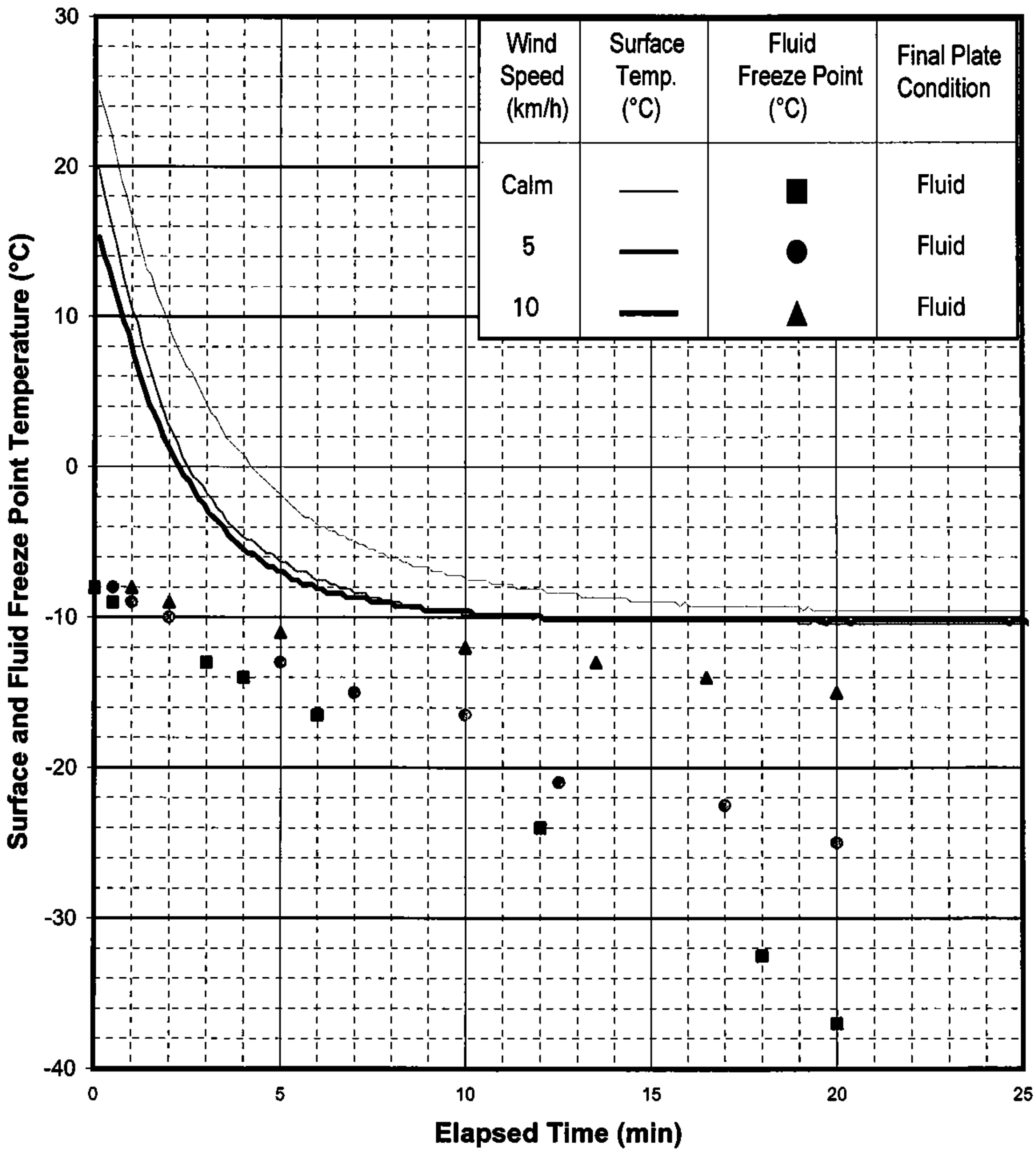
Fluid Freeze Point and Surface Temperature Profile, U1 (-8), OAT = -10°C



cm1380\analysis\de_only\FRZ_UCAR
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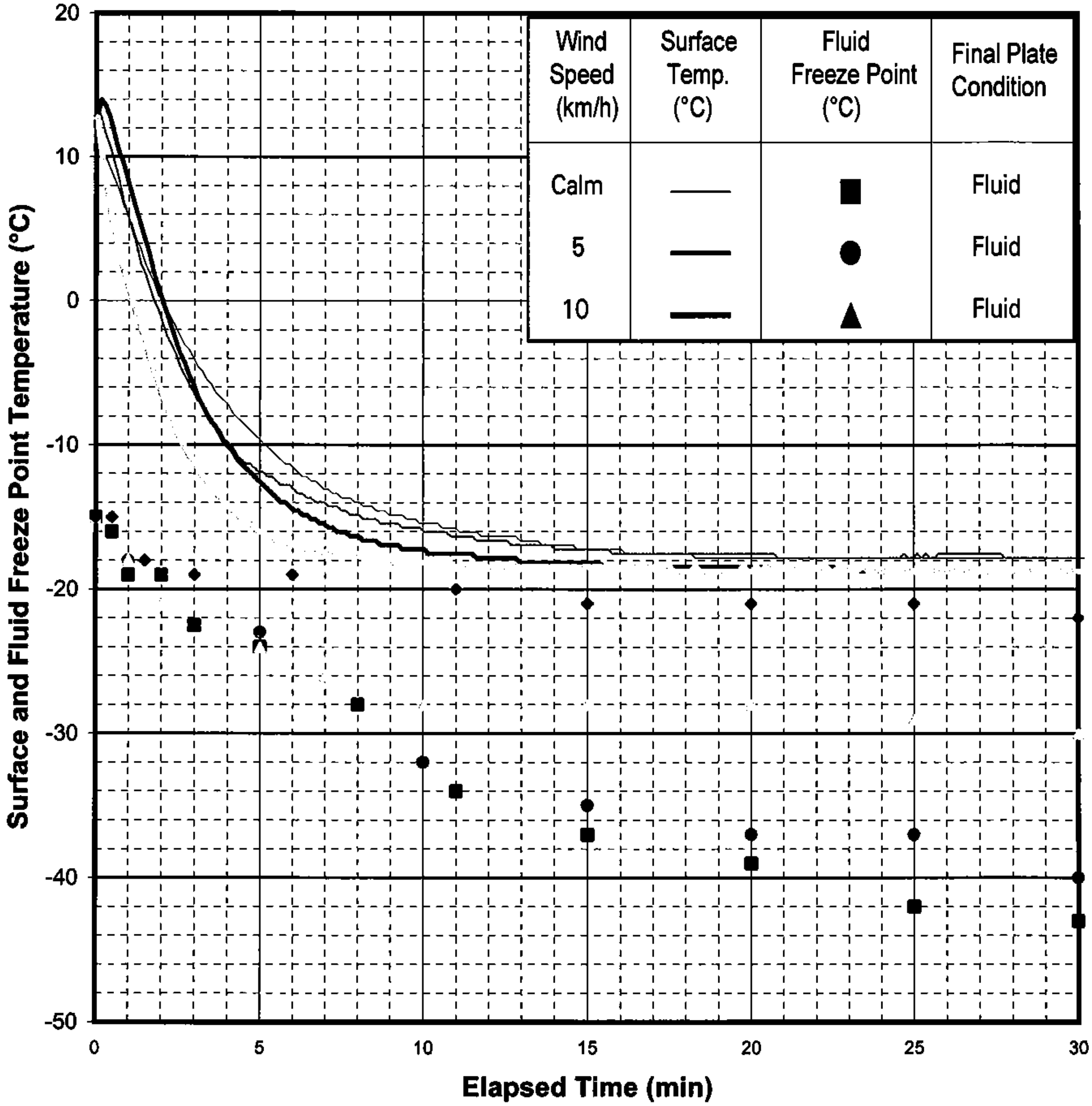
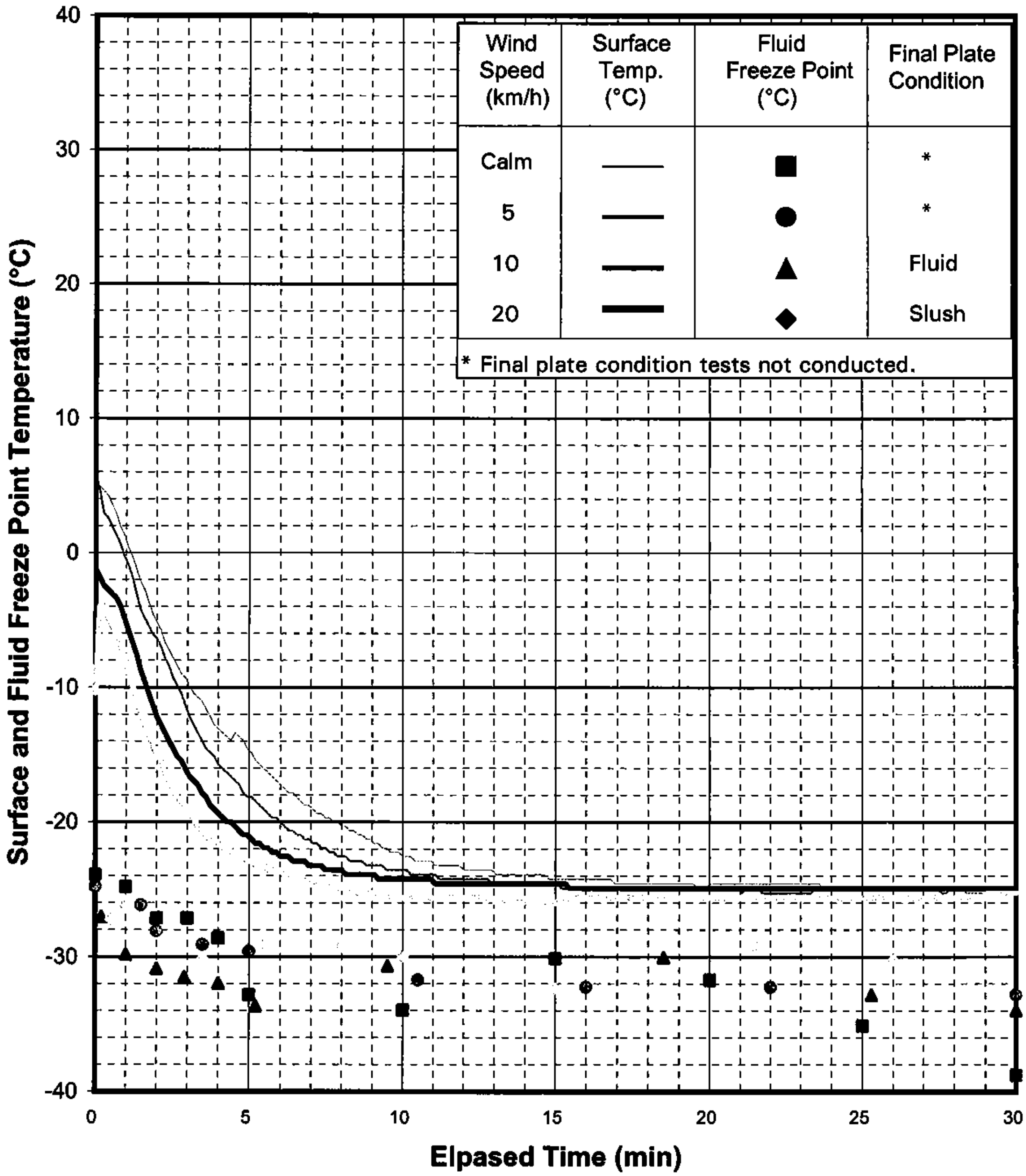
Fluid Freeze Point and Surface Temperature Profile, U1 (-14), OAT = -18°C

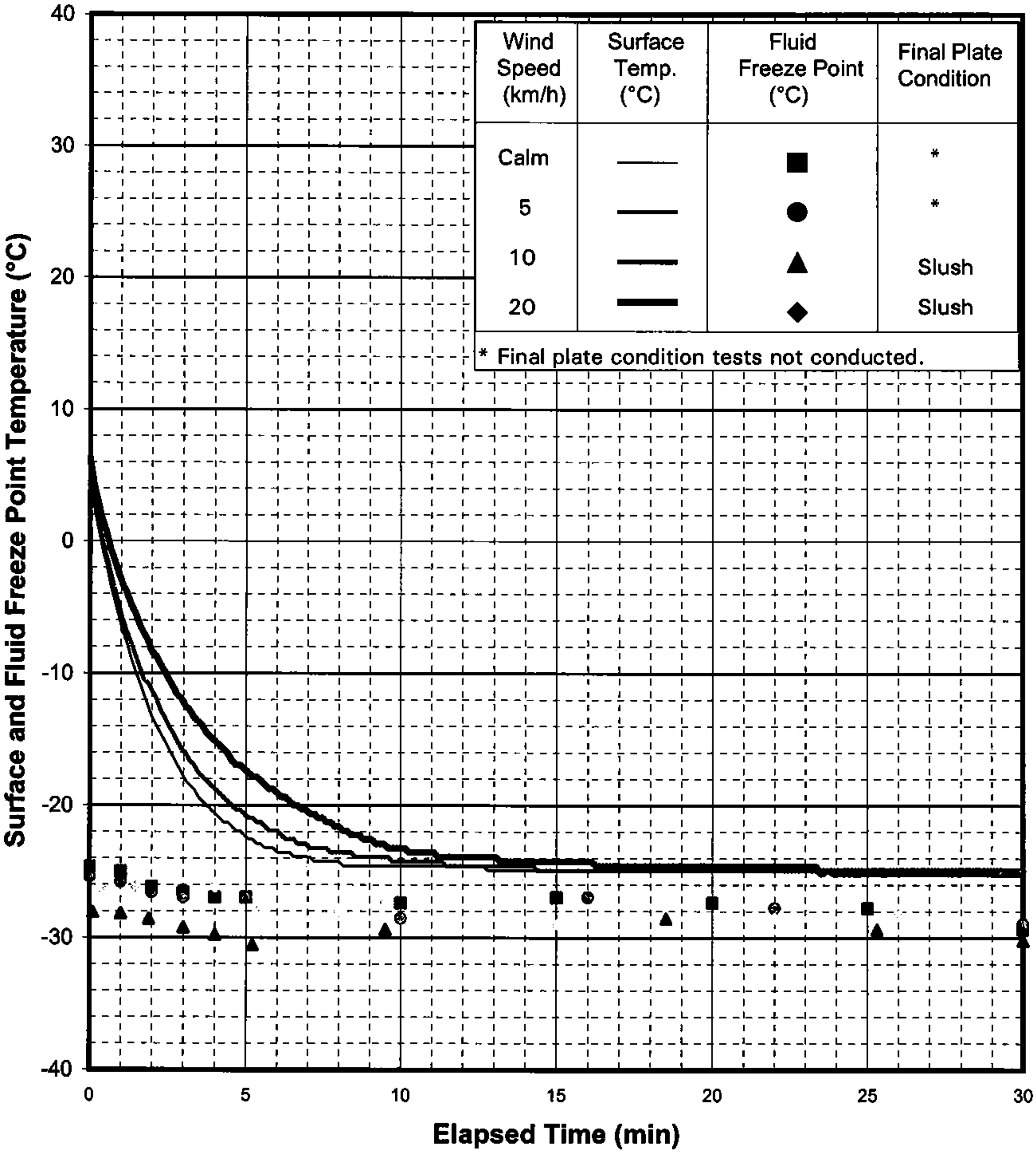


File:g:\cm1380\analysis\de_only\FRZ_UCA2
Printed: 6/12/2006 , 3:40 PM

Fluid Freeze Point and Surface Temperature Profile, U1 (-22), OAT = -25°C



Fluid Freeze Point and Surface Temperature Profile, O1 (-20), OAT = -25°C



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At: -25°C
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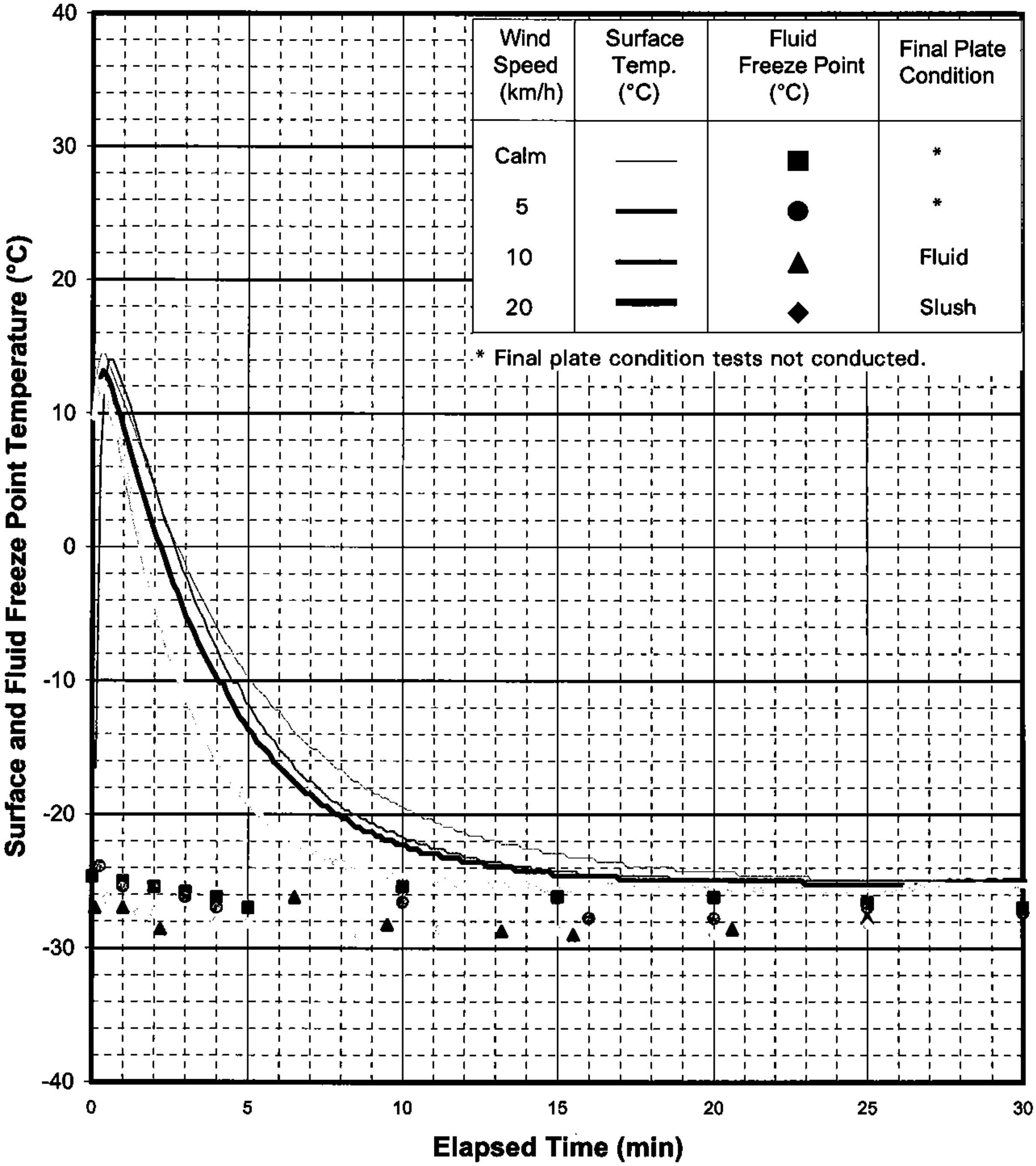
Fluid Freeze Point and Surface Temperature Profile, K II (-21), OAT = -25°C



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AI: -25°C
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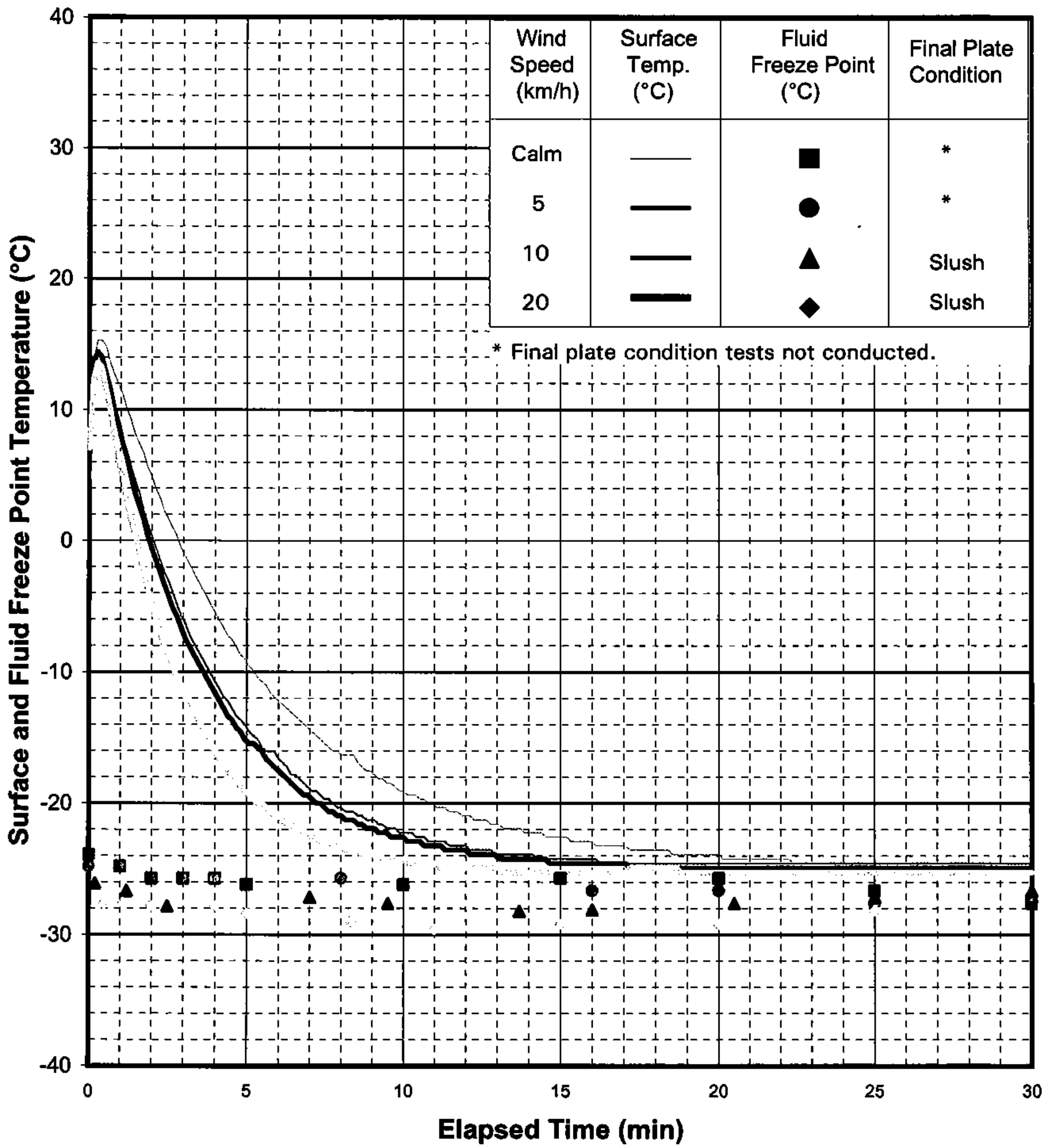
Fluid Freeze Point and Surface Temperature Profile, U IV (-22), OAT = -25°C



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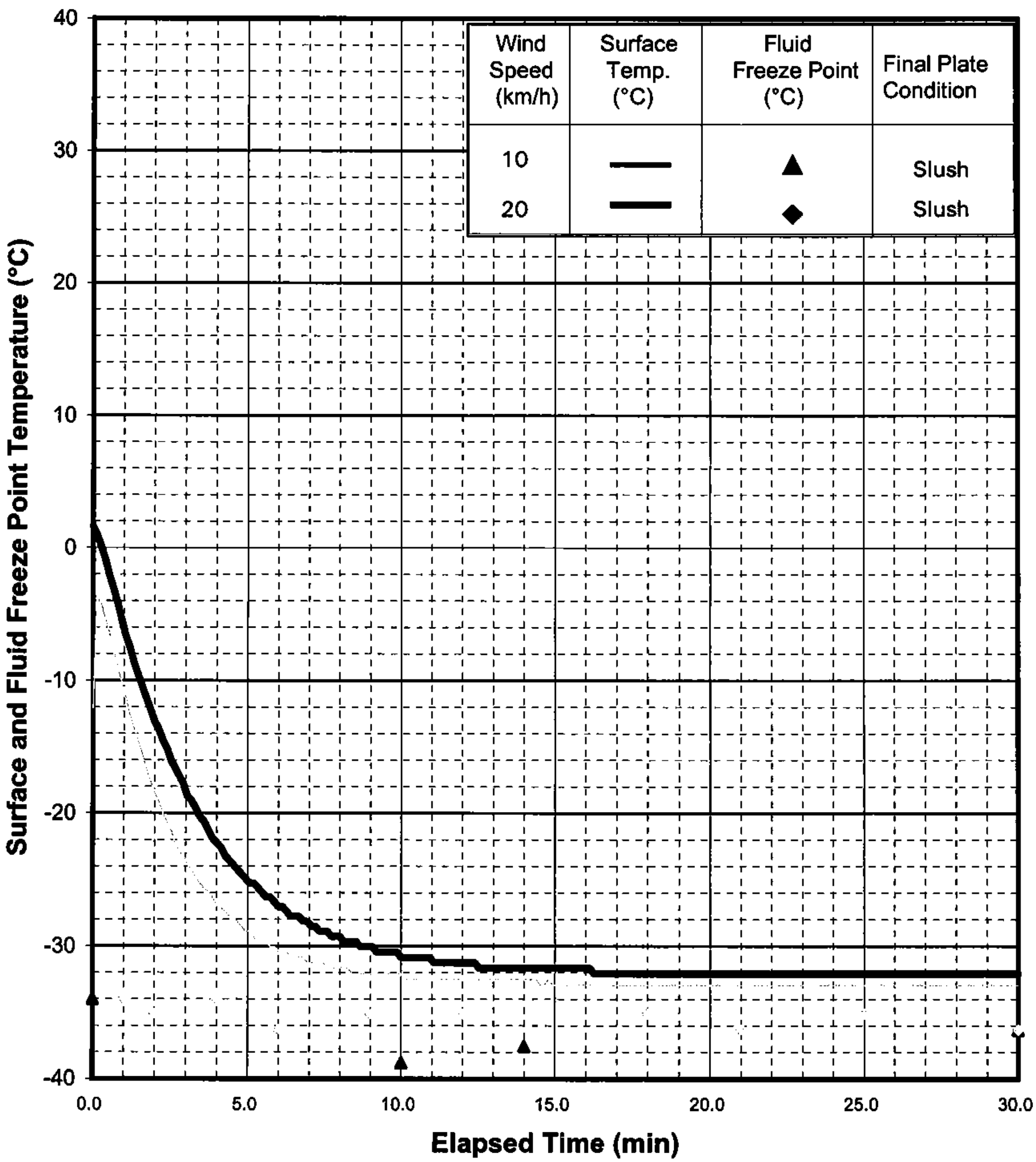
Fluid Freeze Point and Surface Temperature Profile, U1 (-30), OAT = -33°C



File:g:\cm1380\anal\de_only\UCAR-35
At: -35°C
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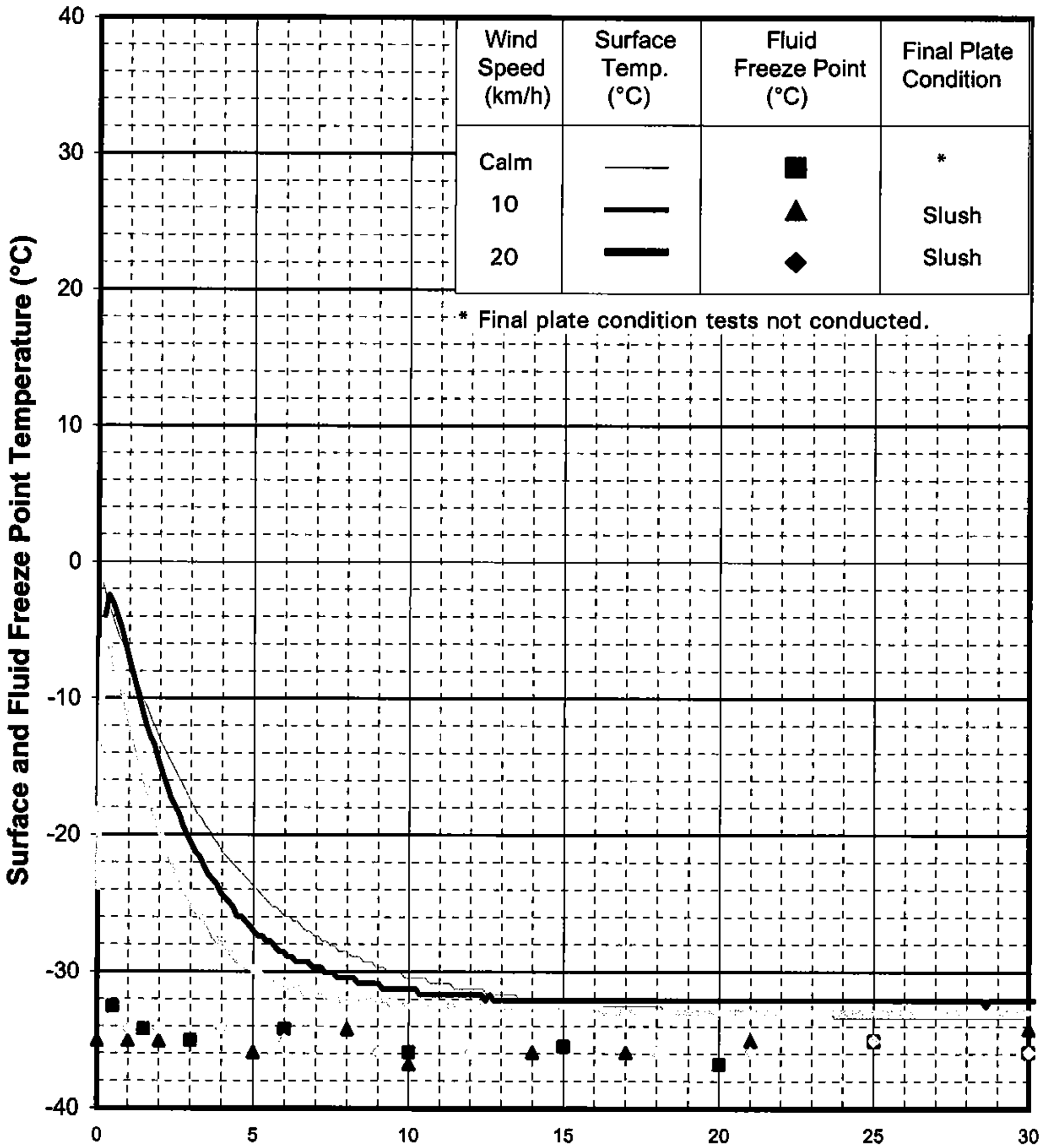
Fluid Freeze Point and Surface Temperature Profile, O1 (-26), OAT = -33°C



Wind Speed (km/h)	Surface Temp. (°C)	Fluid Freeze Point (°C)	Final Plate Condition
Calm	——	■	*
10	——	▲	Slush
20	——	◆	Slush

* Final plate condition tests not conducted.

Fluid Freeze Point data adjusted to reflect initial -3°C buffer

File:g:\cm1380\analysis\de_only\OCT1-35
At: -33°C
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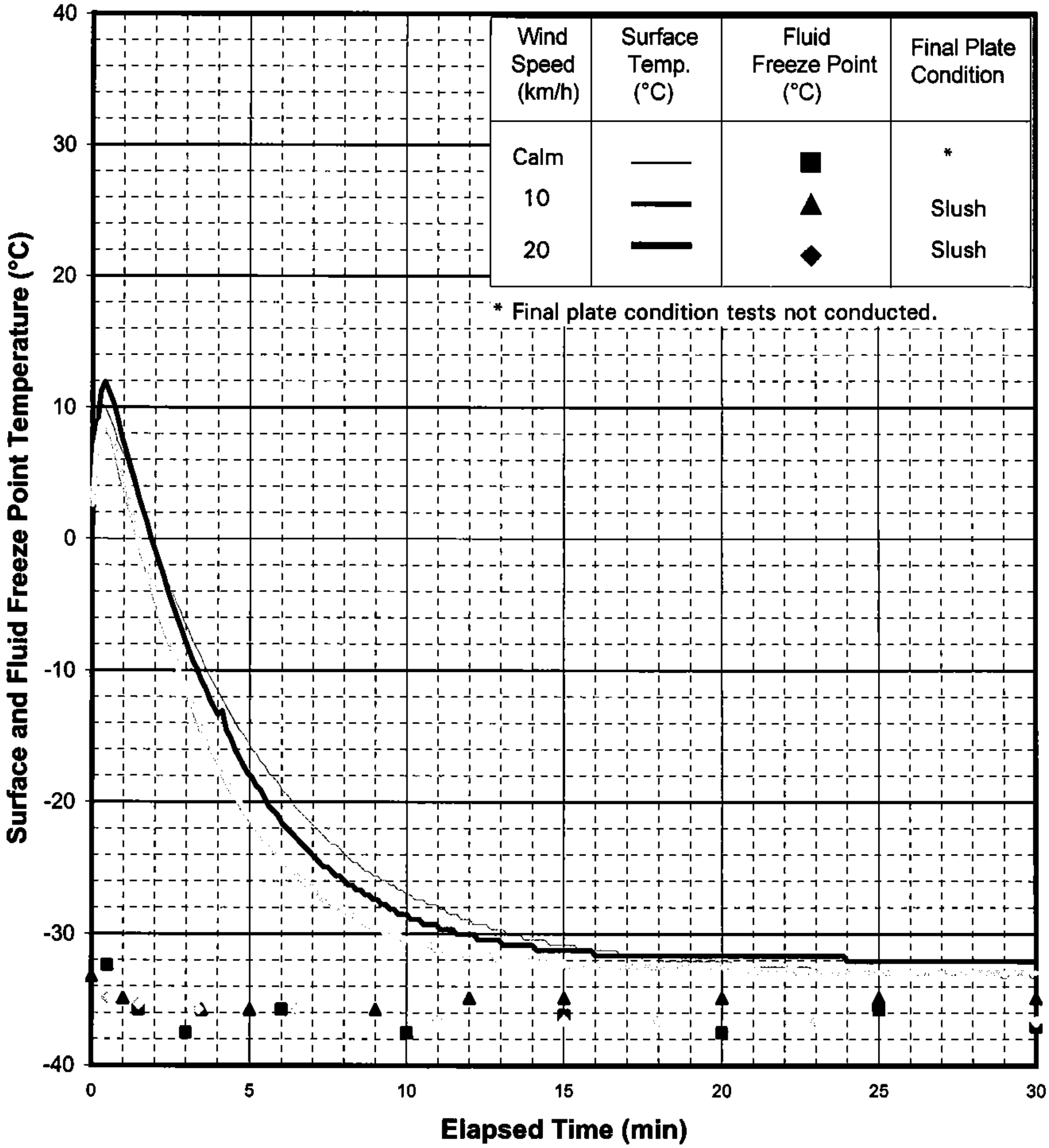
Fluid Freeze Point and Surface Temperature Profile, K II (-27), OAT = -33°C



Fluid Freeze Point data adjusted to reflect initial -3°C buffer

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At: -33°C
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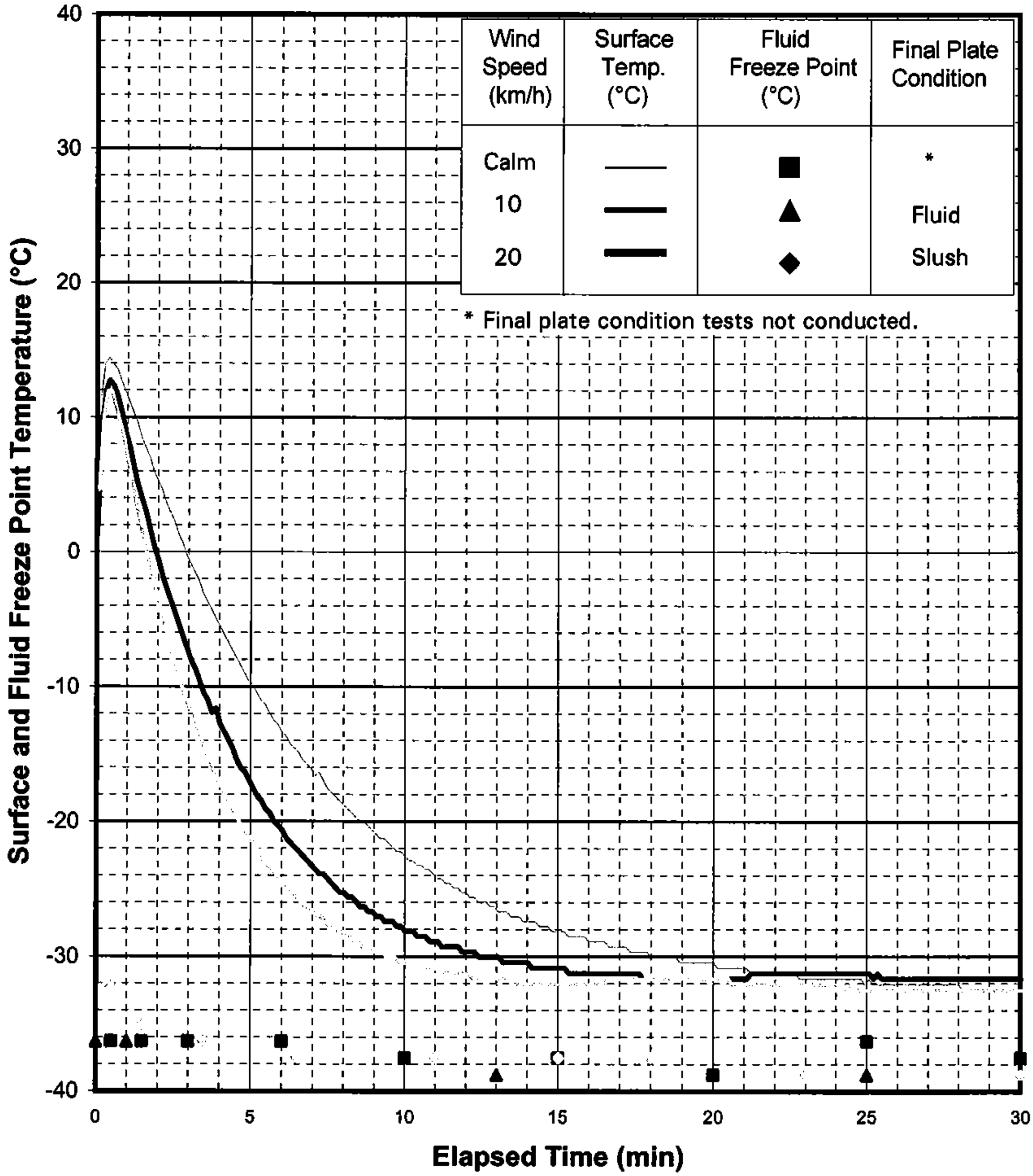
Fluid Freeze Point and Surface Temperature Profile, U IV (-30), OAT = -33°C



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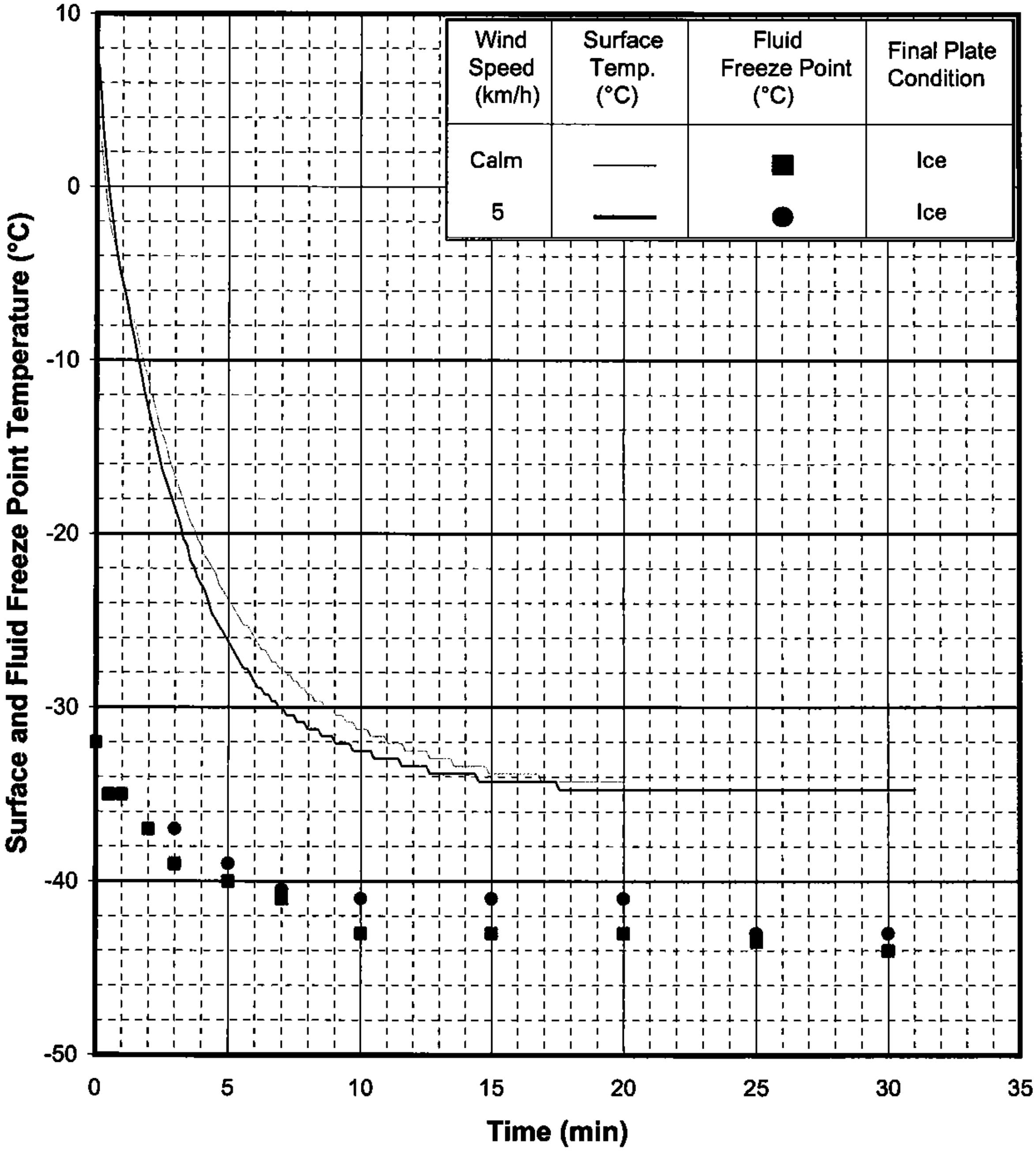
Fluid Freeze Point and Surface Temperature Profile, U1 (-30), OAT = -33°C



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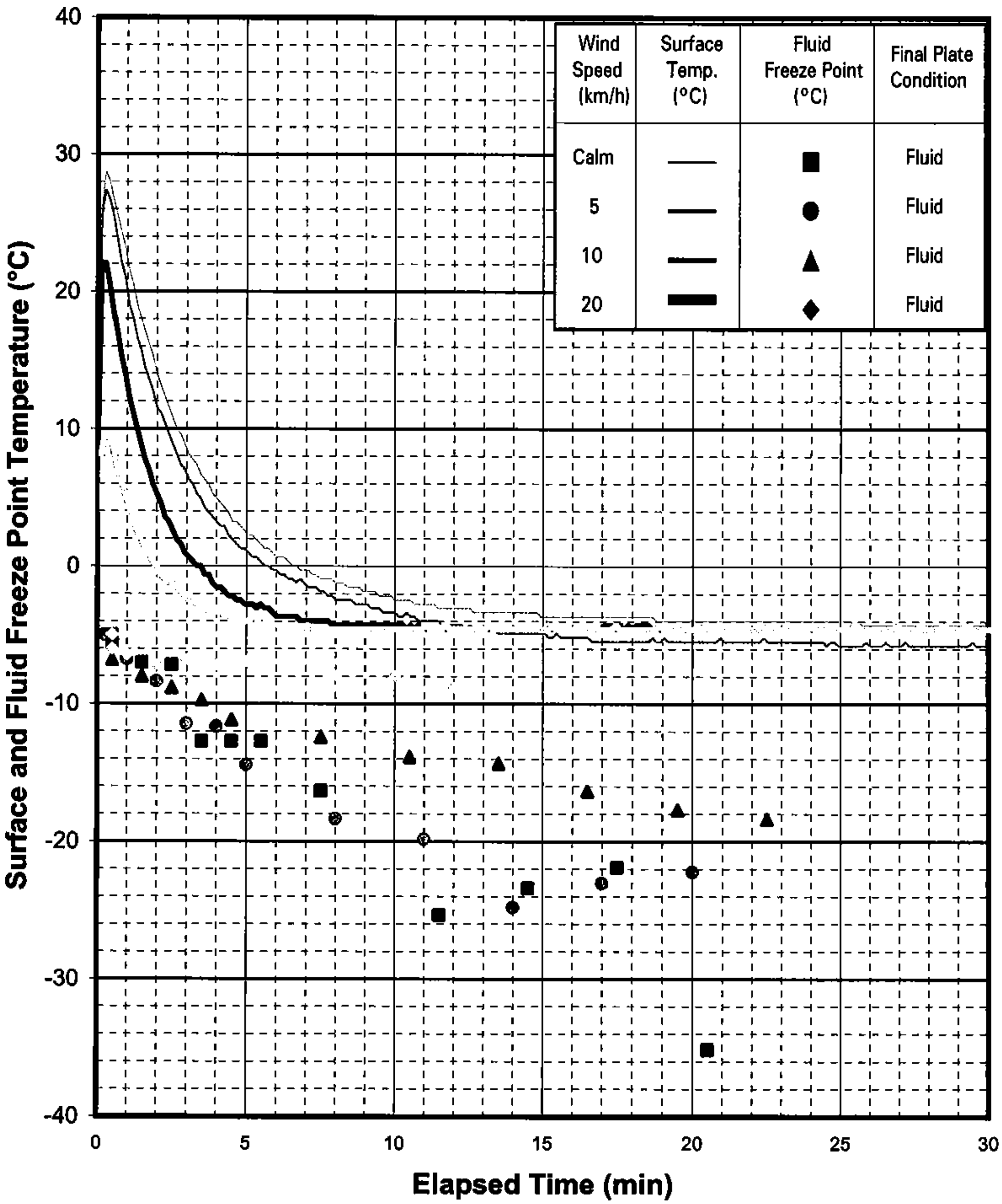
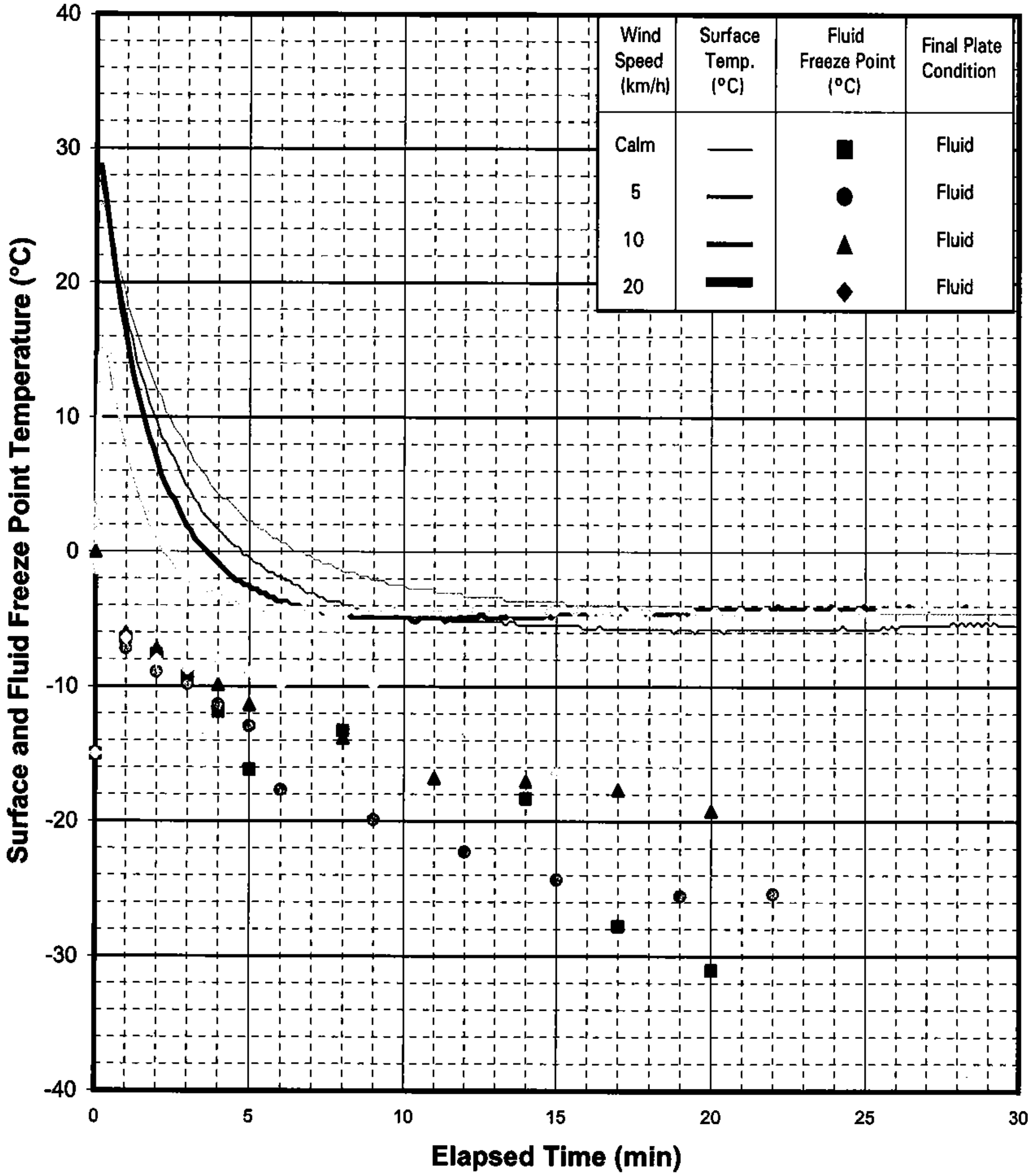
Fluid Freeze Point and Surface Temperature Profile, U1 (-5), OAT = -5°C

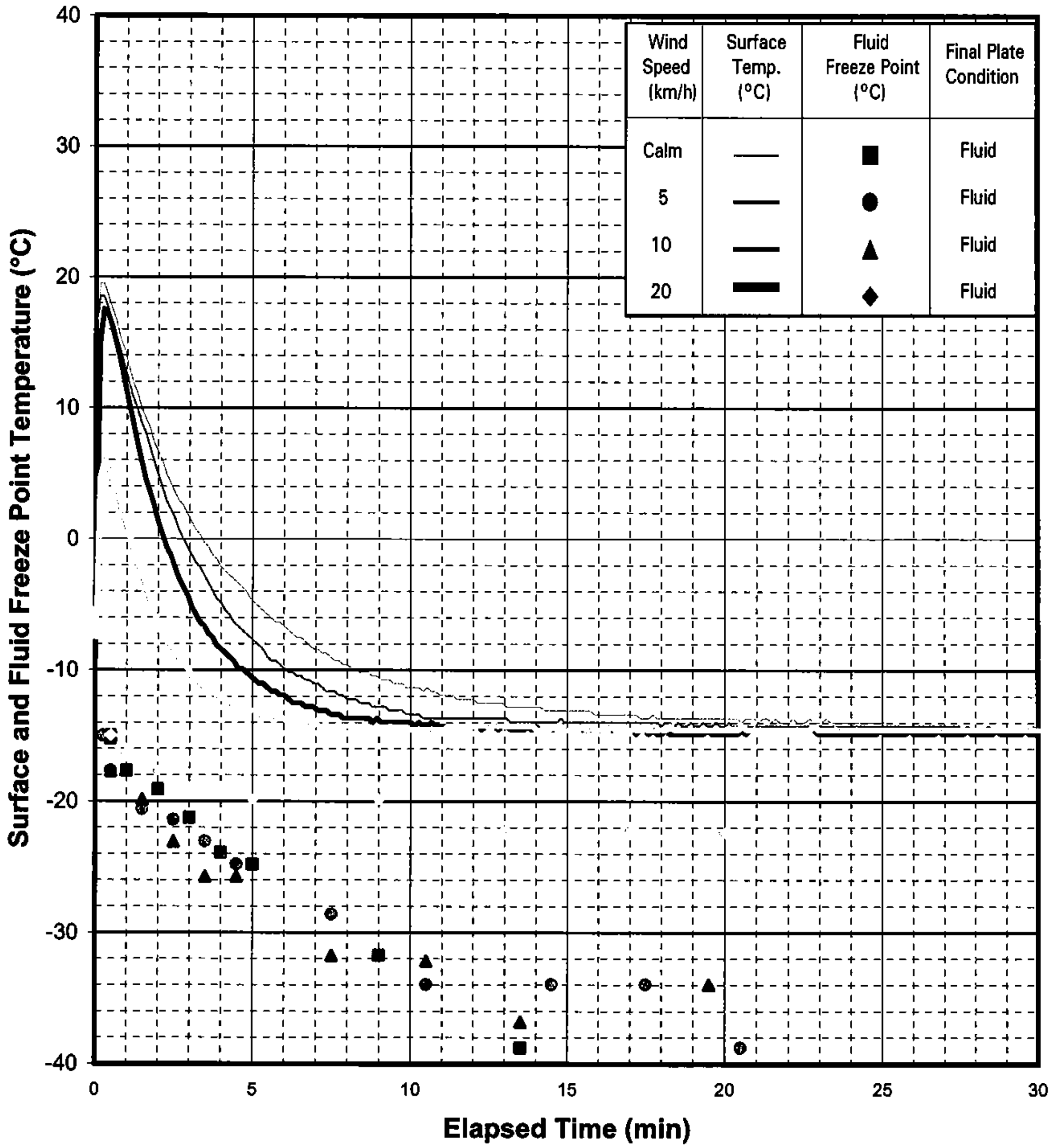


Fluid Freeze Point and Surface Temperature Profile, O1 (-5), OAT = -5°C



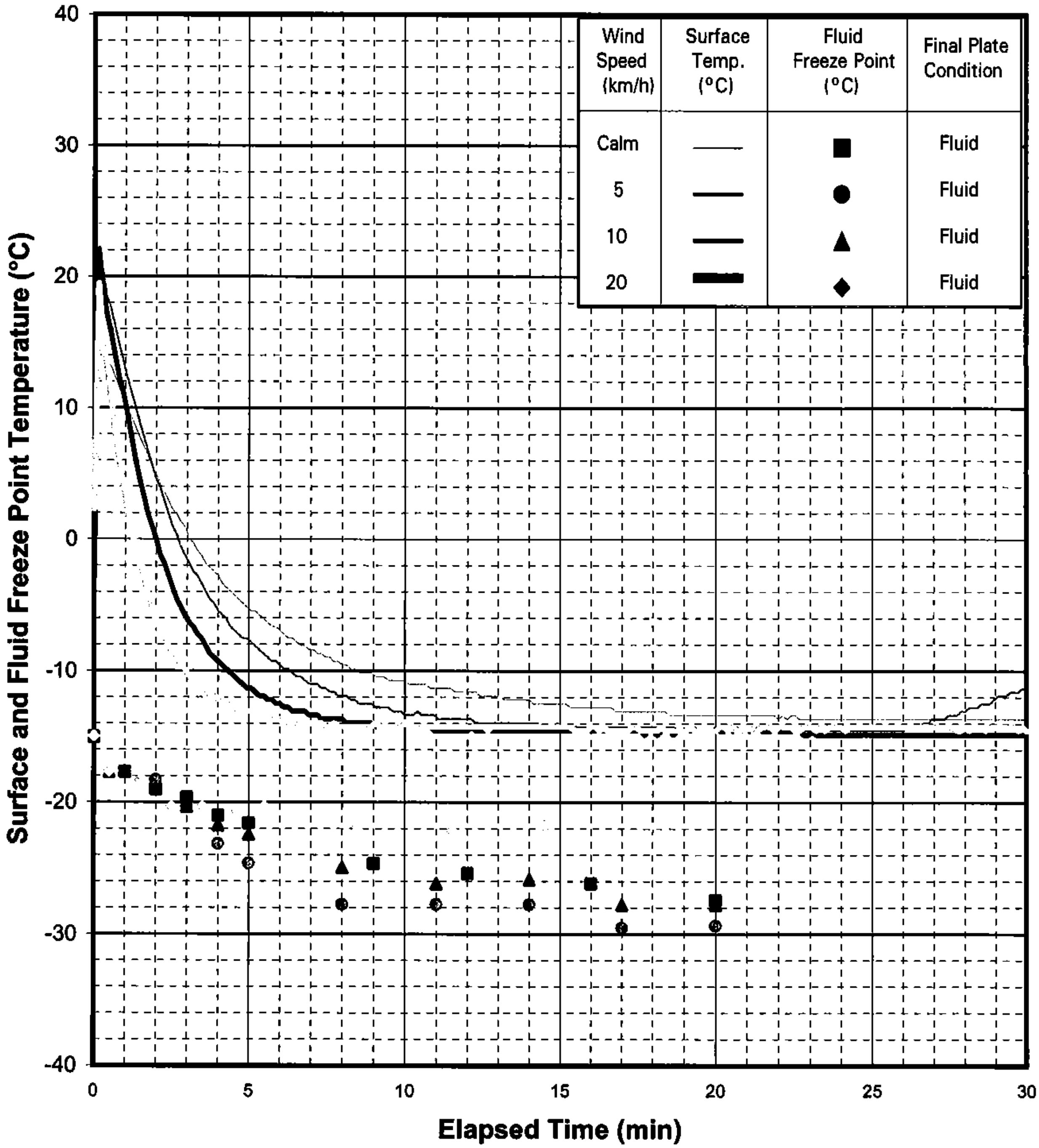
File:h:\cm1380\analide_only\OCT1-5A
At: -5°C
Printed: 6/12/2006 , 3:42 PM

Fluid Freeze Point and Surface Temperature Profile, U1 (-15), OAT = -15°C



cm1380\analysis\de_only\UCAR-15
Printed: 6/12/2006 , 3:45 PM

Fluid Freeze Point and Surface Temperature Profile, O1 (-15), OAT = -15°C



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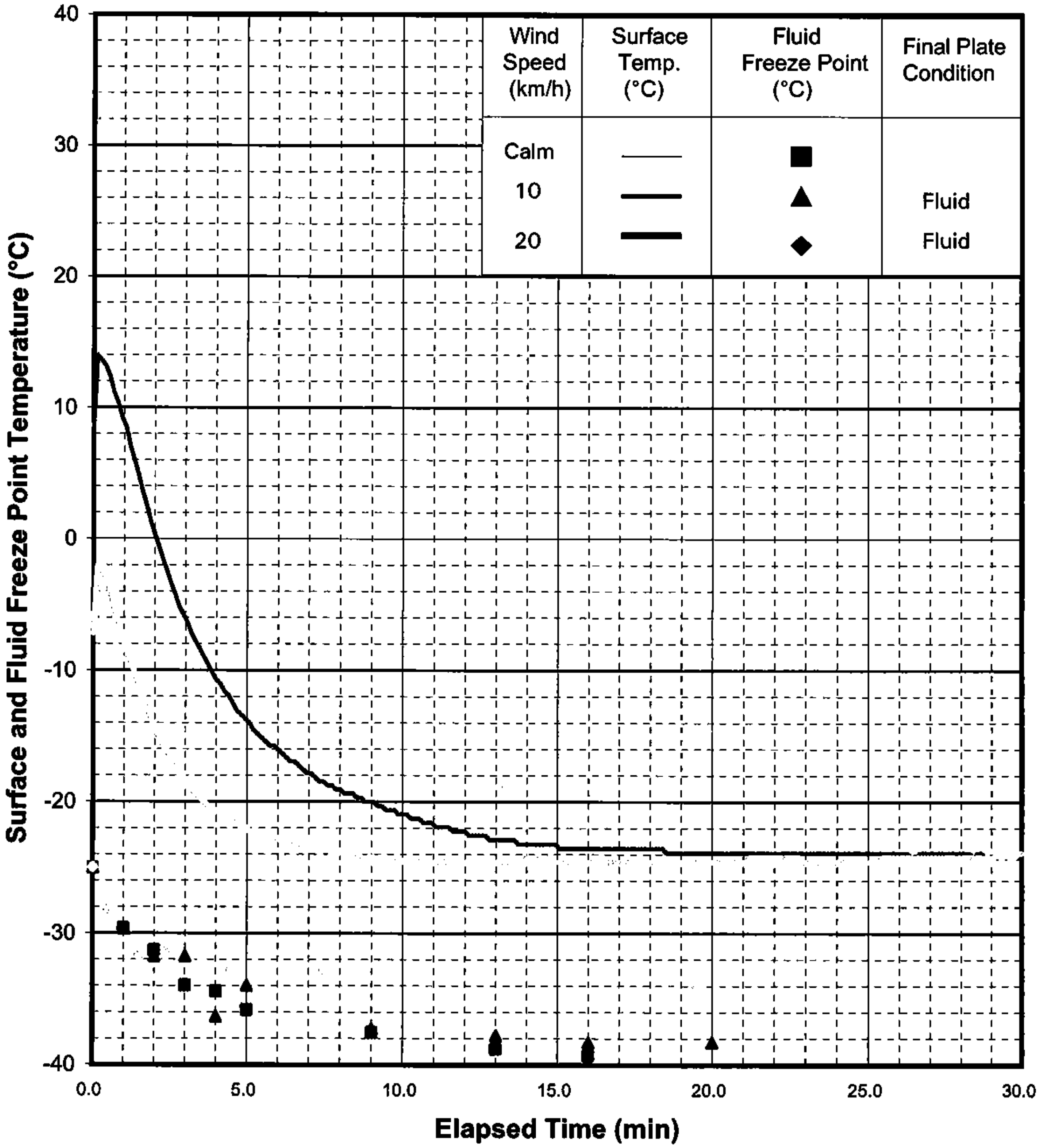
At: -15°C
Printed: 6/12/2006 , 3:45 PM

Fluid Freeze Point and Surface Temperature Profile, U1 (-25), OAT = -25°C



File:h:\cm1380\anal\de_only\UCAR-25A
At: -25°C
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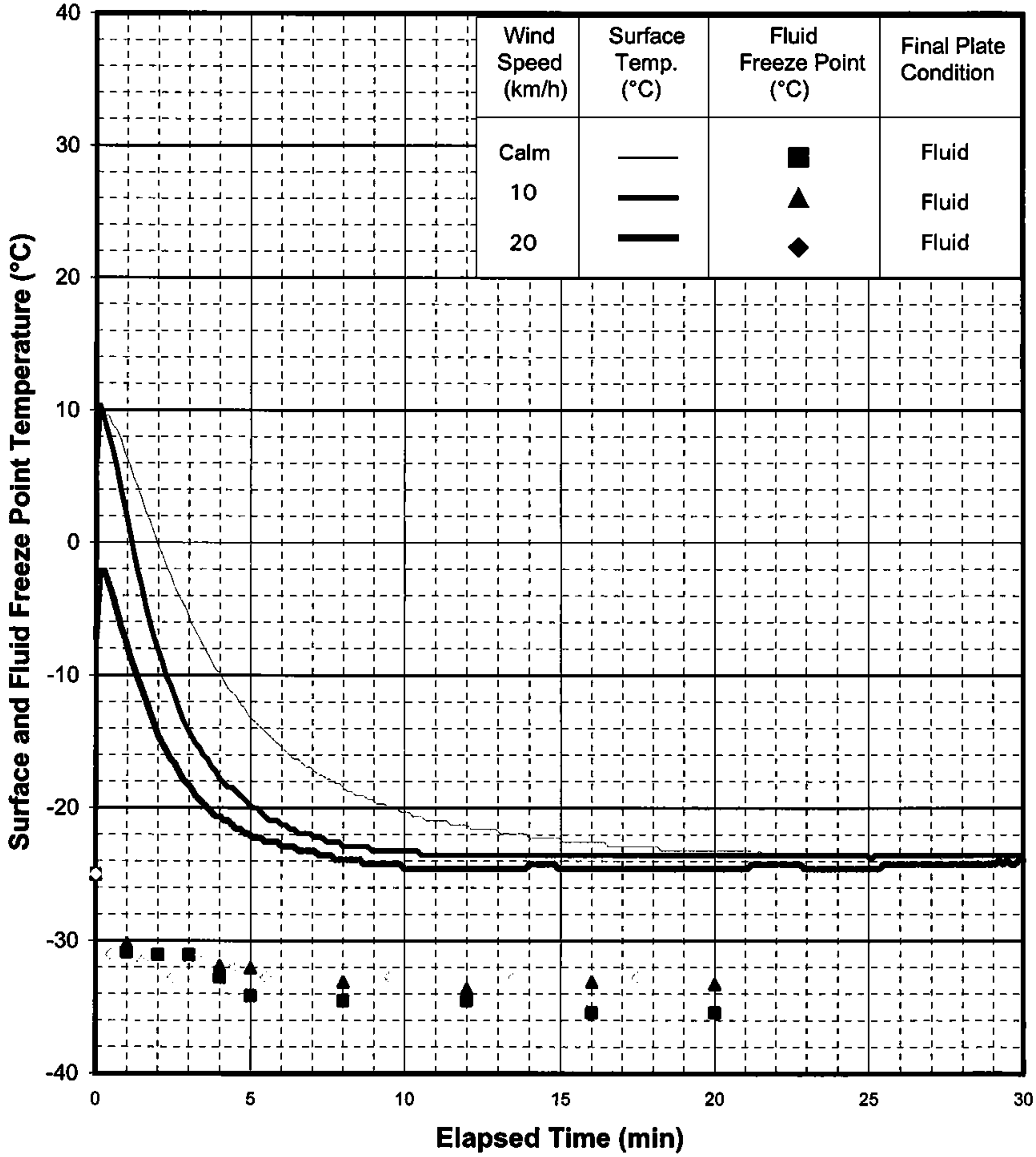
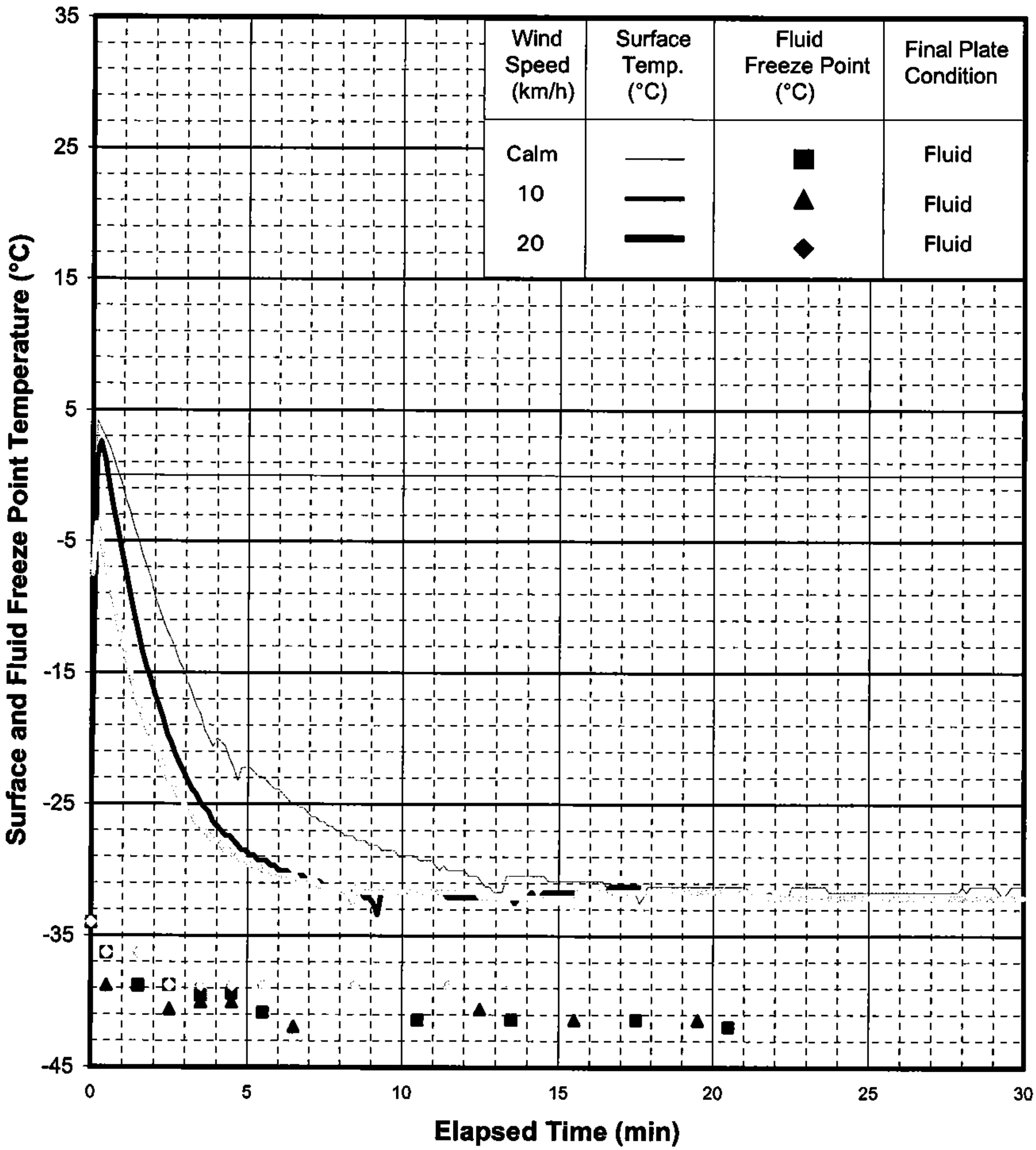
Fluid Freeze Point and Surface Temperature Profile, O1 (-25), OAT = -25°C



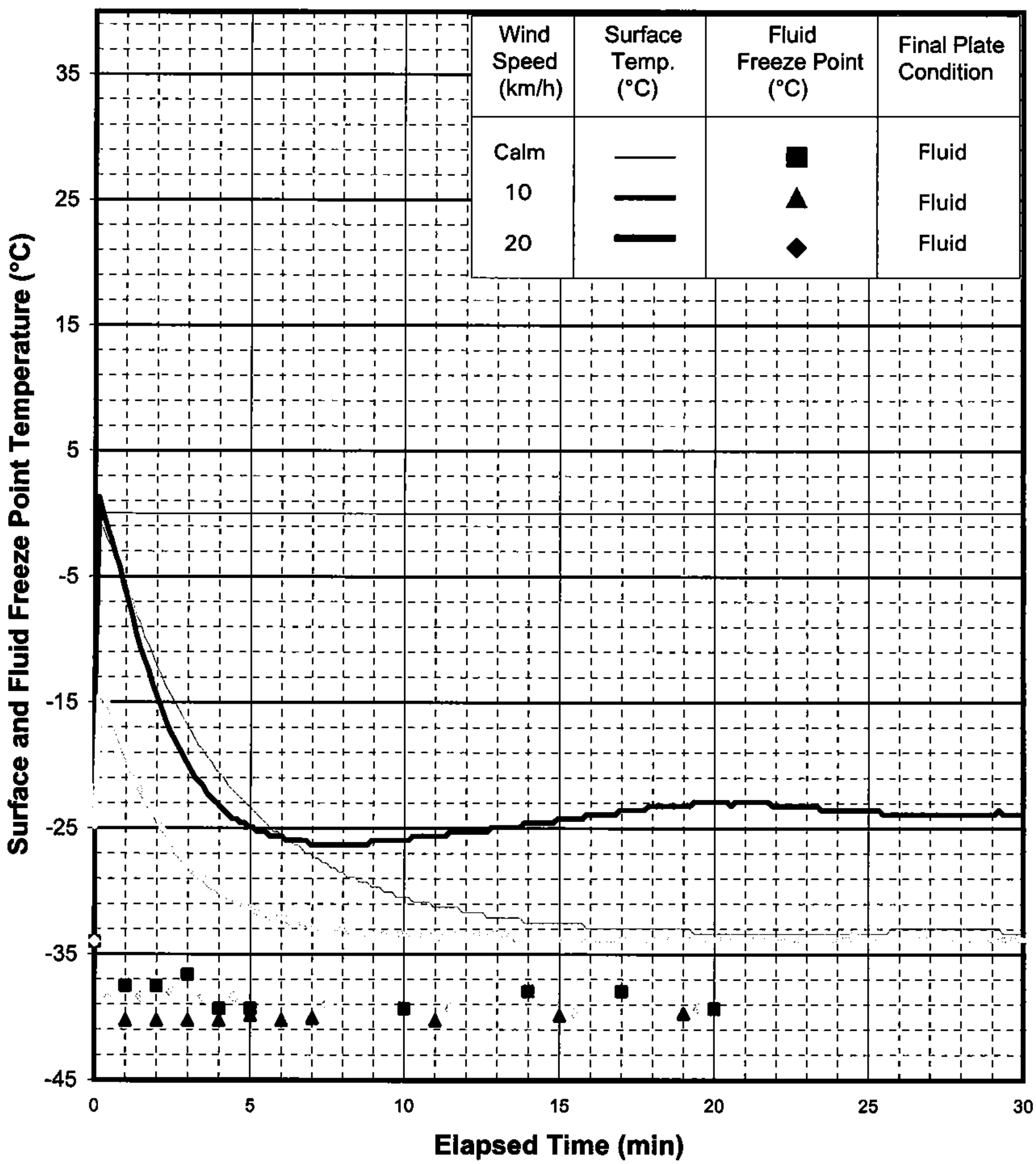
Wind Speed (km/h)	Surface Temp. (°C)	Fluid Freeze Point (°C)	Final Plate Condition
Calm	————	■	Fluid
10	━━━━	▲	Fluid
20	▬▬▬▬	◆	Fluid

File:h:\cm1380\analysis_only\OCT1-25A
Al: -25°C
Printed: 6/12/2006, 3:48 PM

Fluid Freeze Point and Surface Temperature Profile, U1 (-34), OAT = -34°C



Fluid Freeze Point and Surface Temperature Profile, O1 (-34), OAT = -34°C



File:g:\cm1338\analde_only\OCT1-34
At: -34°C
Printed: 6/12/2006 , 3:46 PM