TP 13478E

Aircraft Deicing Fluid Freeze Point Buffer Requirements for Deicing Only Conditions

Prepared for

Transportation Development Centre
On behalf of
Civil Aviation

Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

APS AVIATION INC.

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by

Peter Dawson,
Medhat Hanna,
Michael Chaput,
Antoni Peters, and
Nicolas Blais

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Prepared by:
Peter Dawson
Consultant
Date May 30, 2000

And by: Medhat Hanna, Michael Chaput, Antoni Peters, and Nicolas Blais

Reviewed by:
John D'Avirro
Program Manager
Date May 25, 2000

Approved by:
R.V. Potter, Ph.D.
Vice-President Programs & QA
Date May 25, 2000

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Un sommaire français se trouve avant la table des matières.

PREFACE

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

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

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

- TP 13477E Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1998-99 Winter;
- TP 13478E Aircraft Deicing Fluid Freeze Point Buffer Requirements for Deicing Only Conditions;
- TP 13479E Contaminated Aircraft Takeoff Test for the 1998-99 Winter;
- TP 13480E Air Velocity Distribution Behind Wing-Mounted Aircraft Engines;
- TP 13481E Feasibility of Use of Ice Detection Sensors for End-of-Runway Wing Checks;
- TP 13482E Evaluation of Warm Fuel as an Alternative Approach to Deicing;
- TP 13483E Hot Water Deicing of Aircraft;
- TP 13484E Characteristics of Failure of Aircraft Anti-Icing Fluids Subjected to Precipitation;
- TP 13485E Aircraft Full-Scale Test Program for the 1998-99 Winter;
- TP 13486E Evaluation of Snow Weather Data for Aircraft Anti-Icing Holdover Times;
- TP 13487E Development of a Plan to Implement a Full-Scale Test Site; and
- TP 13488E A Snow Generation System – Prototype Testing.

This report, TP 13478E, has the following objective:

- To gather enough supplemental experimental data to support the development of a *deicing-only* table as an industry guideline.

This objective was met by conducting a series of laboratory tests on flat plates and field tests on aircraft. Laboratory tests examined the following as variable test parameters: fluid temperature, concentration and quantity, wind speed, relative humidity, test surface material, cold-soaked surfaces, and the removal of snow contamination. Field tests examined loss of fluid temperature from spray nozzle to wing and the removal of snow contamination from wing surfaces.

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Peter Dawson, Medhat Hanna, Michael Chaput, Antoni Peters, and Nicolas Blais

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1100 René Lévesque Blvd. West
Suite 1340
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Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Twelve reports (including this one) were produced as part of this winter's research program (1998-99). Their subject matter is outlined in the preface. This project was cosponsored by the Federal Aviation Administration (FAA) and the SAE.

16. Abstract

A research program was conducted to develop supplementary information to support the development of a *deicing only* table to provide guidelines for the application of lower-concentrate deicing fluids.

This study examines the spread between ambient temperature and fluid freezing point temperature for *deicing only* conditions. Currently, no guidelines for this condition exist; by default, the guideline for ongoing precipitation conditions applies. A previous study (TP 13315E) documented significant enrichment in fluid concentration following application on test surfaces, as a result of evaporation of water from the fluid mix. That enrichment, demonstrated as a drop in fluid freezing point, supports the use of low-concentrate fluids during *deicing only* conditions.

This study also examines several operational variables that might affect the extent of fluid enrichment. These include fluid type, initial concentration, and the quantity and temperature of the applied fluid. The effects of wind and humidity, various materials used in fabrication of aircraft surfaces, cold-soaked surfaces, and the contaminant-removal process are also examined.

The final fluid condition (frozen or not) and the increase in fluid concentration as a result of evaporation following application on the test surface are documented. The progressive change in fluid concentration (fluid-freezing point temperature) is compared to the temperature profile of the treated surface as it cools after application of heated fluid.

It was concluded that:

- the *deicing only* procedure does not provide protection during active frost;
- SAE Type II PG fluids are unsuitable for the procedure;
- *deicing only* procedures should emphasize the importance of applying generous quantities of fluid and maintaining the highest possible fluid temperature; and
- other variables examined did not invalidate the *deicing only* concept.

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1100, boul. René-Lévesque Ouest
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Les rapports sur les essais réalisés pour le compte de Transports Canada au cours des hivers passés peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de recherche de l'hiver 1998-1999 a donné lieu à douze rapports (dont celui-ci). Le contenu de ces rapports est donné dans la préface. Les travaux dont rend compte le présent rapport ont été financés par la Federal Aviation Administration (FAA) et la SAE.

16. Résumé

Le programme de recherche avait pour objet d'obtenir des données complémentaires pour étayer l'élaboration d'une table des marges de sécurité pour la procédure de *dégivrage simple* (à une seule étape) devant déboucher sur des lignes directrices pour l'application de fluides dégivrants faiblement concentrés.

Cette étude examine l'écart à maintenir entre la température ambiante et le point de congélation du fluide, lorsqu'il est utilisé *à seules fins de dégivrage*. Présentement, comme il n'existe pas de ligne directrice pour cette procédure, on applique la ligne directrice prévue pour des conditions de précipitations continues. Une étude antérieure (TP 13315E) faisait état d'une forte hausse de la concentration du fluide après son application sur les surfaces d'essai, par suite de l'évaporation d'eau. Cet enrichissement du fluide, qui s'accompagne d'une chute de son point de congélation, plaide en faveur de l'utilisation de fluides faiblement concentrés pour une procédure de *dégivrage simple*.

Cette étude examine aussi plusieurs variables opérationnelles susceptibles d'influer sur l'enrichissement du fluide, dont le type de fluide, sa concentration initiale et la quantité et la température du fluide appliqué. Les effets du vent et de l'humidité, des divers matériaux utilisés pour la fabrication des surfaces des aéronefs, des surfaces sur-refroidies et de l'enlèvement des contaminants sont également examinés.

Les données colligées avaient trait à l'état final du fluide (gelé ou non) et à la hausse de la concentration du fluide, par suite de l'évaporation d'eau après la pulvérisation de la surface d'essai. La hausse progressive de la concentration du fluide (et la baisse concomitante de son point de congélation) est mise en rapport avec le profil de température de la surface traitée, au cours de son refroidissement suivant l'application de fluide chauffé.

L'étude a débouché sur les conclusions suivantes :

- la procédure de *dégivrage simple* (à une étape) n'offre pas de protection contre l'accrétion de givre;
- les fluides PG de type II, selon la SAE, ne conviennent pas à cette procédure;
- la procédure de *dégivrage simple* devrait insister sur l'importance d'appliquer généreusement le fluide et de le maintenir à la température la plus élevée possible;
- les autres variables examinées n'ont pas invalidé le concept de *dégivrage simple*.

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EXECUTIVE SUMMARY

At the request of the Transportation Development Centre (TDC) of Transport Canada and the U.S. Federal Aviation Administration (FAA), APS Aviation undertook a research program to examine fluid freeze point (FFP) buffer requirements for *deicing only* conditions.

Background

During the 1997-98 winter season, APS Aviation conducted a research program to examine FFP buffer requirements for two operational conditions. Results were reported in TP 13315E, *Aircraft Deicing Fluid Freeze Point Buffer Requirements: Deicing Only and First Step of Two-Step Deicing*.

The first condition (*deicing only*) applies to operating conditions when active precipitation has ceased, and the sole requirement is to remove accumulated contamination, thereby producing clean critical surfaces for takeoff. Protection against ongoing precipitation is not required. The goal of the *deicing only* study was to generate experimental data for the development of a *deicing only* table to serve as an industry guideline.

The second condition concerned the standard two-step deicing procedure, in which 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 goal of this portion of the study was to evaluate freezing point limits for fluids used in the first step.

Results were presented and discussed at the May 1998 annual meeting of the SAE G-12 Committee, Aircraft Ground Deicing, and in greater detail at a special meeting convened for that purpose in August 1998 at the FAA William J. Hughes Technical Center. Study findings presented at those meetings included the following:

- New and quantified information on fluid enrichment due to evaporation after spraying;
- Information on the influence of wind on the rate of surface cooling and on fluid evaporation; and
- An improved understanding of the anti-icing protection role played by the transfer of heat from the deicing fluid to the wing surface, as compared to the FFP depressant property of the Type I fluid, which is progressively diminished as the fluid is quickly diluted under moderate precipitation.

Feedback from industry participants identified several concerns related to applying the study results directly to field operations. It was decided that a series of supplemental tests would be conducted to address these concerns.

Problems requiring supplementary testing included:

- Fluid quantities tested;
- Temperature of the test fluid;
- Examination of fluids mixed to the current buffer limit to serve as a baseline;
- High wind conditions;
- High relative humidity (RH);
- Cold-soaked surfaces;
- Loss of heat due to removal of snow;
- Effect of composite surface materials;
- Effects on non-powered flight control surfaces; and
- Freezing on the ramp.

Because some of these focused on the selected values of variables used in the experimental process, preparatory work was necessary to define a range of variables that reflect actual field operations. This included field tests to confirm values as well as research to identify typical operational conditions. These variables were then used to develop a matrix of laboratory tests to address the concerns highlighted at industry meetings. A set of field tests on aircraft was also designed.

Results and Conclusions

Quantity of Fluid Applied

The quantity of fluid applied by the deicing operator was shown to have an impact on the degree of FFP enhancement. In all tests conducted, however, the degree of enhancement achieved by the lower fluid quantity was still significant and supported the use of low-buffer fluids for *deicing only* conditions. Because the proposed concept makes use of a lower cost, low-concentrate fluid, procedures for *deicing only* conditions should emphasize the need to apply adequate amounts of fluid.

Fluid Temperatures

1. Snow-Removal Conditions

The temperature of the fluid at time of application has a significant effect on the enhancement of the FFP. Wind conditions in conjunction with a low initial fluid temperature can produce unsatisfactory results. Several conclusions can be drawn from this set of tests exploring the impact of fluid temperatures:

Regarding Type II propylene glycol-based fluids:

i. These fluids do not provide any significant FFP enhancement, in either calm or windy conditions.

Regarding Type I ethylene and propylene glycol-based fluids:

ii. The temperature of the fluids at time of application has a significant effect on the enhancement of FFP. Fluid temperatures of 60°C consistently produced greater enhancements in FFP than the colder fluid temperatures tested (50°C and 40°C).

iii. At the milder outside air temperature (OAT) condition tested (-5°C), wind in combination with lower fluid temperatures can limit FFP enhancement to an unsatisfactory level when used in conjunction with a fluid having a 0°C freeze point buffer (FFP = OAT):

- In calm conditions, a satisfactory level of FFP enhancement was achieved for all fluid temperatures tested; and

- In 20 kph winds, an unsatisfactory level of FFP enhancement was achieved for fluids having initial temperatures of 40°C and 50°C.

iv. In cold OAT conditions (-25°C), wind conditions did not prevent a satisfactory level of FFP enhancement from being achieved for all fluid temperatures tested. This enhanced performance at cold temperatures is associated with the greater initial proportion of glycol in the cold temperature fluid mix.

Adequate fluid temperatures can be supported by sound operational practices, in which the spray nozzle is positioned as close as possible to the wing surface.

2. Frost-Removal Conditions

Only a slight degree of FFP enhancement can be expected from fluid applications in the small quantities typical of frost sprays. Although freezing did not occur in tests in which frost was inactive, and the temperature profiles for test surface and FFP did not intersect, the spread between the two temperatures was marginal.

High Winds

At an OAT of -5°C, the high winds tested (30 kph) produced greater FFP enhancement than that achieved with 20 kph winds. At an OAT of -25°C, 30 kph winds produced results equal to those for 20 kph winds.

Effect of Current FFP Buffer

At ambient temperatures just below freezing (-5°C), fluids mixed to the current 10ºC buffer showed more improvement than those mixed to a freezing point equal to OAT.

At colder ambient temperatures (-25°C), fluids mixed to the current 10ºC buffer showed less improvement than those mixed to a freezing point equal to OAT.
High Relative Humidity (RH)

A high humidity did not reduce the enhancement of fluid strength as long as an active frost condition did not exist. When the humidity level and OAT were such that frost was active, only temporary protection against frost was provided.

Removal of Snow

Removing snow from the test surface did result in some reduction of FFP enhancement as compared to tests on bare test surfaces. But the FFP enhancement remained significant, even when a small amount of fluid was applied during snow removal.

During field trials on aircraft, the deicing operator sprayed more fluid during tests in which snow was actually removed than during those on a bare wing in which he simulated removal. The additional fluid compensated for any heat loss during actual snow removal and produced levels of FFP enhancement similar to those observed on a bare surface.

Cold-soaked Wings

The *deicing only* concept, using an FFP temperature equal to ambient temperature is not valid for a cold-soaked wing condition, when the humidity is such that frost actively forms on the cold surface.

Composite and Painted Surfaces

Composite surfaces provided an FFP improvement near that of the standard aluminum test plate. Kevlar and glass-fibre surfaces performed as well as or better than the standard test plate; the carbon-fibre and the aluminum-honeycomb core plates performed at a slightly lower level.

The polyurethane-painted aluminum surfaces (red and blue) performed as well as the standard test plate.

Type II Propylene Glycol-Based Fluids

The performance of heated Type II PG-based fluids throughout the test series indicated that they do not provide any significant level of freezing point enhancement, and they are not recommended for *deicing only* applications.

Conclusions

Overall, it was concluded that:

- the *deicing only* procedure does not provide protection during active frost;
- SAE Type II PG fluids are unsuitable for the procedure;
- procedures should emphasize the importance of applying generous quantities of fluid, and of maintaining the highest possible fluid temperature; and
- other concerns examined do not invalidate the *deicing only* procedure.

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SOMMAIRE

À la demande du Centre de développement des transports (CDT) de Transports Canada et de la U.S. Federal Aviation Administration (FAA), APS Aviation a entrepris un programme de recherche visant à définir les exigences en matière de marge de sécurité contre le gel lors d'opérations de dégivrage simple.

Contexte

Au cours de l'hiver 1997-1998, APS Aviation a mené un programme de recherche visant à définir les exigences en matière de marge de sécurité contre le gel dans deux conditions de mise en œuvre des fluides dégivrants. Les résultats sont consignés dans le rapport
TP 13315E, Aircraft Deicing Fluid Freeze Point Buffer Requirements: Deicing Only and First Step of Two-Step Deicing.

La première condition opérationnelle (*dégivrage simple*) est celle où la précipitation a cessé : il s'agit alors d'enlever les contaminants, c'est-à-dire de nettoyer les surfaces critiques en vue du décollage. Il n'y a pas lieu de protéger les surfaces contre une précipitation continue. Le but de l'étude sur les conditions de *dégivrage simple* était de produire des données expérimentales en vue de l'élaboration d'une table de marges de sécurité pour la procédure *dégivrage simple* devant servir de ligne directrice à l'industrie de l'aviation.

La deuxième condition opérationnelle correspond à la procédure standard à deux étapes, soit l'application d'un premier fluide destiné à dégivrer les surfaces, puis d'un deuxième fluide, par-dessus le premier, visant à doter les surfaces d'une protection antigivrage (pendant une certaine période désignée «durée d'efficacité»). Ce volet de l'étude avait pour but d'évaluer les marges de sécurité à prendre en compte pour les fluides utilisés à la première étape.

Les résultats ont été présentés et discutés lors de la réunion annuelle du Comité G-12 de la SAE sur le dégivrage des aéronefs au sol, qui a eu lieu en mai 1998. Ils ont été examinés plus en détail lors d'une réunion spéciale tenue expressément à cette fin en août 1998, au William J. Hughes Technical Center de la FAA. Voici un aperçu des résultats présentés lors de ces réunions :

- nouvelles données quantitatives sur l'enrichissement du fluide dû à l'évaporation d'eau après la pulvérisation;
- information sur l'influence du vent sur le taux de refroidissement de la surface et l'évaporation du fluide;
- meilleure compréhension du rôle du transfert de chaleur entre le fluide dégivrant et la voilure dans la protection antigivrage, par rapport aux

propriétés antigel du fluide de type I, lesquelles s'atténuent progressivement, à mesure que le fluide absorbe la précipitation.

Pour dissiper les craintes suscitées dans le milieu de l'aviation par une application trop immédiate des résultats de l'étude aux opérations sur le terrain, il a été décidé d'entreprendre une nouvelle série d'essais.

De nouveaux essais étaient nécessaires pour étudier ce qui suit :

- quantités de fluides;
- température des fluides d'essai;
- caractérisation, aux fins de constituer une base de comparaison, des fluides dilués aux concentrations voulues pour offrir la marge de sécurité contre le gel actuellement exigée;
- vents forts;
- humidité relative élevée;
- surfaces sur-refroidies;
- déperdition de chaleur par suite d'enlèvement de la neige;
- effet des matériaux constituant la surface;
- effets sur les gouvernes non motorisées;
- température sous le point de congélation sur l'aire de trafic.

Comme certains de ces problèmes tenaient aux valeurs affectées aux variables utilisées lors des expériences, il a fallu d'abord définir une gamme de variables se rapprochant des conditions réelles. Des essais en vraie grandeur ont donc eu lieu pour confirmer ces valeurs, de même qu'une recherche pour définir les conditions opérationnelles types. Ces variables ont alors servi à mettre au point un programme d'essais en laboratoire devant dissiper les craintes soulevées aux réunions par des représentants de l'industrie. Une série d'essais en vraie grandeur a également été mise au point.

Résultats et conclusions

Quantité de fluide appliqué

La quantité de fluide appliquée par le préposé au dégivrage s'est révélée influer sur l'abaissement du point de congélation du fluide (PCF). À tous les essais, le degré d'amélioration du PCF obtenu même avec la quantité minimale de fluide était significative et appuyait l'utilisation de fluides offrant une faible marge de sécurité contre le gel pour une opération de *dégivrage simple*. Comme ce concept de *dégivrage simple* utilise un fluide peu coûteux et faiblement concentré, la procédure devrait insister sur la nécessité d'appliquer de bonnes quantités de fluide.

Température du fluide

1. Enlèvement de neige

La température du fluide au moment de la pulvérisation a un effet significatif sur l'abaissement du PCF. Mais la présence de vent conjuguée à une faible température initiale du fluide risque de produire de piètres résultats. Plusieurs conclusions peuvent être tirées de ces essais portant sur les effets de la température du fluide :

Fluides de type II à base de propylène glycol :

i. Ces fluides ne produisent pas un abaissement significatif du PCF, en présence ou en absence de vent.

Fluides de type I à base d'éthylène et de propylène glycol :

ii. La température des fluides au moment de l'application influe de façon significative sur l'abaissement du PCF. Les fluides chauffés à 60 °C avant d'être pulvérisés avaient systématiquement un effet plus grand que les fluides chauffés à une température inférieure (50 °C et 40 °C).

iii. À une température de l'air extérieur (OAT) relativement douce (-5 °C), un fluide assez froid appliqué en présence de vent peut produire un abaissement insuffisant du PCF lorsque son application précède celle d'un fluide dont la marge de sécurité contre le gel est de 0 °C (dont le point de congélation est égal à la température extérieure) :

- en l'absence de vent, tous les fluides mis à l'essai ont affiché un degré satisfaisant d'amélioration du PCF;

- par vents de 20 km/h, les fluides pulvérisés à des températures de 40 °C et de 50 °C ont affiché un degré insatisfaisant d'amélioration du PCF.

iv. À une valeur OAT faible (-25 °C), le facteur vent n'a empêché aucun des fluides mis à l'essai, peu importe sa température, d'offrir un degré satisfaisant d'amélioration du PCF. Cette optimisation de la performance à faible température est attribuable à la plus forte teneur initiale en glycol des fluides affichant les températures les plus faibles.

Des températures de fluide adéquates peuvent être optimisées par des méthodes judicieuses d'application, qui consistent à rapprocher le plus possible la buse de pulvérisation de la surface de l'aile.

2. Enlèvement de givre

On peut s’attendre à une légère diminution du PCF par suite de l’application des faibles quantités de fluides habituellement mises en oeuvre pour l’enlèvement de givre. Lors des essais, réalisés une fois terminée la période d’accrétion de givre, le fluide n’a pas gelé et son point de congélation est demeuré en deçà des profils de température des surfaces d’essai, mais l’écart entre ces deux températures était minime.

Vents forts

À une OAT de 5 °C, les conditions de vent fort (30 km/h) reproduites aux fins des essais ont abaissé davantage le PCF que lorsque les vents soufflaient à 20 km/h. À une OAT de 25 °C, des vents de 30 km/h ont produit des résultats équivalents à ceux obtenus avec des vents de 20 km/h.

Effet de la marge de sécurité actuelle contre le gel

À des températures ambiantes juste sous le point de congélation (-5 °C), les fluides préparés pour répondre à la marge de sécurité actuelle contre le gel, soit 10 degrés Celsius, se sont avérés plus performants, pour ce qui est de l’abaissement du point de congélation, que ceux préparés pour que leur point de congélation soit égal à l’OAT.

À des températures ambiantes plus faibles (-25 °C), les fluides préparés pour répondre à la marge de sécurité actuelle contre le gel, soit 10 degrés Celsius, se sont révélés moins performants, pour ce qui est de l’abaissement du point de congélation, que ceux préparés pour que leur point de congélation soit égal à l’OAT.

Humidité relative élevée

Une humidité élevée n’a pas nui à l’enrichissement du fluide, en dehors de toute condition d’accrétion de givre. Lorsque le degré d’humidité et l’OAT étaient propices à l’accrétion de givre, seule une protection temporaire contre le givrage était assurée.

Enlèvement de neige

Les essais qui comportaient l’enlèvement de neige sur la surface d’essai ont révélé un degré moindre d’abaissement du PCF, par rapport aux essais menés avec des surfaces d’essai nues. Mais l’amélioration du PCF demeurait notable, même lorsque la quantité de fluide appliquée pendant l’enlèvement de la neige était faible.

Lors des essais mettant en jeu des avions en vraie grandeur, le préposé au dégivrage pulvérisait davantage de fluide au cours des essais où il enlevait réellement de la neige qu'au cours de ceux où il simulait l'enlèvement de la neige sur une aile nue. Le surplus de fluide compensait pour la perte de chaleur associée à l'enlèvement de la neige et produisait un abaissement du point de congélation similaire à ceux observés lors des essais sur surface nue.

Ailes sur-refroidies

Le concept de *dégivrage simple*, à l'aide d'un fluide dont le point de congélation est égal à la température ambiante n'est pas valide pour une aile sur-refroidie, lorsque l'humidité est telle que du givre se forme sur la surface.

Surfaces composites et revêtues de peinture

Les surfaces composites affichaient une amélioration du PCF semblable à celle obtenue avec les plaques d'essai standard en aluminium. Les surfaces en Kevlar et en fibre de verre se sont comportées aussi bien sinon mieux que la plaque d'essai standard; les plaques en fibre de carbone et les plaques à âme alvéolaire en aluminium offraient un degré de performance légèrement moindre.

Les surfaces en aluminium revêtues de peinture polyuréthanne (rouge et bleue) ont produit des résultats aussi bons que la plaque d'essai standard.

Fluides de type II à base de propylène glycol

Dans toute la série d'essais, les performances des fluides type II à base de propylène glycol chauffés ont révélé que ces fluides ne procurent pas un degré significatif d'amélioration du PCF, et ils ne sont pas recommandés pour une procédure de *dégivrage simple*.

Conclusions

Voici, de façon globale, les conclusions de l'étude :

- la procédure de *dégivrage simple* n'offre pas de protection antigivrage en condition d'accrétion de givre;
- les fluides PG de type II, selon la SAE, ne conviennent pas à cette procédure;
- la procédure devrait insister sur l'importance d'appliquer généreusement le fluide et de le maintenir à la température la plus élevée possible;
- les autres paramètres étudiés n'ont pas invalidé le concept de *dégivrage simple*.

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GLOSSARY

APS	APS Aviation Inc.
CEF	Climatic Engineering Facility
C/FIMS	Contaminant/Fluid Integrity Monitoring System
COX	Cox & Company, Inc.
EG	Ethylene Glycol
FAA	Federal Aviation Administration
FFP	Fluid Freeze Point
FPD	Freeze Point Depressant
NRC	National Research Council Canada
OAT	Outside Air Temperature
PG	Propylene Glycol
PMG	PMG Test and Research Centre
READAC	Remote Environmental Automatic Data Acquisition Concept
RH	Relative Humidity
RVSI	Robotic Vision System Inc.
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre
UCAR	Union Carbide

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1. INTRODUCTION

At the request of the Transportation Development Centre (TDC) of Transport Canada and the Federal Aviation Administration (FAA), William J. Hughes Technical Centre, APS Aviation undertook a research program to examine fluid freeze point (FFP) buffer requirements for *deicing only* conditions.

1.1 Background

1.1.1 Previous Research

During the 1997-98 winter season, APS Aviation conducted a research program to examine FFP buffer requirements for two specific operational conditions. Results were reported in TP 13315E, *Aircraft Deicing Fluid Freeze Point Buffer Requirements Program: Deicing Only and First Step of Two-Step Deicing* (1). The findings from the 1998-99 study are supplementary to the results reported in TP 13315E.

The first condition (*deicing only*) applied to situations in which active precipitation had ceased, and the sole requirement was to remove accumulated contamination, producing clean critical surfaces. Protection against precipitation was not required.

The goal of the *deicing only* study was to generate experimental data for the development of a *deicing only table* as an industry guideline. This portion of the program was initiated by the FAA and supported by the FAA and TDC.

The second condition concerned the standard two-step deicing procedure, in which the application of a first-step fluid is used to deice the surface, and a second-step fluid is oversprayed to provide anti-icing protection.

The goal of this portion of the study was to evaluate freezing-point limits for fluids used in the first step. This portion of the program was initiated by US Airways Inc. and supported by both FAA and TDC.

Results were presented and discussed at the May 1998 annual meeting of the SAE G-12 Committee, Aircraft Ground Deicing, and in greater detail at a special meeting convened for that purpose in August 1998 at the FAA William J. Hughes Technical Center. Discussion on the presented findings is reflected in the minutes of those meetings (2,3).

The study findings presented at those meetings included:

- New and quantified information on fluid enrichment due to evaporation after spraying;
- Information on the influence of wind on the rate of surface cooling and evaporation; and
- An improved understanding of the anti-icing protection role that is played by heat transfer from the deicing fluid to the wing surface, as compared to the FFP depressant property of the Type I fluid, which is progressively diminished (because it is quickly diluted under moderate precipitation).

Feedback from industry participants identified several problems related to applying study results directly to field operations. Later, it was decided that a series of supplemental tests would be conducted to address concerns specific to *deicing only* conditions.

Regarding the study on first step fluid, the underlying goal was to have a FFP buffer guideline that was consistent for the two conditions (*deicing only*, and during precipitation), thereby simplifying the management of fluids. Because the buffer for *deicing only* conditions settled at a more conservative value than the current guidelines for the first-step FFP buffer (–3ºC), no more tests were planned for the first step fluid buffer.

1.1.2 Deicing Only Conditions

The main industry document on aircraft deicing is the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) ARP4737, *Aircraft Deicing/Anti-icing Methods with Fluids* (4). Excerpts are included in Appendix B (*Guidelines for the Application of SAE Type I Fluid Mixtures as a Function of Outside Air Temperature*). It provides guidelines for the methods and procedures of aircraft deicing and anti-icing ground operations and specifies temperature limits for fluids.

The temperature-related limits in SAE ARP4737 for SAE Type I deicing fluid application are shown in Appendix F. Here, Type I deicing fluid is used either alone to serve 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.

The main focus of ARP4737 is on operating conditions that require anti-icing to provide a period of protection against ice or snow contamination. Until very recently, protection of critical surfaces during winter storms for the interval between deicing and takeoff has been a major challenge. Recent developments in anti-icing have resulted in new fluids designed to provide long periods of protection (holdover times). This important development has lessened the need for an exclusive focus on anti-icing protection.

In the one-step procedure in which the fluid has a dual role, (deicing and anti-icing), fluid strength must be maintained to provide a freeze point of at least 10°C (18°F) below outside air temperature. The difference between the outside air temperature and the FFP is referred to as the FFP buffer. After precipitation has ceased, a buffer of this magnitude might be more conservative than necessary. Because no guidelines exist for conditions other than ongoing precipitation, airline procedures for *deicing only* conditions follow the only guidelines available (established for the more severe ongoing precipitation conditions). In consequence, the deicing operation uses a fluid mixture having a higher concentration of glycol than might be necessary, resulting in less-than-optimal cost effectiveness and unnecessary stress on the environment.

A preliminary study examining changes in fluid concentration following the application of a heated fluid to test surfaces was reported in Transportation Development Centre report TP 13131E, *Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1996-97 Winter* (5). This 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. The study's authors concluded that an inherent buffer could result.

In a review (1996/1997) of fluid-strength requirements for various operating conditions, Transportation Development Centre report TP 13129E, *Examination of the Role of Fluid Freeze Point Buffers* (6) concluded that some situations provide an opportunity to reduce fluid strength from currently recommended levels.

1.1.3 Deicing Only Concept

The publication of guidelines for *deicing only* conditions would complement existing procedures and provide airlines with support and encouragement to institute more cost-effective and environmentally responsible procedures. A *deicing only* table would identify limits for fluid concentrations (FFP buffers) appropriate to the condition.

The purpose of the 1997-98 study (1) was to develop a *deicing only* table. Areas of investigation included the following:

- Establishing the extent of change to fluid strength after application on the aircraft surface;

- Examining the interaction between the temperature of the heated surface and the changing freezing point of the applied fluid; and
- Establishing the limits of initial fluid concentration for various ambient air/wind speed combinations.

The *deicing only* table is to be produced in a form similar to current SAE ARP4737 tables that provide guidelines for the application of the different types of fluid mixtures as a function of OAT. Table 1.1 illustrates a possible form for a *deicing only* table. The fluid freeze point (FP) values shown in the table are hypothetical and are used only as examples.

Table 1.1

Anticipated Form of Deicing Only Table

OAT		**Deicing Medium**	**Weather Conditions**
ºC	**ºF**		
Above 1º	Above 34º	Unheated water	Temperature steady or rising No freezing precipitation
Above 0º	Above 32º	Water heated to 60ºC (140ºF) minimum at the nozzle	
0º to –3º	32º to –27º	Deice with a heated suitable mix of Type I fluid with FP at least –3ºC(27ºF)	Temperature steady or rising No precipitation No active frost
Below –3º to –35º	Below –27º to –31º	Heated suitable mix of Type I fluid with FP equal to or below OAT	
Below –35º	Below –31º	Heated suitable mix of Type I fluid with FP at least 10ºC(18ºF) below OAT	

Note: For heated fluids, a fluid temperature not less than 60ºC(140ºF) at the nozzle is desirable. Upper temperature limit shall not exceed fluid and aircraft manufacturers recommendations.
Consider the use of heated facilities or mechanical devices.

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

1.1.4 Outcome of Industry Discussions on Study Findings

During extended industry discussion of the 1997-98 study, some problems were highlighted. These were about the application of findings in field operations. It was agreed that more information and testing were necessary to solve those problems. The topics requiring supplementary testing included the following:

- Temperature of the test fluid;
- Fluid quantities tested;
- Fluids mixed to the current buffer limit to serve as a baseline;
- High wind conditions;
- High relative humidity;
- Cold-soaked surfaces;
- Fluid heat lost by melting snow;
- Composite surface materials;
- Non-powered flight control surfaces; and
- Fluid freezing on the ramp.

The nature of these problems is described in more detail, along with the test approach taken in each case, in Chapter 2.

1.2 Work Statement

Appendix A presents the work statement for the APS Aviation Winter 1998-99 research program. Section 5.3 of Appendix A, Supplementary Data for Deicing Only Table, describes this project.

1.3 Goals

The goal of this project was to produce additional test data to solve problems mentioned at industry meetings and to support final construction of a *Deicing Only* Table.

A two-stage approach was necessary. Because some of the problems were focused on the selected values of test variables used in the testing process, preparatory work was undertaken to define a range of variables that reflect actual field operations. Preparation included field tests to confirm values, as well as research to identify typical operational conditions. These variables were then used in developing a matrix of laboratory tests. A short series of field tests on aircraft were also designed.

Laboratory trials were conducted over two weeks in January 1999 at the PMG Test and Research Centre at Blainville, Quebec. Trials on operational aircraft were conducted at the Central Deicing Facility at Montreal International Airport (Dorval).

A separate study examining environmental issues related to expended glycol-based deicing/anti-icing fluids was conducted, and results are reported in Appendix G. Primary objectives of that study were to:

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

2. METHODOLOGY

This section describes efforts to define values for test parameters, the test conditions selected to satisfy the various needs mentioned at industry meetings, the experimental methods followed, and the equipment and personnel requirements.

2.1 Identification of Test Approaches and Parameters to Answer Industry Questions

Values for test parameters had to be defined before developing final test procedures. These included the following:

- Quantity of fluid applied to test surfaces;
- Temperature of the fluid; and
- Values for RH (both typical and high) during actual *deicing only* conditions.

The other test parameters were defined during industry discussions.

2.1.1 Quantity of Fluid

In *deicing only* tests, a standard quantity of 0.5 L had been applied to test surfaces. At industry meetings, it was noted that this quantity might not represent all conditions.

To establish a range of representative values, several airlines were asked for data. The data made available were generally on a range of aircraft sizes and typical categories of precipitation. Using surfaces for a characteristic aircraft within each category of aircraft, the reported quantities of deicing fluid sprayed for various conditions were converted to equivalent quantities for an area the size of a test plate, as shown in the following table.

Deicing Fluid Quantities Reported – Equivalent per Test Plate

Aircraft Type	Frost (L/plate)	Light Snow (L/plate)	Medium Snow (L/plate)	Heavy Snow (L/plate)	Overnight Snow Accumulation (L/plate)
Commuter	0.2 - 0.4	0.4 - 0.6	0.5 - 1.3	0.7 - 2.3	0.7 –1.5
Small Narrow-body	0.1 - 0.4	0.4 - 1.0	0.6 - 1.0	1.0 - 1.7	1.0 - 2.4
Large Narrow-body	0.1 - 0.3	0.2 - 0.4	0.5	0.7 - 0.9	0.6 - 0.7
Small Wide-body	0.1 - 0.2	0.2 - 0.3	0.4	0.5 - 0.7	0.5
Large Wide-body	0.1	0.1	0.3	0.5	0.3

In general, *deicing only* operations would be expected early in the morning, following overnight precipitation that has ended. For snowfall occurring and then ending during the daytime, it is unlikely that an operator would switch from *normal deicing procedures* to *deicing only procedures* after snowfall. Thus, the typical accumulation that would be encountered for *deicing only* would be snow after overnight storms or overnight frost.

After reviewing the data, it was decided to use test quantities as follows:

1. Tests representing snow removal: 0.5 and 0.25 L per plate;
2. Tests representing frost removal: 0.1 L per plate.

Because it is impossible to achieve complete plate coverage by pouring a small quantity of fluid (such as that selected to represent frost sprays) it was decided to apply fluids for those tests by spraying instead of pouring.

2.1.2 Fluid Temperature

The *deicing only* trials involved fluid applied at a standard temperature of 60°C, representing the minimal nozzle temperature recommended by the SAE ARP4737 guidelines.

Depending on the distance from fluid nozzle to aircraft surface and control of the spray pattern, considerable heat loss in the applied fluid can be involved. The deicing operator can adjust the spray nozzle over a range of spray patterns. A wide, fan-shaped, low-energy pattern that covers a wide area is typically used for frost removal; a concentrated high-energy stream could be used to flush snow or frozen precipitation from surfaces. It could be used also to reach more distant surfaces.

2.1.2.1 Procedure to Assess Temperature Drop

To evaluate the loss in fluid temperature from nozzle to surface, a set of field trials was developed. Procedures, along with test data and reports, are included in Appendix D. Basically, these trials consisted of spraying fluid from a deicing vehicle onto a test-wing foil and measuring the temperature as it left the nozzle and at the surface of the foil.

Special equipment was assembled to measure the temperature at the nozzle and at the wing surface. The nozzle apparatus consisted of a thermistor probe installed in a section of tubing mounted on a long handle. The tubing was inserted into the fluid stream and held there until the temperature reading stabilized. This apparatus is shown in Photo 2.1. It was improved for the second test by replacing the thermistor probe with a thermocouple, which gave a faster response time.

The wing-surface apparatus consisted of thermistor probes installed in plastic cups about 2.5 cm deep. Each cup was inset in a styrofoam block, which, in turn, was installed in an aluminum tray (designed for a previous test to be mounted on wing surfaces). Tray legs were attached to the wing surface by rubber suction cups. Spray rapidly filled the plastic cups and then overflowed continuously. This resulted in rapid replacement of the fluid in the cups, thereby ensuring that any initial fluid heat loss was overcome. The temperature measured was the fluid's true temperature just before it reached the wing surface. Pictures of the apparatus at the wing, and of the overall set-up, are given in Photos 2.2 and 2.3.

Fluid strength, at the nozzle and at the wing, was measured to see if any evaporation of water from the mixture occurred in the spray. To get a fluid sample, a long-handled probe containing a test tube was inserted into the fluid stream at the nozzle and at the wing. The test tube was immediately stoppered when withdrawn from the fluid stream.

Several tests were conducted, varying the distance from nozzle to wing and controlling the nozzle setting to represent spray patterns for snow and frost removal.

Two trial sessions were conducted to assess the temperature drop for a range of temperature differentials between fluid (tank) temperature and outside ambient temperature (OAT).

2.1.2.2 Comments on Trials

In both trials, a significant drop in fluid temperature between tank and at nozzle exit was noted. When the temperature indicator in the truck cab showed close to 60EC, the temperature measured at the nozzle exit was about 10ºC colder. The full drop in temperature from tank to wing has two distinct aspects: the drop from tank to nozzle exit and the drop in the fluid stream from nozzle to wing. If this is common to all deicing vehicles, then the current SAE minimum temperature limit of 60°C at the nozzle could be met only by heating the fluid in the tank to 70°C. As well, a tank-heat upper limit of 80°C would limit the nozzle temperature to a maximum of 70°C.

The starting distance for sprays of 1.7 m (5.5 feet) was established by asking the operator to place the bucket where he normally would. Although the original goal was to test sprays from as far as 9 m (30 ft.), it was found that the longer distances were not valid for the frost-spray pattern, which could not reach the surface. The operator stated that he would never even consider deicing from such long distances.

As the deicing bucket was relocated progressively farther from the test wing, the operator adjusted the nozzle to a more solidified spray cone to achieve a better reach. This caused the unexpected result of a smaller drop in temperature at the longest distance (run 4). Adjustment of the fluid nozzle reflects what would happen in an actual operation. To explore this, the tests were repeated at 3 m (10 ft.) and 4.5 m (15 ft.), fixing the spray nozzle to the 3 m (10-foot) pattern. This resulted in a temperature drop with increased distance.

In no run was there a measurable change in fluid strength between the nozzle exit and at the target surface.

2.1.2.3 Results of Trials

As tests were conducted at various initial fluid temperatures, the data were normalized to indicate results from a temperature (at the nozzle) of 60°C. This adjustment was based on the assumption that the absolute value of the temperature drop is not greatly affected by small changes to the initial temperature.

The resulting temperatures at the wing are shown in the following table.

	Distance		Fluid Temp at Nozzle	Fluid Temp at Wing	
	M	ft.	(°C)	OAT -5°C	OAT -25°C
Frost Spray	1.7	5.5	60	48	18
	3	10	60	35	25
	4.5	15	60	40	22
Snow Spray	1.7	5.5	60	57	41
	4.5	15	60	56	35
	7.5	25	60	42	43

These results indicate that temperatures for tests representing frost removal had to be different from those representing snow removal:

- For tests representing frost removal (using a fluid quantity of 0.1 L), fluid temperatures of 50, 35, and 20°C were selected; and

- For tests representing snow removal (using fluid quantities of 0.5 and 0.25 L), fluid temperatures of 60, 50, and 40°C were selected.

2.1.3 High RH

Ambient conditions involving high levels of relative humidity were of concern because of potential reduction of water evaporation from the deicing fluid mix and thereby of fluid-strength enhancement. Tests were planned at levels of relative humidity that represented typical high values during *deicing only* conditions for snow and frost removal. This required some investigation to determine representative values for high humidity in actual operations.

To determine values for relative humidity after snowstorms, weather records for Dorval were reviewed to identify dates and times. The hourly values of relative humidity were then charted, and the time of the snowstorm's end was noted. Table 2.1 illustrates this process.

The goal was to learn the value of RH during the deicing period after snowstorms. Examples are shown for snowstorms ending late evening, early morning, and during the day. For all of these periods, records show RH values up to mid 80 percent.

The same analysis could not be made for frost, because frost is not reported in historical records. To determine high values for RH during *deicing only* for frost removal, a theoretical calculation was conducted.

2.1.3.1 Frost Occurrence on Exposed Surfaces

The causal factors for the occurrence of frost are a combination of ambient air temperature, the level of humidity in the air, the surface temperature of any exposed body, and the existence, or non-existence, of wind.

The amount of humidity in air is expressed as the *water vapour mixing ratio*, which reports the quantity of water vapour per fixed quantity of air. A common measure of the mixing ratio is *grams of water vapour per kg of air*. The amount of water vapour that can be retained by air is dependent on the air temperature; warm air can support more water vapour than cold air. When air is cooled to the point where no more water vapour can be supported, the air is said to have reached *saturation*. That ultimate level of water vapour that can be supported by air at a set temperature is defined as the *saturation mixing ratio*.

Relative humidity is a measure of the current level of humidity in the air (existing water vapour mixing ratio) as a percentage of that level of humidity that would result in saturation (saturation mixing ratio).

The *dew point* is the air temperature at which a fixed amount of humidity in the air results in saturation, i.e. no additional water vapour can be supported, and water starts to come out of the air in the form of dew. As the air cools at day’s end, its capacity to support water vapour is progressively lessened. Eventually the cooling air temperature may reach dew point for that particular level of humidity, at which time dew will start to form.

If an exposed surface happens to be at a temperature lower than the OAT, the layer of air immediately over the surface may also be colder than OAT. In this case, the dew point within this layer of air will be reached earlier than otherwise, and dew will be seen to form on that particular surface.

At temperatures above freezing, the air becomes *saturated with respect to water*. At temperatures below freezing, the air can become *saturated with respect to ice* as well as with respect to water. The dew point with respect to ice, or the frost point, is the temperature at which air becomes saturated with respect to ice, and where frost will begin to form. The *frost point is always higher than the dew point* for a given amount of humidity in the air. Thus when ambient temperature is below freezing, and is falling, the frost point will be reached before the dew point, and frost formation will be seen to occur. As in the case of dew formation, if the temperature of an exposed body and the layer of air just over the surface is colder than OAT, the air within that layer will reach frost point earlier than otherwise. Frost can occur as a result of the ambient air temperature dropping enough to become saturated with respect to ice (i.e., it reaches its frost point), or as the result of the temperature of an exposed body being colder than OAT.

The temperature of an exposed body can be colder than OAT as a result of the radiant exchange of heat between that body and the open sky. On clear nights when heat is radiated into the open sky, the net result of this exchange is a loss of heat in the exposed body, and a corresponding temperature drop. Degree of radiation depends on the type of material; metal and glass surfaces are good radiators, and therefore experience heavy frost deposits.

Wind has an effect on frost; high winds prevent frost formation. The mechanism preventing frost formation is through the continued removal of the locally cooled air film above the surface and constant replacement with air at ambient temperature, i.e. higher than the surface temperature and higher than the frost point temperature. A rule of thumb is that frost can form in winds up to 10 kph.

2.1.3.2 Estimating Typical RH Levels Following Periods of Frost

The method of estimation examines the period when the formation of frost has stopped because OAT has warmed. The method assumes that the absolute amount of humidity in the air is constant during this period. The basis of the RH estimation is, for a specified OAT, to note the level of humidity in air at the frost point, and divide that value by the saturation level of humidity for a somewhat warmer OAT. The temperature differential selected for calculation was 2°C. Because an increase in OAT by a differential greater than 2°C would produce lower RH values, this selection provides an estimate of RH on the high side of the range (more severe for test purposes) that would normally be experienced.

The calculation makes use of standard meteorological tables that report, for a range of OAT values, the saturation mixing ratio over ice and the saturation mixing ratio over water.

Three OAT values were selected (–25, –10, –5°C). The saturation mixing ratio (grams of water vapour per kilogram of air) over ice was noted for each OAT value. The value for OAT was then raised by 2°C to represent an increase of temperature that would terminate frost. The saturation mixing ratio over water for the new OAT was noted. The two ratios were then compared to calculate the RH at the new temperature.

An example calculation of RH at an OAT of –8°C following a period of frost at –10°C follows:

$$\text{RH (at } -8^\circ\text{C)} = \frac{\text{amount of water vapour in the air at -8°C}}{\text{amount of water vapour needed to be saturated at -8°C}}$$

$$= \frac{\text{water vapour mixing ratio when frost is forming at -10°C}}{\text{saturation mixing ratio over water at -8°C}}$$

$$= \frac{\text{saturation mixing ratio over ice at -10°C}}{\text{saturation mixing ratio over water at -8°C}}$$

$$= \frac{1.627}{2.099}$$

$$= 78\%$$

This form of estimation gave the following result for various temperatures:

Condition when frost is forming		**Condition following cessation of frost**		
OAT (°C)	Saturation-mixing ratio over ice (g of kg/kg of air)	New OAT (°C)	Saturation-mixing ratio over water (g of kg/kg of air)	RH (%)
–25	0.3955	–23	.6037	66
–10	1.627	–8	2.099	78
–5	2.518	–3	3.075	82

Based on this calculation plus the snowstorm history, a value of 90 percent RH was selected to represent any high-humidity condition after snowstorms or frosting periods.

2.1.4 Baseline FFP Buffer Limit

The benefit that evaporation brings to fluids mixed at the currently required buffer (FFP 10°C lower than OAT for SAE Type I fluids) has not been quantified. The 1997-98 tests examined fluid mixtures with FFP equal to and above OAT.

The current series of tests was designed to use fluid mixes having freezing-point buffers at 3°C and 10°C for both Type I and Type II fluids. (Despite the fact that the required buffer for Type II fluids below –25ºC is 7ºC.)

TABLE 2.1

RELATIVE HUMIDITY VALUES DURING AND AFTER SNOWFALLS

	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
05-Feb-97																				96	95	**95**	95	92
06-Feb-97	86	90	89	88	87	85	83	81	80															
06-Mar-97												96	95	93	**94**	78	63	54	47					
10-Mar-97									94	94	93	**99**	84	75	68	66								
22-Mar-97	94	94	92	**91**	93	91	77	74	70															
31-Mar-97													91	85	86	88	84	**84**	84	77	73	72		

Time of day (hh:mm)

Note: Heavy vertical lines indicate end of snowfall.

2.1.5 High Wind Conditions

1997-98 tests were performed with winds up to 20 kph. It was believed that this speed was not high enough to represent field conditions.

The current series of tests was designed with wind speeds of 30 kph. Because frost does not occur in windy conditions, the experimental design for high winds tests only for removing snow.

2.1.6 Composite Surfaces

It was noted that some aircraft critical surfaces are commonly made of composite materials and that some of these respond differently in terms of heat retention and evaporation.

The current series of tests was designed to include test plates made of composite materials typically used in aircraft construction. This subject was to be further investigated through trials on operational aircraft having surfaces of representative materials.

2.1.7 Cold-soaked Wings

It was noted that the natural buffer provided by evaporation might not be enough to provide protection if the wing were in a cold-soaked condition and the wing-skin temperature were several degrees below OAT. It was noted also that a zero buffer fluid might not protect against frost re-forming on a cold-soaked surface after deicing.

The current series of tests was designed to include trials on cold-soaked boxes. These tests were to be run in conjunction with high-humidity tests, when deposition of frost on the cold-soaked surfaces would be expected. Existing data indicate that the greatest difference between the skin temperature of a cold-soaked wing and OAT is –4°C. For these trials, a conservative value of –5°C was selected as the test-temperature differential between cold-soaked box surfaces and ambient temperature.

2.1.8 Removal of Snow

In the 1997-98 test procedures, fluids were applied on a bare plate. In industry discussion, it was contended that removal of contaminant (snow) from the surface would absorb heat and thereby reduce the extent of evaporation and the related enhancement of fluid strength.

The current series of tests was designed to include trials in which snow was removed from the plate surface by spraying. Because deicing operators do not limit the amount of fluid applied in field operations, but continue spraying until the wing is cleaned to their satisfaction, the laboratory tests were designed to duplicate this procedure.

Snow-removal tests were designed for standard flat plates covered with a specific depth of snow. Snow was removed by applying fluid, both by pouring (using the fluid spreaders) and by spraying (using sprayers developed for that purpose). The depth of snow used as a reference was specified as the most that could be removed by pouring the standard amount of test fluid (0.5 L).

Results of laboratory trials were to be confirmed by field trials on operational aircraft, in which snow deposits on wings would be removed by the normal spray process. This procedure is described in Section 2.3.

2.1.9 Non-powered Flight Control Surfaces

The effect of a low-buffer fluid on non-powered flight-control surfaces was questioned. It was noted that any frozen fluid might constrict movement of these controls, whereas no effect would be noticeable with powered control surfaces.

Because the DC-9 has non-powered elevator-control tabs, it was proposed to conduct field trials on it to examine the impact on freedom of movement of these controls.

2.2 Description of Laboratory Test Procedures

The test procedure is described in Appendix B, *Experimental Program – Laboratory Trials for the Development of Supplemental Data to Support a* ***Deicing Only*** *Table.*

2.2.1 Test Sites

A series of laboratory experiments were conducted at PMG (Photo 2.4). This facility is equipped with a large environmental chamber suitable for the tests required in this study. The chamber can produce temperatures from a low of –55°C to a high of 65°C. Chamber dimensions are: length 16.5 m, width 6.5 m and height 4 m. Tests were conducted over two weeks. The proximity of the facility to Montreal removed the need for hotel stays and thereby reduced project costs.

A brief set of supplemental trials was conducted at National Research Council Canada Climatic Engineering Facility (NRC CEF).

2.2.2 Description of Test Procedure

Regardless of the problem under examination, the basic test approach was similar for all tests. Fluid heated to a specific temperature was applied to a test surface by either pouring or spraying. The fluid strength and surface temperature were then measured continually. Any incidence of freezing on the test surface was noted.

Test variables included ambient temperature, wind speed, RH, test-surface material, and fluid type and strength. Clean, uncontaminated test surfaces were used except in the case of a special series of tests designed to learn the impact of removing snow contamination.

Because these trials were designed for *deicing only* conditions, they were conducted under dry conditions.

2.2.2.1 Overview of Test Matrix

Because several variables were related in each use, the number of tests required would be very large, in the neighbourhood of 2000. To limit the number, and still provide reliable results, the variables were limited to select test values. An overview of the resulting test conditions is shown in Table 2.2. The final test design was based on 270 separate tests.

TABLE 2.2 (Pg. 1/4)

Test Plan for Development of *Deicing Only* Table

VARY FLUID QUANTITY AND TEMPERATURE - SNOW

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)[1]			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XOH	X	XOH							1		1		1	1		1	(a)	(a)	1	
-15																					
-25					XOH	X	XOH			1		1		1	1		1	(a)	(a)	1	
-35																					

Note: (a) Conduct tests only on 0.5 liter.

VARY FLUID QUANTITY AND TEMPERATURE - FROST

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	50	35	20	70	90
-5	XOH	X	XOH							1						1	1	1	1	1	
-15																					
-25					XOH	X	XOH			1						1	1	1	1	1	
-35																					

TABLE 2.2 (Pg. 2/4)

Test Plan for Development of *Deicing Only* Table

CURRENT BUFFER AS REFERENCE

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XOH	X	XOH							1	1	1		1			1			1	
-15																					
-25					XOH	X	XOH			1	1	1		1			1			1	
-35																					

HIGH WIND

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XH		XH										1	1			1			1	
-15																					
-25					XH		XH						1	1			1			1	
-35																					

TABLE 2.2 (Pg. 3/4)

Test Plan for Development of *Deicing Only* Table

HIGH RELATIVE HUMIDITY

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XOH		X							1		1		1			1			1	1
-15																					
-25					XOH		X			1		1		1			1			1	1
-35																					

COLD SOAKED SURFACE (Using Cold Soak Boxes)

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-10	-15	-18	-25	-30	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XH	X	XH							1				1	1	1	(a)	(b)			1
-15																					
-25					XH	X	XH			1				1	1	1	(a)	(c)			1
-35																					

Note: (a) Fluid Temperature = 60°C for quantities 0.5, 0.25 L

(b) Fluid Temperature = 50°C for quantities 0.1 L

(c) Fluid Temperature = 25°C for quantities 0.1 L

TABLE 2.2 (Pg. 4/4)

Test Plan for Development of *Deicing Only* Table

REMOVAL OF SNOW BY SPRAYING

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	X		X							1				Spray until clean			1			1	
-15			X		X					1							1			1	
-25																					
-35																					

Note: Parallel tests on snow-covered and bare plates

Test snow to three thicknesses

If tests are outdoors, expose plates to existing wind

EVAPORATION ON COMPOSITE SURFACES

(ASSUME 6 SAMPLE TYPES)

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	X									1		1		1			1			1	
-15																					
-25					X					1		1		1			1			1	
-35																					

Ambient test temperatures were –5 and –25°C for all tests, except those involving snow removal in which case test temperatures were –5 and –15°C.

The freezing point of the fluid mix was selected to give a range of values, with FFP equal to OAT and lower than OAT by 3 and 10°C.

A range of wind speeds was generated for some tests. Because frost does not occur during windy conditions, tests representing sprays for frost removal and tests on cold-soaked boxes were conducted in calm conditions.

Test fluids included SAE Type I fluids (both ethylene glycol- and propylene glycol-based) and propylene glycol-based SAE Type II fluid, mixed to FFP as indicated. For tests representing frost removal, 0.1 L was used at fluid temperatures of 50, 35, and 20°C. For tests representing snow conditions, 0.5 and 0.25 L were used at fluid temperatures of 60, 50, and 40°C. Tests to remove snow involved spraying in whatever quantity was required to produce a clean surface. Quantities were measured.

The standard condition for RH was 70 percent, with 90 percent specified for high-humidity conditions.

Testing on surfaces composed of composite materials and painted surfaces included the following:

- Aluminum honeycomb;
- Carbon fibre surface without backing;
- Carbon fibre surface on honeycomb backing;
- Glass fibre surface on honeycomb backing
- Kevlar surface on honeycomb backing;
- Red polyurethane paint on aluminium; and
- Blue polyurethane paint on aluminum.

2.2.2.2 Fluid Preparation

As with the previous *deicing only* laboratory trials, the process of managing and preparing the supply of heated fluids for testing was critical. A fluid-management team was instituted. It was responsible for the following 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 dispensing quantities of heated fluids into vacuum containers or sprayer apparatus;

- Delivering test samples to the test team;
- Pouring or spraying test samples onto plates under test team supervision;
- Cleaning fluid applicators and vacuum containers to prepare for the next series of tests; and
- Maintaining the water pots used to generate desired levels of humidity.

This support role required detailed planning of procedures and equipment and good co-ordination between test members. The specialized equipment is described in Section 2.2.4.

2.2.2.3 Conducting the Trials

Two test teams, each consisting of two people, conducted the trials. Within each, the team leader ensured accuracy of conditions and co-ordinated fluid requirements and application with the fluid-management team. In general, each team was able to conduct tests on a maximum of two plates simultaneously.

The test scheduling and control sheet (Table 2.3) was used to co-ordinate and record test schedules.

Each evening, support technicians were advised of the conditions (temperature and relative humidity) required for the following morning. Usually a technician began preparation one to two hours before the planned start time.

Ambient temperature was given a final adjustment before using test-plate temperature values as the control. RH and ambient air temperature were measured continually using a Vaisala RH meter designed for cold temperatures.

Variable-speed fans (Photo 2.5) generated wind at the required speed. Wind speeds were measured, at several locations across the test stand, before and after each run.

RH was maintained for standard conditions of 70 percent RH by hot plates and water pots (Photo 2.6) placed in the test chamber. This approach proved satisfactory in maintaining desired levels of humidity. High levels for specified test conditions of 90 percent RH were generated by special equipment put in place and operated by laboratory staff. This is described in Section 2.2.4

When the desired conditions were reached, team leaders initiated testing.

TABLE 2.3 (Pg. 1/6)

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			1	FQ	T1E	-5	CALM	-5	0.25	60	70	A	
			2	FQ,FT,RH	T1E	-5	CALM	-5	0.5	60	70	A	
			3	FT	T1E	-5	CALM	-5	0.5	50	70	A	
			4	FT	T1E	-5	CALM	-5	0.5	40	70	A	
			5	FQ	T1E	-5	CALM	-8	0.25	60	70	A	
			6	FQ,FT,B	T1E	-5	CALM	-8	0.5	60	70	A	
			7	FT	T1E	-5	CALM	-8	0.5	50	70	A	
			8	FT	T1E	-5	CALM	-8	0.5	40	70	A	
			9	FQ	T1E	-5	CALM	-15	0.25	60	70	A	
			10	FQ,FT,B,RH	T1E	-5	CALM	-15	0.5	60	70	A	
			11	FT	T1E	-5	CALM	-15	0.5	50	70	A	
			12	FT	T1E	-5	CALM	-15	0.5	40	70	A	
			13	FR	T1E	-5	CALM	-5	0.1	50	70	A	
			14	FR	T1E	-5	CALM	-5	0.1	35	70	A	
			15	FR	T1E	-5	CALM	-5	0.1	20	70	A	
			16	FR	T1E	-5	CALM	-8	0.1	50	70	A	
			17	FR	T1E	-5	CALM	-8	0.1	35	70	A	
			18	FR	T1E	-5	CALM	-8	0.1	20	70	A	
			19	FR	T1E	-5	CALM	-15	0.1	50	70	A	
			20	FR	T1E	-5	CALM	-15	0.1	35	70	A	
			21	FR	T1E	-5	CALM	-15	0.1	20	70	A	
			22	FQ	T1P	-5	CALM	-5	0.25	60	70	A	
			23	FQ,FT,RH	T1P	-5	CALM	-5	0.5	60	70	A	
			24	FT	T1P	-5	CALM	-5	0.5	50	70	A	
			25	FT	T1P	-5	CALM	-5	0.5	40	70	A	
			26	FQ	T1P	-5	CALM	-15	0.25	60	70	A	
			27	FQ,FT,B	T1P	-5	CALM	-15	0.5	60	70	A	
			28	FT	T1P	-5	CALM	-15	0.5	50	70	A	
			29	FT	T1P	-5	CALM	-15	0.5	40	70	A	
			30	FR	T1P	-5	CALM	-5	0.1	50	70	A	
			31	FR	T1P	-5	CALM	-5	0.1	35	70	A	
			32	FR	T1P	-5	CALM	-5	0.1	20	70	A	
			33	FR	T1P	-5	CALM	-15	0.1	50	70	A	
			34	FR	T1P	-5	CALM	-15	0.1	35	70	A	
			35	FR	T1P	-5	CALM	-15	0.1	20	70	A	
			36	FQ	T2P	-5	CALM	-5	0.25	60	70	A	
			37	FQ,FT,RH	T2P	-5	CALM	-5	0.5	60	70	A	
			38	FT	T2P	-5	CALM	-5	0.5	50	70	A	
			39	FT	T2P	-5	CALM	-5	0.5	40	70	A	
			40	FQ	T2P	-5	CALM	-15	0.25	60	70	A	
			41	FQ,FT,B	T2P	-5	CALM	-15	0.5	60	70	A	
			42	FT	T2P	-5	CALM	-15	0.5	50	70	A	
			43	FT	T2P	-5	CALM	-15	0.5	40	70	A	
			44	FR	T2P	-5	CALM	-5	0.1	50	70	A	
			45	FR	T2P	-5	CALM	-5	0.1	35	70	A	
			46	FR	T2P	-5	CALM	-5	0.1	20	70	A	

TABLE 2.3 (Pg. 2/6)

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			47	FR	T2P	-5	CALM	-15	0.1	50	70	A	
			48	FR	T2P	-5	CALM	-15	0.1	35	70	A	
			49	FR	T2P	-5	CALM	-15	0.1	20	70	A	
			50	C1	T1E	-5	CALM	-5	0.5	60	70	C1	
			51	C2	T1E	-5	CALM	-5	0.5	60	70	C2	
			52	C3	T1E	-5	CALM	-5	0.5	60	70	C3	
			53	C4	T1E	-5	CALM	-5	0.5	60	70	C4	
			54	C5	T1E	-5	CALM	-5	0.5	60	70	C5	
			55	C6	T1E	-5	CALM	-5	0.5	60	70	C6	
			56	C7	T1E	-5	CALM	-5	0.5	60	70	C7	
			57	C1	T1E	-5	20	-5	0.5	60	70	C1	
			58	C2	T1E	-5	20	-5	0.5	60	70	C2	
			59	C3	T1E	-5	20	-5	0.5	60	70	C3	
			60	C4	T1E	-5	20	-5	0.5	60	70	C4	
			61	C5	T1E	-5	20	-5	0.5	60	70	C5	
			62	C6	T1E	-5	20	-5	0.5	60	70	C6	
			63	C7	T1E	-5	20	-5	0.5	60	70	C7	
			64	FT	T1E	-5	20	-5	0.5	50	70	A	
			65	FT	T1E	-5	20	-5	0.5	40	70	A	
			66	FQ	T1E	-5	20	-5	0.25	60	70	A	
			67	FQ,FT,RH	T1E	-5	20	-5	0.5	60	70	A	
			68	FQ	T1E	-5	20	-8	0.25	60	70	A	
			69	FQ,FT,B	T1E	-5	20	-8	0.5	60	70	A	
			70	FT	T1E	-5	20	-8	0.5	50	70	A	
			71	FT	T1E	-5	20	-8	0.5	40	70	A	
			72	FQ	T1E	-5	20	-15	0.25	60	70	A	
			73	FQ,FT,B,RH	T1E	-5	20	-15	0.5	60	70	A	
			74	FT	T1E	-5	20	-15	0.5	50	70	A	
			75	FT	T1E	-5	20	-15	0.5	40	70	A	
			76	FQ	T1P	-5	20	-5	0.25	60	70	A	
			77	FQ,FT,RH	T1P	-5	20	-5	0.5	60	70	A	
			78	FT	T1P	-5	20	-5	0.5	50	70	A	
			79	FT	T1P	-5	20	-5	0.5	40	70	A	
			80	FQ	T1P	-5	20	-15	0.25	60	70	A	
			81	FQ,FT,B	T1P	-5	20	-15	0.5	60	70	A	
			82	FT	T1P	-5	20	-15	0.5	50	70	A	
			83	FT	T1P	-5	20	-15	0.5	40	70	A	
			84	FQ	T2P	-5	20	-5	0.25	60	70	A	
			85	FQ,FT,RH	T2P	-5	20	-5	0.5	60	70	A	
			86	FT	T2P	-5	20	-5	0.5	50	70	A	
			87	FT	T2P	-5	20	-5	0.5	40	70	A	
			88	FQ	T2P	-5	20	-15	0.25	60	70	A	
			89	FQ.FT,B	T2P	-5	20	-15	0.5	60	70	A	
			90	FT	T2P	-5	20	-15	0.5	50	70	A	
			91	FT	T2P	-5	20	-15	0.5	40	70	A	
			92	HW	T1E	-5	30	-5	0.5	60	70	A	

TABLE 2.3 (Pg. 3/6)

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			93	HW	T1E	-5	30	-15	0.5	60	70	A	
			94	HW	T2P	-5	30	-5	0.5	60	70	A	
			95	HW	T2P	-5	30	-15	0.5	60	70	A	
			96	B	T1E	-5	10	-5	0.5	60	70	A	
			97	B	T1E	-5	10	-8	0.5	60	70	A	
			98	B	T1E	-5	10	-15	0.5	60	70	A	
			99	B	T1P	-5	10	-5	0.5	60	70	A	
			100	B	T1P	-5	10	-15	0.5	60	70	A	
			101	B	T2P	-5	10	-5	0.5	60	70	A	
			102	B	T2P	-5	10	-15	0.5	60	70	A	
			103	RS	T1E	-5	CALM	-5	0.5	60	70	A	X
			104	RS	T1E	-5	CALM	-5	0.5	60	70	A	X
			105	RS	T1E	-5	CALM	-5	AR	60	70	A	X
			106	RS	T1E	-5	CALM	-5	AR	60	70	A	Y
			107	RS	T1E	-5	CALM	-5	AR	60	70	A	Z
			108	RS	T1E	-5	CALM	-5	0.5	60	70	A	bare
			109	RS	T1E	-5	CALM	-15	AR	60	70	A	X
			110	RS	T1E	-5	CALM	-15	AR	60	70	A	Y
			111	RS	T1E	-5	CALM	-15	AR	60	70	A	Z
			112	RS	T1E	-5	CALM	-15	0.5	60	70	A	bare
			113	RH	T1E	-5	20	-15	0.5	60	90	A	
			114	RH	T1E	-5	20	-5	0.5	60	90	A	
			115	RH	T1P	-5	20	-5	0.5	60	90	A	
			116	RH	T2P	-5	20	-5	0.5	60	90	A	
			117	RH	T1E	-5	CALM	-15	0.5	60	90	A	
			118	RH	T1E	-5	CALM	-5	0.5	60	90	A	
			119	RH	T1P	-5	CALM	-5	0.5	60	90	A	
			120	RH	T2P	-5	CALM	-5	0.5	60	90	A	
			121	CS	T1E	-5	CALM	-5	0.5	60	90	CS	
			122	CS	T1E	-5	CALM	-5	0.25	60	90	CS	
			123	CS	T1E	-5	CALM	-10	0.5	60	90	CS	
			124	CS	T1E	-5	CALM	-10	0.25	60	90	CS	
			125	CS	T1E	-5	CALM	-15	0.5	60	90	CS	
			126	CS	T1E	-5	CALM	-15	0.25	60	90	CS	
			127	CS	T2P	-5	CALM	-5	0.25	60	90	CS	
			128	CS	T2P	-5	CALM	-5	0.5	60	90	CS	
			129	CS	T2P	-5	CALM	-15	0.25	60	90	CS	
			130	CS	T2P	-5	CALM	-15	0.5	60	90	CS	
			131	CS	T1E	-5	CALM	-5	0.1	50	90	CS	
			132	CS	T1E	-5	CALM	-10	0.1	50	90	CS	
			133	CS	T1E	-5	CALM	-15	0.1	50	90	CS	
			134	CS	T2P	-5	CALM	-5	0.1	50	90	CS	
			135	CS	T2P	-5	CALM	-15	0.1	50	90	CS	
			136	FQ	T1E	-25	CALM	-25	0.25	60	70	A	
			137	FQ,FT,RH	T1E	-25	CALM	-25	0.5	60	70	A	
			138	FT	T1E	-25	CALM	-25	0.5	50	70	A	

TABLE 2.3 (Pg. 4/6)

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			139	FT	T1E	-25	CALM	-25	0.5	40	70	A	
			140	FQ	T1E	-25	CALM	-28	0.25	60	70	A	
			141	FQ,FT,B	T1E	-25	CALM	-28	0.5	60	70	A	
			142	FT	T1E	-25	CALM	-28	0.5	50	70	A	
			143	FT	T1E	-25	CALM	-28	0.5	40	70	A	
			144	FQ	T1E	-25	CALM	-35	0.25	60	70	A	
			145	FQ,FT.B,RH	T1E	-25	CALM	-35	0.5	60	70	A	
			146	FT	T1E	-25	CALM	-35	0.5	50	70	A	
			147	FT	T1E	-25	CALM	-35	0.5	40	70	A	
			148	FR	T1E	-25	CALM	-25	0.1	50	70	A	
			149	FR	T1E	-25	CALM	-25	0.1	35	70	A	
			150	FR	T1E	-25	CALM	-25	0.1	20	70	A	
			151	FR	T1E	-25	CALM	-28	0.1	50	70	A	
			152	FR	T1E	-25	CALM	-28	0.1	35	70	A	
			153	FR	T1E	-25	CALM	-28	0.1	20	70	A	
			154	FR	T1E	-25	CALM	-35	0.1	50	70	A	
			155	FR	T1E	-25	CALM	-35	0.1	35	70	A	
			156	FR	T1E	-25	CALM	-35	0.1	20	70	A	
			157	FQ	T1P	-25	CALM	-25	0.25	60	70	A	
			158	FQ,FT,RH	T1P	-25	CALM	-25	0.5	60	70	A	
			159	FT	T1P	-25	CALM	-25	0.5	50	70	A	
			160	FT	T1P	-25	CALM	-25	0.5	40	70	A	
			161	FQ	T1P	-25	CALM	-35	0.25	60	70	A	
			162	FQ,FT,B	T1P	-25	CALM	-35	0.5	60	70	A	
			163	FT	T1P	-25	CALM	-35	0.5	50	70	A	
			164	FT	T1P	-25	CALM	-35	0.5	40	70	A	
			165	FR	T1P	-25	CALM	-25	0.1	50	70	A	
			166	FR	T1P	-25	CALM	-25	0.1	35	70	A	
			167	FR	T1P	-25	CALM	-25	0.1	20	70	A	
			168	FR	T1P	-25	CALM	-35	0.1	50	70	A	
			169	FR	T1P	-25	CALM	-35	0.1	35	70	A	
			170	FR	T1P	-25	CALM	-35	0.1	20	70	A	
			171	FQ	T2P	-25	CALM	-25	0.25	60	70	A	
			172	FQ,FT,RH	T2P	-25	CALM	-25	0.5	60	70	A	
			173	FT	T2P	-25	CALM	-25	0.5	50	70	A	
			174	FT	T2P	-25	CALM	-25	0.5	40	70	A	
			175	FQ	T2P	-25	CALM	-35	0.25	60	70	A	
			176	FQ,FT,B	T2P	-25	CALM	-35	0.5	60	70	A	
			177	FT	T2P	-25	CALM	-35	0.5	50	70	A	
			178	FT	T2P	-25	CALM	-35	0.5	40	70	A	
			179	FR	T2P	-25	CALM	-25	0.1	50	70	A	
			180	FR	T2P	-25	CALM	-25	0.1	35	70	A	
			181	FR	T2P	-25	CALM	-25	0.1	20	70	A	
			182	FR	T2P	-25	CALM	-35	0.1	50	70	A	
			183	FR	T2P	-25	CALM	-35	0.1	35	70	A	
			184	FR	T2P	-25	CALM	-35	0.1	20	70	A	

TABLE 2.3 (Pg. 5/6)

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			185	C1	T1E	-25	CALM	-25	0.5	60	70	C1	
			186	C2	T1E	-25	CALM	-25	0.5	60	70	C2	
			187	C3	T1E	-25	CALM	-25	0.5	60	70	C3	
			188	C4	T1E	-25	CALM	-25	0.5	60	70	C4	
			189	C5	T1E	-25	CALM	-25	0.5	60	70	C5	
			190	C6	T1E	-25	CALM	-25	0.5	60	70	C6	
			191	C7	T1E	-25	CALM	-25	0.5	60	70	C7	
			192	C1	T1E	-25	20	-25	0.5	60	70	C1	
			193	C2	T1E	-25	20	-25	0.5	60	70	C2	
			194	C3	T1E	-25	20	-25	0.5	60	70	C3	
			195	C4	T1E	-25	20	-25	0.5	60	70	C4	
			196	C5	T1E	-25	20	-25	0.5	60	70	C5	
			197	C6	T1E	-25	20	-25	0.5	60	70	C6	
			198	C7	T1E	-25	20	-25	0.5	60	70	C7	
			199	FQ	T1E	-25	20	-25	0.25	60	70	A	
			200	FQ,FT,RH	T1E	-25	20	-25	0.5	60	70	A	
			201	FT	T1E	-25	20	-25	0.5	50	70	A	
			202	FT	T1E	-25	20	-25	0.5	40	70	A	
			203	FQ	T1E	-25	20	-28	0.25	60	70	A	
			204	FQ,FT,B	T1E	-25	20	-28	0.5	60	70	A	
			205	FT	T1E	-25	20	-28	0.5	50	70	A	
			206	FT	T1E	-25	20	-28	0.5	40	70	A	
			207	FQ	T1E	-25	20	-35	0.25	60	70	A	
			208	FQ,FT,B,RH	T1E	-25	20	-35	0.5	60	70	A	
			209	FT	T1E	-25	20	-35	0.5	50	70	A	
			210	FT	T1E	-25	20	-35	0.5	40	70	A	
			211	FQ	T1P	-25	20	-25	0.25	60	70	A	
			212	FQ,FT,RH	T1P	-25	20	-25	0.5	60	70	A	
			213	FT	T1P	-25	20	-25	0.5	50	70	A	
			214	FT	T1P	-25	20	-25	0.5	40	70	A	
			215	FQ	T1P	-25	20	-35	0.25	60	70	A	
			216	FQ,FT,B	T1P	-25	20	-35	0.5	60	70	A	
			217	FT	T1P	-25	20	-35	0.5	50	70	A	
			218	FT	T1P	-25	20	-35	0.5	40	70	A	
			219	FQ	T2P	-25	20	-25	0.25	60	70	A	
			220	FQ,FT,RH	T2P	-25	20	-25	0.5	60	70	A	
			221	FT	T2P	-25	20	-25	0.5	50	70	A	
			222	FT	T2P	-25	20	-25	0.5	40	70	A	
			223	FQ	T2P	-25	20	-35	0.25	60	70	A	
			224	FQ,FT,B	T2P	-25	20	-35	0.5	60	70	A	
			225	FT	T2P	-25	20	-35	0.5	50	70	A	
			226	FT	T2P	-25	20	-35	0.5	40	70	A	
			227	HW	T1E	-25	30	-25	0.5	60	70	A	
			228	HW	T1E	-25	30	-35	0.5	60	70	A	
			229	HW	T2P	-25	30	-25	0.5	60	70	A	
			230	HW	T2P	-25	30	-35	0.5	60	70	A	

TABLE 2.3 (Pg. 6/6)

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			231	B	T1E	-25	10	-25	0.5	60	70	A	
			232	B	T1E	-25	10	-28	0.5	60	70	A	
			233	B	T1E	-25	10	-35	0.5	60	70	A	
			234	B	T1P	-25	10	-25	0.5	60	70	A	
			235	B	T1P	-25	10	-35	0.5	60	70	A	
			236	B	T2P	-25	10	-25	0.5	60	70	A	
			237	B	T2P	-25	10	-35	0.5	60	70	A	
			238	RS	T1E	-15	CALM	-15	0.5	60	70	A	X
			239	RS	T1E	-15	CALM	-15	0.5	60	70	A	X
			240	RS	T1E	-15	CALM	-15	AR	60	70	A	X
			241	RS	T1E	-15	CALM	-15	AR	60	70	A	Y
			242	RS	T1E	-15	CALM	-15	AR	60	70	A	Z
			243	RS	T1E	-15	CALM	-15	0.5	60	70	A	bare
			244	RS	T1E	-15	CALM	-25	AR	60	70	A	X
			245	RS	T1E	-15	CALM	-25	AR	60	70	A	Y
			246	RS	T1E	-15	CALM	-25	AR	60	70	A	Z
			247	RS	T1E	-15	CALM	-25	0.5	60	70	A	bare
			248	RH	T1E	-25	20	-35	0.5	60	90	A	
			249	RH	T1E	-25	20	-25	0.5	60	90	A	
			250	RH	T1P	-25	20	-25	0.5	60	90	A	
			251	RH	T2P	-25	20	-25	0.5	60	90	A	
			252	RH	T1E	-25	CALM	-35	0.5	60	90	A	
			253	RH	T1E	-25	CALM	-25	0.5	60	90	A	
			254	RH	T1P	-25	CALM	-25	0.5	60	90	A	
			255	RH	T2P	-25	CALM	-25	0.5	60	90	A	
			256	CS	T1E	-25	CALM	-25	0.1	25	90	CS	
			257	CS	T1E	-25	CALM	-30	0.1	25	90	CS	
			258	CS	T1E	-25	CALM	-35	0.1	25	90	CS	
			259	CS	T2P	-25	CALM	-25	0.1	25	90	CS	
			260	CS	T2P	-25	CALM	-35	0.1	25	90	CS	
			261	CS	T1E	-25	CALM	-25	0.5	60	90	CS	
			262	CS	T1E	-25	CALM	-25	0.25	60	90	CS	
			263	CS	T1E	-25	CALM	-30	0.5	60	90	CS	
			264	CS	T1E	-25	CALM	-30	0.25	60	90	CS	
			265	CS	T1E	-25	CALM	-35	0.5	60	90	CS	
			266	CS	T1E	-25	CALM	-35	0.25	60	90	CS	
			267	CS	T2P	-25	CALM	-25	0.5	60	90	CS	
			268	CS	T2P	-25	CALM	-25	0.25	60	90	CS	
			269	CS	T2P	-25	CALM	-35	0.5	60	90	CS	
			270	CS	T2P	-25	CALM	-35	0.25	60	90	CS	

They were responsible for scheduling and for tracking progress. A scheduling and control sheet (Table 2.3) was used.

Following application of the fluid, tests were run for 20 minutes, conforming to procedures followed in the original series of tests. This provided enough time to allow plate temperatures to cool beyond the point of fluid enhancement by evaporation.

Plate temperatures were monitored throughout the test run by thermistor probes installed on plate surfaces and by data loggers. Thermistor probes were mounted at the 22.5 cm (9”) line on the plate’s upper surface. Temperatures were allowed to return to ambient laboratory temperature before the next test.

Fluid strength was measured continually by hand-held Brix-scale refractometers (Photo 2.7). Measurements were taken often enough to support a temperature profile for FFP. A representative mix of fluids was collected by the procedure for lifting samples for fluid-strength measurement. This involved running the fluid-sampling tool the full length of the plate, from bottom to top, but avoiding fluid from the drip line. Because the freezing points were equal to or below OAT, freezing was not expected. This eliminated the need to run duplicate tests for fluid freezing on undisturbed surfaces. In the case of cold-soaked box tests, when active frost did occur, fluid sampling was restricted to one side of the surface, leaving the other undisturbed for observation.

Tests on cold-soaked boxes (Photo 2.8) required an additional support team of two people to operate the fluid chiller and to charge and replace the boxes. For these tests, a reference box with a bare (no fluid) surface was maintained to demonstrate that frost was in fact being deposited continually. Surfaces were scraped clean of any frost deposits before the application of fluid.

Snow-removal tests were conducted on standard flat plates. Some were conducted with fluid poured (using the fluid spreaders) and others with fluid applied (by spraying, using special sprayers developed for that purpose).

When fluid was applied by pouring, a layer of snow was first spread over the plate, using a hand-held shaker developed for that purpose. This was natural snow recovered from the grounds around PMG. The reference depth was specified as the most that could be removed by pouring the standard test fluid amount (0.5 L). Several trials were conducted to establish the reference depth. The snow temperature maintained was colder than that of the plate, to prevent sticking. Tests consisted of pouring the heated fluid with the fluid spreader, confirming that all snow had been removed, and then measuring fluid Brix values as described previously. The test was repeated to verify results.

When fluid was sprayed, snow was first applied to the plate, using the shaker as described above. Three depths of snow were examined: a depth equal to the reference depth learned from the pour tests, and depths at two times and four times that depth. This resulted in tests on snow 0.1, 0.2, and 0.4 cm deep. The amount of heated fluid was not pre-selected; the spray was continued until all snow was removed. The fluid concentration was then measured continually. The amount of fluid sprayed was measured by weighing the sprayer before and after the test run. A parallel test following standard test procedures on a bare plate was conducted as a control case for comparison of fluid enrichment.

Videotaped and photographic records of the test set-up and of any unusual or unexpected results were maintained.

2.2.3 Data Forms

A single data form (Brix Progression, Figure 2.1) was used for these test data experiments. It had the dual purpose of test-fluid order form and test-data recording. The form was initiated by each team leader, who noted requirements for the next run, Run #, fluid type and freezing point, type of test surface type, fluid quantity, and fluid temperature.

The form was then passed to the fluid-preparation team, who recorded temperature and strength.

Each data sheet required recording of ambient temperature, RH, wind speeds, and data specific to each test run as shown on the form.

2.2.4 Equipment

Conduct of these trials required a wide variety of support equipment.

2.2.4.1 Fluid Preparation

Quantities of the various fluids were premixed to the required strength before transporting them to the test site.

FIGURE 2.1

DEICING ONLY TRIALS
BRIX PROGRESSION

DATE: January , 1999

OAT: ________ **°C**

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

Run #: ________

Fluid: ________

Surface Type: ________

Thermistor Channel #: ________

Start Time : ________ (hh:mm:ss)

Initial Fluid Amount: ________ **Litres**

Initial Fluid Temperature: ________ **°C**

Initial Fluid Brix: ________

Frost Appearance Time: ________

Snow Depth (for snow removal trials): ________

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

Comments on Final Plate Condition: ________

Run #: ________

Fluid: ________

Surface Type: ________

Thermistor Channel #: ________

Start Time : ________ (hh:mm:ss)

Initial Fluid Amount: ________ **Litres**

Initial Fluid Temperature: ________ **°C**

Initial Fluid Brix: ________

Frost Appearance Time: ________

Snow Depth (for snow removal trials): ________

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

Comments on Final Plate Condition: ________

MEASUREMENTS BY: ________

HAND WRITTEN BY: ________

A microwave oven (Photo 2.9) was used to heat the fluids. After the first few tests, the fluid-management team developed a good understanding of the time needed to heat the test quantities. Target temperatures for the heating process were slightly higher than that specified for the tests to compensate for temperature drop during fluid handling before application.

Specified quantities of prepared fluids were poured into thermos containers for *pour* tests. Quantities judged to be enough for *spray* tests were poured into the sprayer tank. The final temperature and strength were measured at this point. The thermos containers were then placed, along with the data sheet, in a carrying tray (Photo 2.10).

2.2.4.2 Fluid Application

Spreaders (Photo 2.11) developed for the original series of tests (1997-98) ensured a consistent and even application of fluid over the surface. Spreaders were washed and dried` between applications to avoid contamination by residues from previous tests. Fluids, spreaders, and sprayers were kept on standby in a warm area before application.

A special fluid sprayer was assembled for tests representing frost-removal sprays. Because a very small amount was involved (0.1 L), a small container was necessary. Some thought was given to using off-the-shelf equipment such as compressed air-paint sprayers, but they did not produce the needed spray pattern. A short piece of PVC piping, with screw caps at either end, was used to make a small receptacle of the correct size. The cap at one end was modified to accept a sprayer nozzle, and the cap at the other end was modified with a compressed air fitting. Walls of the container were wrapped in insulation. The 0.1 L of prepared fluid was poured into the body of the sprayer by removing the spray-nozzle cap. At the test stand, an air-pressure hose from a portable air compressor (regulated at 25 psi) was attached for spraying. Photos 2.12 and 2.13 illustrate it. This sprayer performed very well, providing a pattern, on a small scale, similar to that seen for frost removal in field operations.

Spray equipment for snow-removal trials consisted of the body of a portable fire extinguisher modified with an air-pressure fitting (Photo 2.14). A nozzle from a garden sprayer was installed. An air-pressure hose from a portable air compressor (regulated at 25 psi) was attached. This produced a spray pattern (Photo 2.15) similar to that used in field operations (when snow is removed by a combination of melting and flushing). The unit was weighed before and after each application to learn the quantity of fluid applied.

2.2.4.3 Test Stand Set-up

A standard test stand (like the one for testing fluid holdover time) was used. Because the laboratory floor consisted of metal plates over concrete, it was necessary to provide special protection to prevent test fluid from spilling onto the floor. A large drip tray (Photo 2.16), made of plywood and plastic film, was placed under the stand to capture any fluid that flowed from the plates. Fluid in the tray was periodically collected with a wet/dry vacuum cleaner. Non-slip mats were placed about the work area.

2.2.4.4 Test Surfaces

In addition to standard bare-aluminum test plates, plates made of composite materials typically found in aircraft construction were used. The designations and description of these surfaces were as follows:

C1	Aluminum honeycomb
C2	Carbon-fibre surface without backing, painted grey polyurethane
C3	Carbon-fibre surface on honeycomb backing, painted grey polyurethane
C4	Glass-fibre surface on honeycomb backing, painted grey polyurethane
C5	Kevlar surface on honeycomb backing, painted grey polyurethane
C6	Aluminum plates painted red enamel
C7	Aluminum plates painted blue enamel

On testing with the painted plates, it was observed that fluid very quickly drained off, leaving a dry surface behind. It was suspected that this effect was associated with the enamel paint that had been used in their preparation. After the first set of tests, these plates were repainted using an aircraft polyurethane paint corresponding to that of the composite plates.

C8	Aluminum plates painted red polyurethane
C9	Aluminum plates painted silver/grey polyurethane

Photos 2.17 and 2.18 show the aluminum honeycomb and carbon fibre on honeycomb plates.

Cold-soaked boxes (7.5cm/3in deep) used for fluid-holdover testing were also used as test surfaces. Photo 2.11 shows two of the boxes during testing.

2.2.4.5 Measuring Instruments

Thermistor probes mounted on test plates, in conjunction with a data logger, were used continually to track temperatures of surfaces. The data logger was linked to a laptop PC, which provided a continuous real-time display of surface temperatures.

Hand-held Brix-scale refractometers were used to measure fluid concentrations. Samples for Brix measurements were lifted with strips of flexible plastic sheeting.

Winds were measured with a hand-held anemometer (Photo 2.19). This was done at several points across the stand, before and after test runs.

RH was measured by a Vaisala cold-temperature-RH unit (Photo 2.20). The probe was secured to the test stand, and the instrument was placed in an adjoining heated room along with the PC displaying test-surface temperature. Both the RH meter and the PC displays were visible in the test area through a connecting window.

An electronic scale was provided by PMG for measuring frost-deposition rates.

2.2.4.6 Equipment for Generating Test Conditions

Ambient test temperature was produced by the laboratory. The laboratory is supposed to be capable of producing temperatures from –55°C to +65°C ± 0.5°C with a cooling rate of 20°C/hr adjustable.

Portable fans were rented from a movie-production company to generate the winds. These fans were fitted with adjustable speed controls that delivered desired speeds without the need for moving the fans. Having once identified the setting that would deliver a desired speed, it was noted for use in later tests.

To simulate natural snow on a wing, a snow shaker was adapted from a plastic shipping box for milk containers, fitted with a wire-mesh screen. Natural snow taken from snow banks around the building site was placed in it and shaken over the test plate. The wire mesh restrained and broke up any large lumps of snow. Snow was distributed (Photo 2.21) evenly over the surface until the desired depth was achieved.

Cold-soaked box tests used a liquid-nitrogen bath to cool the glycol, which was then used to fill the boxes.

Humidity levels in the test chamber were controlled in several ways. The standard level was specified at 70 percent RH. This level was supported by several hot plates and water pots placed at the rear of the cold chamber. These were turned on and off to maintain humidity in the desired range.

Staff attempts to produce specified levels of high humidity (90 percent RH) were more complex. The initial attempt used a spray nozzle attached to a portable car-wash unit. The latter, with its supply of heated water, was placed in an adjoining room. The delivery hose was passed through an access port to a spray nozzle behind the cold chamber (Photo 2.22). This set-up did deliver high humidity but resulted in an ambient condition similar to freezing fog. This resulted in precipitation at 1.7 g/dm^2/hr.

A second, more successful, attempt to generate high humidity used a 34 kW steam generator (Photo 2.23). This unit was placed outside the cold chamber. It blew high-humidity air through ducts. It was able to generate a satisfactory level of humidity without the high deposition rate of the first attempt. When it was in operation, the ambient air became quite foggy, due to suspended particles of moisture in the air. Through trial and error, a satisfactory procedure was settled on. This provided both high humidity and clear air. The procedure involved generating the desired level of humidity with the steam generator, then turning it off and maintaining the humidity with many hot plates and water pots (as used to maintain the standard reference level of humidity). The steam generator was turned on occasionally between tests to provide an additional burst of humidity.

2.2.5 Fluids

Fluids used in these laboratory experiments included SAE Type I fluid, both ethylene glycol-based and propylene glycol-based, and SAE Type II fluid, propylene glycol-based.

Fluid brands used for testing included:

	Brand Name	**Symbol for Tests**
SAE Type I	UCAR ADF	T1E
SAE Type I	Octagon Octaflo	T1P
SAE Type II	Clariant 1906	T2P

These were mixed to provide three levels of FFP for testing: a freezing point equal to the test ambient temperature and freezing points 3°C and 10°C colder.

2.2.6 Personnel and Participation

PMG staff provided technical support and prepared laboratory ambient conditions in readiness for testing.

Representatives from the FAA and Transport Canada's TDC participated as observers at various tests.

APS Aviation designed, coordinated, and conducted the trials. Data were gathered and analyzed by APS.

2.3 Description of Procedures for Field Trials on Aircraft

This test procedure is described in Appendix C, *Experimental Program - Aircraft Trials for the Development of a* ***Deicing Only*** *Table.*

2.3.1 Test Sites

Trials on aircraft and on a wing foil were conducted at the Central Deicing Facility at Dorval.

2.3.2 Description of Test Procedure

Trials on aircraft were planned to confirm that laboratory findings on the following problems were repeatable in field trials:

- Fluid enrichment following the actual removal of snow; and
- Influence of composite materials and painted aluminum surfaces on the enrichment of fluid through evaporation.

The following problem was to be examined only in field trials:

- Effect of frozen fluid on freedom of movement of non-powered flight-control surfaces.

Trials were planned on aircraft for two sessions.

2.3.2.1 Snow-Removal Trials

Trials were initiated by APS based on forecast weather conditions and confirmation of availability of aircraft, aircraft towing, and deicing ground crews. Dry weather with calm winds and ambient air temperature lower than -5ºC was specified.

A US Airways Boeing 737 was made available. The operator’s ground handler towed it to the deicing centre. APS staff then prepared it for tests, mounting thermistor probes on wing surfaces at pre-defined locations.

The outer third of the wing was used for testing, based on previous test results showing that area to be the most critical (demonstrating faster heat loss and earlier freezing).

Aéromag 2000 provided the deicing vehicle and their staff, who sprayed fluids heated to specified temperatures and mixed to specified freezing points. Fluid application was according to standard procedures.

Tests were conducted with UCAR ADF Type I fluid mixed to a FFP lower than OAT.

An initial control case test on a bare wing was performed. Fluid was sprayed according to the operator's standard procedure, simulating removal of light snow. Fluid strength was then measured continually until test end (20 minutes) at indicated locations on the wing surface. This test was repeated to confirm results.

A covering of 0.5 cm of snow was distributed (Photo 2.24) over the outer third of the wing surface (Photo 2.25), using the hand-held shaker developed for laboratory trials. The reference depth used in the laboratory trials was 0.1 cm, and tests were conducted as well on depths of 0.2 and 0.4 cm. Snow used in aircraft trials was recovered from the local area. It was not fresh snow and had been exposed to rain; consequently, it was very granular and dense.

A spray operator cleaned snow from the wing surface (Photo 2.26) according to standard spray procedure, and fluid strength was measured (Photo 2.27) continually at indicated places.

The test was repeated with 1.5 cm of snow.

2.3.2.2 Trials To Determine Freedom Of Movement Of Non-Powered Flight Controls

This trial was planned for conduct on a DC-9.

This test involved spraying the horizontal stabilizer with an unheated deicing fluid mixed to a freezing point 5°C above OAT. An interval was allowed to pass. Freedom of movement of the non-powered elevator-control tabs was then evaluated by a pilot using normal flight controls and an observer where the movement of elevator control tabs could be monitored.

The procedure required the presence of a certified mechanic to ensure serviceability and airworthiness of the flight-control surface after the test. During the 1998-99 winter, none of the current DC-9 operators at Dorval Airport agreed to participate in a trial.

2.3.2.3 Influence of Composite Materials

This trial required a wing construction that included composite material surfaces. Considerable effort was expended to find suitable aircraft types for testing, by identifying airlines that operated them at Dorval or at a nearby airport and asking operators to participate. In the end, the quest for test aircraft was unsuccessful; these tests were not done.

The detailed test procedure is described in Appendix C.

2.3.3 Data Forms

Data forms used in the aircraft trials are listed below:

- Figure 2.2 General form (every test);
- Figure 2.3 General form (once per session); and
- Figure 2.4 Brix form for aircraft wing.

These forms are included in the detailed test procedure (Appendix C).

2.3.4 Equipment

Equipment included the thermistor probe and data logger used to track wing-skin temperatures over the test period.

The snow shaker developed for the laboratory trials was used to spread snow over the wing.

Hand-held Brix-scale refractometers were used to measure fluid concentrations. Fluid samples for Brix measurements were lifted with strips of flexible plastic sheeting.

Other equipment used was common to full-scale fluid-holdover trials conducted on aircraft and listed in Appendix C.

2.3.5 Fluids

SAE Type I UCAR ADF mixed to a freezing point of –12°C was used. Fluid temperature, as indicated by the deicing vehicle instrumentation, was 78°C.

FIGURE 2.2

GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY PLATE/WING COORDINATOR)

AIRCRAFT TYPE: DC-9 F100 B-737 RJ

DATE: ____________________

RUN #: ____________________

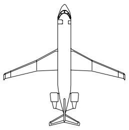
WING: PORT (A) STARBOARD (B)

WIND SPEED: __________ kph

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: ____________________

File:g:\cm1514\report\de_only\BRX_FORM
At: GFORM 2
Printed: 4/14/2005, 3:08 PM

FIGURE 2.3

GENERAL FORM (ONCE PER SESSION)

(TO BE FILLED IN BY OVERALL COORDINATOR)

AIRPORT: YUL

AIRCRAFT TYPE: DC-9

EXACT PAD LOCATION OF TEST: ____________________

AIRLINE: ____________________

DATE: ____________________

FIN #: ____________________

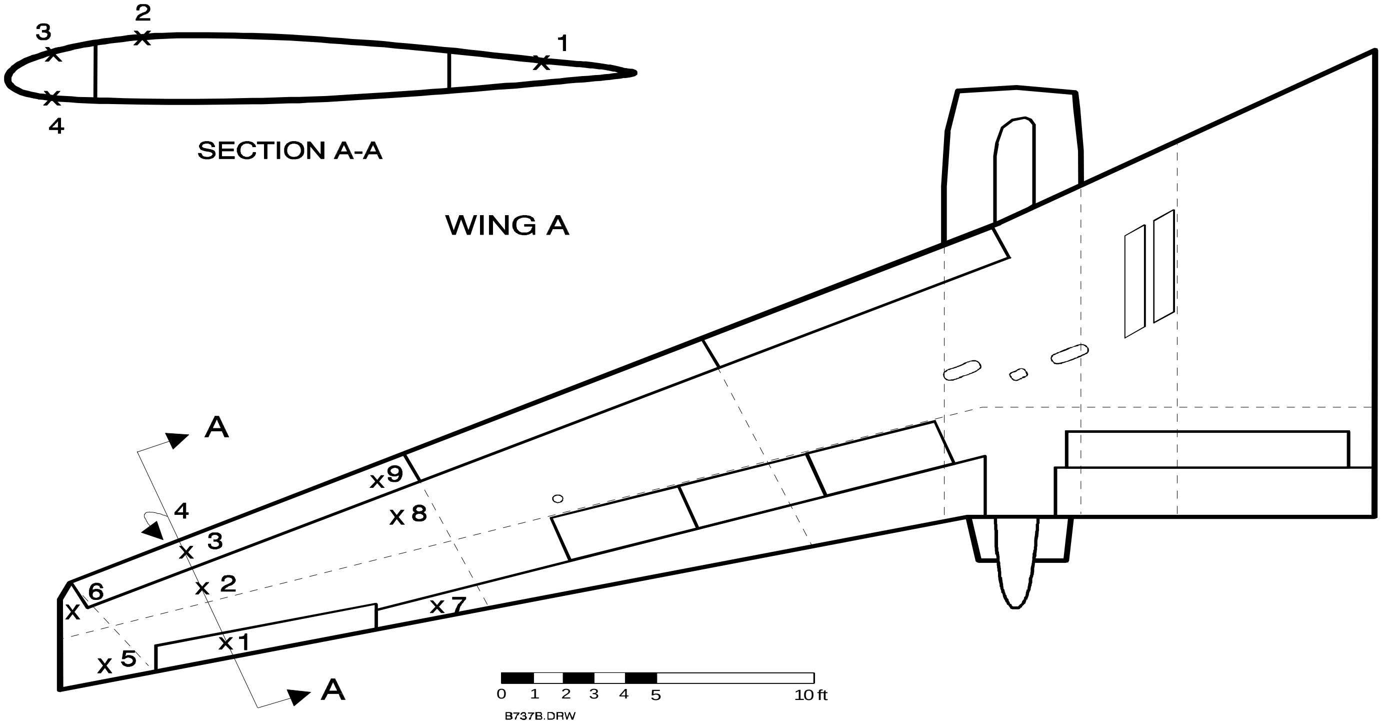
APPROX. AIR TEMPERATURE: ________ ºC

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

R/H: ________ %

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

Thermistor Probes Mounting Locations



COMMENTS: ____________________

MEASUREMENTS BY: ____________________

HAND WRITTEN BY: ____________________

File:g:\cm1514\report\de_only\DE_GFORM
At: GFORM 1
Printed: 4/14/2005, 3:09 PM

FIGURE 2.4

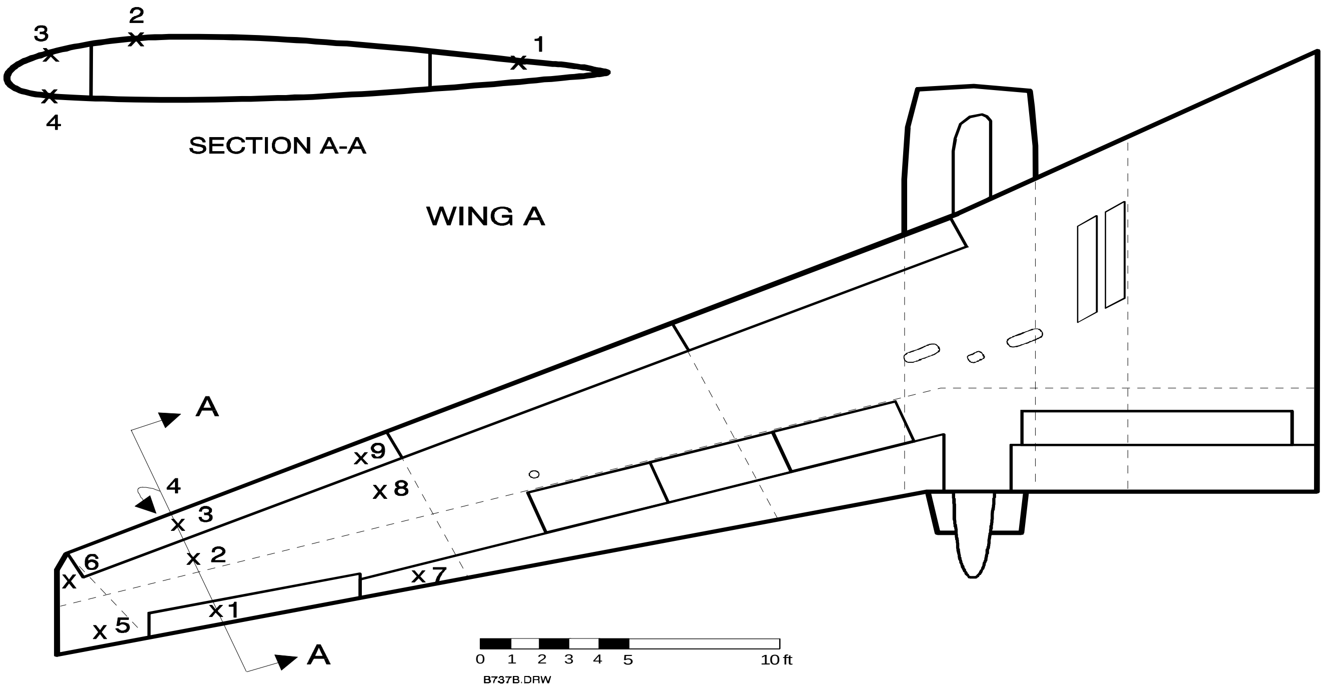
BRIX FORM FOR AIRCRAFT WING

DATE: ______________________ **RUN #:** ______________

Final Drip Line Brix: ______________ **Snow Depth on Wing:** ______________

Location 1		Location 2		Location 3		Location 4		Location 5	
Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix

Thermistor Probes Mounting Locations



Note: - indicate area covered by snow, on wing diagram.

- Record snow depth.

COMMENTS: ______________________________________

BRIX MEASUREMENTS BY: ______________________

HAND WRITTEN BY: ______________________

2.3.6 Personnel

APS Aviation staff designed, coordinated, and conducted the trials. Data were gathered and analyzed by APS.

Aéromag 2000 provided the deicing vehicle and staff; they conducted spray operations in conformity with their standard procedures.

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Photo 2.1
Measuring Fluid Temperature at Nozzle

Photo 2.2
Measuring Fluid Temperature at Wing

Photo 2.3

Measuring Drop in Fluid Temperature

Photo 2.4

PMG Test Facility

Photo 2.5

Variable Speed Fans

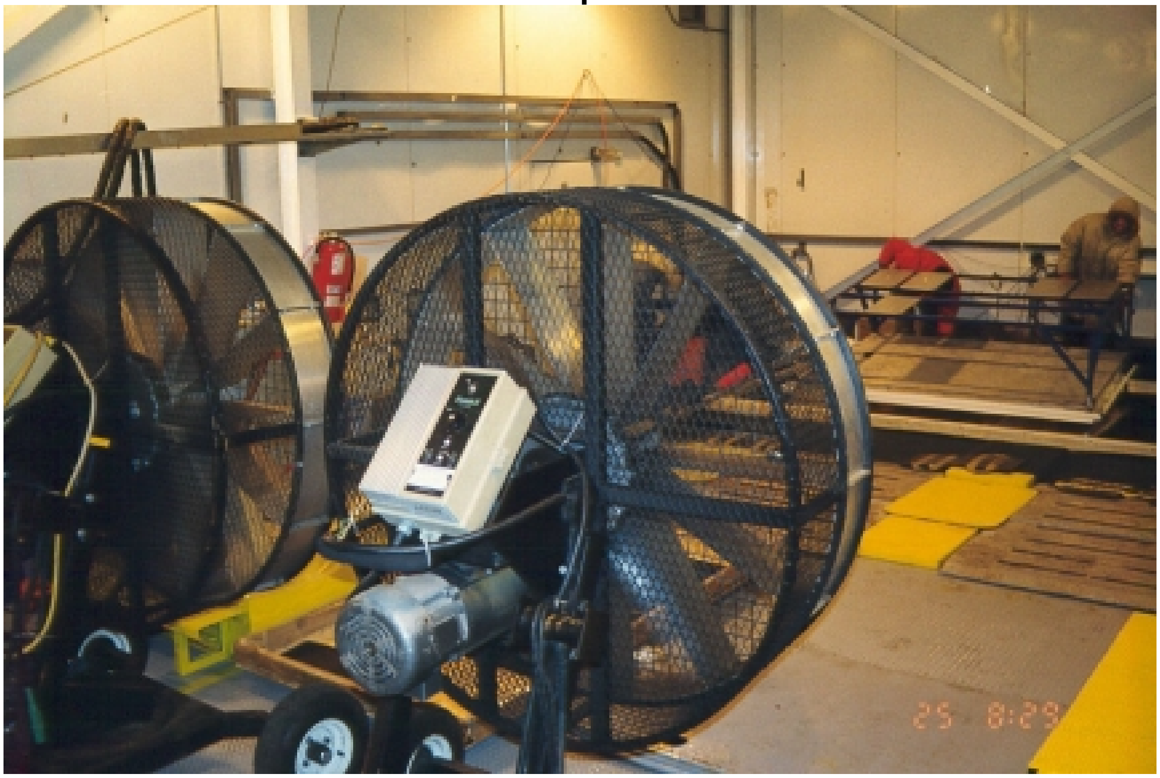


Photo 2.6

Humidity Pots

Photo 2.7
Using a Brix-Scale Refractometer

Photo 2.8
Fluid Contamination on Cold-Soaked Box Surface

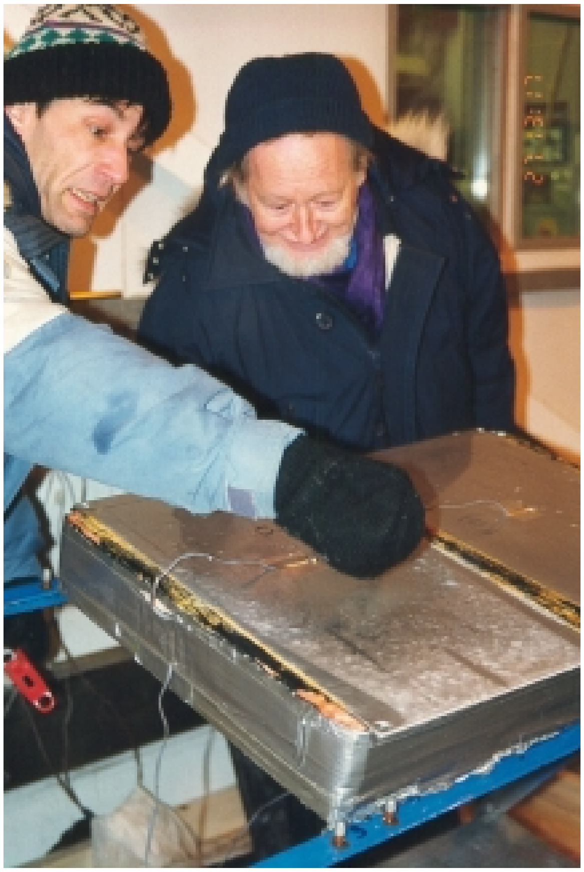


Photo 2.9

Heading Fluid in Microwave

Photo 2.10

Thermos in Carrying Tray

Photo 2.11
Applying Fluid with Spreader

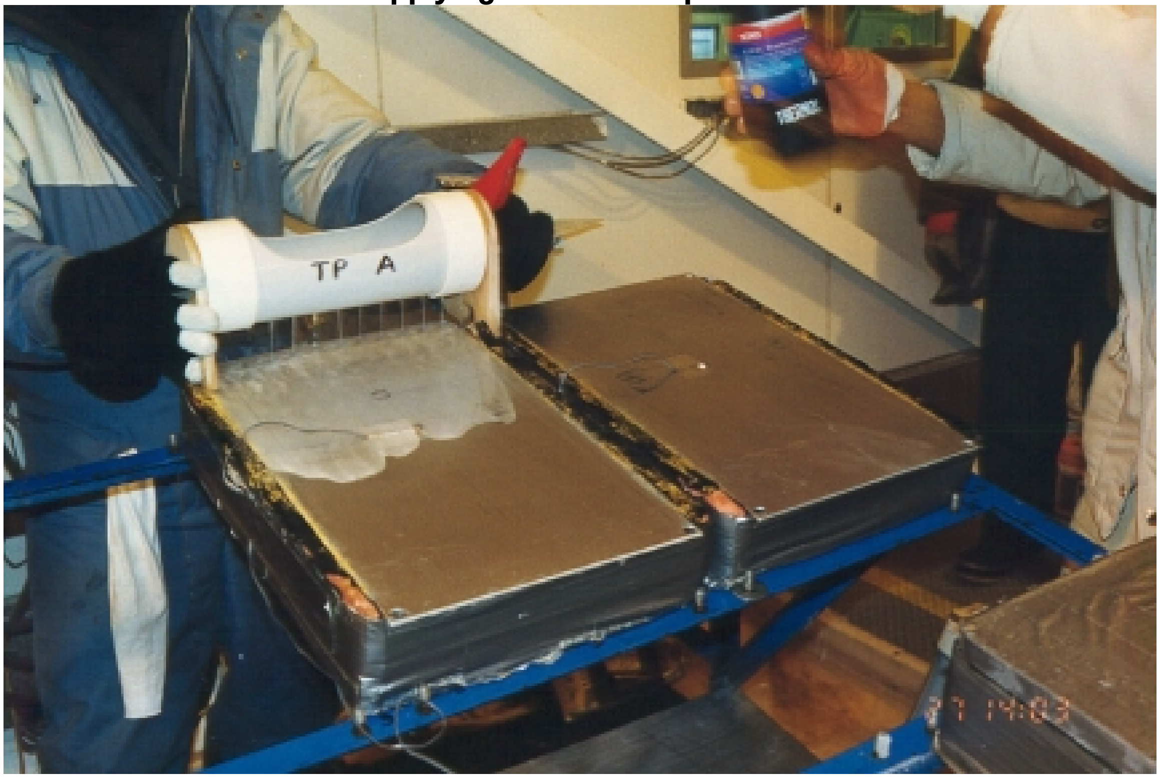


Photo 2.12
Sprayer for 0.1 L Frost Sprays

Photo 2.13

Assembled Sprayer for Frost Sprays

Photo 2.14

Sprayer for Snow Deicing

Photo 2.15

Removing Snow with Sprayer

Photo 2.16

Test Stand

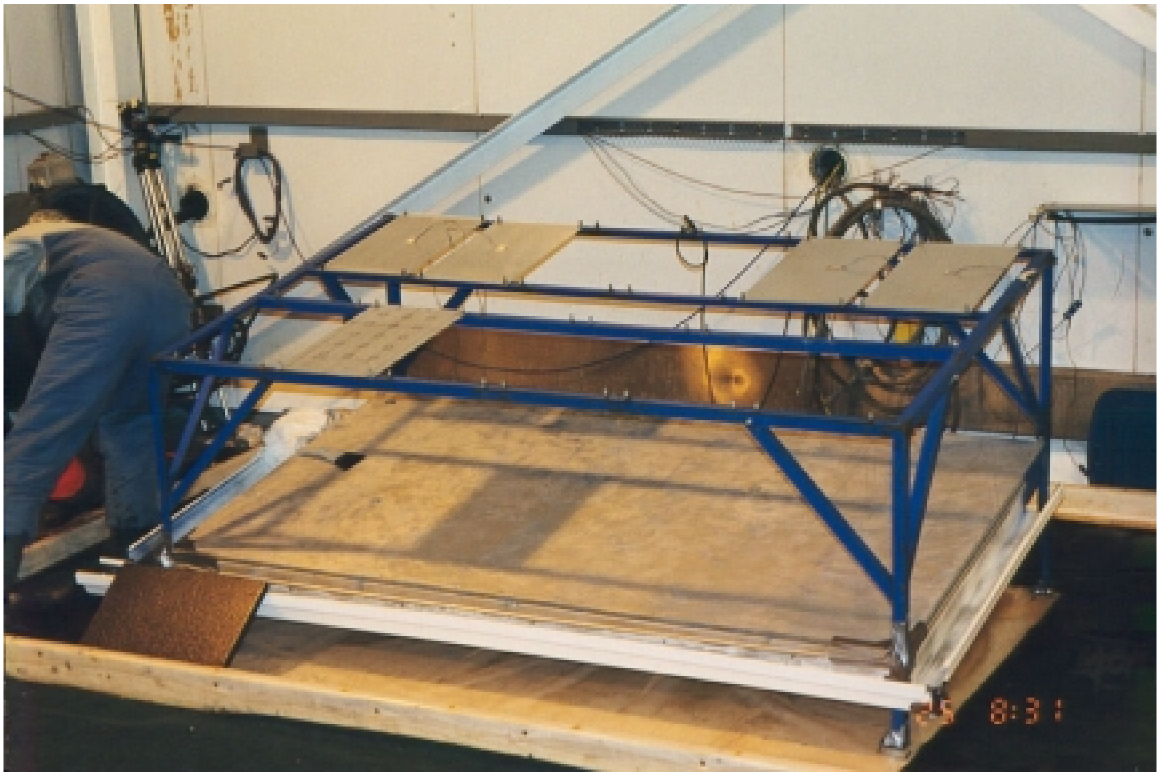


Photo 2.17

Aluminum-Honeycomb Surface

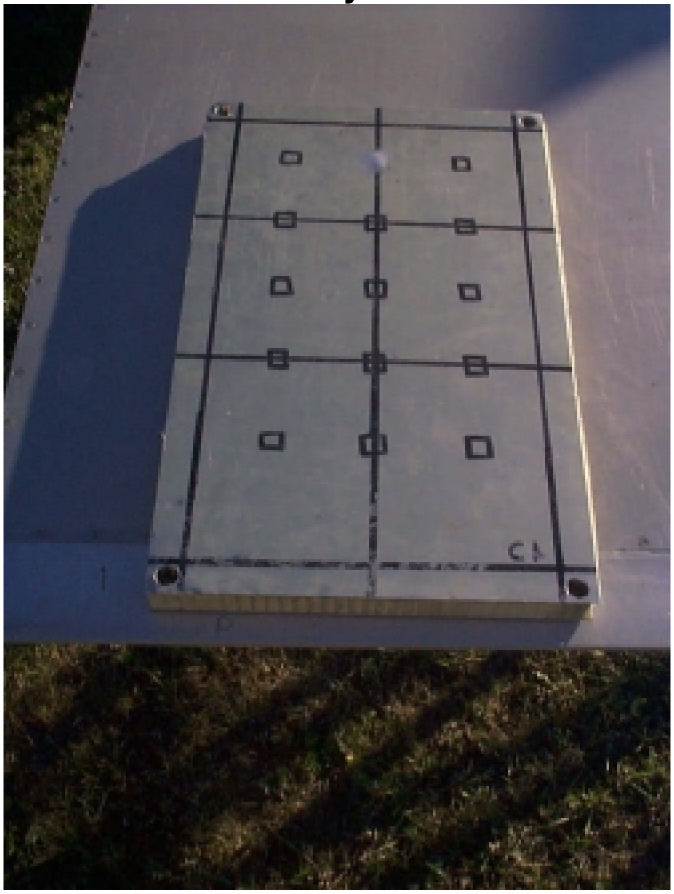


Photo 2.18

Carbon Fibre on Honeycomb Surface

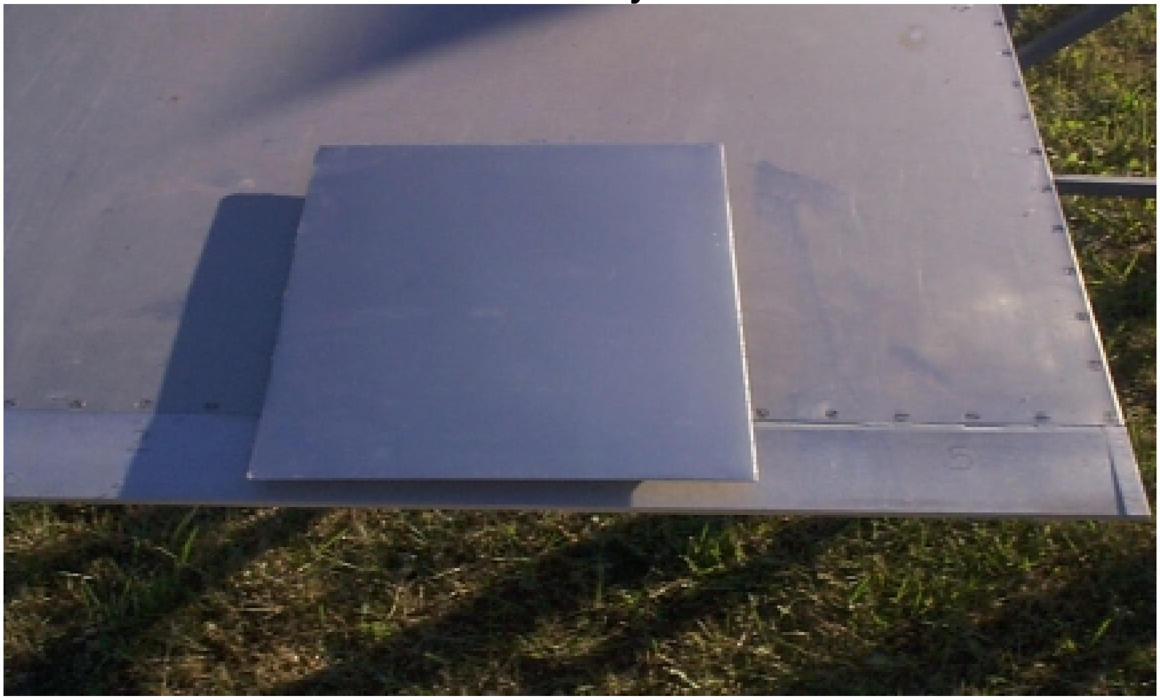


Photo 2.19

Hand-Held Anemometer

Photo 2.20

Vaisala RH Meter

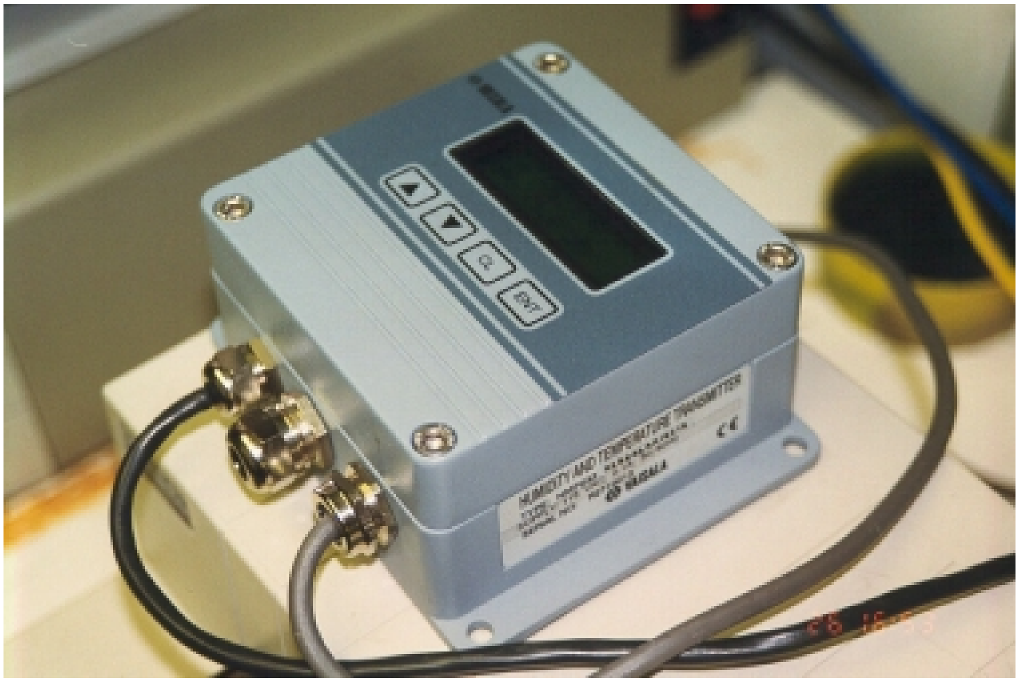


Photo 2.21

Applying Snow to Plate

Photo 2.22

High Humidity via Water Mist

Photo 2.23

High Humidity via Steam Generator

Photo 2.24

Applying Snow to Wing

Photo 2.25

Layer of Snow on Wing

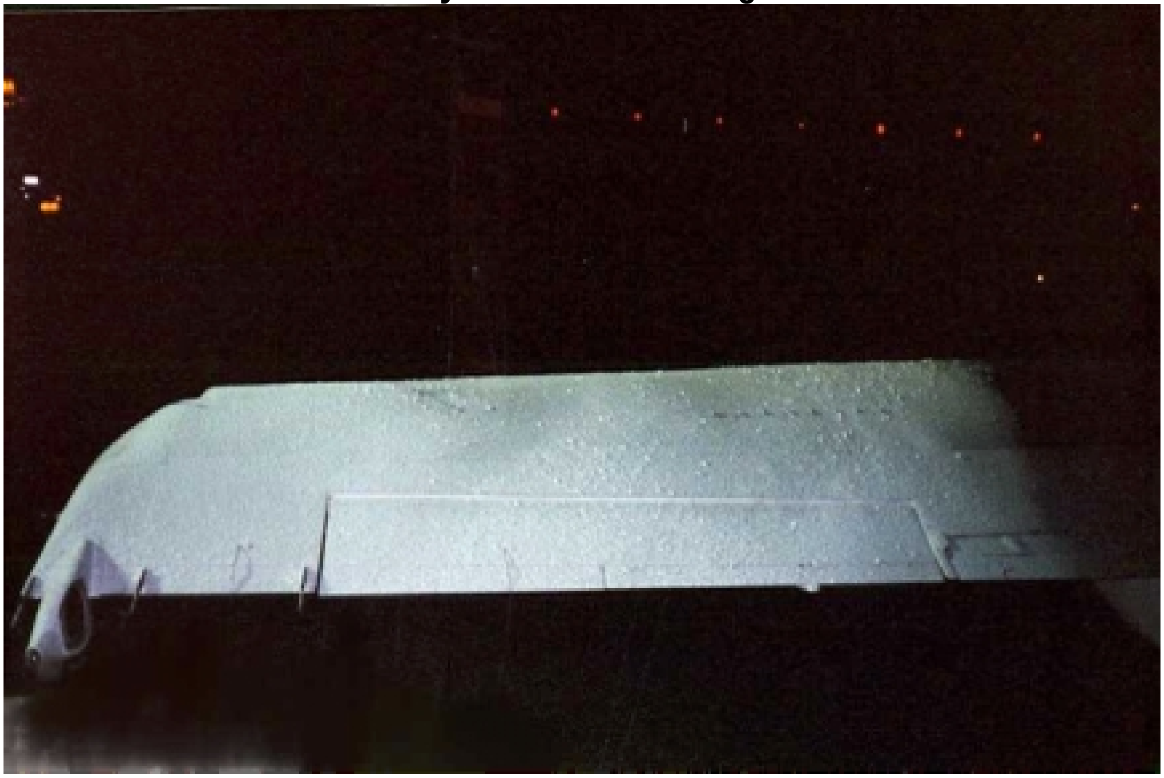


Photo 2.26

Removing Snow with De-icing Spray

Photo 2.27
Measuring Fluid Strength

3. DESCRIPTION AND PROCESSING OF DATA

3.1 Laboratory Trials

The main series of laboratory trials were conducted at PMG from 18 to 28 January 1999. This resulted in 308 tests.

A supplementary trial session to further examine the test condition simulating a cold-soaked wing was conducted at the NRC CEF on 26 March 1999. It resulted in 23 more tests.

A complete log of trials is shown in Table 3.1 for tests at PMG and Table 3.2 for tests at NRC CEF.

Some column headings in the logs require comment:

Test no. is simply a data-record identifier, not a test-sequence indicator.

Form no. is the number of the data form on which test results are recorded. The form was designed to allow recording of two tests.

Run no. corresponds to the Run # shown on the Test Scheduling and Control Sheet (Table 2.3). Duplicate runs are identified by an alphabetical indicator attached to the run #.

Fluid name reflects the mix and type of fluid used. A code such as T1E is used: T1 or T2 denotes Type I or Type II; E or P denotes ethylene or propylene glycol-based fluid.

Thermistor # is a record of the thermistor data channel to enable matching with individual tests results.

Initial fluid amount reflects specific amounts for tests in which fluids were poured and AR (as required) for tests in which fluid was applied by spray. For the latter type, the measured fluid amount is indicated in the *Comments* column.

In addition to the logged information, for each test an ongoing record of plate temperature was maintained on a data logger, and a record of measured progressive Brix values was recorded on the data form.

To display the results of each test, the measured fluid strength was converted to FFP and then charted on a graph along with plate temperature. Figure 3.1 shows an example for test ID#02 (the designations *Run no*.

TABLE 3.1 (Pg 1/7)

DEICING ONLY TESTS AT PMG – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point (°C)	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount (Litres)	Initial Fluid Temp. (°C)	Initial Fluid Brix (°C)	Snow Depth (cm)	OAT (°C)	RH (%)	Wind Speed (kph)	Comments
1	6	Jan-18-99	1	15:55:47	-5	T1E	1	ALUMINUM	1	0.25	61.1	10		-5	77%	0	
2	6	Jan-18-99	2	15:58:23	-5	T1E	1	ALUMINUM	2	0.50	59.3	10		-5	77%	0	
3	2	Jan-18-99	2a	12:58:43	-5	T1E	1	ALUMINUM	2	0.50	60.9	10		-5	60%	0	
4	7	Jan-18-99	3	16:21:25	-5	T1E	1	ALUMINUM	1	0.50	50.5	10		-5	77%	0	
5	7	Jan-18-99	4	16:23:38	-5	T1E	1	ALUMINUM	2	0.50	40.9	10		-5	77%	0	
6	27	Jan-20-99	5	10:09:30	-8	T1E	1	ALUMINUM	1	0.25	60.0	14		-5	68%	0	
7	27	Jan-20-99	6	10:09:30	-8	TIE	1	ALUMINUM	2	0.50	60.0	14		-5	68%	0	
8	29	Jan-20-99	7	10:37l22	-8	T1E	1	ALUMINUM	1	0.50	50.0	14		-5	69%	0	
9	29	Jan-20-99	8	10:38:27	-8	T1E	1	ALUMINUM	2	0.50	40.0	14		-5	69%	0	
10	31	Jan-20-99	9	11:07:10	-15	T1E	1	ALUMINUM	1	0.25	60.0	19		-5	70%	0	
11	31	Jan-20-99	10	11:07:57	-15	T1E	1	ALUMINUM	2	0.50	60.0	19		-5	70%	0	
12	2	Jan-18-99	10a	12:56:10	-15	T1E	1	ALUMINUM	1	0.50	59.9	19		-5	60%	0	
13	33	Jan-20-99	11	11:33:32	-15	T1E	1	ALUMINUM	2	0.50	50.0	19		-5	72%	0	
14	35	Jan-20-99	12	12:07:16	-15	T1E	1	ALUMINUM	1	0.50	40.0	19		-5	72%	0	
15	37	Jan-20-99	13	13:26:56	-5	T1E	1	ALUMINUM	1	0.10	50.0	10		-5	74%	0	
16	94	Jan-25-99	13R	11:08:48	-5	T1E	1	ALUMINUM	2	0.10	50.0	10		-5	86%	0	
17	35	Jan-20-99	14	12:06:40	-5	T1E	1	ALUMINUM	2	0.10	35.0	10		-5	74%	0	
18	38	Jan-20-99	15	13:46:57	-5	T1E	1	ALUMINUM	3	0.10	20.0	14		-5	74%	0	
19	94	Jan-25-99	15R	11:08:19	-5	T1E	1	ALUMINUM	1	0.10	20.0	10		-5	81%	0	
20	37	Jan-20-99	16	13:27:32	-8	T1E	1	ALUMINUM	2	0.10	50.0	14		-5	74%	0	
21	96	Jan-25-99	16R	11:36:45	-8	T1E	1	ALUMINUM	1	0.10	50.0	14		-5	84%	0	
22	38	Jan-20-99	17	13:49:02	-8	T1E	1	ALUMINUM	4	0.10	35.0	10		-5	75%	0	
23	72	Jan-21-99	17R	16:22:30	-8	T1E	1	ALUMINUM	1	0.10	35.0	14		-5	74%	0	
24	39	Jan-20-99	18	14:02:18	-8	T1E	1	ALUMINUM	1	0.10	20.0	14		-5	75%	0	
25	96	Jan-25-99	18R	11:37:19	-8	T1E	1	ALUMINUM	2	0.10	20.0	14		-5	74%	0	
26	39	Jan-20-99	19	14:02:50	-15	T1E	1	ALUMINUM	2	0.10	50.0	19		-5	75%	0	
27	98	Jan-25-99	19R	11:59:39	-15	T1E	1	ALUMINUM	1	0.10	50.0	19		-5	80%	0	
28	41	Jan-20-99	20	14:28:21	-15	T1E	1	ALUMINUM	1	0.10	35.0	19		-5	75%	0	
29	98	Jan-25-99	20R	12:00:15	-15	T1E	1	ALUMINUM	2	0.10	35.0	19		-5	80%	0	
30	41	Jan-20-99	21	14:28:40	-15	T1E	1	ALUMINUM	2	0.10	20.0	19		-5	75%	0	
31	100	Jan-25-99	21R	13:07:14	-15	T1E	1	ALUMINUM	1	0.10	20.0	19		-5	79%	0	
32	5	Jan-18-99	22	15:56:04	-5	T1P	1	ALUMINUM	3	0.25	59.3	13		-5	75%	0	
33	5	Jan-18-99	23	15:58:43	-5	T1P	1	ALUMINUM	4	0.50	59.3	13		-5	75%	0	
34	1	Jan-18-99	23a	12:43:57	-5	T1P	1	ALUMINUM	3	0.50	59.6	13		-5	60%	0	
35	8	Jan-18-99	24	16:24:29	-5	T1P	1	ALUMINUM	3	0.50	50.5	13		-5	79%	0	
36	8	Jan-18-99	25	16:28:55	-5	T1P	1	ALUMINUM	4	0.50	41.1	13		-5	39%	0	
37	28	Jan-20-99	26	10:16:33	-15	T1P	1	ALUMINUM	3	0.25	60.0	24		-5	68%	0	
38	28	Jan-20-99	27	10:14:10	-15	T1P	1	ALUMINUM	3	0.50	60.0	24		-5	68%	0	
39	30	Jan-20-99	28	10:44:51	-15	T1P	1	ALUMINUM	3	0.50	50.0	24		-5	70%	0	
40	30	Jan-20-99	29	10:47:13	-15	T1P	1	ALUMINUM	4	0.50	40.0	24		-5	70%	0	
41	32	Jan-20-99	30	11:14:44	-5	T1P	1	ALUMINUM	3	0.10	50.0	13		-5	71%	0	
42	32	Jan-20-99	31	11:16:37	-5	T1P	1	ALUMINUM	4	0.10	35.0	13		-5	71%	0	
43	34	Jan-20-99	32	11:46:52	-5	T1P	1	ALUMINUM	3	0.10	20.0	13		-5	72%	0	
44	50	Jan-21-99	33	9:30:40	-15	T1P	1	ALUMINUM	3	0.10	50.0	24		-5	68%	0	
45	50	Jan-21-99	34	9:32:05	-15	T1P	1	ALUMINUM	4	0.10	35.0	24		-5	68%	0	

TABLE 3.1 (Pg 2/7)

DEICING ONLY TESTS AT PMG – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point (°C)	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount (Litres)	Initial Fluid Temp. (°C)	Initial Fluid Brix (°C)	Snow Depth (cm)	OAT (°C)	RH (%)	Wind Speed (kph)	Comments
46	52	Jan-21-99	35	9:59:20	-15	T1P	1	ALUMINUM	3	0.10	20.0	24		-5	69%	0	
47	52	Jan-21-99	36	9:57:53	-5	T2P	2	ALUMINUM	4	0.10	60.0	13		-5	69%	0	
48	34	Jan-20-99	37	11:50:10	-5	T2P	2	ALUMINUM	4	0.50	60.0	13		-5	69%	0	
49	1	Jan-18-99	37a	12:47:25	-5	T2P	2	ALUMINUM	4	0.50	60.2	13		-5	60%	0	
50	36	Jan-20-99	38	12:14:47	-5	T2P	2	ALUMINUM	3	0.50	50.0	13		-5	73%	0	
51	36	Jan-20-99	39	12:18:36	-5	T2P	2	ALUMINUM	4	0.50	40.0	13		-5	73%	0	
52	40	Jan-20-99	40	14:16:48	-15	T2P	2	ALUMINUM	3	0.25	60.0	24		-5	75%	0	
53	95	Jan-25-99	40R	11:21:22	-15	T2P	2	ALUMINUM	3	0.25	60.0	24		-5	80%	0	
54	40	Jan-20-99	41	14:13:30	-15	T2P	2	ALUMINUM	4	0.50	60.0	24		-5	75%	0	
55	72	Jan-21-99	41R	16:22:53	-15	T2P	2	ALUMINUM	2	0.50	60.0	24		-5	80%	0	
56	42	Jan-20-99	42	14:53:15	-15	T2P	2	ALUMINUM	3	0.50	50.0	24		-5	74%	0	
57	95	Jan-25-99	42R	11:21:47	-15	T2P	2	ALUMINUM	4	0.50	50.0	24		-5	80%	0	
58	42	Jan-20-99	43	14:57:32	-15	T2P	2	ALUMINUM	4	0.50	40.0	24		-5	74%	0	
59	73	Jan-21-99	43R	16:26:17	-15	T2P	2	ALUMINUM	3	0.50	40.0	24		-5	75%	0	
60	45	Jan-20-99	44	15:35:55	-5	T2P	2	ALUMINUM	3	0.10	50.0	13		-5	75%	0	
61	97	Jan-25-99	44R	11:45:33	-5	T2P	2	ALUMINUM	3	0.10	50.0	13		-5	80%	0	
62	45	Jan-20-99	45	15:38:41	-5	T2P	2	ALUMINUM	4	0.10	35.0	13		-5	75%	0	
63	73	Jan-21-99	45R	16:25:28	-5	T2P	2	ALUMINUM	4	0.10	35.0	13		-5	80%	0	
64	47	Jan-20-99	46	16:10:46	-5	T2P	2	ALUMINUM	3	0.10	20.0	13		-5	74%	0	
65	97	Jan-25-99	46R	11:46:04	-5	T2P	2	ALUMINUM	4	0.10	20.0	13		-5	80%	0	
66	47	Jan-20-99	47	16:08:28	-15	T2P	2	ALUMINUM	4	0.10	50.0	24		-5	74%	0	
67	75	Jan-21-99	47R	16:51:20	-15	T2P	2	ALUMINUM	3	0.10	50.0	24		-5	75%	0	
68	49	Jan-20-99	48	16:38:55	-15	T2P	2	ALUMINUM	3	0.10	35.0	24		-5	74%	0	
69	99	Jan-25-99	48R	13:00:00	-15	T2P	2	ALUMINUM	3	0.10	35.0	24		-5	79%	0	
70	49	Jan-20-99	49	16:39:52	-15	T2P	2	ALUMINUM	4	0.10	20.0	24		-5	74%	0	
71	75	Jan-21-99	49R	16:52:30	-15	T2P	2	ALUMINUM	4	0.10	20.0	24		-5	79%	0	
72	43	Jan-20-99	50	14:57:30	-5	T1E	1	ALUMINUM HONEYCOMB	1	0.50	60.0	10		-5	74%	0	
73	100	Jan-25-99	50R	13:07:47	-5	T1E	1	ALUMINUM HONEYCOMB	2	0.50	60.0	10		-5	79%	0	
74	43	Jan-20-99	51	14:58:14	-5	T1E	1	CARBON FIBRE	2	0.50	60.0	10		-5	74%	0	
75	99	Jan-25-99	51R	13:02:16	-5	T1E	1	CARBON FIBRE	4	0.50	60.0	10		-5	79%	0	
76	51	Jan-21-99	52	9:35:11	-5	T1E	1	CARBON FIBRE HONEYCOMB	1	0.50	60.0	10		-5	69%	0	
77	102	Jan-25-99	52R	14:05:18	-5	T1E	1	CARBON FIBRE HONEYCOMB	1	0.50	60.0	10		-5	79%	0	
78	44	Jan-20-99	53	15:30:50	-5	T1E	1	GLASS FIBRE HONEYCOMB	2	0.50	60.0	10		-5	74%	0	
79	102	Jan-25-99	53R	14:05:44	-5	T1E	1	GLASS FIBRE HONEYCOMB	2	0.50	60.0	10		-5	79%	0	
80	46	Jan-20-99	54	15:56:08	-5	T1E	1	KEVLAR HONEYCOMB	1	0.50	60.0	10		-5	74%	0	
81	101	Jan-25-99	54R	13:30:30	-5	T1E	1	KEVLAR HONEYCOMB	4	0.50	60.0	10		-5	79%	0	
82	46	Jan-20-99	55	15:56:38	-5	T1E	1	ALUMINUM RED ENAMEL	2	0.50	60.0	10		-5	74%	0	
83	48	Jan-20-99	56	16:27:56	-5	T1E	1	ALUMINUM BLUE ENAMEL	1	0.50	60.0	10		-5	75%	0	
84	66	Jan-21-99	57	14:11:30	-5	T1E	1	ALUMINUM HONEYCOMB	1	0.50	60.0	10		-5	74%	20	
85	66	Jan-21-99	58	14:12:05	-5	T1E	1	CARBON FIBRE	2	0.50	60.0	10		-5	74%	20	
86	69	Jan-21-99	59	14:51:34	-5	T1E	1	CARBON FIBRE HONEYCOMB	1	0.50	60.0	10		-5	74%	20	
87	69	Jan-21-99	60	14:52:02	-5	T1E	1	GLASS FIBRE HONEYCOMB	2	0.50	60.0	10		-5	74%	20	
88	71	Jan-21-99	61	15:43:10	-5	T1E	1	KEVLAR HONEYCOMB	1	0.50	60.0	10		-5	74%	20	
89	71	Jan-21-99	62	15:43:40	-5	T1E	1	ALUMINUM RED ENAMEL	2	0.50	60.0	10		-5	74%	20	

TABLE 3.1 (Pg 3/7)

DEICING ONLY TESTS AT PMG – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point (°C)	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount (Litres)	Initial Fluid Temp. (°C)	Initial Fluid Brix (°C)	Snow Depth (cm)	OAT (°C)	RH (%)	Wind Speed (kph)	Comments
90	70	Jan-21-99	63	15:18:56	-5	T1E	1	ALUMINUM BLUE ENAMEL	3	0.50	60.0	10		-5	74%	20	
91	55	Jan-21-99	64	10:43:10	-5	T1E	1	ALUMINUM	1	0.50	50.0	10		-5	71%	20	
92	55	Jan-21-99	65	10:44:00	-5	T1E	1	ALUMINUM	2	0.50	40.0	10		-5	71%	20	
93	57	Jan-21-99	66	11:09:07	-5	T1E	1	ALUMINUM	1	0.25	60.0	10		-5	73%	20	
94	57	Jan-21-99	67	11:09:50	-5	T1E	1	ALUMINUM	2	0.50	60.0	10		-5	73%	20	
95	4	Jan-18-99	67a	13:33:48	-5	T1E	1	ALUMINUM	2	0.50	61.1	10		-5	60%	20	
96	59	Jan-21-99	68	11:35:30	-8	T1E	1	ALUMINUM	1	0.25	60.0	14		-5	73%	20	
97	59	Jan-21-99	69	11:36:17	-8	T1E	1	ALUMINUM	2	0.50	60.0	14		-5	73%	20	
98	61	Jan-21-99	70	12:08:33	-8	T1E	1	ALUMINUM	1	0.50	50.0	14		-5	73%	20	
99	61	Jan-21-99	71	12:09:11	-8	T1E	1	ALUMINUM	2	0.50	40.0	14		-5	73%	20	
100	62	Jan-21-99	72	13:15:04	-15	T1E	1	ALUMINUM	1	0.25	60.0	19		-5	74%	20	
101	62	Jan-21-99	73	13:15:48	-15	T1E	1	ALUMINUM	2	0.50	60.0	19		-5	74%	20	
102	4	Jan-18-99	73a	13:31:15	-15	T1E	11	ALUMINUM	1	0.50	61.1	19		-5	60%	20	
103	64	Jan-21-99	74	13:41:30	-15	T1E	1	ALUMINUM	1	0.50	50.0	19		-5	74%	20	
104	64	Jan-21-99	75	13:42:05	-15	T1E	1	ALUMINUM	2	0.50	40.0	19		-5	74%	20	
105	54	Jan-21-99	76	10:40:10	-5	T1P	1	ALUMINUM	3	0.25	60.0	13		-5	71%	20	
106	54	Jan-21-99	77	10:41:23	-5	T1P	1	ALUMINUM	4	0.50	60.0	13		-5	71%	20	
107	3	Jan-18-99	77a	13:29:14	-5	T1P	1	ALUMINUM	3	0.50	61.1	13		-5	60%	20	
108	56	Jan-21-99	78	11:05:45	-5	T1P	1	ALUMINUM	3	0.50	50.0	13		-5	73%	20	
109	56	Jan-21-99	79	11:06:53	-5	T1P	1	ALUMINUM	4	0.50	40.0	13		-5	73%	20	
110	58	Jan-21-99	80	11:32:20	-15	T1P	1	ALUMINUM	3	0.25	60.0	24		-5	73%	20	
111	58	Jan-21-99	81	11:33:34	-15	T1P	1	ALUMINUM	4	0.50	60.0	24		-5	73%	20	
112	60	Jan-21-99	82	11:57:24	-15	T1P	1	ALUMINUM	3	0.50	50.0	24		-5	73%	20	
113	60	Jan-21-99	83	11:58:14	-15	T1P	1	ALUMINUM	4	0.50	40.0	24		-5	73%	20	
114	63	Jan-21-99	84	13:24:19	-5	T2P	2	ALUMINUM	3	0.25	60.0	13		-5	74%	20	
115	63	Jan-21-99	85	13:25:20	-5	T2P	2	ALUMINUM	4	0.52	60.0	13		-5	74%	20	
116	3	Jan-18-99	85a	13:31:43	-5	T2P	2	ALUMINUM	4	0.50	61.2	13		-5	60%	20	
117	65	Jan-21-99	86	13:50:31	-5	T2P	2	ALUMINUM	3	0.50	50.0	13		-5	74%	20	
118	65	Jan-21-99	87	13:51:40	-5	T2P	2	ALUMINUM	4	0.50	40.0	13		-5	74%	20	
119	67	Jan-21-99	88	14:19:11	-15	T2P	2	ALUMINUM	3	0.25	60.0	24		-5	74%	20	
120	67	Jan-21-99	89	14:20:04	-15	T2P	2	ALUMINUM	4	0.50	60.0	24		-5	74%	20	
121	68	Jan-21-99	90	14:49:47	-15	T2P	2	ALUMINUM	3	0.50	50.0	24		-5	74%	20	
122	68	Jan-21-99	91	14:48:50	-15	T2P	2	ALUMINUM	4	0.50	40.0	24		-5	74%	20	
123	88	Jan-25-99	92	8:38:20	-5	T1E	1	ALUMINUM	1	0.50	60.0	10		-5	67%	30	
124	88	Jan-25-99	93	8:39:20	-15	T1E	1	ALUMINUM	2	0.50	60.0	19		-5	67%	30	
125	89	Jan-25-99	94	8:46:45	-5	T2P	2	ALUMINUM	3	0.50	60.0	13		-5	68%	30	
126	89	Jan-25-99	95	8:47:39	-15	T2P	2	ALUMINUM	4	0.50	60.0	24		-5	68%	30	
127	90	Jan-25-99	96	10:03:07	-5	T1E	1	ALUMINUM	1	0.50	60.0	10		-5	79%	10	
128	90	Jan-25-99	97	10:03:31	-8	T1E	1	ALUMINUM	2	0.50	60.0	14		-5	79%	10	
129	92	Jan-25-99	98	10:30:48	-15	T1E	1	ALUMINUM	1	0.50	60.0	19		-5	81%	10	
130	91	Jan-25-99	99	10:11:33	-5	T1P	1	ALUMINUM	3	0.50	60.0	13		-5	79%	10	
131	91	Jan-25-99	100	10:12:25	-15	T1P	1	ALUMINUM	4	0.50	60.0	13		-5	79%	10	
132	93	Jan-25-99	101	10:37:56	-5	T2P	2	ALUMINUM	3	0.50	60.0	13		-5	81%	10	
133	93	Jan-25-99	102	10:38:20	-15	T2P	2	ALUMINUM	4	0.50	60.0	24		-5	81%	10	
134	51	Jan-21-99	103	9:33:47	-5	T1E	1	ALUMINUM	2	0.50	60.0	10	0.2	-5	69%	0	

TABLE 3.1 (Pg 4/7)

DEICING ONLY TESTS AT PMG – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point (°C)	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount (Litres)	Initial Fluid Temp. (°C)	Initial Fluid Brix (°C)	Snow Depth (cm)	OAT (°C)	RH (%)	Wind Speed (kph)	Comments
135	105	Jan-25-99	103R	15:57:39	-5	T1E	1	ALUMINUM	1	0.50	60.4	10	0.1	-5	80%	0	
136	53	Jan-21-99	104	10:01:56	-5	T1E	1	ALUMINUM	1	0.50	60.0	10	0.2	-5	69%	0	
137	103	Jan-25-99	105	15:10:00	-5	T1E	1	ALUMINUM	1	AR	60.0	10	0.1	-5	79%	0	452 g = 444 ml
138	103	Jan-25-99	106	15:11:25	-5	T1E	1	ALUMINUM	2	AR	60.0	10	0.2	-5	79%	0	412 g= 405 ml
139	104	Jan-25-99	107	15:32:15	-5	T1E	1	ALUMINUM	3	AR	60.0	10	0.4	-5	80%	0	
140	105	Jan-25-99	107R	15:48:39	-5	T1E	1	ALUMINUM	2	AR	61.1	11	0.4	-5	80%	0	684 g = 672 ml
141	53	Jan-21-99	108	10:02:30	-5	T1E	1	ALUMINUM	2	0.50	60.0	10		-5	80%	0	
142	104	Jan-25-99	108R	15:38:40	-5	T1E	1	ALUMINUM	4	0.50	60.0	10		-5	80%	0	
143	106	Jan-25-99	109	16:15:51	-15	T1E	1	ALUMINUM	3	AR	60.0	19	0.1	-5	80%	0	440 g = 424 ml
144	106	Jan-25-99	110	16:16:55	-15	T1E	1	ALUMINUM	4	AR	60.0	19	0.2	-5	80%	0	614 g = 591 ml
145	107	Jan-25-99	111	16:29:37	-15	T1E	1	ALUMINUM	1	AR	59.3	19	0.4	-5	80%	0	442 g = 426 ml
146	74	Jan-21-99	112	16:47:11	-15	T1E	1	ALUMINUM	1	0.50	60.0	19		-5	75%	0	
147	107	Jan-25-99	112R	16:33:59	-15	T1E	1	ALUMINUM	2	0.50	58.8	19		-5	0%	0	
148	133	Jan-27-99	113R	11:51:47	-15	T1E	1	ALUMINUM	1	0.50	60.0	19		-5	86%	20	
149	135	Jan-27-99	113	10:05:41	-15	T1E	1	ALUMINUM	1	0.50	60.0	19		-5	89%	20	
150	133	Jan-27-99	114R	11:52:23	-5	T1E	1	ALUMINUM	2	0.50	60.0	10		-5	86%	20	
151	135	Jan-27-99	114	10:06:27	-5	T1E	1	ALUMINUM	2	0.50	60.0	10		-5	89%	20	
152	136	Jan-27-99	115	10:10:34	-5	T1P	1	ALUMINUM	3	0.50	60.0	13		-5	89%	20	frost
153	138	Jan-27-99	115R	11:54:24	-5	T1P	1	ALUMINUM	3	0.50	60.0	13		-5	86%	20	
154	136	Jan-27-99	116	10:11:31	-5	T2P	2	ALUMINUM	4	0.50	60.0	13		-5	89%	20	frost
155	138	Jan-27-99	116R	11:54:49	-5	T2P	2	ALUMINUM	4	0.50	60.0	13		-5	86%	20	
156	134	Jan-27-99	117	10:42:52	-15	T1E	1	ALUMINUM	1	0.50	60.0	19		-5	84%	0	
157	134	Jan-27-99	118	10:43:15	-5	T1E	1	ALUMINUM	2	0.50	60.0	10		-5	84%	0	
158	137	Jan-27-99	119	10:59:41	-5	T1P	1	ALUMINUM	3	0.50	60.0	13		-5	80%	0	
159	137	Jan-27-99	120	11:00:06	-5	T2P	2	ALUMINUM	4	0.50	60.0	13		-5	80%	0	
160	139	Jan-27-99	121	13:11:30	-5	T1E	1	COLD-SOAK	1	0.50	60.0	10		-5	90%	0	ice
161	139	Jan-27-99	122	13:12:09	-5	T1E	1	COLD-SOAK	2	0.25	60.0	10		-5	90%	0	ice
162	142	Jan-27-99	123	14:05:22	-10	T2P	2	COLD-SOAK	1	0.50	60.0	15		-5	92%	0	ice
163	142	Jan-27-99	124	14:05:57	-10	T1E	1	COLD-SOAK	2	0.25	60.0	15		-5	92%	0	ice
164	146	Jan-27-99	125	15:30:41	-15	T1E	1	COLD-SOAK	1	0.50	60.0	19		-5	91%	0	
165	146	Jan-27-99	126	15:31:22	-15	T1E	1	COLD-SOAK	2	0.25	60.0	19		-5	91%	0	
166	140	Jan-27-99	127	13:15:45	-5	T2P	2	COLD-SOAK	3	0.25	60.0	13		-5	91%	0	frost
167	140	Jan-27-99	128	13:16:17	-5	T2P	2	COLD-SOAK	4	0.50	60.0	13		-5	91%	0	frost
168	141	Jan-27-99	129	14:04:23	-15	T2P	2	COLD-SOAK	3	0.25	60.0	24		-5	92%	0	
169	141	Jan-27-99	130	14:04:47	-15	T2P	2	COLD-SOAK	4	0.50	60.0	24		-5	92%	0	
170	144	Jan-27-99	131	16:03:48	-5	T1E	1	COLD-SOAK	1	0.10	50.0	10		-5	91%	0	ice
171	144	Jan-27-99	132	16:04:10	-10	T1E	1	COLD-SOAK	2	0.10	50.0	15		-5	91%	0	ice
172	145	Jan-27-99	133	15:44:20	-15	T1E	1	COLD-SOAK	5	0.10	50.0	19		-5	91%	0	frost at top of plate
173	143	Jan-27-99	134	15:35:23	-5	T2P	2	COLD-SOAK	3	0.10	50.0	13		-5	95%	0	ice
174	143	Jan-27-99	135	15:48:08	-15	T2P	2	COLD-SOAK	4	0.10	50.0	24		-5	95%	0	
175	9	Jan-19-99	136	9:07:20	-25	T1E	1	ALUMINUM	1	0.25	60.1	25		-25	69%	0	
176	9	Jan-19-99	137	9:09:16	-25	T1E	1	ALUMINUM	2	0.50	59.9	25		-25	69%	0	
177	11	Jan-19-99	138	9:42:34	-25	T1E	1	ALUMINUM	1	0.50	51.1	25		-25	71%	0	
178	11	Jan-19-99	139	9:44:00	-25	T1E	1	ALUMINUM	2	0.50	40.7	25		-25	71%	0	

TABLE 3.1 (Pg 5/7)

DEICING ONLY TESTS AT PMG – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point (°C)	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount (Litres)	Initial Fluid Temp. (°C)	Initial Fluid Brix (°C)	Snow Depth (cm)	OAT (°C)	RH (%)	Wind Speed (kph)	Comments
179	13	Jan-19-99	140	10:11:47	-28	T1E	1	ALUMINUM	1	0.25	59.4	27		-25	70%	0	
180	13	Jan-19-99	141	10:13:41	-29	T1E	1	ALUMINUM	2	0.50	59.9	27		-25	70%	0	
181	15	Jan-19-99	142	10:42:09	-28	T1E	1	ALUMINUM	1	0.50	49.5	27		-25	68%	0	
182	17	Jan-19-99	143	11:37:16	-28	T1E	1	ALUMINUM	1	0.50	41.1	27		-25	71%	0	
183	109	Jan-26-99	144	9:11:46	-35	T1E	1	ALUMINUM	1	0.25	60.0	30		-25	71%	0	
184	109	Jan-26-99	145	9:12:19	-35	T1E	1	ALUMINUM	2	0.50	60.0	30		-25	71%	0	
185	110	Jan-26-99	146	9:36:32	-35	T1E	1	ALUMINUM	1	0.50	50.0	30		-25	71%	0	
186	110	Jan-26-99	147	9:37:03	-35	T1E	1	ALUMINUM	2	0.50	40.0	30		-25	71%	0	
187	15	Jan-19-99	148	10:39:30	-25	T1E	1	ALUMINUM	2	0.10	50.0	25		-25	71%	0	
188	113	Jan-26-99	149	10:22:56	-25	T1E	1	ALUMINUM	1	0.10	35.0	25		-25	71%	0	
189	113	Jan-26-99	150	10:23:36	-25	T1E	1	ALUMINUM	2	0.10	20.0	25		-25	71%	0	specks of contamination
190	115	Jan-26-99	151	10:54:01	-28	T1E	1	ALUMINUM	1	0.10	50.0	27		-25	71%	0	
191	115	Jan-26-99	152	10:54:40	-28	T1E	1	ALUMINUM	2	0.10	35.0	27		-25	71%	0	
192	117	Jan-26-99	153	11:19:08	-28	T1E	1	ALUMINUM	1	0.10	20.0	27		-25	71%	0	
193	117	Jan-26-99	154	11:19:36	-35	T1E	1	ALUMINUM	2	0.10	50.0	30		-25	71%	0	
194	119	Jan-26-99	155	11:43:01	-35	T1E	1	ALUMINUM	1	0.10	35.0	30		-25	70%	0	
195	119	Jan-26-99	156	11:43:21	-35	T1E	1	ALUMINUM	2	0.10	20.0	30		-25	70%	0	
196	10	Jan-19-99	157	9:07:09	-25	T1P	1	ALUMINUM	3	0.25	60.2	31		-25	69%	0	
197	10	Jan-19-99	158	9:11:40	-25	T1P	1	ALUMINUM	4	0.50	61.1	31		-25	69%	0	
198	12	Jan-19-99	159	9:42:35	-25	T1P	1	ALUMINUM	3	0.50	51.1	31		-25	72%	0	
199	12	Jan-19-99	160	9:46:37	-25	T1P	1	ALUMINUM	4	0.50	40.8	31		-25	72%	0	
200	14	Jan-19-99	161	10:18:44	-35	T1P	1	ALUMINUM	3	0.25	60.7	37		-25	68%	0	
201	14	Jan-19-99	162	10:22:13	-35	T1P	1	ALUMINUM	4	0.50	60.7	37		-25	68%	0	
202	16	Jan-19-99	163	11:16:40	-35	T1P	1	ALUMINUM	3	0.50	50.5	37		-25	67%	0	
203	114	Jan-26-99	164	10:46:34	-35	T1P	1	ALUMINUM	3	0.50	40.0	37		-25	71%	0	
204	16	Jan-19-99	165	11:08:30	-25	T1P	1	ALUMINUM	4	0.10	51.7	31		-25	71%	0	
205	108	Jan-26-99	166	8:59:52	-25	T1P	1	ALUMINUM	3	0.10	35.0	31		-25	71%	0	
206	108	Jan-26-99	167	9:00:21	-25	T1P	1	ALUMINUM	4	0.10	20.0	31		-25	71%	0	
207	111	Jan-26-99	168	9:42:12	-35	T1P	1	ALUMINUM	3	0.10	50.0	37		-25	71%	0	
208	111	Jan-26-99	169	9:42:50	-35	T1P	1	ALUMINUM	4	0.10	35.0	37		-25	71%	0	
209	112	Jan-26-99	170	10:13:49	-35	T1P	1	ALUMINUM	3	0.10	20.0	37		-25	71%	0	
210	112	Jan-26-99	171	10:14:30	-25	T2P	2	ALUMINUM	4	0.25	60.0	31		-25	71%	0	
211	114	Jan-26-99	172	10:47:30	-25	T2P	2	ALUMINUM	4	0.50	60.0	31		-25	71%	0	
212	116	Jan-26-99	173	11:09:40	-25	T2P	2	ALUMINUM	3	0.50	50.0	31		-25	71%	0	
213	116	Jan-26-99	174	11:10:09	-25	T2P	2	ALUMINUM	4	0.50	40.0	31		-25	71%	0	
214	118	Jan-26-99	175	11:37:42	-35	T2P	2	ALUMINUM	3	0.25	60.0	35		-25	71%	0	
215	118	Jan-26-99	176	11:38:04	-35	T2P	2	ALUMINUM	4	0.50	60.0	35		-25	71%	0	
216	121	Jan-26-99	177	13:17:15	-35	T2P	2	ALUMINUM	3	0.50	50.0	35		-25	71%	0	
217	121	Jan-26-99	178	13:17:40	-35	T2P	2	ALUMINUM	4	0.50	40.0	35		-25	71%	0	
218	123	Jan-26-99	179	13:47:12	-25	T2P	2	ALUMINUM	3	0.10	50.0	31		-25	71%	0	
219	125	Jan-26-99	180	14:12:24	-25	T2P	2	ALUMINUM	3	0.10	35.0	31		-25	71%	0	
220	126	Jan-26-99	181	14:52:12	-25	T2P	2	ALUMINUM	3	0.10	20.0	31		-25	71%	0	
221	129	Jan-26-99	182	15:35:24	-35	T2P	2	ALUMINUM	3	0.10	50.0	35		-25	72%	0	
222	128	Jan-26-99	183	15:25:31	-35	T2P	2	ALUMINUM	1	0.10	35.0	35		-25	71%	0	

TABLE 3.1 (Pg 6/7)

DEICING ONLY TESTS AT PMG – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point (°C)	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount (Litres)	Initial Fluid Temp. (°C)	Initial Fluid Brix (°C)	Snow Depth (cm)	OAT (°C)	RH (%)	Wind Speed (kph)	Comments
223	127	Jan-26-99	184	15:03:12	-35	T2P	2	ALUMINUM	4	0.10	20.0	35		-25	71%	0	
224	120	Jan-26-99	185	13:06:18	-25	T1E	1	ALUMINUM HONEYCOMB	1	0.50	60.0	25		-25	71%	0	
225	120	Jan-26-99	186	13:06:54	-25	T1E	1	CARBON FIBRE	2	0.50	60.0	25		-25	71%	0	
226	122	Jan-26-99	187	13:32:30	-25	T1E	1	CARBON FIBRE HONEYCOMB	1	0.50	60.0	25		-25	70%	0	
227	122	Jan-26-99	188	13:33:01	-25	T1E	1	GLASS FIBRE HONEYCOMB	2	0.50	60.0	25		-25	70%	0	
228	124	Jan-26-99	189	14:05:23	-25	T1E	1	KEVLAR HONEYCOMB	1	0.50	60.0	25		-25	70%	0	
229	124	Jan-26-99	190	14:05:52	-25	T1E	1	ALUMINUM RED POLY	2	0.50	60.0	25		-25	70%	0	
230	126	Jan-26-99	191	14:57:48	-25	T1E	1	ALUMINUM BLUE POLY	1	0.50	60.0	25		-25	71%	0	
231	147	Jan-28-99	192	11:47:14	-25	T1E	1	ALUMINUM HONEYCOMB	1	0.50	60.0	25		-25	72%	20	
232	147	Jan-28-99	193	11:48:59	-25	T1E	1	CARBON FIBRE	2	0.50	60.0	25		-25	72%	20	
233	148	Jan-28-99	194	13:00:43	-25	T1E	1	CARBON FIBRE HONEYCOMB	1	0.50	60.0	25		-25	71%	20	
234	148	Jan-28-99	195	13:01:15	-25	T1E	1	GLASS FIBRE HONEYCOMB	2	0.50	60.0	25		-25	71%	20	
235	149	Jan-28-99	196	13:37:48	-25	T1E	1	KEVLAR HONEYCOMB	1	0.50	60.0	25		-25	71%	20	
236	149	Jan-28-99	197	13:38:43	-25	T1E	1	ALUMINUM RED POLY	2	0.50	60.0	25		-25	71%	20	
237	150	Jan-28-99	198	14:02:49	-25	T1E	1	ALUMINUM BLUE POLY	1	0.50	60.0	25		-25	70%	20	
238	19	Jan-19-99	199	13:47:50	-25	T1E	1	ALUMINUM	1	0.25	59.3	25		-25	72%	20	
239	19	Jan-19-99	200	13:49:11	-25	T1E	1	ALUMINUM	2	0.50	59.3	25		-25	72%	20	
240	20	Jan-19-99	201	14:20:12	-25	T1E	1	ALUMINUM	1	0.50	50.5	25		-25	71%	20	
241	20	Jan-19-99	202	14:21:10	-25	T1E	1	ALUMINUM	2	0.50	41.1	25		-25	71%	20	
242	22	Jan-19-99	203	14:56:40	-28	T1E	1	ALUMINUM	1	0.25	60.5	27		-25	73%	20	
243	22	Jan-19-99	204	14:58:00	-28	T1E	1	ALUMINUM	2	0.50	59.6	28		-25	73%	20	
244	24	Jan-19-99	205	15:29:47	-28	T1E	1	ALUMINUM	1	0.50	51.0	27		-25	73%	20	
245	24	Jan-19-99	206	15:31:13	-28	T1E	1	ALUMINUM	2	0.50	40.5	27		-25	73%	20	
246	130	Jan-26-99	207	16:08:48	-35	T1E	1	ALUMINUM	1	0.25	60.0	30		-25	72%	20	
247	130	Jan-26-99	208	16:09:25	-35	T1E	1	ALUMINUM	2	0.50	60.0	30		-25	72%	20	
248	132	Jan-26-99	209	16:38:31	-35	T1E	1	ALUMINUM	1	0.50	50.0	30		-25	72%	20	
249	132	Jan-26-99	210	16:38:59	-35	T1E	1	ALUMINUM	2	0.50	40.0	30		-25	72%	20	
250	18	Jan-19-99	211	14:09:44	-25	T1P	1	ALUMINUM	3	0.25	59.3	31		-25	71%	20	
251	18	Jan-19-99	212	14:13:40	-25	T1P	1	ALUMINUM	4	0.50	60.9	31		-25	71%	20	
252	21	Jan-19-99	213	14:42:39	-25	T1P	1	ALUMINUM	3	0.50	50.0	31		-25	72%	20	
253	21	Jan-19-99	214	14:46:28	-25	T1P	1	ALUMINUM	4	0.50	40.7	31		-25	72%	20	
254	23	Jan-19-99	215	15:15:24	-25	T1P	1	ALUMINUM	3	0.25	58.8	31		-25	73%	20	
255	23	Jan-19-99	216	15:18:26	-25	T1P	1	ALUMINUM	4	0.50	30.8	31		-25	73%	20	
256	131	Jan-26-99	217	16:20:05	-35	T1P	1	ALUMINUM	3	0.50	50.0	37		-25	71%	20	
257	131	Jan-26-99	218	16:20:50	-35	T1P	1	ALUMINUM	4	0.50	40.0	37		-25	71%	20	
258	151	Jan-28-99	219	11:43:18	-25	T2P	2	ALUMINUM	3	0.25	60.0	31		-25	71%	20	
259	151	Jan-28-99	220	11:45:01	-25	T2P	2	ALUMINUM	4	0.50	60.0	31		-25	71%	20	
260	152	Jan-28-99	221	12:55:05	-25	T2P	2	ALUMINUM	3	0.50	50.0	31		-25	71%	20	
261	152	Jan-28-99	222	12:55:40	-25	T2P	2	ALUMINUM	4	0.50	40.0	31		-25	71%	20	
262	153	Jan-28-99	223	13:25:01	-35	T2P	2	ALUMINUM	3	0.25	60.0	35		-25	71%	20	
263	153	Jan-28-99	224	13:25:33	-35	T2P	2	ALUMINUM	4	0.50	60.0	35		-25	71%	20	
264	154	Jan-28-99	225	13:52:40	-35	T2P	2	ALUMINUM	3	0.50	50.0	35		-25	71%	20	
265	154	Jan-28-99	226	13:53:08	-35	T2P	2	ALUMINUM	4	0.50	50.0	35		-25	71%	20	
266	25	Jan-19-99	227	16:01:34	-25	T1E	1	ALUMINUM	1	0.50	60.0	25		-25	72%	30	

TABLE 3.1 (Pg 7/7)

DEICING ONLY TESTS AT PMG – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point (°C)	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount (Litres)	Initial Fluid Temp. (°C)	Initial Fluid Brix (°C)	Snow Depth (cm)	OAT (°C)	RH (%)	Wind Speed (kph)	Comments
267	25	Jan-19-99	228	16:02:30	-35	T1E	1	ALUMINUM	2	0.50	60.5	30		-25	72%	30	
268	26	Jan-19-99	229	16:24:35	-25	T1P	1	ALUMINUM	3	0.50	60.3	31		-25	72%	30	
269	26	Jan-19-99	230	16:19:56	-35	T1P	1	ALUMINUM	4	0.50	60.5	30		-25	72%	30	
270	155	Jan-28-99	231	15:43:58	-25	T1E	1	ALUMINUM	1	0.50	60.0	25		-25	73%	10	
271	155	Jan-28-99	232	15:57:59	-28	T1E	1	ALUMINUM	2	0.50	60.0	27		-25	73%	10	
272	156	Jan-28-99	233	16:05:01	-35	T1E	1	ALUMINUM	4	0.50	60.0	30		-25	73%	10	
273	157	Jan-28-99	234	14:44:35	-25	T1P	1	ALUMINUM	3	0.50	60.0	31		-25	71%	10	
274	157	Jan-28-99	235	14:45:03	-35	T1P	1	ALUMINUM	4	0.50	60.0	37		-25	71%	10	
275	158	Jan-28-99	236	15:18:30	-25	T2P	2	ALUMINUM	3	0.50	60.0	31		-25	72%	10	
276	158	Jan-28-99	237	15:18:51	-35	T2P	2	ALUMINUM	4	0.50	60.0	35		-25	72%	10	
277	159	Jan-28-99	238	9:27:45	-15	T1E	1	ALUMINUM	3	0.50	60.0	19	0.1	-15	78%	0	
278	159	Jan-28-99	239	9:26:58	-15	T1E	1	ALUMINUM	4	0.50	60.0	19	0.1	-15	78%	0	
279	160	Jan-28-99	240	9:40:33	-15	T1E	1	ALUMINUM	1	AR	60.0	19	0.1	-15	77%	0	298 g = 286 ml
280	160	Jan-28-99	241	9:42:13	-15	T1E	1	ALUMINUM	2	AR	60.0	19	0.2	-15	77%	0	526 g = 507 ml
281	161	Jan-28-99	242	10:08:35	-15	T1E	1	ALUMINUM	1	AR	60.0	19	0.4	-15	78%	0	668 g = 643 ml
282	161	Jan-28-99	243	10:12:22	-15	T1E	1	ALUMINUM	2	0.50	60.0	19		-15	78%	0	
283	162	Jan-28-99	244	10:00:20	-25	T1E	1	ALUMINUM	3	AR	60.0	25	0.1	-15	78%	0	466 g = 443 ml
284	162	Jan-28-99	245	10:01:15	-25	T1E	1	ALUMINUM	4	AR	60.0	25	0.2	-15	78%	0	384 g = 365 ml
285	163	Jan-28-99	246	10:26:34	-25	T1E	1	ALUMINUM	3	AR	60.0	25	0.4	-15	78%	0	530 g = 504 ml
286	163	Jan-28-99	247	10:30:56	-25	T1E	1	ALUMINUM	4	0.50	60.0	25		-15	78%	0	
287	79	Jan-22-99	248	10:37:15	-35	T1E	1	ALUMINUM	1	0.50	60.0	30		-25	76%	20	contamination
288	79	Jan-22-99	249	10:38:20	-25	T1E	1	ALUMINUM	2	0.50	60.0	25		-25	76%	20	contamination
289	78	Jan-22-99	250	10:12:35	-25	T1P	1	ALUMINUM	3	0.50	60.0	31		-25	76%	20	
290	78	Jan-22-99	251	10:02:00	-25	T2P	2	ALUMINUM	4	0.50	60.0	31		-25	76%	20	
291	77	Jan-22-99	252	9:06:50	-35	T1E	1	ALUMINUM	1	0.50	60.0	30		-25	78%	0	streaks of contamination
292	77	Jan-22-99	253	9:07:26	-25	T1E	1	ALUMINUM	2	0.50	60.0	25		-25	78%	0	streaks of contamination
293	76	Jan-22-99	254	8:43:51	-25	T1P	1	ALUMINUM	3	0.50	60.0	31		-25	78%	0	
294	76	Jan-22-99	255	8:44:55	-25	T2P	2	ALUMINUM	4	0.50	60.0	31		-25	78%	0	
295	80	Jan-22-99	256	11:19:42	-25	T1E	1	COLD-SOAK	1	0.10	25.0	25		-25	76%	0	slush
296	80	Jan-22-99	257	11:20:38	-30	T1E	1	COLD-SOAK	2	0.10	25.0	28		-25	76%	0	contamination
297	82	Jan-22-99	258	12:00:11	-35	T1E	1	COLD-SOAK	1	0.10	25.0	30		-25	76%	0	contamination
298	81	Jan-22-99	259	11:45:50	-25	T2P	2	COLD-SOAK	4	0.10	25.0	31		-25	76%	0	
299	81	Jan-22-99	260	11:28:30	-35	T2P	2	COLD-SOAK	3	0.10	25.0	35		-25	76%	0	
300	82	Jan-22-99	261	12:01:40	-25	T1E	1	COLD-SOAK	2	0.50	60.0	25		-25	76%	0	contamination
301	85	Jan-22-99	262	14:16:28	-25	T1E	1	COLD-SOAK	2	0.25	60.0	25		-25	77%	0	contamination
302	85	Jan-22-99	263	14:09:05	-30	T1E	1	COLD-SOAK	5	0.50	60.0	28		-25	77%	0	contamination
303	84	Jan-22-99	264	13:11:21	-30	T1E	1	COLD-SOAK	1	0.50	60.0	28		-25	77%	0	contamination
304	84	Jan-22-99	265	13:12:05	-35	T1E	1	COLD-SOAK	2	0.25	60.0	30		-25	77%	0	contamination
305	87	Jan-22-99	266	14:38:50	-35	T1E	1	COLD-SOAK	2	0.25	60.0	30		-25	77%	0	contamination
306	83	Jan-22-99	267	12:59:25	-25	T2P	2	COLD-SOAK	3	0.50	60.0	31		-25	77%	0	contamination
307	83	Jan-22-99	268	13:01:28	-25	T2P	2	COLD-SOAK	4	0.25	60.0	31		-25	77%	0	contamination
308	86	Jan-22-99	269	14:18:34	-35	T2P	2	COLD-SOAK	3	0.50	60.0	35		-25	77%	0	contamination
309	86	Jan-22-99	270	14:48:11	-35	T2P	2	COLD-SOAK	5	0.25	60.0	35		-25	77%	0	

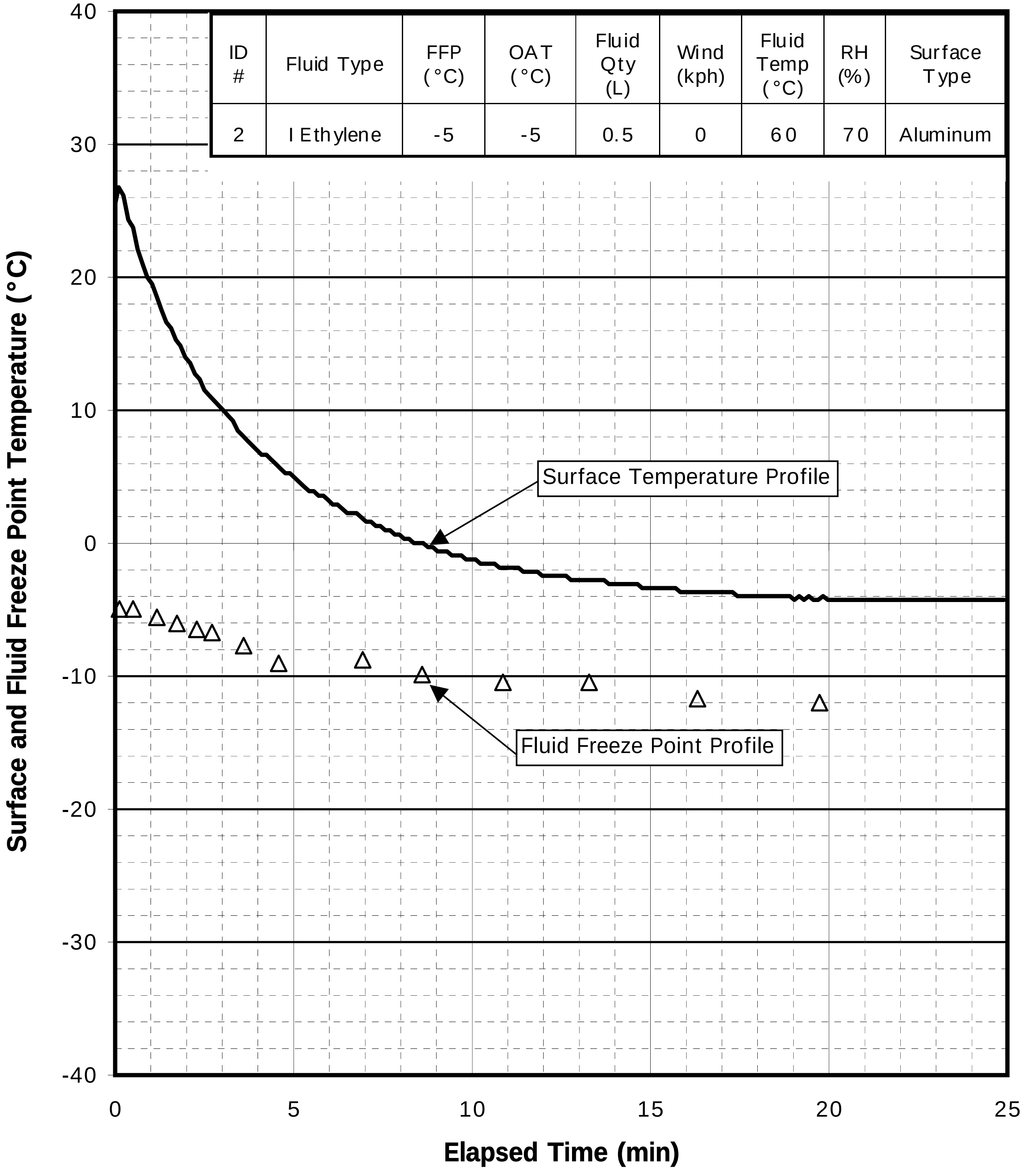
TABLE 3.2
DEICING ONLY TESTS AT NRC – WINTER 1998/99

Test No.	Form No.	Date	Run No.	Start Time (Local)	Fluid Freeze Point	Fluid Name	Fluid Type	Surface Type	Thermistor #	Initial Fluid Amount	Initial Fluid Temp	Initial Fluid Brix	Time to 0°C (min)	OAT (°C)	RH Before Test	RH After Test	RH (%)	Wind Speed (kph)	Comments
1	1	Mar-26-99	401	10:36:15	-5	T1E	1	COLDSOAK BOX	4	0.50	61	10	1.2	-5	69	69	69%	0	Ice 10:34
2	2	Mar-26-99	402	10:38:44	-5	T1E	1	COLDSOAK BOX	2	0.50	51	10.00	1.2	-5	68.8	68.8	69%	0	Ice 10:40
3	3	Mar-26-99	403	10:49:31	-5	T1E	1	COLDSOAK BOX	3	0.25	61	9.75	0.4	-5	68.8	68.3	69%	0	Ice 10:51
3	4	Mar-26-99	404	10:57:35	-5	T1E	1	COLDSOAK BOX	1	0.25	51	9.75	0.5	-5	68	67.8	68%	0	Ice
4	5	Mar-26-99	405	13:27:14	-5	T1E	1	COLDSOAK BOX	4	0.50	61	10.00	1.1	-5	67.6	67.6	68%	20	ice 13:30
5	5	Mar-26-99	406	13:27:38	-5	T1E	1	COLDSOAK BOX	3	0.50	51	10.00	1.2	-5	67.6	67.6	68%	20	ice 13:30
6	6	Mar-26-99	407	13:37:34	-5	T1E	1	COLDSOAK BOX	6	0.25	60	10.00	3.0	-5	67.6	67.3	67%	20	ice 13:41
7	6	Mar-26-99	408	13:38:42	-5	T1E	1	COLDSOAK BOX	1	0.25	50	10.00	0.5	-5	67.6	67.3	67%	20	ice 13:40
8	7	Mar-26-99	409	11:16:12	-10	T1E	1	COLDSOAK BOX	2	0.50	61	15.00	1.1	-5	68.2	67.4	68%	0	Ice 11:30
9	8	Mar-26-99	410	11:18:39	-10	T1E	1	COLDSOAK BOX	4	0.50	51	15.00	1.2	-5	67.5	67.7	68%	0	ice 11:36
10	9	Mar-26-99	411	11:26:36	-10	T1E	1	COLDSOAK BOX	6	0.25	60	15.00	0.5	-5	67.5	67.2	67%	0	
11	10	Mar-26-99	412	11:28:50	-10	T1E	1	COLDSOAK BOX	5	0.25	51	15.25	0.3	-5	67.5	67.5	68%	0	Ice 11:48
12	11	Mar-26-99	413	13:56:40	-10	T1E	1	COLDSOAK BOX	5	0.50	61	14.75	1.2	-5	68	68.5	68%	20	Ice 14:13
13	11	Mar-26-99	414	13:58:36	-10	T1E	1	COLDSOAK BOX	2	0.50	51	14.75	0.9	-5	67.5	68.5	68%	20	Ice 14:13
14	12	Mar-26-99	415	14:08:25	-10	T1E	1	COLDSOAK BOX	3	0.25	60	14.75	0.5	-5	64.1	68.9	67%	20	Ice 14:24
15	12	Mar-26-99	416	14:09:55	-10	T1E	1	COLDSOAK BOX	4	0.25	51	14.75	0.3	-5	64.1	68.9	67%	20	
16	13	Mar-26-99	417	11:42:06	-15	T1E	1	COLDSOAK BOX	3	0.50	60	19.00	1.6	-5	67.6	67.2	67%	0	
17	14	Mar-26-99	418	11:50:24	-15	T1E	1	COLDSOAK BOX	2	0.50	51	19.00	0.9	-5	67.3	67.6	67%	0	
18	15	Mar-26-99	419	11:59:54	-15	T1E	1	COLDSOAK BOX	4	0.25	60	19.00	0.7	-5	67.1	67.2	67%	0	
19	16	Mar-26-99	420	11:53:10	-15	T1E	1	COLDSOAK BOX	1	0.25	51	19.00	0.7	-5	67.1	66.8	67%	0	
20	17	Mar-26-99	421	14:35:53	-15	T1E	1	COLDSOAK BOX	1	0.50	58	19.00	1.1	-5	68.7	68.1	68%	20	
21	17	Mar-26-99	422	14:32:45	-15	T1E	1	COLDSOAK BOX	6	0.50	51	19.00	0.7	-5	68.7	68.1	68%	20	
22	18	Mar-26-99	423	14:43:00	-15	T1E	1	COLDSOAK BOX	5	0.25	61	19.00	0.4	-5	67.2	68.7	68%	20	Ice 14:57
23	18	Mar-26-99	424	14:46:04	-15	T1E	1	COLDSOAK BOX	2	0.25	51	19.00	0.1	-5	67.2	68.7	68%	20	Ice 14:57

FIGURE 3.1

Fluid Freeze Point and Surface Temperature Profile

ID# 02



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2	I Ethylene	-5	-5	0.5	0	60	70	Aluminum

and *ID#* are both used for the *Run #* shown on the Test Scheduling and Control Sheet, Table 2.3). A complete set of charts for all laboratory tests is contained in Appendix E.

In Figure 3.1, the solid line reflects the plate temperature as it reaches a peak temperature during fluid application and then cools toward ambient temperature. Triangular data points show the FFP at elapsed times after fluid application. In this figure, FFP values drop due to the evaporation of water after application of the heated fluid-water mix.

The spread between plate temperature and FFP is the significant element of this study, as it indicates that freezing will or will not occur. In Figure 3.1, a substantial spread is maintained throughout the test.

To examine the impact on FFP enhancement of the various problems addressed in this study, results from selected tests (which provide a range of values for the variable under examination, with other variables are held constant) were presented on a single chart. Figure 3.2 is an example. The impact of changing fluid temperature is examined. Three solid lines represent temperature profiles of the plates for the three tests reported, and the comparison indicates the impact of fluid temperature on plate-surface temperature, in terms of both peak value and cooling rate. In this figure, Test ID#10 with a fluid temperature of 60°C involved a higher peak and a longer time to cool than the other tests reported, which had fluid temperatures of 50 and 40°C.

The data points representing freezing points for the three tests provide a basis of comparison. Here, the freezing points for the fluid applied at 60°C show greater enhancement (freeze at a lower temperature) than for those applied at 50 and 40°C.

In Chapter 4, this type of chart is put to extensive use in examining the impact of various problems being studied.

3.2 Aircraft Trials

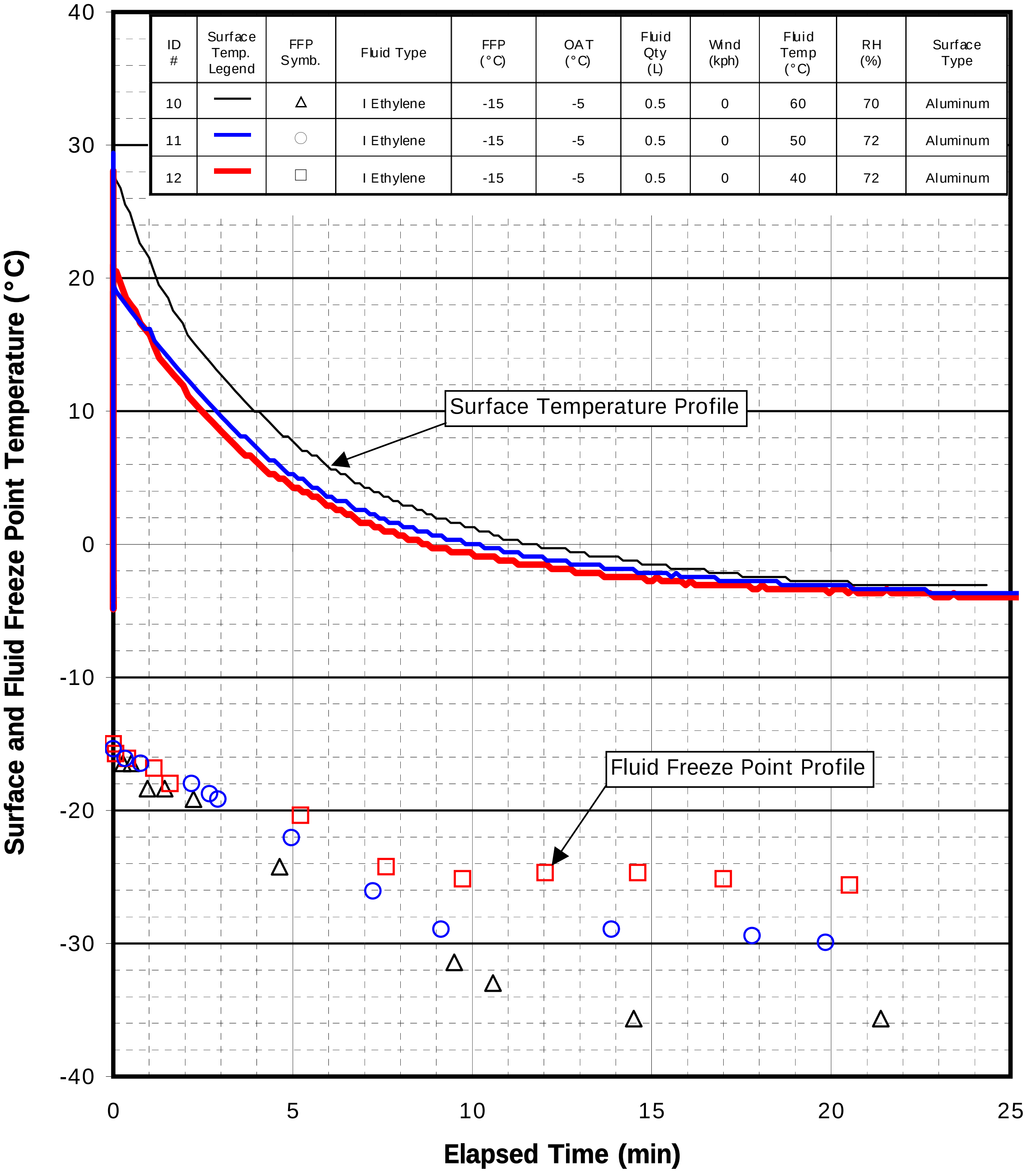
Snow-removal trials were conducted on a US Airways Boeing 737, overnight on 15/16 February 1999. Four trials were completed, including one with snow 0.5 cm deep, one with snow 1.5 cm deep, and two tests on a bare wing to serve as a control.

Ambient air temperature ranged from –7 to –9°C. Winds were calm, and relative humidity was 85 percent.

FIGURE 3.2

Fluid Freeze Point and Surface Temperature Profile Comparison

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -5°C, FFP -15°C, Type I EG Fluid, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
10	―	△	I Ethylene	-15	-5	0.5	0	60	70	Aluminum
11	―	○	I Ethylene	-15	-5	0.5	0	50	72	Aluminum
12	―	□	I Ethylene	-15	-5	0.5	0	40	72	Aluminum

The aircraft was towed from the passenger terminal to the deicing centre around 0100 h after its cabin had been prepared for the morning flight. On arrival, it was noted that the wings were frosted, indicating an active frost condition. Thermistor probes were installed at selected points on the wing to record skin temperatures continually.

Data from these tests were presented in charts similar to those of the laboratory trials. Figure 3.3 is a sample, showing skin temperatures and FFP at specific locations on the wing. Charts from the four tests are discussed in Chapter 4.

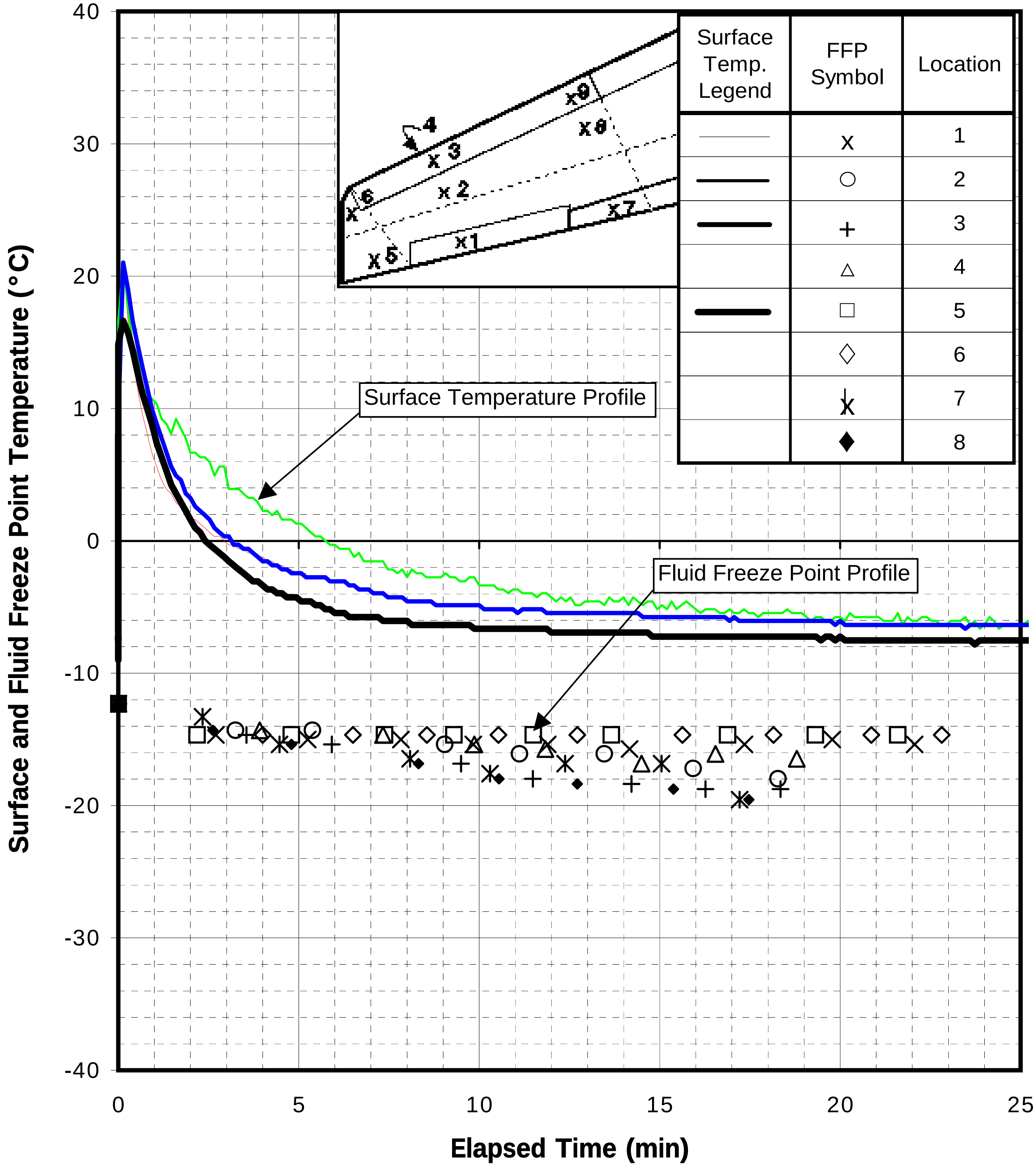
FIGURE 3.3

Fluid Freeze Point and Surface Temperature Profile Comparison

AIRCRAFT DEICING ONLY TRIALS – RUN # 2

US Airways B737

Feb. 15/16, 1999, OAT = -8°C



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4. DATA ANALYSIS AND OBSERVATIONS

In this section, test results are examined and discussed in connection with each of the industry concerns.

4.1 Laboratory Trials

4.1.1 Quantity of Fluid

Figures 4.1 to 4.4 present graphs showing test-surface temperature profiles and FFP. Each reports on results in which two quantities (0.5 and 0.25 L) were applied by pouring.

The four figures cover the following matrix of conditions:

Figure #	OAT (°C)	FFP (°C)	Fluid Type	Wind (kph)	Fluid Qty (litres)
4.1	–5	–5	T1E	Calm	0.5, 0.25
4.2	–5	–15	T1E	Calm	0.5, 0.25
4.3	–5	–5	T1P	Calm	0.5, 0.25
4.4	–5	–5	T1E	20	0.5, 0.25

Other parameters (such as fluid temperature, relative humidity, and surface type) were held constant. In each figure, fluid quantities of 0.25 and 0.5 L are reported.

In Figure 4.1, comparison of the surface-temperature profiles for the two tests shows that more fluid resulted in a higher peak and a longer time to cool. Fluid freeze points displayed improvements for both quantities, dropping to –12°C (from initial –5ºC) for the 0.5 L test and to –10°C for the 0.25 L test.

Figure 4.2 reports on tests run with FFP of –15°C. Comparison of the surface-temperature profiles for the two tests reported showed again that more fluid resulted in a higher peak and a longer time to cool. Fluid freeze points displayed improvements for both quantities, dropping to –36°C (from initial –15ºC) for the 0.5 L test and to –31°C for the 0.25 L test. These findings, as compared to those reported in Figure 4.1, indicate that a greater improvement in FFP results from mixes having a larger initial proportion of glycol. This corresponds to findings reported for the initial series of trials conducted during the 1997-98 season (1).

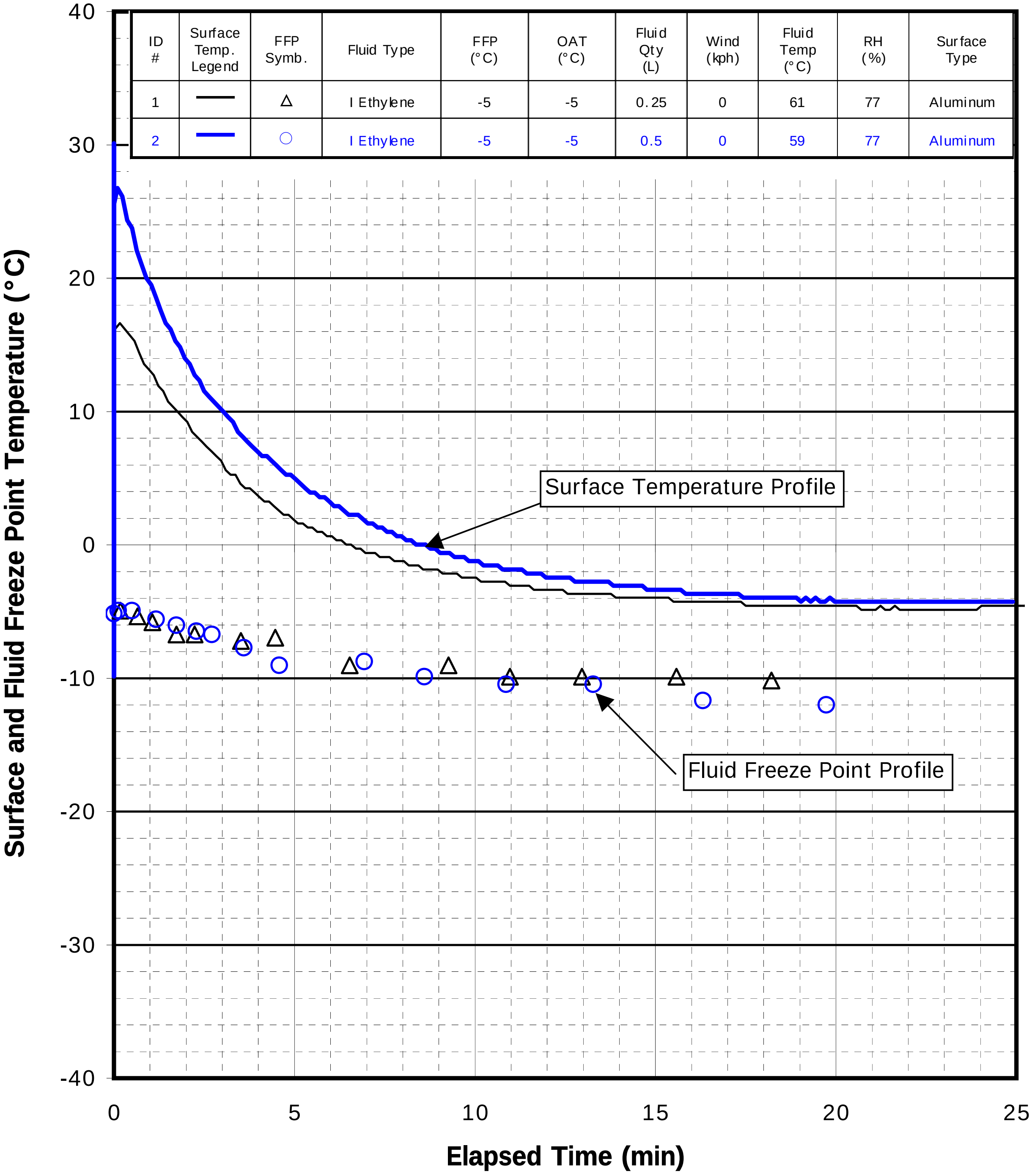
Figure 4.3 reports on tests conducted with propylene glycol-based Type I

FIGURE 4.1

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Quantity

OAT -5°C, FFP -5°C, Type I EG Fluid, Winds Calm



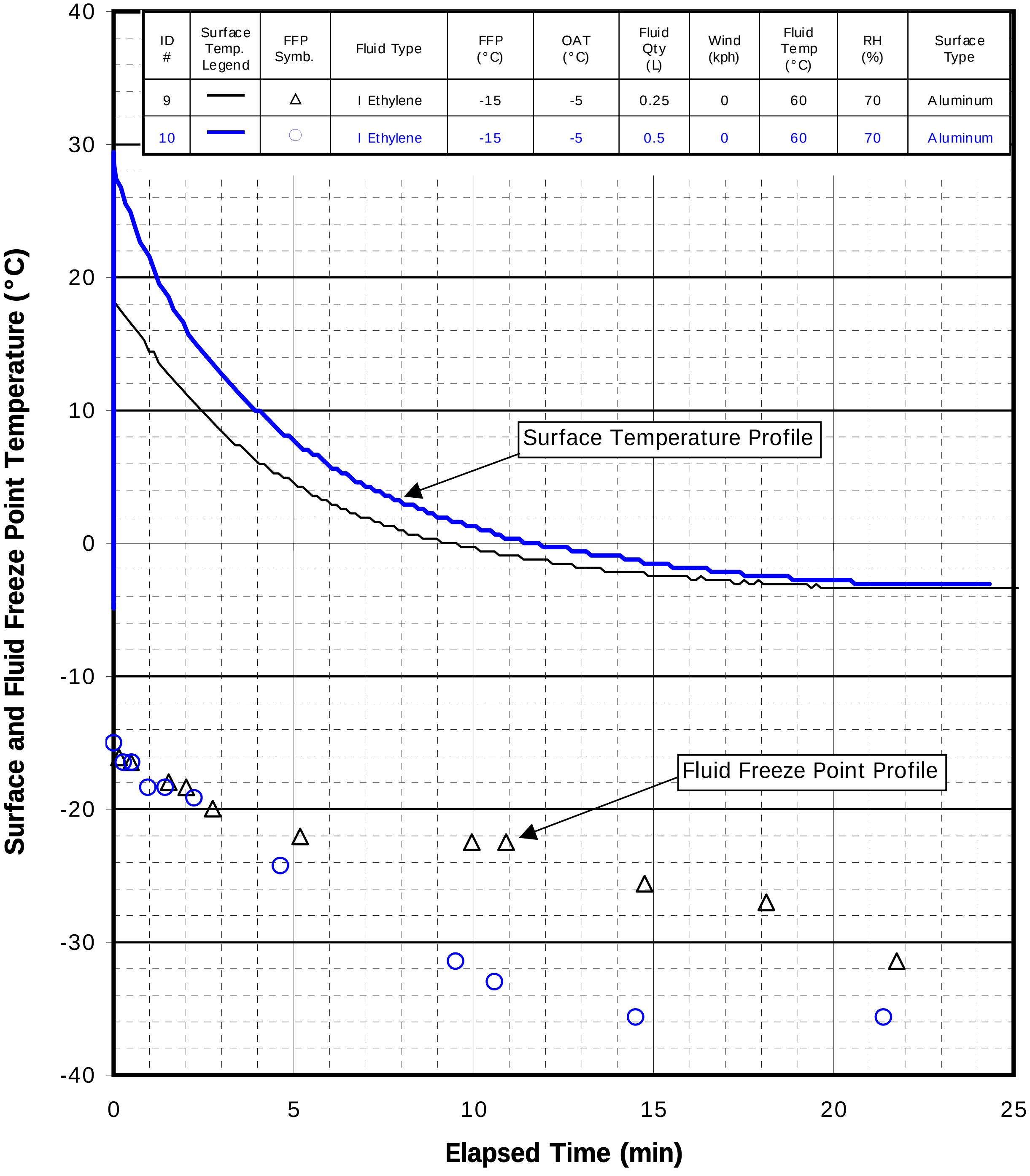
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
1	—	△	I Ethylene	-5	-5	0.25	0	61	77	Aluminum
2	▬	○	I Ethylene	-5	-5	0.5	0	59	77	Aluminum

FIGURE 4.2

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Quantity

OAT -5°C, FFP -15°C, Type I EG Fluid, Winds Calm



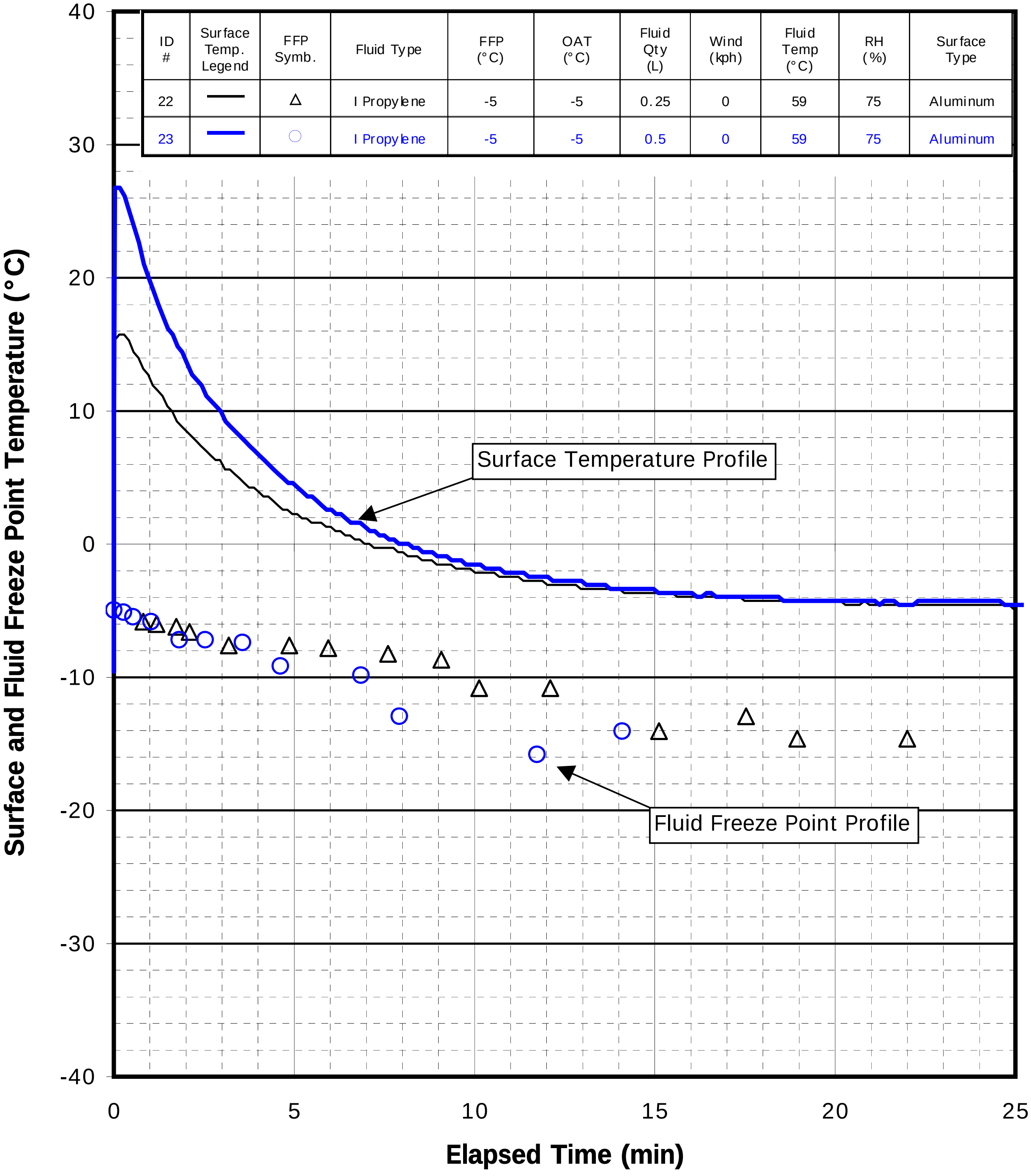
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
9	—	△	I Ethylene	-15	-5	0.25	0	60	70	Aluminum
10	—	○	I Ethylene	-15	-5	0.5	0	60	70	Aluminum

FIGURE 4.3

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Quantity

OAT -5°C, FFP -5°C, Type I PG Fluid, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
22	—	△	I Propylene	-5	-5	0.25	0	59	75	Aluminum
23	—	○	I Propylene	-5	-5	0.5	0	59	75	Aluminum

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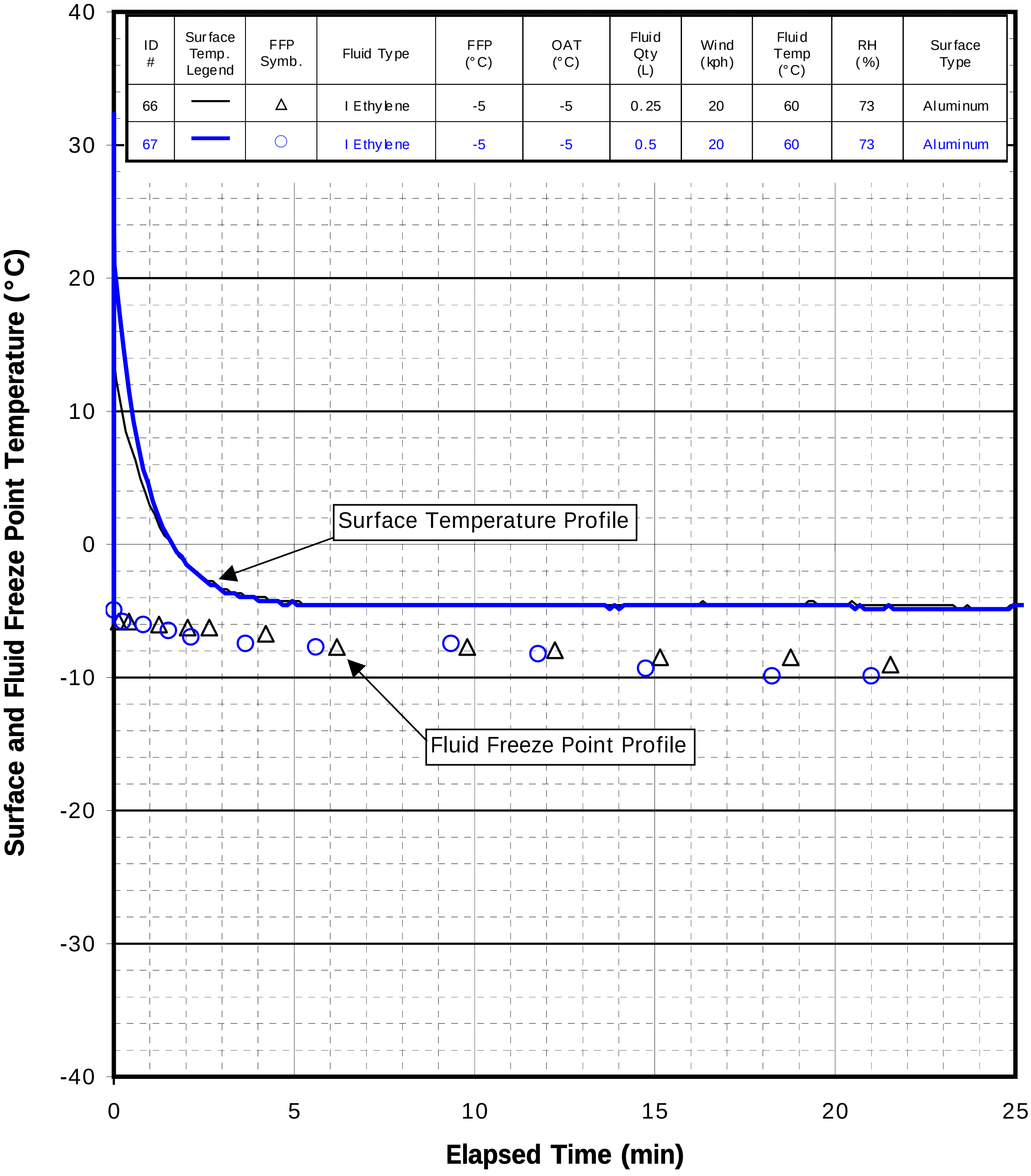
FIGURE 4.4

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Quantity

OAT -5°C, FFP -5°C, Type I EG Fluid, Wind 20 kph



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
66	—	△	I Ethylene	-5	-5	0.25	20	60	73	Aluminum
67	—	○	I Ethylene	-5	-5	0.5	20	60	73	Aluminum

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fluid. In Figure 4.3, comparison of the surface-temperature profiles shows that more fluid resulted in a higher peak and a longer time to cool. Fluid freeze points display improvements for both quantities. The degree of enhancement for the 0.5 L quantity test indicates that propylene glycol-based fluid provides a higher degree of FFP enhancement than ethylene glycol-based fluid (Figure 4.3 vs. 4.1) in these conditions.

Figure 4.4 reports on tests conducted with wind at 20 kph, as opposed to previous tests conducted in calm conditions. When it is compared to Figure 4.1, the test-surface temperature for the wind condition is seen to reach a lower peak, and the cooling rate is much faster. The FFP improvement in the wind condition is somewhat less, but still appreciable, with the FFP dropping to –9 and –10°C (from –5ºC) for the two quantities tested.

In summary, the quantity of fluid applied has an impact on the degree of FFP enhancement. But in all reported cases, the degree of enhancement for the lower quantity was still significant and supported the use of low-buffer fluids for *deicing only* conditions.

4.1.2 Fluid Temperatures

4.1.2.1 Tests Representing Snow Removal

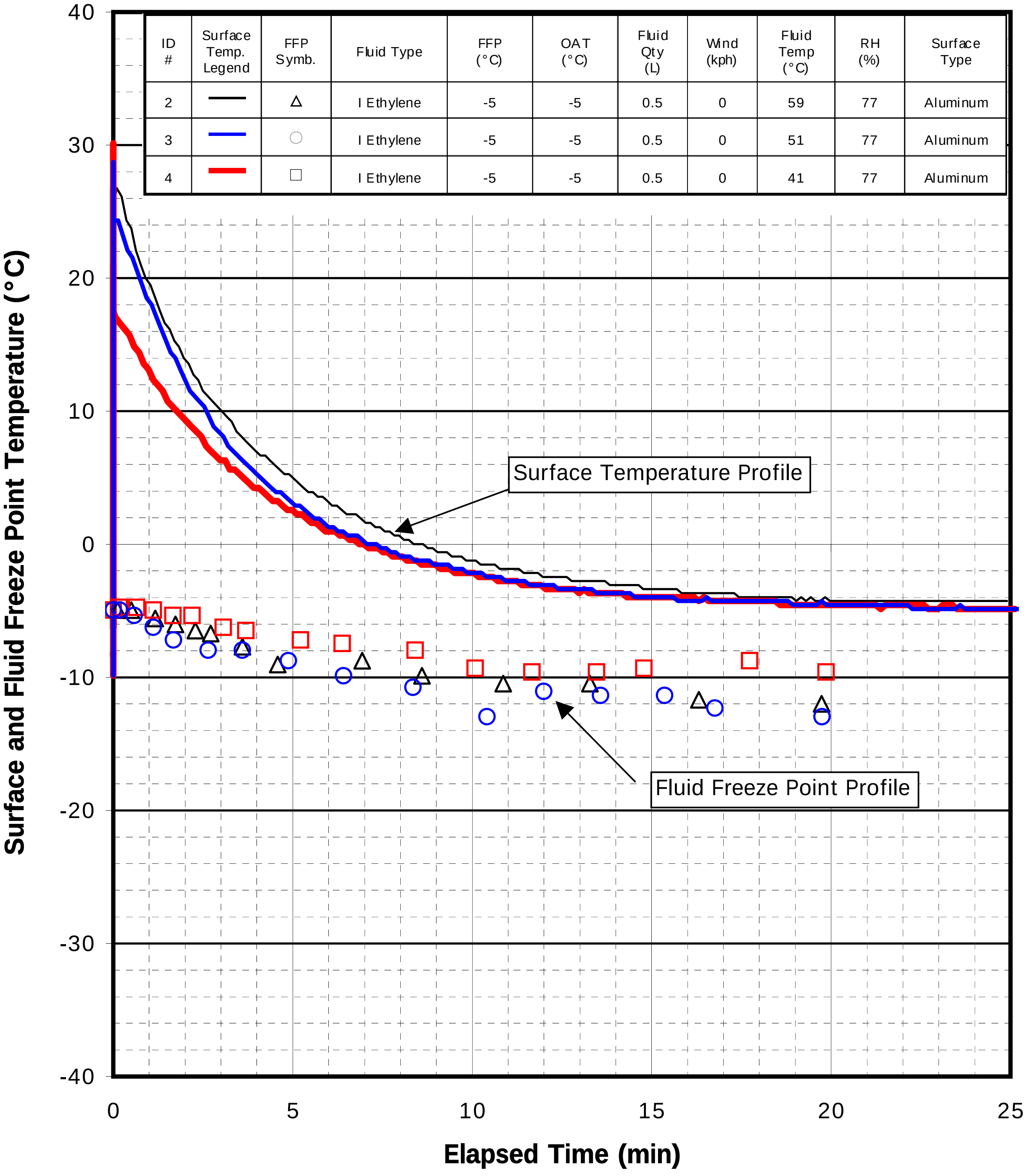
Figures 4.5 to 4.13 present results for tests in which various fluid temperatures were examined in test conditions representing application (quantities and temperatures) for snow removal. Actual snow-removal tests are reported in Section 4.1.6. In all figures, results from tests using fluid temperatures of 60, 50, and 40°C are reported. Tests representing frost removal, in which different fluid temperatures were examined, are discussed in Subsection 4.1.2.2.

Figures 4.5 to 4.13 report results for conditions as shown in the following matrix:

FIGURE 4.5

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -5°C, FFP -5°C, Type I EG Fluid, Winds Calm



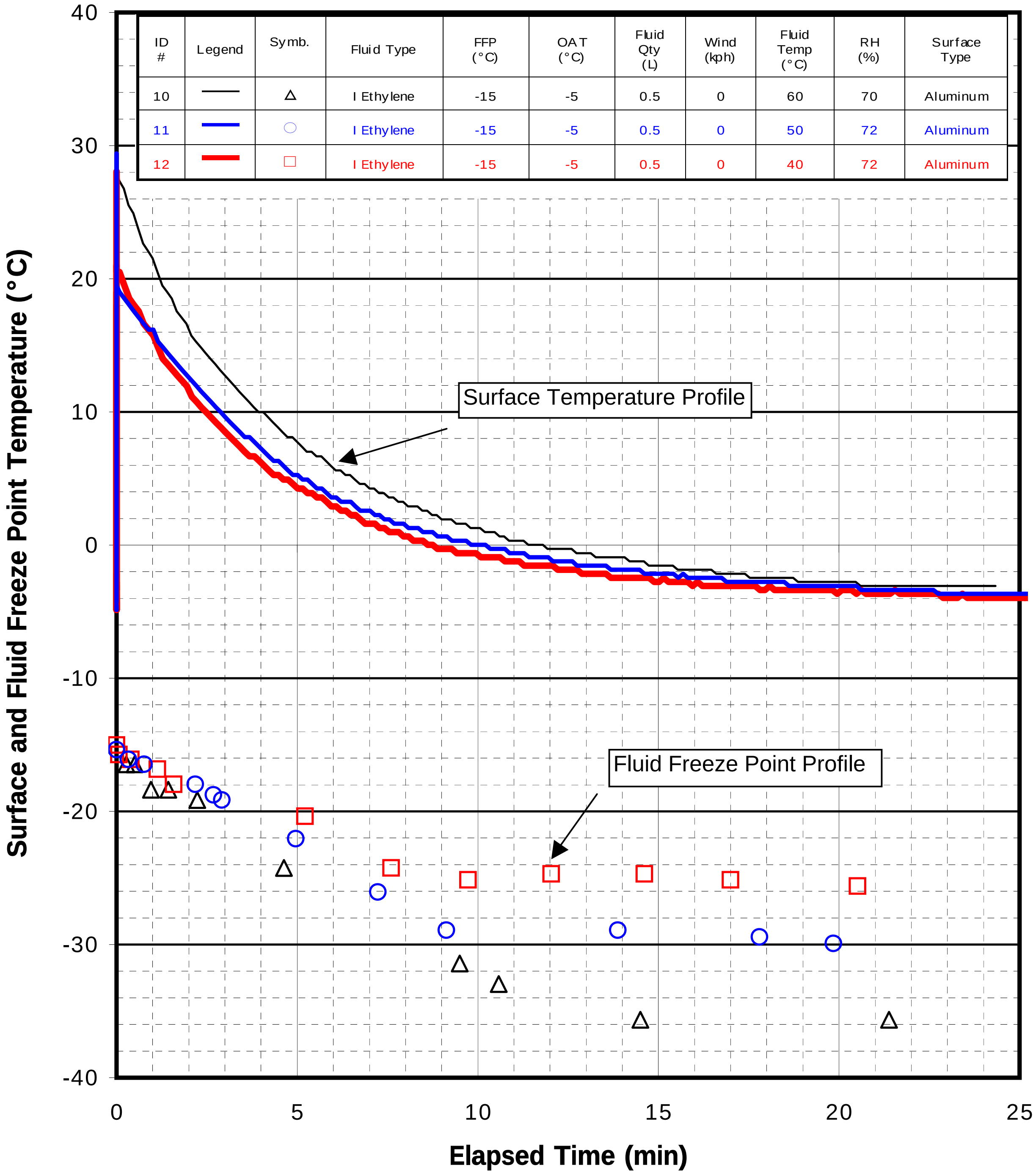
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2	—	△	I Ethylene	-5	-5	0.5	0	59	77	Aluminum
3	—	○	I Ethylene	-5	-5	0.5	0	51	77	Aluminum
4	—	□	I Ethylene	-5	-5	0.5	0	41	77	Aluminum

FIGURE 4.6

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature - Snow Removal

ID# 10, 11 & 12



ID #	Legend	Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
10	—	△	I Ethylene	-15	-5	0.5	0	60	70	Aluminum
11	—	○	I Ethylene	-15	-5	0.5	0	50	72	Aluminum
12	—	□	I Ethylene	-15	-5	0.5	0	40	72	Aluminum

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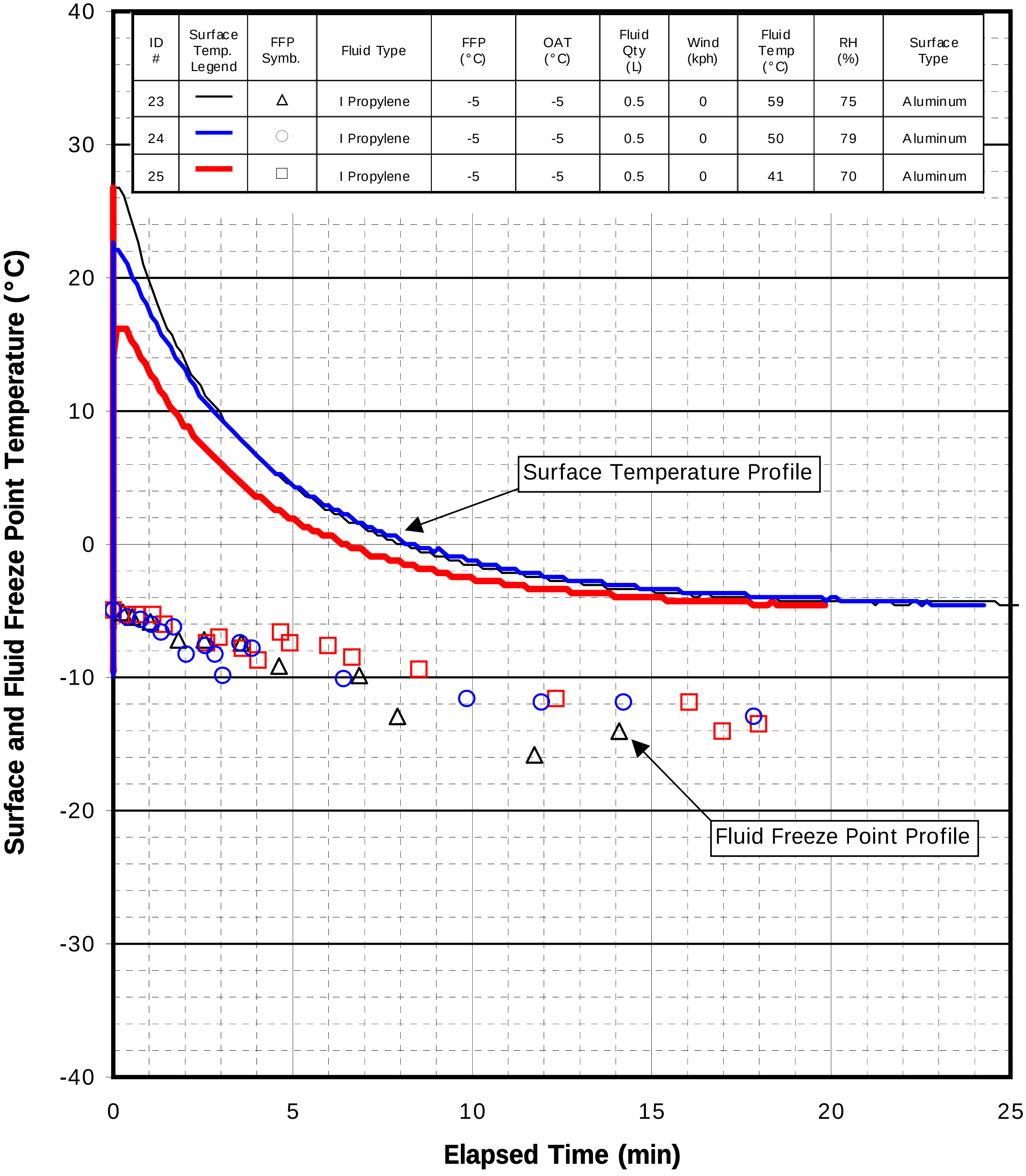
FIGURE 4.7

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -5°C, FFP -5°C, Type I PG Fluid, Winds Calm

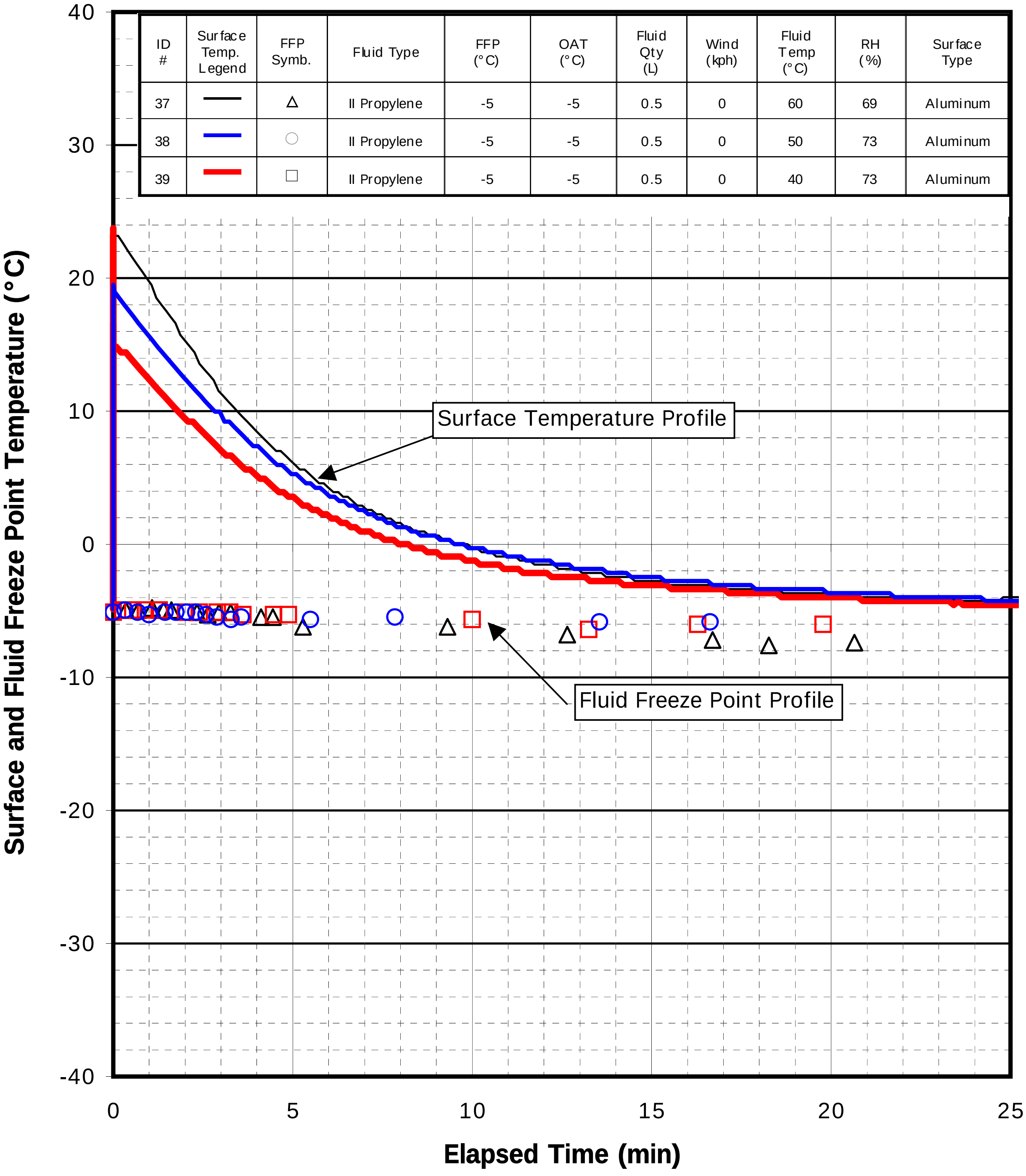


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
23	—	△	I Propylene	-5	-5	0.5	0	59	75	Aluminum
24	━	○	I Propylene	-5	-5	0.5	0	50	79	Aluminum
25	━	□	I Propylene	-5	-5	0.5	0	41	70	Aluminum

FIGURE 4.8

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -5°C, FFP -5°C, Type II PG Fluid, Winds Calm

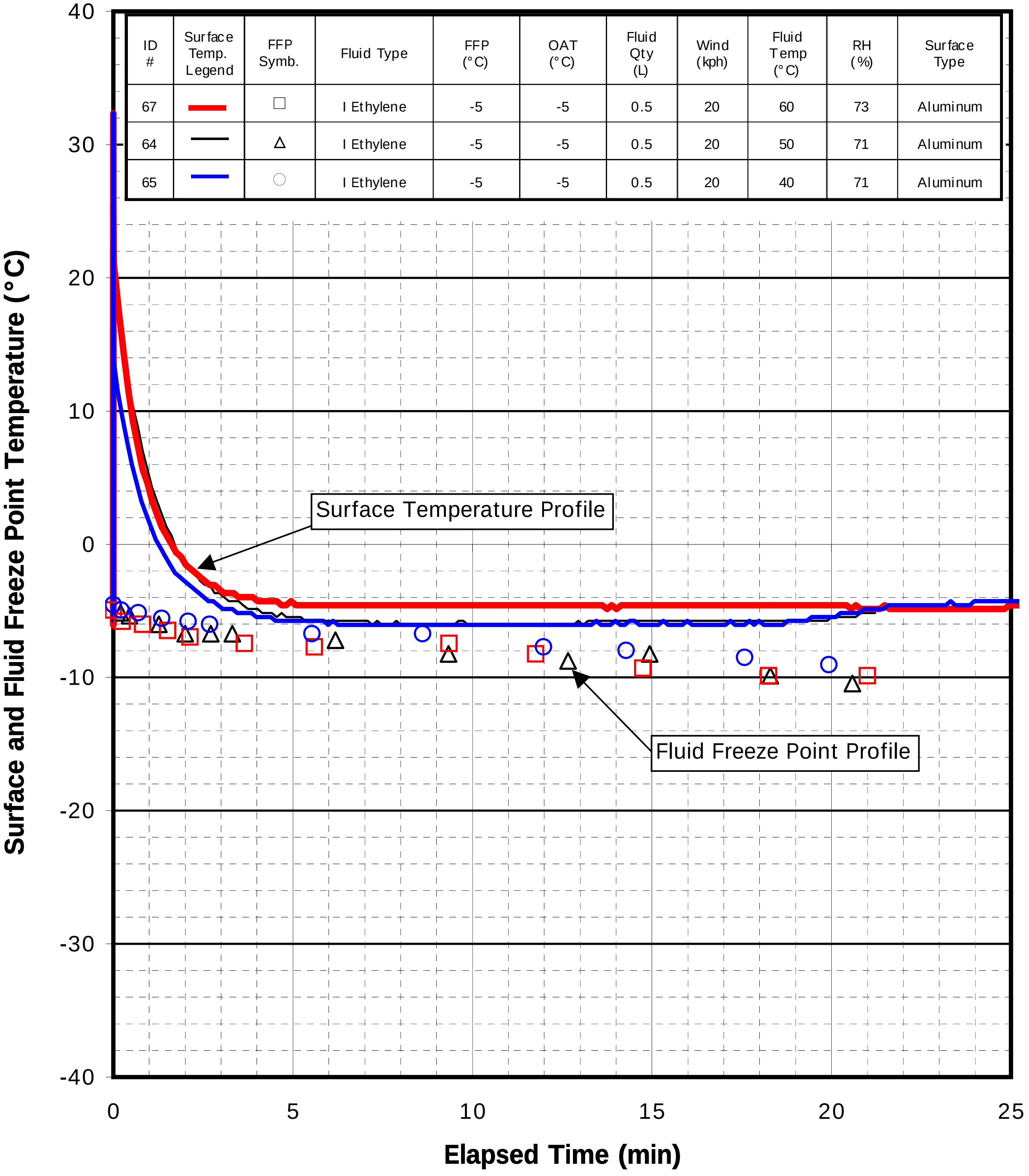


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
37	—	△	II Propylene	-5	-5	0.5	0	60	69	Aluminum
38	—	○	II Propylene	-5	-5	0.5	0	50	73	Aluminum
39	—	□	II Propylene	-5	-5	0.5	0	40	73	Aluminum

FIGURE 4.9

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -5°C, FFP -5°C, Type I EG Fluid, Wind 20 kph



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
67	━	□	I Ethylene	-5	-5	0.5	20	60	73	Aluminum
64	─	△	I Ethylene	-5	-5	0.5	20	50	71	Aluminum
65	━	○	I Ethylene	-5	-5	0.5	20	40	71	Aluminum

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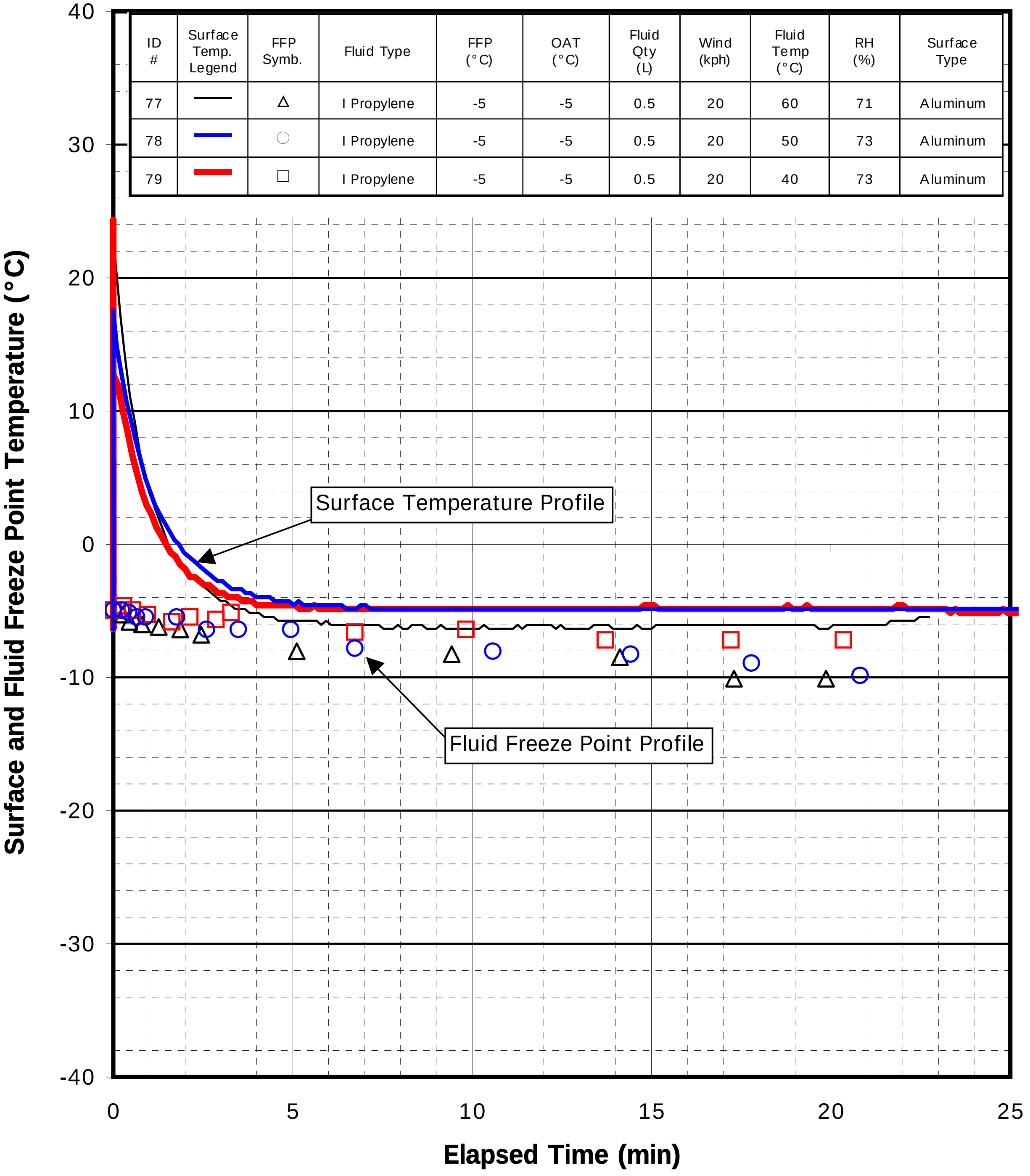
FIGURE 4.10

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -5°C, FFP -5°C, Type I PG Fluid, Wind 20 kph

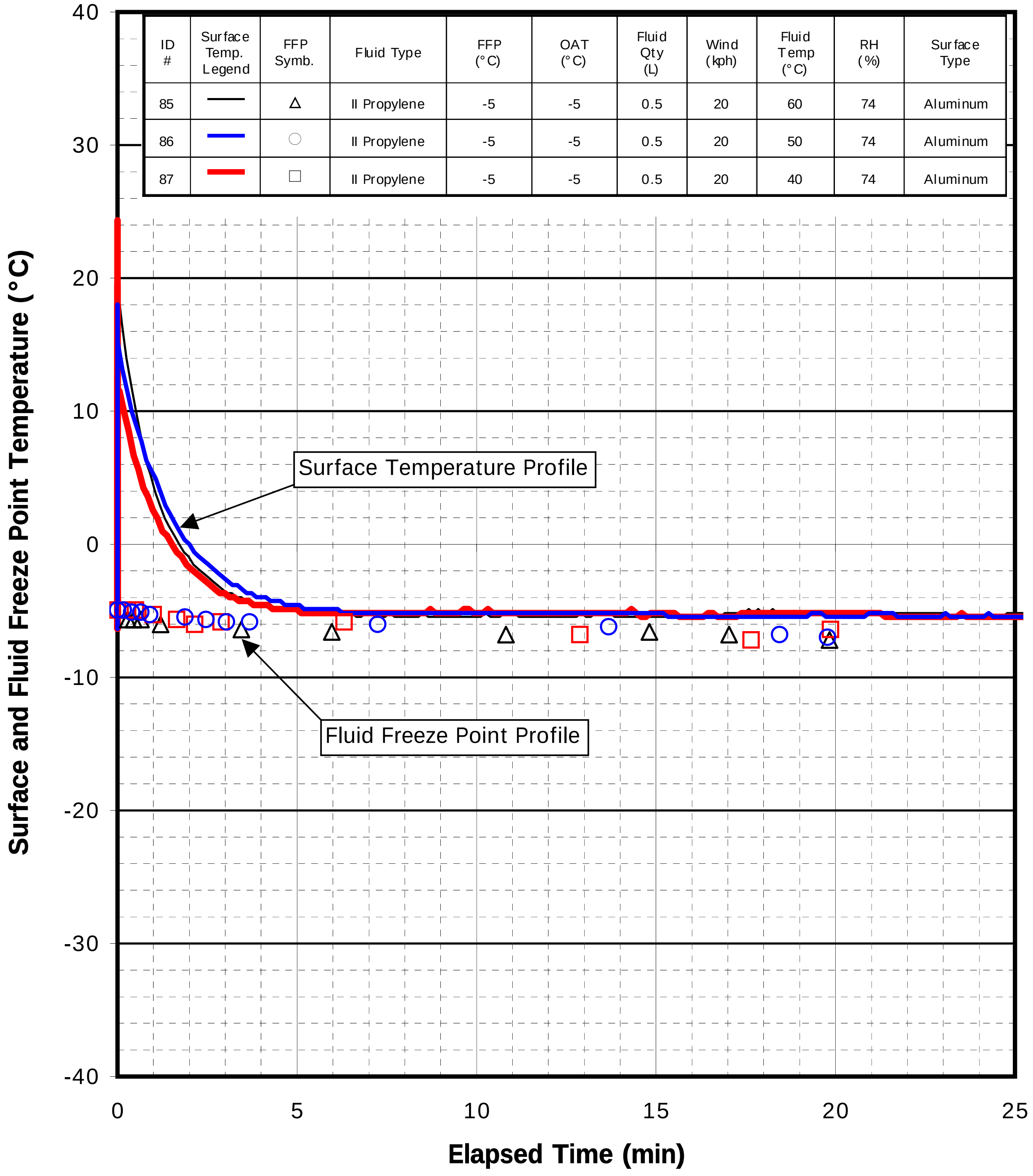


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
77	—	△	I Propylene	-5	-5	0.5	20	60	71	Aluminum
78	—	○	I Propylene	-5	-5	0.5	20	50	73	Aluminum
79	━	□	I Propylene	-5	-5	0.5	20	40	73	Aluminum

FIGURE 4.11

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -5°C, FFP -5°C, Type II PG Fluid, Wind 20 kph



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
85	—	△	II Propylene	-5	-5	0.5	20	60	74	Aluminum
86	—	○	II Propylene	-5	-5	0.5	20	50	74	Aluminum
87	▬	□	II Propylene	-5	-5	0.5	20	40	74	Aluminum

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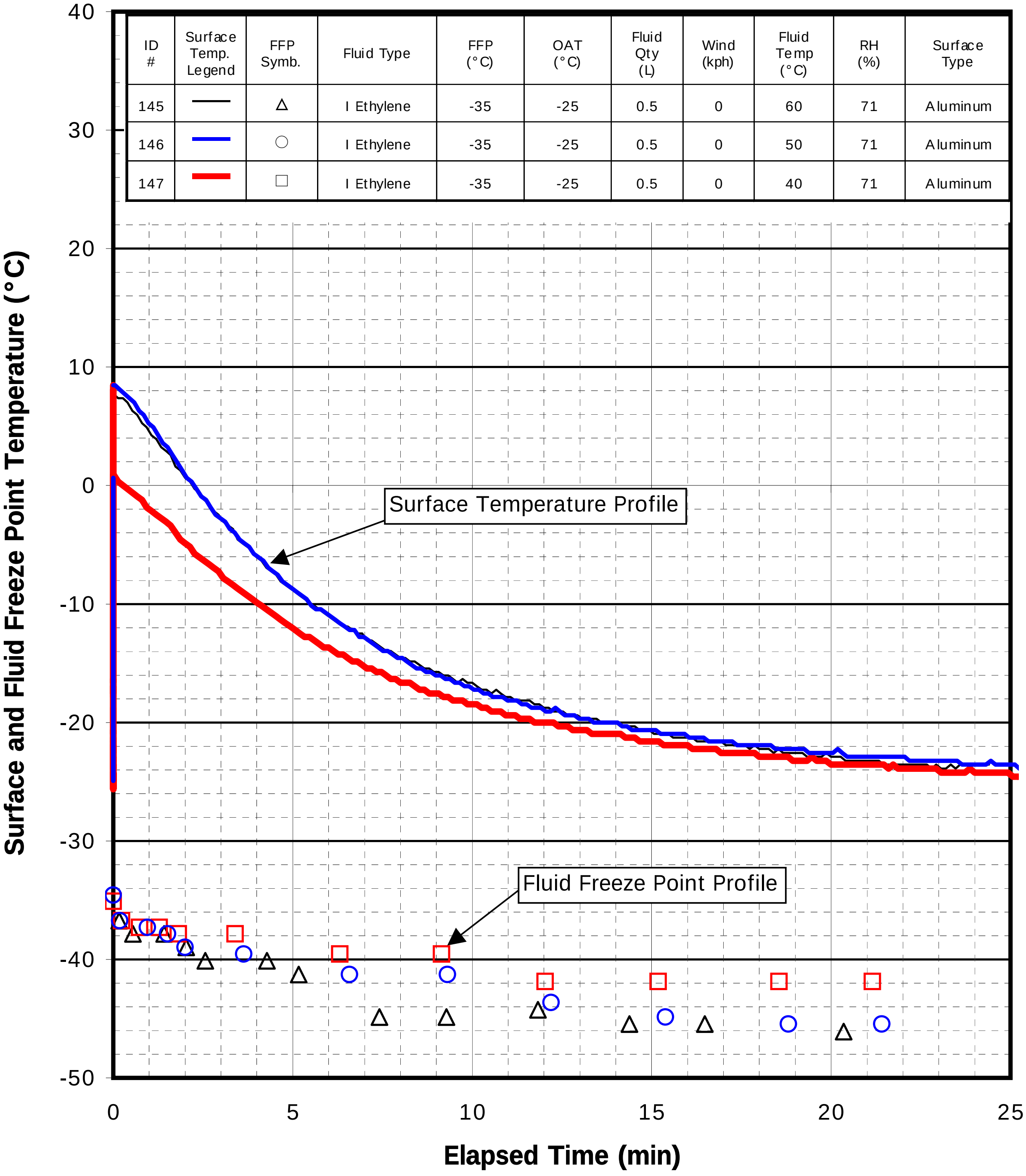
FIGURE 4.12

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -25°C, FFP -35°C, Type I EG Fluid, Winds Calm

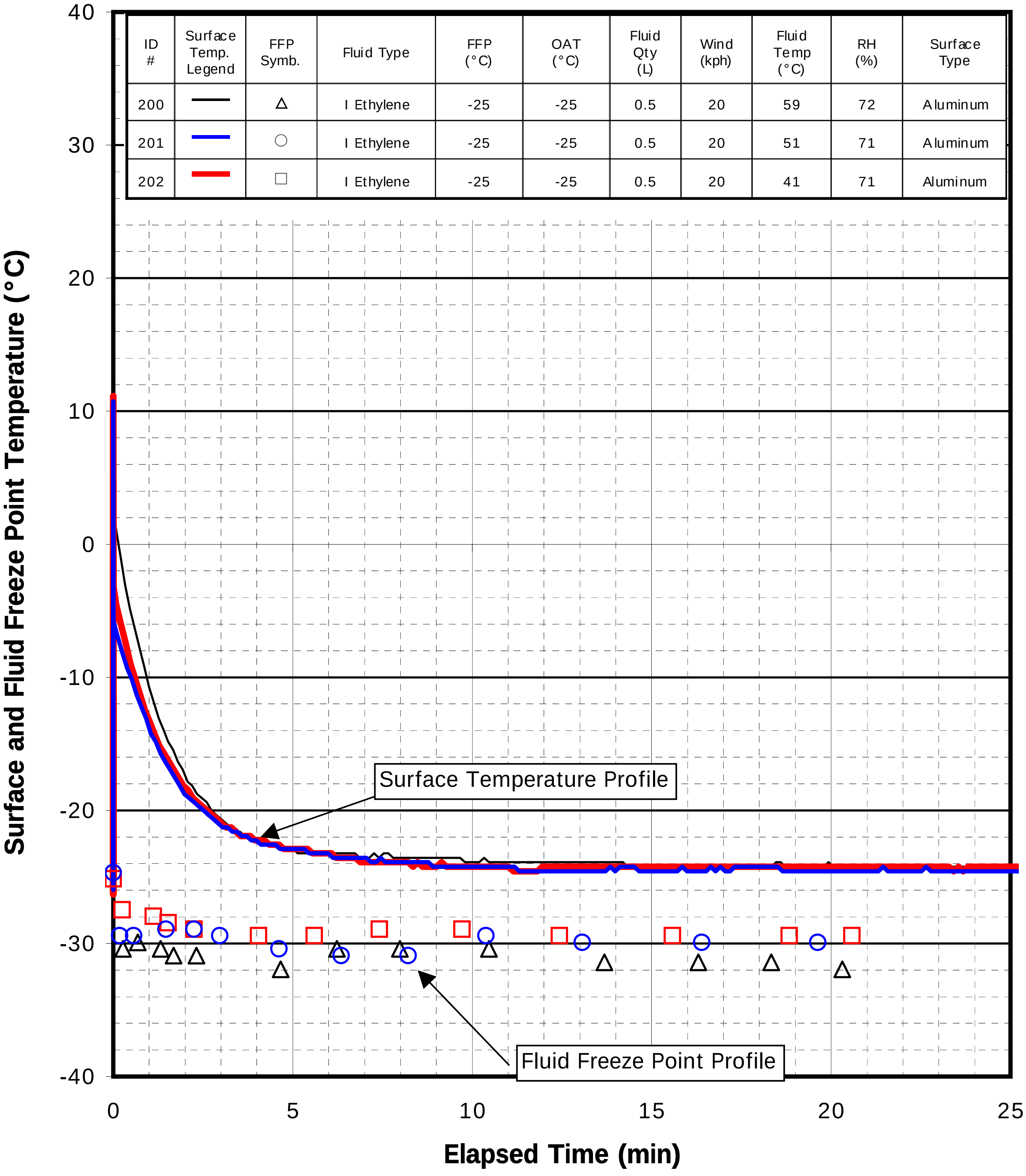


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
145	—	△	I Ethylene	-35	-25	0.5	0	60	71	Aluminum
146	🟦	○	I Ethylene	-35	-25	0.5	0	50	71	Aluminum
147	🟥	□	I Ethylene	-35	-25	0.5	0	40	71	Aluminum

FIGURE 4.13

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Snow Removal
OAT -25°C, FFP -25°C, Type I EG Fluid, Wind 20 kph



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
200	—	△	I Ethylene	-25	-25	0.5	20	59	72	Aluminum
201	—	○	I Ethylene	-25	-25	0.5	20	51	71	Aluminum
202	—	□	I Ethylene	-25	-25	0.5	20	41	71	Aluminum

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Figure #	OAT (°C)	FFP (°C)	Fluid Type	Fluid Temp (°C)	Wind (kph)
4.5	–5	–5	T1E	60, 50, 40	Calm
4.6	–5	–15	T1E	60, 50, 40	Calm
4.7	–5	–5	T1P	60, 50, 40	Calm
4.8	–5	–5	T2P	60, 50, 40	Calm
4.9	–5	–5	T1E	60, 50, 40	20
4.10	–5	–5	T1P	60, 50, 40	20
4.11	–5	–5	T2P	60, 50, 40	20
4.12	–25	–35	T1E	60, 50, 40	Calm
4.13	–25	–25	T1E	60, 50, 40	20

Other parameters (such as fluid quantity, relative humidity, and surface type) were held constant as noted in the legend for each figure.

In Figure 4.5, comparison of the surface-temperature profiles for the three tests shows that the highest fluid temperature resulted in the highest peak and longest time to cool to ambient temperature. Fluid freeze points display improvements at all temperatures tested. At 60 and 50°C, there was little difference in FFP enhancement. At 40°C, it was notably reduced, but still achieved an improvement (drop in FFP) of –4°C.

Figure 4.6 reports on tests run with FFP of –15°C, as opposed to the previous test at FFP of –5°C. Comparison of the surface-temperature profiles for the two tests shows again that the higher fluid temperature resulted in a higher peak and longer time to cool. Fluid freeze points displayed noteworthy improvements for all temperatures, with the greatest improvement for higher-temperature fluid and the least for lower-temperature fluid. As noted in the discussions on fluid quantities, these results indicate that a greater improvement in FFP results from mixes having a higher initial proportion of glycol, at least under these conditions.

Figure 4.7 reports on tests conducted with propylene glycol-based Type I fluid, as opposed to ethylene glycol-based Type I fluid as reported in Figure 4.5. In Figure 4.7, comparison of the surface-temperature profiles shows that the higher fluid temperature resulted in a higher peak and longer time to cool. Fluid freeze points displayed improvements for all temperatures. Although the data show some scatter, the FFP improvement was greatest for the highest fluid temperature, and results for the other two temperatures show no significant difference.

The degree of enhancement for all fluid temperatures indicated that propylene glycol-based fluid provides a higher degree of FFP enhancement than ethylene glycol-based fluid (Figure 4.7 vs. 4.5) in these conditions.

Figure 4.8 reports on tests conducted with propylene glycol-based Type II fluid. Surface-temperature profiles show peak temperature differences directly related to fluid temperatures. Time to cool was somewhat longer than for ethylene glycol-based Type I fluids tested under the same conditions. This fluid displayed very little improvement in FFP, with only a 3°C drop for the test at the highest temperature (Run ID # 37). The other two tests with fluid at 40 and 50°C produced only a 1°C drop in FFP.

Figures 4.9, 4.10, and 4.11 show results for tests conducted under conditions identical to those for Figures 4.5, 4.7, and 4.8 (OAT = FFP = –5°C), except for the introduction of winds of 20 kph. Surfaces cooled very rapidly in all tests. The differential in improvement of FFP among various fluid temperatures was much reduced in tests with windy as opposed to calm conditions.

- For ethylene glycol-based Type I fluids (Figure 4.9), the three temperatures resulted in lowering FFP temperatures by –4°C to –6°C at test end. However, for the tests using fluids (having an initial FFP equal to OAT) at the low temperatures of 40°C and 50°C, the rapid rate of surface cooling, combined with the slow rate of FFP enhancement, caused the FFP profile to come close to the surface temperature profile. A spread between the two curves of less than 2°C was experienced during the early part of the test. This is a real concern, as an intersection of the two curves indicates freezing conditions. The test with a fluid temperature of 60°C also demonstrated a slow improvement to FFP, but experienced a more acceptable separation between the FFP and surface temperature curves, with the closest approach being about 4°C.

- For propylene glycol-based Type I fluids (Figure 4.10), the three temperatures produced FFP drops from –2°C to –5°C, with the expected gradation from the coldest fluid, least change, to hottest fluid, greatest change. The existence of wind along with the lowest temperature fluid tested (40°C), and a fluid with initial FFP equal to OAT, appears to be an unacceptable combination, producing a separation between the FFP and surface temperature curves of only 1°C in the early part of the test run.

- For propylene glycol-based Type II fluids (Figure 4.11), the three temperatures produced FFP drops of –2°C. The small enhancement in FFP for Type II fluids tested with calm winds (Figure 4.8) was even more limited with winds of 20 kph.

Figures 4.12 and 4.13 examine the influence of fluid-temperature differentials at colder ambient temperatures, with and without wind.

- Figure 4.12 reports on conditions identical to Figure 4.6, with the exception of OAT (–25 vs. –5°C). In both cases, the initial fluid freeze point was 10°C below OAT. It is interesting that the time taken for the surface to cool to ambient was very similar for the two OAT conditions (about 20 minutes). The differential in improvement of FFP among various fluid temperatures was much lower in the test at the cold OAT, but still showed greater improvement for higher temperatures. Fluid applied at 40°C showed an FFP enhancement of –7°C.

- Figure 4.13 reports on a test at cold ambient temperatures, with FFP equal to OAT (FFP = OAT = –25°C) and a wind of 20 kph. This test is comparable to the one reported in Figure 4.9, except for the difference in OAT (–25°C vs. –5°C). As was seen in Figure 4.9, with winds of 20 kph, the surface cooled rapidly. However, FFP enhancement was notably greater than that experienced at the warmer temperature, with an improvement of –4°C for fluid temperature of 40°C to –7°C for a fluid temperature of 60°C.

In summary, several conclusions can be drawn from the results shown in this set of figures:

Regarding Type II propylene glycol-based fluid:

i. This fluid does not provide any significant FFP enhancement, in either calm or wind conditions.

Regarding Type I ethylene and propylene glycol-based fluids:

ii. The temperature of the fluid at time of application has a significant effect on the enhancement of fluid freeze point. Fluid temperatures of 60°C consistently produced greater enhancements in FFP than the colder fluid temperatures tested (50°C and 40°C).

iii. At the milder OAT condition tested (–5°C), wind in combination with lower fluid temperatures can limit the extent of FFP enhancement to an unsatisfactory level when used in conjunction with a fluid having a 0°C freeze point buffer (FFP = OAT):

  - In calm wind conditions, a satisfactory level of FFP enhancement was achieved for all fluid temperatures tested; and
  - In conditions of wind at 20 kph, an unsatisfactory level of FFP enhancement was achieved for fluids having initial temperatures of 40°C and 50°C.

iv. In cold OAT conditions (-25°C), wind conditions did not prevent a satisfactory level of FFP enhancement from being achieved for all fluid temperatures tested. This enhanced performance at cold temperatures is associated with the greater initial proportion of glycol in the cold temperature fluid mix.

4.1.2.2 Test Representing Frost Removal

Figures 4.14 to 4.17 present results for tests in which various fluid temperatures were examined in conditions representing application for frost removal. In all figures, results using temperatures of 50, 35, and 20°C are reported.

These figures report results for conditions as shown in the following matrix:

Figure #	OAT (°C)	FFP (°C)	Fluid Type	Fluid Temp (°C)	Wind (kph)
4.14	–5	–5	T1E	50, 35, 20	Calm
4.15	–5	–15	T1E	50, 35, 20	Calm
4.16	–5	–5	T2P	50, 35, 20	Calm
4.17	–25	–25	T1E	50, 35, 20	Calm

Other parameters (such as fluid quantity, relative humidity, and surface type) were held constant as noted in the legend for each figure. As these were trials representing frost removal, wind conditions were not tested. As noted in the discussion on test parameters, the fluid quantity used for frost removal trials was 0.2 L, applied by spraying.

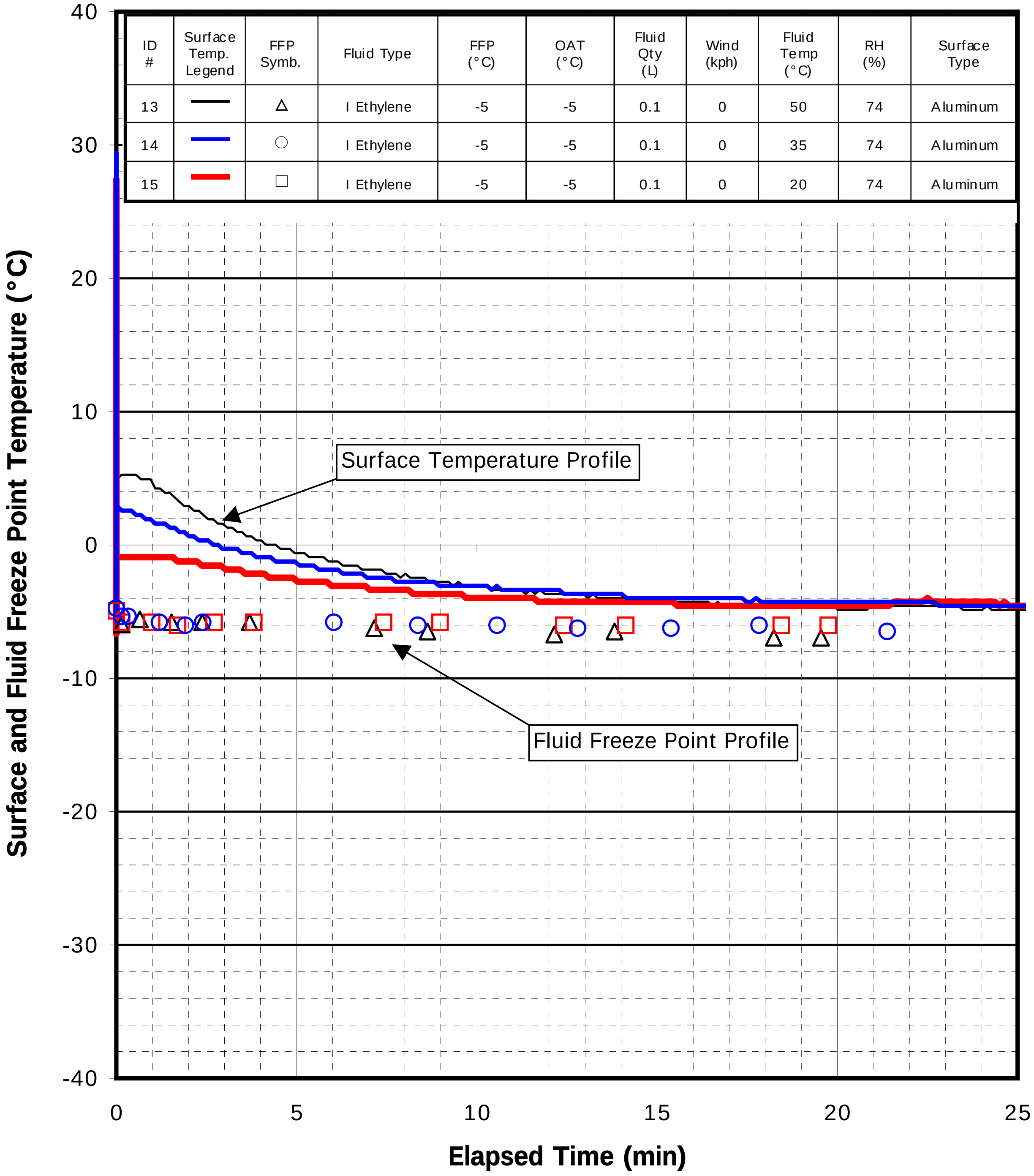
Figure 4.14 illustrates the much-reduced peak temperature reached by the surfaces, as compared to tests representing snow removal. The time to cool to ambient temperature was the same (about 20 minutes) as seen previously for these test conditions. The peak surface-temperature values were directly related to the fluid temperatures tested (50, 35, and 20°C). The improvement in FFP was minimal for all three tests, producing a drop of –2°C for the warmest fluid and –1°C for the coolest. Most of the improvement in FFP occurred at the beginning of the test, just after fluid application. As a result, the temperature profiles of the plate and of the FFP did not intersect, and freezing on the surface did not occur.

Figure 4.15 reports on tests similar to those in Figure 4.14, except that the fluid was mixed to an FFP 10°C colder than OAT. Surface-temperature

FIGURE 4.14

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Frost Removal
OAT -5°C, FFP -5°C, Type I EG Fluid, Winds Calm

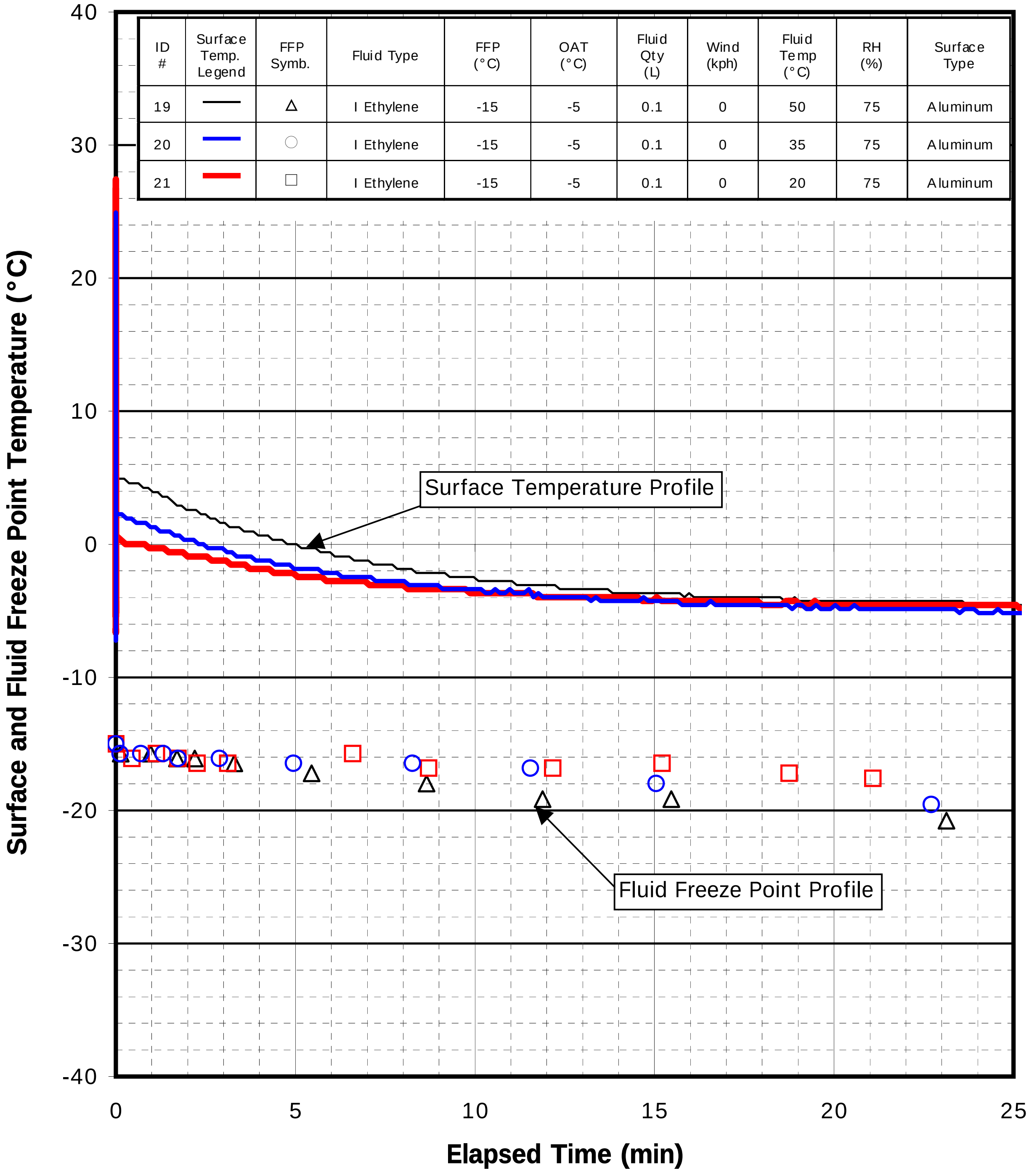


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
13	━	△	I Ethylene	-5	-5	0.1	0	50	74	Aluminum
14	━	○	I Ethylene	-5	-5	0.1	0	35	74	Aluminum
15	━	□	I Ethylene	-5	-5	0.1	0	20	74	Aluminum

FIGURE 4.15

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Frost Removal
OAT -5°C, FFP -15°C, Type I EG Fluid, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
19	─	△	I Ethylene	-15	-5	0.1	0	50	75	Aluminum
20	━	○	I Ethylene	-15	-5	0.1	0	35	75	Aluminum
21	━	□	I Ethylene	-15	-5	0.1	0	20	75	Aluminum

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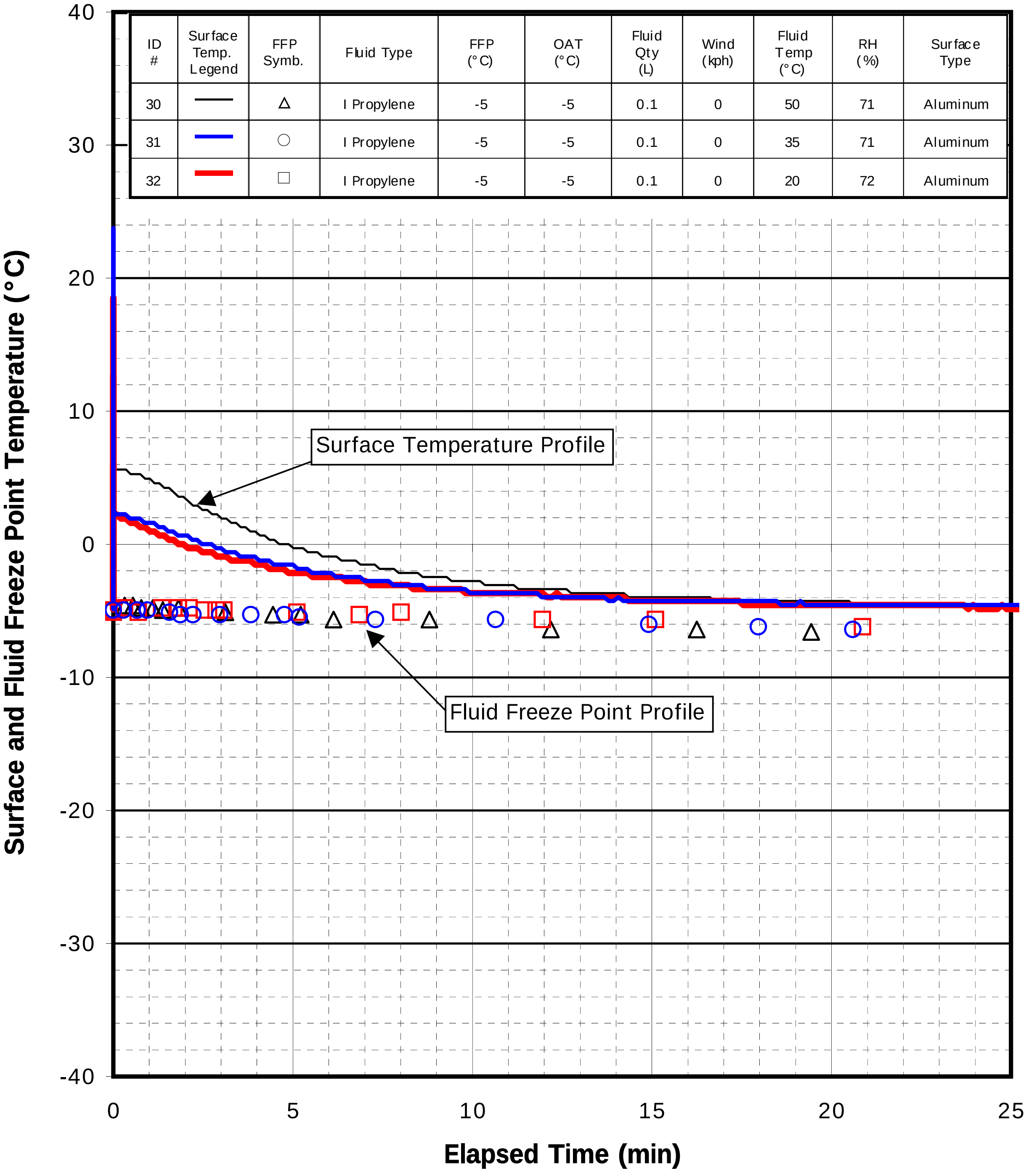
FIGURE 4.16

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Frost Removal
OAT -5°C, FFP -5°C, Type I PG Fluid, Winds Calm

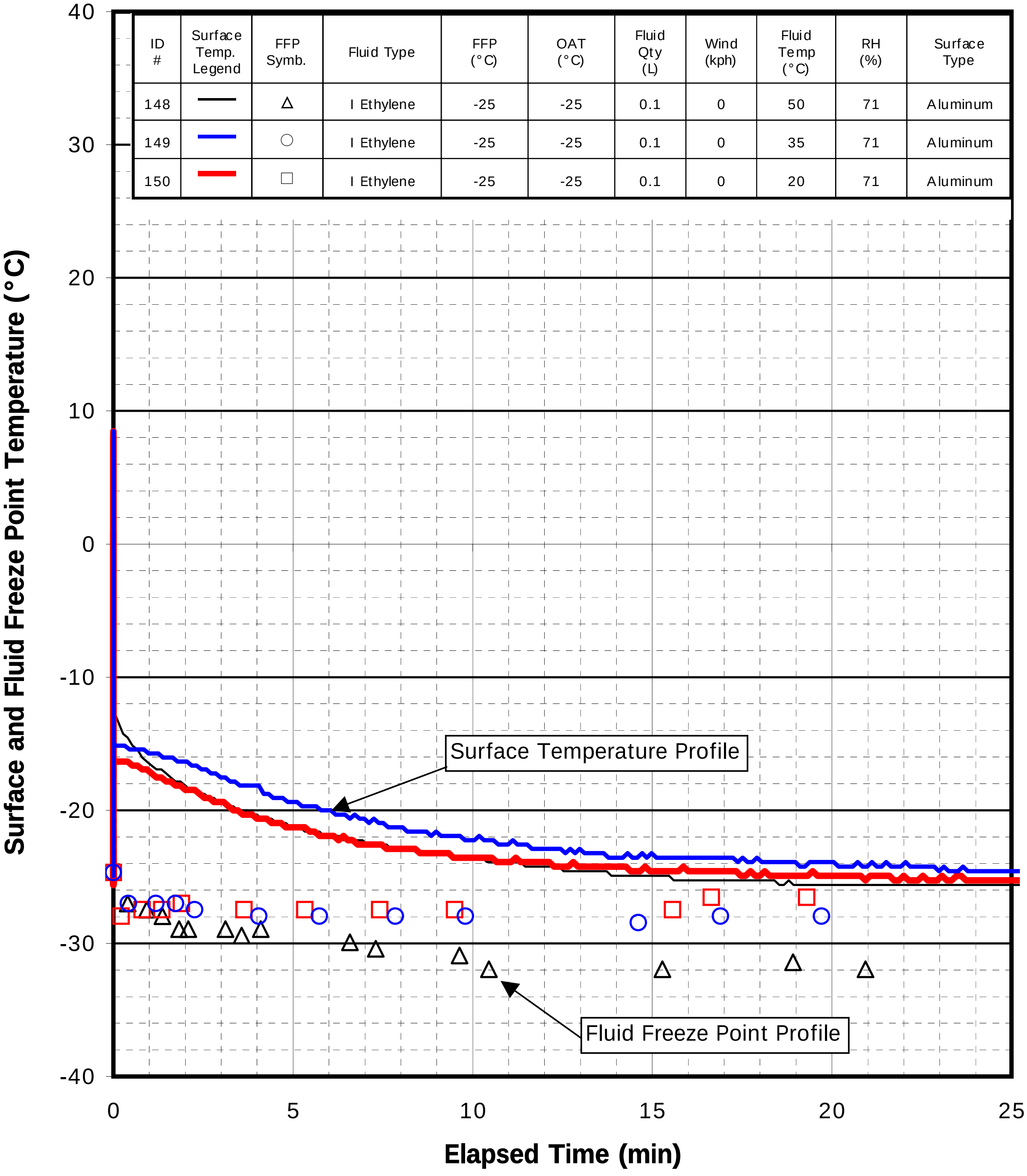


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
30	—	△	I Propylene	-5	-5	0.1	0	50	71	Aluminum
31	—	○	I Propylene	-5	-5	0.1	0	35	71	Aluminum
32	—	□	I Propylene	-5	-5	0.1	0	20	72	Aluminum

FIGURE 4.17

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature – Tests Representing Frost Removal
OAT -25°C, FFP -25°C, Type I EG Fluid, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
148	—	△	I Ethylene	-25	-25	0.1	0	50	71	Aluminum
149	▬	○	I Ethylene	-25	-25	0.1	0	35	71	Aluminum
150	▬	□	I Ethylene	-25	-25	0.1	0	20	71	Aluminum

profiles behaved as in Figure 4.14. FFP profiles showed a greater improvement, with the warmest fluid FFP dropping by –6°C and the coldest by –2°C.

Figure 4.16 reports on tests similar to those in Figure 4.14 except that a Type I propylene glycol-based fluid was used. Results were the same as those for the ethylene glycol-based fluid, with an enhancement in FFP of about –1°C. Again, no freezing was noted.

Figure 4.17 reports on tests conducted with an ethylene glycol-based Type I fluid at OAT and FFP of –25°C. The FFP demonstrated an improvement, in the early stages of the trial, much greater than at warmer ambient temperature. As the trial progressed, FFP values started to increase, indicating some precipitation. To understand this better, an examination of the frost point at the test OAT was performed.

Examination of Frost Condition

The recorded RH during the trial was 71 percent. Reference to tables of saturation-mixing ratios over water at an OAT of –25°C show that the amount of water vapour, when the air is saturated, is .5048 grams of vapour/kg of air. At 71 percent RH, the ratio of water vapour in the air is .3584.

Reference to tables of saturation-mixing ratios over ice show that this ratio of water vapour results in saturation (frost point) at an OAT between –25 and –26°C. The increase in FFP was initiated at about the time that the surface temperature reached –25°C, and so it is surmised that frost deposition was actually occurring, with dilution of the fluid and an associated increase in FFP.

The conclusion is that the RH of 71 percent was in reality a high-humidity condition at the ambient temperature, and that active frost was indeed occurring. Because this does not constitute a *deicing only* condition, the results of this test are irrelevant to the study goal. But, the test did demonstrate that the *deicing only* concept of application of fluids mixed to FFPs equivalent to OAT is inappropriate for active frost conditions.

The conclusion drawn from the tests reported in the previous figures is that only a very slight degree of FFP enhancement can be expected from fluid applications in such small quantities. Although freezing did not occur, and the temperature profiles for test surface and FFP did not intersect, the difference between the two temperatures is marginal for purposes of the *deicing only* concept.

4.1.3 High Winds

Figures 4.18 to 4.21 present results for tests examining the impact of high wind speeds on fluid evaporation and FFP enhancement. In these tests, wind speeds of 0, 20, and 30 kph are examined.

These figures report results for test conditions as shown in the following matrix:

Figure #	OAT (°C)	FFP (°C)	Fluid Type	Wind (kph)
4.18	-5	-5	T1E	Calm, 20, 30
4.19	-5	-15	T1E	Calm, 20, 30
4.20	-5	-5	T1P	Calm, 20, 30
4.21	-25	-25	T1E	Calm, 20, 30

Other parameters (such as fluid quantity, relative humidity, fluid temperature, and surface type) were constant, as noted in the legend for each figure.

In Figure 4.18, comparison of the surface-temperature profiles shows the surface cooling more rapidly under windy conditions. Fluid freeze points displayed improvements at all wind speeds tested. The highest speed (30 kph) produced an unexpected and unexplained result, in which the FFP values were actually lower than for tests with speeds at either calm or 20 kph. It is unknown whether this was an anomaly or a direct result of the higher wind speed.

Figure 4.19 reports on similar tests, except that the fluid was mixed to an FFP of –15°C. Results were similar to the previous set insofar as fluid enhancement was least for the test conducted at a wind speed of 10 kph. At test end, it was equivalent for calm winds and winds of 30 kph.

Figure 4.20 reports on similar tests, except that a Type II propylene glycol-based fluid was applied. As in previous tests using this fluid, the degree of enhancement was minimal. There was no noticeable difference in results for various wind speeds.

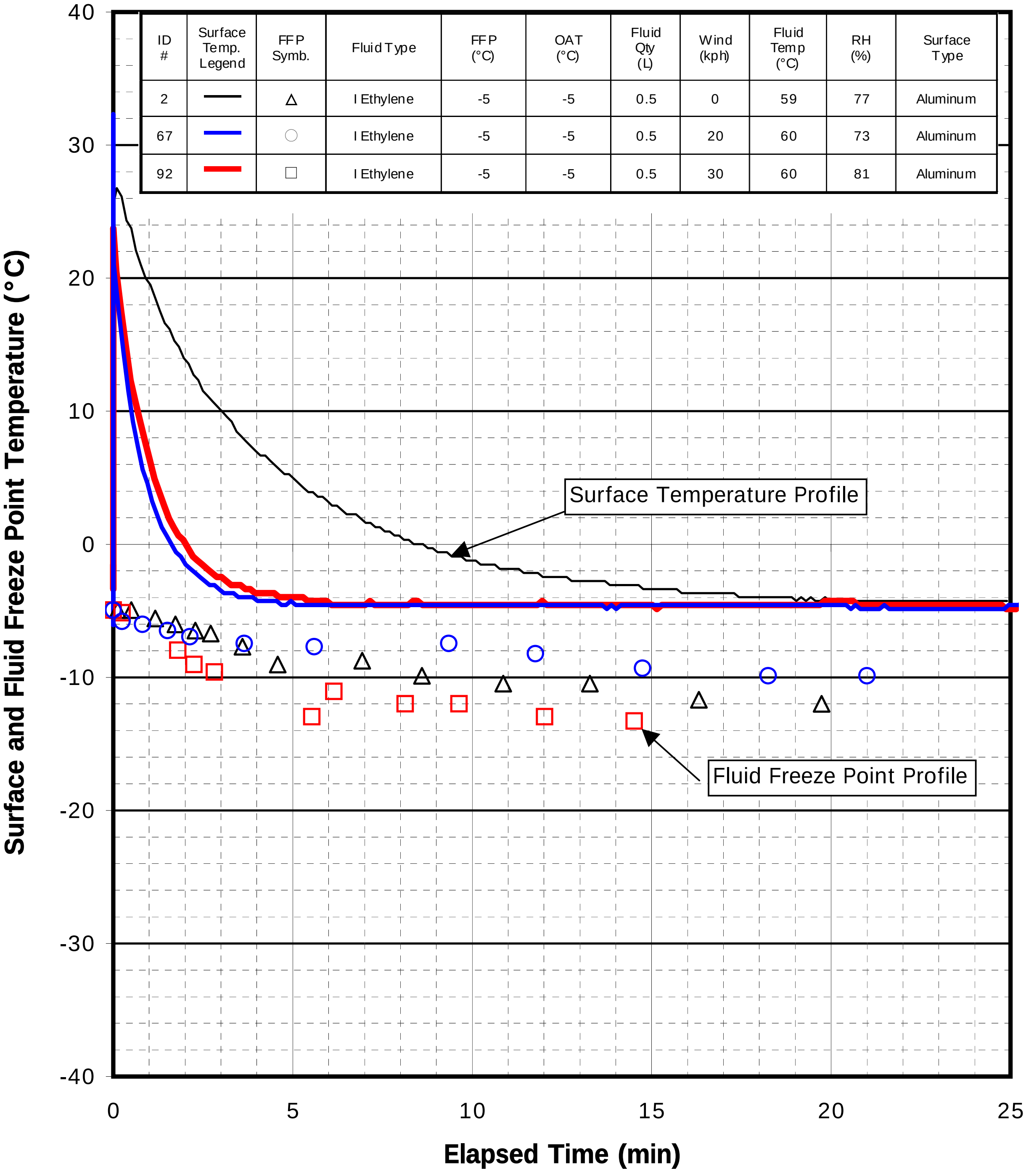
Figure 4.21 reports on tests conducted at an OAT and FFP of –25°C. In this set, the improvement in FFP for the fluid tested with calm wind was the greatest, producing a freezing point drop of –13°C. Winds of 20 and 30 kph produced an equal degree of FFP enhancement, with FFP dropping by –7°C.

FIGURE 4.18

Fluid Freeze Point and Surface Temperature Profile

High Wind

OAT -5°C, FFP -5°C, Type I EG Fluid



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2	—	△	I Ethylene	-5	-5	0.5	0	59	77	Aluminum
67	—	○	I Ethylene	-5	-5	0.5	20	60	73	Aluminum
92	—	□	I Ethylene	-5	-5	0.5	30	60	81	Aluminum

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FIGURE 4.19

Fluid Freeze Point and Surface Temperature Profile

Vary Fluid Temperature

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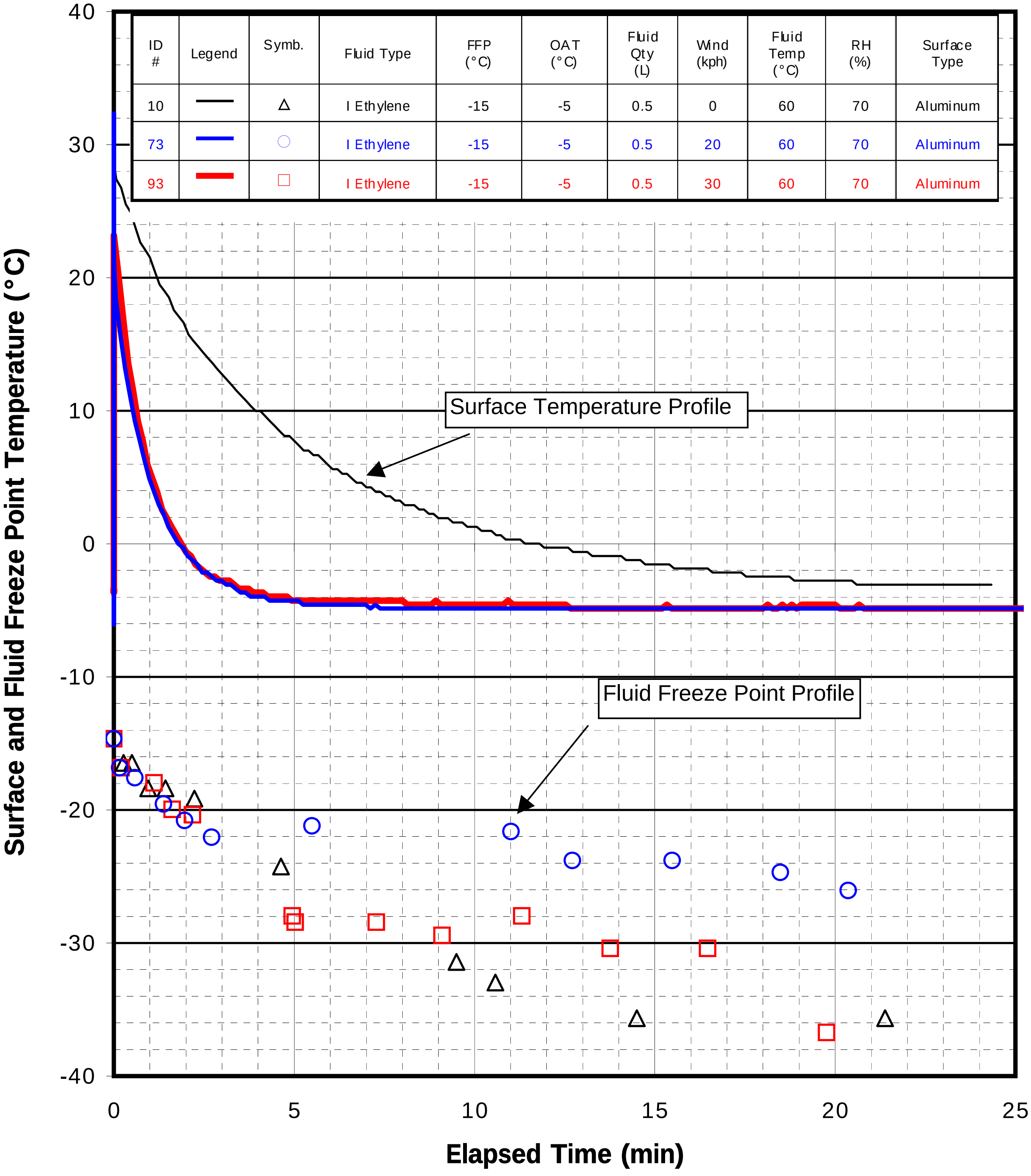

ID #	Legend	Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
10	—	△	I Ethylene	-15	-5	0.5	0	60	70	Aluminum
73	—	○	I Ethylene	-15	-5	0.5	20	60	70	Aluminum
93	—	□	I Ethylene	-15	-5	0.5	30	60	70	Aluminum

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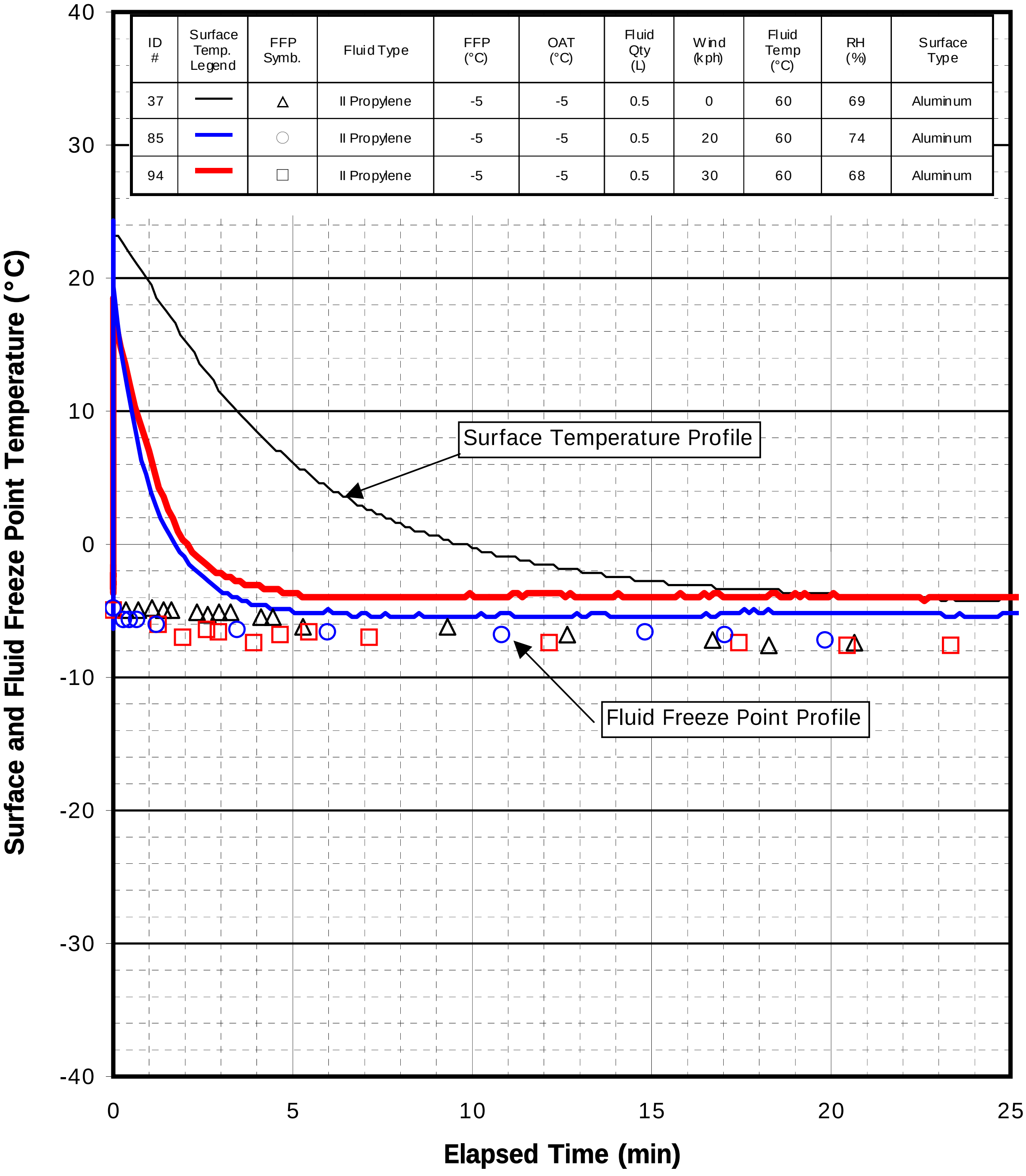
FIGURE 4.20

Fluid Freeze Point and Surface Temperature Profile

High Wind

OAT -5°C, FFP -5°C, Type II PG Fluid



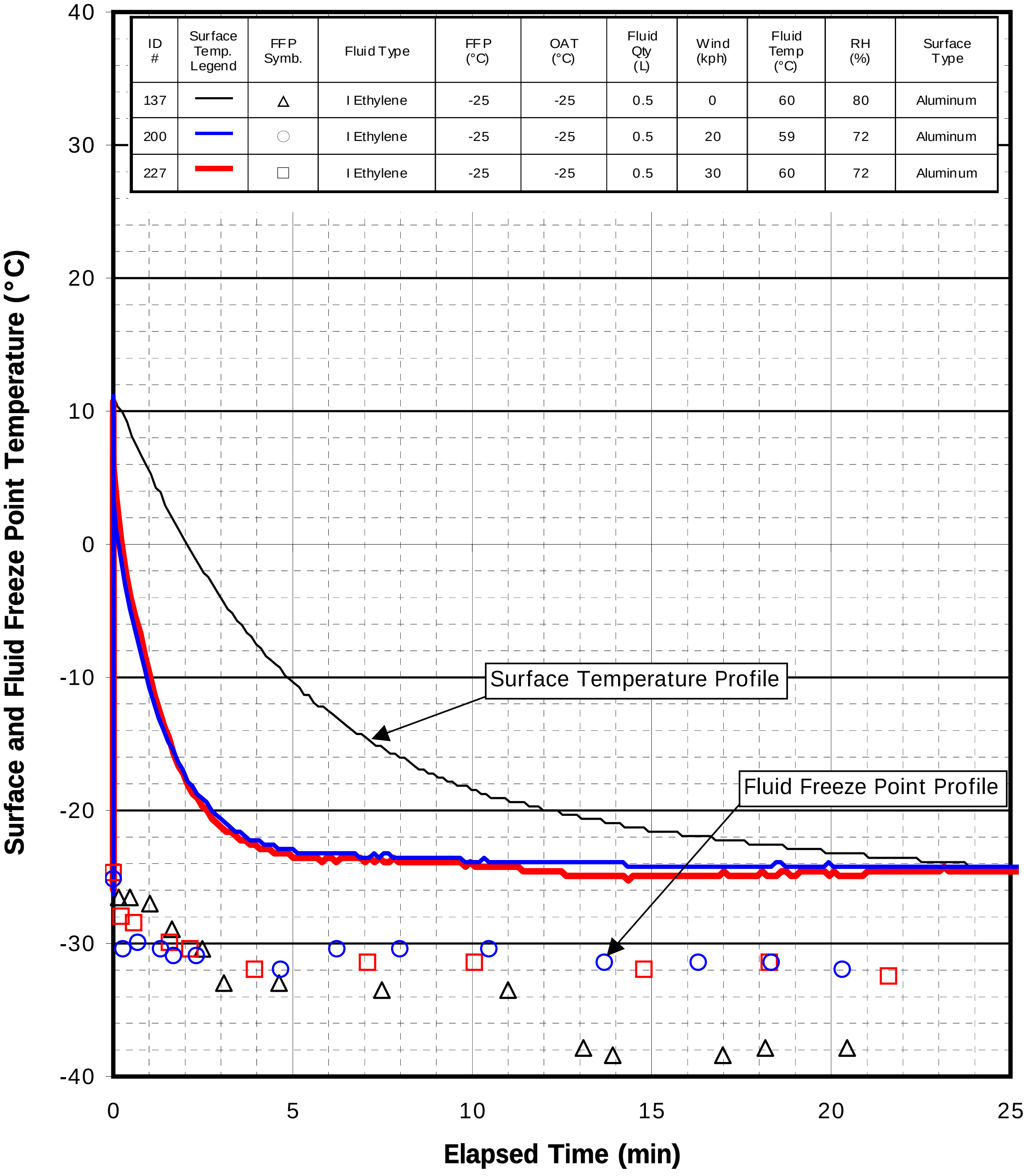
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
37	—	△	II Propylene	-5	-5	0.5	0	60	69	Aluminum
85	—	○	II Propylene	-5	-5	0.5	20	60	74	Aluminum
94	—	□	II Propylene	-5	-5	0.5	30	60	68	Aluminum

FIGURE 4.21

Fluid Freeze Point and Surface Temperature Profile

High Wind

OAT -25°C, FFP -25°C, Type I EG Fluid



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
137	—	△	I Ethylene	-25	-25	0.5	0	60	80	Aluminum
200	—	○	I Ethylene	-25	-25	0.5	20	59	72	Aluminum
227	—	□	I Ethylene	-25	-25	0.5	30	60	72	Aluminum

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In summary, at an OAT of –5°C, the high winds tested (30 kph) produced better results than those achieved during winds of 20 kph. At an OAT of –25°C, the high winds (30 kph) produced results equal to those achieved with winds of 20 kph.

4.1.4 Impact of Current Fluid-Freezing Point Buffer

Figures 4.22 to 4.25 present results for tests examining FFP enhancement for fluids mixed to current buffer regulations. The currently approved buffer for the use of Type I fluid as the second step of a two-step procedure is 10°C below OAT. In these tests, FFPs equivalent to OAT, OAT –3°C, and OAT –10°C (FFP buffer values of 0°C, 3°C and 10°C below OAT) were examined.

These figures report results for test conditions as shown in the following matrix:

Figure #	**OAT (°C)**	**FFP (°C)**	**Fluid Type**	**Wind (kph)**
4.22	–5	–5, –8, –15	T1E	Calm
4.23	–5	–5, –15	T1P	Calm
4.24	–5	–5, –8, –15	T1E	20
4.25	–25	–25, –28, –35	T1E	Calm

Other parameters (such as fluid quantity, relative humidity, fluid temperature, and surface type) were held constant as noted in the legend for each figure.

As illustrated in Figure 4.22, the extent to which freezing points for an ethylene glycol-based fluid improved (dropped) under these conditions (OAT = –5°C, calm winds) was a direct function of the initial strength tested. At test end, the FFP of the mixtures showed enhanced freezing points as follows:

Initial FFP (°C)	**Final FFP (°C)**	**Drop in FFP (°C)**
–5	–12	–7
–8	–26	–18
–15	–35	–20

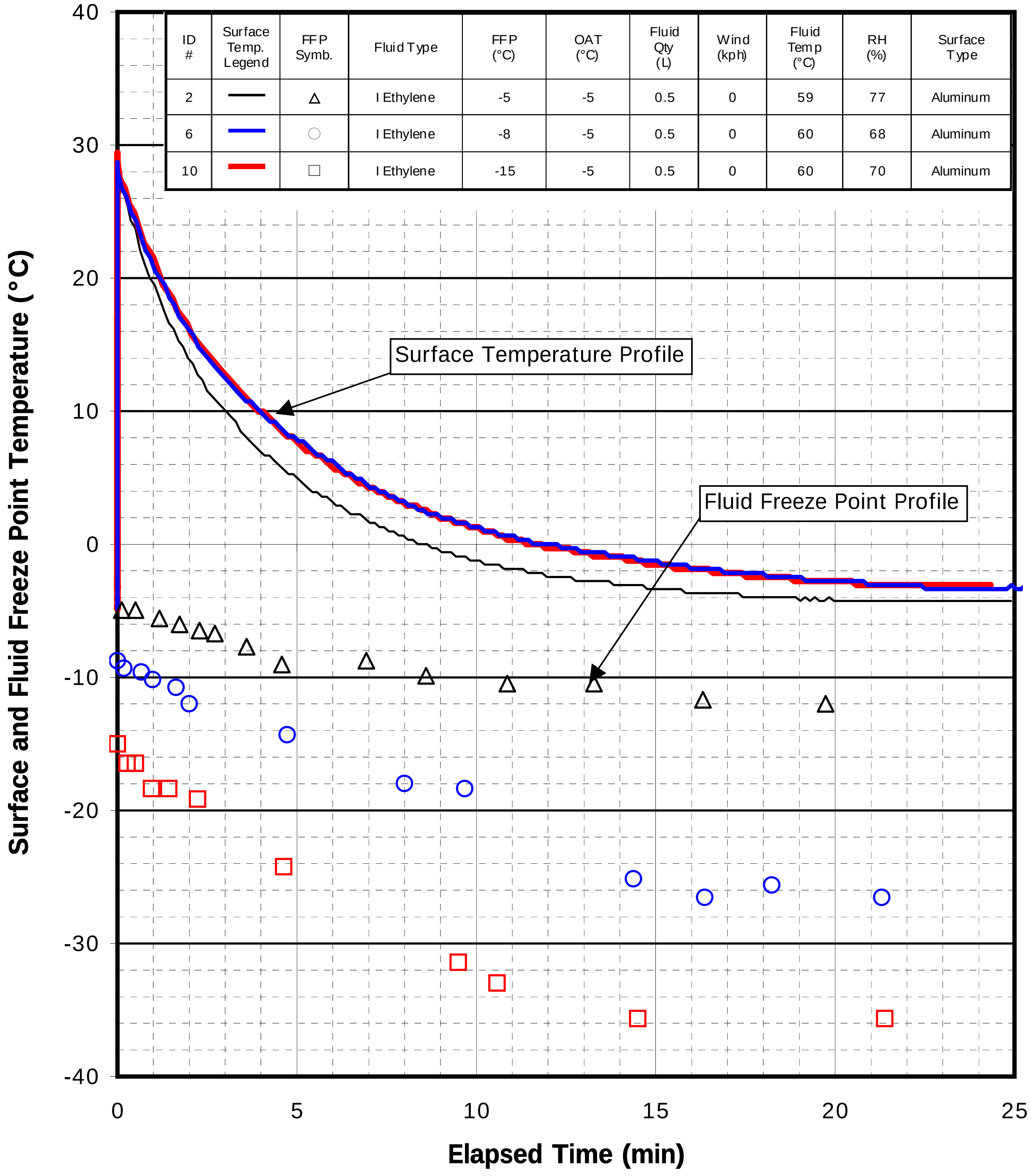
As noted in earlier discussions on test results, the extent of FFP enhancement relates to the absolute amount of glycol in the initial mix. At

FIGURE 4.22

Fluid Freeze Point and Surface Temperature Profile

Buffer

OAT -5°C, Type I EG Fluid, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2	—	△	I Ethylene	-5	-5	0.5	0	59	77	Aluminum
6	—	○	I Ethylene	-8	-5	0.5	0	60	68	Aluminum
10	—	□	I Ethylene	-15	-5	0.5	0	60	70	Aluminum

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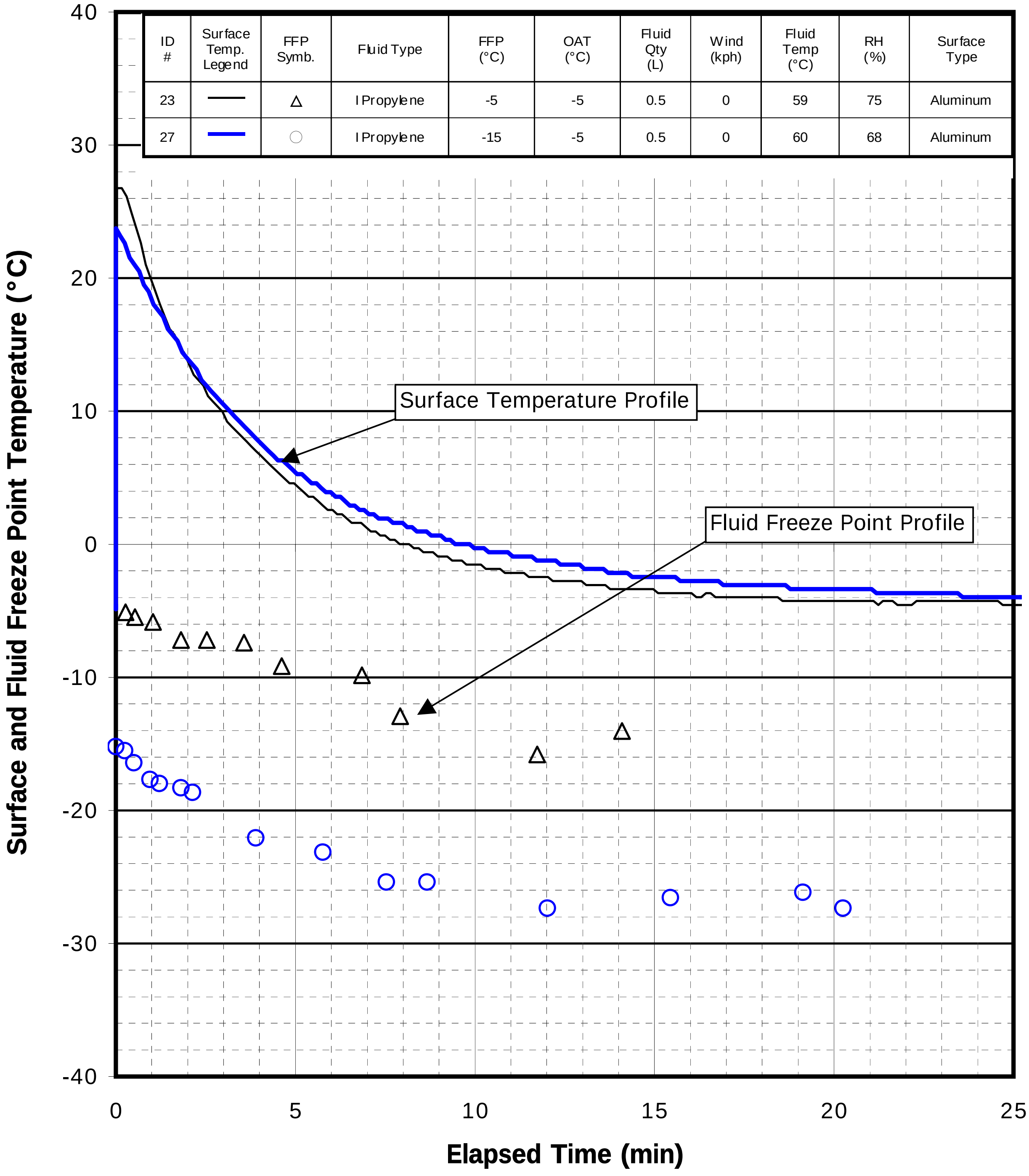
FIGURE 4.23

Fluid Freeze Point and Surface Temperature Profile

Buffer

OAT -5°C, Type I PG Fluid, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
23	—	△	I Propylene	-5	-5	0.5	0	59	75	Aluminum
27	—	○	I Propylene	-15	-5	0.5	0	60	68	Aluminum

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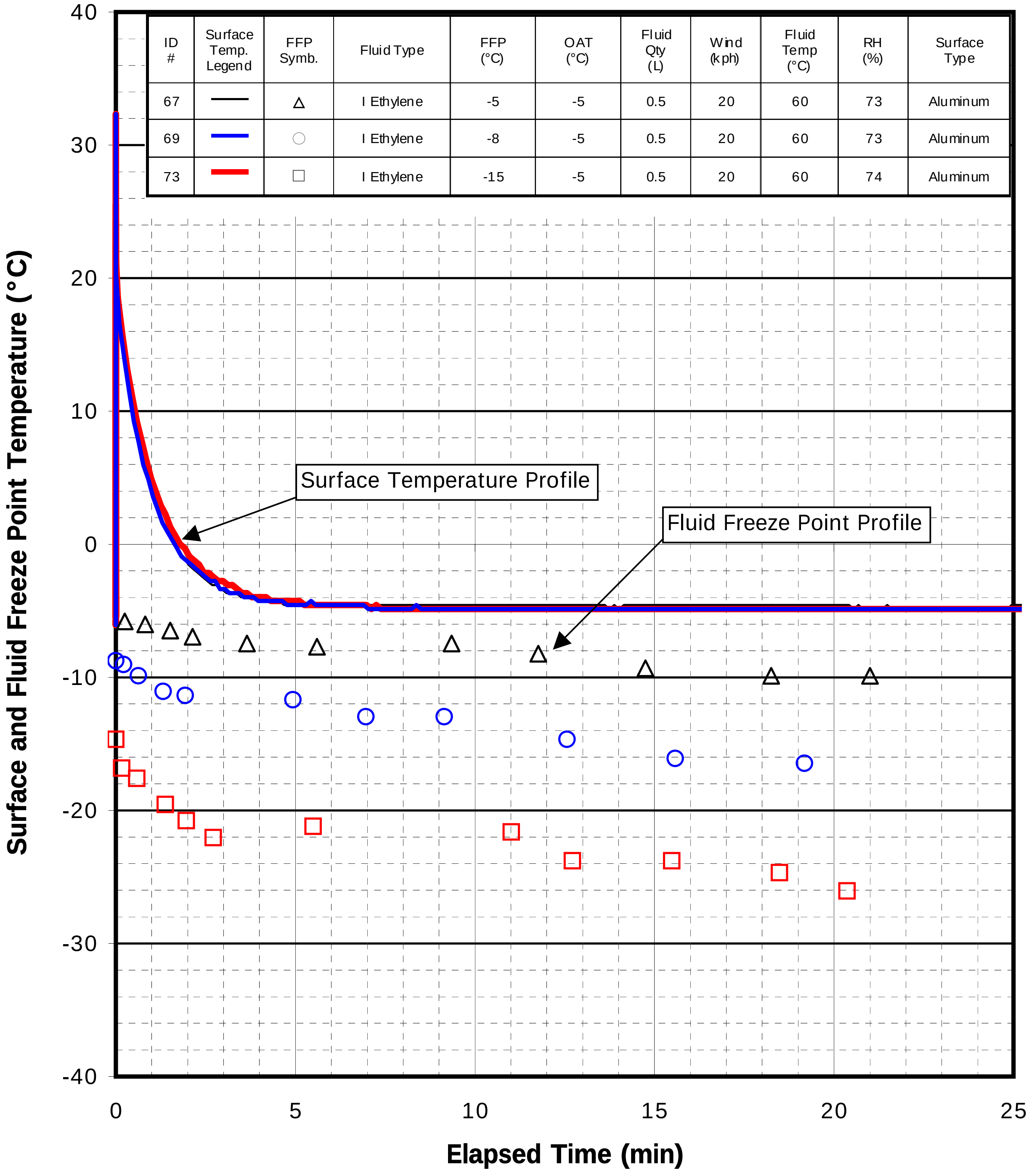
FIGURE 4.24

Fluid Freeze Point and Surface Temperature Profile

Buffer

OAT -5°C, Type I EG Fluid, Wind 20 kph



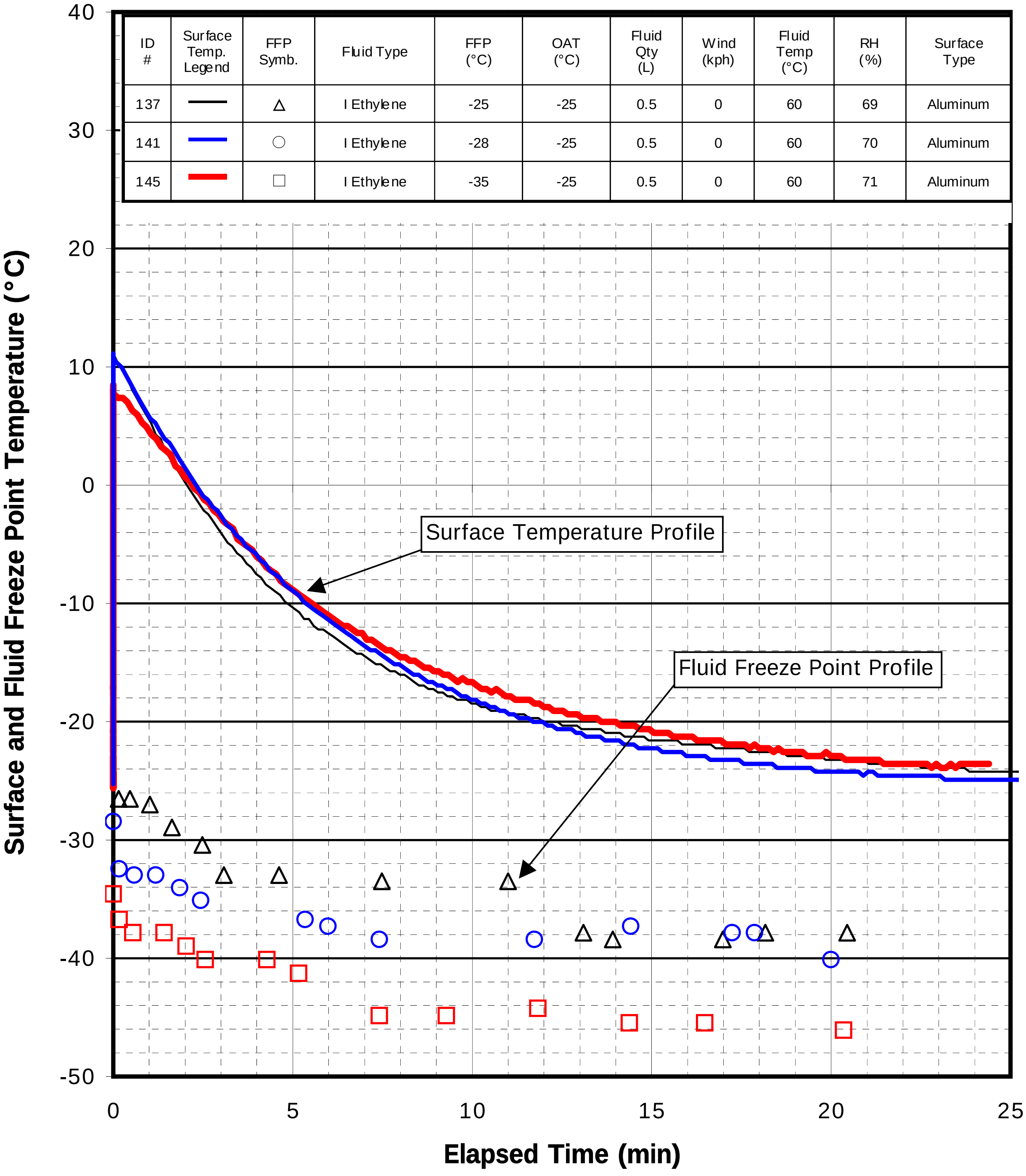
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
67	—	△	I Ethylene	-5	-5	0.5	20	60	73	Aluminum
69	—	○	I Ethylene	-8	-5	0.5	20	60	73	Aluminum
73	—	□	I Ethylene	-15	-5	0.5	20	60	74	Aluminum

FIGURE 4.25

Fluid Freeze Point and Surface Temperature Profile

Buffer

OAT -25°C, Type I EG Fluid, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
137	—	△	I Ethylene	-25	-25	0.5	0	60	69	Aluminum
141	—	○	I Ethylene	-28	-25	0.5	0	60	70	Aluminum
145	—	□	I Ethylene	-35	-25	0.5	0	60	71	Aluminum

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warmer ambient temperatures, such as –5°C, fluids mixed to an FFP equal to ambient have a very small amount of glycol, and the extent of freezing point enhancement is correspondingly low.

In Figure 4.23, note that a propylene glycol-based fluid showed similar results for improved (dropped) FFP. At test end, the FFP of the fluid mixtures had shown enhanced freezing points as follows:

Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
–5	–14	–9
–15	–27	–12

Figure 4.24 reports results from tests similar to those reported in Figure 4.22, with the addition of wind at 20 kph. At test end, the FFP of the fluid mixtures showed enhanced freezing points as follows:

Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
–5	–10	–5
–8	–16	–8
–15	–26	–11

Again, the fluid having the greatest initial strength showed the greatest improvement in FFP. In all cases, however, the wind caused a reduction in the absolute value of the improvement in FFP. This conforms to previous observations on the impact of wind.

Figure 4.25 reports results from tests conducted at an OAT of –25°C. At test end, the FFP of the fluid mixtures showed enhanced freezing points as follows:

Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
–25	–38	–13
–28	–40	–12
–35	–46	–9

In this set of tests, the absolute improvement in FFP was similar for all initial strengths.

In summary, at ambient temperatures just below freezing (such as these tests at –5°C), fluids mixed to the current 10º buffer show a greater improvement than those mixed to a freezing point equal to OAT.

At colder ambient temperatures, such as that tested at –25°C, fluids mixed to the current 10º buffer showed an extent of improvement similar to those mixed to a freezing point equal to OAT.

4.1.5 High Relative Humidity

Figures 4.27 to 4.31 present results for tests examining the impact of high RH on fluid evaporation and FFP enhancement.

These figures report results for test conditions as shown in the following matrix:

Figure #	OAT (°C)	FFP (°C)	Fluid Type	RH (%)
4.26	–5	–5	T1E	60, 77, 84
4.27	–5	–15	T1E	60, 70, 84
4.28	–5	–5	T1P	60, 75, 80
4.29	–5	–5	T2P	60, 69, 80
4.30	–25	–25	T1E	69, 78

Other parameters (such as fluid quantity, wind, fluid temperature, and surface type) were held constant as noted in the legend for each figure.

In Figure 4.26, the extent to which freezing points for an ethylene glycol-based fluid improved (dropped) under these test conditions (FFP = OAT = –5°C, calm winds) varied significantly. Contrary to expectations, the greatest FFP enhancement was seen for the test at the highest RH (84 percent) level, as shown in the following table:

RH (%)	Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
60	–5	–18	–13
77	–5	–12	–7
84	–5	–34	–29

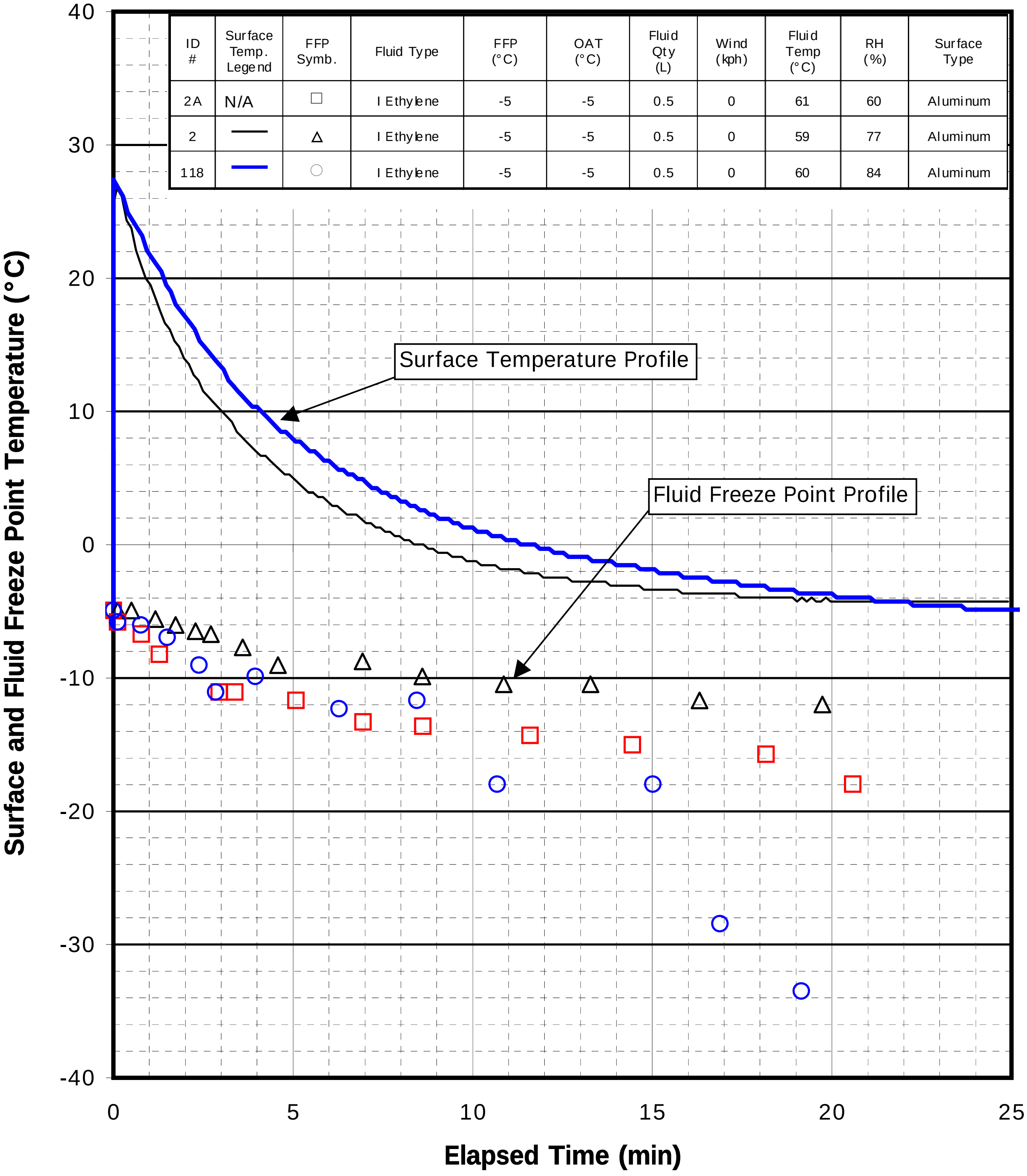
Figure 4.27 reports on a similar test with the exception that the initial FFP was –15°C. Very little difference was noted for final FFP for the different values of RH.

FIGURE 4.26

Fluid Freeze Point and Surface Temperature Profile

High RH

OAT -5°C, FFP -5°C, Type I EG Fluid



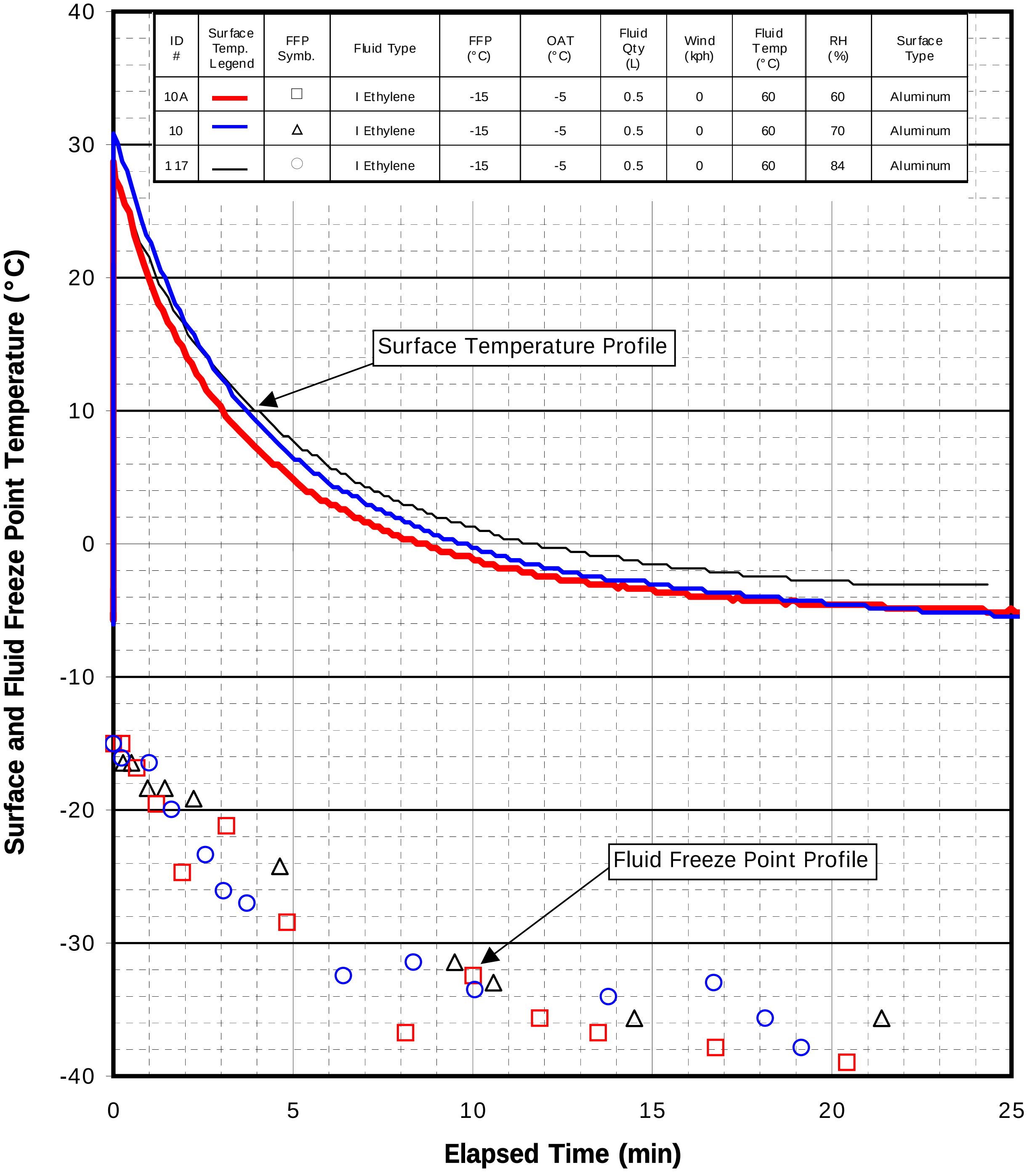
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2A	N/A	□	I Ethylene	-5	-5	0.5	0	61	60	Aluminum
2	—	△	I Ethylene	-5	-5	0.5	0	59	77	Aluminum
118	—	○	I Ethylene	-5	-5	0.5	0	60	84	Aluminum

FIGURE 4.27

Fluid Freeze Point and Surface Temperature Profile

High RH

OAT -5°C, FFP -15°C, Type I EG Fluid



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
10A	🟥	□	I Ethylene	-15	-5	0.5	0	60	60	Aluminum
10	🟦	△	I Ethylene	-15	-5	0.5	0	60	70	Aluminum
117	⬛	○	I Ethylene	-15	-5	0.5	0	60	84	Aluminum

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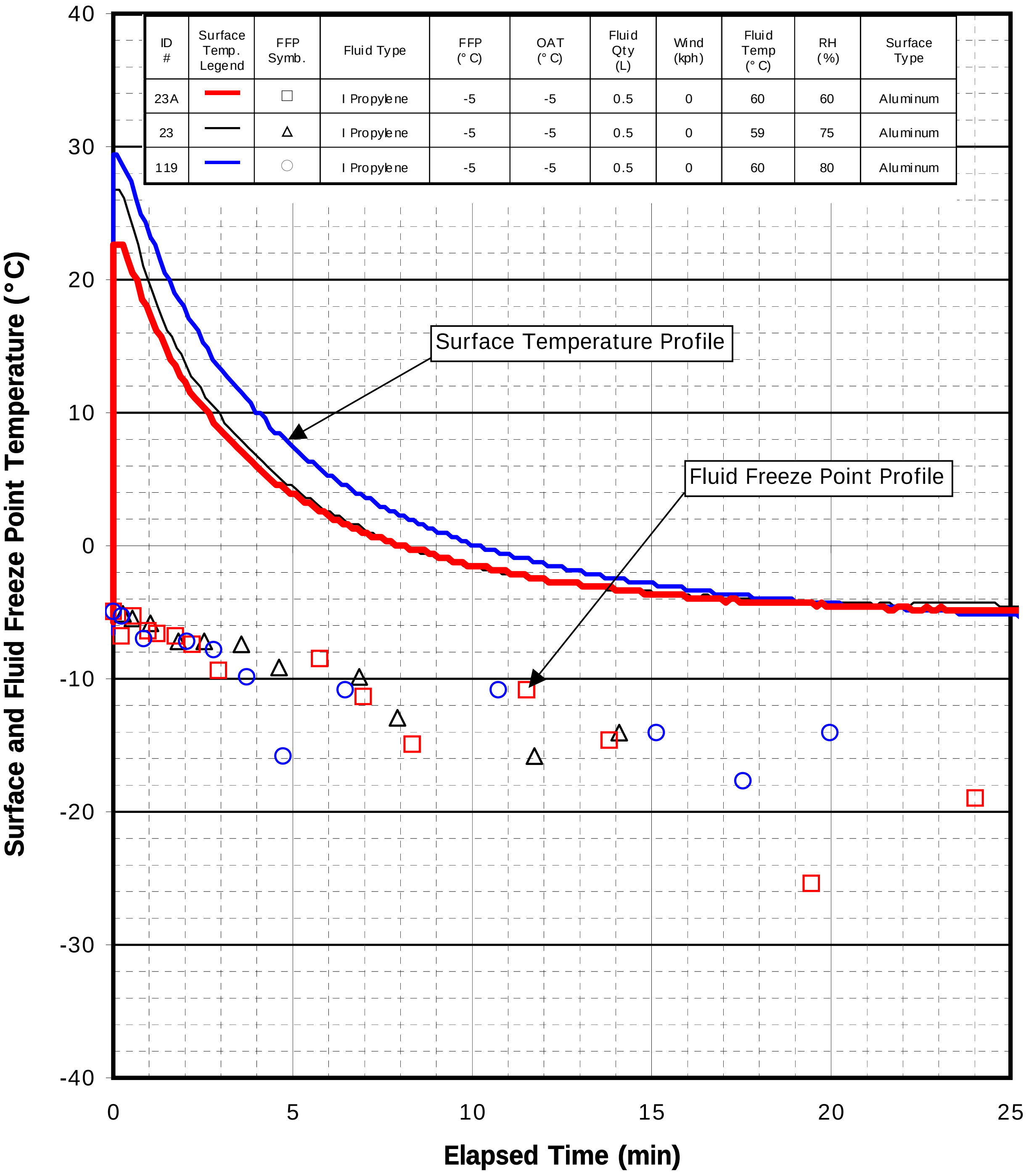
FIGURE 4.28

Fluid Freeze Point and Surface Temperature Profile

High RH

OAT -5°C, FFP -5°C, Type I PG Fluid



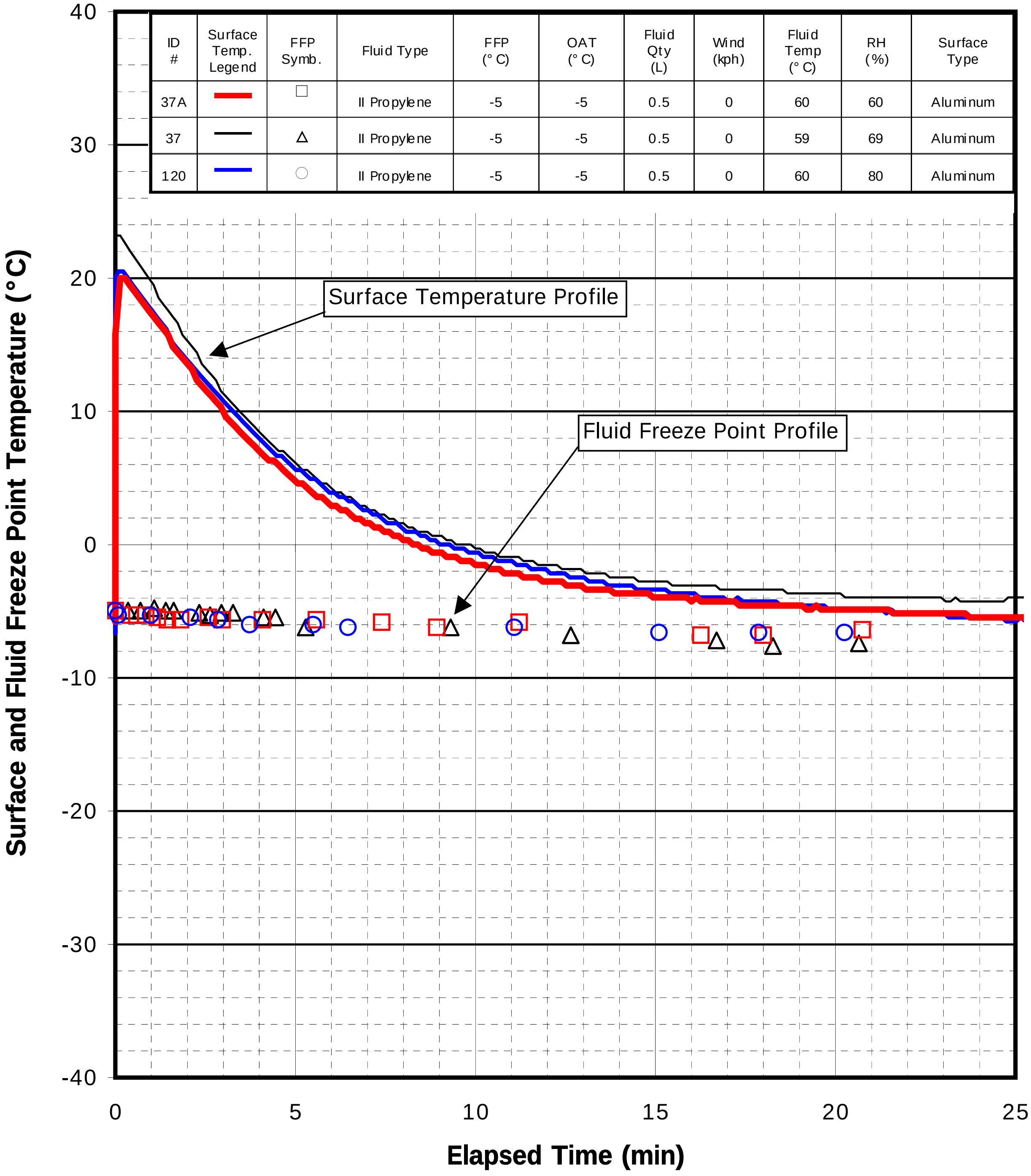
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (° C)	OAT (° C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (° C)	RH (%)	Surface Type
23A	—	□	I Propylene	-5	-5	0.5	0	60	60	Aluminum
23	—	△	I Propylene	-5	-5	0.5	0	59	75	Aluminum
119	—	○	I Propylene	-5	-5	0.5	0	60	80	Aluminum

FIGURE 4.29

Fluid Freeze Point and Surface Temperature Profile

High RH

OAT -5°C, FFP -5°C, Type II PG Fluid



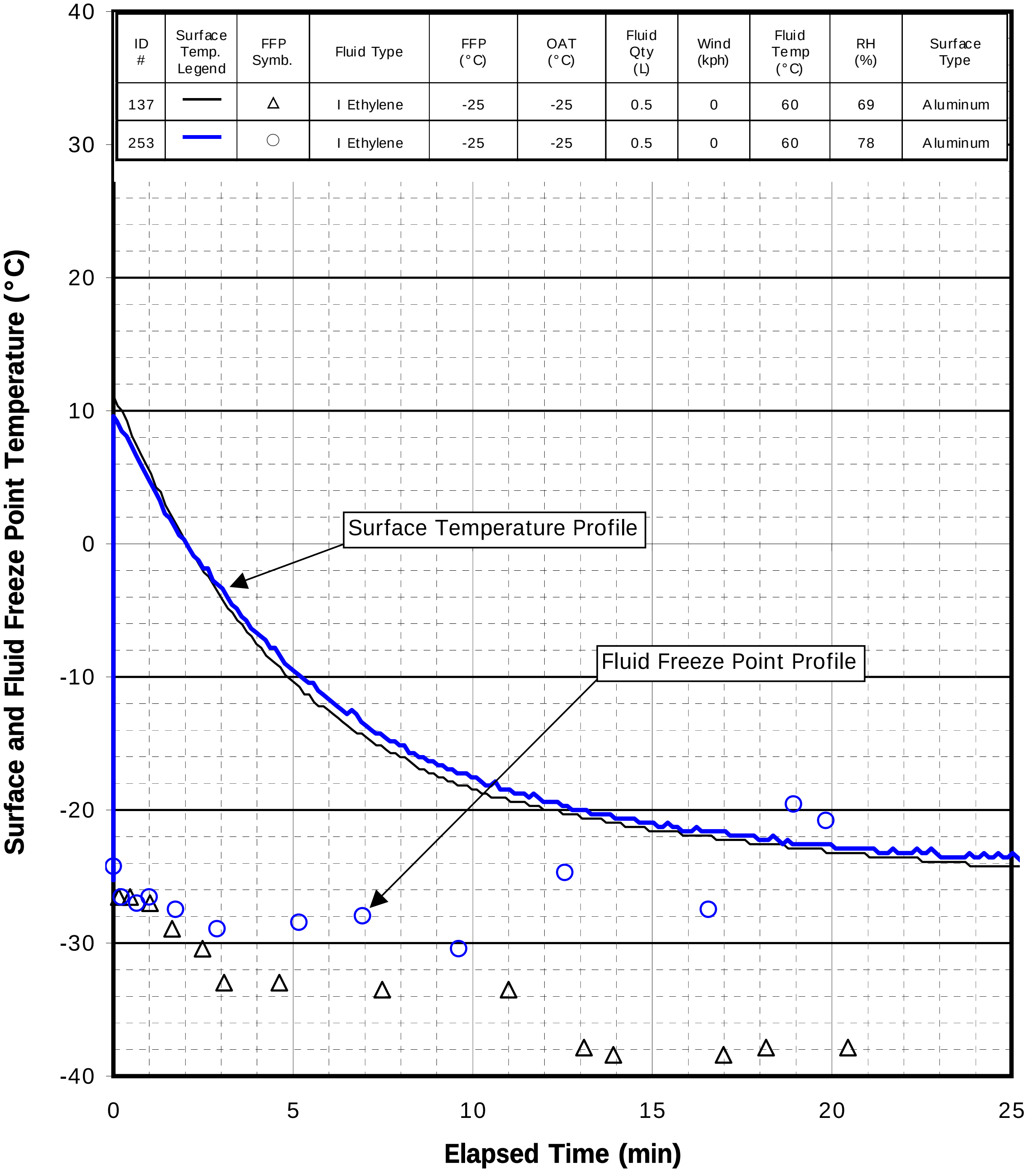
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (° C)	OAT (° C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (° C)	RH (%)	Surface Type
37A	▬	□	II Propylene	-5	-5	0.5	0	60	60	Aluminum
37	—	△	II Propylene	-5	-5	0.5	0	59	69	Aluminum
120	▬	○	II Propylene	-5	-5	0.5	0	60	80	Aluminum

FIGURE 4.30

Fluid Freeze Point and Surface Temperature Profile

High RH

OAT -25°C, FFP -25°C, Type I EG Fluid



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
137	—	△	I Ethylene	-25	-25	0.5	0	60	69	Aluminum
253	—	○	I Ethylene	-25	-25	0.5	0	60	78	Aluminum

RH (%)	Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
60	–15	–39	–24
70	–15	–36	–21
84	–15	–38	–23

Figure 4.28 reports on a test similar to Figure 4.27 with the exception that a propylene glycol-base Type I fluid was used. Although some differences were noted for final FFP for the different values of RH, there was a good deal of scatter in the data for all tests. The high value of RH did not have a notable impact.

RH (%)	Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
60	–5	–19	–14
75	–5	–14	–9
80	–5	–18	–13

Figure 4.29 reports on a test similar to Figure 4.27 with the exception that a propylene glycol-base Type II fluid was used. As seen from the results of other trials using this fluid, the extent of enhancement is quite minimal. The various levels of RH did not affect the FFP enhancement.

Figure 4.30 reports on tests conducted at an OAT of –25°C. In this series of tests, the high humidity resulted in an elevation of the FFP, indicating some degree of precipitation.

RH (%)	Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
69	–25	–38	–13
78	–25	–19	+6

Reference to tables of saturation-mixing ratios over water (as discussed in Section 2.1.3.1) at an OAT of –25°C shows that the amount of water vapour, when the air is saturated, is .5048 grams of vapour/kg of air. At 78 percent RH, the ratio of water vapour in the air is .3938. Reference to tables of saturation mixing ratios over ice shows that at an OAT of –25°C, the saturated mixing ratio is .3955. In other words, the test ambient temperature of –25°C was conducted at the frost point for the recorded level of RH in the air. This condition resulted in frost deposition, with accompanying dilution of the fluid, and related elevation of the FFP. This supports the previous conclusion that application of a fluid mix having an FFP equal to OAT provides only temporary protection against frost in an active frost condition.

In summary, results of these trials indicate that the condition of high humidity when frost is inactive does not detrimentally affect the enhancement of fluid strength. When the humidity level and OAT are such that frost is active, only temporary protection against frost deposition is provided.

4.1.6 Removal of Snow

Figures 4.31 to 4.33 present results for tests examining the impact of the removal of snow and whether heat loss in the process is detrimental to the enhancement of FFP.

These figures report results for test conditions as shown in the following matrix:

Figure #	OAT (°C)	FFP (°C)	Fluid Type	Fluid Qty (litres)	Method of Application	Depth of Snow (cm)
4.31	–5	–5	T1E	0.5	Pour	0, 0.1, 0.2
4.32	–5	–15	T1E	variable	Pour and spray	0, 0.1, 0.2, 0.4
4.33	–5	–5	T1P	variable	Pour and spray	0, 0.1, 0.2, 0.4
4.34	–15	–15	T1E	variable	Pour and spray	0, 0.1, 0.2, 0.4

Other parameters (such as wind, fluid temperature, and surface type) are held constant as noted in the legend for each figure.

Figure 4.31 reports results for the trials of removing snow by pouring.

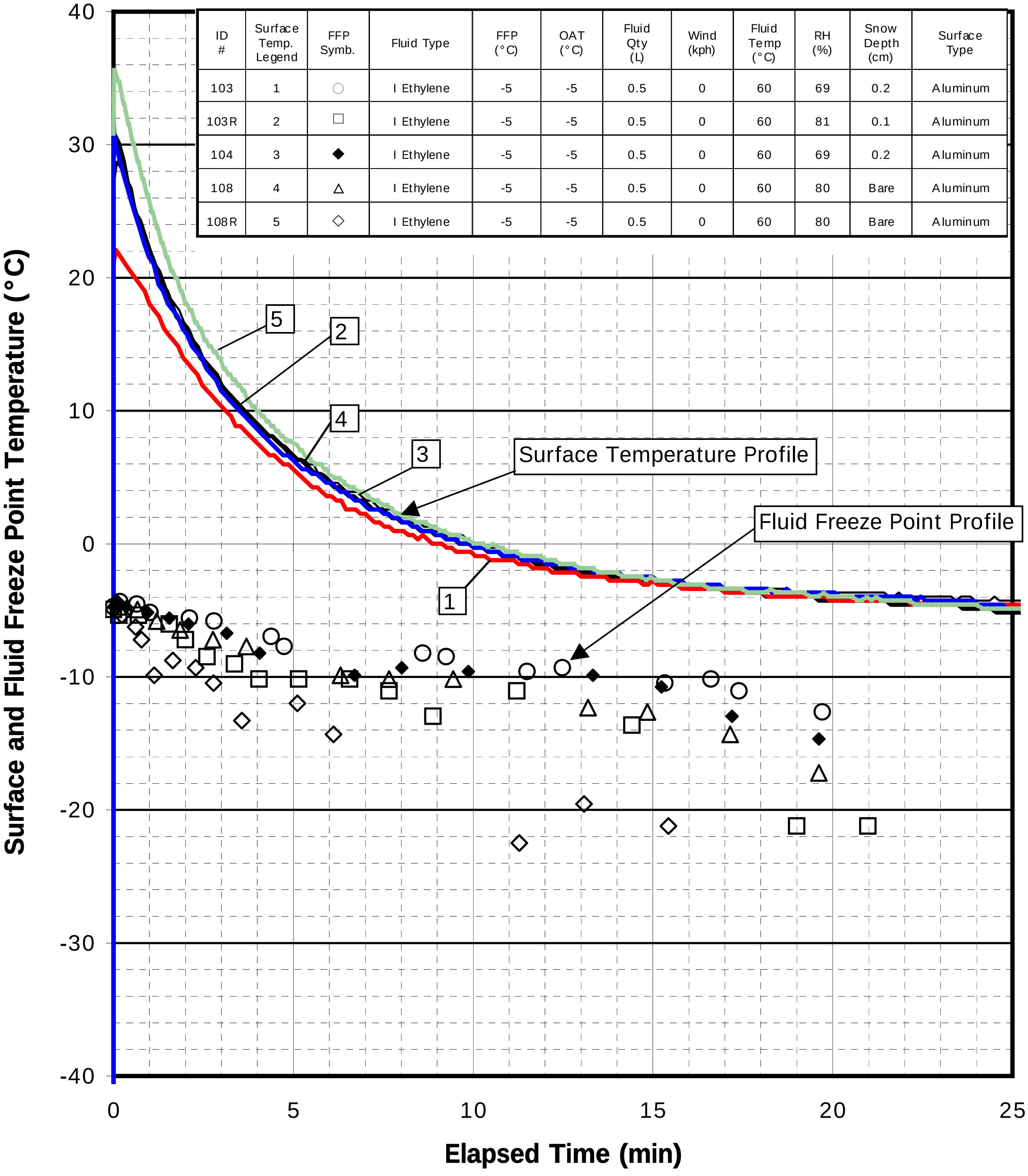
Test ID#s 108 and 108R serve as control cases, representing those tests in which fluid was applied to bare surfaces. Tests 103 and 104 used recently fallen snow collected from the surroundings. They showed that a snow depth on the test surface of 0.2 cm could be removed by pouring 0.5 L of fluid. Because the tests could not be completed by the end of the day, the series was continued on a later date. The condition of the natural snow collected on the later date had changed from a fresh fallen snow, to a granular, dense snow. Tests to learn the reference depth for this type of snow showed it to be only 0.1 cm. Thus the three tests were conducted with the reference depth for the particular type of snow encountered.

As for the FFP profiles for Tests # 103 and 104, the process of snow removal *by pouring* diminished the FFP enhancement, as compared to Test # 108 (conducted on a bare surface on the same date). Test 103R,

FIGURE 4.31

Fluid Freeze Point and Surface Temperature Profile

Removal of Snow by Pouring
OAT -5°C, FFP -5°C, Type I EG Fluid

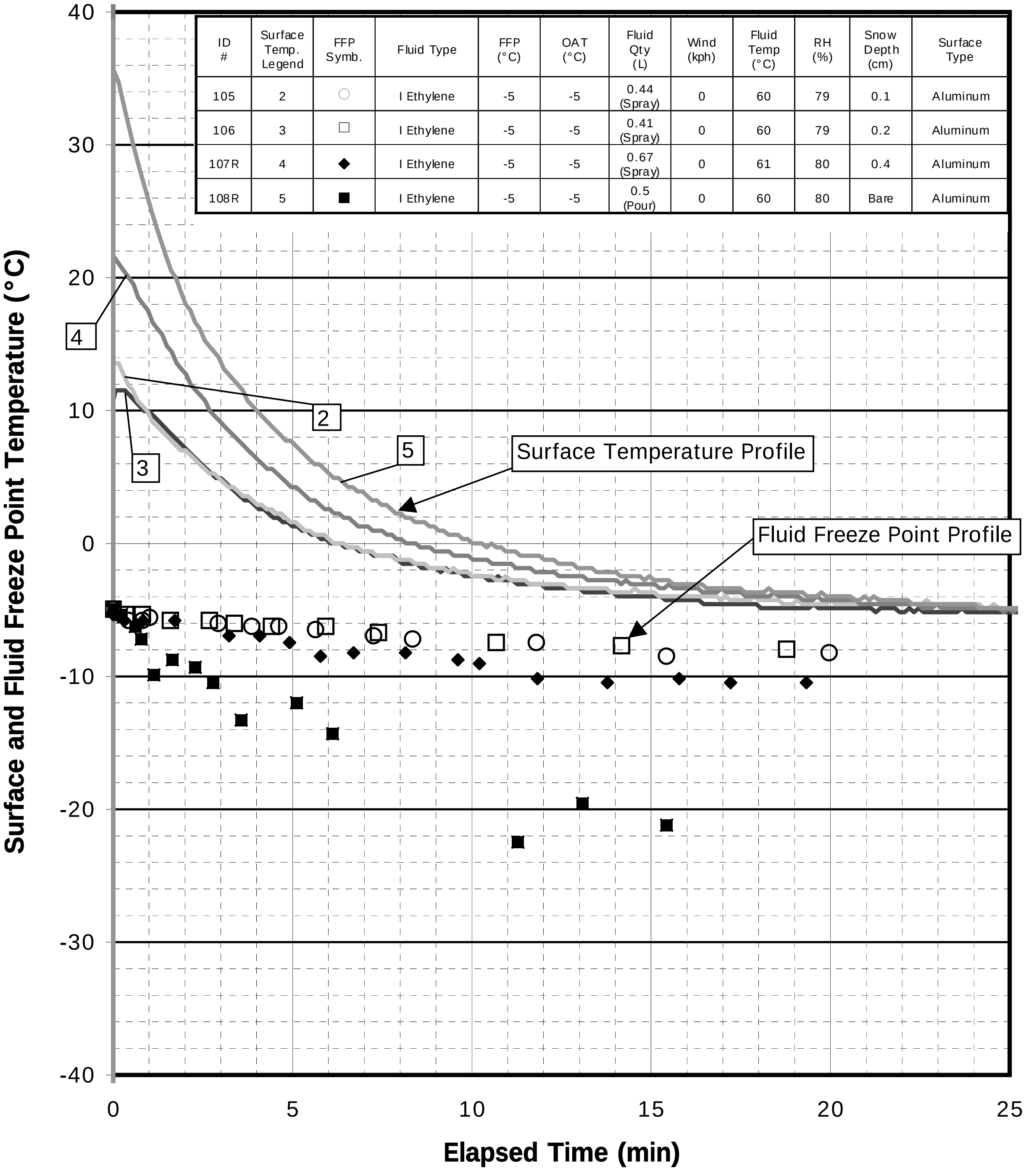


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Depth (cm)	Surface Type
103	1	○	I Ethylene	-5	-5	0.5	0	60	69	0.2	Aluminum
103R	2	□	I Ethylene	-5	-5	0.5	0	60	81	0.1	Aluminum
104	3	◆	I Ethylene	-5	-5	0.5	0	60	69	0.2	Aluminum
108	4	△	I Ethylene	-5	-5	0.5	0	60	80	Bare	Aluminum
108R	5	◇	I Ethylene	-5	-5	0.5	0	60	80	Bare	Aluminum

FIGURE 4.32

Fluid Freeze Point and Surface Temperature Profile

Removal of Snow by Spraying
OAT -5°C, FFP -5°C, Type I EG Fluid



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Depth (cm)	Surface Type
105	2	○	I Ethylene	-5	-5	0.44 (Spray)	0	60	79	0.1	Aluminum
106	3	□	I Ethylene	-5	-5	0.41 (Spray)	0	60	79	0.2	Aluminum
107R	4	◆	I Ethylene	-5	-5	0.67 (Spray)	0	61	80	0.4	Aluminum
108R	5	■	I Ethylene	-5	-5	0.5 (Pour)	0	60	80	Bare	Aluminum

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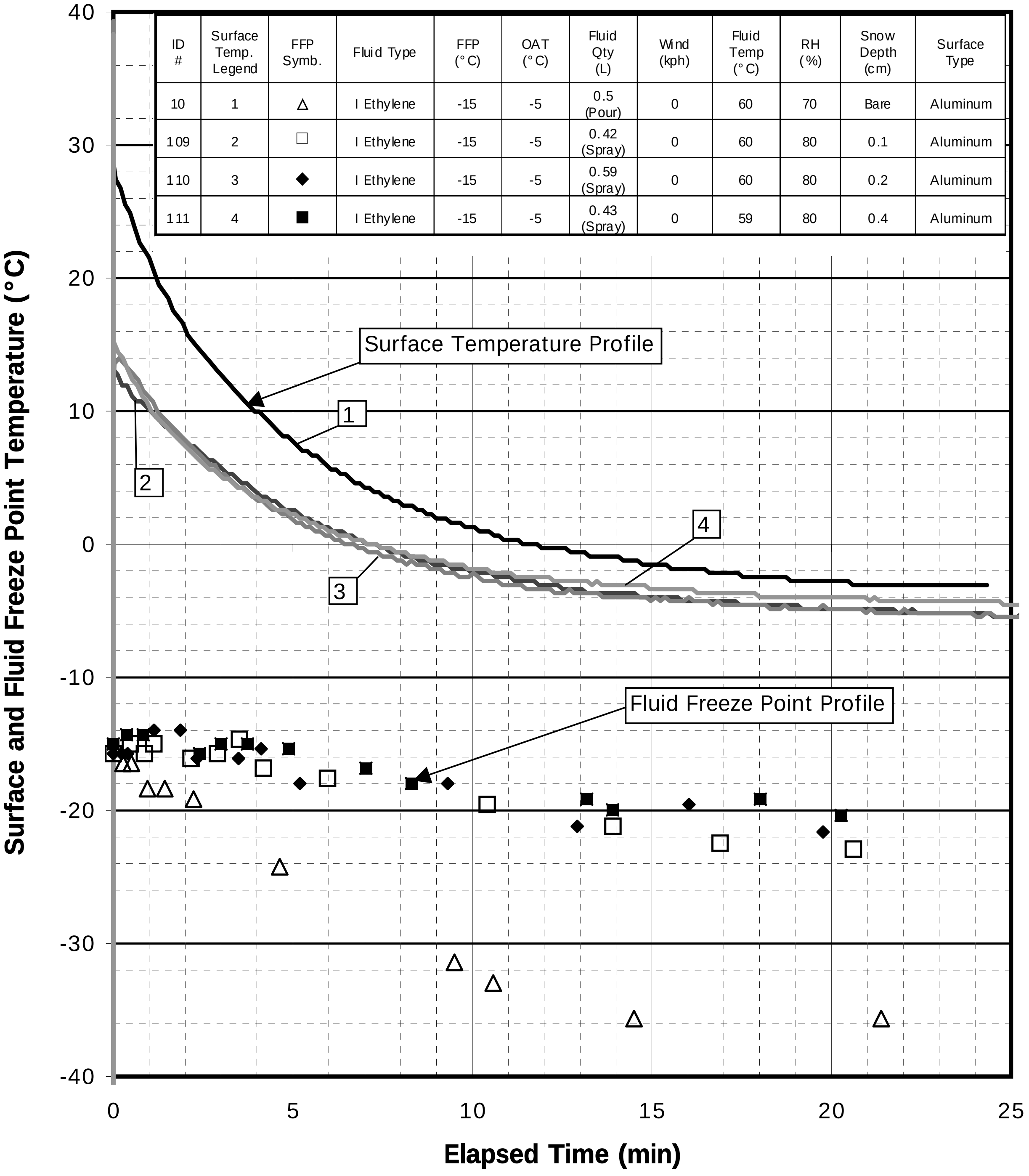
FIGURE 4.33

Fluid Freeze Point and Surface Temperature Profile

Removal of Snow by Spraying

OAT -5°C, FFP -15°C, Type I EG Fluid



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Depth (cm)	Surface Type
10	1	△	I Ethylene	-15	-5	0.5 (Pour)	0	60	70	Bare	Aluminum
109	2	□	I Ethylene	-15	-5	0.42 (Spray)	0	60	80	0.1	Aluminum
110	3	◆	I Ethylene	-15	-5	0.59 (Spray)	0	60	80	0.2	Aluminum
111	4	■	I Ethylene	-15	-5	0.43 (Spray)	0	59	80	0.4	Aluminum

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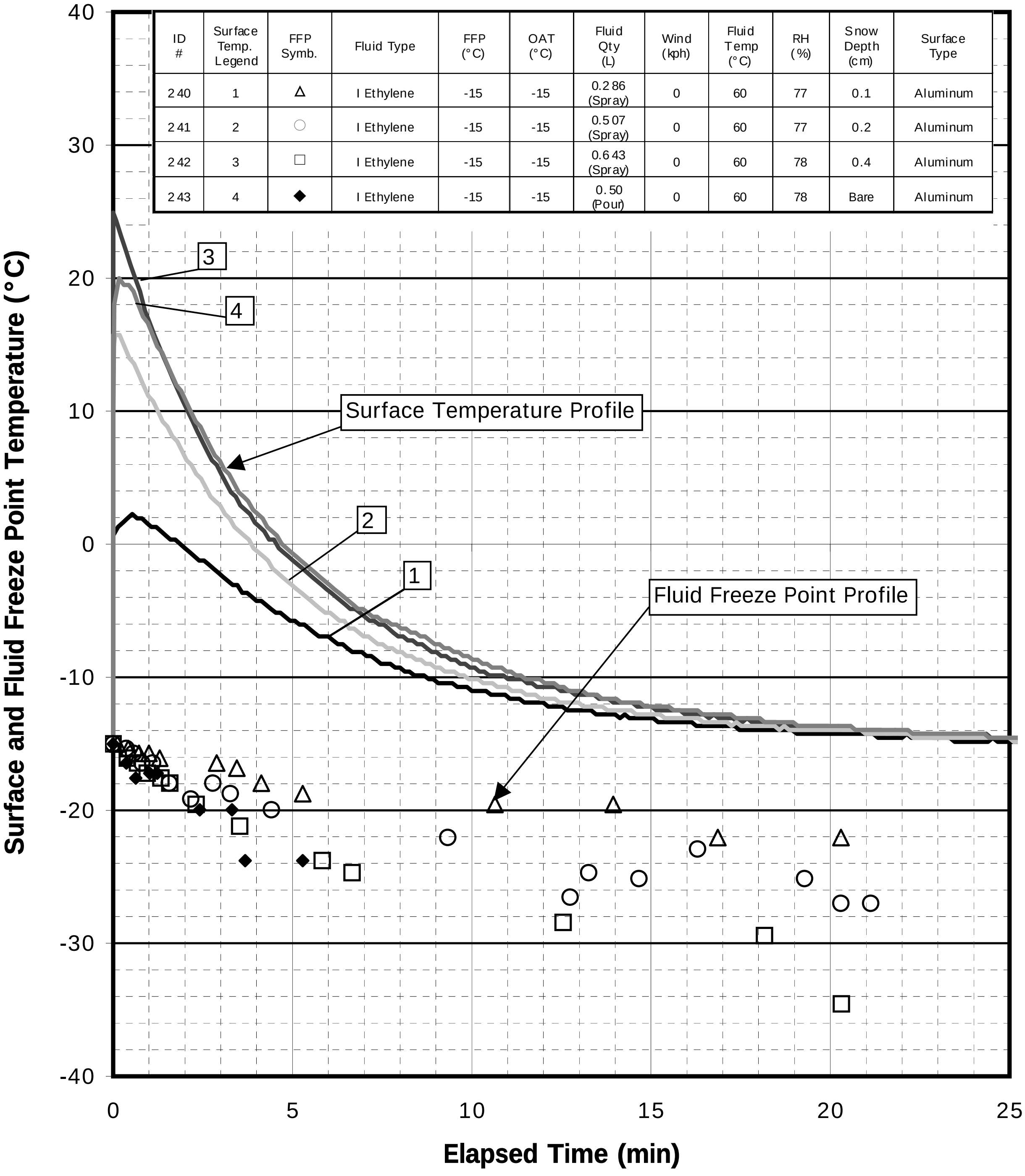
FIGURE 4.34

Fluid Freeze Point and Surface Temperature Profile

Removal of Snow by Spraying
OAT -15°C, FFP -15°C, Type I EG Fluid



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Depth (cm)	Surface Type
240	1	△	I Ethylene	-15	-15	0.286 (Spray)	0	60	77	0.1	Aluminum
241	2	○	I Ethylene	-15	-15	0.507 (Spray)	0	60	77	0.2	Aluminum
242	3	□	I Ethylene	-15	-15	0.643 (Spray)	0	60	78	0.4	Aluminum
243	4	◆	I Ethylene	-15	-15	0.50 (Pour)	0	60	78	Bare	Aluminum

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conducted at the later date on the denser snow, produced a greater FFP enhancement than the other tests, but less than for Test 108R.

Figure 4.32 reports results for the trials of removing snow by spraying.

Test ID# 108R is a control case, representing those tests in which fluid was applied to a bare surface. All tests reported here were conducted on the same date. The snow was granular and dense, having a reference depth of 0.1 cm.

Enhancements in FFP from the *snow removal by spraying* tests were as follows:

Snow Depth (cm)	**Fluid Qty (litres)**	**Initial FFP (°C)**	**Final FFP (°C)**	**Drop in FFP (°C)**
Bare	0.5 (poured)	–5	–21	–16
0.1	0.44 (sprayed)	–5	–8	–3
0.2	0.41 (sprayed)	–5	–8	–3
0.4	0.67 (sprayed)	–5	–11	–6

For spray tests, the greater enhancement was seen for the test with the deepest snow. This is believed to be related to the greater quantity of fluid applied.

Figure 4.33 reports results for the trials of removing snow by spraying, for fluids having initial FFPs 10°C below OAT.

Test ID# 10 serves as a control case, representing those tests in which fluid was applied to a bare surface. All tests reported here were conducted on the same date, with the same type of snow.

Snow Depth (cm)	**Fluid Qty (litres)**	**Initial FFP (°C)**	**Final FFP (°C)**	**Drop in FFP (°C)**
Bare	0.25 (poured)	–15	–31	–16
Bare	0.5 (poured)	–15	–36	–21
0.1	0.42 (sprayed)	–15	–23	–8
0.2	0.59 (sprayed)	–15	–22	–7
0.4	0.43 (sprayed)	–15	–20	–5

Figure 4.34 reports results for the trials of removing snow by spraying, for an OAT and FFP of –15°C.

All tests reported here were conducted on the date, with the same type of snow.

Snow Depth (cm)	Fluid Qty (litres)	Initial FFP (°C)	Final FFP (°C)	Drop in FFP (°C)
Bare	0.5 (poured)	–15	–24	–9
0.1	0.29 (sprayed)	–15	–22	–7
0.2	0.51 (sprayed)	–15	–27	–12
0.4	0.64 (sprayed)	–15	–35	–20

Test ID# 243 is a control case, representing tests in which fluid was applied to a bare surface. The surface dried quickly, preventing further measurement of FFP. The trials resulted in significant improvements in FFP, even the test in which a very small quantity of fluid was used.

In summary, these trials indicate that removing snow from the surface does result in a reduction of the FFP enhancement, as compared to tests on bare surfaces. But, the extent of FFP enhancement that remained was significant, even when under 0.5 L of fluid was applied.

4.1.7 Cold-soaked Wings

Figures 4.35 to 4.46 present results for tests examining the impact of a cold-soaked wing on FFP enhancement. Tests reported in Figures 4.35 to 4.40 were conducted as part of the initial series at PMG, and involved tests on both cold-soaked boxes and standard flat-plate surfaces. Supplementary tests conducted at NRC are reported in Figures 4.41 to 4.46; these involved only cold-soaked-box surfaces. Wind conditions were included for tests at NRC. The temperature of the cold-soaked-box surfaces was controlled at an initial value of 5°C below that of OAT. The cooling fluid in the cold-soaked boxes was not constantly cooled during the test run. Test fluid was applied by pouring, except as noted.

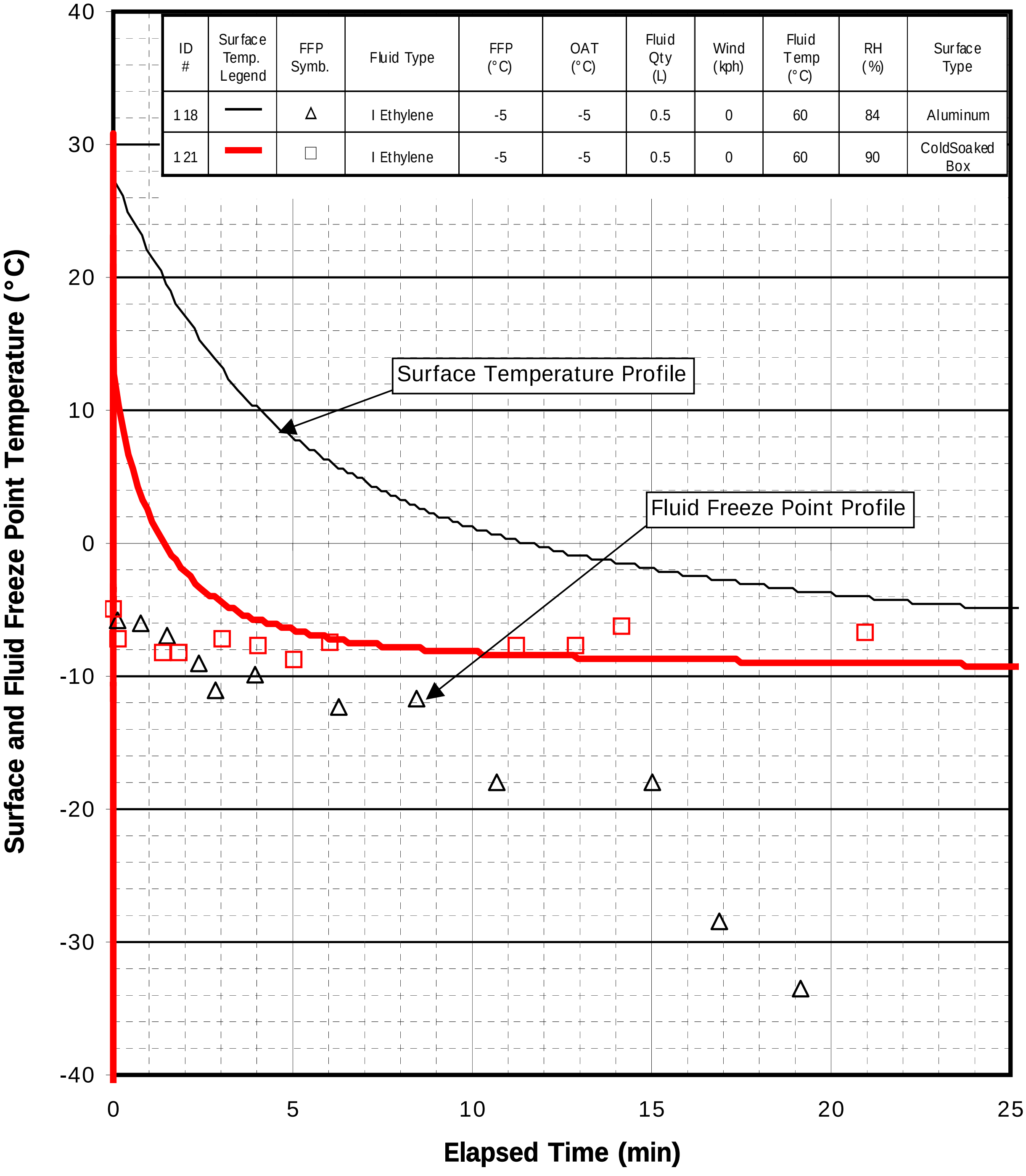
Test conditions were as shown in the following matrix:

FIGURE 4.35

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C

OAT -5°C, FFP -5°C, 0.5 L, Winds Calm



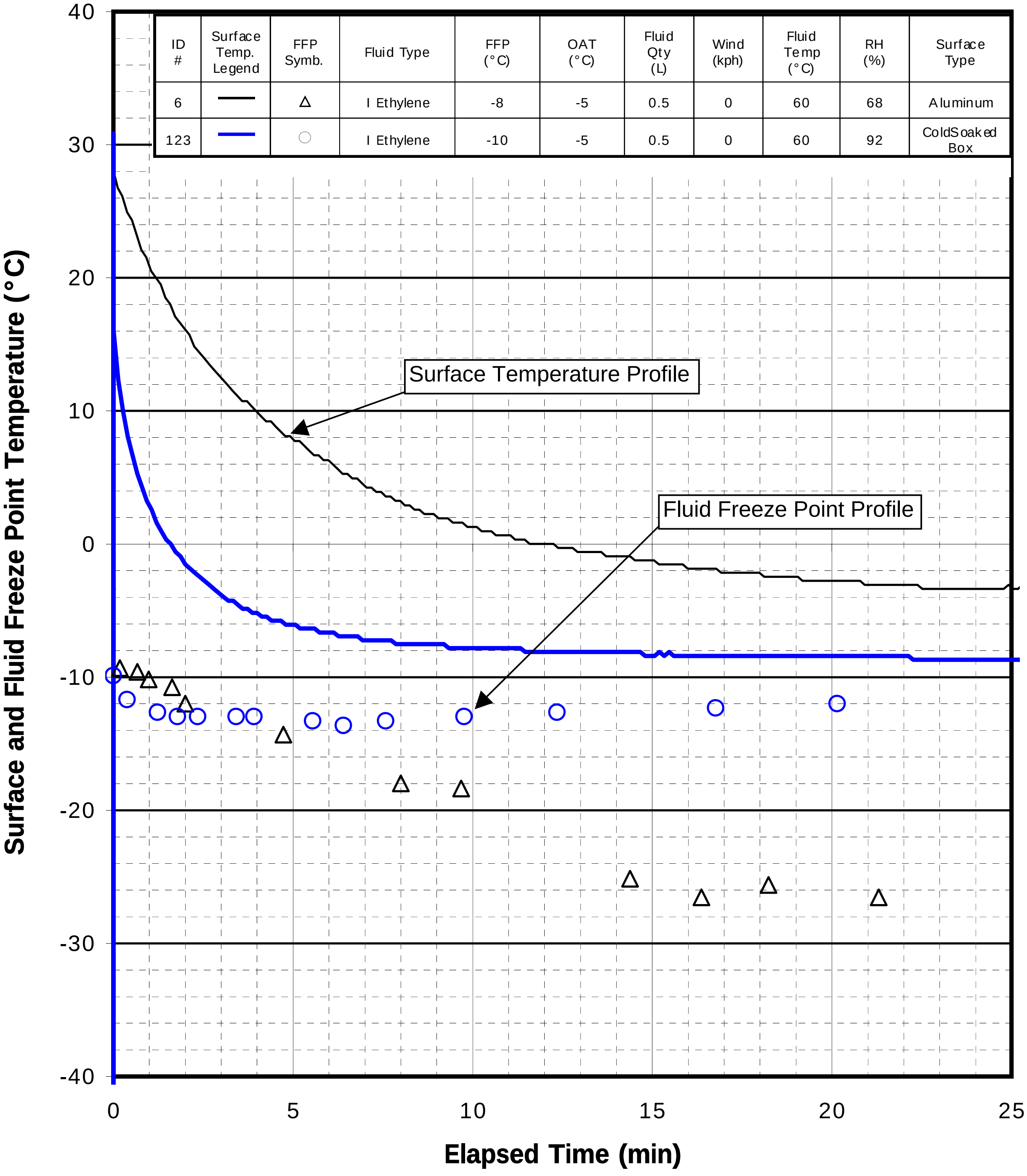
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
118	—	△	I Ethylene	-5	-5	0.5	0	60	84	Aluminum
121	▬	□	I Ethylene	-5	-5	0.5	0	60	90	ColdSoaked Box

FIGURE 4.36

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C

OAT -5°C, FFP -10°C, 0.5 L, Winds Calm

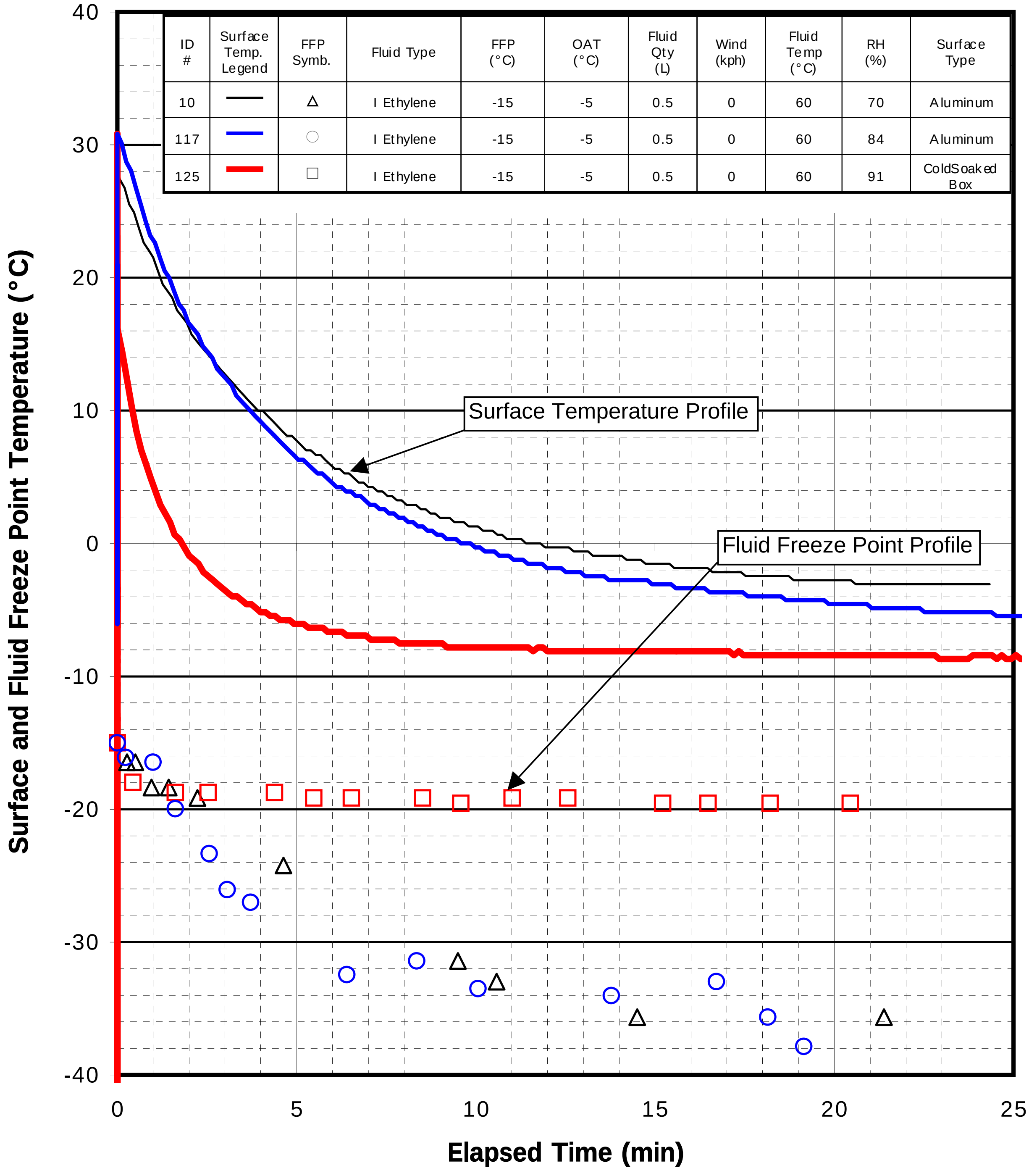


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
6	—	△	I Ethylene	-8	-5	0.5	0	60	68	Aluminum
123	—	○	I Ethylene	-10	-5	0.5	0	60	92	ColdSoaked Box

FIGURE 4.37

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C
OAT -5°C, FFP -15°C, 0.5 L, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
10	—	△	I Ethylene	-15	-5	0.5	0	60	70	Aluminum
117	—	○	I Ethylene	-15	-5	0.5	0	60	84	Aluminum
125	—	□	I Ethylene	-15	-5	0.5	0	60	91	ColdSoaked Box

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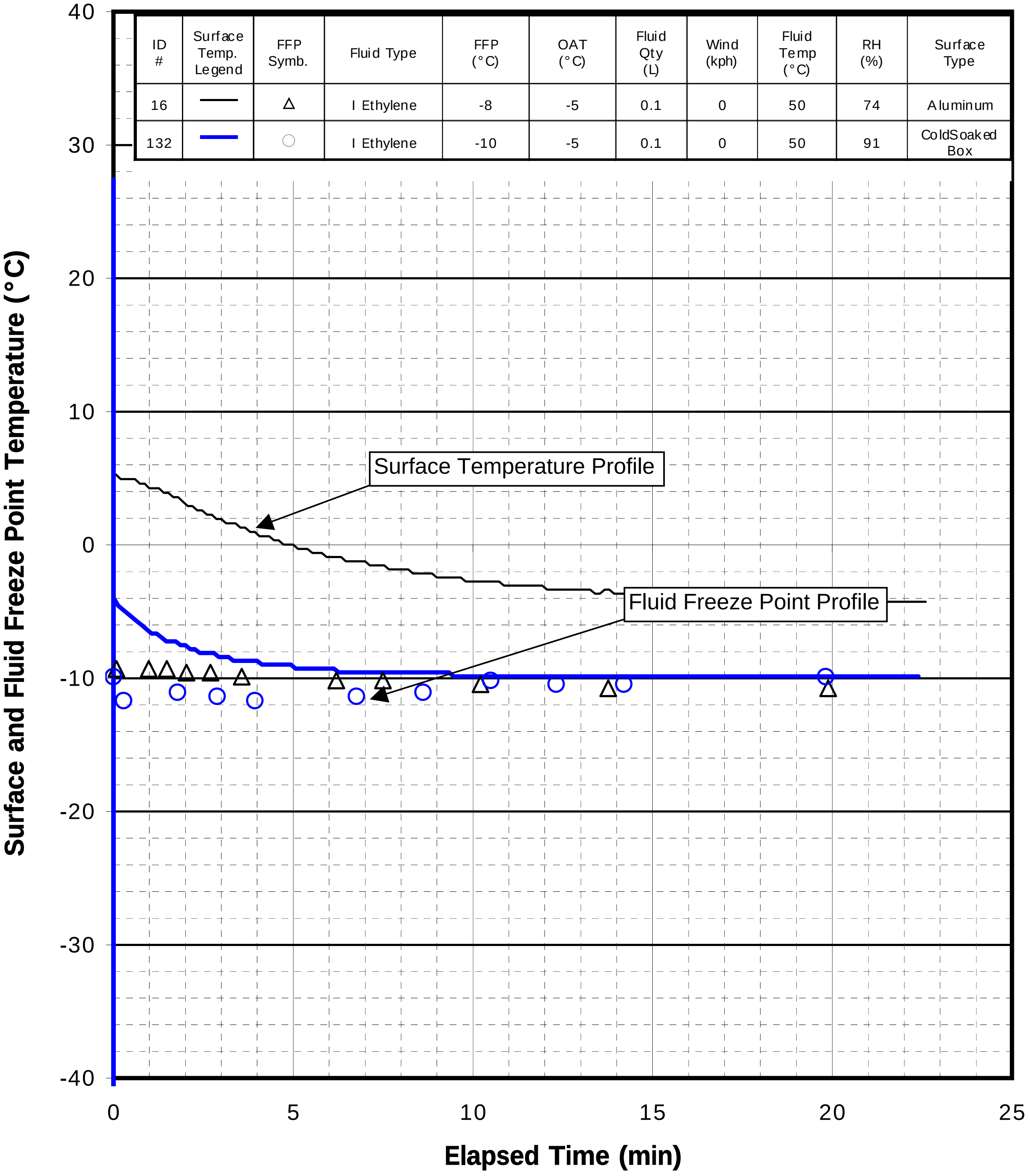
FIGURE 4.38

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C
OAT -5°C, FFP -10°C, 0.1 L, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
16	—	△	I Ethylene	-8	-5	0.1	0	50	74	Aluminum
132	—	○	I Ethylene	-10	-5	0.1	0	50	91	ColdSoaked Box

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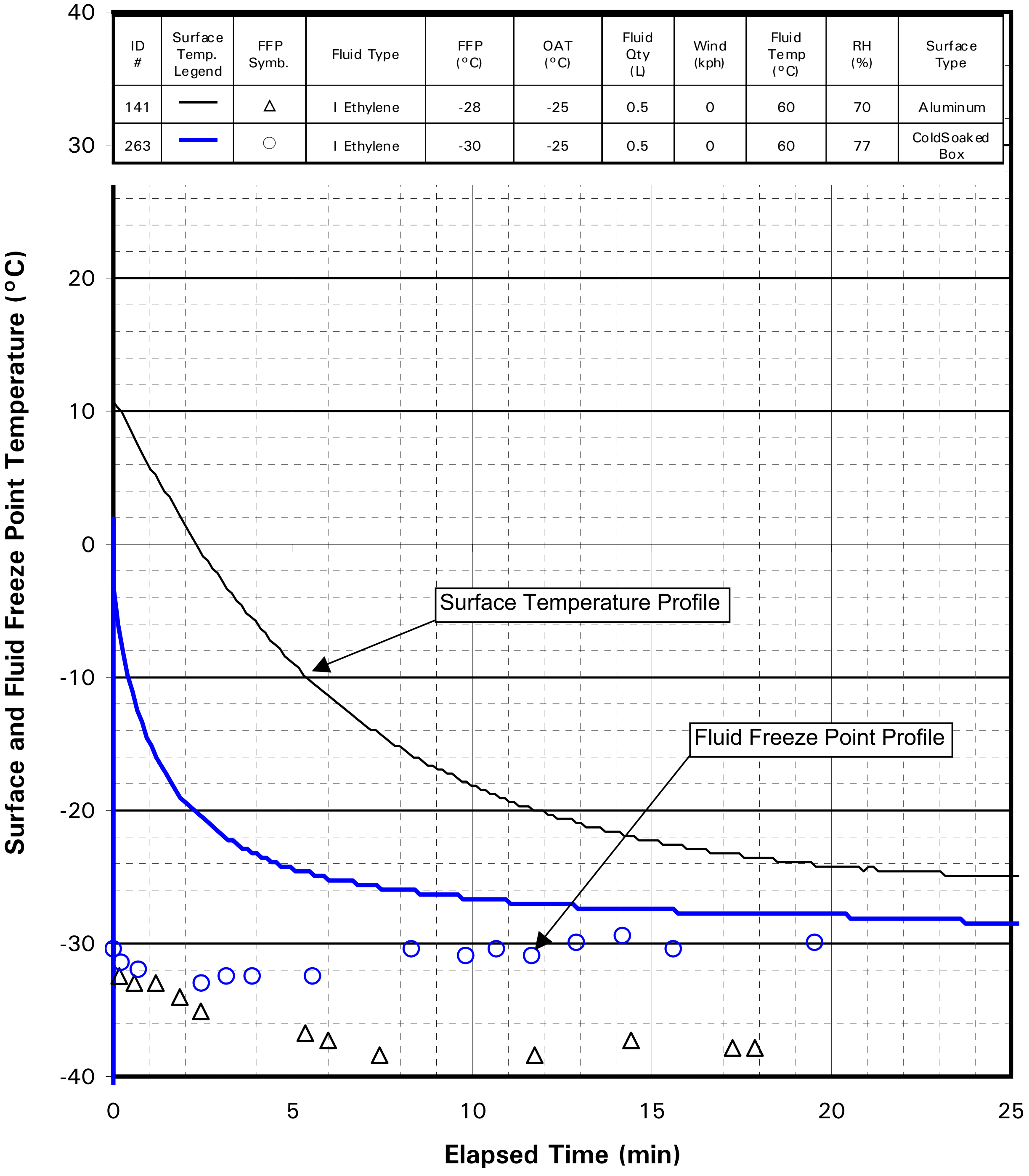
FIGURE 4.39

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -30°C

OAT -25°C, FFP -30°C, 0.5 L, Winds Calm

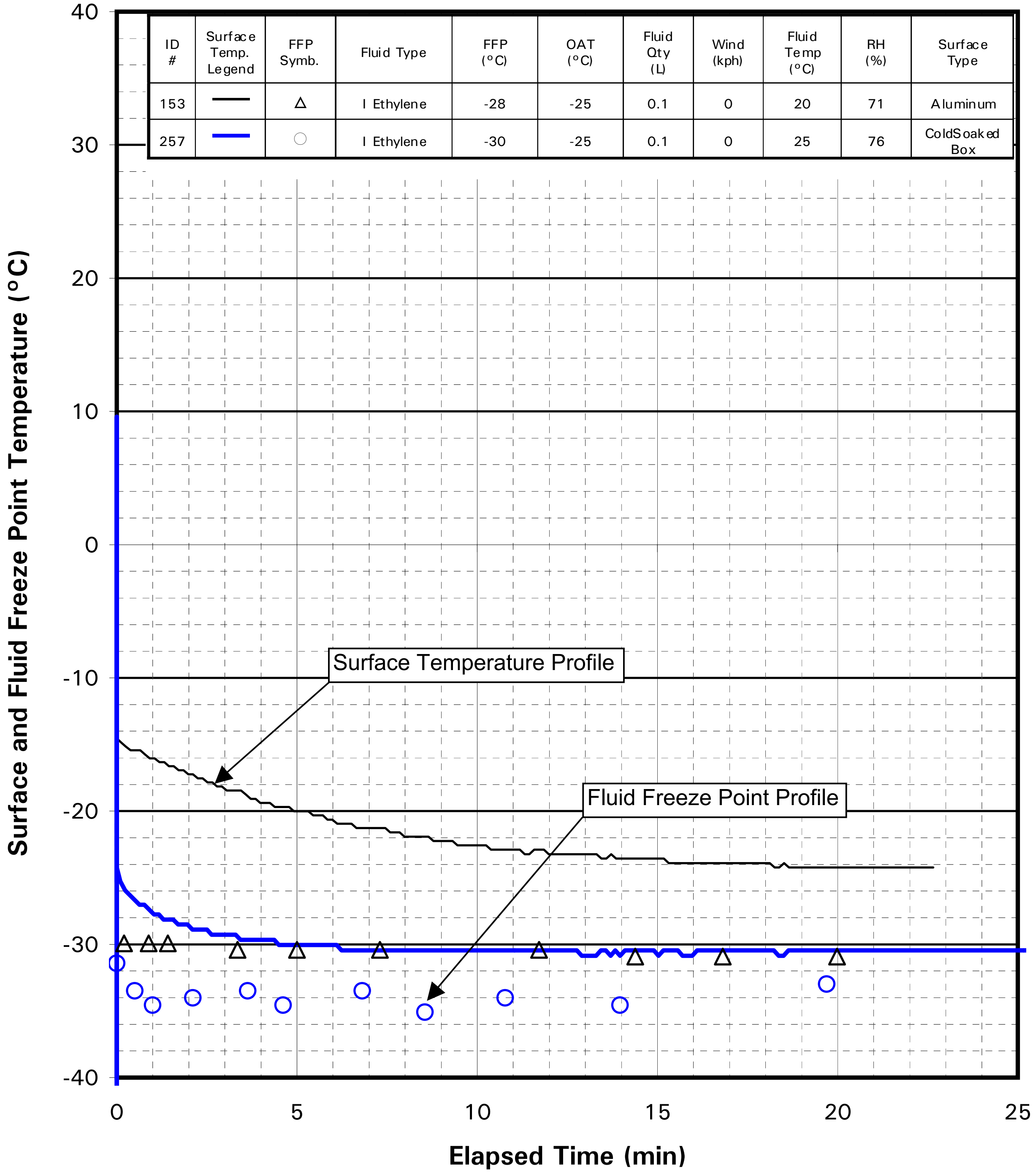


ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
141	—	△	I Ethylene	-28	-25	0.5	0	60	70	Aluminum
263	━	○	I Ethylene	-30	-25	0.5	0	60	77	ColdSoaked Box

FIGURE 4.40

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -30°C
OAT -25°C, FFP -30°C, 0.1 L, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
153	—	Δ	I Ethylene	-28	-25	0.1	0	20	71	Aluminum
257	—	○	I Ethylene	-30	-25	0.1	0	25	76	ColdSoaked Box

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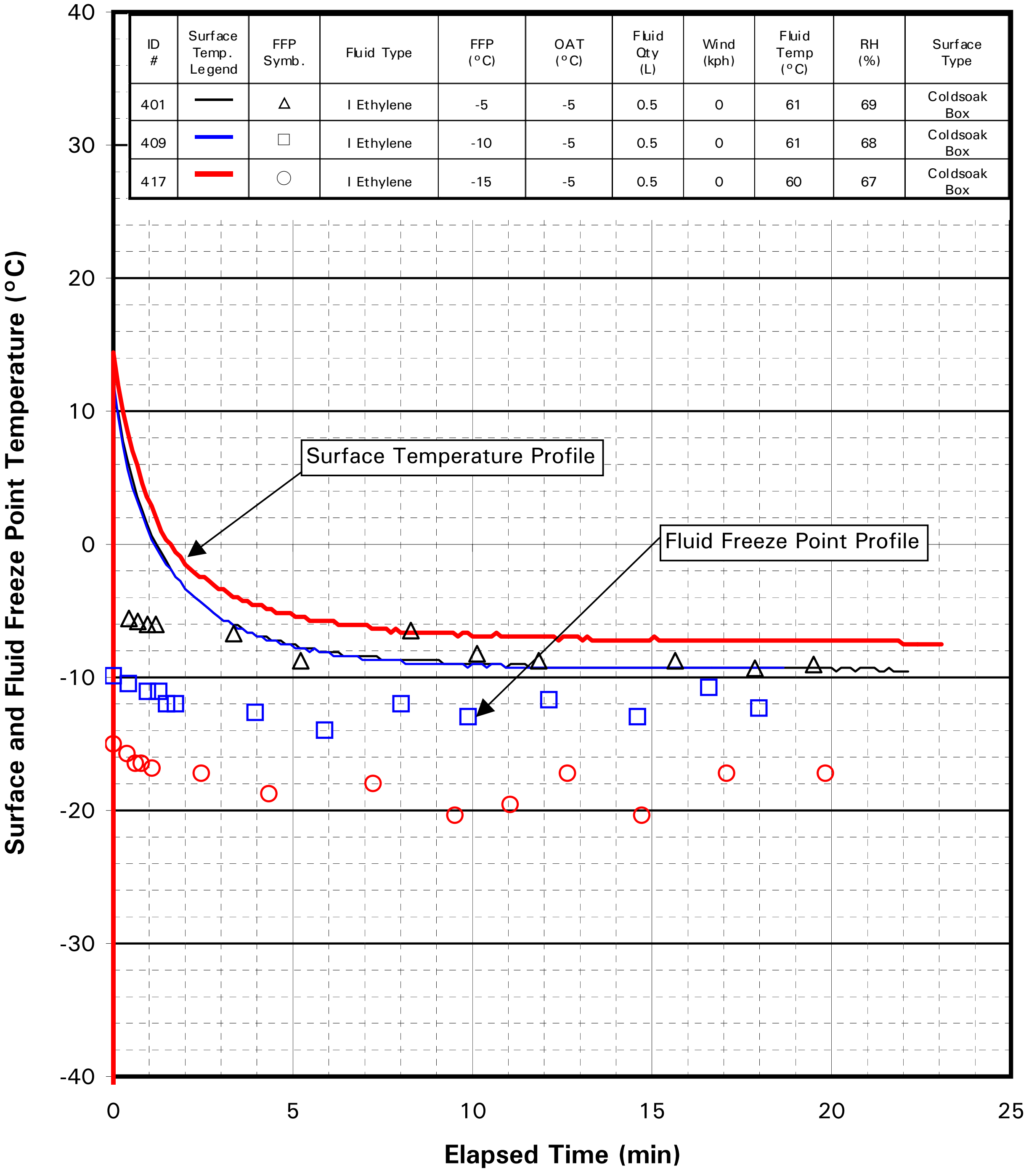
FIGURE 4.41

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C

OAT -5°C, FFP Variable, 0.5 L, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
401	—	△	I Ethylene	-5	-5	0.5	0	61	69	Coldsoak Box
409	—	□	I Ethylene	-10	-5	0.5	0	61	68	Coldsoak Box
417	—	○	I Ethylene	-15	-5	0.5	0	60	67	Coldsoak Box

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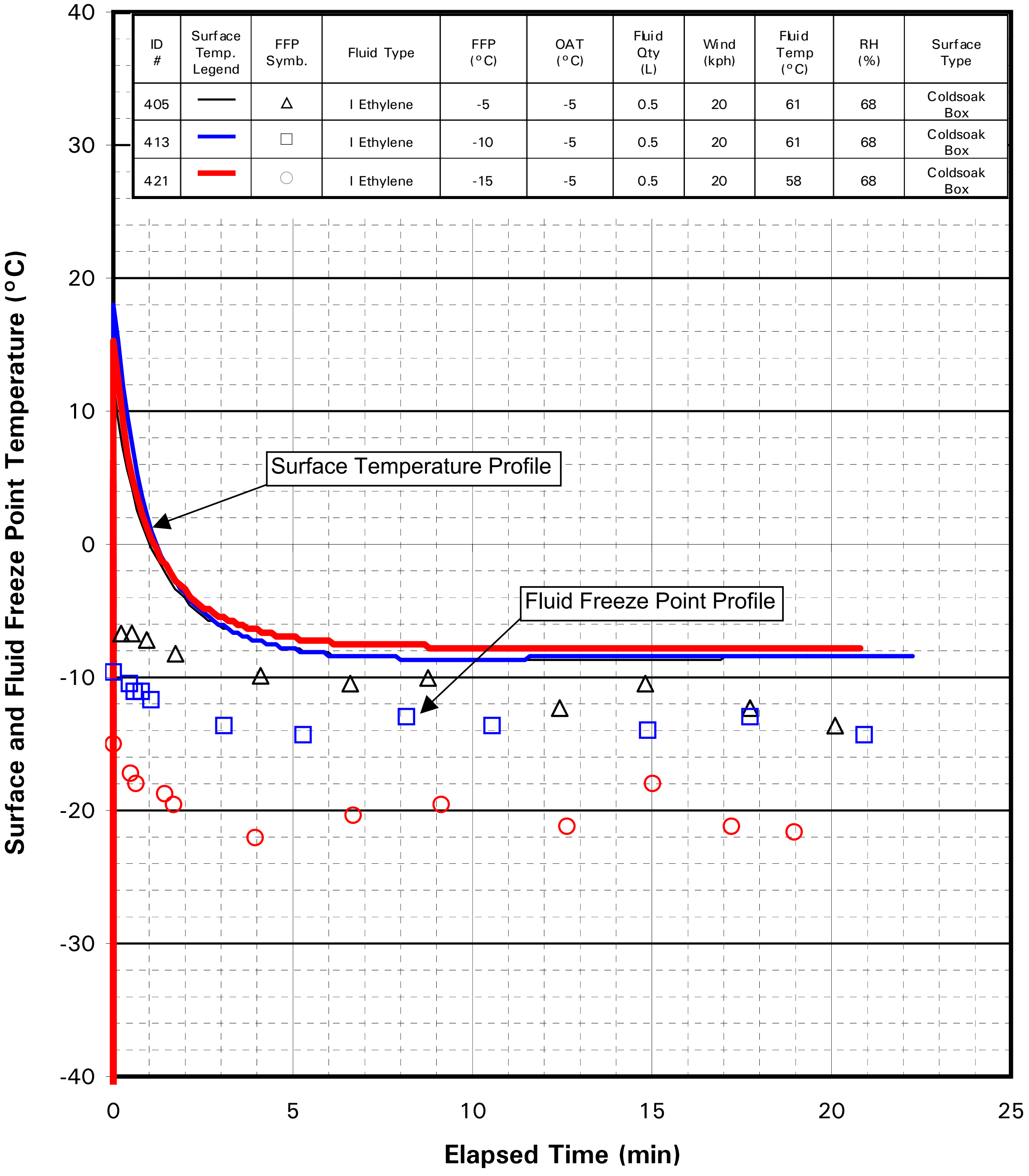
FIGURE 4.42

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C
OAT -5°C, FFP Variable, 0.5 L, Wind 20 kph



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
405	▬	△	I Ethylene	-5	-5	0.5	20	61	68	Coldsoak Box
413	🟦	□	I Ethylene	-10	-5	0.5	20	61	68	Coldsoak Box
421	🟥	○	I Ethylene	-15	-5	0.5	20	58	68	Coldsoak Box

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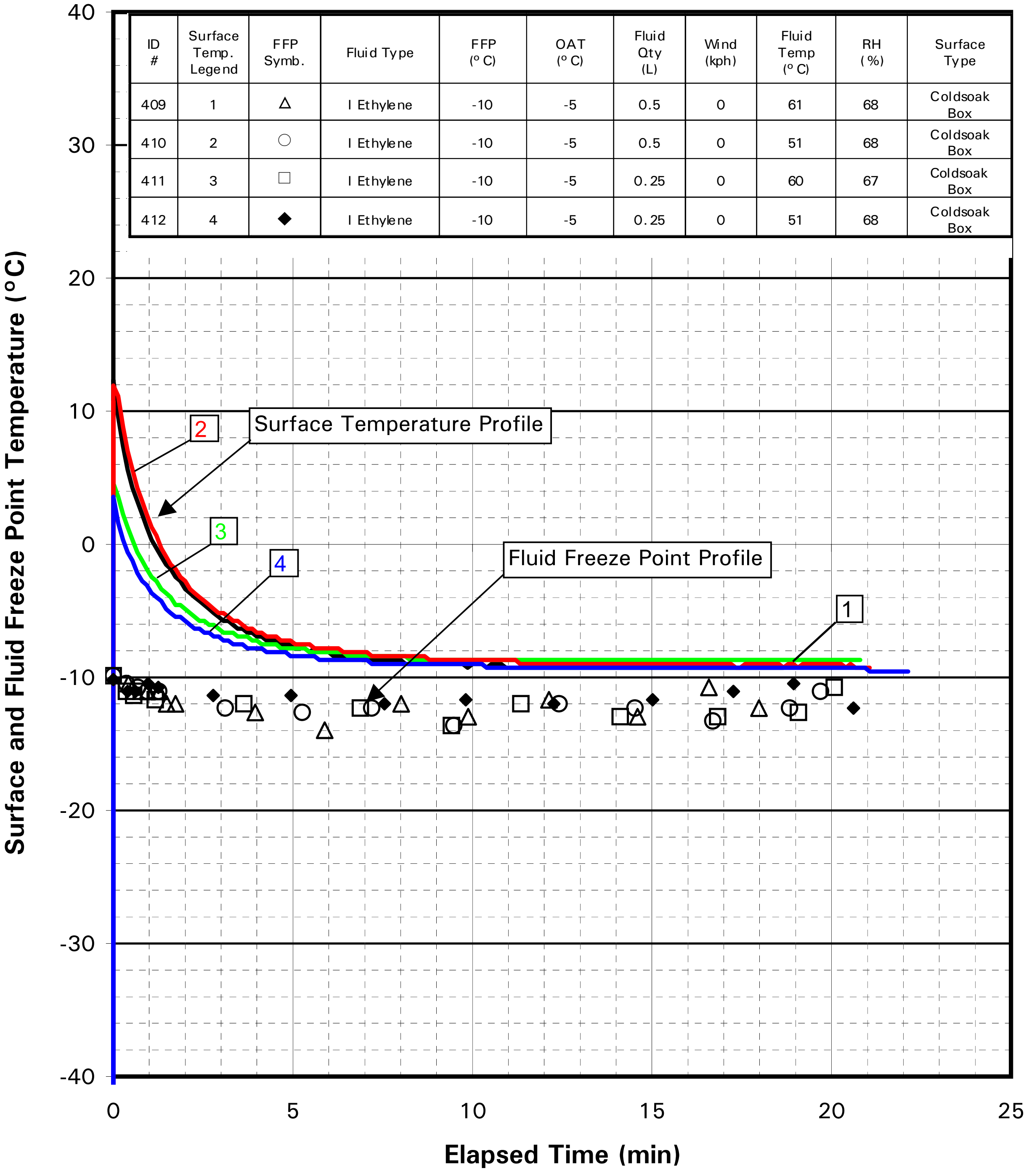
FIGURE 4.43

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C

OAT -5°C, FFP -10°C, 0.5 and 0.25 L, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (° C)	OAT (° C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (° C)	RH (%)	Surface Type
409	1	△	I Ethylene	-10	-5	0.5	0	61	68	Coldsoak Box
410	2	○	I Ethylene	-10	-5	0.5	0	51	68	Coldsoak Box
411	3	□	I Ethylene	-10	-5	0.25	0	60	67	Coldsoak Box
412	4	◆	I Ethylene	-10	-5	0.25	0	51	68	Coldsoak Box

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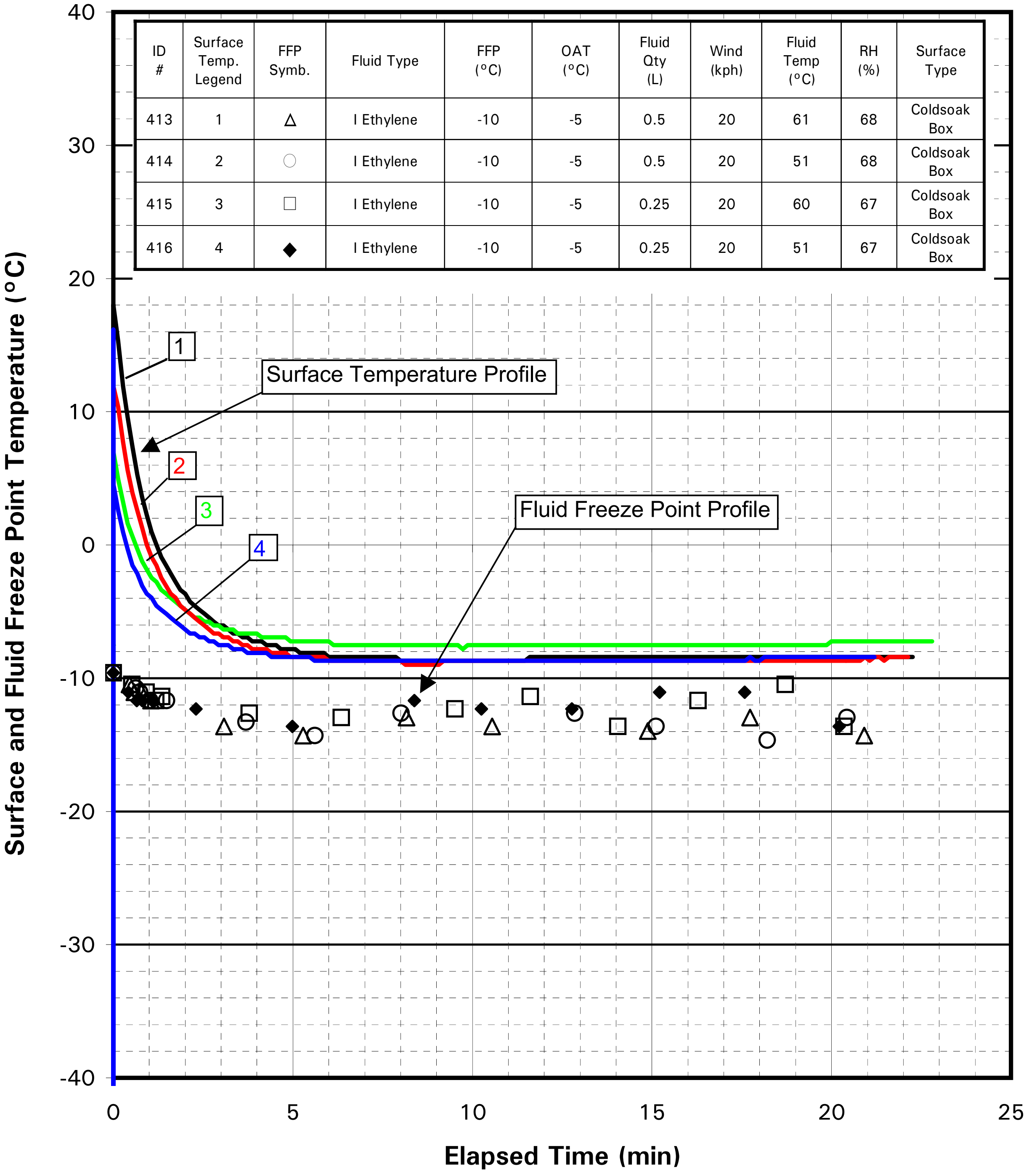
FIGURE 4.44

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C

OAT -5°C, FFP -10°C, 0.5 and 0.25 L, Wind 20 kph



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
413	1	△	I Ethylene	-10	-5	0.5	20	61	68	Coldsoak Box
414	2	○	I Ethylene	-10	-5	0.5	20	51	68	Coldsoak Box
415	3	□	I Ethylene	-10	-5	0.25	20	60	67	Coldsoak Box
416	4	◆	I Ethylene	-10	-5	0.25	20	51	67	Coldsoak Box

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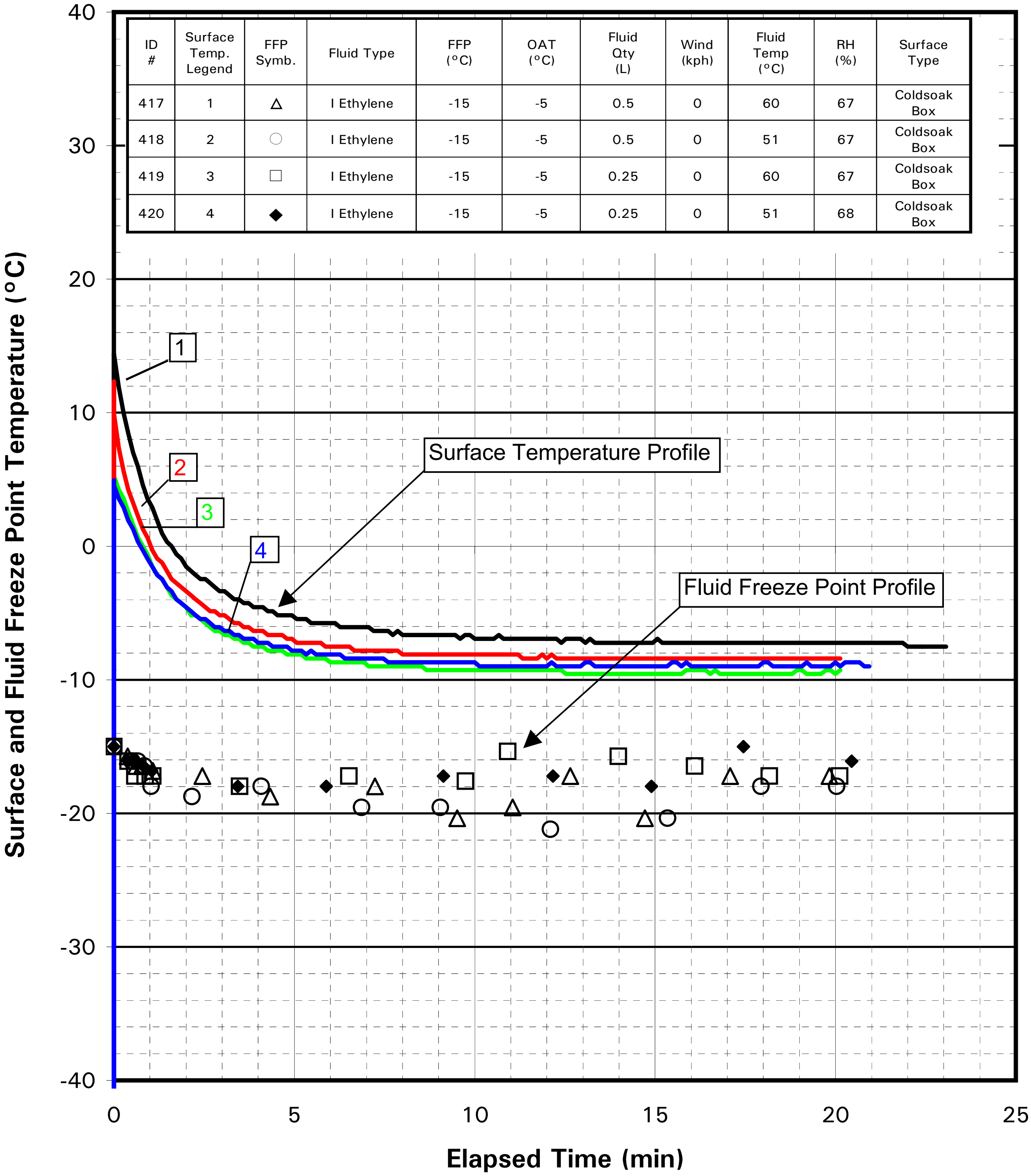
FIGURE 4.45

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C

OAT -5°C, FFP -15°C, 0.5 and 0.25 L, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
417	1	△	I Ethylene	-15	-5	0.5	0	60	67	Coldsoak Box
418	2	○	I Ethylene	-15	-5	0.5	0	51	67	Coldsoak Box
419	3	□	I Ethylene	-15	-5	0.25	0	60	67	Coldsoak Box
420	4	◆	I Ethylene	-15	-5	0.25	0	51	68	Coldsoak Box

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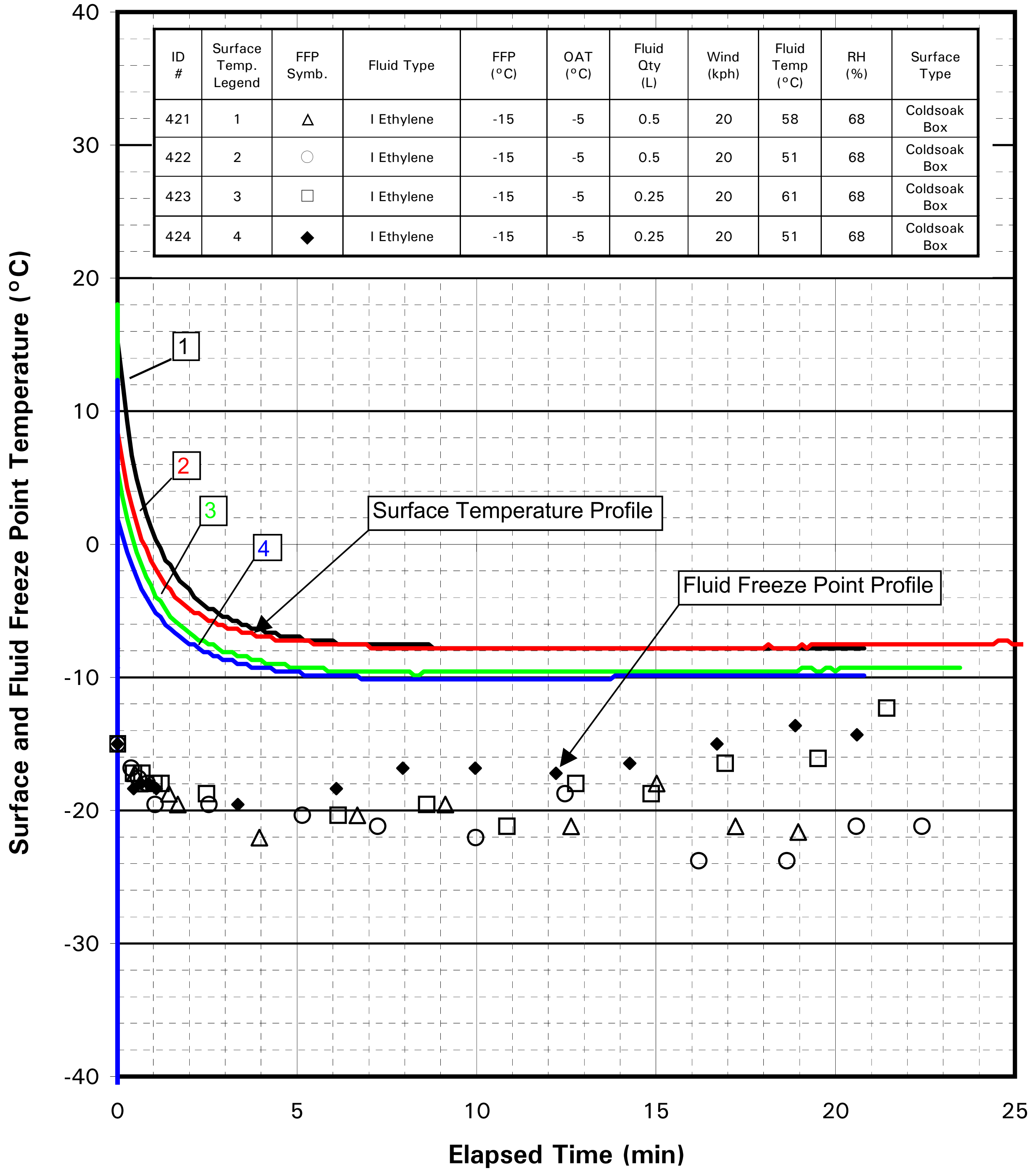
FIGURE 4.46

Fluid Freeze Point and Surface Temperature Profile

Cold-Soaked Boxes -10°C
OAT -5°C, FFP -15°C, 0.5 and 0.25 L, Winds Calm



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
421	1	△	I Ethylene	-15	-5	0.5	20	58	68	Coldsoak Box
422	2	○	I Ethylene	-15	-5	0.5	20	51	68	Coldsoak Box
423	3	□	I Ethylene	-15	-5	0.25	20	61	68	Coldsoak Box
424	4	◆	I Ethylene	-15	-5	0.25	20	51	68	Coldsoak Box

Figure #	OAT (°C)	FFP (°C)	Fluid Type	Fluid Qty (litres)	Wind (kph)	Fluid Temp (°C)	RH (%)
4.35	–5	–5	T1E	0.5	Calm	60	90
4.36	–5	–8, –10	T1E	0.5	Calm	60	92
4.37	–5	–15	T1E	0.5	Calm	60	91
4.38	–5	–8, –10	T1E	0.1 (spray)	Calm	50	91
4.39	–25	–28, –30	T1E	0.5	Calm	60	77
4.40	–25	–28, –30	T1E	0.1 (spray)	Calm	20, 25	76
4.41	–5	–5, –10,–15	T1E	0.5	Calm	60	68
4.42	–5	–5, –10,–15	T1E	0.5	20	60	68
4.43	–5	–10	T1E	0.5, 0.25	Calm	60, 50	68
4.44	–5	–10	T1E	0.5, 0.25	20	60, 50	68
4.45	–5	–15	T1E	0.5, 0.25	Calm	60, 50	67
4.46	–5	–15	T1E	0.5, 0.25	20	60, 50	68

Figure 4.35 compares results from a trial on a standard flat-plate test surface conducted at RH levels of 84 percent, with that of a trial on a cold-soaked box surface at a RH level of 90 percent. The initial FFP of the applied fluid was equal to OAT (–5°C) in both trials.

Examination of Frost Condition

Reference to tables of saturation mixing ratios over water at an OAT of –5°C show that the amount of water vapour, when the air is saturated, is 2.518 grams of vapour/kg of air. At –5°C, the frost point is the same as the dew point. Thus, at an RH of 84 percent, frost deposition would not be expected for the plate test in which the plate temperature was equal to OAT.

In the cold-soaked-box trial, which was conducted at 90 percent RH, the box-surface temperature was –10°C. Without wind, the air immediately over the surface would be expected to be at a similar temperature.

At 90 percent RH, the ratio of water vapour in the ambient air (OAT = –5°C) is 2.266 grams of vapour/kg of air. At an OAT of –10°C, the saturation-mixing ratio with respect to ice is 1.627. This condition resulted in frost deposition, with accompanying dilution of the fluid, and related elevation of the FFP as shown in the figure. The FFP profile showed an initial improvement (drop) but then increased, intersecting the surface-temperature profile, at which point freezing would be expected. The test record shows that ice was reported after 13 minutes into the test run, which corresponds well with the time of intersection of the temperature profiles.

Figure 4.36 compares results from a trial on a standard flat-plate test surface conducted at RH levels of 68 percent, with that of a trial on a cold-soaked-box surface at an RH level of 92 percent. The initial freezing points of the applied fluids were –8°C and –10°C, respectively.

As in the previous case, the cooling action on the layer of air immediately over the cold-soaked-box surface resulted in frost deposition and dilution of the fluid mix. The FFP profile showed a steady climb; had the trial run continued, it would have intersected the surface temperature profile. The test record shows that ice had started to form along the plate edges.

Figure 4.37 compares results from similar trials with the exception that the initial FFP of the applied fluid was –15°C. The FFP profile of the fluid on the cold-soaked-box surface in this case showed an enhancement of –4°C and then stayed at that FFP. The additional glycol provided enough capacity to prevent an increase in the FFP (and related freezing).

Figure 4.38 presents results from trials representing typical frost-removal sprays, using 0.1 L of fluid at 50°C, applied by spraying. The initial FFP was –8°C and –10°C for the plate test and cold-soaked-box test, respectively. The FFP of the fluid on the plate demonstrated an initial enhancement of –2°C and then slowly improved to –3°C. The FFP of the fluid on the cold-soaked box demonstrated an initial enhancement of –2°C but then degraded (climbed) with the FFP profile intersecting the box-surface-temperature profile after about 10 minutes. Ice was reported, forming along the surface edge, after 6 minutes.

Figure 4.39 reports results from trials conducted at an OAT of –25°C. The attempt to produce high humidity resulted in a condition similar to freezing fog. The measured precipitation rate on a flat plate was 1.7g/dm^2/hr. The precipitation rate on a cold-soaked-box surface would have been somewhat greater. The FFP profile for the fluid on the box surface shows the expected dilution. Streaks of solid contamination did appear on the surface after 8 minutes.

The trial on the flat plate conducted at an RH level of 70 percent showed initial enhancement from an initial FFP of –28°C to –39°C after about 10 minutes. Examining saturation-mixing ratios for this OAT indicates that the frost point was between –26 and –27°C, just below the existing OAT. The FFP profile climbed in the last half of the trial run, indicating that some deposition was probably occurring.

Figure 4.40 presents results from trials representing typical frost-removal sprays but at an OAT of –25°C. In this case, the FFP on the cold-soaked box demonstrated an initial enhancement of –4°C but then started to climb, indicating dilution.

The remaining figures report on trials conducted at NRC at an OAT of –5°C. The cold-soaked-box temperature was –10ºC. At an ambient temperature of –5°C, a relative humidity of 62 percent is enough to cause frost deposition on a surface whose temperature is –10°C. Because humidity in the laboratory throughout the test period ranged from 67 percent to 69 percent, active frost deposition on the surfaces of the cold-soaked boxes would be expected.

Figures 4.41 and 4.42 report on two sets of tests that are similar except that the latter was conducted with a wind of 20 kph. Initial values of FFP were –5, –10,and –15°C in both sets.

In trials on fluid with FFP of –5°C (equal to OAT) in calm conditions, the FFP profile showed little enhancement and intersected the surface temperature profile. The addition of wind enhanced the extent of improvement and avoided intersection of curves.

Trials on fluids with an initial FFP of –10ºC and –15ºC in calm conditions demonstrated an initial enhancement (drop) followed by a slow elevation due to frost deposition. In wind conditions, the FFP curves flattened out after the initial dip.

In these comparisons of calm versus wind, the wind had the effect of reducing frost deposition through the mechanism of constantly replacing the layer of air over the cold-soaked-box surface with ambient air. The temperature of ambient air was above the frost point, whereas air cooled to box temperature was below the frost point. In other words, tests reported in Figure 4.41 were conducted in active frost (and gave unsatisfactory results), whereas those in Figure 4.42 were conducted at a lower rate of frost (and gave satisfactory results).

Figures 4.43 and 4.44 report on two series of tests conducted with mixes at FFP of –10°C (same temperature as the cold-soaked box), using quantities of 0.5 and 0.25 L. Fluid temperatures of 50 and 60°C were tested. Trials in Figure 4.42 were conducted in calm conditions, whereas those in Figure 4.44 were conducted with a wind of 20 kph.

The enhancement to FFP was not very different for any of the trials reported in Figure 4.43. Larger quantities did demonstrate a somewhat greater improvement in the early stages, but not as frost deposition continued.

The main impact of wind in the trials reported in Figure 4.44 was to differentiate results produced by the two fluid quantities. The FFP profiles resulting from the smaller quantities showed a rate of dilution (steeper curve) greater than for the larger quantities.

Figures 4.45 and 4.46 report on two series of tests, one with wind and one calm) conducted with fluid mixes at FFP of –15°C. In tests conducted in calm conditions, the fluid quantity variable had no effect on the extent of FFP enhancement at test end. The windy condition (Figure 4.46) produced more FFP enhancement early in the test run, relative to the calm wind condition. Following the initial improvement, FFP profiles for the two tests with less fluid climbed steeply, whereas the profiles for the tests with more fluid stayed somewhat flat. Of the eight test runs conducted with fluid mixed to a FFP of –15°C, the two with fluid quantities of 0.25 L, in wind, were the only runs that involved ice formation.

In summary, this series of tests demonstrated that the *deicing only* concept, using a FFP equal to OAT, is unsuitable for an active frost condition.

4.1.8 Composite and Painted Surfaces

Figures 4.47 to 4.52 present results for tests examining the impact of composite and painted surfaces.

These figures report results for test conditions as shown in the following matrix:

Figure #	OAT (°C)	FFP (°C)	Fluid Type	Wind (kph)	Surface Type
4.47	–5	–5	T1E	Calm	Composites
4.48	–5	–5	T1E	20	Composites
4.49	–25	–25	T1E	Calm	Composites
4.50	–5	–5	T1E	Calm	Painted
4.51	–25	–25	T1E	Calm	Painted
4.52	–25	–25	T1E	20	Painted

Other parameters (such as fluid quantity, and temperature) were held constant as noted in the legend for each figure.

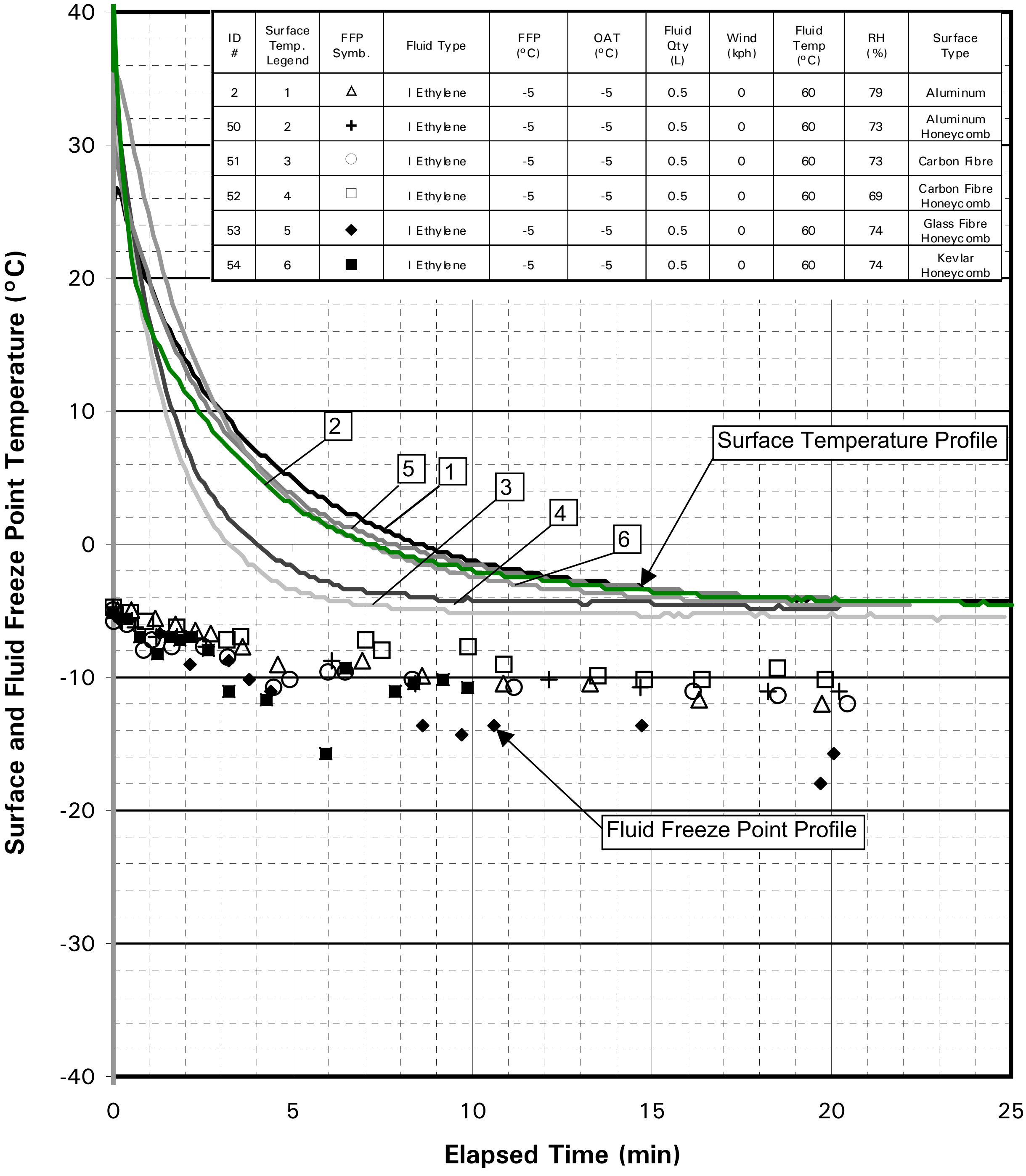
Figure 4.47 reports results for the trials on surfaces made of composite materials, as shown in the legend. The glass-fibre surface showed the

FIGURE 4.47

Fluid Freeze Point and Surface Temperature Profile

Special Plates

OAT -5°C, Winds Calm, Composites



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2	1	△	I Ethylene	-5	-5	0.5	0	60	79	Aluminum
50	2	+	I Ethylene	-5	-5	0.5	0	60	73	Aluminum Honeycomb
51	3	○	I Ethylene	-5	-5	0.5	0	60	73	Carbon Fibre
52	4	□	I Ethylene	-5	-5	0.5	0	60	69	Carbon Fibre Honeycomb
53	5	◆	I Ethylene	-5	-5	0.5	0	60	74	Glass Fibre Honeycomb
54	6	■	I Ethylene	-5	-5	0.5	0	60	74	Kevlar Honeycomb

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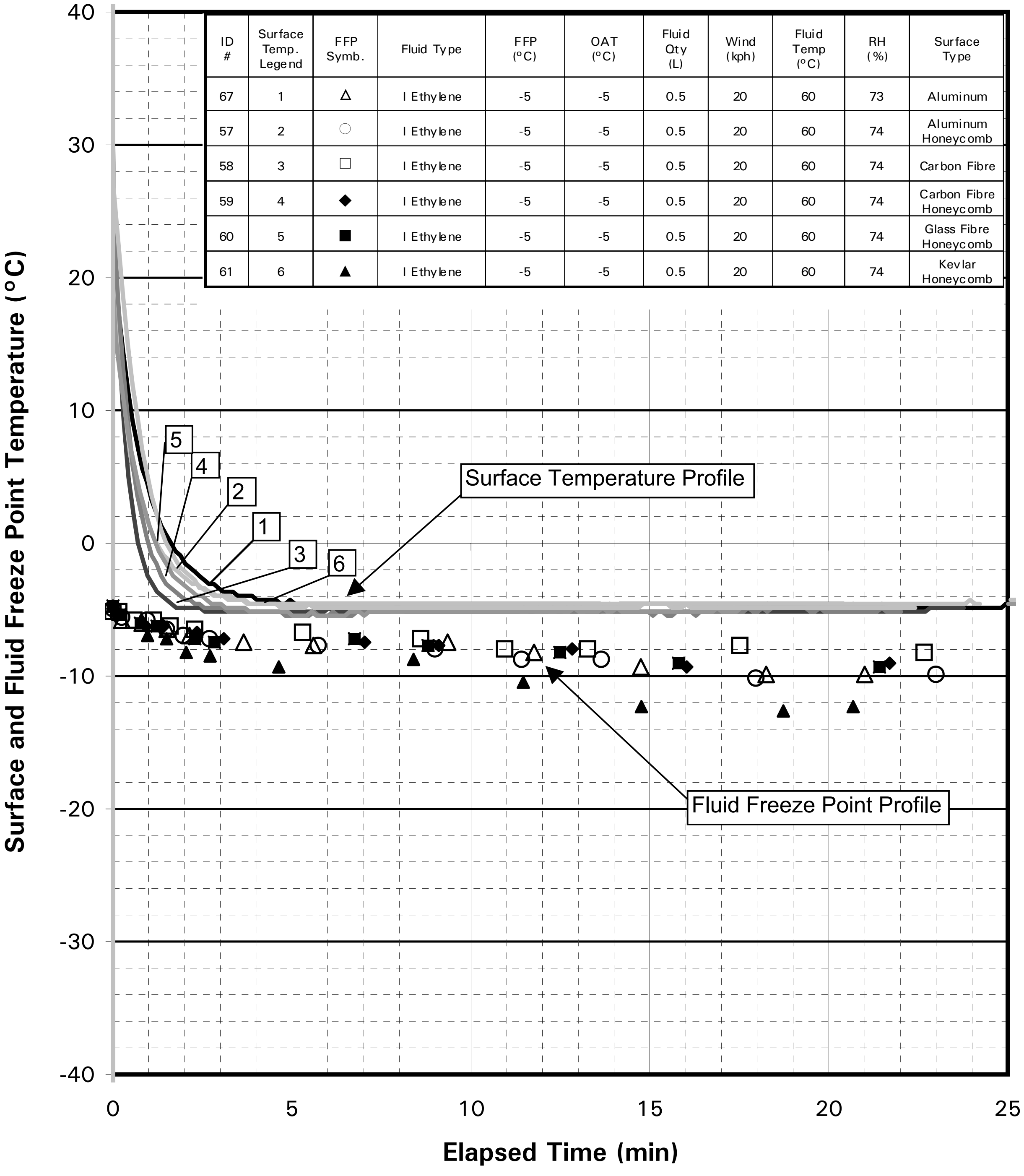
FIGURE 4.48

Fluid Freeze Point and Surface Temperature Profile

Special Plates

OAT -5°C, Wind 20 kph, Composites



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
67	1	△	I Ethylene	-5	-5	0.5	20	60	73	Aluminum
57	2	○	I Ethylene	-5	-5	0.5	20	60	74	Aluminum Honeycomb
58	3	□	I Ethylene	-5	-5	0.5	20	60	74	Carbon Fibre
59	4	◆	I Ethylene	-5	-5	0.5	20	60	74	Carbon Fibre Honeycomb
60	5	■	I Ethylene	-5	-5	0.5	20	60	74	Glass Fibre Honeycomb
61	6	▲	I Ethylene	-5	-5	0.5	20	60	74	Kevlar Honeycomb

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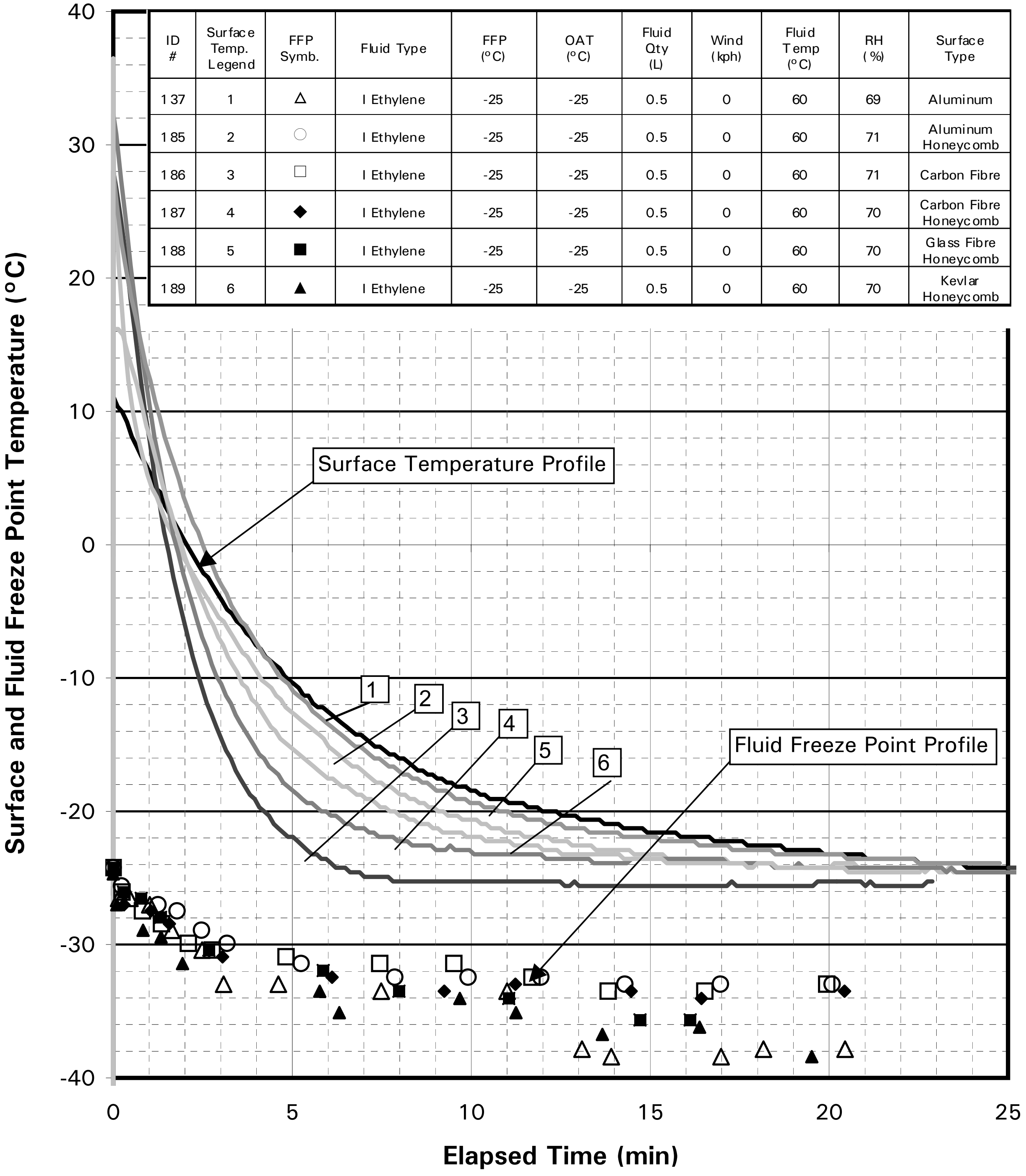
FIGURE 4.49

Fluid Freeze Point and Surface Temperature Profile

Special Plates

OAT -25°C, Winds Calm, Composites



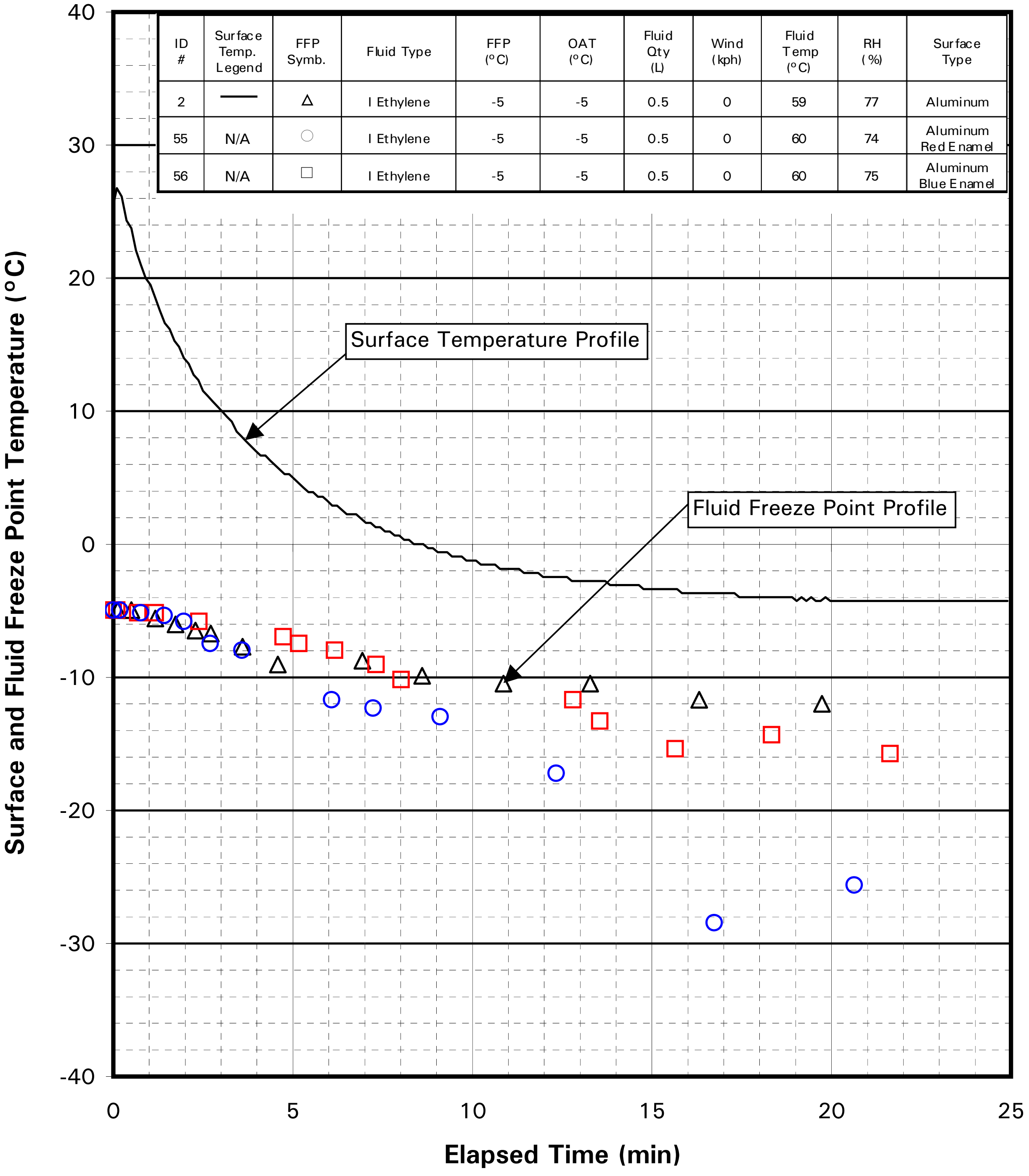
ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
137	1	△	I Ethylene	-25	-25	0.5	0	60	69	Aluminum
185	2	○	I Ethylene	-25	-25	0.5	0	60	71	Aluminum Honeycomb
186	3	□	I Ethylene	-25	-25	0.5	0	60	71	Carbon Fibre
187	4	◆	I Ethylene	-25	-25	0.5	0	60	70	Carbon Fibre Honeycomb
188	5	■	I Ethylene	-25	-25	0.5	0	60	70	Glass Fibre Honeycomb
189	6	▲	I Ethylene	-25	-25	0.5	0	60	70	Kevlar Honeycomb

FIGURE 4.50

Fluid Freeze Point and Surface Temperature Profile

Special Plates

OAT -5°C, Winds Calm, Painted



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2	——	△	I Ethylene	-5	-5	0.5	0	59	77	Aluminum
55	N/A	○	I Ethylene	-5	-5	0.5	0	60	74	Aluminum Red Enamel
56	N/A	□	I Ethylene	-5	-5	0.5	0	60	75	Aluminum Blue Enamel

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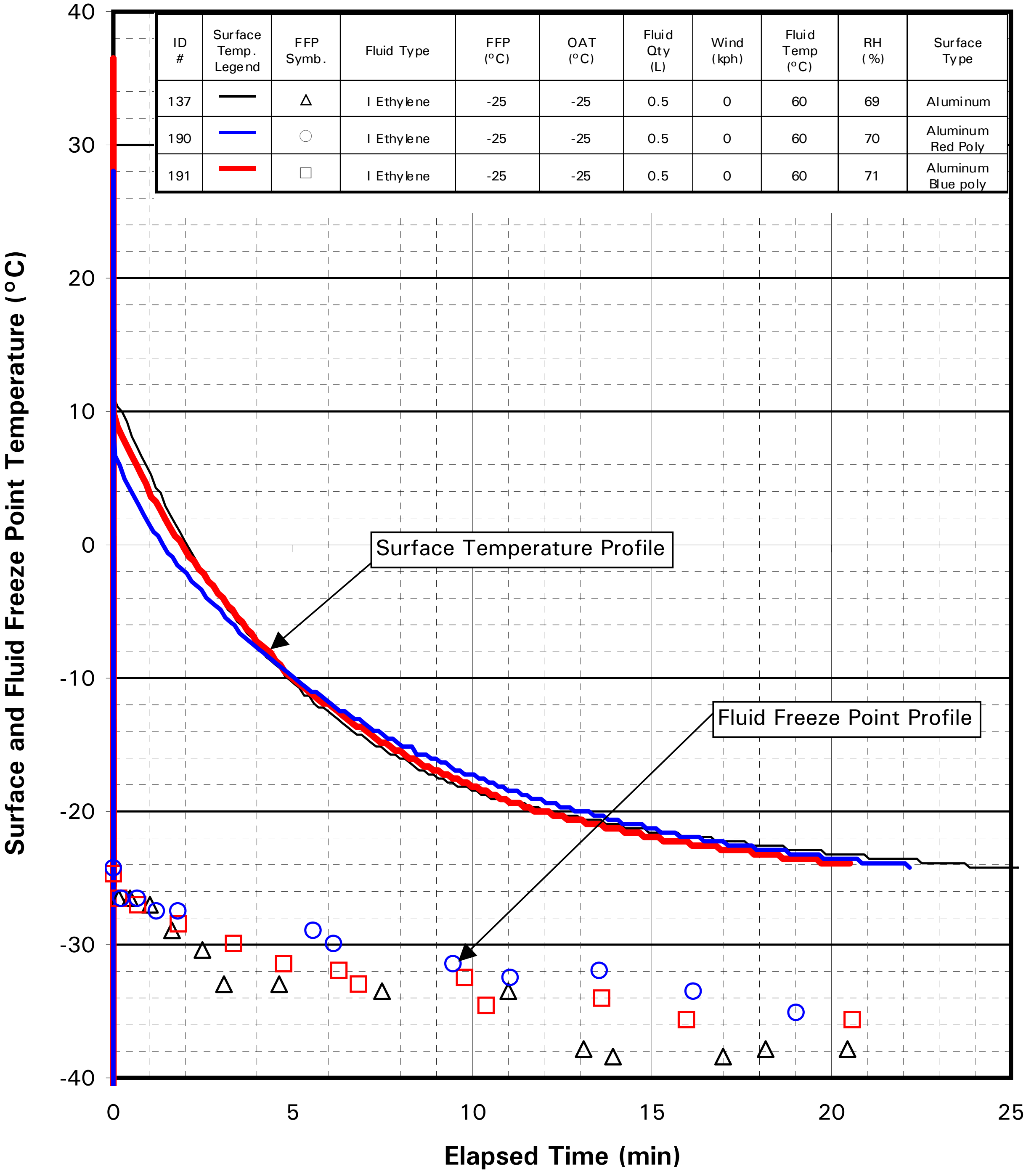
FIGURE 4.51

Fluid Freeze Point and Surface Temperature Profile

Special Plates

OAT -25°C, Winds Calm, Painted



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
137	━	△	I Ethylene	-25	-25	0.5	0	60	69	Aluminum
190	━	○	I Ethylene	-25	-25	0.5	0	60	70	Aluminum Red Poly
191	━	□	I Ethylene	-25	-25	0.5	0	60	71	Aluminum Blue poly

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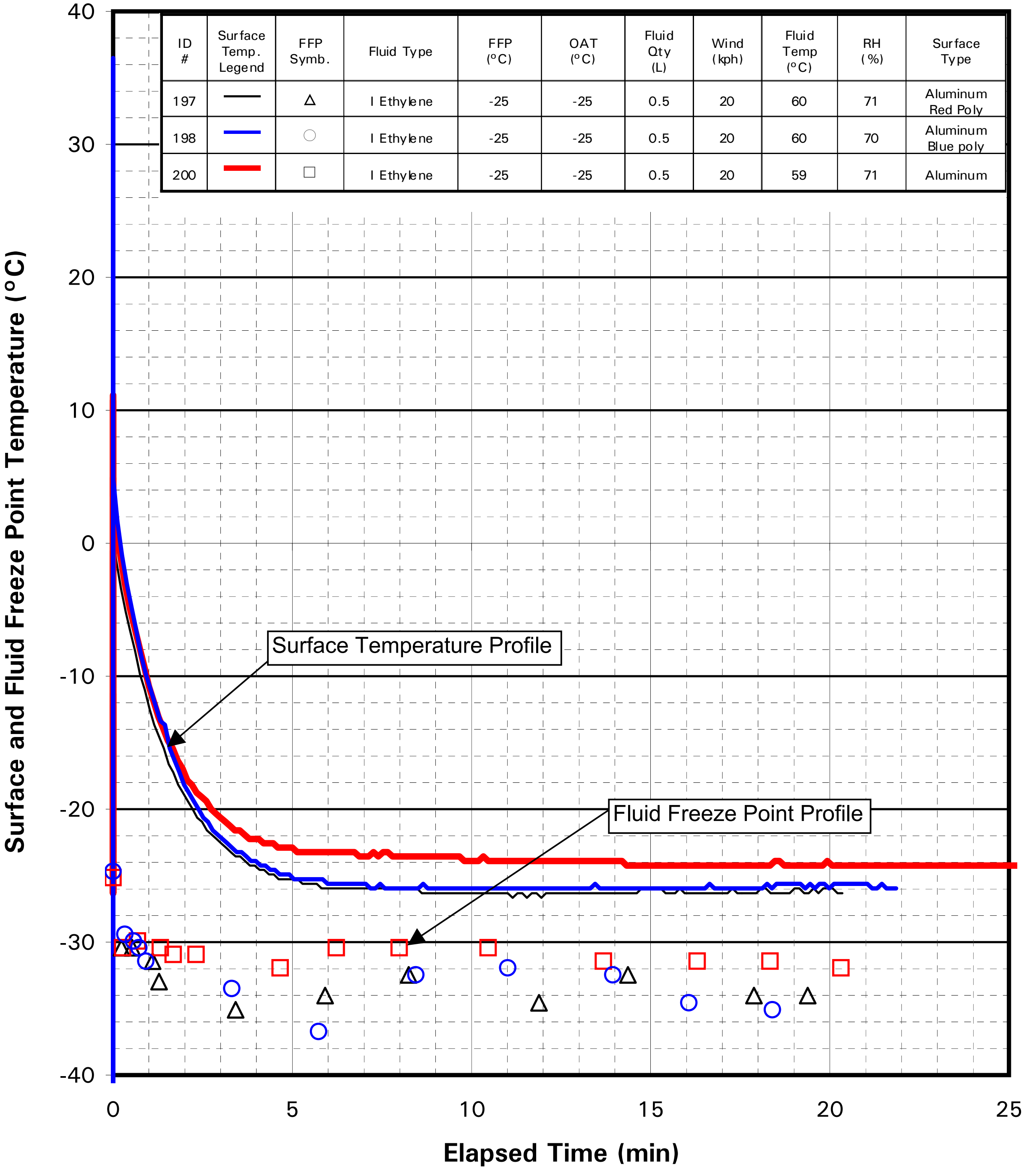
FIGURE 4.52

Fluid Freeze Point and Surface Temperature Profile

Special Plates

OAT -25°C, Wind 20 kph, Painted



ID #	Surface Temp. Legend	FFP Symb.	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
197	—	△	I Ethylene	-25	-25	0.5	20	60	71	Aluminum Red Poly
198	—	○	I Ethylene	-25	-25	0.5	20	60	70	Aluminum Blue poly
200	▬	□	I Ethylene	-25	-25	0.5	20	59	71	Aluminum

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highest degree of enhancement, significantly better than the standard aluminum test plate. The Kevlar surface was completely dry after 10 minutes. Other materials performed at about the same level as the standard aluminum plate.

Figure 4.48 reports results for a similar series of trials but with a 20 kph wind. The Kevlar surface demonstrated the highest degree of enhancement. Other materials performed at about the same level as the standard aluminum test plate (FFP enhancement of –5°C) – except the carbon-fibre surface, which produced a final FFP enhancement of –3°C.

Figure 4.49 reports results for a series of trials at an OAT of –25°C and a 20 kph wind. The Kevlar surface and the standard plate were the best performers, with FFP enhancements of –13°C. Other materials produced a final FFP enhancement ranging from –8°C to –10°C.

Figure 4.50 reports results for trials on painted-aluminum test surfaces, as shown in the legend. In this series, the painted surfaces performed much better than the aluminum one. When these results were discussed, it was learned that enamel paint had been used. Because this is not typically used for aircraft, new surfaces using polyurethane paint were prepared for later tests.

Figure 4.51 reports results for trials on surfaces prepared with a polyurethane paint, as shown in the legend. These tests were performed at an OAT of –25°C with calm winds. Painted surfaces produced a slightly lower extent of FFP enhancement than the standard aluminum one (–10ºC versus –13ºC).

Figure 4.52 reports on a similar series of tests but with a 20 kph wind. Painted surfaces performed slightly better than the standard aluminium one.

In summary, performance of the composite surfaces ranged around the performance of the standard aluminum plate. Kevlar and glass-fibre surfaces performed as well as or better than the standard test plate, but carbon-fibre and aluminium-honeycomb core plates performed at a slightly lower level.

The polyurethane-painted aluminum surfaces (red and blue) performed as well as the standard test plate.

4.2 Field Trials on Aircraft

4.2.1 Removal of Snow

These trials were conducted on a US Airways B-737 aircraft at Dorval. An active frost condition existed; the wings were frosted on arrival at the Central Deicing Facility.

Figures 4.53 to 4.56 present results for tests examining whether the heat lost during snow removal is detrimental to the enhancement of FFP. Snow was applied over the test area on the wing. The deicing operator removed it by spraying according to standard practice. In the case of the bare wing, the operator was asked to spray as if there were a light covering of snow. Fluid amounts were not prescribed; they were at the operator's discretion, applying whatever quantities were required to produce a clean wing.

These figures report results for test conditions as shown in the following matrix:

Figure #	Run #	OAT (°C)	RH (%)	FFP (°C)	Fluid Type	Depth of Snow (cm)
4.53	1	–7	84	–12	T1E	Bare
4.54	2	–7	82	–12	T1E	0.5
4.55	3	–8	85	–12	T1E	1.5
4.56	4	–9	85	–12	T1E	Bare

Figure 4.53 reports on a trial conducted on a bare wing as a reference for snow-removal trials.

Fluid coverage for this trial (the first trial in the session) was not as heavy as expected. This observation is supported by the temperature profile for the leading edge, in which hardly any rise in temperature was shown. The quantity of fluid applied to the wing was not measured because the operator first sprayed a liberal quantity on the ground to clear the hose of cold fluid and then immediately sprayed the wing. The test was repeated (run 4) to gather more data.

FFP profiles for the various locations on the wing showed an FFP enhancement range from –2 to –5°C.

Figure 4.54 reports on a trial conducted on a wing section covered with 0.5 cm of snow. The temperature profiles show a much higher peak, compared to the previous trial, indicating the higher quantity and better

FIGURE 4.53

Fluid Freeze Point and Surface Temperature Profile

AIRCRAFT *DEICING ONLY* TRIALS – RUN #1

US Airways B737

Feb. 15/16, 1999, OAT = -8°C

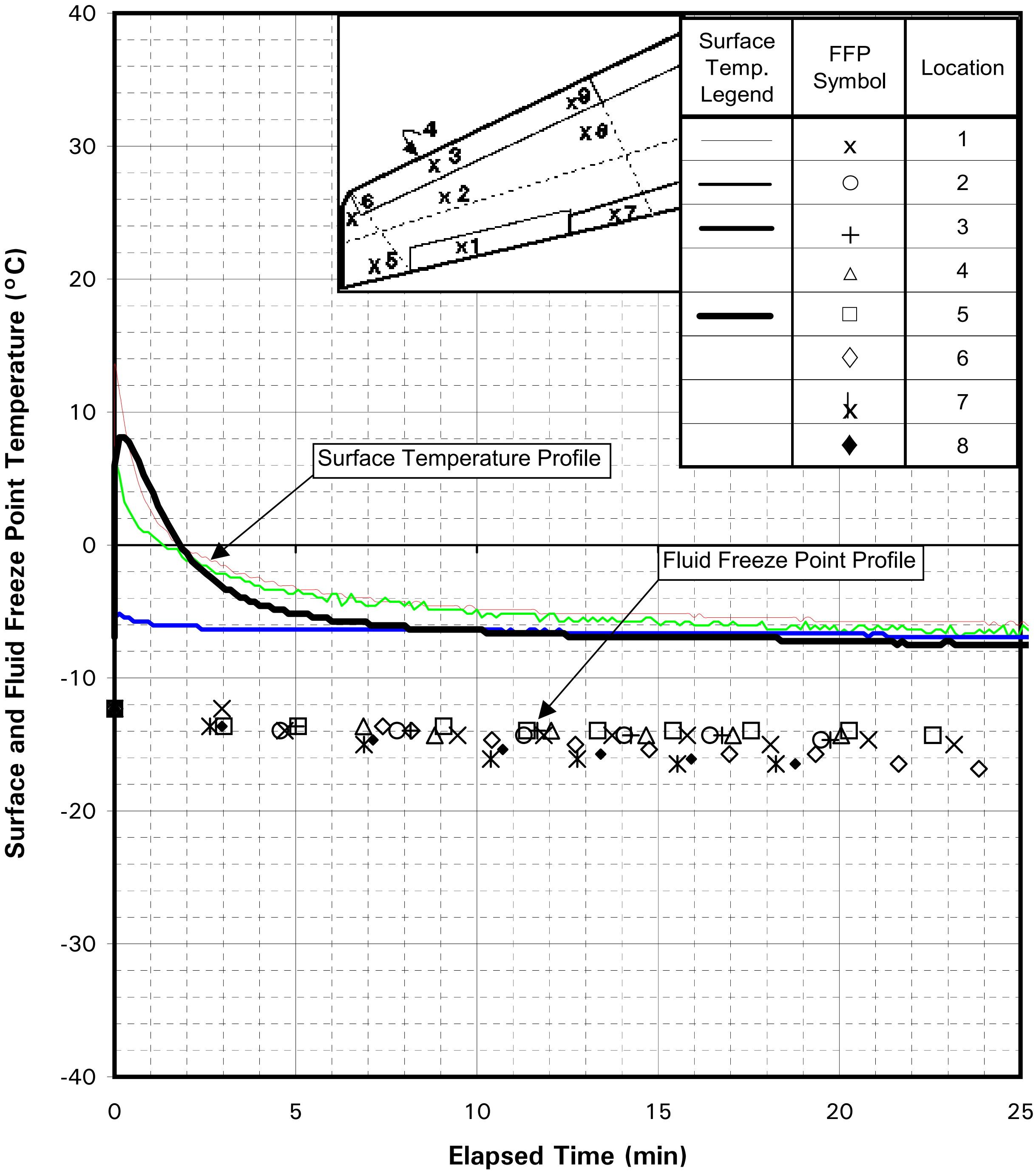

FIGURE 4.54

Fluid Freeze Point and Surface Temperature Profile

AIRCRAFT *DEICING ONLY* TRIALS – RUN #2

US Airways B737

Feb. 15/16, 1999, OAT = -8°C

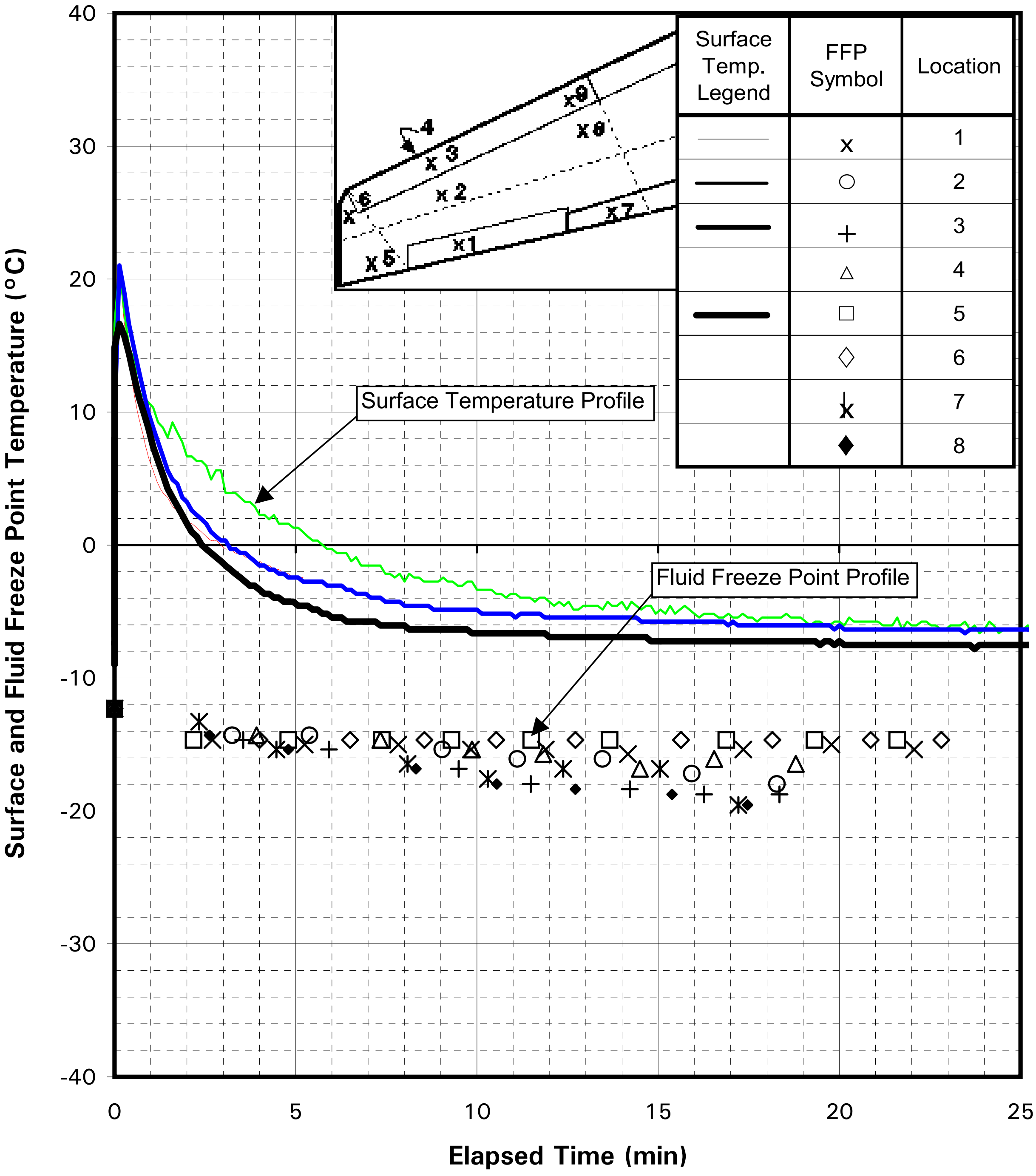

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FIGURE 4.55

Fluid Freeze Point and Surface Temperature Profile

AIRCRAFT *DEICING ONLY* TRIALS – RUN #3

US Airways B737

Feb. 15/16, 1999, OAT = -8°C

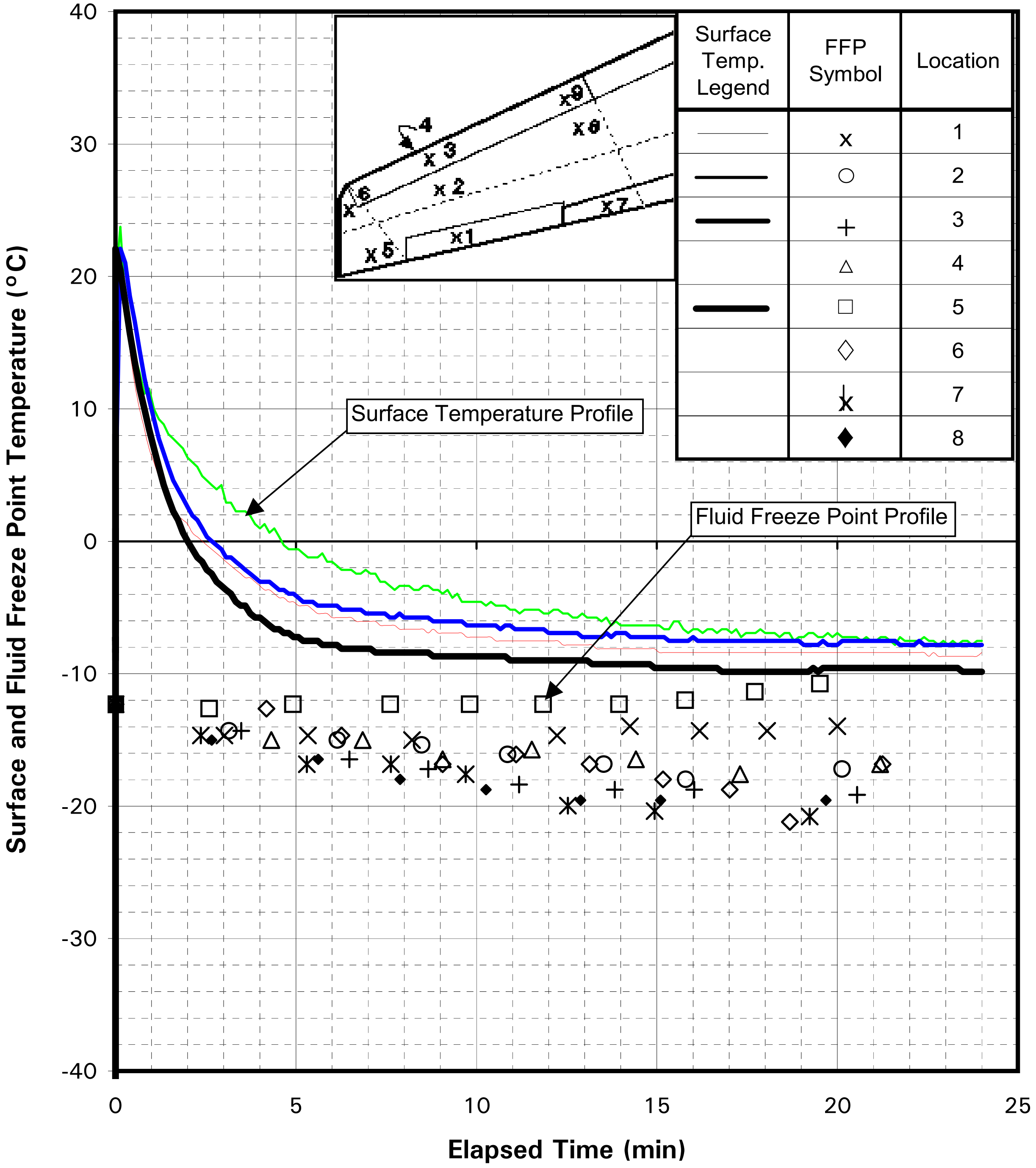

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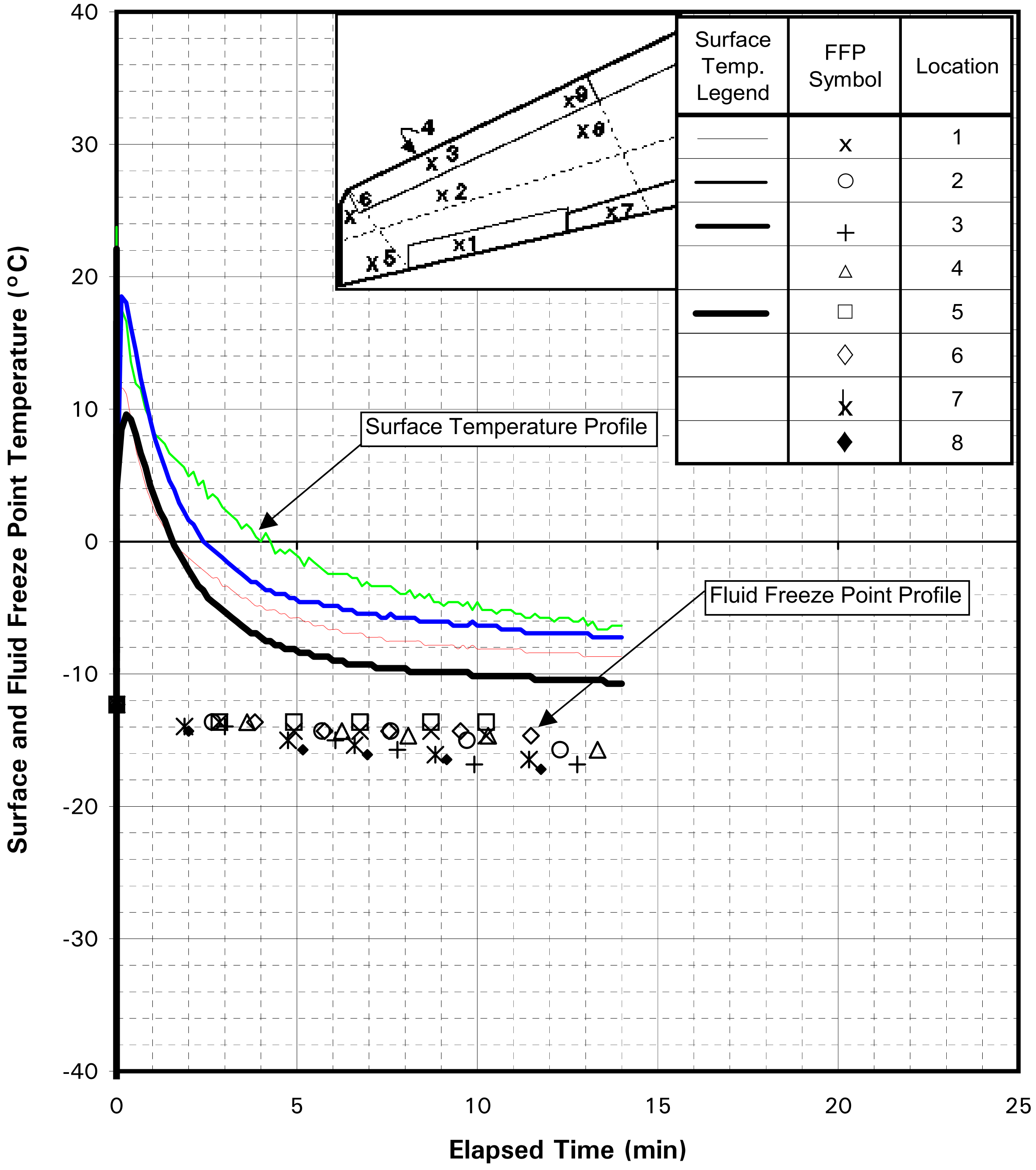
FIGURE 4.56

Fluid Freeze Point and Surface Temperature Profile

AIRCRAFT *DEICING ONLY* TRIALS – RUN #4

US Airways B737

Feb. 15/16, 1999, OAT = -10°C



coverage in fluid application when the operator had real contamination to remove.

The FFP profiles for the various locations on the wing showed an FFP enhancement ranging from –3 to –7°C. This extent of enhancement is similar to the results of the laboratory trials reported in Figures 4.32 and 4.33.

Figure 4.55 reports on a trial conducted on a wing section covered with 1.5 cm of snow. The temperature profiles are similar to those of the previous snow-removal trial.

The FFP profiles for various locations on the wing showed widely varying results, with two locations (outboard wing and aileron) showing an elevation in FFP. At location 5 on the outboard wing, the snow was not completely cleaned. This might have been due to operator practice, in which the initial spray target is just inboard from the wingtip. As a result, any snow on the surface outboard of the targeted point is not subjected to the normal flushing action of the fluid stream, and is cleaned only through melting action of heated fluid. In this test, the remaining snow caused dilution locally, as shown in the FFP curve for location 5.

Location 1 showed a measurement point on the aileron. This location had been based on previous tests that showed this surface, along with the outer wing, as the first to cool after fluid application. The FFP profile shows an initial improvement to –13°C and then an upward turn to –12°C by test end. Examination of the previous test shows a similar result. It is believed that the rapid cooling of this particular surface, in combination with an active frost condition, produced this result.

The other locations produced FFP improvements ranging from –5 to –9°C.

Figure 4.56 was another test on a bare wing. The FFP profile is very similar to those tests involving snow removal. Forty-six litres of fluid were applied, compared to 107 for the test reported in Figure 4.55.

In summary, the operator sprayed more fluid in the tests in which snow contamination was removed than in tests on bare wings. The additional fluid compensated for any heat loss in melting snow and produced similar levels of FFP enhancement.

4.2.2 Tests on Composite Surfaces

The search for test aircraft to satisfy trials examining the impact of composite surfaces involved identifying suitable aircraft that included a selection of composite materials in the wing components and then contacting several airlines.

Eligible aircraft included the following:

- Saab 340;
- Airbus A320;
- Airbus A340;
- Fokker 100;
- Boeing 737-400 or later; and
- Boeing 777.

The Bombardier Regional Jet initially proposed for these trials was excluded from the list, because its wing structure is composed entirely of aluminum.

Detailed information on type and locations of composite materials was gathered with the help of airlines and aircraft manufacturers. United Airlines and Saab were particularly co-operative in providing detailed information on wing structures.

Unfortunately, and despite much effort, aircraft for testing were not made available; these trials were not conducted.

4.2.3 Tests on Non-powered Flight Control Surfaces

These tests were not performed due to non-availability of both test aircraft and certified mechanics.

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5. CONCLUSIONS

5.1 Quantity of Fluid Applied

The quantity of fluid applied by the deicing operator was shown to have an impact on the degree of FFP enhancement. But in all tests conducted, the degree of enhancement delivered by the lower quantity was still significant and supported the use of low-buffer fluids for *deicing only* conditions. Because the proposed concept makes use of lower cost, low-concentrate fluid, procedures for *deicing only* conditions should include generous amounts of fluid.

5.2 Fluid Temperatures

5.2.1 Tests Representing Snow Removal

Fluid temperature at the time of application has a significant effect on the enhancement of the fluid freeze point. Wind conditions in conjunction with a low initial fluid temperature can produce unsatisfactory results. Several conclusions can be drawn from this set of tests:

Type II propylene glycol-based fluid:

i. This fluid does not provide any significant amount of FFP enhancement, in either calm or wind conditions.

Type I ethylene and propylene glycol-based fluids:

ii. The temperature of the fluid at time of application has a significant effect on the enhancement of fluid freeze point. Fluid temperatures of 60°C consistently produced greater enhancements in FFP than the colder fluid temperatures tested (50°C and 40°C).

iii. At the milder OAT condition tested (–5°C), wind in combination with lower fluid temperatures can limit the extent of FFP enhancement to an unsatisfactory level when used in conjunction with a fluid having a 0°C freeze point buffer (FFP = OAT):

- In calm wind conditions, a satisfactory level of FFP enhancement was achieved for all fluid temperatures tested; and

- In conditions of wind at 20 kph, an unsatisfactory level of FFP enhancement was achieved for fluids having initial temperatures of 40°C and 50°C.

iv. In cold OAT conditions (–25°C), wind conditions did not prevent a satisfactory level of FFP enhancement from being achieved for all fluid temperatures tested. This enhanced performance at cold temperatures is associated with the greater initial proportion of glycol in the cold temperature fluid mix.

Adequate fluid temperatures can be supported by sound operational practices in which the spray nozzle is positioned as close as possible to the wing surface.

5.2.2 Tests Representing Frost Removal

Only a very slight degree of FFP enhancement can be expected from fluid applications in the small quantities typical of frost-removal sprays. Although freezing did not occur when frost was inactive, and the temperature profiles for test surface and FFP did not intersect, the spread between the two temperature curves was marginal.

5.3 High Winds

At an OAT of –5°C, high winds tested (30 kph) produced a greater extent of FFP enhancement than winds of 20 kph. At an OAT of –25°C, high winds produced results equivalent to winds of 20kph.

5.4 Impact of Current FFP Buffer

At ambient temperatures just below freezing (–5°C), fluids mixed to the current 10ºC buffer showed a greater improvement than those mixed to a freezing point equal to OAT.

At colder ambient temperatures (–25°C), fluids mixed to the current 10ºC buffer showed improvement equivalent to those mixed to a freezing point equal to OAT.

5.5 High Relative Humidity

High humidity, *when frost is inactive*, does not detrimentally affect the enhancement of fluid strength. When the humidity level and OAT are such that frost is active, only temporary protection against frost deposition is provided.

5.6 Removal of Snow

These trials indicate that removing snow from the test surface does result in some reduction of FFP enhancement, compared to tests on bare surfaces. But, the remaining extent of FFP enhancement is significant, even when 0.5 L is applied.

5.6.1 Field Trials on Aircraft

The operator sprayed more fluid in tests in which snow contamination was removed than in those on bare wings in which the operator was simulating the removal of snow. The additional fluid compensated for any heat loss in melting snow and produced similar levels of FFP enhancement.

5.7 Cold-soaked Wings

This series of tests demonstrated that the *deicing only* concept, using a fluid with a FFP equal to OAT, is not valid for an active frost condition. This conclusion applies equally to a cold-soaked wing condition when the relative humidity is such that frost actively forms on the surface.

5.8 Composite and Painted Surfaces

Performance of the various composite surfaces ranged around the performance of the standard aluminum test plate. Kevlar and glass-fibre surfaces performed as well as or better than the standard test plate; the carbon fibre and the aluminium-honeycomb core plates performed at a slightly lower level.

Polyurethane-painted aluminum surfaces (red and blue) performed as well as the standard test plate.

5.9 Type II Propylene Glycol-Based Fluids

Observations on the performance of Type II PG based fluid, throughout the test series, indicate that it provides no significant level of FFP enhancement; it is not recommended for the *deicing only* procedure.

5.10 General Conclusions

In summary it is concluded that:

- The *deicing only* concept does not provide protection during active frost conditions, primarily because of the small quantities of fluid typical of frost sprays.
- Similarly, protection is not provided for a cold-soaked wing condition when the relative humidity is such that frost is actively forming on the cold surface.
- SAE Type II PG fluids are unsuitable for the *deicing only* procedure.
- *Deicing only* procedures should emphasize the importance of applying generous quantities of fluid, and of maintaining the highest possible fluid.
- The influence of other concerns examined in these trials does not invalidate the *deicing only* procedure.

6. RECOMMENDATIONS

It is recommended that:

- The *deicing only* concept not be applied during active frost conditions (trials showed that only temporary protection was provided against frost formation);

- The *deicing only* concept not be applied for cold-soaked wing conditions in conjunction with a level of humidity that could cause active frost deposition on the cold surface;

- Type II propylene glycol-based fluids are unsuitable for the *deicing only* procedure;

- Procedures for the *deicing only* concept should encourage the use of generous quantities of fluid, and the protection of fluid temperatures by locating the spray nozzle as near as possible to the wing surface; and

- The examination of other problems examined in response to industry feedback has not produced findings that would invalidate the *deicing only* concept.

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APPENDIX A

WORK STATEMENT

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 98/99

(December 1998)

1. INTRODUCTION

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

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

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

The development of ULTRA by Union Carbide stimulated all the fluid manufacturers to produce new long lasting anti-icing fluids defined as Type IV. All the Type IV fluids were upgraded in early 1996 and therefore all table conditions need to be re-evaluated and the table revised if necessary. Certain special conditions for which advance planning is particularly difficult such as low temperatures with precipitation, rain or other precipitation on cold soaked surfaces, and precipitation rates as high as 25 $gm/dm^2/hr$ 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 for special deicing conditions were not completed. All these areas are the subjects for the further research that is planned for the 98/99 winter.

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

2. PROGRAM OBJECTIVE (MCR 16)

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

3. PROGRAM SUB-OBJECTIVES

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

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

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

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

4. PROJECT OBJECTIVES

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

5. DETAILED STATEMENT OF WORK

5.1. General

5.1.1. Planning and Control

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

5.1.2. Safety and Security

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

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

5.2.1. Newly Certified Fluids

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

5.2.2. Low Viscosity Type IV Anti-icing Fluids

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

5.2.2.1.Flat Plate Tests for New Type IV Fluids

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

5.2.2.2.Effect on Holdover Time of Viscosity

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

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

5.2.3. Recycled Fluids as Type I Fluids

5.2.3.1.Holdover Times

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

5.2.3.2.Compatibility with Type IV Fluids

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

5.3. Supplementary Data for Deicing Only Table

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

5.3.1. Establish Quantity of Fluid for Field Tests.

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

5.3.2. Establish Temperature of Fluid for Field Tests

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

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

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

5.3.3. Perform tests at current buffer limit as baseline.

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

5.3.4. Simulate High Wind Conditions

Tests shall be performed using NRC fans producing winds up to 30 kph for comparison with the earlier series of tests with speeds up to 20 kph

5.3.5. High Relative Humidity

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

5.3.6. Cold Soaked Wings

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

5.3.7. Effect of Snow Removal on Fluid Heat Input

Perform tests to establish whether removal of snow results in extesive amounts of heat being carried away and insufficient heat being transferred to the wing during deicing.

Expose flat plates to snowfall (either natural or as simulated by approved equipment) and protect snow catches of various thicknesses. Tests shall be run in an area protected from further snowfall. Fluid shall be applied with a hand sprayer, until the plate is cleaned, measuring the amount of fluid applied. The final fluid concentration on the plate shall be measured. The heat lost in fluid run off shall be measured. Parallel tests will be conducted on bare surfaces.

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

5.3.8. Effect of Composite Surfaces on Evaporation

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

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

Conduct field tests on a sample aircraft.

5.3.9. Unpowered Flight Control Surfaces

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

5.3.10.Field Tests on Aircraft

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

5.3.11.Laboratory Tests

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

5.4. Flow of Contaminated Fluids from Wings during Takeoff

5.4.1. Requirement

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

A test plan shall be developed jointly with NRC.

Two days of testing at Mirabel Airport shall be planned.

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

Data collected during these trials shall include:

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

5.4.2. Conduct of Trials and Assembly of Results

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

5.5. Aircraft Full-Scale Tests

5.5.1. Purpose of Tests

Conduct full-scale aircraft tests:

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

5.5.2. Planning and Coordination

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

5.5.3. Testing

All tests and dry runs shall be performed using the methodology developed in the conduct of similar tests for Transport Canada in past years.

Test planning will be based on the following aircraft and facilities:

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

5.5.4. Test Measurements

Make the following measurements during the conduct of each test:

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

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

5.5.5. Pilot Observations

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

5.5.6. Remote Sensor Records

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

5.6. Snowmaking Methods and Laboratory Testing for Holdover Times

5.6.1. Evaluation of Winter Weather Data

5.6.1.1.Snow Rates

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

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

5.6.1.2.Fog Deposition Rates

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

5.6.1.3. Frost Deposition Rates

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

5.6.2. Snowmaking Methods

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

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

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

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

5.7. Documentation of Appearance of Fluid Failure for Pilots

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

5.7.1. Documentation of Failures

Finalise documentation of failure through limited further research as follows:

5.7.1.1.

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

5.7.1.2.

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

5.7.1.3.

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

5.7.1.4.

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

5.7.2. Conduct of trials/assembly of results

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

5.7.3. Pilot Observations

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

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

5.8.1. Requirement

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

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

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

5.8.2. Planning

A Project Plan shall be prepared which will include:

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

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

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

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

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

5.8.3. Coordination

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

5.8.4. Field Trials

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

The trials shall be designed to address issues such as:

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

5.8.5. Test Personnel and Participation

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

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

5.8.6. Study Results

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

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

5.9. Ice Detection Sensor Certification Testing

5.9.1. Minimum Ice Thickness Detectable in Tactile Tests

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

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

TDC shall assist in the experimental design

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

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

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

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

5.9.2. Field Tests for Sensor Distance and View Angle Limits

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

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

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

5.10. Planning a Wing Deicing Test Site

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

The plan shall include the acquisition of a surplus complete wing, from either a scrapped or an accidented moderate sized aircraft or an outboard section of a larger aircraft. The wing section should if possible include ailerons and leading edge slats

The design of the test site shall include a test area that could contain and recover sprayed fluids. Installation of the wing should entail a mounting designed to allow the wing to be rotated relative to current winds. The site must be secure yet allow ease of access and ability to install inexpensive solutions to control sprayed fluid.

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

wing purchase and delivery,
site lease and development, and
wing mount design and fabrication.

5.11. Evaluation of Hot (and Cold) Water Deicing

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

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

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

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

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

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

5.12. Evaluation of Warm Refuelling

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

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

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

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

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

5.13. Engine Air Velocity Distributions near Deicing Vehicles

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

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

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

Photograph and video record the conduct of all tests.

5.14. Provision of Support Services

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

5.14.1.Re-Hydration

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

5.14.2.Frost Tests on a Regional Jet

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

5.14.3.Ice-Phobic Materials Evaluation

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

5.14.4.Evaluation of Infra-Red Thermometers

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

5.14.5.Frost Self-Elimination

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

5.14.6.Environmental Impact Assessment

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

5.14.7.An Approach to Establish Wing Contamination

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

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

5.14.8. Accident/incident Database Analysis

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

5.14.9.Other activities

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

APPENDIX B

EXPERIMENTAL PROGRAM LABORATORY TRIALS FOR THE DEVELOPMENT OF SUPPLEMENTAL DATA TO SUPPORT *DEICING ONLY* TABLE

CM1514.001

EXPERIMENTAL PROGRAM
LABORATORY TRIALS FOR THE DEVELOPMENT OF SUPPLEMENTAL DATA TO SUPPORT A *DEICING ONLY* TABLE

Winter 1998/99

APS AVIATION INC.

April 15, 2005
Version 1.1

EXPERIMENTAL PROGRAM
LABORATORY TRIALS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE
Winter 1998/99

APS will conduct a series of tests on flat plates and cold-soaked boxes at the PMG Test and Research Centre at Blainville, Quebec, and on aircraft at Montreal International Airport (Dorval). This document provides the detailed procedures and equipment required for the conduct of tests at the PMG facility. The experimental program for aircraft testing is contained in a separate document.

1. OBJECTIVES

This project addresses the following objective:

i) To investigate the significance of considerations raised in response to results from research on the subject during the Winter 1997/98 season. Data developed in this course of this investigation will be consolidated with data from previous research to support development of 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.

Considerations to be investigated in this series of tests includes;

- quantity of test fluid
- temperature of test fluid
- tests at current fluid buffer limit
- high wind conditions
- high relative humidity
- cold-soaked wings
- fluid heat expended by removal of snow
- effect of composite aircraft surfaces.

2. TEST REQUIREMENTS

2.1 Preparatory Work to Establish Test Parameters

2.1.1 Fluid Temperature (loss from deicing nozzle to wing)

Tests will be conducted to determine the loss in sprayed fluid temperature between the nozzle and wing, for different distances, spray patterns and outside air temperatures. The procedures for these tests is included in a separate document.

Base case fluid temperature will be established from test results.

2.1.2 High Relative Humidity

Weather histories will be examined to determine typical levels of relative humidity during spray sessions following snow storms and frost formation on wings.

A test value for typical high relative humidity will be established from test results.

2.1.3 Fluid Amounts

Several carriers will be contacted to determine typical fluid amounts sprayed by aircraft size and weather condition, and compared to test fluid quantity (0.5 liters) to assess whether the quantity selected for test is a reasonable representation of actual operations.

2.2 Tests at the PMG Test Centre

Tests at the PMG Test Centre will be scheduled over a two week period. Test variables will include air temperature, wind speeds, relative humidity and a variety of test surfaces. The fluid concentrations to be tested are selected to provide data points at several fluid freeze point buffer values for each ambient temperature tested. SAE Type I fluids (both ethylene and propylene-based) and an SAE Type II fluid (propylene-based) will be tested. Tests are to be conducted in dry non-precipitation conditions with winds at a controlled velocity. Attachment I presents a detailed plan for this series of tests.

The outcome of each test will be a record of test fluid strength as it changes progressively on the test surface during the test run, and a description of any fluid remaining at test end.

Data collected will include progressive tracking of plate surface temperature as measured by installed thermistors.

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.

A series of tests will be conducted to examine the signicance of removal of snow of various depths from the test surface.

3. EQUIPMENT AND FLUIDS

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

Fluids will be applied heated to the test temperature selected, as shown on the test matrix.

Test fluids will include;
- SAE Type I UCAR XL54 (ethylene-based)
- SAE Type I Octaflo (propylene-based) and
- SAE Type II Clariant (propylene-based).

The reference fluid will be the UCAR XL54 Type I fluid.

4. PERSONNEL

Two test teams of two personnel each will conduct tests at the PMG Test Centre. Each team will normally conduct tests on two test surfaces simultaneously, and the two teams will work independently on the same test stand.

A third team of four personnel will be responsible for support to the tests team. Their chief responsibilities will be the provision of accurately prepared test fluids to support ongoing testing in the most efficient manner.

An overall coordinator will be present.

Duties of each team member is shown in Attachment III.

5. TEST PLAN

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

A detailed test plan is provided in Attachment V.

6. DATA FORMS

The following data forms are required:

- Attachment IV Data form for *Deicing Only* Table Trials;

FIGURE I

Test Plan for Development of Deicing Only Table

VARY FLUID QUANTITY AND TEMPERATURE - SNOW

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)^1			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XOH	X	XOH							1		1		1	1		1	(a)	(a)	1	
-15																					
-25					XOH	X	XOH			1		1		1	1		1	(a)	(a)	1	
-35																					

Note: (a) Conduct tests only on 0.5 liter.

VARY FLUID QUANTITY AND TEMPERATURE - FROST

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	50	35	20	70	90
-5	XOH	X	XOH							1						1	1	1	1	1	
-15																					
-25					XOH	X	XOH			1						1	1	1	1	1	
-35																					

FIGURE I

Test Plan for Development of Deicing Only Table

CURRENT BUFFER AS REFERENCE

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XOH	X	XOH							1	1	1		1			1			1	
-15																					
-25					XOH	X	XOH			1	1	1		1			1			1	
-35																					

HIGH WIND

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XH		XH										1	1			1			1	
-15																					
-25					XH		XH						1	1			1			1	
-35																					

FIGURE I

Test Plan for Development of Deicing Only Table

HIGH RELATIVE HUMIDITY

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XOH		X							1		1		1			1			1	1
-15																					
-25					XOH		X			1		1		1			1			1	1
-35																					

COLD SOAKED SURFACE (Using Cold Soak Boxes)

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-10	-15	-18	-25	-30	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	XH	X	XH							1				1	1	1	(a)	(b)			1
-15																					
-25					XH	X	XH			1				1	1	1	(a)	(c)			1
-35																					

Note: (a) Fluid Tempearture = 60°C for quantities 0.5, 0.25 liters

(b) Fluid Tempearture = 50°C for quantities 0.1 liters

(c) Fluid Tempearture = 25°C for quantities 0.1 liters

FIGURE I

Test Plan for Development of Deicing Only Table

REMOVAL OF SNOW BY SPRAYING

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	X		X							1				Spray until clean			1			1	
-15			X		X					1							1			1	
-25																					
-35																					

Note: Parallel tests on snow covered and bare plates

Test snow to three thicknesses

If tests are outdoors, expose plates to wind as existent

EVAPORATION ON COMPOSITE SURFACES

(ASSUME 6 SAMPLE TYPES)

TYPE I ETHYLENE	X
TYPE I PROPYLENE	O
TYPE II PROPYLENE	H

OAT (°C)	Fluid Freeze Point (°C)									Wind Speed (kph)				Fluid QTY (litres)			Fluid Temperature (°C)			RH (%)	
	-5	-8	-15	-18	-25	-28	-35	-38	-45	Calm	10	20	30	0.5	0.25	0.1	60	50	40	70	90
-5	X									1		1		1			1			1	
-15																					
-25					X					1		1		1			1			1	
-35																					

ATTACHMENT I
DEVELOP *DEICING ONLY* TABLE
DETAIL TEST PROCEDURE

Tests at the PMG Test Centre

1. PREPARATION

Prepare test surfaces prior to transporting to the PMG Test Centre:
- Buff any existing plates planned for use, removing all traces of markings;
- Place dots as reference marks at crosshair positions.

Prepare fluid mixes in advance, in well marked containers.

Prepare equipment for transport to the PMG Test Centre.

2. PRE TEST SET-UP

Establish initial temperature and relative humidity in the test chamber.

Set up equipment for test support, including fluid heating equipment.

Confirm operation of fans, and ability to produce required wind velocities.

Set up fluid cooling unit for cold-soak tests.

Install thermistor system and confirm operation of thermistors and temperature loggers.

3. PROCEDURES

3.1 Tests on Plates

Wind rates will be measured at several locations across the test stand before and after each run. Winds will be established through use of large floor fans. The use of two fans is proposed to provide a more uniform flow over the width of the stand.

Standard general test procedures for conducting tests at the PMG Test Centre apply:
- Synchronizing watches and logging equipment apply.

- Cleaning test surfaces prior to application of fluids.

Fluids are to be heated to specified temperatures. 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 for 20 minutes.

As initial fluid freeze points will be at ambient temperature and higher, freezing should not occur.

Plate temperatures will be monitored throughout by means of installed thermistor probes and data loggers.

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

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

Fluid contamination sensor cameras will be not be used as freezing is not expected to occur.

3.2 Tests on Cold-soaked Boxes

Tests on cold soaked boxes are intended to assess the influence of cold soaking on the gain in fluid strength following fluid application, as well as to observe whether the fluid prevents the reformation of frost. The fluid in the boxes will be cooled to 5°C below ambient temperature. Tests will be conducted in the selected high humidity environment to promote the growth of frost. A reference box, with no fluid applied, will be maintained to demonstrate that frost is being deposited on an ongoing basis.

Test surfaces will be scraped clear of frost prior to application of fluid.

3.3 Tests to Evaluate the Impact of Snow Removal

Snow removal tests will be performed both with fluid applied with the fluid spreaders, and with sprayed fluid using garden sprayers. These trials will be conducted on standard flat plates.

3.3.1 Tests with Fluid Applied using fluid spreaders

A layer of snow will be spread over the plate using a hand held flour sifter. The depth of snow applied will be the maximum amount that the standard test fluid amount (0.5 liters) is capable of removing from the surface. Several trials, based on an initial expectation of 0.1 cm deep, may be necessary to determine this depth. The snow temperature will be colder than the plate, to prevent sticking.

The tests will consist of pouring the heated fluid with the fluid spreader, confirming that all snow has been removed, and then measuring fluid Brix values as described previously. The test will be repeated to determine repeatability of results.

3.3.2 Tests with Fluid Applied using a Garden Sprayer

Snow will be applied to the plate as described above. Three different depths of snow will be examined; a base case depth equal to the depth determined in the previous section, and depths at 2X and 3X that depth.

The amount of heated fluid will not be pre-determined, but the fluid spray will be continued until all snow is removed. The fluid concentration will then be measured on a progressive basis as described previously. The amount of fluid applied through spraying will be measured by weighing the garden sprayer before and after.

A parallel test will be run following standard test procedures (Section 3.1) to determine any difference in fluid enrichment.

ATTACHMENT II

NATIONAL RESEARCH COUNCIL COLD CHAMBER TESTS

DEICING ONLY

TEST EQUIPMENT CHECKLIST

TASK	*PMG Cold Chamber*	
	Resp.	**Status**
Logistics for Every Test		
Rent Van/Car		
Call Site Personnel		
Test Equipment		
Special Stand x 1		
Laptop computer		
Desktop computer + monitor		
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 Thermistors		
Refractometer x 4		
Tie wraps		
Tags (Labels) for plate designation on stand		
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 for Boxes		
Fluid collection system for stand		
Wet/dry vacuum		
Non-slip mats for beside stand		
Absorbent matting for floor		
Garden sprayer		
Snow shaker		
Tub for Snow		
Scale (for weighing sprayer)		
Nitrogen bath		
Nitrogen supply		

ATTACHMENT III
PERSONNEL ASSIGNMENT

Overall Coordinator

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

Test Team Leader 1 & 2

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

Fluids Manager & Team

- 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;
- Ensures fluid temperature and Brix is measured and recorded at time of fluid application;
- Ensures spent fluid is continually collected from stand area;
- Ensures cold soak boxes are prepared with fluid to the specified temperature.

Plate Observer 1 & 2

- Responsible to monitor condition of plate surfaces and to alert other team members of change in condition; and
- Complete data form including record of fluid condition at time of application.

Photographer (Duty performed by Test Team Member)

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

ATTACHMENT IV

DEICING ONLY TRIALS
BRIX PROGRESSION

DATE: January , 1999

OAT: ______ °C

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

Run #: ______

Fluid: ______

Surface Type: ______

Thermistor Channel #: ______

Start Time : ______ (hh:mm:ss)

Initial Fluid Amount: ______ **Litres**

Initial Fluid Temperature: ______ **°C**

Initial Fluid Brix: ______

Frost Appearance Time: ______

Snow Depth (for snow removal trials): ______

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

Comments on Final Plate Condition: ______

Run #: ______

Fluid: ______

Surface Type: ______

Thermistor Channel #: ______

Start Time : ______ (hh:mm:ss)

Initial Fluid Amount: ______ **Litres**

Initial Fluid Temperature: ______ **°C**

Initial Fluid Brix: ______

Frost Appearance Time: ______

Snow Depth (for snow removal trials): ______

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

Comments on Final Plate Condition: ______

MEASUREMENTS BY: ______

HAND WRITTEN BY: ______

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			1	FQ	T1E	-5	CALM	-5	0.25	60	70	A	
			2	FQ,FT,RH	T1E	-5	CALM	-5	0.5	60	70	A	
			3	FT	T1E	-5	CALM	-5	0.5	50	70	A	
			4	FT	T1E	-5	CALM	-5	0.5	40	70	A	
			5	FQ	T1E	-5	CALM	-8	0.25	60	70	A	
			6	FQ,FT,B	T1E	-5	CALM	-8	0.5	60	70	A	
			7	FT	T1E	-5	CALM	-8	0.5	50	70	A	
			8	FT	T1E	-5	CALM	-8	0.5	40	70	A	
			9	FQ	T1E	-5	CALM	-15	0.25	60	70	A	
			10	FQ,FT,B,RH	T1E	-5	CALM	-15	0.5	60	70	A	
			11	FT	T1E	-5	CALM	-15	0.5	50	70	A	
			12	FT	T1E	-5	CALM	-15	0.5	40	70	A	
			13	FR	T1E	-5	CALM	-5	0.1	50	70	A	
			14	FR	T1E	-5	CALM	-5	0.1	35	70	A	
			15	FR	T1E	-5	CALM	-5	0.1	20	70	A	
			16	FR	T1E	-5	CALM	-8	0.1	50	70	A	
			17	FR	T1E	-5	CALM	-8	0.1	35	70	A	
			18	FR	T1E	-5	CALM	-8	0.1	20	70	A	
			19	FR	T1E	-5	CALM	-15	0.1	50	70	A	
			20	FR	T1E	-5	CALM	-15	0.1	35	70	A	
			21	FR	T1E	-5	CALM	-15	0.1	20	70	A	
			22	FQ	T1P	-5	CALM	-5	0.25	60	70	A	
			23	FQ,FT,RH	T1P	-5	CALM	-5	0.5	60	70	A	
			24	FT	T1P	-5	CALM	-5	0.5	50	70	A	
			25	FT	T1P	-5	CALM	-5	0.5	40	70	A	
			26	FQ	T1P	-5	CALM	-15	0.25	60	70	A	
			27	FQ,FT,B	T1P	-5	CALM	-15	0.5	60	70	A	
			28	FT	T1P	-5	CALM	-15	0.5	50	70	A	
			29	FT	T1P	-5	CALM	-15	0.5	40	70	A	
			30	FR	T1P	-5	CALM	-5	0.1	50	70	A	
			31	FR	T1P	-5	CALM	-5	0.1	35	70	A	
			32	FR	T1P	-5	CALM	-5	0.1	20	70	A	
			33	FR	T1P	-5	CALM	-15	0.1	50	70	A	
			34	FR	T1P	-5	CALM	-15	0.1	35	70	A	
			35	FR	T1P	-5	CALM	-15	0.1	20	70	A	
			36	FQ	T2P	-5	CALM	-5	0.25	60	70	A	
			37	FQ,FT,RH	T2P	-5	CALM	-5	0.5	60	70	A	
			38	FT	T2P	-5	CALM	-5	0.5	50	70	A	
			39	FT	T2P	-5	CALM	-5	0.5	40	70	A	
			40	FQ	T2P	-5	CALM	-15	0.25	60	70	A	

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			41	FQ,FT,B	T2P	-5	CALM	-15	0.5	60	70	A	
			42	FT	T2P	-5	CALM	-15	0.5	50	70	A	
			43	FT	T2P	-5	CALM	-15	0.5	40	70	A	
			44	FR	T2P	-5	CALM	-5	0.1	50	70	A	
			45	FR	T2P	-5	CALM	-5	0.1	35	70	A	
			46	FR	T2P	-5	CALM	-5	0.1	20	70	A	
			47	FR	T2P	-5	CALM	-15	0.1	50	70	A	
			48	FR	T2P	-5	CALM	-15	0.1	35	70	A	
			49	FR	T2P	-5	CALM	-15	0.1	20	70	A	
			50	C1	T1E	-5	CALM	-5	0.5	60	70	C1	
			51	C2	T1E	-5	CALM	-5	0.5	60	70	C2	
			52	C3	T1E	-5	CALM	-5	0.5	60	70	C3	
			53	C4	T1E	-5	CALM	-5	0.5	60	70	C4	
			54	C5	T1E	-5	CALM	-5	0.5	60	70	C5	
			55	C6	T1E	-5	CALM	-5	0.5	60	70	C6	
			56	C7	T1E	-5	CALM	-5	0.5	60	70	C7	
			57	C1	T1E	-5	20	-5	0.5	60	70	C1	
			58	C2	T1E	-5	20	-5	0.5	60	70	C2	
			59	C3	T1E	-5	20	-5	0.5	60	70	C3	
			60	C4	T1E	-5	20	-5	0.5	60	70	C4	
			61	C5	T1E	-5	20	-5	0.5	60	70	C5	
			62	C6	T1E	-5	20	-5	0.5	60	70	C6	
			63	C7	T1E	-5	20	-5	0.5	60	70	C7	
			64	FT	T1E	-5	20	-5	0.5	50	70	A	
			65	FT	T1E	-5	20	-5	0.5	40	70	A	
			66	FQ	T1E	-5	20	-5	0.25	60	70	A	
			67	FQ,FT,RH	T1E	-5	20	-5	0.5	60	70	A	
			68	FQ	T1E	-5	20	-8	0.25	60	70	A	
			69	FQ,FT,B	T1E	-5	20	-8	0.5	60	70	A	
			70	FT	T1E	-5	20	-8	0.5	50	70	A	
			71	FT	T1E	-5	20	-8	0.5	40	70	A	
			72	FQ	T1E	-5	20	-15	0.25	60	70	A	
			73	FQ,FT,B,RH	T1E	-5	20	-15	0.5	60	70	A	
			74	FT	T1E	-5	20	-15	0.5	50	70	A	
			75	FT	T1E	-5	20	-15	0.5	40	70	A	
			76	FQ	T1P	-5	20	-5	0.25	60	70	A	
			77	FQ,FT,RH	T1P	-5	20	-5	0.5	60	70	A	
			78	FT	T1P	-5	20	-5	0.5	50	70	A	
			79	FT	T1P	-5	20	-5	0.5	40	70	A	
			80	FQ	T1P	-5	20	-15	0.25	60	70	A	

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			81	FQ,FT,B	T1P	-5	20	-15	0.5	60	70	A	
			82	FT	T1P	-5	20	-15	0.5	50	70	A	
			83	FT	T1P	-5	20	-15	0.5	40	70	A	
			84	FQ	T2P	-5	20	-5	0.25	60	70	A	
			85	FQ,FT,RH	T2P	-5	20	-5	0.5	60	70	A	
			86	FT	T2P	-5	20	-5	0.5	50	70	A	
			87	FT	T2P	-5	20	-5	0.5	40	70	A	
			88	FQ	T2P	-5	20	-15	0.25	60	70	A	
			89	FQ.FT,B	T2P	-5	20	-15	0.5	60	70	A	
			90	FT	T2P	-5	20	-15	0.5	50	70	A	
			91	FT	T2P	-5	20	-15	0.5	40	70	A	
			92	HW	T1E	-5	30	-5	0.5	60	70	A	
			93	HW	T1E	-5	30	-15	0.5	60	70	A	
			94	HW	T2P	-5	30	-5	0.5	60	70	A	
			95	HW	T2P	-5	30	-15	0.5	60	70	A	
			96	B	T1E	-5	10	-5	0.5	60	70	A	
			97	B	T1E	-5	10	-8	0.5	60	70	A	
			98	B	T1E	-5	10	-15	0.5	60	70	A	
			99	B	T1P	-5	10	-5	0.5	60	70	A	
			100	B	T1P	-5	10	-15	0.5	60	70	A	
			101	B	T2P	-5	10	-5	0.5	60	70	A	
			102	B	T2P	-5	10	-15	0.5	60	70	A	
			103	RS	T1E	-5	CALM	-5	0.5	60	70	A	X
			104	RS	T1E	-5	CALM	-5	0.5	60	70	A	X
			105	RS	T1E	-5	CALM	-5	AR	60	70	A	X
			106	RS	T1E	-5	CALM	-5	AR	60	70	A	Y
			107	RS	T1E	-5	CALM	-5	AR	60	70	A	Z
			108	RS	T1E	-5	CALM	-5	0.5	60	70	A	bare
			109	RS	T1E	-5	CALM	-15	AR	60	70	A	X
			110	RS	T1E	-5	CALM	-15	AR	60	70	A	Y
			111	RS	T1E	-5	CALM	-15	AR	60	70	A	Z
			112	RS	T1E	-5	CALM	-15	0.5	60	70	A	bare
			113	RH	T1E	-5	20	-15	0.5	60	90	A	
			114	RH	T1E	-5	20	-5	0.5	60	90	A	
			115	RH	T1P	-5	20	-5	0.5	60	90	A	
			116	RH	T2P	-5	20	-5	0.5	60	90	A	
			117	RH	T1E	-5	CALM	-15	0.5	60	90	A	
			118	RH	T1E	-5	CALM	-5	0.5	60	90	A	
			119	RH	T1P	-5	CALM	-5	0.5	60	90	A	
			120	RH	T2P	-5	CALM	-5	0.5	60	90	A	

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			121	CS	T1E	-5	CALM	-5	0.5	60	90	CS	
			122	CS	T1E	-5	CALM	-5	0.25	60	90	CS	
			123	CS	T1E	-5	CALM	-10	0.5	60	90	CS	
			124	CS	T1E	-5	CALM	-10	0.25	60	90	CS	
			125	CS	T1E	-5	CALM	-15	0.5	60	90	CS	
			126	CS	T1E	-5	CALM	-15	0.25	60	90	CS	
			127	CS	T2P	-5	CALM	-5	0.25	60	90	CS	
			128	CS	T2P	-5	CALM	-5	0.5	60	90	CS	
			129	CS	T2P	-5	CALM	-15	0.25	60	90	CS	
			130	CS	T2P	-5	CALM	-15	0.5	60	90	CS	
			131	CS	T1E	-5	CALM	-5	0.1	50	90	CS	
			132	CS	T1E	-5	CALM	-10	0.1	50	90	CS	
			133	CS	T1E	-5	CALM	-15	0.1	50	90	CS	
			134	CS	T2P	-5	CALM	-5	0.1	50	90	CS	
			135	CS	T2P	-5	CALM	-15	0.1	50	90	CS	
			136	FQ	T1E	-25	CALM	-25	0.25	60	70	A	
			137	FQ,FT,RH	T1E	-25	CALM	-25	0.5	60	70	A	
			138	FT	T1E	-25	CALM	-25	0.5	50	70	A	
			139	FT	T1E	-25	CALM	-25	0.5	40	70	A	
			140	FQ	T1E	-25	CALM	-28	0.25	60	70	A	
			141	FQ,FT,B	T1E	-25	CALM	-28	0.5	60	70	A	
			142	FT	T1E	-25	CALM	-28	0.5	50	70	A	
			143	FT	T1E	-25	CALM	-28	0.5	40	70	A	
			144	FQ	T1E	-25	CALM	-35	0.25	60	70	A	
			145	FQ,FT.B,RH	T1E	-25	CALM	-35	0.5	60	70	A	
			146	FT	T1E	-25	CALM	-35	0.5	50	70	A	
			147	FT	T1E	-25	CALM	-35	0.5	40	70	A	
			148	FR	T1E	-25	CALM	-25	0.1	50	70	A	
			149	FR	T1E	-25	CALM	-25	0.1	35	70	A	
			150	FR	T1E	-25	CALM	-25	0.1	20	70	A	
			151	FR	T1E	-25	CALM	-28	0.1	50	70	A	
			152	FR	T1E	-25	CALM	-28	0.1	35	70	A	
			153	FR	T1E	-25	CALM	-28	0.1	20	70	A	
			154	FR	T1E	-25	CALM	-35	0.1	50	70	A	
			155	FR	T1E	-25	CALM	-35	0.1	35	70	A	
			156	FR	T1E	-25	CALM	-35	0.1	20	70	A	
			157	FQ	T1P	-25	CALM	-25	0.25	60	70	A	
			158	FQ,FT,RH	T1P	-25	CALM	-25	0.5	60	70	A	
			159	FT	T1P	-25	CALM	-25	0.5	50	70	A	
			160	FT	T1P	-25	CALM	-25	0.5	40	70	A	

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			161	FQ	T1P	-25	CALM	-35	0.25	60	70	A	
			162	FQ,FT,B	T1P	-25	CALM	-35	0.5	60	70	A	
			163	FT	T1P	-25	CALM	-35	0.5	50	70	A	
			164	FT	T1P	-25	CALM	-35	0.5	40	70	A	
			165	FR	T1P	-25	CALM	-25	0.1	50	70	A	
			166	FR	T1P	-25	CALM	-25	0.1	35	70	A	
			167	FR	T1P	-25	CALM	-25	0.1	20	70	A	
			168	FR	T1P	-25	CALM	-35	0.1	50	70	A	
			169	FR	T1P	-25	CALM	-35	0.1	35	70	A	
			170	FR	T1P	-25	CALM	-35	0.1	20	70	A	
			171	FQ	T2P	-25	CALM	-25	0.25	60	70	A	
			172	FQ,FT,RH	T2P	-25	CALM	-25	0.5	60	70	A	
			173	FT	T2P	-25	CALM	-25	0.5	50	70	A	
			174	FT	T2P	-25	CALM	-25	0.5	40	70	A	
			175	FQ	T2P	-25	CALM	-35	0.25	60	70	A	
			176	FQ,FT,B	T2P	-25	CALM	-35	0.5	60	70	A	
			177	FT	T2P	-25	CALM	-35	0.5	50	70	A	
			178	FT	T2P	-25	CALM	-35	0.5	40	70	A	
			179	FR	T2P	-25	CALM	-25	0.1	50	70	A	
			180	FR	T2P	-25	CALM	-25	0.1	35	70	A	
			181	FR	T2P	-25	CALM	-25	0.1	20	70	A	
			182	FR	T2P	-25	CALM	-35	0.1	50	70	A	
			183	FR	T2P	-25	CALM	-35	0.1	35	70	A	
			184	FR	T2P	-25	CALM	-35	0.1	20	70	A	
			185	C1	T1E	-25	CALM	-25	0.5	60	70	C1	
			186	C2	T1E	-25	CALM	-25	0.5	60	70	C2	
			187	C3	T1E	-25	CALM	-25	0.5	60	70	C3	
			188	C4	T1E	-25	CALM	-25	0.5	60	70	C4	
			189	C5	T1E	-25	CALM	-25	0.5	60	70	C5	
			190	C6	T1E	-25	CALM	-25	0.5	60	70	C6	
			191	C7	T1E	-25	CALM	-25	0.5	60	70	C7	
			192	C1	T1E	-25	20	-25	0.5	60	70	C1	
			193	C2	T1E	-25	20	-25	0.5	60	70	C2	
			194	C3	T1E	-25	20	-25	0.5	60	70	C3	
			195	C4	T1E	-25	20	-25	0.5	60	70	C4	
			196	C5	T1E	-25	20	-25	0.5	60	70	C5	
			197	C6	T1E	-25	20	-25	0.5	60	70	C6	
			198	C7	T1E	-25	20	-25	0.5	60	70	C7	
			199	FQ	T1E	-25	20	-25	0.25	60	70	A	
			200	FQ,FT,RH	T1E	-25	20	-25	0.5	60	70	A	

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			201	FT	T1E	-25	20	-25	0.5	50	70	A	
			202	FT	T1E	-25	20	-25	0.5	40	70	A	
			203	FQ	T1E	-25	20	-28	0.25	60	70	A	
			204	FQ,FT,B	T1E	-25	20	-28	0.5	60	70	A	
			205	FT	T1E	-25	20	-28	0.5	50	70	A	
			206	FT	T1E	-25	20	-28	0.5	40	70	A	
			207	FQ	T1E	-25	20	-35	0.25	60	70	A	
			208	FQ,FT,B,RH	T1E	-25	20	-35	0.5	60	70	A	
			209	FT	T1E	-25	20	-35	0.5	50	70	A	
			210	FT	T1E	-25	20	-35	0.5	40	70	A	
			211	FQ	T1P	-25	20	-25	0.25	60	70	A	
			212	FQ,FT,RH	T1P	-25	20	-25	0.5	60	70	A	
			213	FT	T1P	-25	20	-25	0.5	50	70	A	
			214	FT	T1P	-25	20	-25	0.5	40	70	A	
			215	FQ	T1P	-25	20	-35	0.25	60	70	A	
			216	FQ,FT,B	T1P	-25	20	-35	0.5	60	70	A	
			217	FT	T1P	-25	20	-35	0.5	50	70	A	
			218	FT	T1P	-25	20	-35	0.5	40	70	A	
			219	FQ	T2P	-25	20	-25	0.25	60	70	A	
			220	FQ,FT,RH	T2P	-25	20	-25	0.5	60	70	A	
			221	FT	T2P	-25	20	-25	0.5	50	70	A	
			222	FT	T2P	-25	20	-25	0.5	40	70	A	
			223	FQ	T2P	-25	20	-35	0.25	60	70	A	
			224	FQ,FT,B	T2P	-25	20	-35	0.5	60	70	A	
			225	FT	T2P	-25	20	-35	0.5	50	70	A	
			226	FT	T2P	-25	20	-35	0.5	40	70	A	
			227	HW	T1E	-25	30	-25	0.5	60	70	A	
			228	HW	T1E	-25	30	-35	0.5	60	70	A	
			229	HW	T2P	-25	30	-25	0.5	60	70	A	
			230	HW	T2P	-25	30	-35	0.5	60	70	A	
			231	B	T1E	-25	10	-25	0.5	60	70	A	
			232	B	T1E	-25	10	-28	0.5	60	70	A	
			233	B	T1E	-25	10	-35	0.5	60	70	A	
			234	B	T1P	-25	10	-25	0.5	60	70	A	
			235	B	T1P	-25	10	-35	0.5	60	70	A	
			236	B	T2P	-25	10	-25	0.5	60	70	A	
			237	B	T2P	-25	10	-35	0.5	60	70	A	
			238	RS	T1E	-15	CALM	-15	0.5	60	70	A	X
			239	RS	T1E	-15	CALM	-15	0.5	60	70	A	X
			240	RS	T1E	-15	CALM	-15	AR	60	70	A	X

TEST SCHEDULING AND CONTROL SHEET

FROST SPRAY TEMP AND QTY	FR
VARY FLUID TEMPERATURE	FT
VARY FLUID QUANTITY	FQ
HIGH WIND	HW
HIGH RH	RH
CURRENT BUFFER AS REFERENCE	B
COLD SOAKED SURFACE	CS

Proposed Test Period	Time Fluid Needed	Test Team (1) or (2)	Run #	Test Objective	Fluid Type	OAT (°C)	Wind (kph)	FFP (°C)	Fluid Qty.	Fluid Temp. (°C)	RH (%)	Surface	Snow Thick.
			241	RS	T1E	-15	CALM	-15	AR	60	70	A	Y
			242	RS	T1E	-15	CALM	-15	AR	60	70	A	Z
			243	RS	T1E	-15	CALM	-15	0.5	60	70	A	bare
			244	RS	T1E	-15	CALM	-25	AR	60	70	A	X
			245	RS	T1E	-15	CALM	-25	AR	60	70	A	Y
			246	RS	T1E	-15	CALM	-25	AR	60	70	A	Z
			247	RS	T1E	-15	CALM	-25	0.5	60	70	A	bare
			248	RH	T1E	-25	20	-35	0.5	60	90	A	
			249	RH	T1E	-25	20	-25	0.5	60	90	A	
			250	RH	T1P	-25	20	-25	0.5	60	90	A	
			251	RH	T2P	-25	20	-25	0.5	60	90	A	
			252	RH	T1E	-25	CALM	-35	0.5	60	90	A	
			253	RH	T1E	-25	CALM	-25	0.5	60	90	A	
			254	RH	T1P	-25	CALM	-25	0.5	60	90	A	
			255	RH	T2P	-25	CALM	-25	0.5	60	90	A	
			256	CS	T1E	-25	CALM	-25	0.1	25	90	CS	
			257	CS	T1E	-25	CALM	-30	0.1	25	90	CS	
			258	CS	T1E	-25	CALM	-35	0.1	25	90	CS	
			259	CS	T2P	-25	CALM	-25	0.1	25	90	CS	
			260	CS	T2P	-25	CALM	-35	0.1	25	90	CS	
			261	CS	T1E	-25	CALM	-25	0.5	60	90	CS	
			262	CS	T1E	-25	CALM	-25	0.25	60	90	CS	
			263	CS	T1E	-25	CALM	-30	0.5	60	90	CS	
			264	CS	T1E	-25	CALM	-30	0.25	60	90	CS	
			265	CS	T1E	-25	CALM	-35	0.5	60	90	CS	
			266	CS	T1E	-25	CALM	-35	0.25	60	90	CS	
			267	CS	T2P	-25	CALM	-25	0.5	60	90	CS	
			268	CS	T2P	-25	CALM	-25	0.25	60	90	CS	
			269	CS	T2P	-25	CALM	-35	0.5	60	90	CS	
			270	CS	T2P	-25	CALM	-35	0.25	60	90	CS	

APPENDIX C

EXPERIMENTAL PROGRAM
AIRCRAFT TRIALS FOR THE DEVELOPMENT OF *DEICING ONLY* TABLE

CM1514.001

EXPERIMENTAL PROGRAM
AIRCRAFT TRIALS FOR THE DEVELOPMENT OF DEICING ONLY TABLE

Winter 1998/99

APS AVIATION INC.

December 9, 1998
Version 1.0

EXPERIMENTAL PROGRAM
AIRCRAFT TRIALS FOR THE DEVELOPMENT OF DEICING ONLY TABLE

Winter 1998/99
Version 1.0

APS will conduct a series of laboratory tests on flat plates and cold-soaked boxes, 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

Results from Deicing Only and First Step Fluid Buffer trials conducted during last season (Winter 1997/98) were reviewed by carriers, fluid manufacturers and regulatory authorities. While new and sound information was developed regarding the effectiveness of various values of fluid freeze point buffers and the relative importance of heat transfer versus freeze point depressant, issues were raised as to whether actual operational conditions were fully represented in the test parameters. These included:

- Quantity of test fluid;
- Temperature of test fluid;
- Tests at current fluid buffer limit;
- High wind conditions;
- High relative humidity;
- Cold-soaked wings;
- Fluid heat expended by removal of snow; and
- Effect of composite aircraft surfaces.

Of this list, tests on aircraft address the following:

(1) Loss in fluid temperature during the airborne spray phase of fluid application;

(2) Loss of heat during the actual removal of snow from aircraft surfaces;

(3) Influence of composite materials and painted aluminium surfaces on the enrichment of fluid through evaporation; and

(4) Effect of frozen fluid on freedom of movement of unpowered flight control surfaces.

A separate document provides the procedures for (1) evaluating loss in fluid temperature during the airborne spray phase. This document describes the test procedures for (2), (3) and (4).

2. TEST REQUIREMENTS

2.1 Aircraft Tests at Dorval Airport

Trials will be conducted on aircraft on two occasions with the objective of examining the effect on fluid enrichment from heat loss when removing snow from aircraft wings, the influence on fluid enrichment of aircraft surfaces fabricated from newer composite materials, and the potential affect of frozen fluids on the freedom of movement of unpowered flight control surfaces.

One of these tests will be conducted on a McDonnell Douglas DC-9 aircraft (proposed to be a US Airways aircraft) and the other on a *Aircraft X* aircraft. Aircraft availability and towing will be coordinated with the aircraft operator and their local ground handler. Aircraft spraying will be coordinated with Aéromag 2000 using open bucket deicing vehicle.

Tests in dry conditions and at temperature ranges lower than –5°C are planned. Calm winds are desired.

Fluids will be mixed to freeze points equal to the current ambient air temperature and to a 10°C buffer. Attachment I presents a detailed plan for this series of tests.

Trials on the McDonnell Douglas DC-9 aircraft will examine the impact of removal of snow as well as freedom of movement of unpowered flight control surfaces.

Trials on the *Aircraft X* aircraft will examine the influence on fluid enrichment of surfaces fabricated from composite materials. As time permits, further tests will be conducted to evaluate the influence of applying varying amounts of fluid to understand whether there is additional enrichment when additional heat is transferred to the wing.

A complete photo and video record of conduct of tests and results will be maintained.

3. EQUIPMENT

Test equipment is listed in Attachment II.

4. PERSONNEL

A team of seven APS personnel is required for these trials.

A description of the responsibilities and duties of each member of the test team is provided in Attachment 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 the operator's ground handler. APS will mount thermistor probes on wing surfaces 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.

5.1 Snow Removal Tests on McDonnell Douglas DC-9 Aircraft

The outer third of this wing will be used for testing as previous tests have shown that is the most critical area, demonstrating faster heat loss and earlier freezing.

Thermistor probes will be mounted as indicated in Figure 2, to measure temperature profiles on various panels.

A series of tests will be conducted with Union Carbide ADF Type I fluid mixed to a freeze point equal to outside ambient, and then repeated with fluid mixed to a buffer of 10°C colder than outside air temperature.

An initial base case test on a bare wing will be performed. Fluid will be sprayed according to the operator's standard procedure, simulating removal of a coating of light snow. The fluid amount will be recorded. Temperature profiles will be recorded. Fluid freezing is not expected to occur, however the final wing condition will be noted. Fluid Brix profiles will be measured at indicated locations on the wing surface.

A covering of snow to a depth of one cm will then be distributed over the outer third of the wing surface. The snow will be removed by the spray operator according to standard spray procedure. The fluid amount will be recorded. Temperature profiles and fluid Brix profiles will be measured at indicated locations on the wing surface.

The test will then be repeated with snow applied to a depth of three cm.

A final test in this set will repeat the previous test with snow at a depth of 3 cm, but the spray technique will be modified to include a final overspray of fluid after the snow has been removed.

The fluid in the deicing vehicle will then be adjusted to a freeze point 10ºC colder than outside air temperature and the series of tests repeated.

5.2 Trials on Composite Surfaces on the *Aircraft X*

The entire wing will be used for testing, with special attention given to those surfaces fabricated from composite materials.

Thermistor probes will be mounted as indicated in Figure 2, to measure temperature profiles on various panels, including those fabricated from composite materials as well as aluminium.

A series of tests will be conducted with fluid mixed to a freeze point equal to outside ambient, and then repeated with fluid mixed to a buffer of 10ºC colder than outside air temperature.

An initial base case test will be conducted on a bare wing, with the spray operator located a normal distance from the wing in accordance with the operators standard procedures. Fluid will be sprayed according to the operators standard procedure. A light application of fluid will be applied. (Based on Winter 1997/98 trials, this would be equivalent to about 70 litres on a McDonnell Douglas DC-9 wing). The fluid amount will be recorded. Temperature profiles will be recorded. Fluid freezing is not expected to occur, however the final wing condition will be noted. Fluid Brix profiles will be measured at indicated locations on the wing surface.

The test will then be repeated on a bare wing with double that amount and then repeated again with triple that amount (equivalent to 140 and 210 litres per McDonnell Douglas DC-9 wing).

The fluid mix in the deicing vehicle will then be adjusted to a freeze point 10ºC colder than outside air temperature, and the set of tests will then be repeated.

5.3 Trials to determine impact on freedom of movement of unpowered flight controls

This test will involve spraying the horizontal stabiliser with an unheated deicing fluid mixed to a freeze point 5ºC above outside air temperature.

After an interval of time sufficient to allow freezing to occur, freedom of movement of the unpowered elevator control tabs will be evaluated by a pilot using normal flight controls. Movement of the control tabs will be monitored by an observer at the tail.

The services of an aircraft mechanic will be necessary to ensure that the control surfaces are completely free of ice and are fully serviceable prior to returning the aircraft following final deicing at the end of the test session.

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 IV.

6. DATA FORMS

Data forms are listed below:

Figure 2	General Form (Once per Session);
Figure 3	General Form (Every Test);
Figure 4a	Brix Form McDonnell Douglas DC-9;
Figure 4b	Brix Form *Aircraft X*.

7. PROPOSED NOTICE PROCEDURE

i)	Potential for testing	24 to 48 hours prior
ii)	Day of testing - Monitoring throughout day - advise 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;
- *Aircraft X* operator;
- Aéromag 2000;
- US Airways ground handler;
- US Airways aircraft mechanic;
- Transportation Development Centre;
- The Federal Aviation Administration;
- Aéroports de Montréal;

ATTACHMENT I

TEST PLAN FOR AIRCRAFT TRIALS

DEICING ONLY TABLE

WINTER 1998/99

Aircraft Type	OAT (ºC)(1)	Fluid Freeze Point (ºC)(1)	Wing Surface Condition	Snow Depth (cm)	Fluid Spray Amount
DC-9	-8	-8	Bare	-	Light snow spray
			Snow covered	1	Remove snow
			Snow covered	3	Remove snow
			Snow covered	3	Remove snow + overspray
		-18	Bare	-	Light snow spray
			Snow covered	1	Remove snow
			Snow covered	3	Remove snow
			Snow covered	3	Remove snow + overspray
		-3(2)	Bare horizontal stabiliser	-	Light snow removal
Aircraft X	-8	-8	Bare	-	Spray as a light snow (Amount X) Spray 2 times X Spray 3 times X
		-18	Bare	-	Spray as a light snow (Amount X) Spray 2 times X Spray 3 times X

Note (1) An outside air temperature colder than -5ºC is desired. Fluids will be mixed to a freeze point equal to, and 10ºC colder than, outside air temperature.

Note (2) Fluid will be applied unheated, for this trial.

ATTACHMENT II

FULL-SCALE FLUID FAILURE TESTS

TEST EQUIPMENT CHECKLIST

Logistics for Every Test

- Passes / Escort x 1
- Rent Lights and Truck
- Call Personnel
- Advise Airlines (Personnel, A/C Orientation, Equip)
- Monitor Forecast
- Call potential participants

Test Equipment

- Tape Recorder with Mic.(voice) x 2
- Laptop compute x 2
- Thermistor Probe and Logger kit
- Data Forms
- Video Cameras X 2 + 10 batteries + 2 chargers
- Video Cassettes/Films
- Aircraft Wing Forms
- Compass x 1
- RH gauge
- Clipboards
- Space pens and pencils
- Paper Towels
- Rubber squeegees x 2
- Plate Pans X 4
- Electrical Extension Chords
- Tools
- Stop watches
- Pylons
- Laser Pointers x 3
- Storage bins for small equipment
- Temperature Probe x 2
- VHF radios
- Brixometer x 3
- Glass Thermometer
- Flash lights x 4
- Protective clothing
- Tie wraps
- Whistle x 2
- Rolling Stairs x 6
- Tape measure x 4 (2 small, 2 large)
- Wind gauge (Anemometer)
- Mast lights
- Duct Tape
- Test procedure x 10
- Step ladders (platforms) x 4 (2 x 6', 2 x 4')
- Marker for wing
- Non-slip step-ladder for truck
- Generator
- Tubs to transfer snow
- Snow Sifters to distribute snow overwing
- Solvent for wing

OTHER TEST EQUIPMENT (1)

- UCAR ADF Fluid for wings (Aeromag 2000)
- Spray vehicle for XL54 (Aeromag 2000)
- Test Aircraft (A/L)
- Storage Facilities
- Airline Personnel

(1) To be provided by others

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

Refer to Figure 1 for position of equipment and personnel relative to the aircraft. Also refer to the test procedure (Attachment 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;
- Assist in deployment of lighting;
- Ensure areas of wing are identifiable for precise location;
- Pictures to be well lit; and
- Knowledge of test procedures.

Wing Observer (W1 & W2)

- Responsible for setting up wing for test;
- Map out aircraft with pylons and plan view of aircraft;
- Located on rolling stair during test;
- Record measured Brix values progressively during test; and
- Distribute snow over wing as required by test procedures.

Brix Sampler (B1 & B2)

- Assist in installing thermistor probes on aircraft ; 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.

Test Coordinator (TC)

- Direct installation of thermistor probes and loggers; complete cable linkage to loggers and laptop PC in cube van; check integrity;
- Monitor operation of thermistor system during tests;
- Oversee fluid Brix measurement to ensure standardisation between teams;
- Prepare all data forms in advance;

- Complete general data form at beginning of night;
- Complete general data form for each test;
- Record time of fluid application;
- Take sample of fluid from truck nozzle immediately following each spray operation; record Brix value and fluid temperature;
- Call test end;
- Assist wing observers as required; and
- Assist overall coordinator as required.

Overall Coordinator (T6)

- Team coordinator;
- Responsible for area and people;
- Monitor operation of thermistor system during tests;
- Approve any changes necessary to test procedures;
- Coordinate actions of APS team and as required airline personnel;
- Responsible for weather condition observations and forecast, initiate test and calls to tester team;
- Advise Aéromag 2000 of fluid mixes and estimates of quantities required. Assist in preparing mixes during the test session as required.
- Ensure that there are no objects on the ground which may cause foreign object damage 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;
- Ensure all materials are available (pens, paper, batteries, etc.);
- Ensure all equipment is on; and
- Ensure aircraft is not damaged.

ATTACHMENT IV
TEST PROCEDURE

1. PRETEST SET-UP

Monitor weather forecasts seeking an outside air temperature colder than –5°C, with no precipitation and calm or little wind.

When suitable weather is out looked, discuss with aircraft operator and Aéromag 2000 to decide and prepare for tests. Advise Aéromag 2000 of fluid requirements for tests.

Advise all involved.

APS will rent cube van and mast lights.

Aéromag 2000 will prepare to spray fluids as advised for the test. 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 lights and generator; confirm adequate lighting on aircraft wing surface;

vi) Position stairs at aircraft wings;

vii) 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;

viii) Set up van. Install Laptop PC in truck cabin with engine and heater operating to maintain satisfactory temperature for PC operation;

ix) Prepare fluid sampling equipment;

x) Record general test data including fuel load in aircraft wings and ambient conditions;

xi) Establish communication between team members and coordinator; and

xii) Ensure spray personnel are familiar with procedures.

2. INITIALISATION 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. 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 according to procedures. Record amount of fluid sprayed;

ii) Record temperature profile of test surfaces with thermistor probes and loggers. Monitor logging with PC to ensure ongoing data capture;

iii) Measure Brix values on a progressive basis at the points indicated. Measure the final Brix of fluid at the drip line under the leading edge; and

iv) 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 at about 20 minutes following spray application.

FIGURE 1

POSITION OF EQUIPMENT AND PERSONNEL

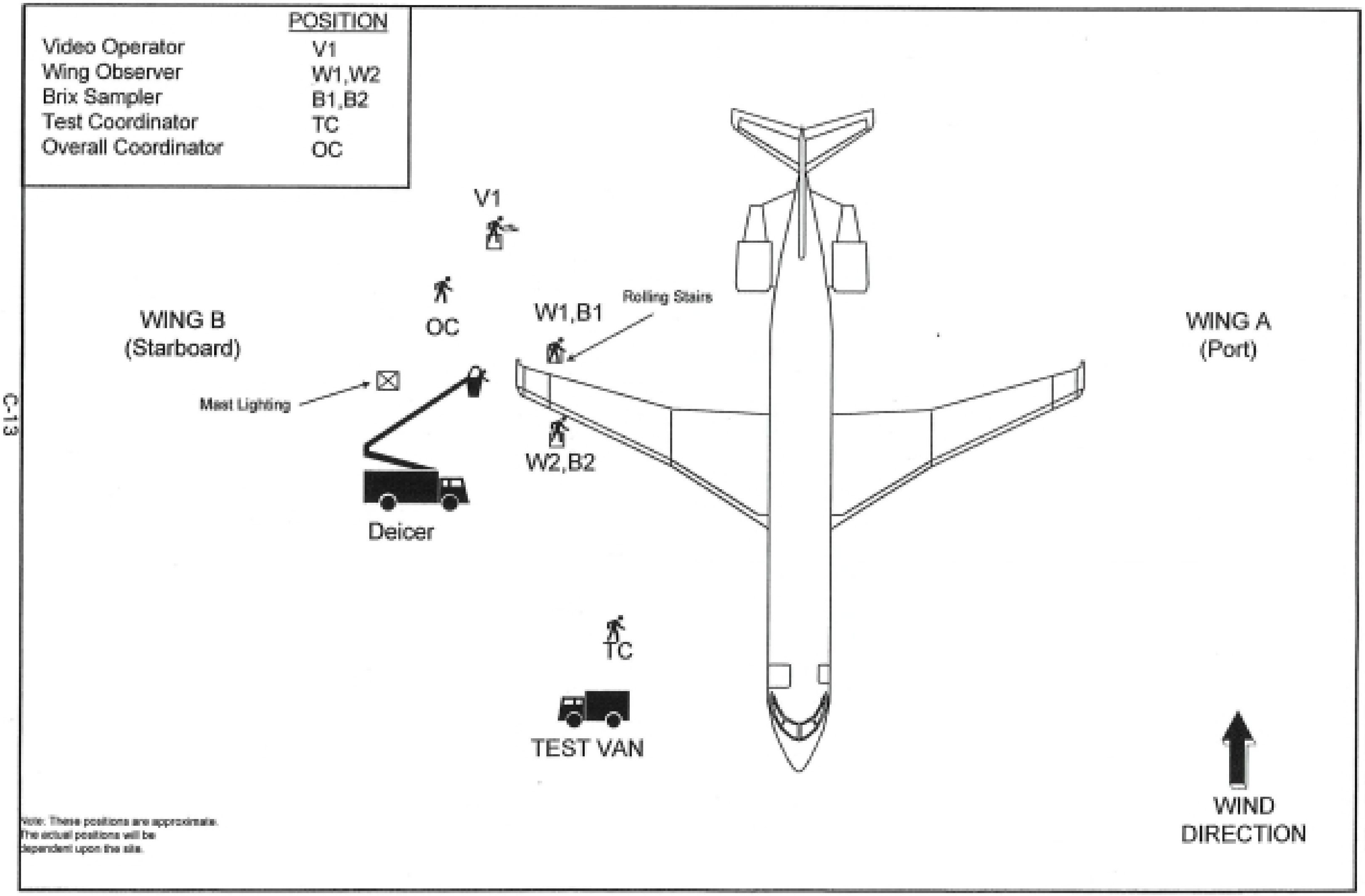


FIGURE 2

GENERAL FORM (ONCE PER SESSION)

(TO BE FILLED IN BY OVERALL COORDINATOR)

AIRPORT: YUL

AIRCRAFT TYPE: DC-9

EXACT PAD LOCATION OF TEST: __________

AIRLINE: __________

DATE: __________

FIN #: __________

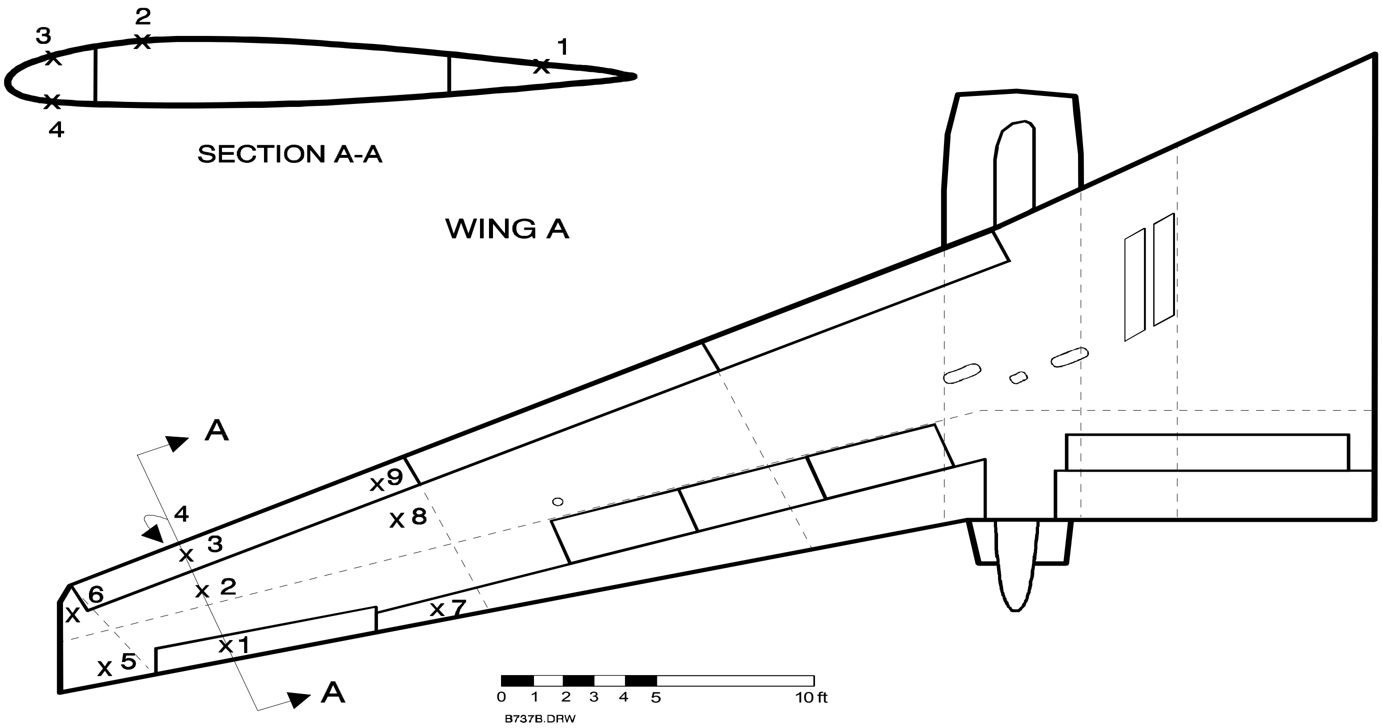
APPROX. AIR TEMPERATURE: _____ °C

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

R/H: _____ %

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

Thermistor Probes Mounting Locations



COMMENTS: __________

MEASUREMENTS BY: __________

HAND WRITTEN BY: __________

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FIGURE 3

GENERAL FORM (EVERY TEST)

(TO BE FILLED IN BY PLATE/WING COORDINATOR)

AIRCRAFT TYPE: DC-9 F100 B-737 RJ

DATE: ______________________

RUN #: ______________

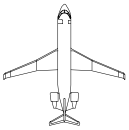
WING: PORT (A) STARBOARD (B)

WIND SPEED: ________ kph

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 4

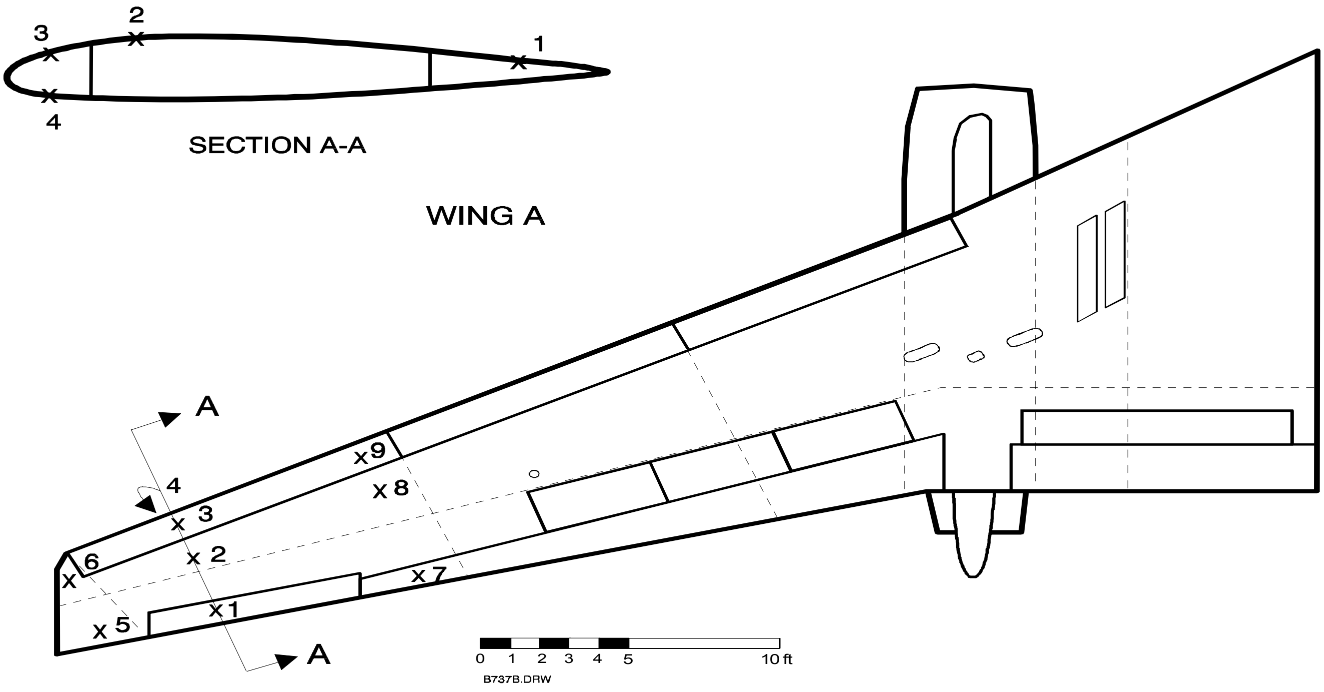
BRIX FORM FOR AIRCRAFT WING

DATE: ____________________ **RUN #:** ____________

Final Drip Line Brix: ____________ **Snow Depth on Wing:** ____________

Location 1		Location 2		Location 3		Location 4		Location 5	
Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix

Thermistor Probes Mounting Locations



Note: - indicate area covered by snow, on wing diagram.

- Record snow depth.

COMMENTS: ____________________

BRIX MEASUREMENTS BY: ____________________

HAND WRITTEN BY: ____________________

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APPENDIX D

EXPERIMENTAL PROGRAM, TEST DATA, AND REPORT

TRIALS TO DETERMINE HEAT LOSS AND CHANGE IN FLUID CONCENTRATION IN FLUID SPRAY

CM1514.001

EXPERIMENTAL PROGRAM

TRIALS TO DETERMINE HEAT LOSS AND CHANGE IN FLUID CONCENTRATION IN FLUID STREAM FROM SPRAY NOZZLE TO WING

Winter 1998/99

APS AVIATION INC.

December 7, 1998
Version 1.0

EXPERIMENTAL PROGRAM
TRIALS TO DETERMINE HEAT LOSS AND CHANGE IN FLUID CONCENTRATION IN FLUID STREAM FROM SPRAY NOZZLE TO WING

Winter 1998/99

This is a preliminary set of tests in preparation for the Deicing Only program.

1 OBJECTIVES

The purpose of these tests is to determine a typical temperature as experienced in normal operations of the deicing fluid at the point when it actually hits the wing surface. As well, any change in fluid strength due to evaporation of water during the airborne spray phase is to be evaluated.

Typical spray patterns as employed for removal of frost, and for snow removal are to be examined, as well as placement of the operator and nozzle at various distances from the test surface.

Findings from these tests will determine test parameters for fluids used in the laboratory trials for deicing only.

2 TEST REQUIREMENTS

Trials will be conducted at the Montreal (Dorval) Airport Central Deicing Facility and at NRC CEF at Ottawa.

The airport trials will be used to confirm that the procedures and equipment are satisfactory, and to document normal spray patterns for frost and snow removal for replication in the laboratory facility.

Outside air temperatures of -5°C or lower, with calm winds, are required for the airport test.

Temperatures of -5°C and -25°C are required for the laboratory tests.

A dead aircraft currently used for deicing training will be used as the test bed for the airport tests.

A wing section will be used in the laboratory.

Deicing vehicles operated by trained, experienced operators will be used to apply the spray in both test sessions.
Type I fluid at standard strength will be used in the test. The fluid will be heated to 60° C.

Attachment I presents a test matrix for these tests.

3 EQUIPMENT

Test equipment is shown in Section 6.

4 PERSONNEL

Personnel requirements and responsibilities are as follows:

Team Leader

- Coordinate test requirements with deicing operator.
- Initiate test session.
- Ensure collection of required data on data form Figure 1.

Thermistor system manager

- Install fluid measurement panel on aircraft wing.
- Install and test thermistor system.
- Monitor temperature levels during spray tests, alerting team leader when temperature has reached a plateau.

Ground Fluid Sampler

- Assist in installation of fluid measurement panel on aircraft wing.
- Take two samples of fluid for Brix measurement for each test condition when temperature has reached plateau.
- Using the probe designed for this purpose, introduce the collection bottle into the fluid stream. When filled, immediately seal fluid sample; measure and record Brix values prior to moving deicing vehicle to next distance setup.
- Advise Team Leader that Brix data are satisfactory.

Fluid Sampler in Bucket

- Measure fluid temperature with thermistor probe at nozzle exit at start and end of each test, by introducing the special probe into the fluid stream. Allow the probe recess to overflow for a period until the thermistor manager indicates a stable temperature has been reached.
- Take Brix samples periodically to confirm ongoing values during test session, using the same probe with test tube inserts.

Video/Photo

- Photograph and video tape each test setup, showing truck and bucket position relative to the wing. Record spray patterns for each test.

5 SUMMARY OF PROCEDURES

Instrumentation developed to measure fluid temperature at the test surface will be installed and tested. A temperature probe designed for the purpose will be placed in the deicing bucket.

The initial operator requirement will be to establish a normal spray pattern, and then to direct that spray pattern, at the required distance, toward the test instrumentation installed to measure fluid temperature. Fluid temperature at the test surface will be monitored from the system monitor, and spraying will continue until a temperature plateau is reached. At that time, the operator will be signaled to stop spraying. Fluid temperature will also be measured at the nozzle during this phase.

Fluid samples will be taken from the spray stream at the nozzle and at the test surface, and immediately sealed. Fluid stream temperature will also be measured at the nozzle by a tester situated in the vehicle deicing bucket

Tests will be repeated for different nozzle to wing distances and for typical spray patterns for frost and snow removal.

TABLE 5.1
TEST MATRIX

OAT ºC	DISTANCE (NOZZLE TO SURFACE) (ft)	SPRAY PATTERN
-5	10	Frost Snow
	20	Frost Snow
	30	Frost Snow
-25	10	Frost Snow
	20	Frost Snow
	30	Frost Snow

6 EQUIPMENT LIST

- Thermistor kit;
- 2 laptop PC with installed logger software;
- Aluminum speed tape;
- Heat gun;
- Ladders to reach wing;
- Wet vacuum for NRC test;
- Measuring tape;
- Wing section for NRC tests;
- Brixometer;
- Data forms;
- Mast light/generator;
- Fuel;
- Video camera;
- Photo camera;
- Security passes;
- RH Meter;
- Wind Anemometer; and
- Extension Cords.

Special equipment designed for this test:

- Temperature measuring trays for surface;
- Temperature probe for bucket;
- Fluid sampling device for ground; and
- Fluid sampling device for bucket.

FIGURE 1

DEICING ONLY TRIALS

TEMPERATURE LOSS IN FLUID SPRAY

Date: ____________________ **Time:** ________________

OAT: ________________ °C **RH:** ________________

Wind Speed: ______________ kph **Wind Direction** ________________

Fluid Type ____________________

Run #	Distance Nozzle to Wing Temp. Probe	Spray Pattern (Snow or Frost)	Stabilized Fluid temp. (°C)		Fluid Brix	
			Wing	Nozzle	Wing	Nozzle

Report on Spray Test Dec07/08 98

The data from this test are included in the attached Excel file.

OAT = -5°C
Wind calm
RH 73%

Procedure

The wing-surface apparatus consisted of thermistor probes installed in plastic cups about 2.5 cm deep. Each cup was inset in a styrofoam block, which, in turn, was installed in an aluminum tray (designed for a previous test to be mounted on wing surfaces). Tray legs were attached to the wing surface by rubber suction cups. Spray rapidly filled the plastic cups and then overflowed continuously. This resulted in rapid replacement of the fluid in the cups, thereby ensuring that any initial fluid heat loss was overcome. The temperature measured was the fluid's true temperature just before it reached the wing surface. The temperature measuring procedure involved directing the desired spray pattern at the device, allowing the cups to fill and continue to run over until the monitored temperature was observed to settle at an upper limit.

A similar approach was used at the nozzle end, but with a hand held device inserted into the fluid stream. This was not the ideal solution from a handling viewpoint and we will rethink this if we do it again. Nevertheless I am confident that the measured temperatures are valid.

Samples for concentration measurement were taken with long handled probes inserted into the fluid stream at the wing and at the nozzle. The probes held test tubes that were immediately stoppered when filled.

The deicing truck was an Elephant Mu, open bucket. We requested the truck fluid to be heated only to 60°C. The temperature indicator in the truck cab was showing close to that value, but the fluid temperature measured at the nozzle exit was about 10 degrees colder. The operator eventually opened the truck in the tank area where a separate temperature gauge was showing about 50°C. We continued tests with fluid at that temperature as it was at least stable. This discrepancy needs to be understood - it means that for any future tests where fluid temperature is a parameter, we should measure the fluid temperature at the nozzle rather that depend on truck gauges.

We used distances as shown on the data report. Our start point of 5.5 feet was established by asking the operator to situate the bucket where he normally would work from. Although our original intent was to test from as far as 30 ft, we found that the longer distances were not valid for the frost spray pattern as it just wouldn't reach the surface. The operator said that they would never even consider spraying from such long distances.

Results for Frost Spray

The drop in temperature for the frost spray pattern was much larger than for snow.

After we had performed the first set (5.5 ft, 10 ft, 15 ft) we realized that the operator was adjusting his nozzle each time the distance changed, to achieve a better reach with a more solidified spray cone. This caused an unexpected result in temperature drop, with a lower drop at the further distance (run 4). This of course is what would happen in an actual operation, but to explore the effect of change to spray pattern, we repeated the tests at 10 ft and 15 ft, fixing the spray nozzle to the 10 ft pattern. This caused the temperature loss to increase with an increase in distance. There was no change in fluid strength in any run.

Results for Snow Spray

The snow spray pattern showed a small drop when moved from 5.5 ft to 15 ft, and a much larger drop when moved to 25 ft. Again, I think that this varied result has to do with operator handling, where he can adjust both the nozzle both for setting and pressure as distance changes in order to get the desired reach and coverage.

Comparison to Vestergaard chart

For comparison purposes I have overlaid the results on a chart that Billi Vestergaard uses in his literature for the Elephant Beta deicer (with the long boom that brings the nozzle to the surface). I averaged our values for the duplicated distances in the frost test. This comparison shows that our frost measurements are very close to his projection. When I discussed his chart with him by e-mail, he reported that his measures were done at a set flow and pressure, compact fluid pattern and delta temperature of 80°C. Our delta Temperature was about 55°C so this is not a pure comparison.

Our results for snow tests show a lesser reduction in temperature than the Vestergaard chart, some of which would be due to the smaller delta T in our tests.

Conclusion

Frost spray patterns have a much greater drop in temperature than snow spray patterns. At the distance where the Aeromag operator says he would normally spray (5.5 ft) the drop was about 12°C. When at 15 ft and with a nozzle setting adjusted by himself, the drop was about 19°C.

Snow spray patterns showed a drop of about 4°C at the distance where the operator would normally work. At a distance of 25 ft (such as when spraying a wide body tailplane from the tip), the loss is about 18°C. Aeromag avoid doing this by approaching the tail from the rear when engines are running, thereby getting the bucket in best position over the tail surface, above the engine exhaust stream.

The purpose of this test was to establish the base case temperature for the lab tests - last year it was 60°C. From the foregoing, it appears that accepting a fluid stream cooling effect of –20°C would satisfy the frost at normal distances, and satisfy snow spray at longer distances, at this OAT. If we deduct this from the lowest nozzle temperature of 60°C then we have 40°C as a base case when OAT is -5°C. A different (lower) base case value would be expected for tests with OAT of –25°C.

Alternatively, rather than changing the base case temperature, we could change the test matrix to have a better combination of "Vary fluid quantity" and "Vary fluid temperature" cells. The proposed range of temperatures in the "Vary fluid temperature" matrix could be changed from (60, 50, 40°C) to (60, 45, 30°C) which would be expected to satisfy fluid temperature drops even at colder temperatures. Currently we had proposed to test only the standard (0.5 liter) amount at varying temperatures. We could change this to include an amount typical of frost sprays (ie 0.1 liter). We would have to adjust somehow to absorb these different tests without increasing the total number of plates.

Regarding testing at -25C, as mentioned earlier, the NRC lab is not available for this, and (I didn't mention) the PMG lab is not suitable for truck spray tests. Rather than waiting and hoping for cold temperatures between now and Jan 11, I am proposing to repeat the test with existing ambient temperature but with a greater delta T between fluid and OAT. A differential of 85 degrees (example fluid at 80 and outside air at -5) should give results similar to fluid at 60 and outside air at -25°C. Let me know if you don't agree, and any other thoughts on this.

Peter Dawson 10 Dec 98

SPRAY TEST DEC 07/08 98

OAT	-5°C
RH	73%
Wind	Calm

Frost Pattern

Run #	Distance (ft)	Distance (m)	Nozzle Temp. (°C)	Wing Temp. (°C)	Differene in Temp. (°C)	Drop/m (°C/m)
2	5.5	1.65	50.2	38.3	-11.9	-7.2
6	10	3	48.8	23.8	-25.0	-8.3
7	10	3	48.8	24.3	-24.5	-8.2
4	15	4.5	48.8	30.1	-18.7	-4.2
8	15	4.5	48.8	23.8	-25.0	-5.6

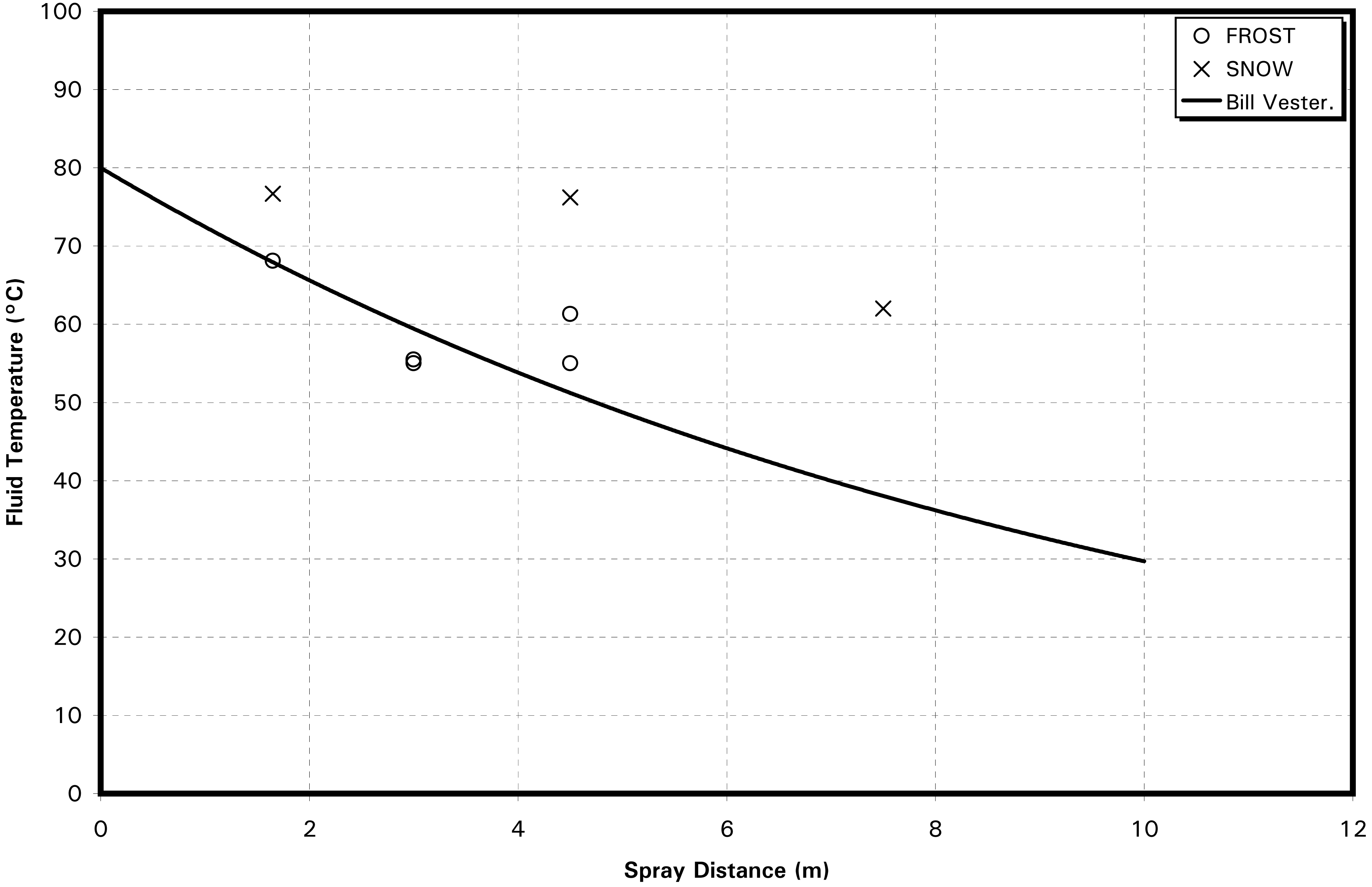
Snow Pattern

Run #	Distance (ft)	Distance (m)	Nozzle Temp. (°C)	Wing Temp. (°C)	Differene in Temp. (°C)	Drop/m (°C/m)
3	15	4.5	47.4	43.6	-3.8	-0.8
5	25	7.5	48.8	30.8	-18.0	-2.4

Note 1 Runs 7 and 8 were performed with the nozzle fixed to the same settings. Normally the operator adjusts the nozzle according to distance to achieve best results

Note 2 No change in fluid strength could be measured for any condition.

Relationship between Spray Distance and Heat Loss



cm1524\analysis\buffer\TMP_LOSS
At: heat loss
Printed: 4/15/2005, 2:58 PM

Report on Spray test Dec16'98

OAT = 0°C
Light wind
RH 48%

This test was planned with a larger delta temperature between fluid and OAT than the initial test on Dec 07, to simulate a condition when OAT is –25°C and Fluid temp is 60°C.

A different device was used to measure fluid temperature in the stream at the nozzle, which worked reasonably well. Other measures were as described in the previous report.

We used the same distances as in the initial tests, however a different spray team was involved. We attempted to hold a fixed nozzle position and spray pattern based on the setting at the normal operating position (the 5.5-ft position), but the operator found that he could not hit the target area with greater distances, and so had to adjust the nozzle setting. The resultant spray pattern was more concentrated, and experienced a lower rate of temperature loss, as was reported previously.

Again we saw a drop in the fluid temperature measured in the stream at the nozzle as compared to the fluid temperature in the tanks, - a 10°C drop. The fluid heater in the truck has a temperature limiter of 80°C and it was set at this limit. We measured the fluid in the tank at 79°C. It appears that the full drop in temperature from tank to wing has two distinct aspects; the drop from tank to nozzle exit and the drop in the fluid stream exposed to OAT. If all trucks operate like this, it would mean that the current SAE lower temperature limit of 60°C at the nozzle could only be met by heating the fluid in the tank to 70 deg C. Also, a tank upper limit of 80 deg C would restrict the nozzle temperature to 70 deg C. This subject probably should be investigated further separately, as it seems that the full potential benefit of applying heated fluid may not be realized in actual operations.

The test results are in the attached excel report.

All the values show a greater drop in fluid temperature from nozzle to wing with the greater delta temperature. The drop with the frost pattern at the 5.5-ft distance was the greatest – dropping from 69 to 27 degrees. When the nozzle was adjusted at a 10-ft distance, the drop changed to 34 degrees.

The temperature loss using the snow pattern at 25 ft was nearly the same for this session as experienced in the previous session, about 17 to 18 degrees.

If we view the two test sessions as representing OAT of -5 and -25°C respectively with an actual fluid temperature at the nozzle of 60°C, the results for fluid temperature at the wing would look as follows

	Distance		OAT -5°C	OAT -25°C
			Fluid Temp at Wing	
	M	ft		
Frost	1.7	5.5	48	18
Frost	3	10	35	25
Frost	4.5	15	40	22
Snow	1.7	5.5	57	41
Snow	4.5	15	56	35
Snow	7.5	25	42	43

Based on this, our test matrix should be somewhat different for frost than for snow.

- When we test with the fluid quantity of 0.1 liter (more typical of frost spray amount), we should use a fluid temp range such as 50, 35, and 20°C.
- When we test the standard quantity of 0.5 liter and 0.25 liter, we should use a fluid temp range of 60, 50 and 40°C.

This would mean a redo of our first two test matrices for fluid quantities and fluid temperatures. I would propose to leave all the rest at the previous test parameters of 0.5 liter and 60°C.

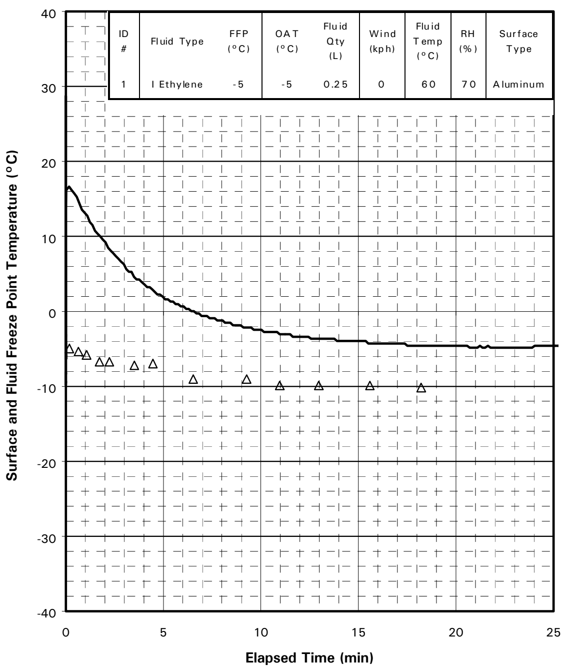
I will discuss with Paul prior to making any changes.

Peter Dawson Dec 17’98

APPENDIX E

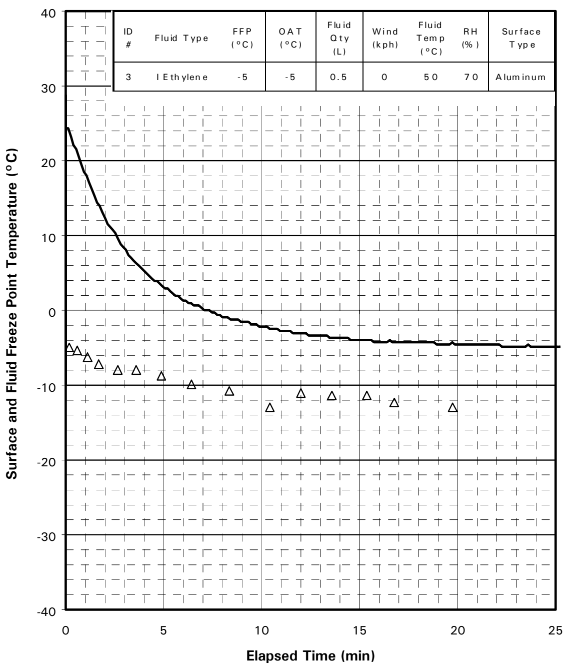
FLUID FREEZE POINT AND SURFACE TEMPERATURE PROFILE

Fluid Freeze Point and Surface Temperature Profile
ID# 01



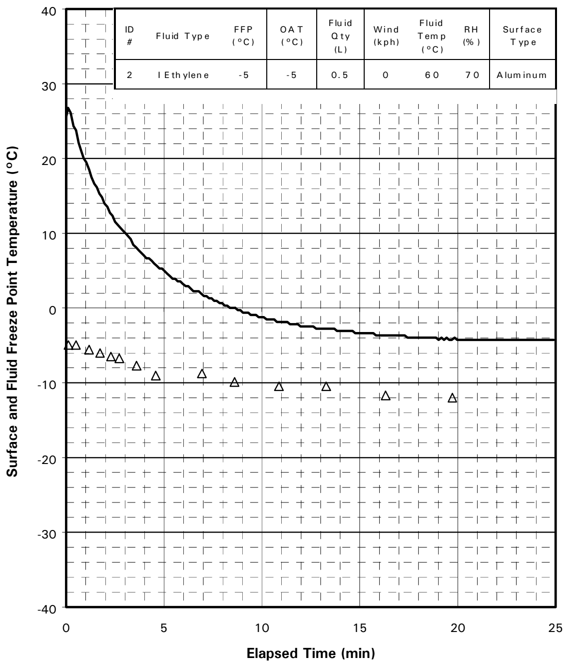
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
1	I Ethylene	-5	-5	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 03



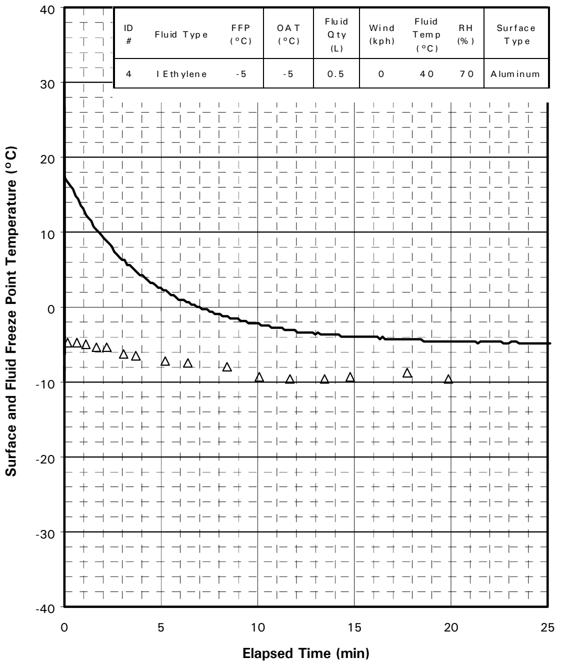
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
3	I Ethylene	-5	-5	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 02

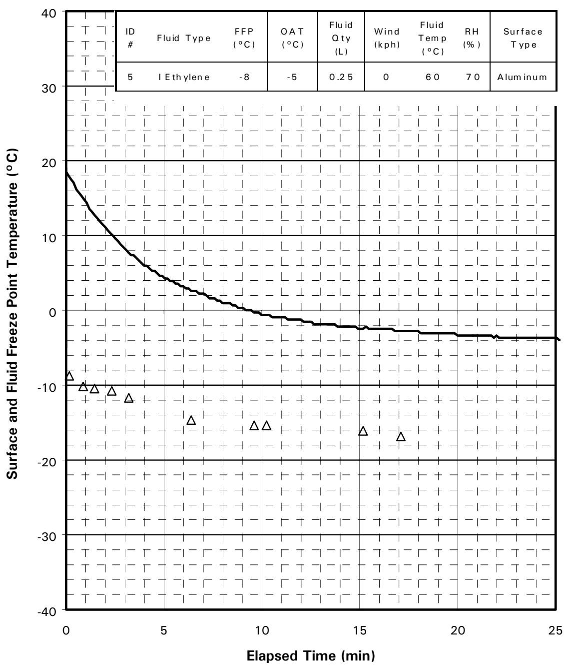


ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
2	I Ethylene	-5	-5	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 04

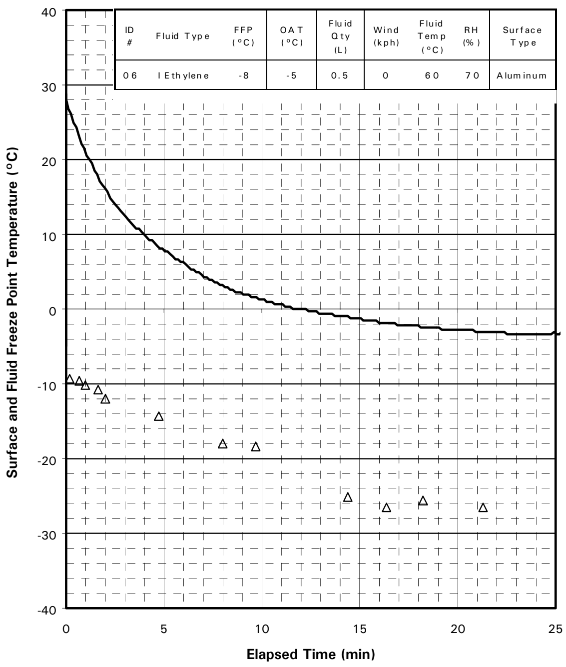


ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
4	I Ethylene	-5	-5	0.5	0	40	70	Aluminum



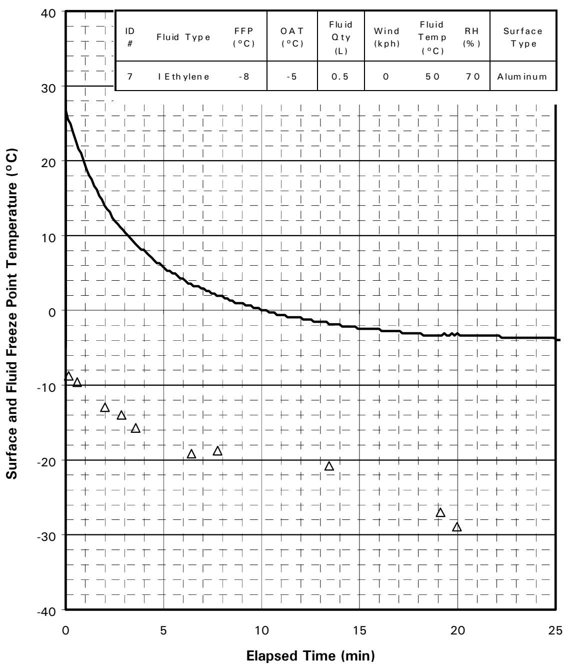
Fluid Freeze Point and Surface Temperature Profile
ID# 05

ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
5	I Ethylene	-8	-5	0.25	0	60	70	Aluminum



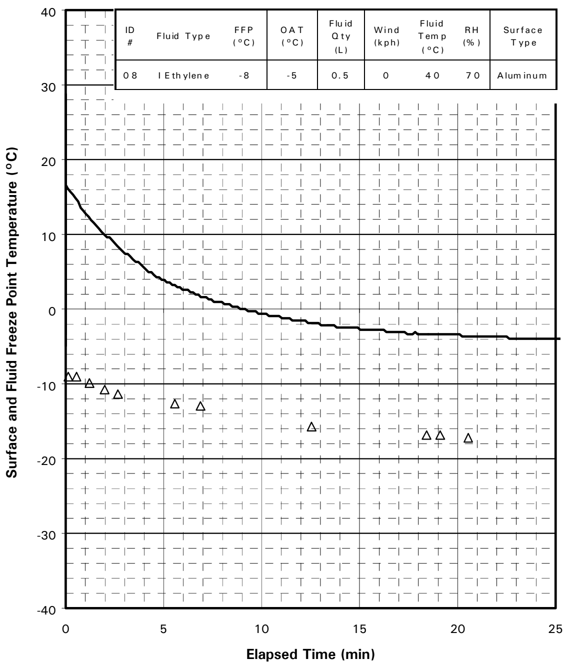
Fluid Freeze Point and Surface Temperature Profile
ID# 06

ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
06	I Ethylene	-8	-5	0.5	0	60	70	Aluminum



Fluid Freeze Point and Surface Temperature Profile
ID# 07

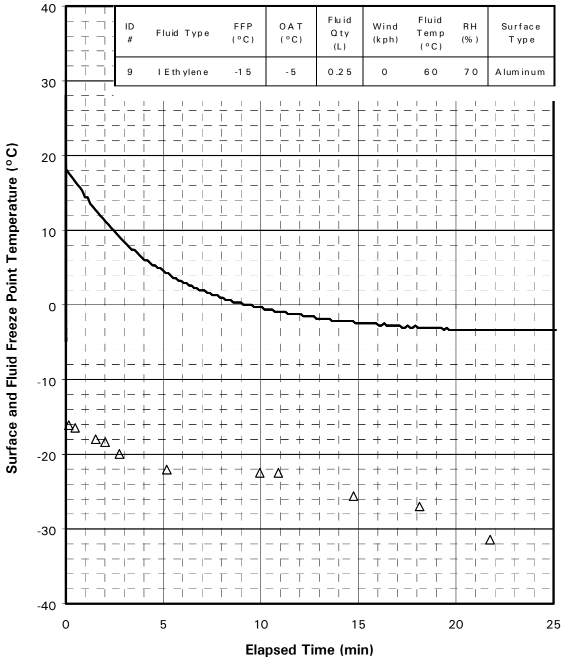
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
7	I Ethylene	-8	-5	0.5	0	50	70	Aluminum



Fluid Freeze Point and Surface Temperature Profile
ID# 08

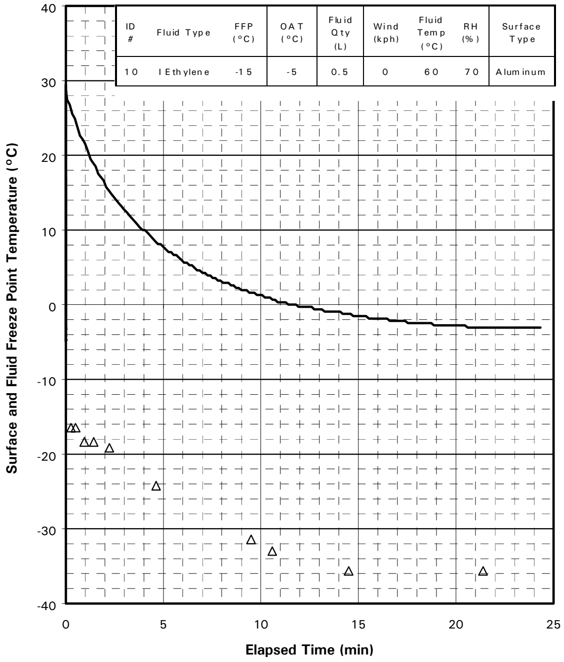
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
08	I Ethylene	-8	-5	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 09



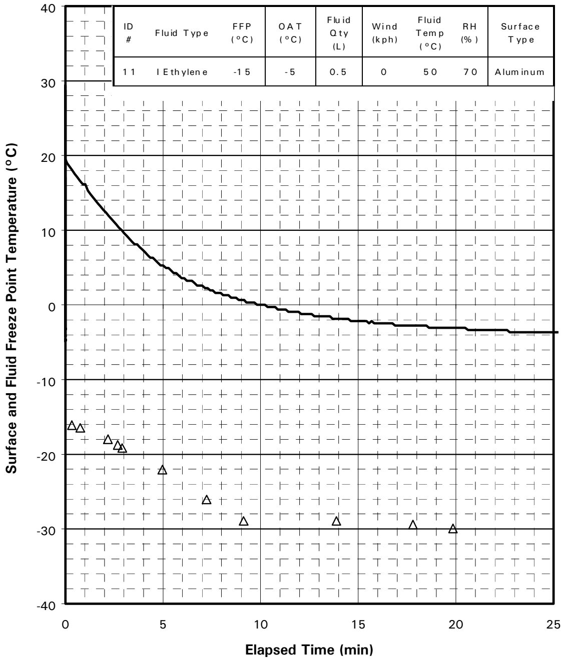
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
9	I Ethylene	-15	-5	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 10



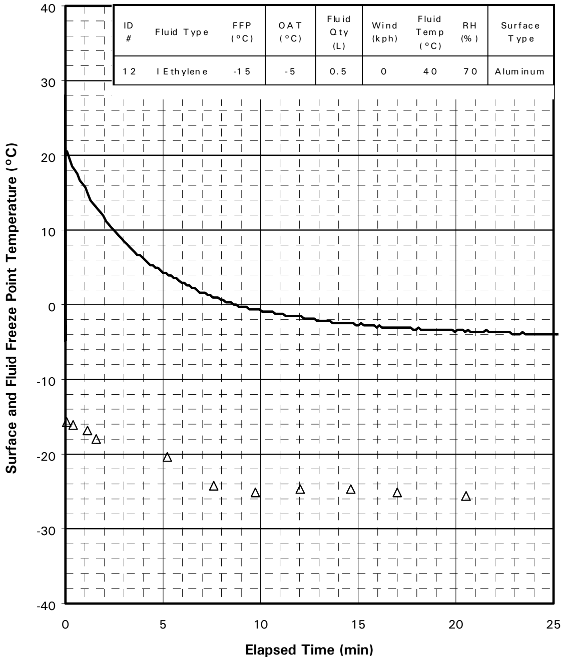
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
10	I Ethylene	-15	-5	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 11



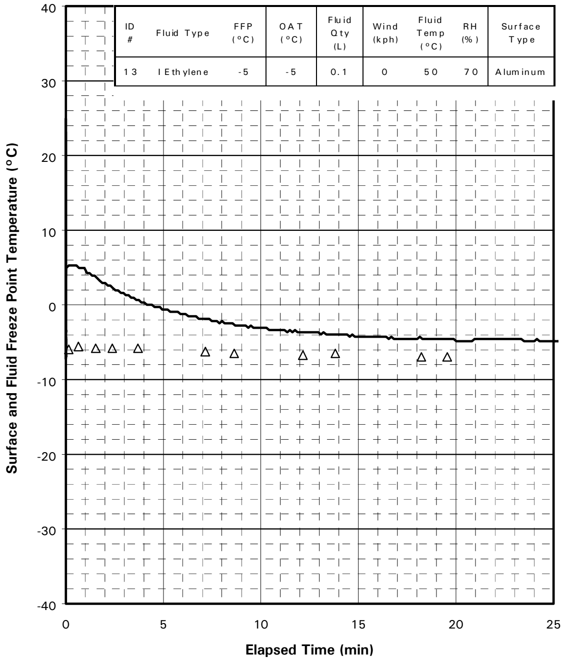
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
11	I Ethylene	-15	-5	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 12



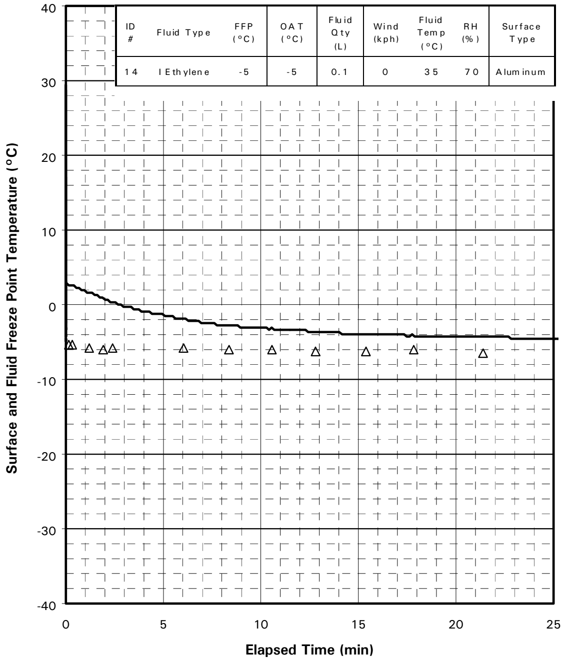
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
12	I Ethylene	-15	-5	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 13



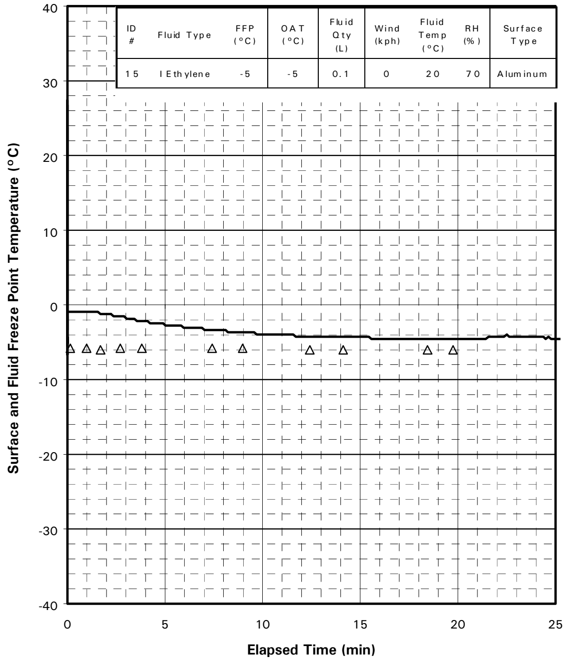
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
13	I Ethylene	-5	-5	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 14



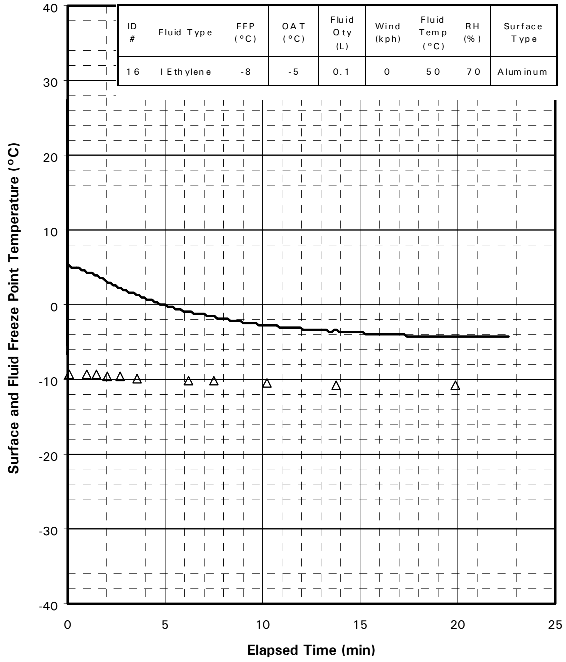
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
14	I Ethylene	-5	-5	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 15



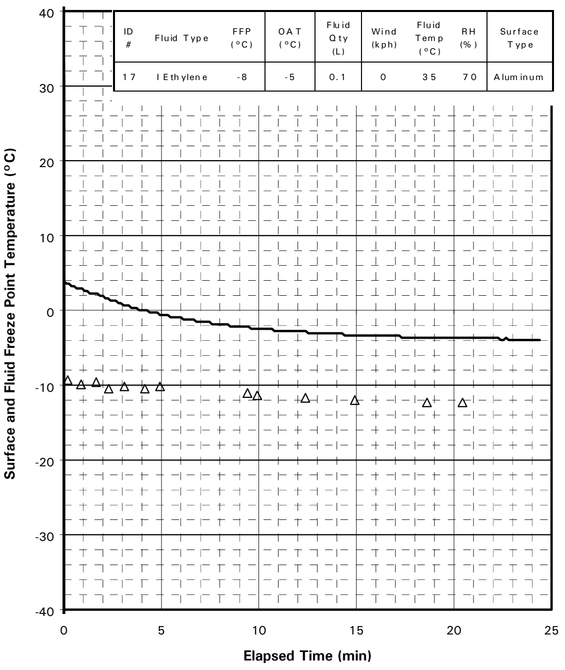
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
15	I Ethylene	-5	-5	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 16



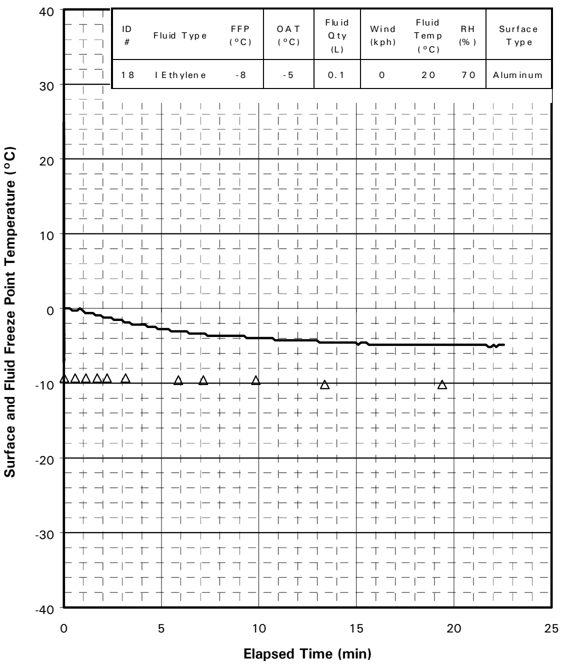
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
16	I Ethylene	-8	-5	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 17



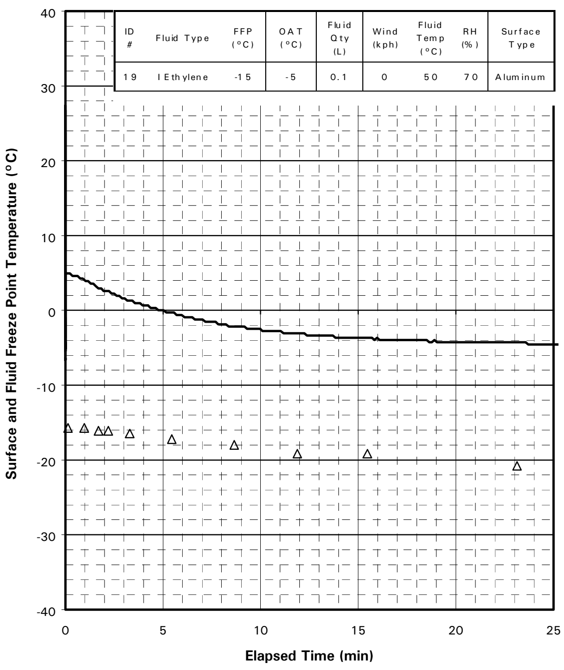
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
17	I Ethylene	-8	-5	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 18



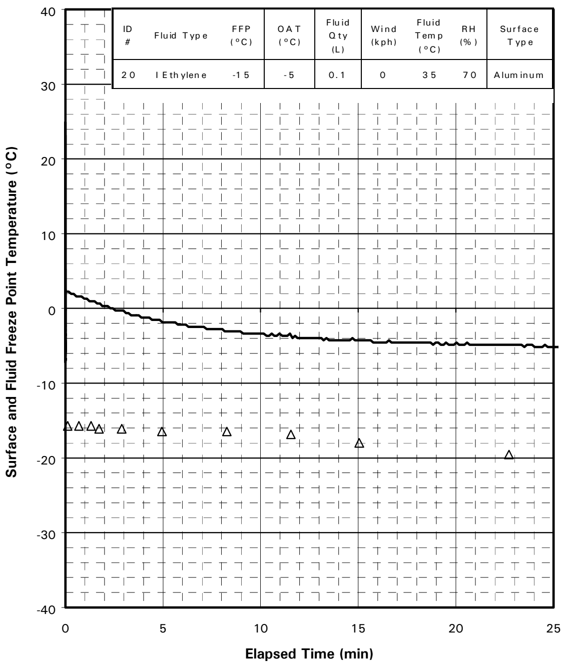
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
18	I Ethylene	-8	-5	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 19



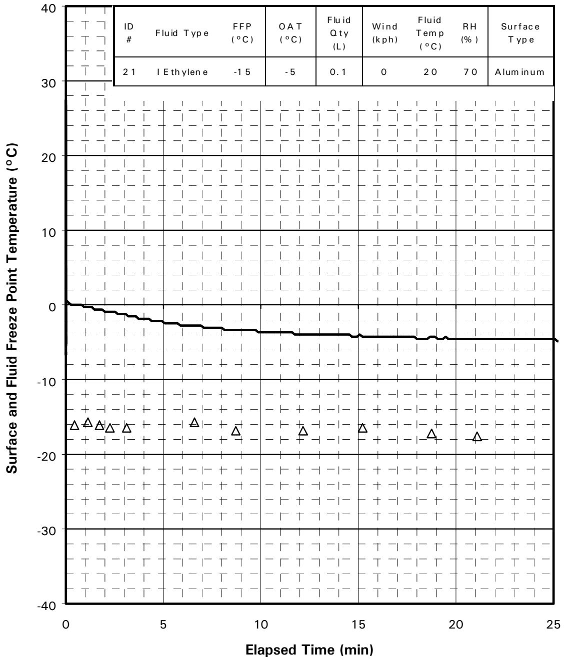
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
19	I Ethylene	-15	-5	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 20



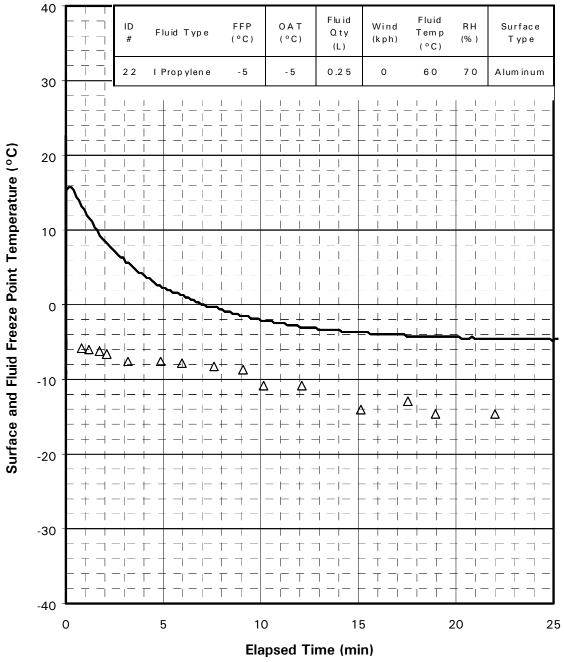
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
20	I Ethylene	-15	-5	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 21



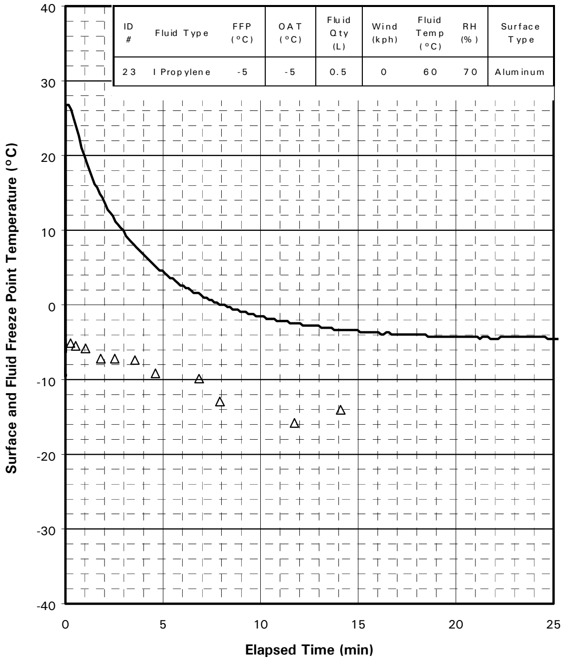
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
21	I Ethylene	-15	-5	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 22



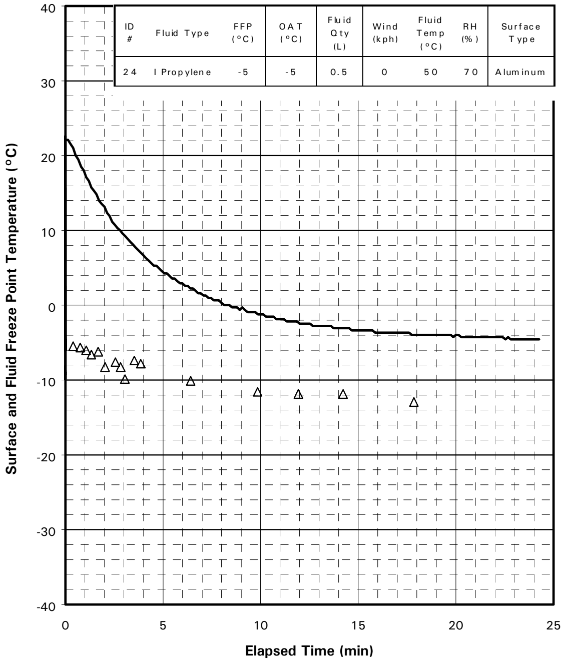
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
22	I Propylene	-5	-5	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 23



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
23	I Propylene	-5	-5	0.5	0	60	70	Aluminum

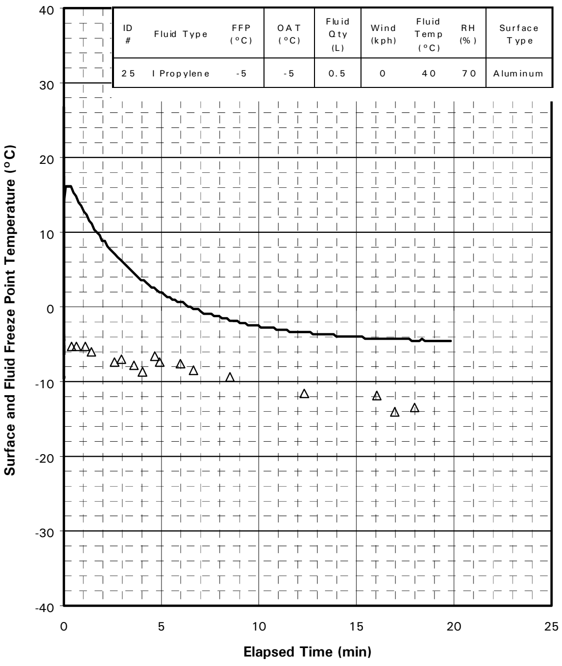
Fluid Freeze Point and Surface Temperature Profile
ID# 24



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
24	I Propylene	-5	-5	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

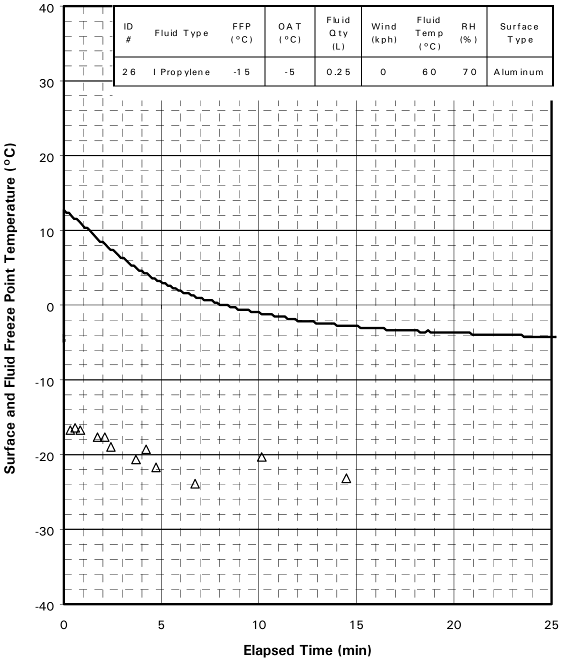
ID# 25



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
25	I Propylene	-5	-5	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

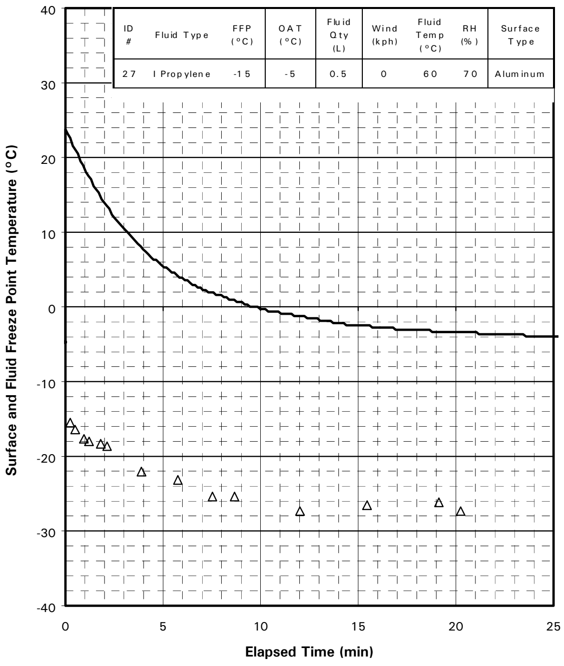
ID# 26



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
26	I Propylene	-15	-5	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

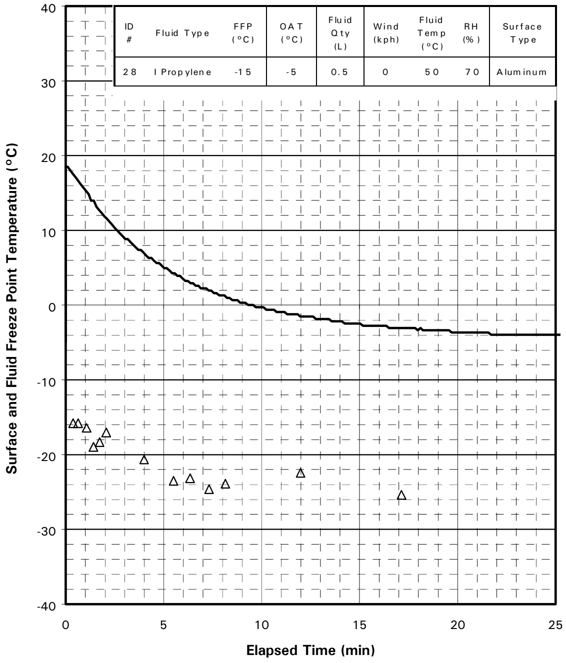
ID# 27



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
27	I Propylene	-15	-5	0.5	0	60	70	Aluminum

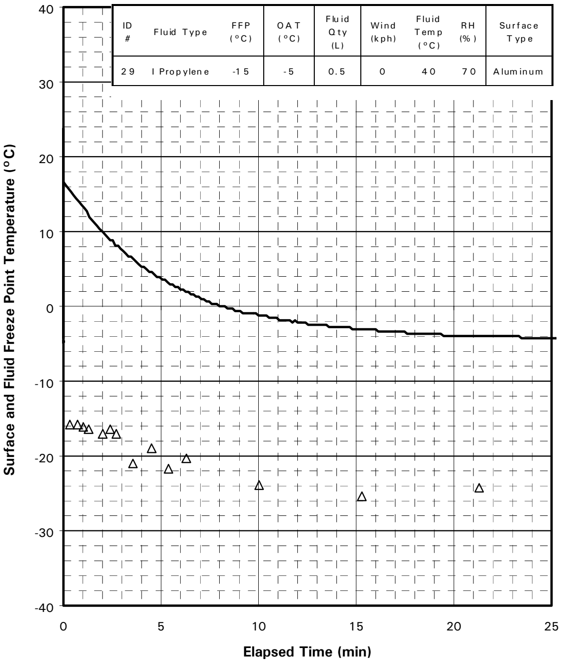
Fluid Freeze Point and Surface Temperature Profile

ID# 28



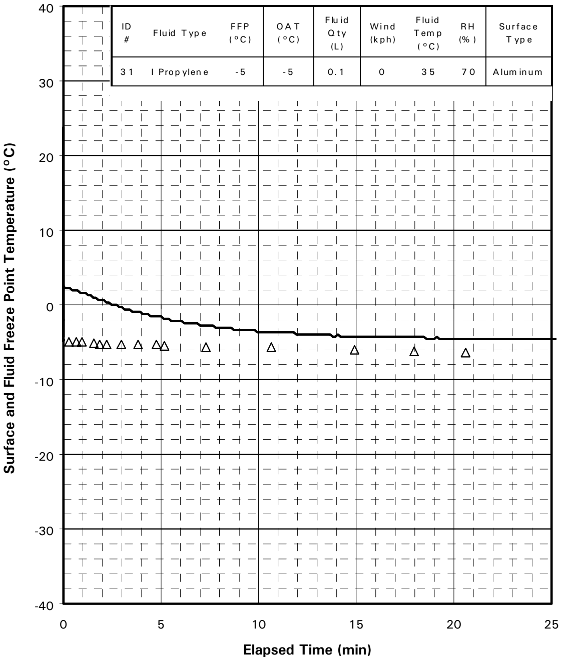
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
28	I Propylene	-15	-5	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 29



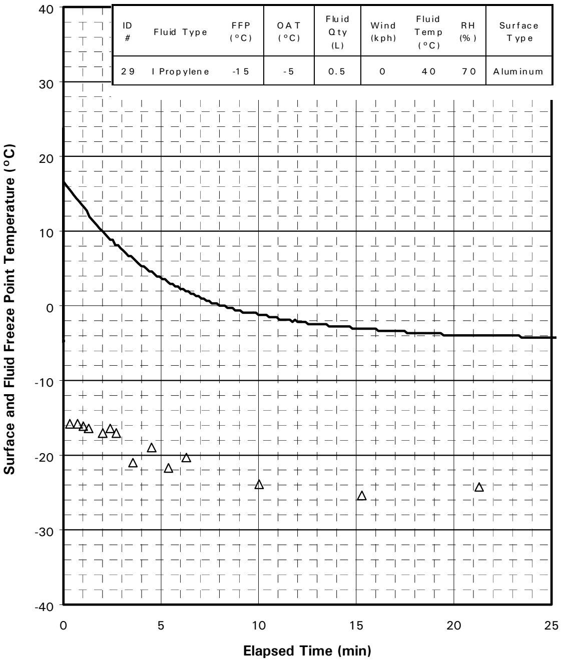
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
29	I Propylene	-15	-5	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 31



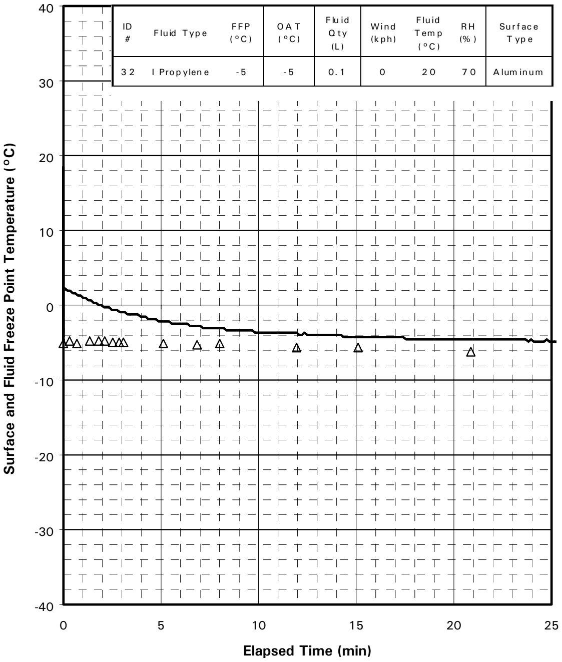
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
31	I Propylene	-5	-5	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 29



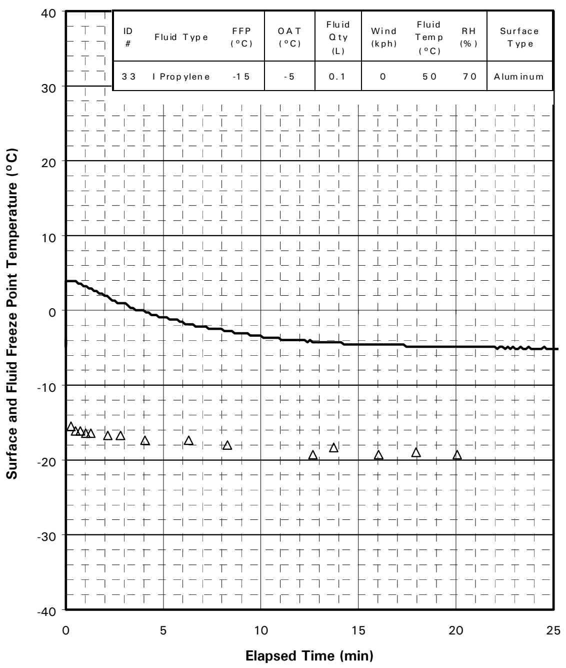
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
29	I Propylene	-15	-5	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 32



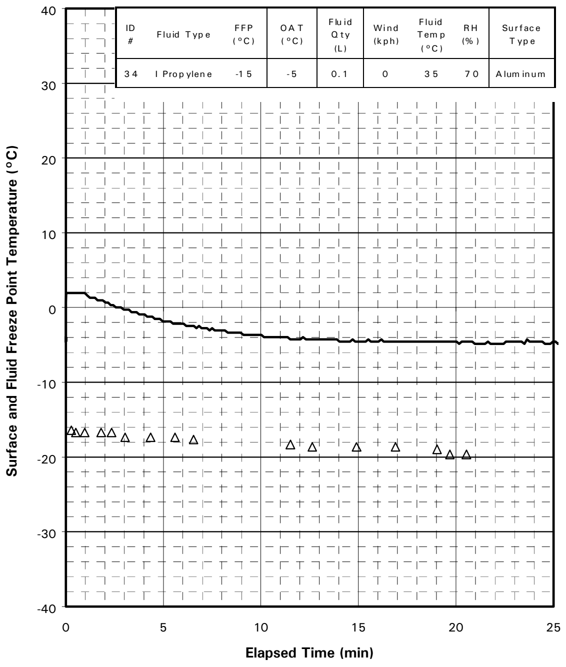
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
32	I Propylene	-5	-5	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 33



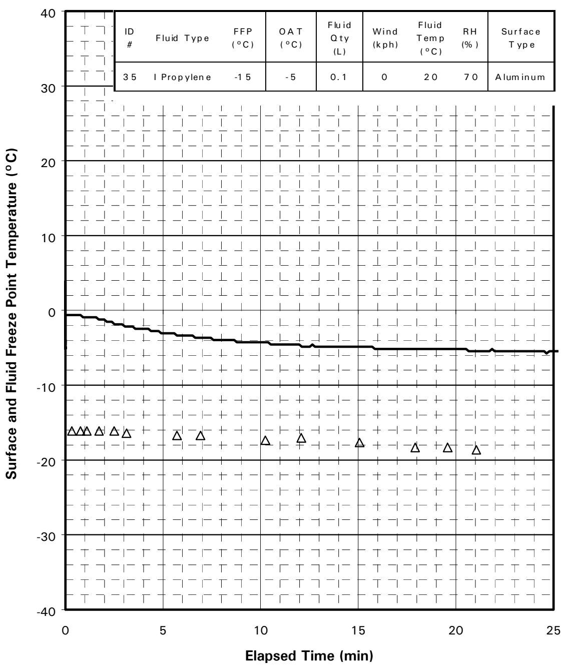
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
33	I Propylene	-15	-5	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 34



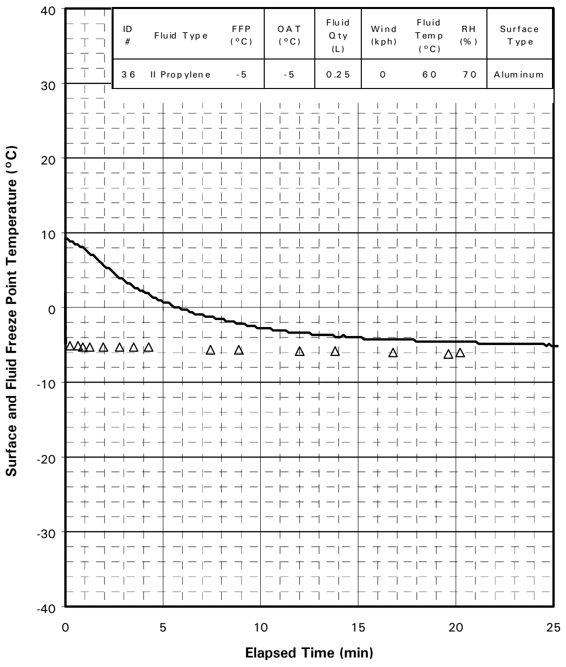
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
34	I Propylene	-15	-5	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 35



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
35	I Propylene	-15	-5	0.1	0	20	70	Aluminum

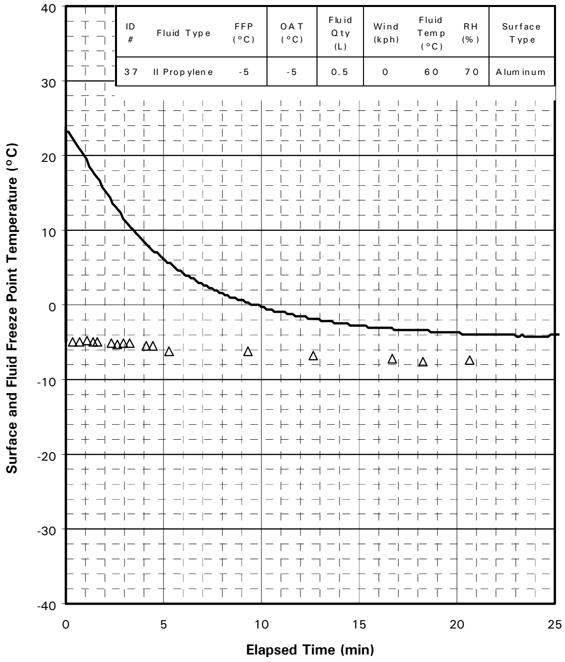
Fluid Freeze Point and Surface Temperature Profile
ID# 36



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
36	II Propylene	-5	-5	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

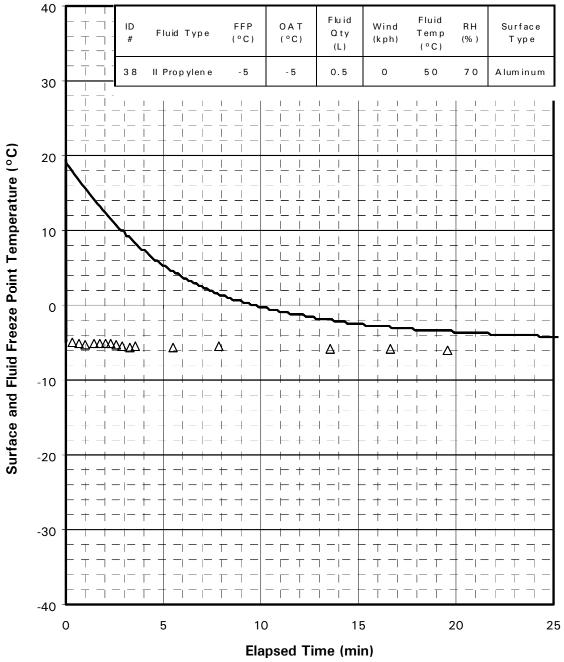
ID# 37



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
37	II Propylene	-5	-5	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

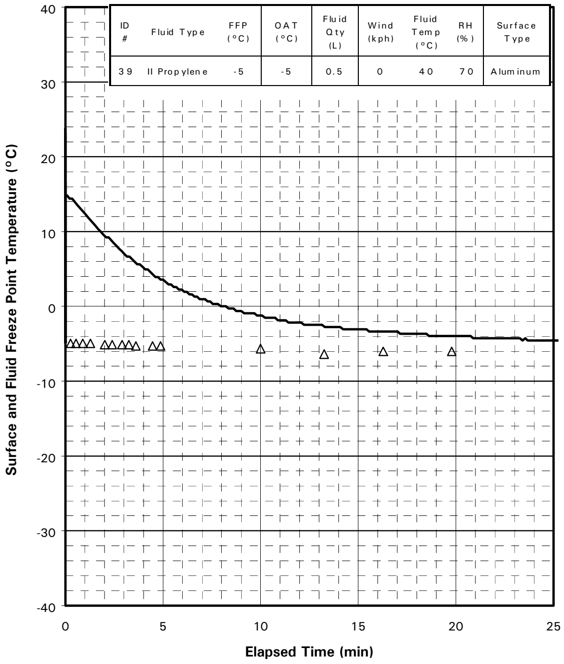
ID# 38



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
38	II Propylene	-5	-5	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

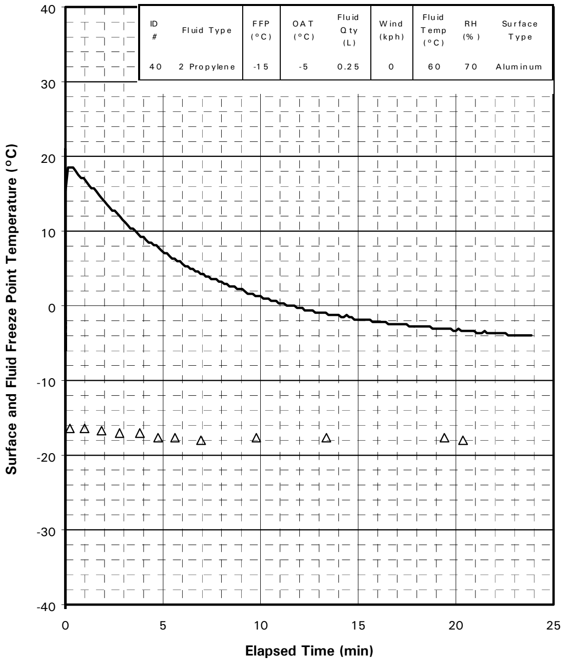
ID# 39



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
39	II Propylene	-5	-5	0.5	0	40	70	Aluminum

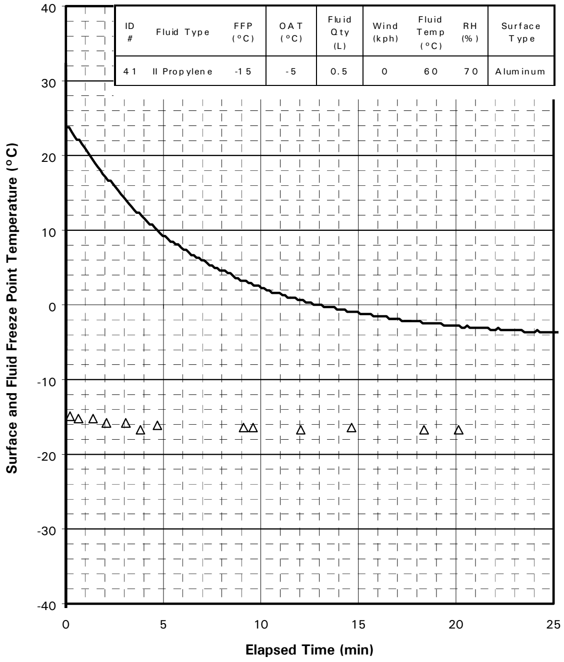
Fluid Freeze Point and Surface Temperature Profile

ID# 40



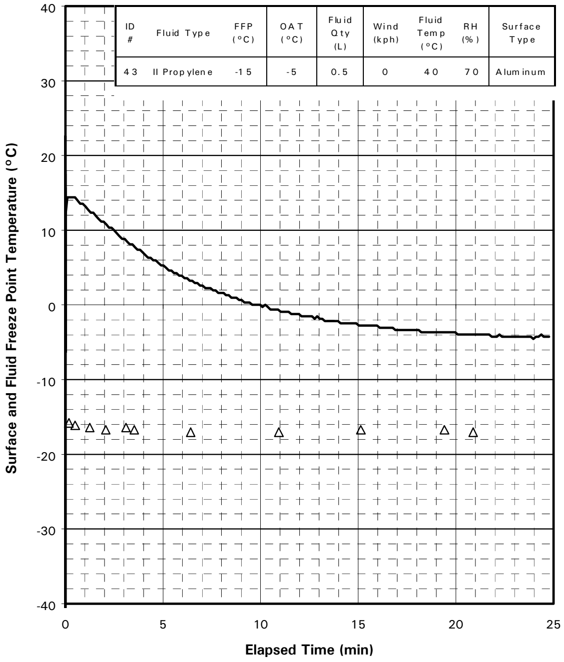
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
40	2 Propylene	-15	-5	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 41



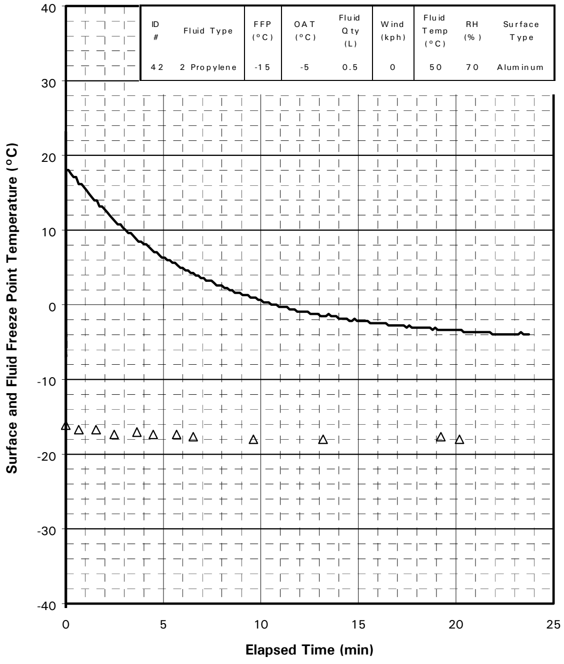
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
41	II Propylene	-15	-5	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 43 (Repeat)



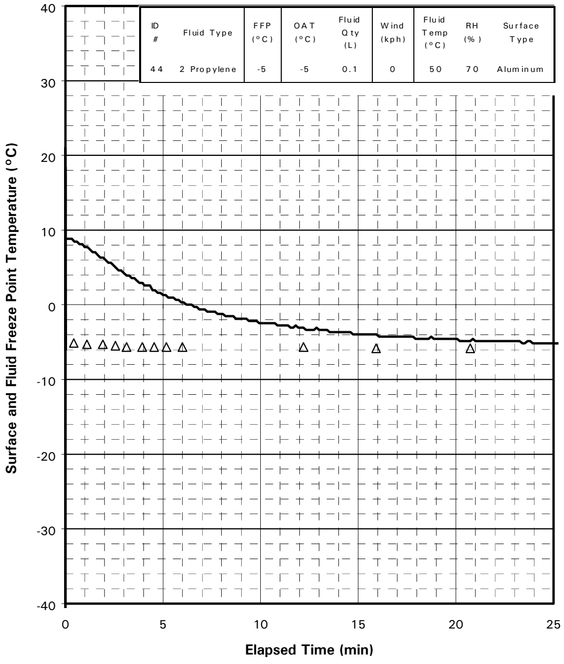
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
43	II Propylene	-15	-5	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 42



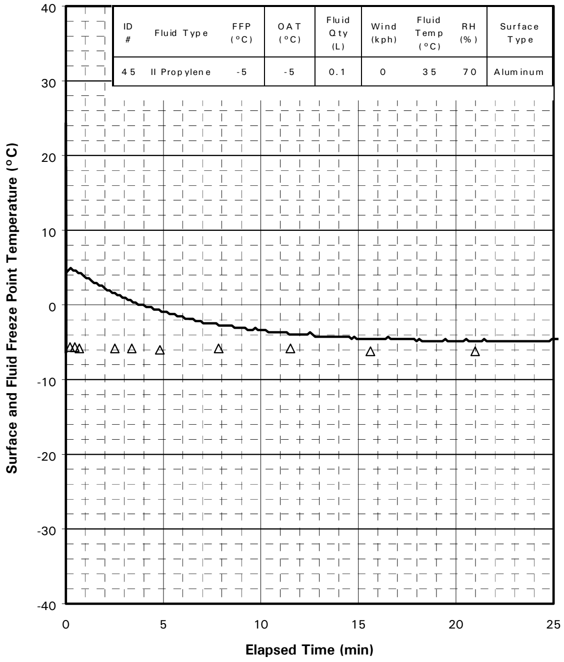
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
42	2 Propylene	-15	-5	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 44



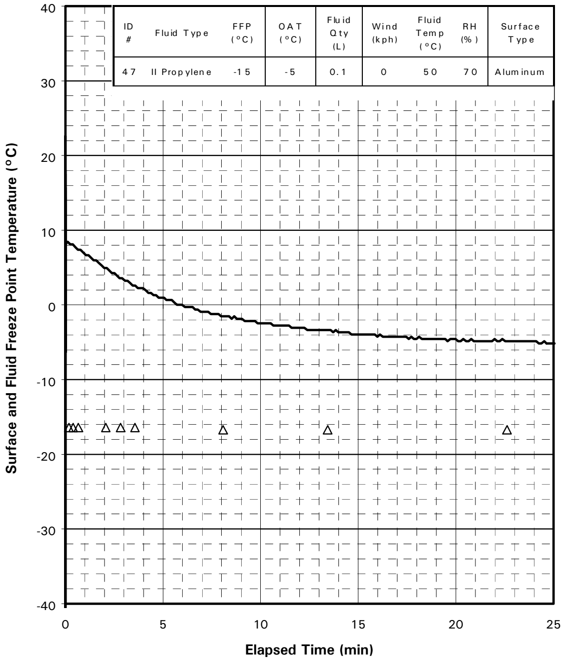
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
44	2 Propylene	-5	-5	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 45 (Repeat)



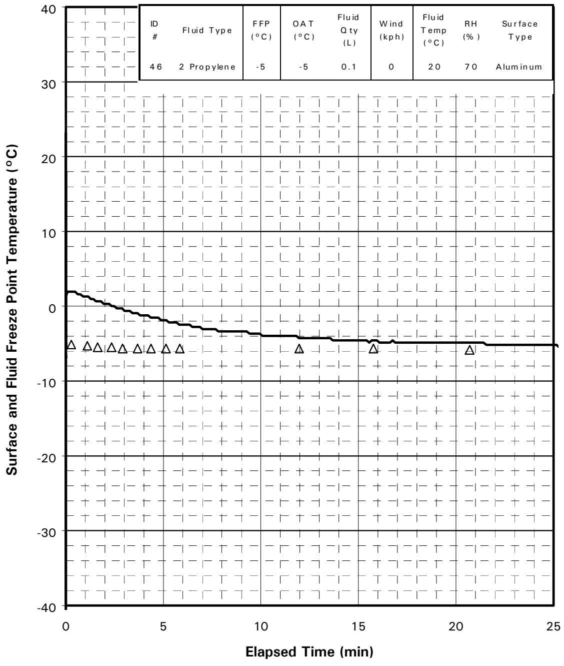
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
45	II Propylene	-5	-5	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 47



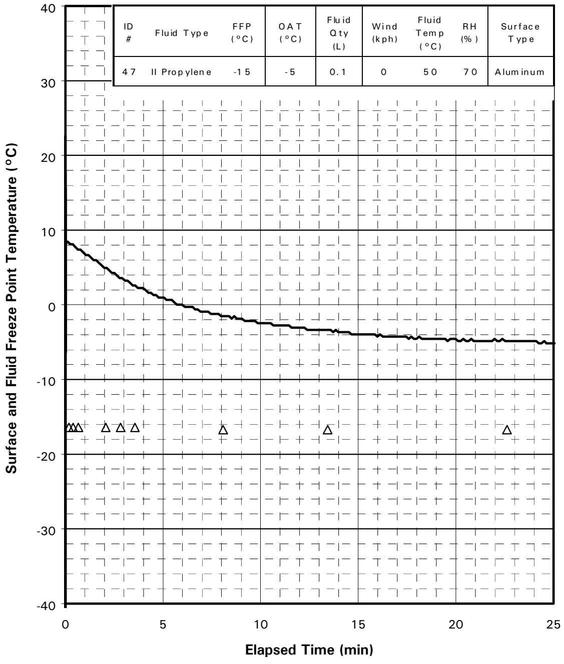
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
47	II Propylene	-15	-5	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 46



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
46	2 Propylene	-5	-5	0.1	0	20	70	Aluminum

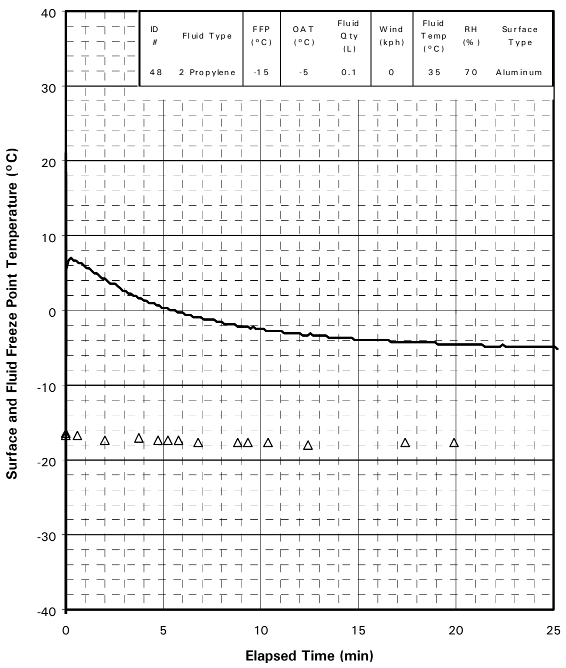
Fluid Freeze Point and Surface Temperature Profile
ID# 47



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
47	II Propylene	-15	-5	0.1	0	50	70	Aluminum

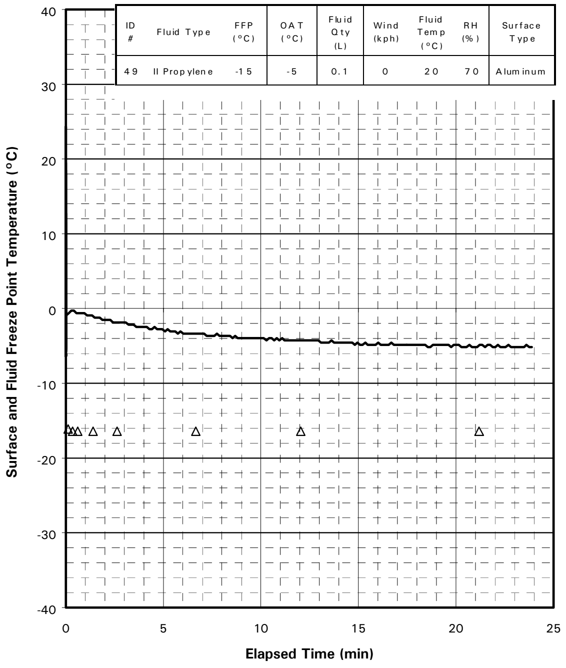
Fluid Freeze Point and Surface Temperature Profile

ID# 48



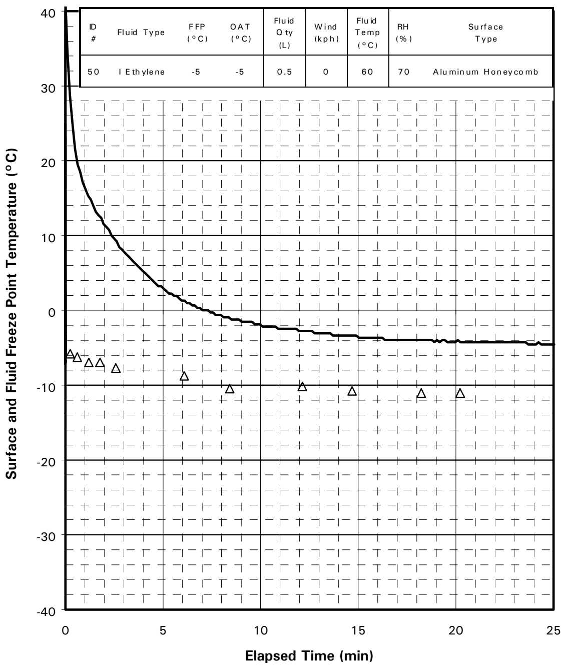
Fluid Freeze Point and Surface Temperature Profile

ID# 49



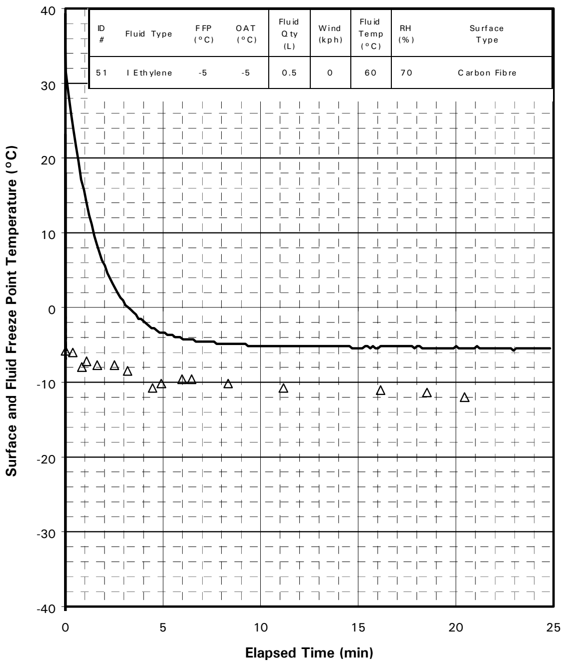
Fluid Freeze Point and Surface Temperature Profile

ID# 50



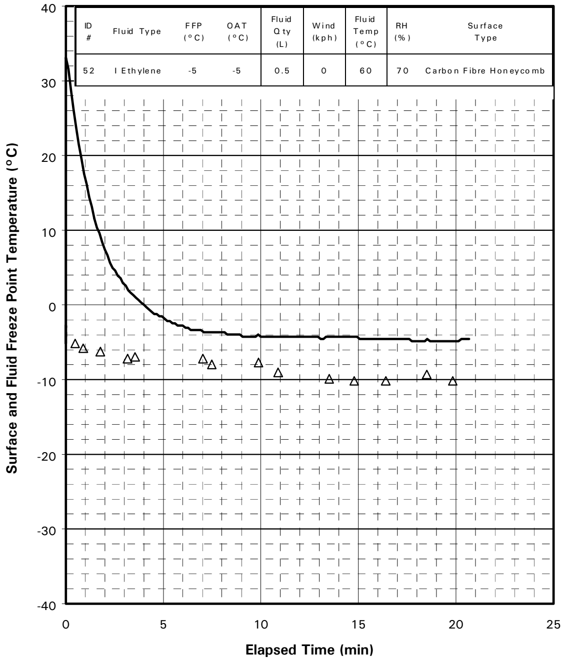
Fluid Freeze Point and Surface Temperature Profile

ID# 51



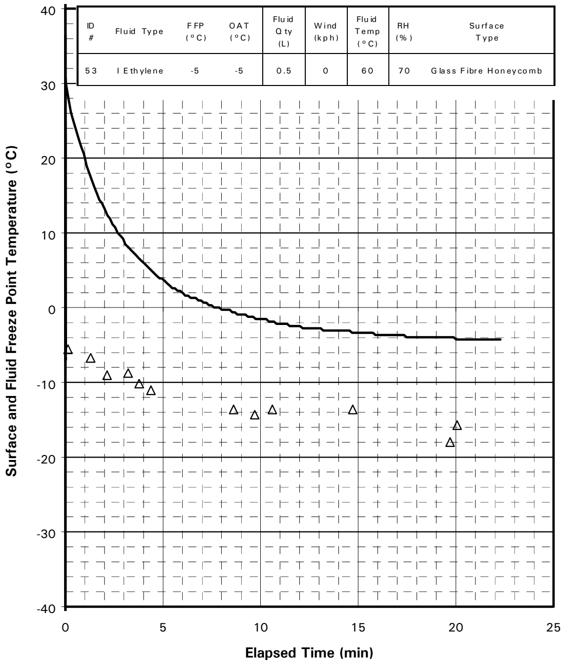
Fluid Freeze Point and Surface Temperature Profile

ID# 52



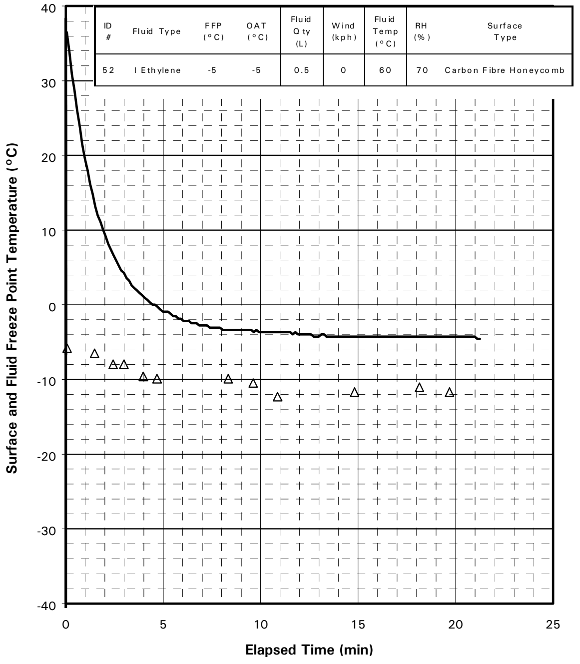
Fluid Freeze Point and Surface Temperature Profile

ID# 53



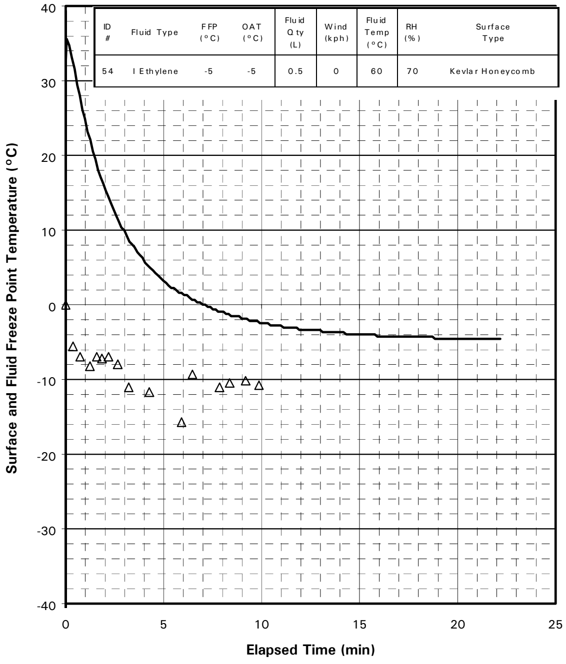
Fluid Freeze Point and Surface Temperature Profile

ID# 52 (Repeat)



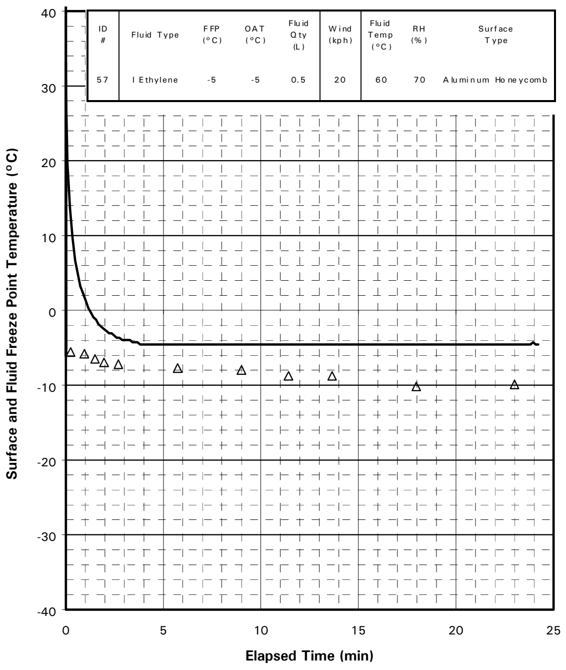
Fluid Freeze Point and Surface Temperature Profile

ID# 54



Fluid Freeze Point and Surface Temperature Profile

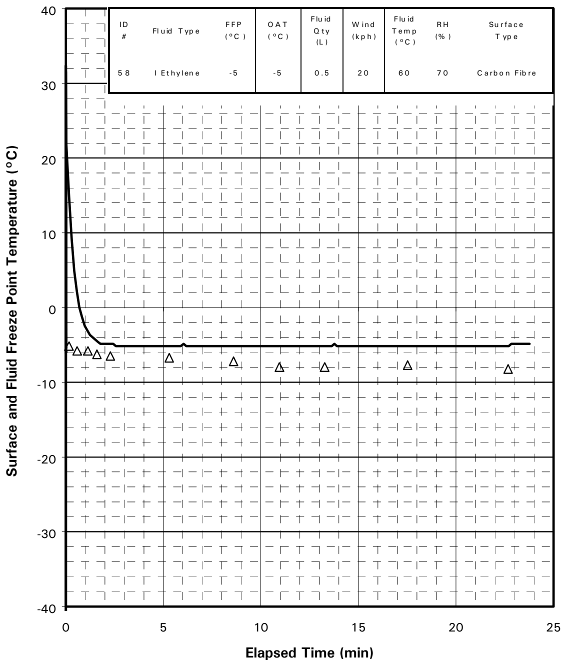
ID# 57



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
57	I Ethylene	-5	-5	0.5	20	60	70	Aluminum Honeycomb

Fluid Freeze Point and Surface Temperature Profile

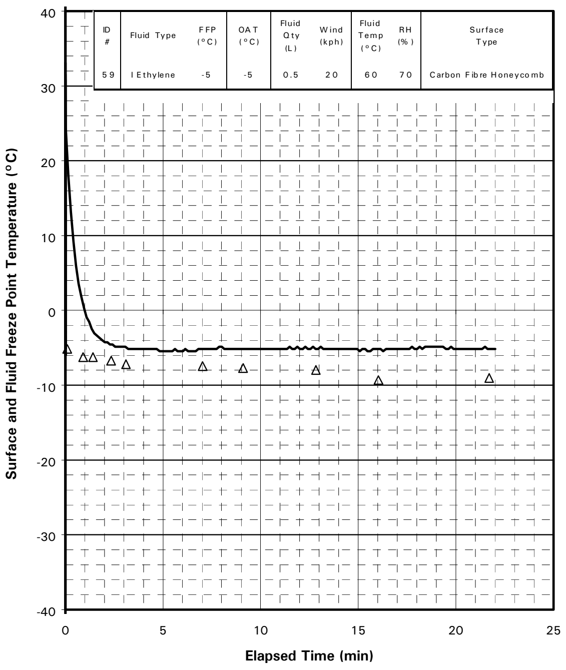
ID# 58



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
58	I Ethylene	-5	-5	0.5	20	60	70	Carbon Fibre

Fluid Freeze Point and Surface Temperature Profile

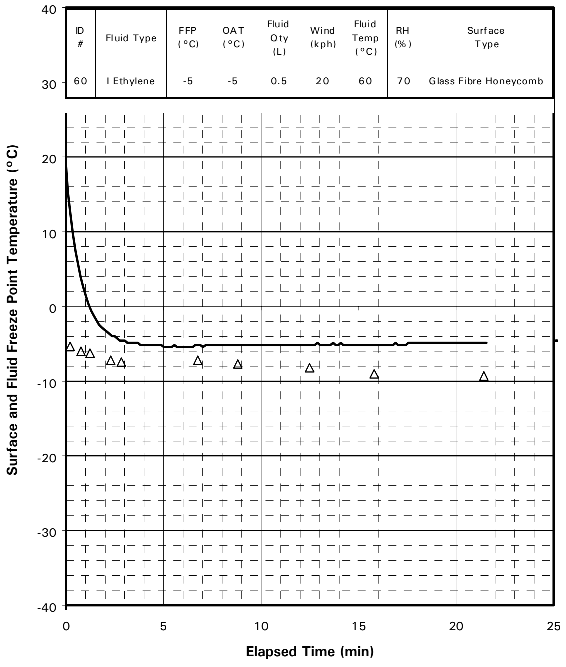
ID# 59



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
59	I Ethylene	-5	-5	0.5	20	60	70	Carbon Fibre Honeycomb

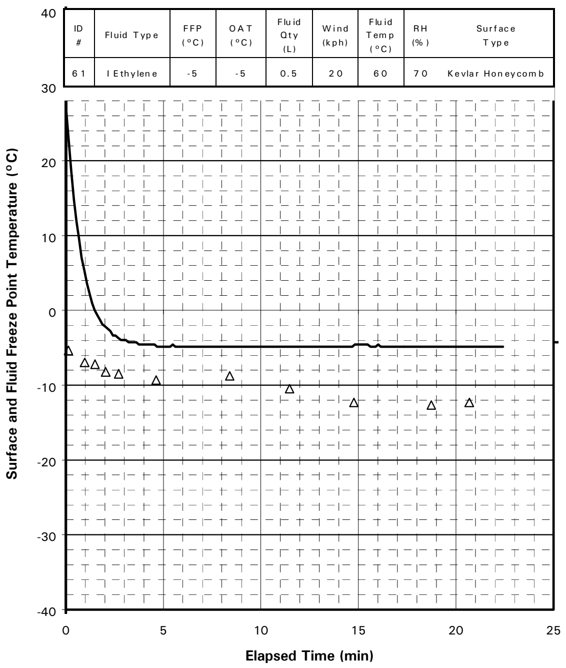
Fluid Freeze Point and Surface Temperature Profile

ID# 60



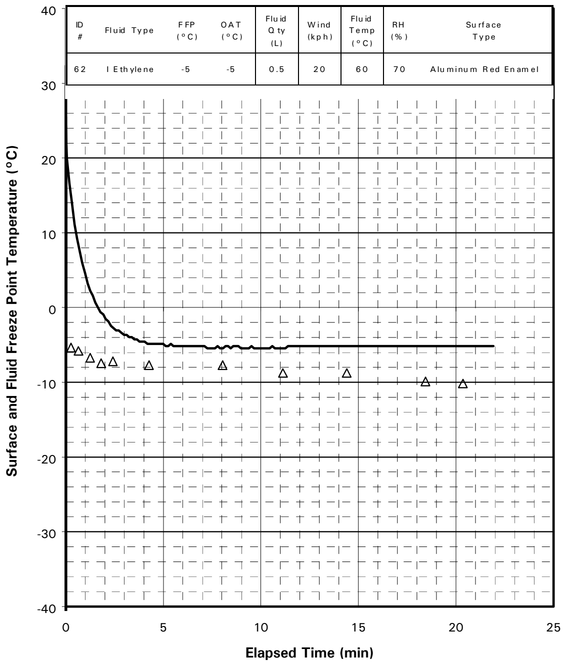
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
60	I Ethylene	-5	-5	0.5	20	60	70	Glass Fibre Honeycomb

Fluid Freeze Point and Surface Temperature Profile
ID# 61



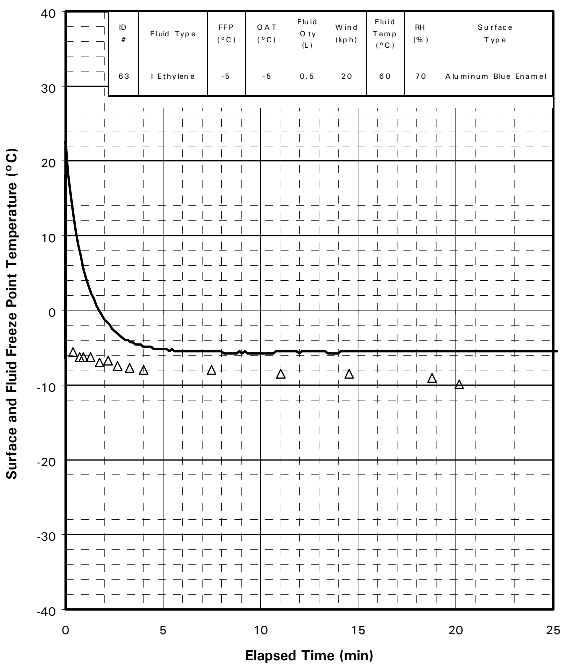
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
61	I Ethylene	-5	-5	0.5	20	60	70	Kevlar Honeycomb

Fluid Freeze Point and Surface Temperature Profile
ID# 62



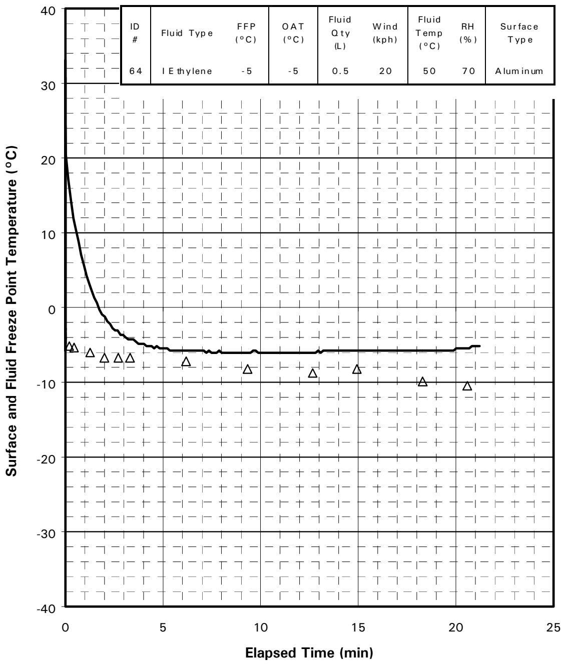
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
62	I Ethylene	-5	-5	0.5	20	60	70	Aluminum Red Enamel

Fluid Freeze Point and Surface Temperature Profile
ID# 63



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
63	I Ethylene	-5	-5	0.5	20	60	70	Aluminum Blue Enamel

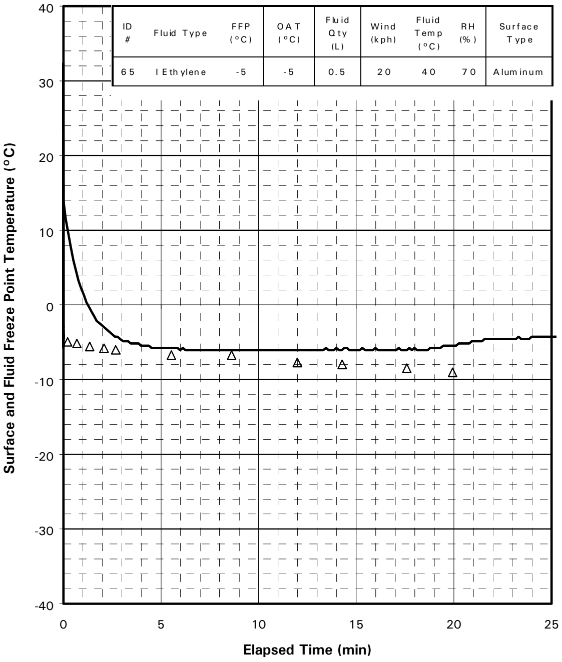
Fluid Freeze Point and Surface Temperature Profile
ID# 64



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
64	I Ethylene	-5	-5	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

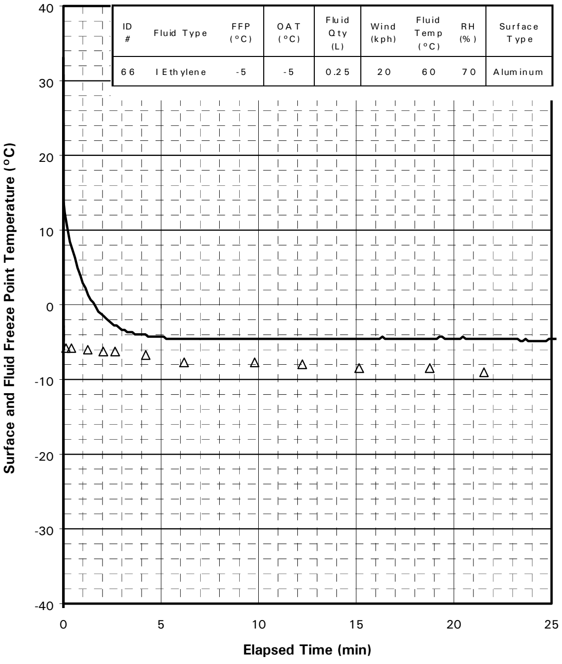
ID# 65



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
65	I Ethylene	-5	-5	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

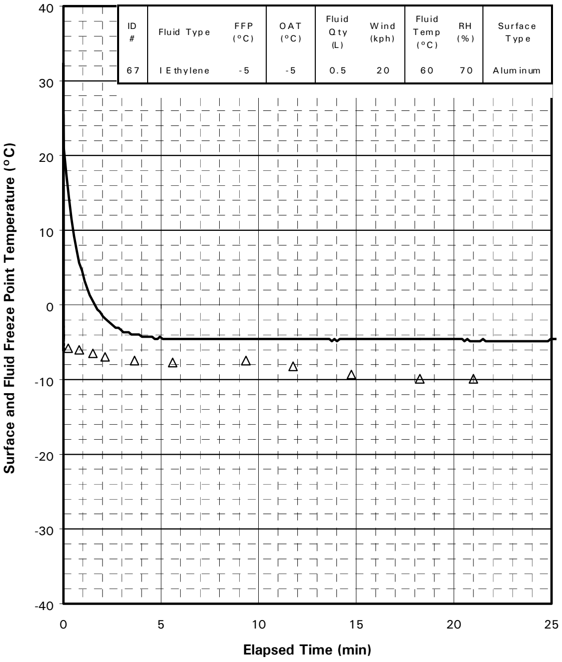
ID# 66



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
66	I Ethylene	-5	-5	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

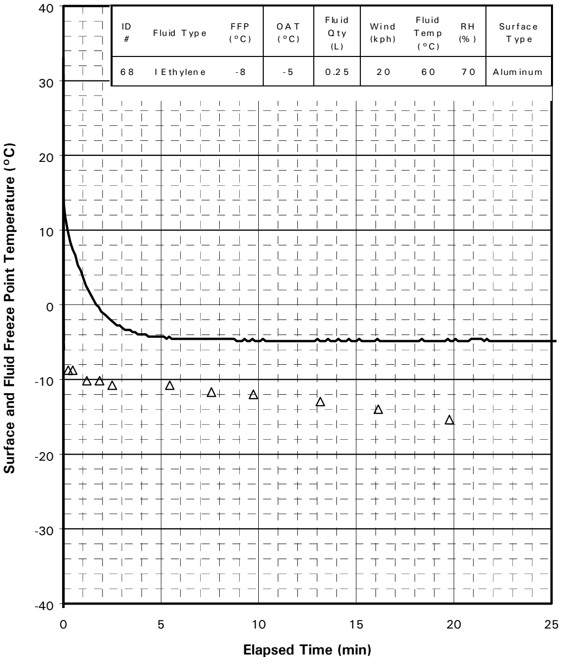
ID# 67



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
67	I Ethylene	-5	-5	0.5	20	60	70	Aluminum

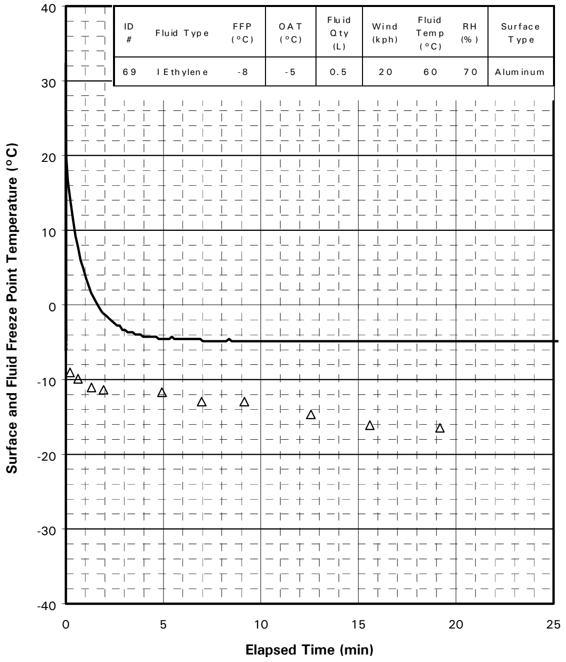
Fluid Freeze Point and Surface Temperature Profile

ID# 68



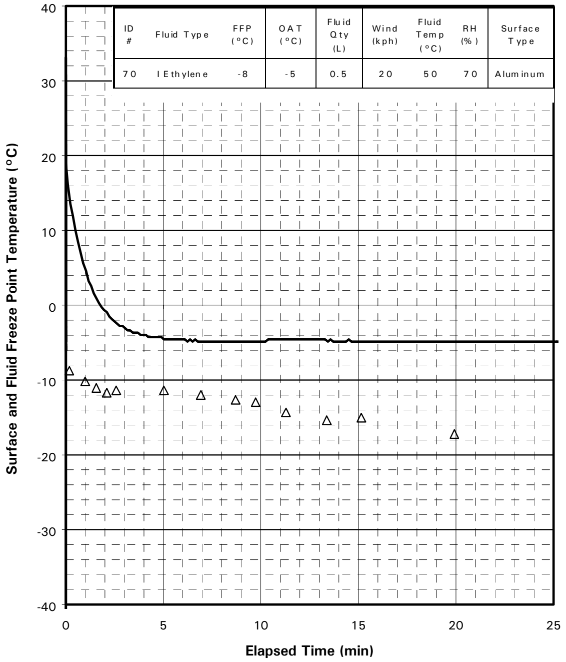
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
68	I Ethylene	-8	-5	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 69



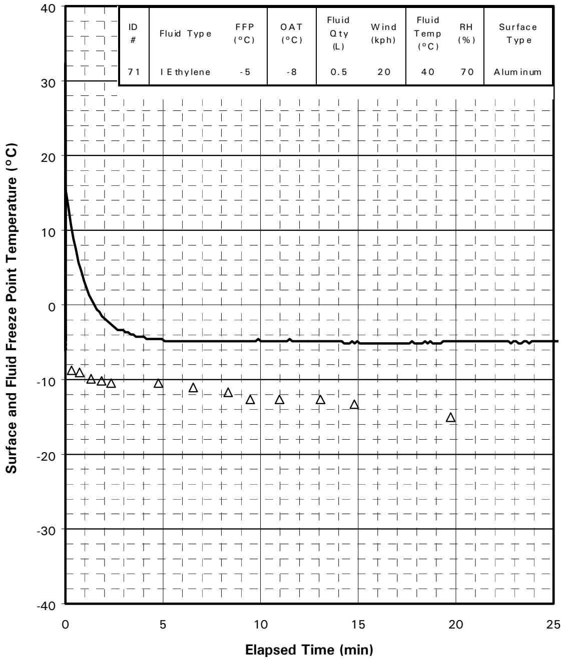
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
69	I Ethylene	-8	-5	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 70



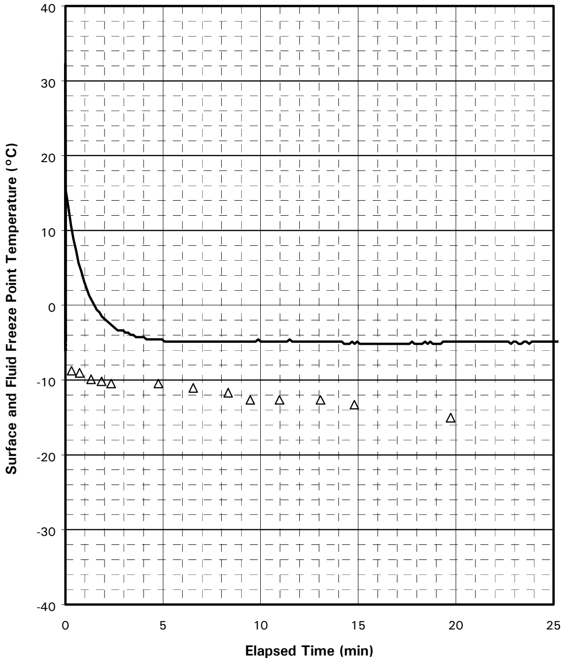
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
70	I Ethylene	-8	-5	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 71

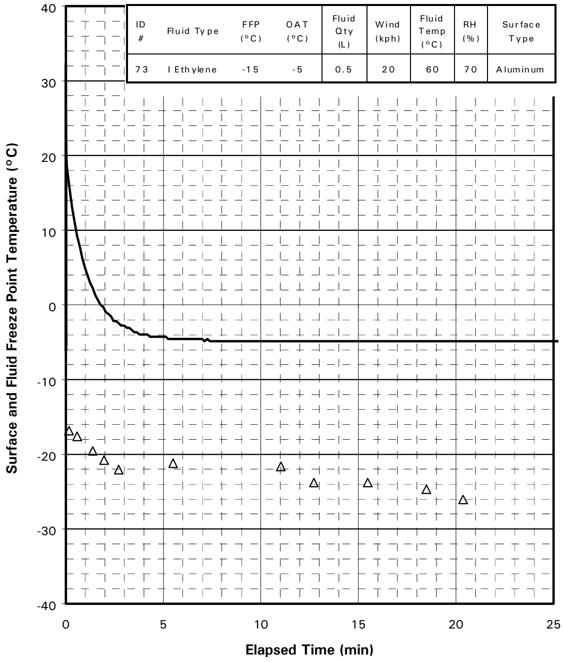


ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
71	I Ethylene	-5	-8	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 72

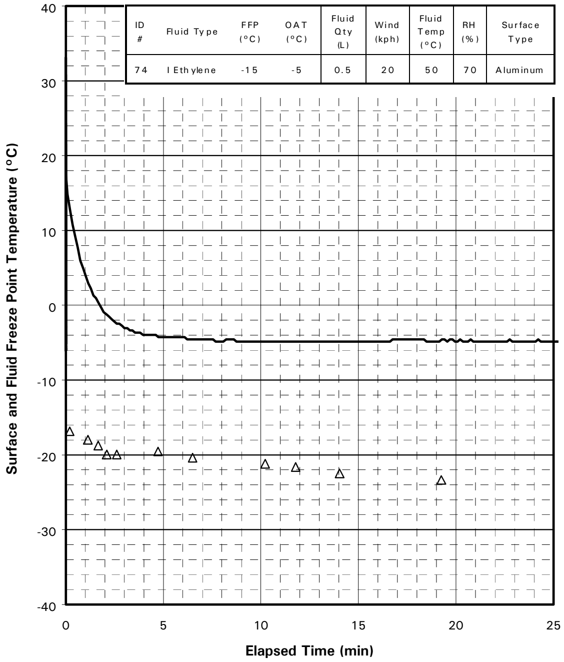


Fluid Freeze Point and Surface Temperature Profile
ID# 73



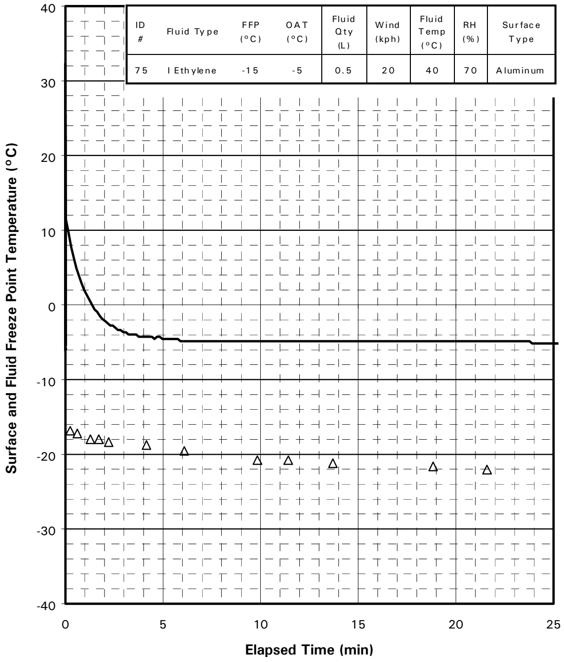
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
73	I Ethylene	-15	-5	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 74



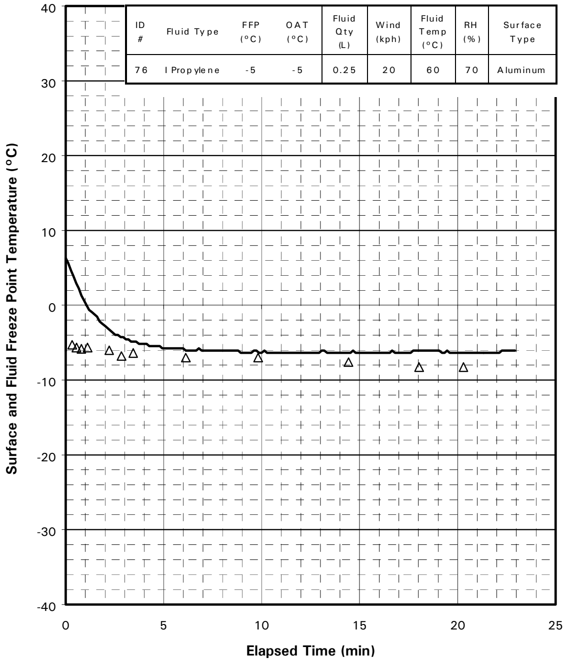
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
74	I Ethylene	-15	-5	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 75



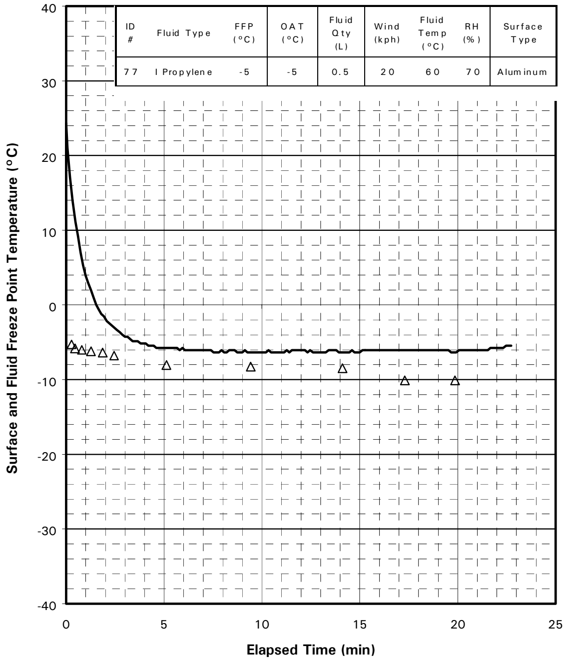
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
75	I Ethylene	-15	-5	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 76



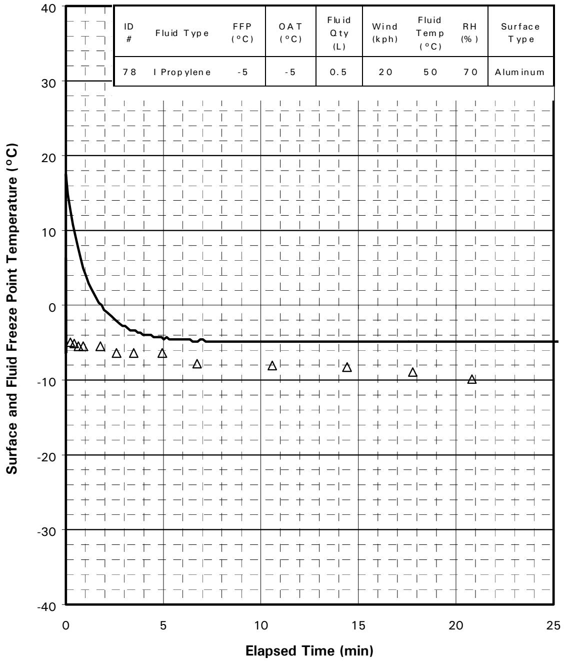
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
76	I Propylene	-5	-5	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 77



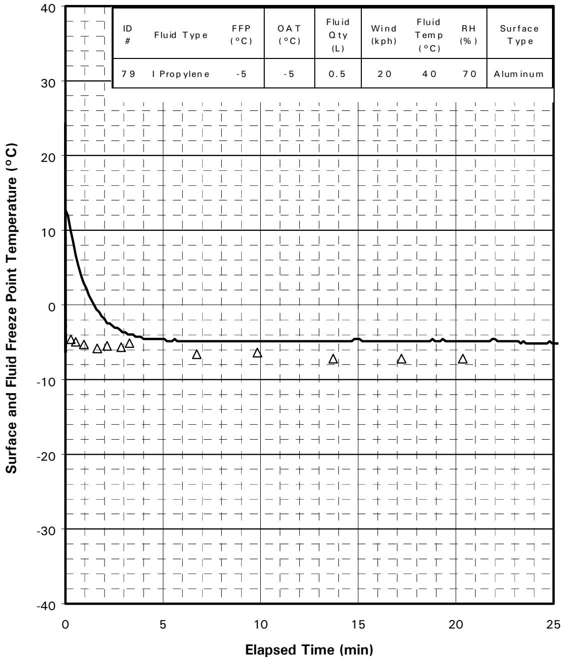
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
77	I Propylene	-5	-5	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 78



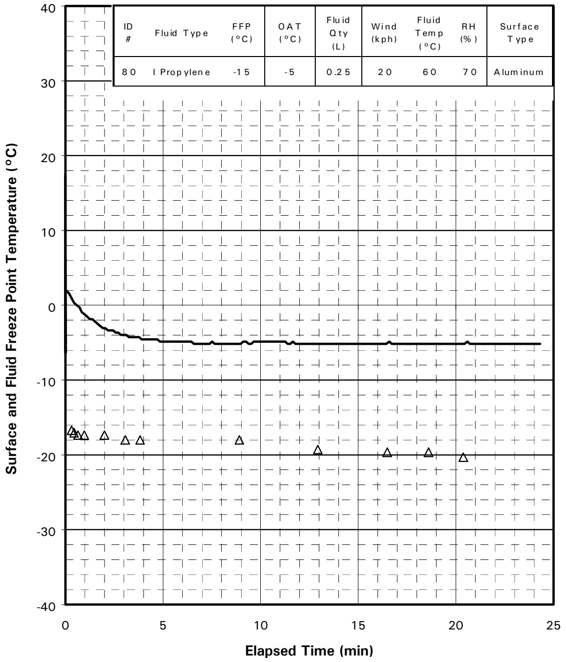
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
78	I Propylene	-5	-5	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 79



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
79	I Propylene	-5	-5	0.5	20	40	70	Aluminum

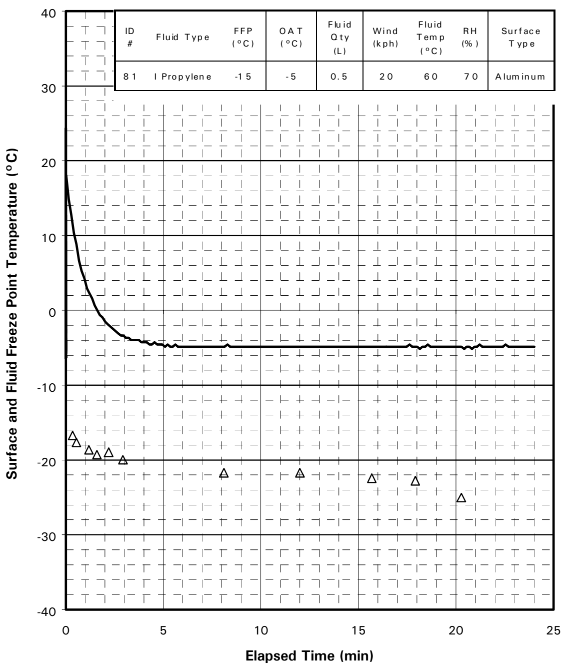
Fluid Freeze Point and Surface Temperature Profile
ID# 80



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
80	I Propylene	-15	-5	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

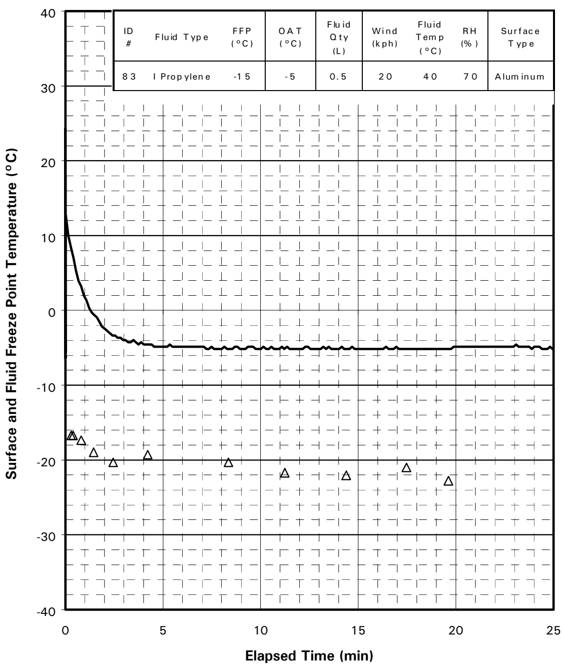
ID# 81



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
81	I Propylene	-15	-5	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

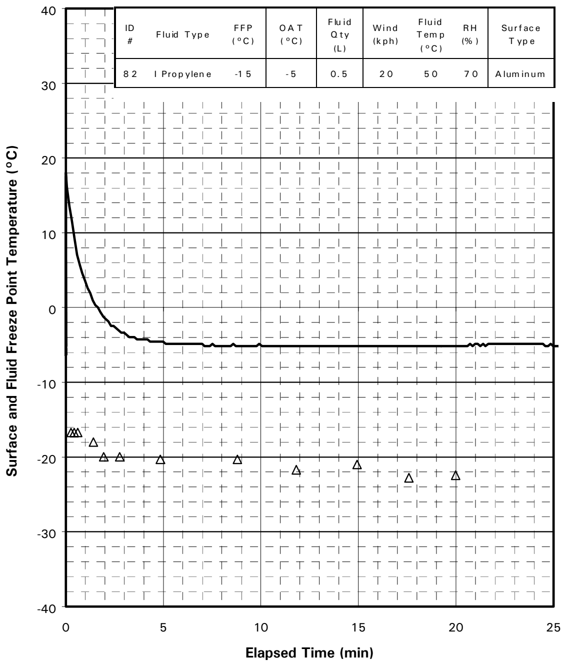
ID# 83



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
83	I Propylene	-15	-5	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

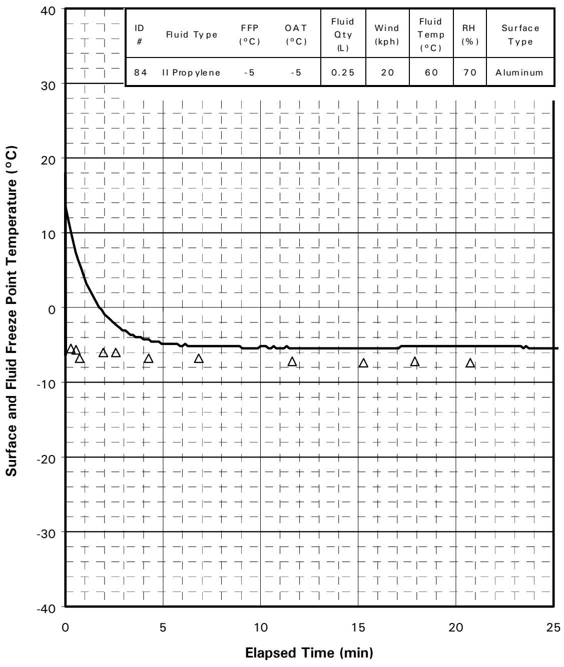
ID# 82



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
82	I Propylene	-15	-5	0.5	20	50	70	Aluminum

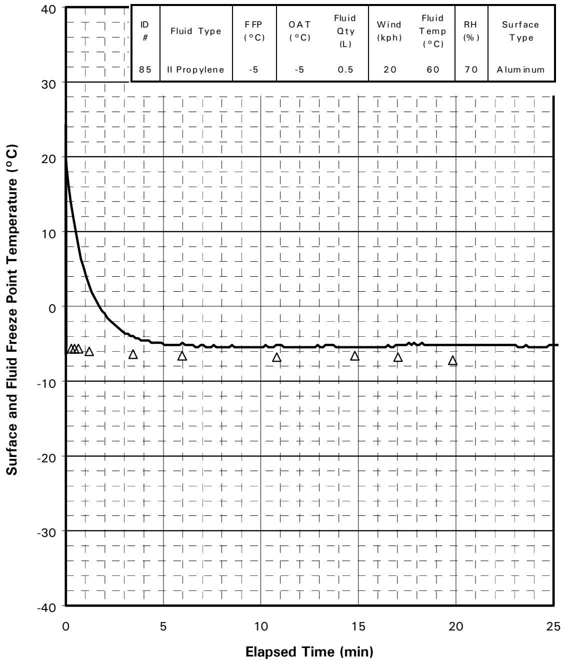
Fluid Freeze Point and Surface Temperature Profile

ID# 84



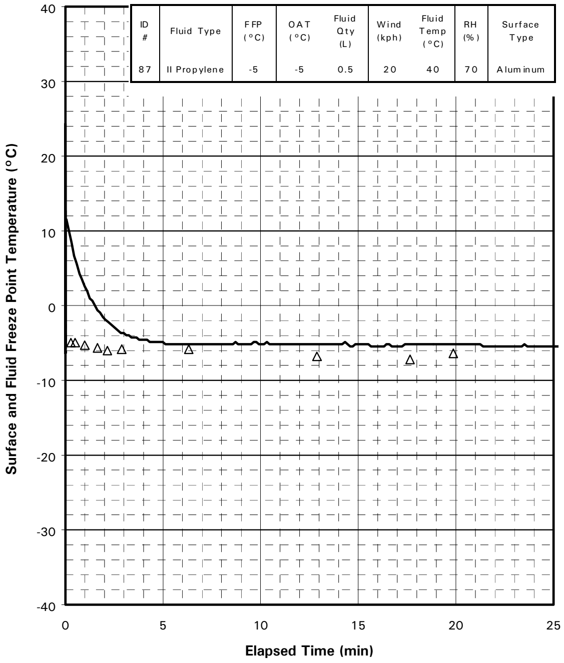
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
84	II Propylene	-5	-5	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 85



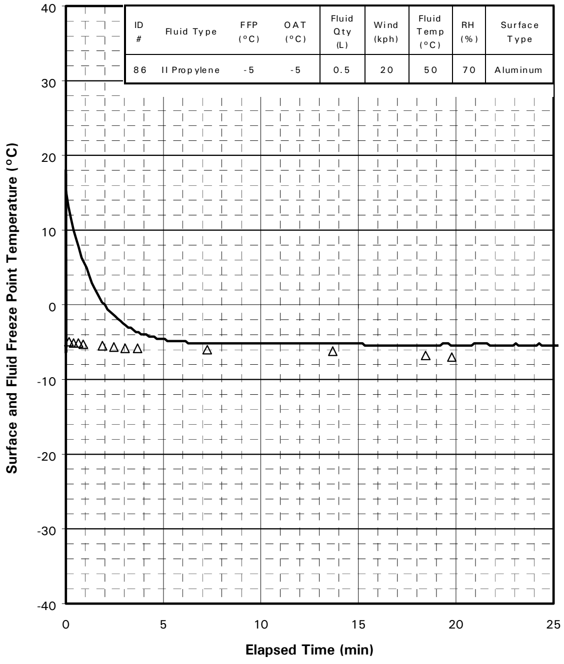
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
85	II Propylene	-5	-5	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 87



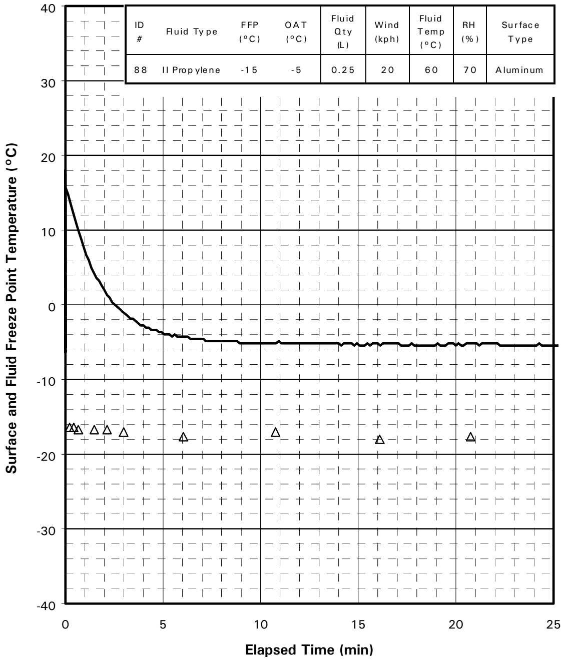
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
87	II Propylene	-5	-5	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 86



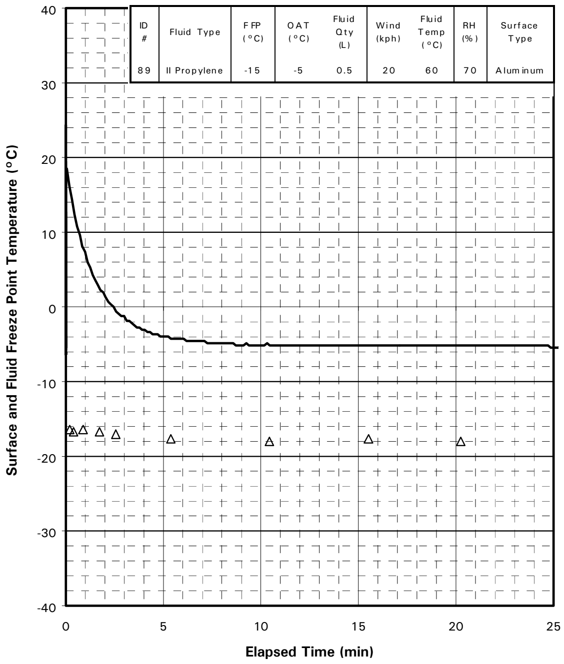
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
86	II Propylene	-5	-5	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 88



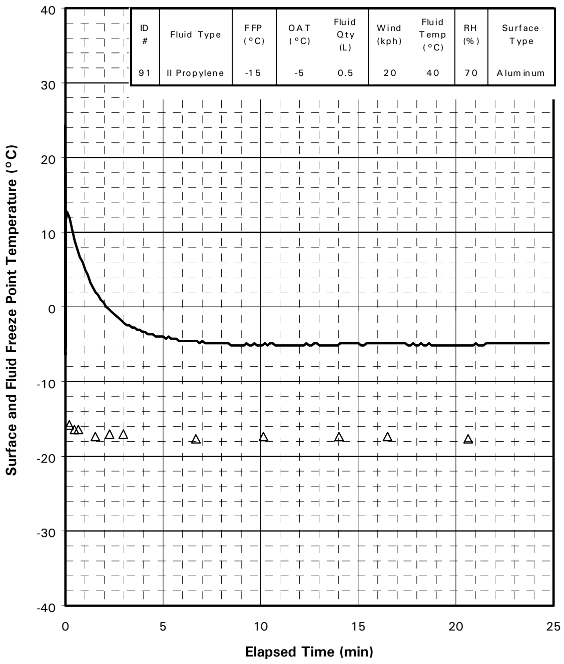
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
88	II Propylene	-15	-5	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 89



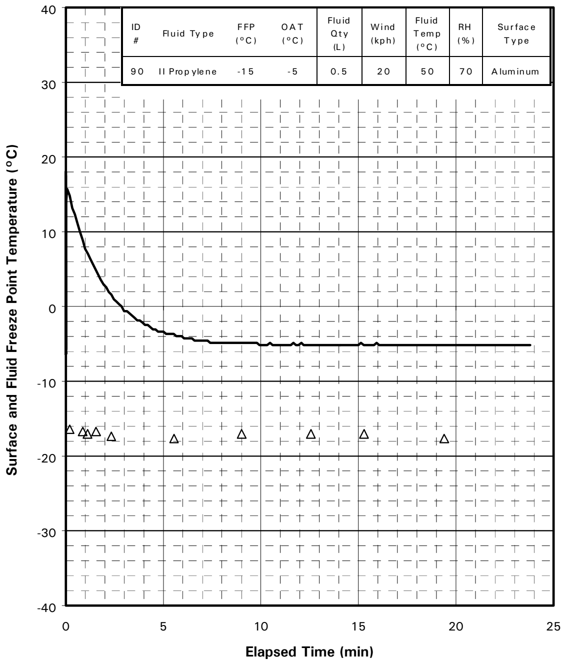
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
89	II Propylene	-15	-5	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 91



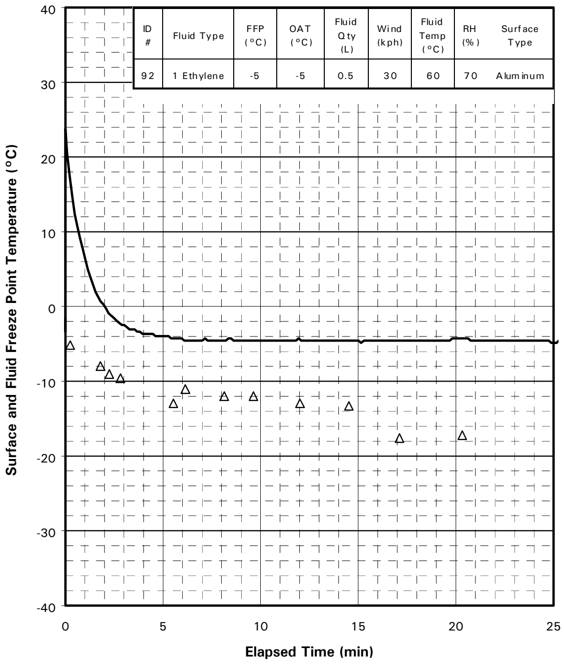
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
91	II Propylene	-15	-5	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 90



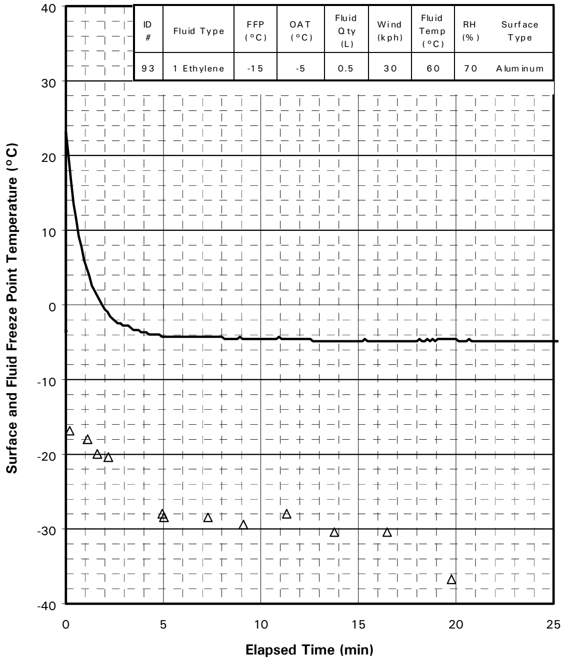
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
90	II Propylene	-15	-5	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 92



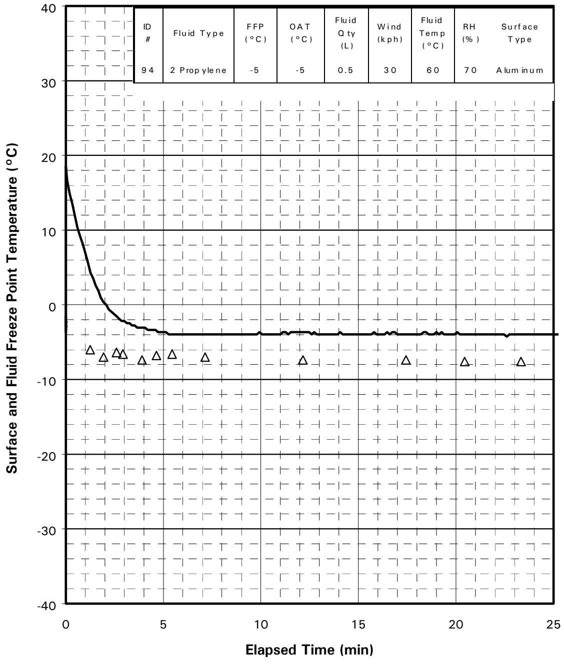
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
92	1 Ethylene	-5	-5	0.5	30	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 93



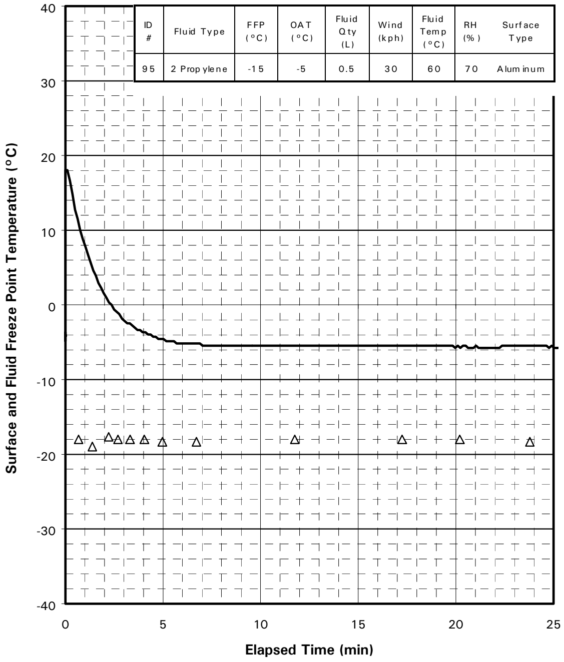
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
93	1 Ethylene	-15	-5	0.5	30	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 94



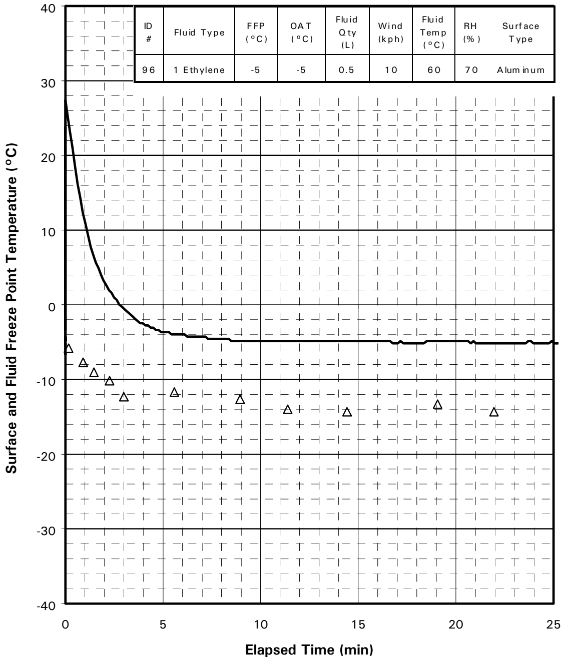
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
94	2 Propylene	-5	-5	0.5	30	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 95



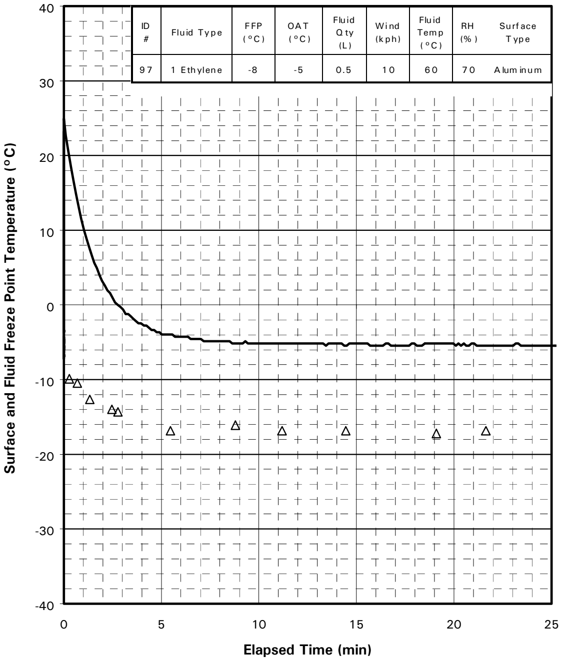
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
95	2 Propylene	-15	-5	0.5	30	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 96



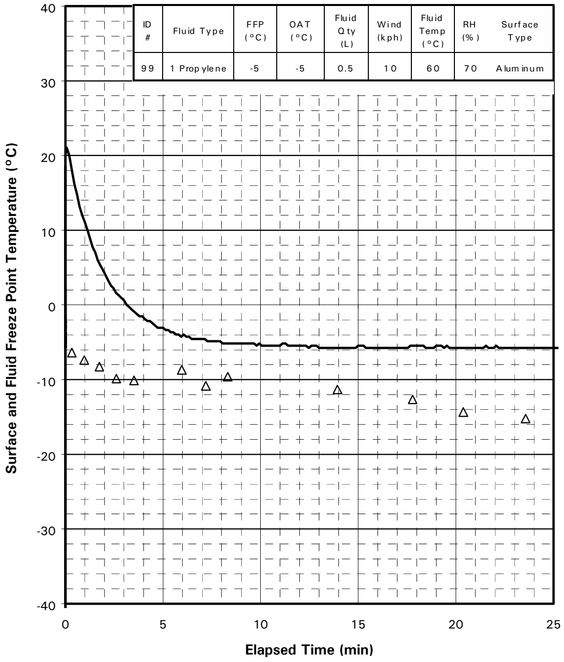
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
96	1 Ethylene	-5	-5	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 97



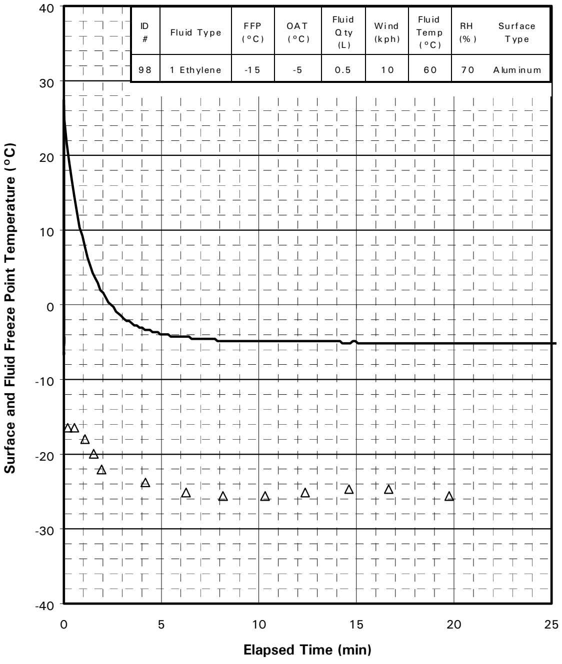
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
97	1 Ethylene	-8	-5	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 99



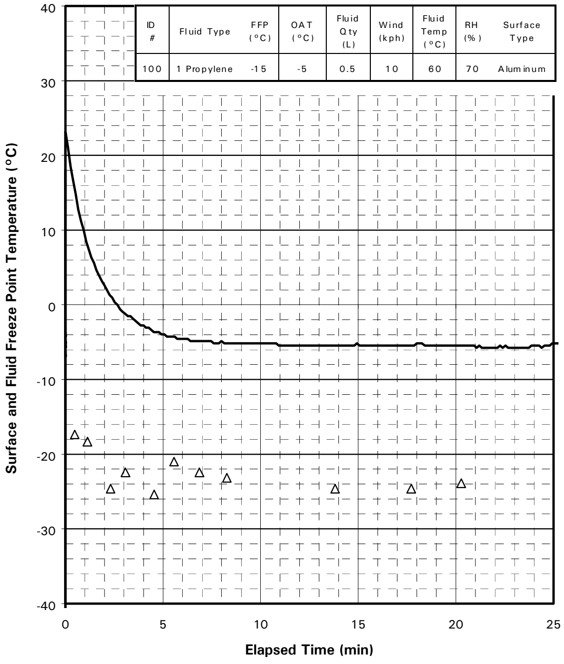
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
99	1 Propylene	-5	-5	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 98



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
98	1 Ethylene	-15	-5	0.5	10	60	70	Aluminum

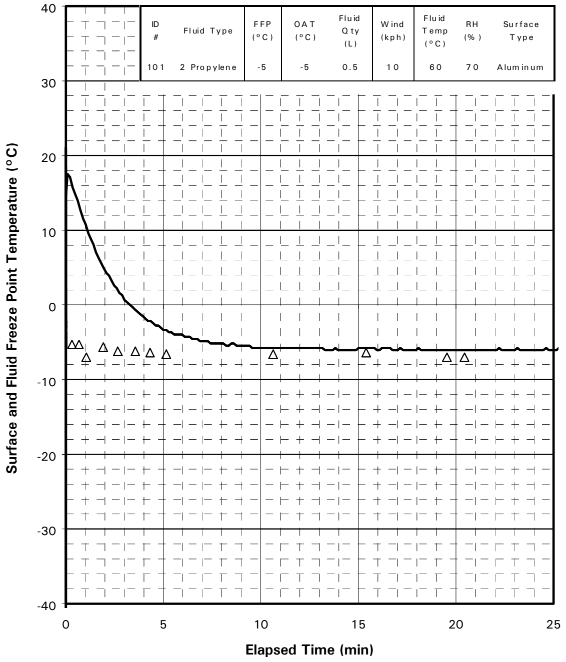
Fluid Freeze Point and Surface Temperature Profile
ID# 100



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
100	1 Propylene	-15	-5	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

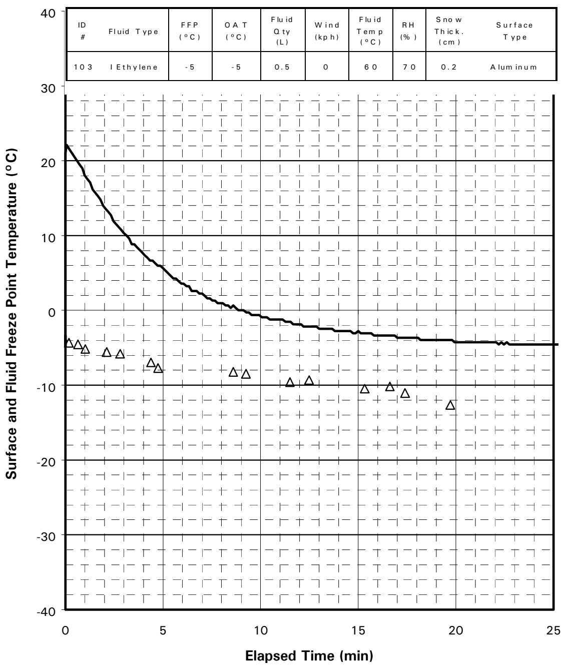
ID# 101



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
101	2 Propylene	-5	-5	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

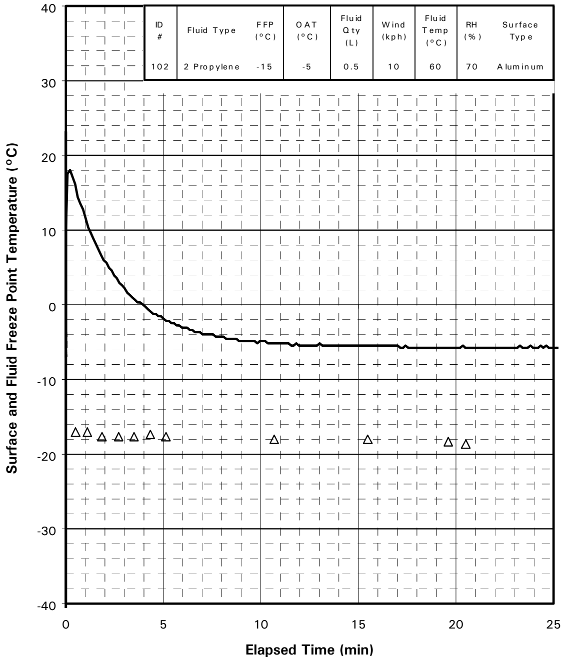
ID# 103



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
103	I Ethylene	-5	-5	0.5	0	60	70	0.2	Aluminum

Fluid Freeze Point and Surface Temperature Profile

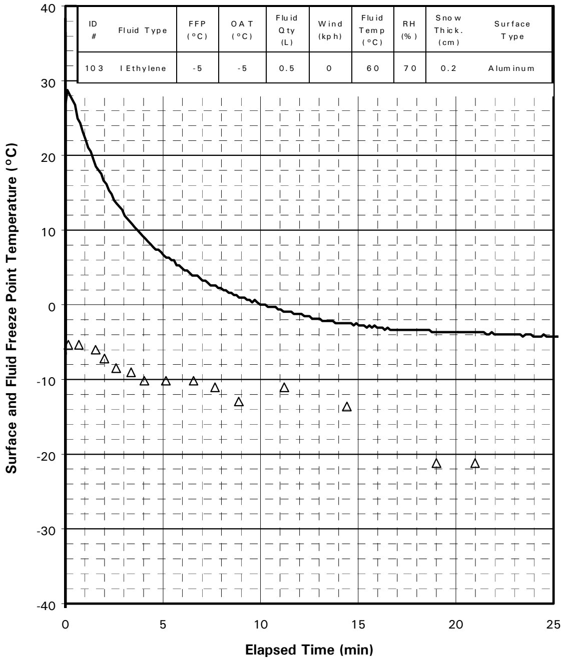
ID# 102



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
102	2 Propylene	-15	-5	0.5	10	60	70	Aluminum

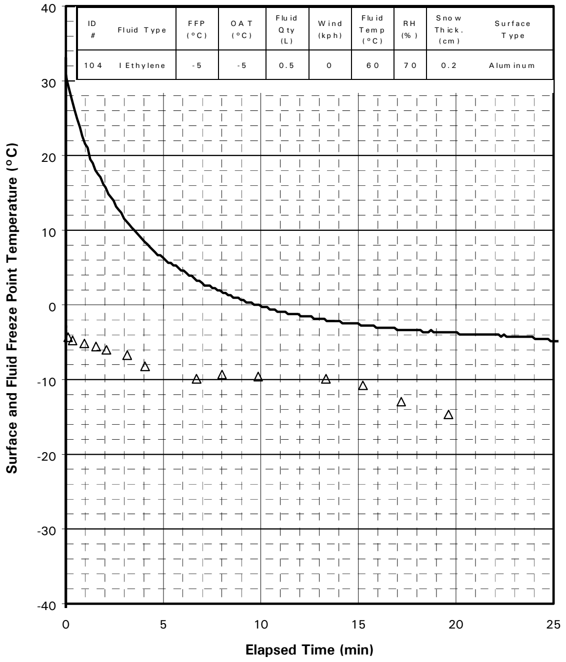
Fluid Freeze Point and Surface Temperature Profile

ID# 103 (Repeat)



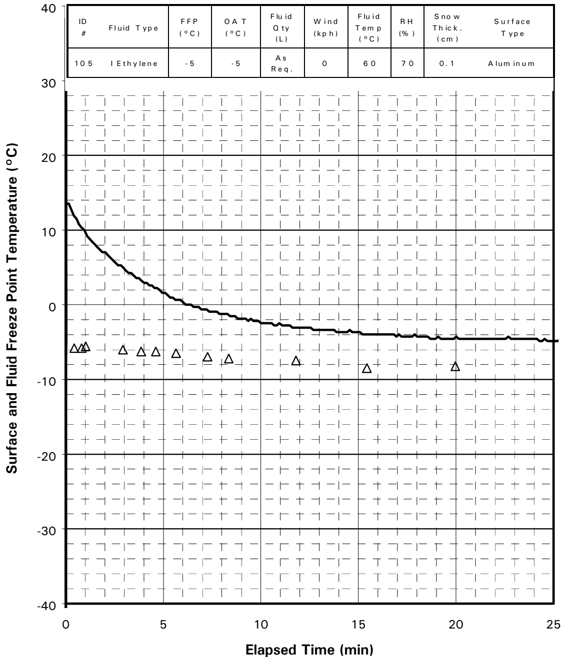
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
103	I Ethylene	-5	-5	0.5	0	60	70	0.2	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 104



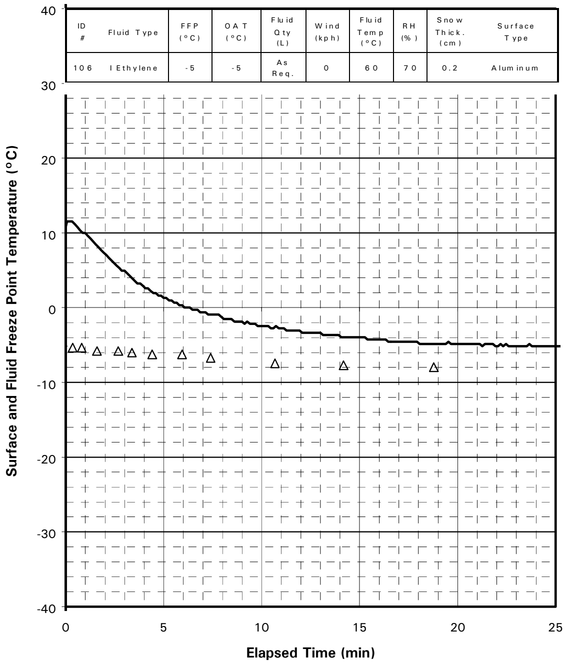
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
104	I Ethylene	-5	-5	0.5	0	60	70	0.2	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 105



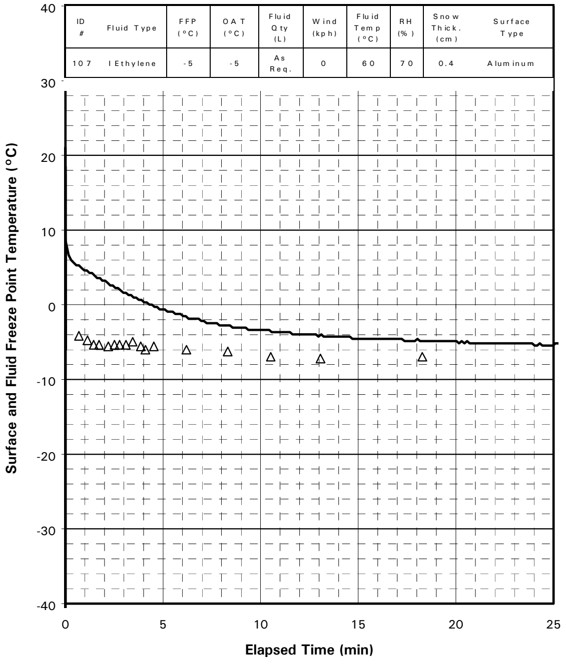
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
105	I Ethylene	-5	-5	As Req.	0	60	70	0.1	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 106



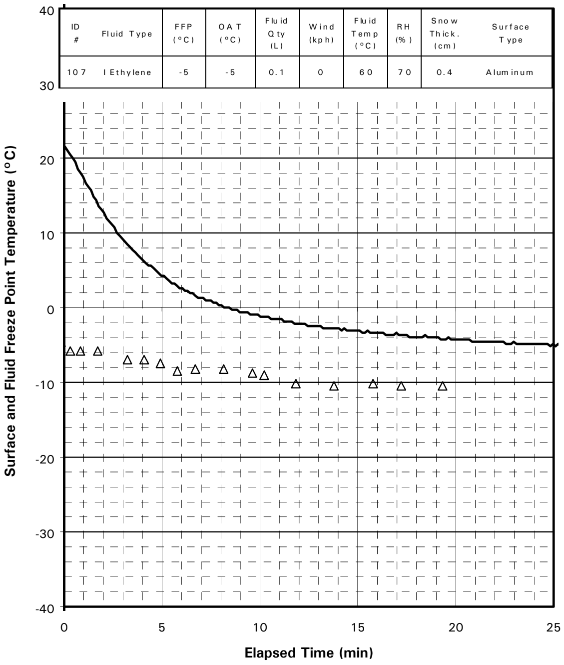
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
106	I Ethylene	-5	-5	As Req.	0	60	70	0.2	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 107

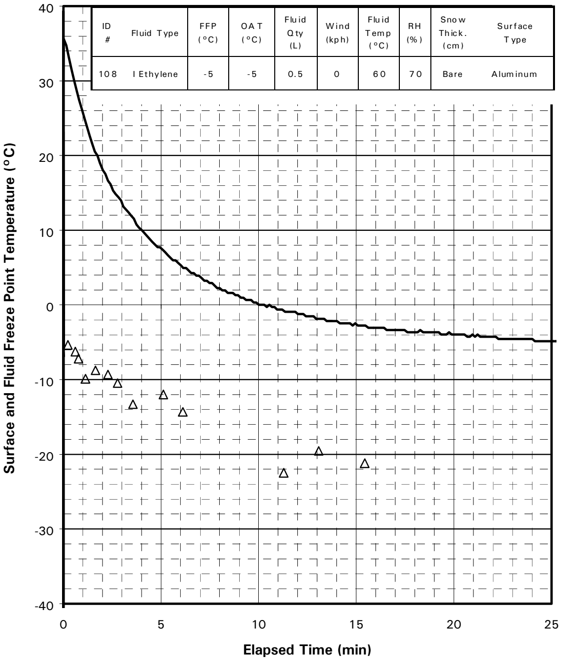


ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
107	I Ethylene	-5	-5	As Req.	0	60	70	0.4	Aluminum

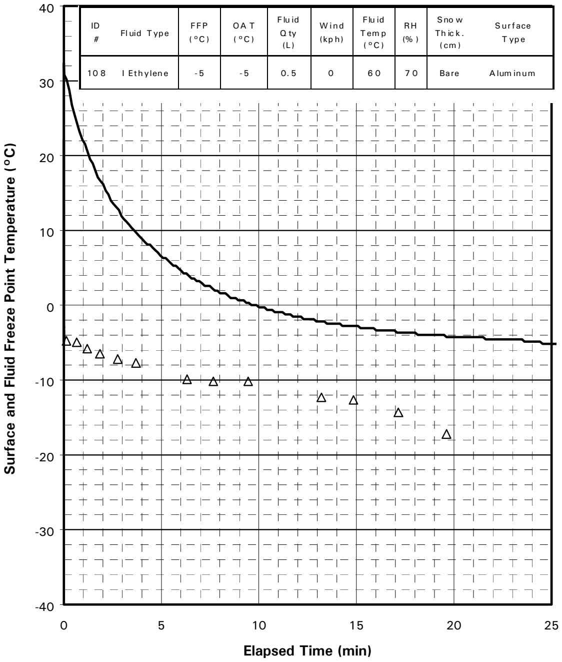
Fluid Freeze Point and Surface Temperature Profile
ID# 107 (Repeat)



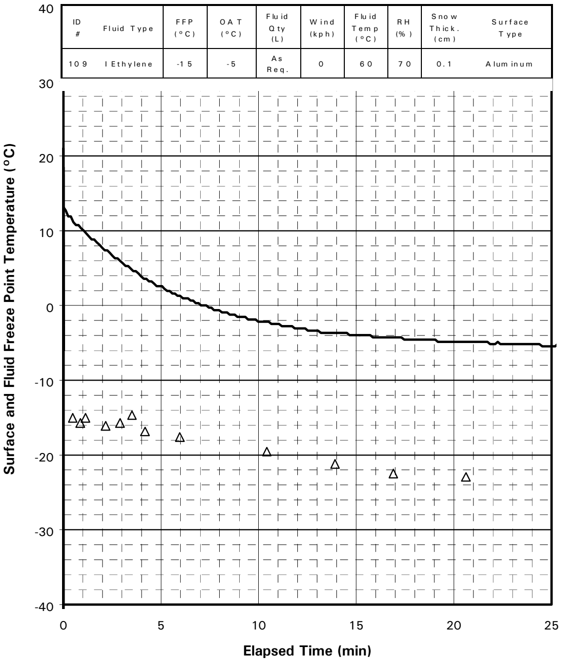
Fluid Freeze Point and Surface Temperature Profile
ID# 108 (Repeat)



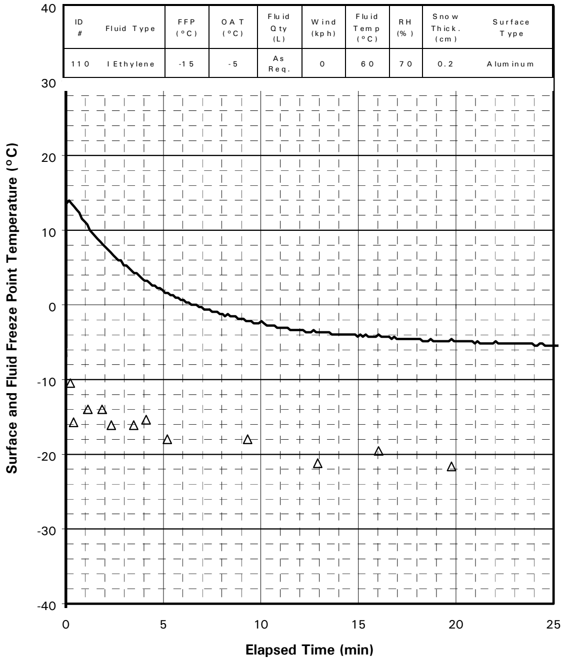
Fluid Freeze Point and Surface Temperature Profile
ID# 108



Fluid Freeze Point and Surface Temperature Profile
ID# 109

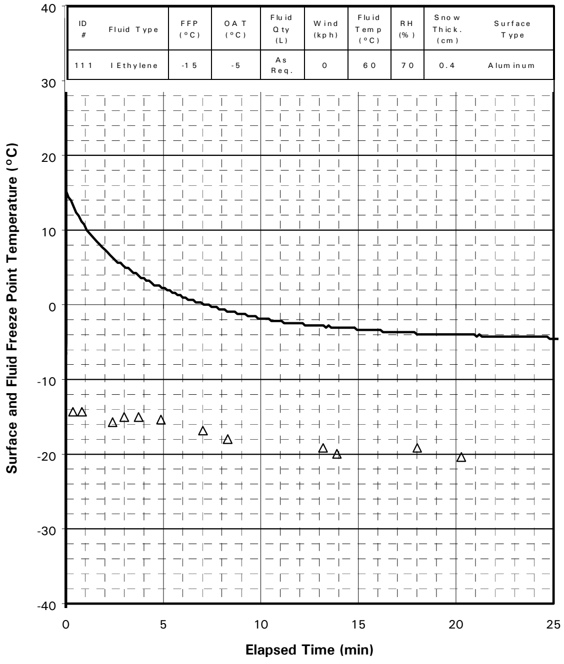


Fluid Freeze Point and Surface Temperature Profile
ID# 110



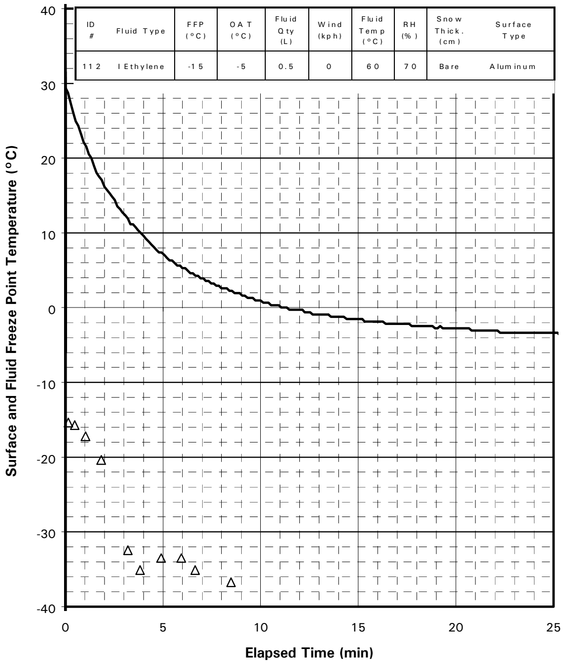
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
110	I Ethylene	-15	-5	As Req.	0	60	70	0.2	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 111



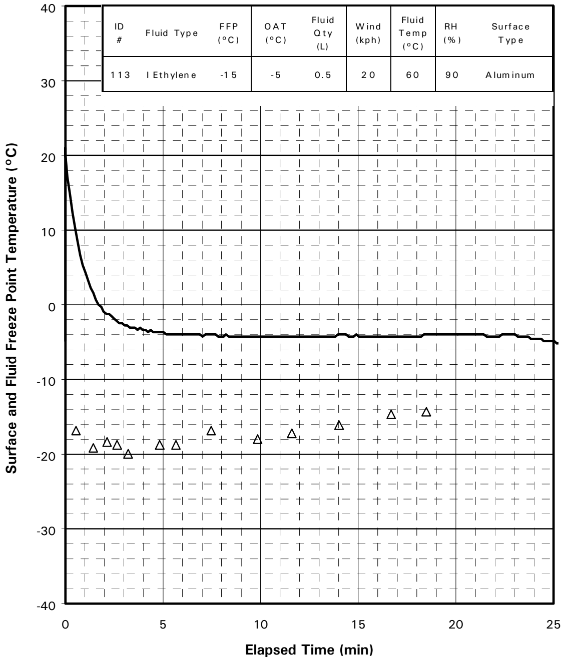
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
111	I Ethylene	-15	-5	As Req.	0	60	70	0.4	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 112



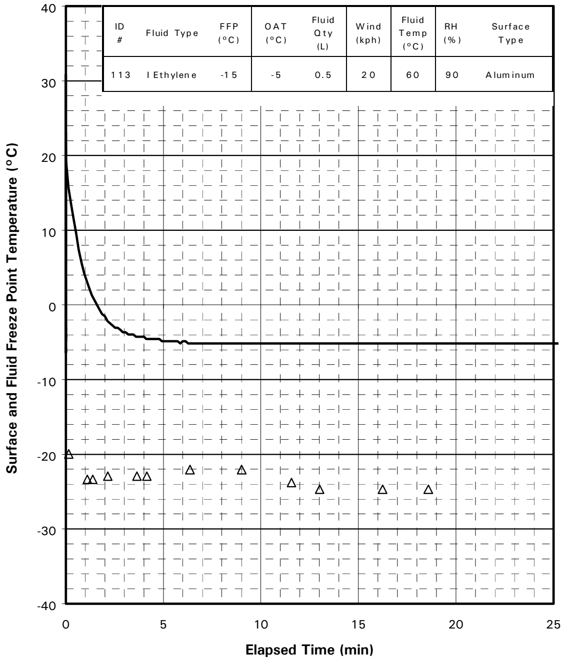
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
112	I Ethylene	-15	-5	0.5	0	60	70	Bare	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 113



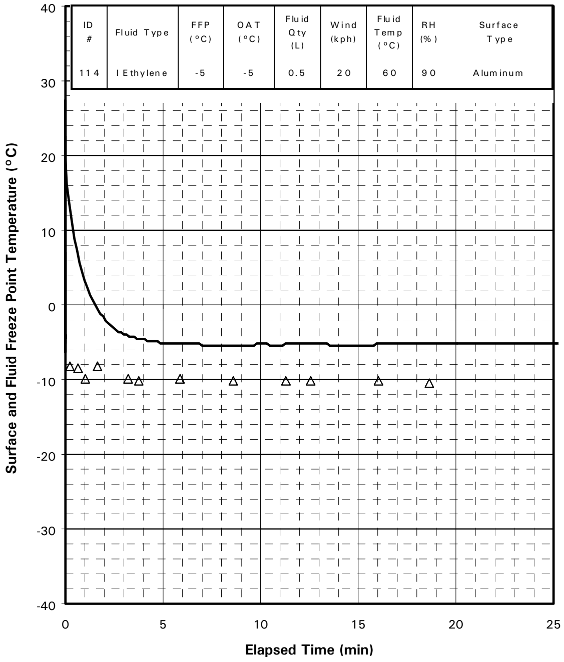
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
113	I Ethylene	-15	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 113 (Repeat)



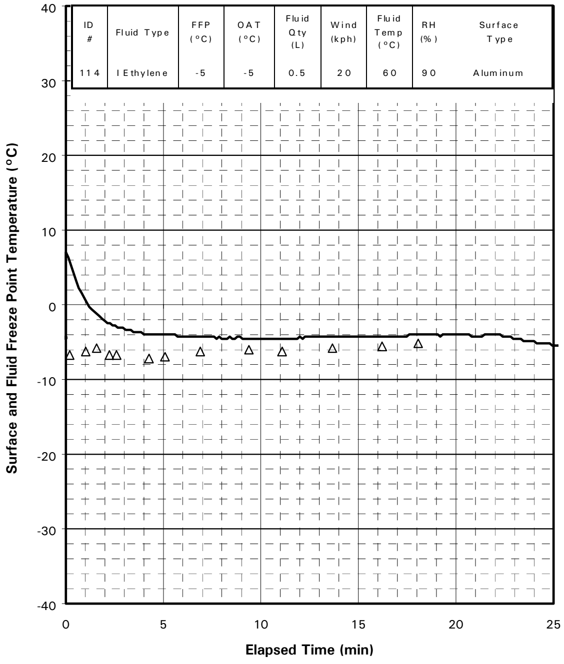
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
113	I Ethylene	-15	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 114 (Repeat)



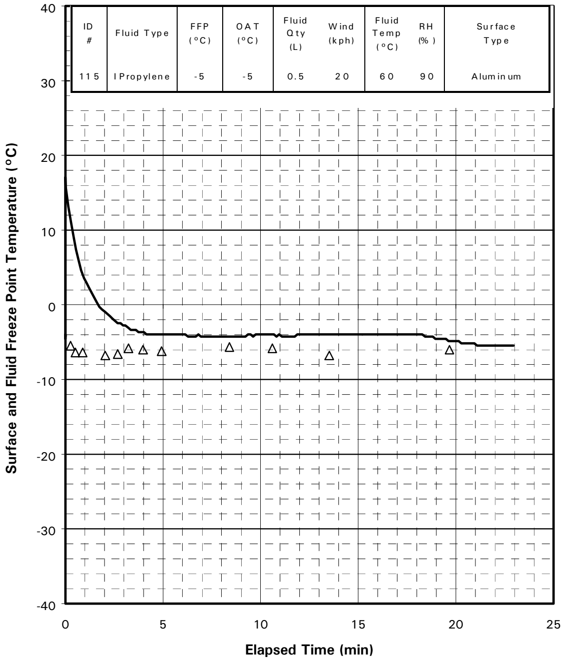
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
114	I Ethylene	-5	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 114



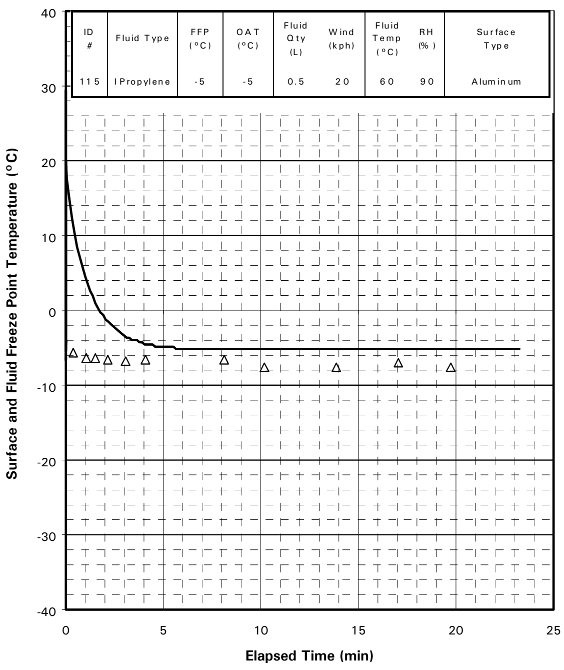
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
114	I Ethylene	-5	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 115



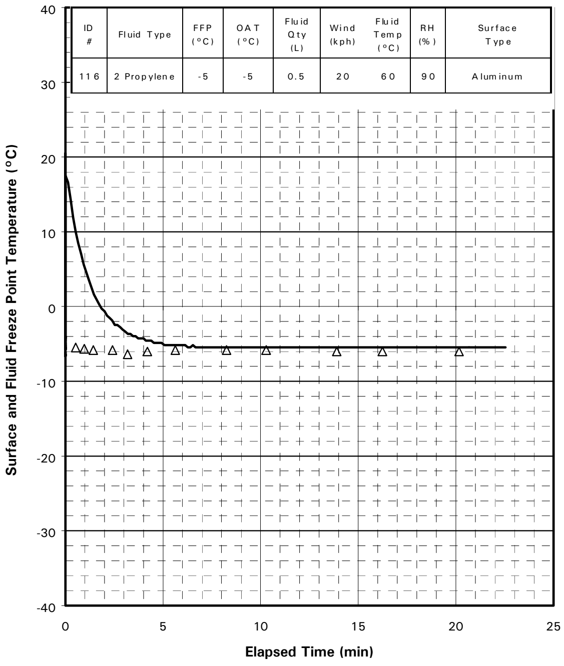
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
115	I Propylene	-5	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 115 (Repeat)



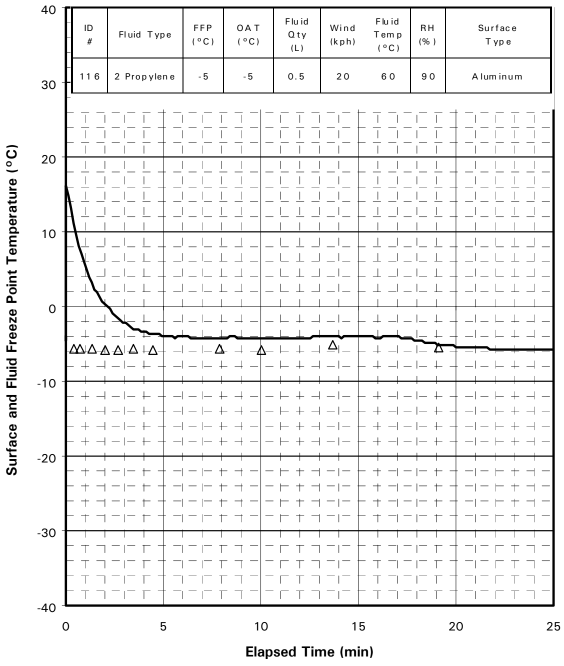
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
115	I Propylene	-5	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 116 (Repeat)



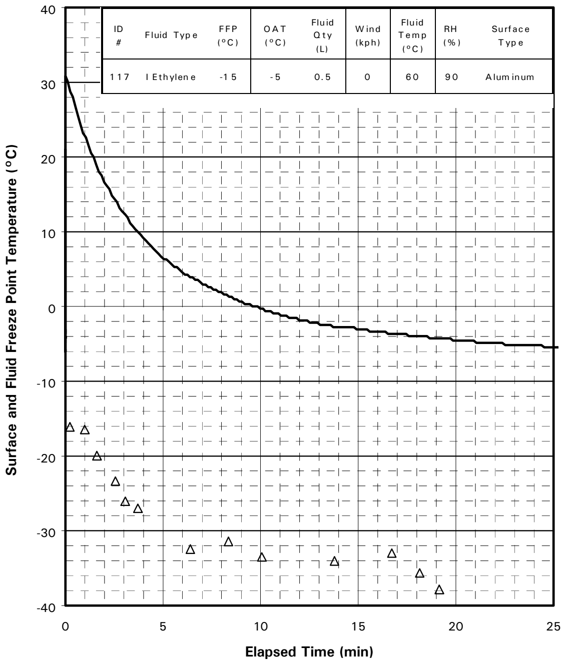
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
116	2 Propylene	-5	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 116



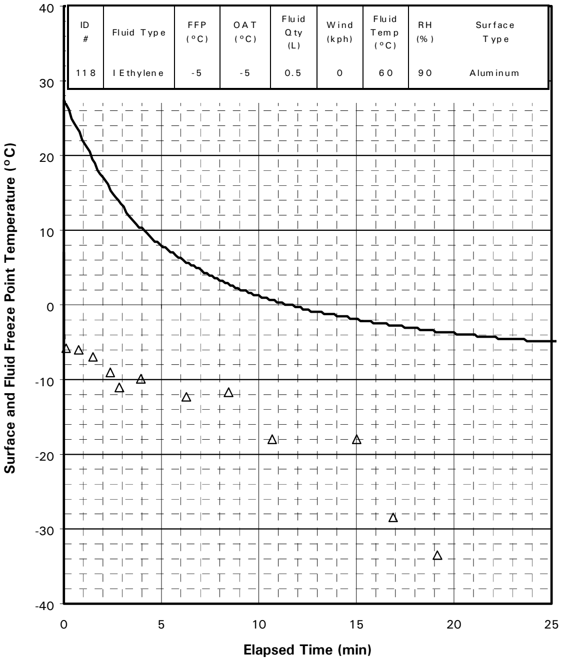
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
116	2 Propylene	-5	-5	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 117



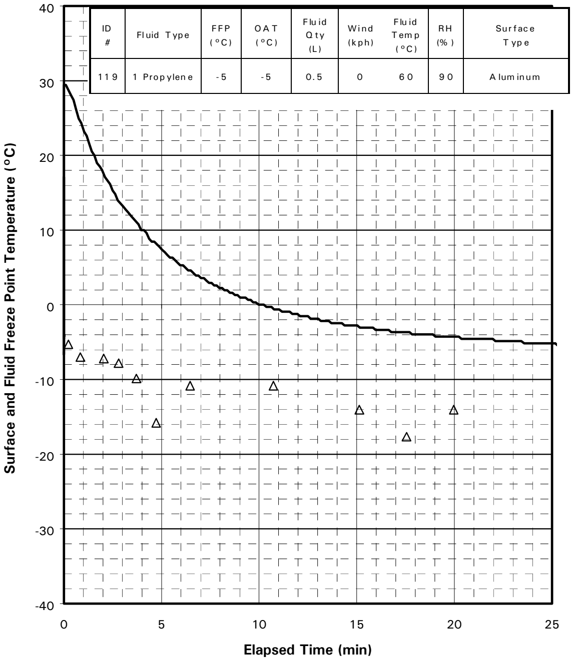
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
117	I Ethylene	-15	-5	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 118



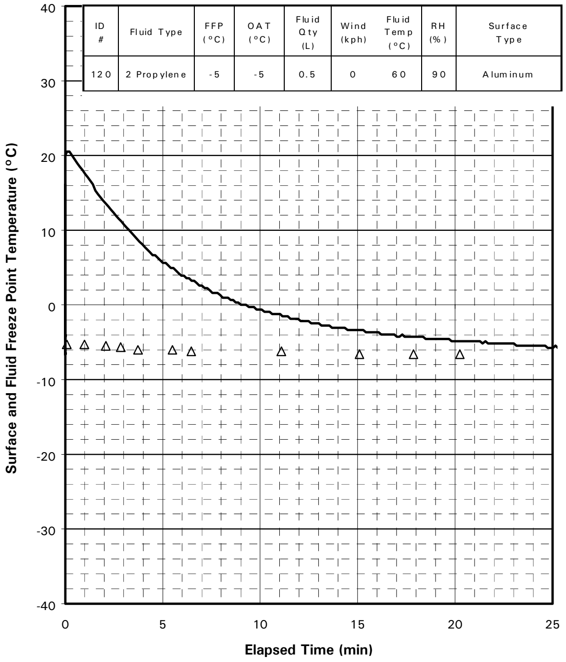
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
118	I Ethylene	-5	-5	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 119



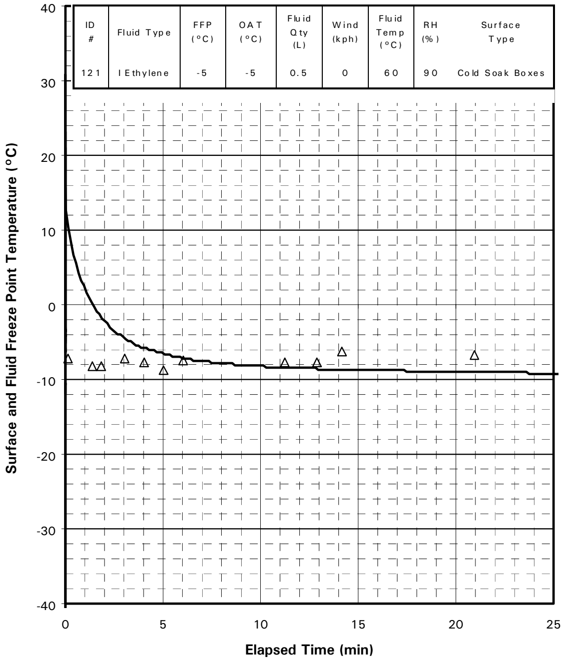
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
119	1 Propylene	-5	-5	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 120



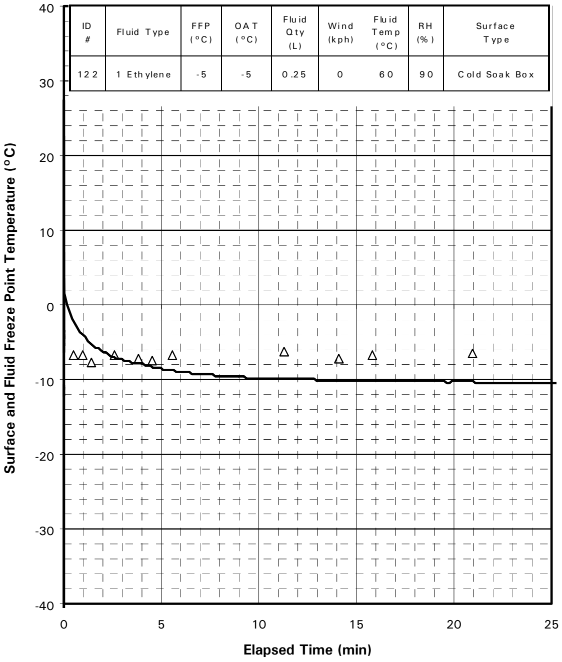
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
120	2 Propylene	-5	-5	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 121



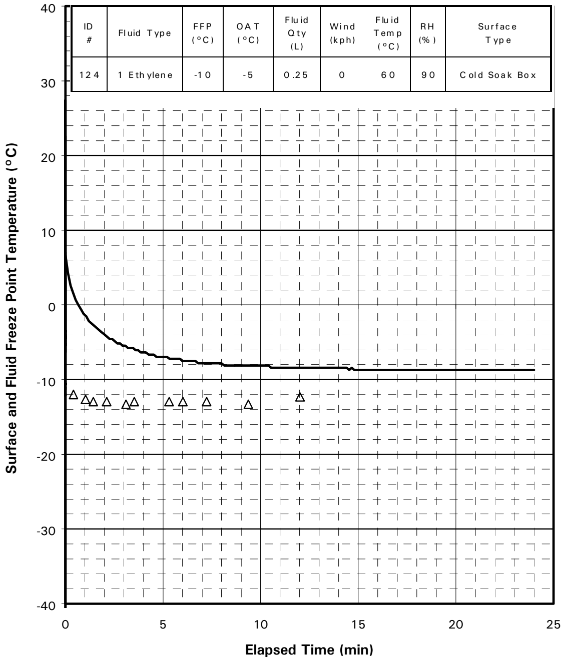
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
121	I Ethylene	-5	-5	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 122



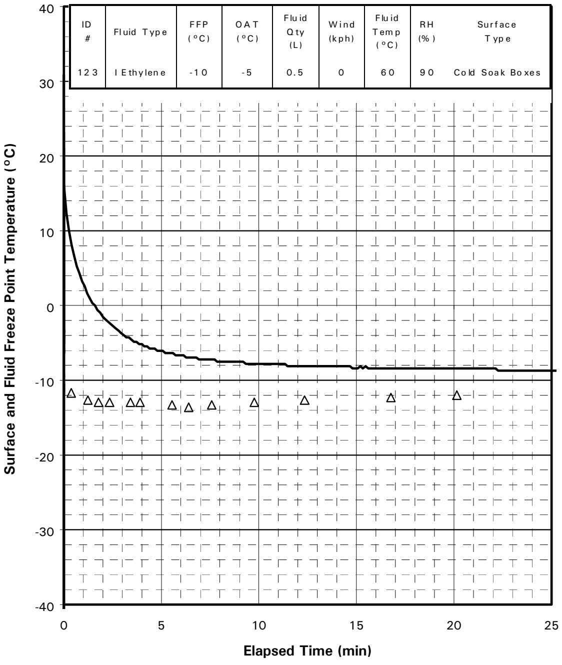
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
122	1 Ethylene	-5	-5	0.25	0	60	90	Cold Soak Box

Fluid Freeze Point and Surface Temperature Profile
ID# 124



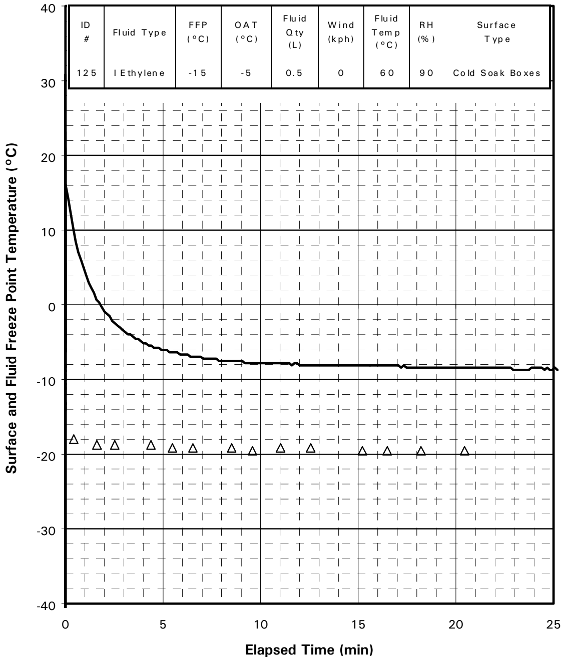
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
124	1 Ethylene	-10	-5	0.25	0	60	90	Cold Soak Box

Fluid Freeze Point and Surface Temperature Profile
ID# 123



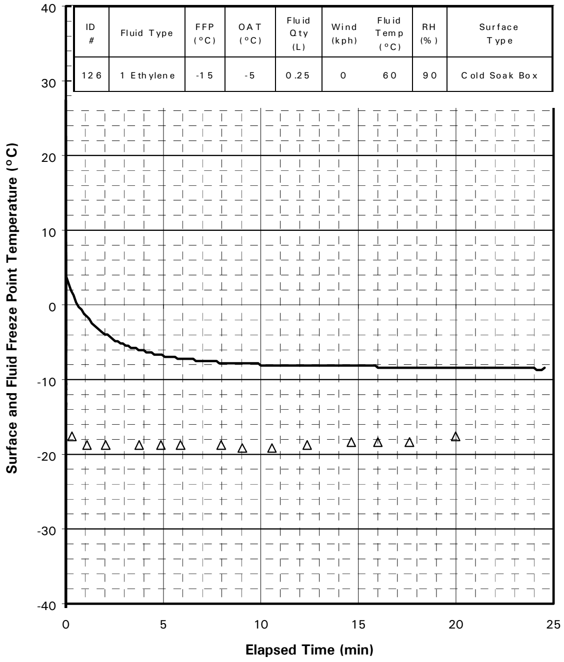
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
123	I Ethylene	-10	-5	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 125



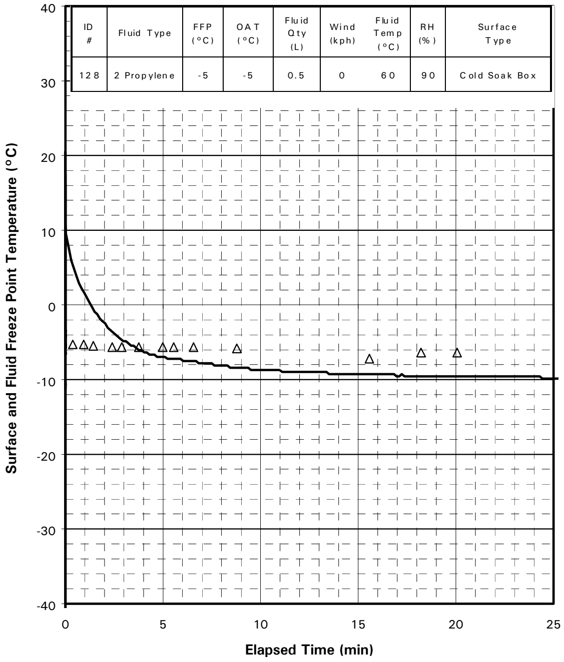
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
125	I Ethylene	-15	-5	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 126



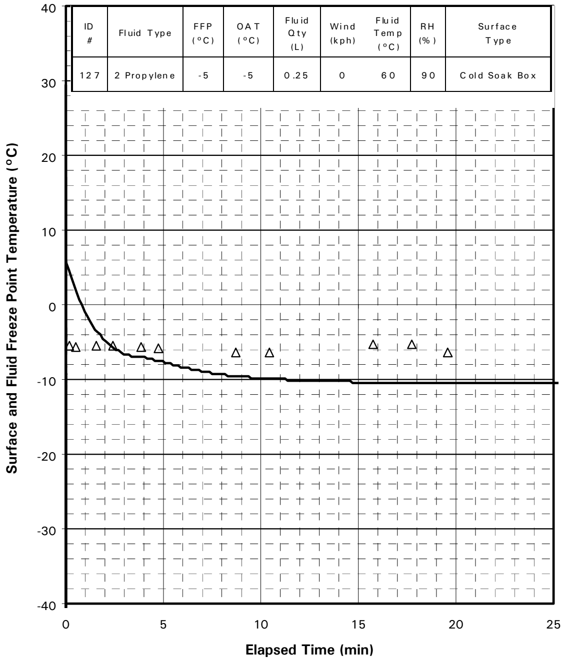
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
126	1 Ethylene	-15	-5	0.25	0	60	90	Cold Soak Box

Fluid Freeze Point and Surface Temperature Profile
ID# 128



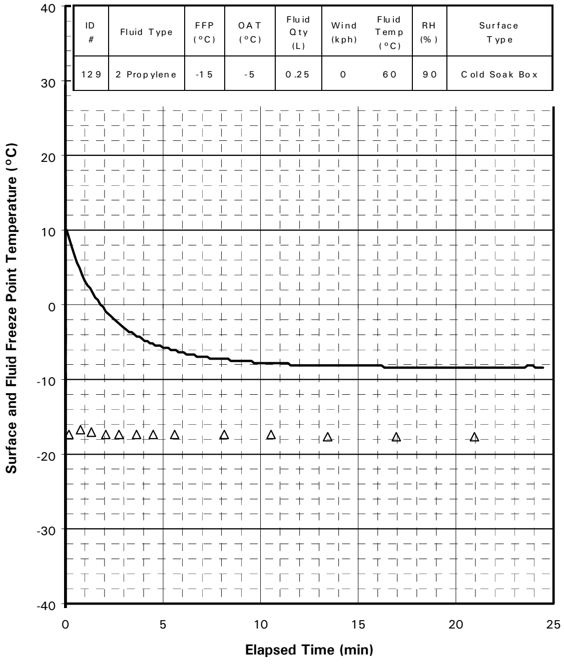
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
128	2 Propylene	-5	-5	0.5	0	60	90	Cold Soak Box

Fluid Freeze Point and Surface Temperature Profile
ID# 127



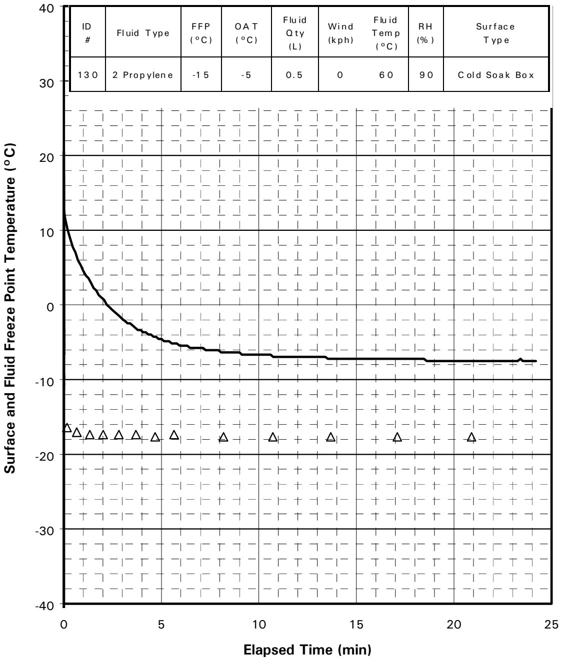
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
127	2 Propylene	-5	-5	0.25	0	60	90	Cold Soak Box

Fluid Freeze Point and Surface Temperature Profile
ID# 129

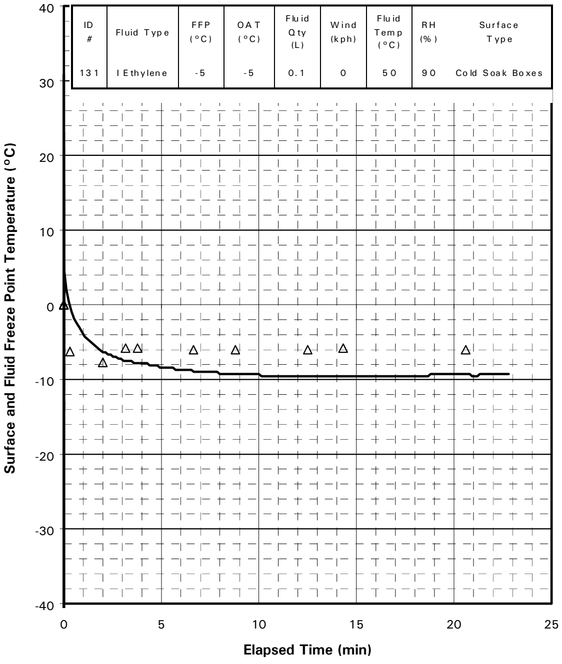


ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
129	2 Propylene	-15	-5	0.25	0	60	90	Cold Soak Box

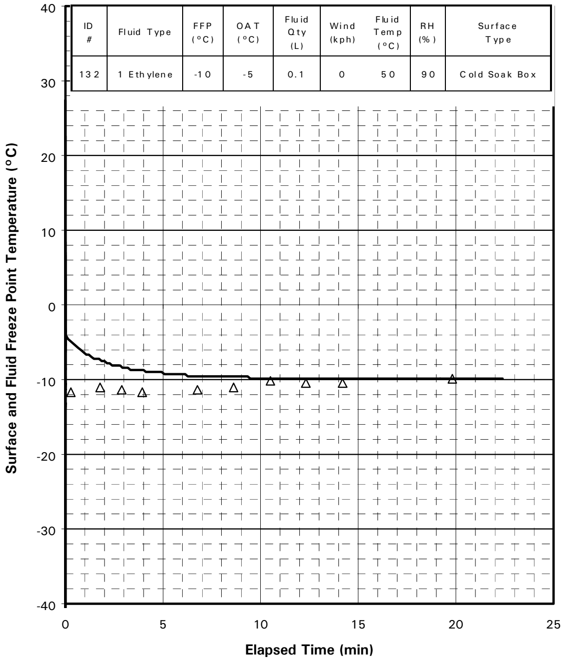
Fluid Freeze Point and Surface Temperature Profile
ID# 130



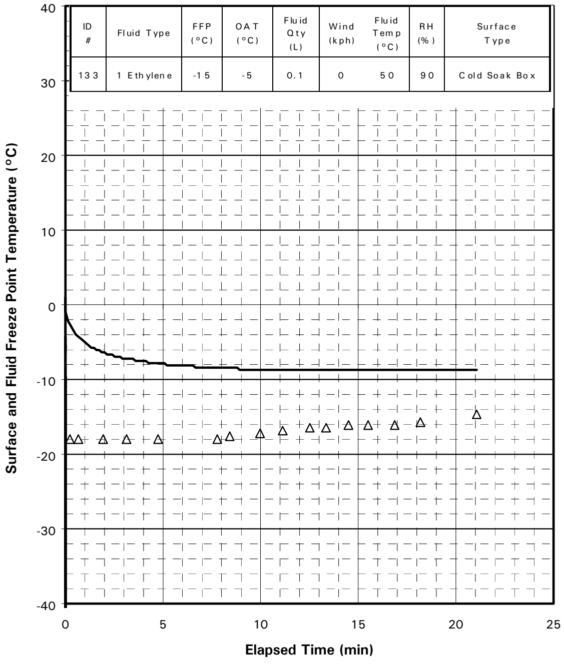
Fluid Freeze Point and Surface Temperature Profile
ID# 131



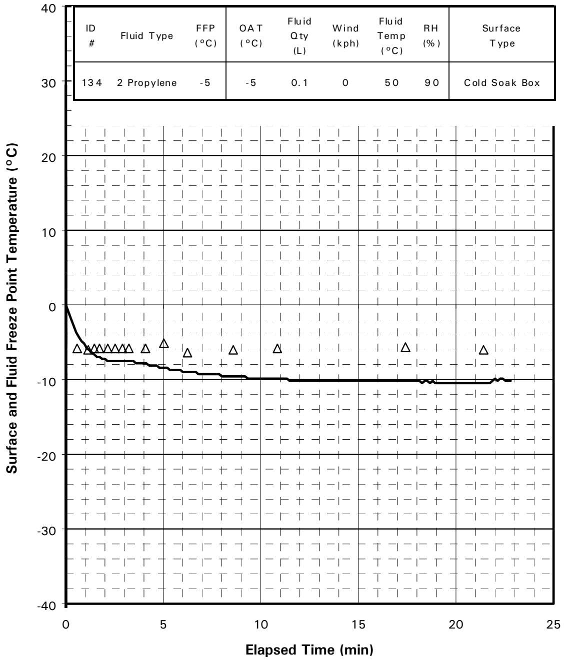
Fluid Freeze Point and Surface Temperature Profile
ID# 132



Fluid Freeze Point and Surface Temperature Profile
ID# 133

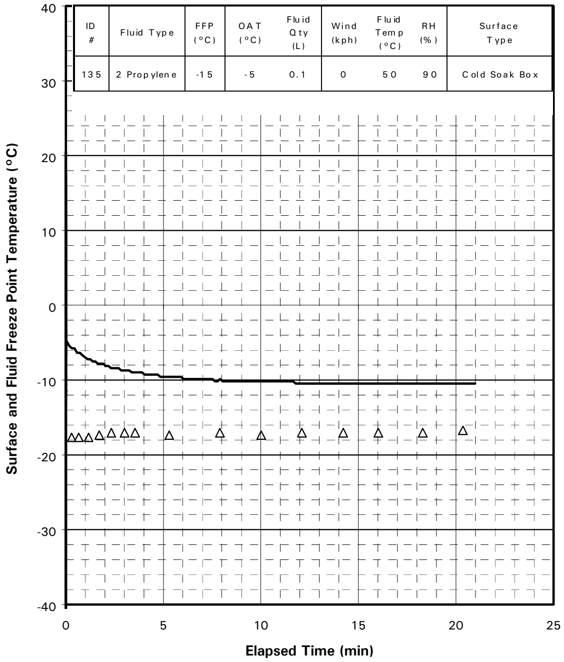


Fluid Freeze Point and Surface Temperature Profile
ID# 134



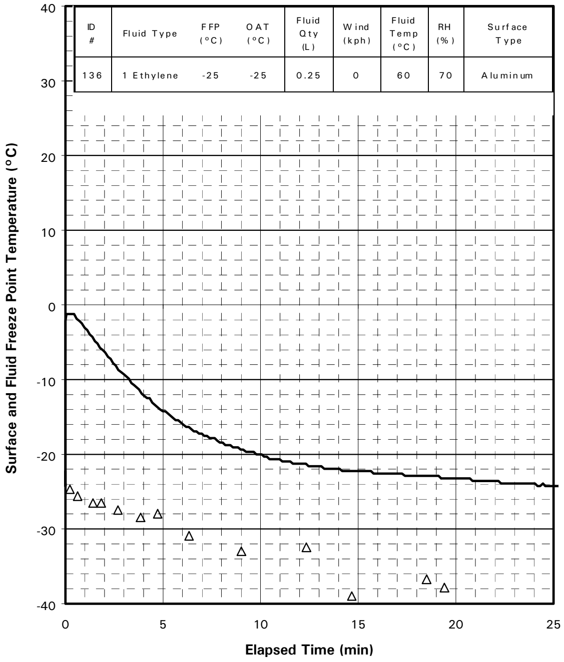
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
134	2 Propylene	-5	-5	0.1	0	50	90	Cold Soak Box

Fluid Freeze Point and Surface Temperature Profile
ID# 135



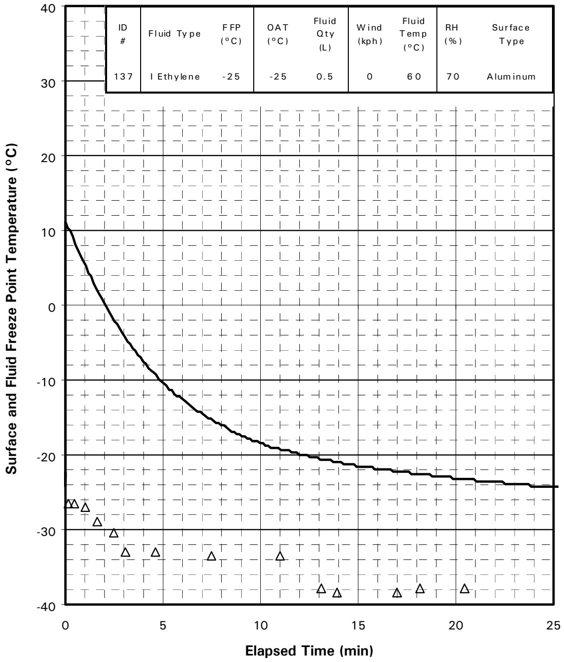
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
135	2 Propylene	-15	-5	0.1	0	50	90	Cold Soak Box

Fluid Freeze Point and Surface Temperature Profile
ID# 136



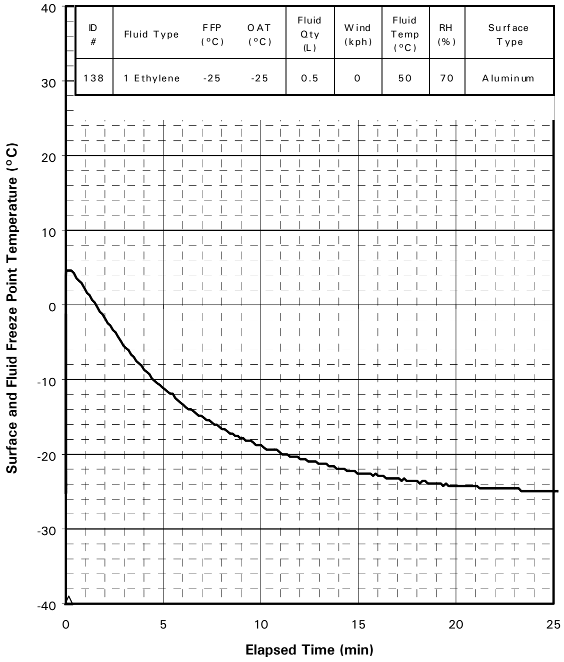
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
136	1 Ethylene	-25	-25	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 137



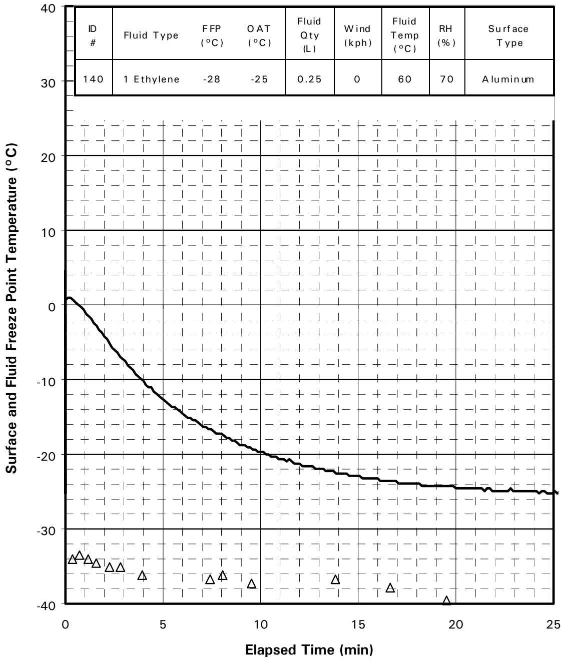
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
137	I Ethylene	-25	-25	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 138



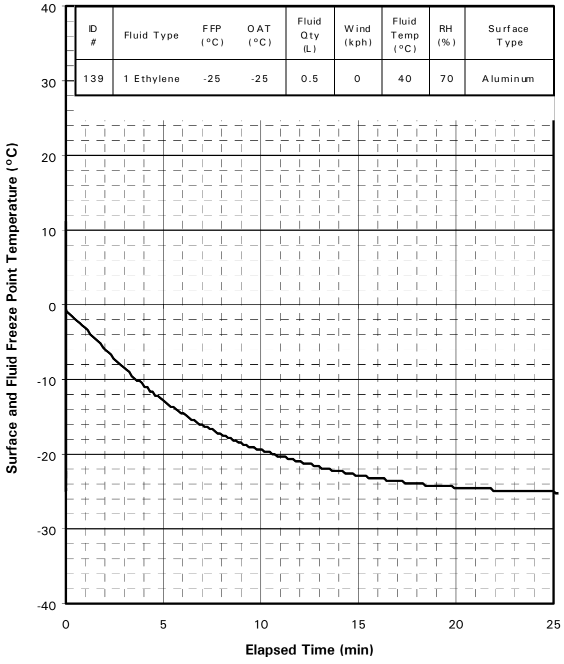
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
138	1 Ethylene	-25	-25	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 140



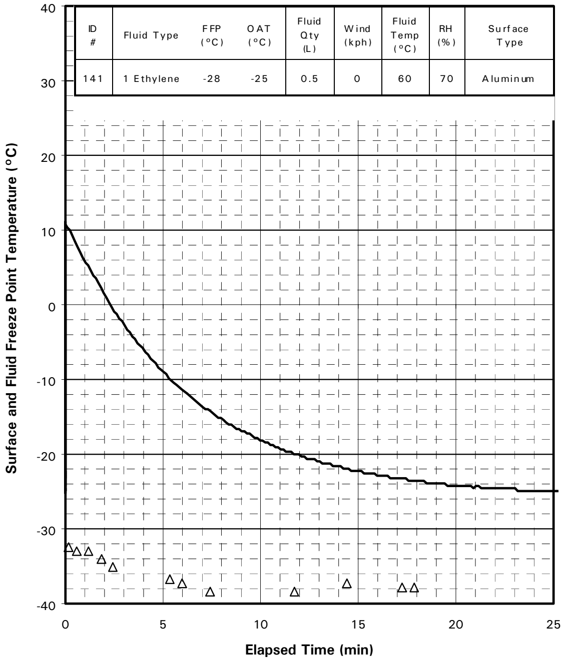
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
140	1 Ethylene	-28	-25	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 139



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
139	1 Ethylene	-25	-25	0.5	0	40	70	Aluminum

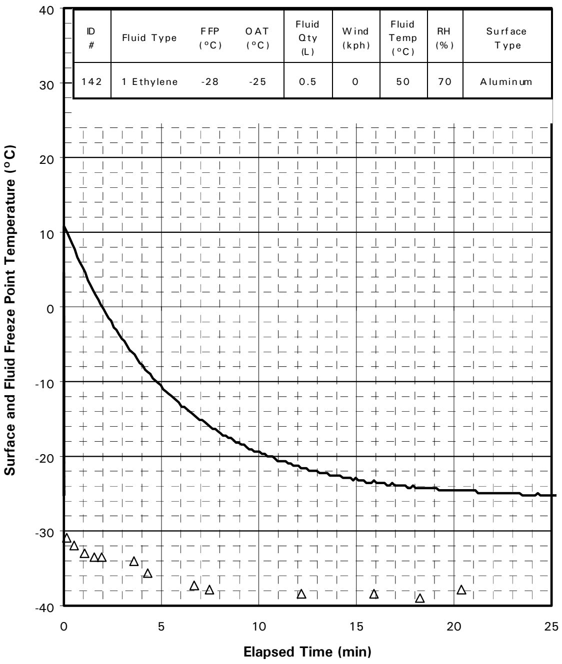
Fluid Freeze Point and Surface Temperature Profile
ID# 141



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
141	1 Ethylene	-28	-25	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

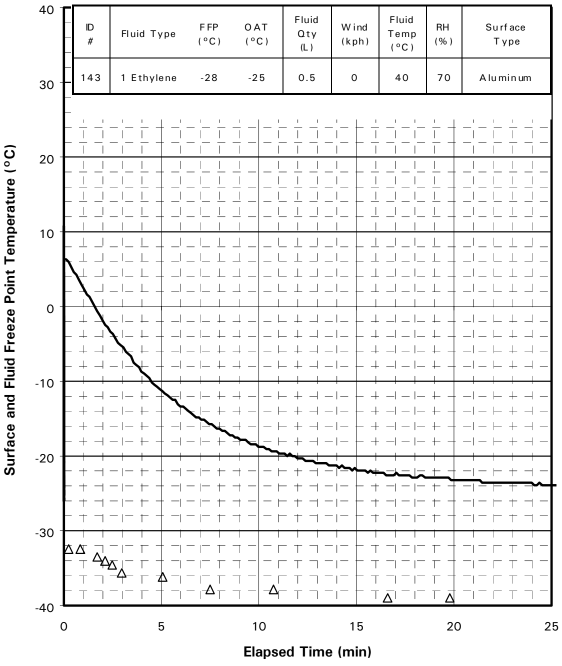
ID# 142



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
142	1 Ethylene	-28	-25	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

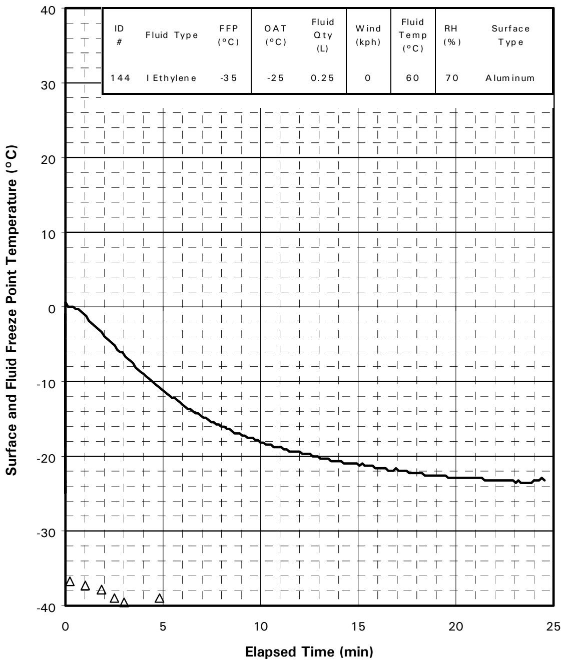
ID# 143



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
143	1 Ethylene	-28	-25	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

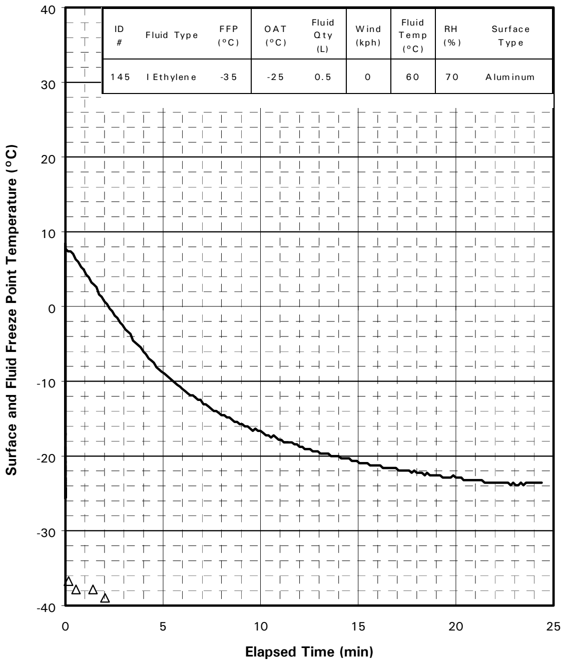
ID# 144



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
144	I Ethylene	-35	-25	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

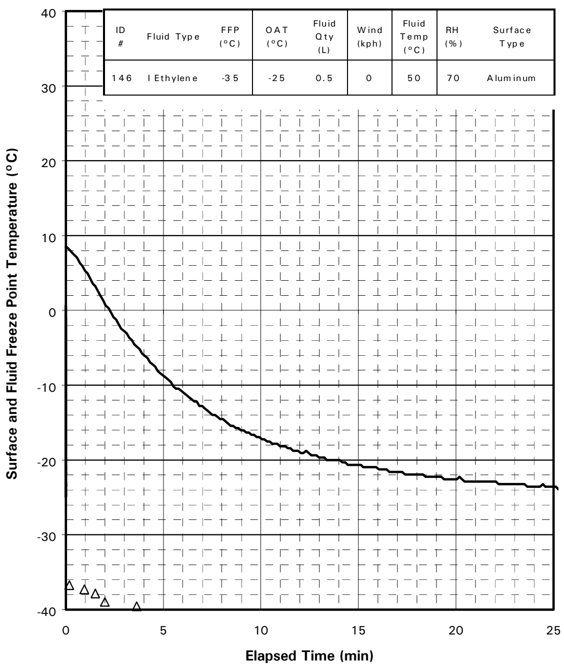
ID# 145



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
145	I Ethylene	-35	-25	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

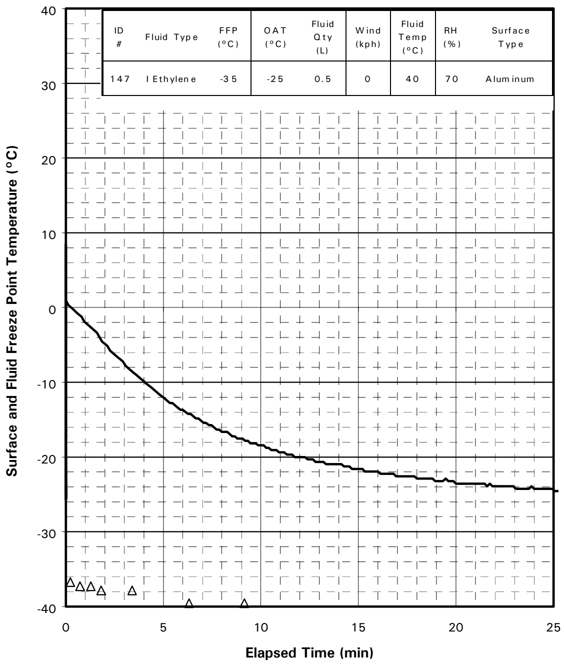
ID# 146



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
146	I Ethylene	-35	-25	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

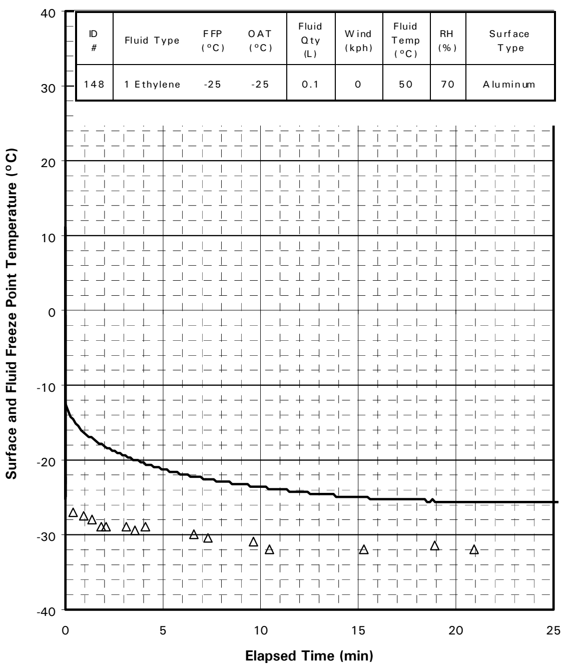
ID# 147



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
147	I Ethylene	-35	-25	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

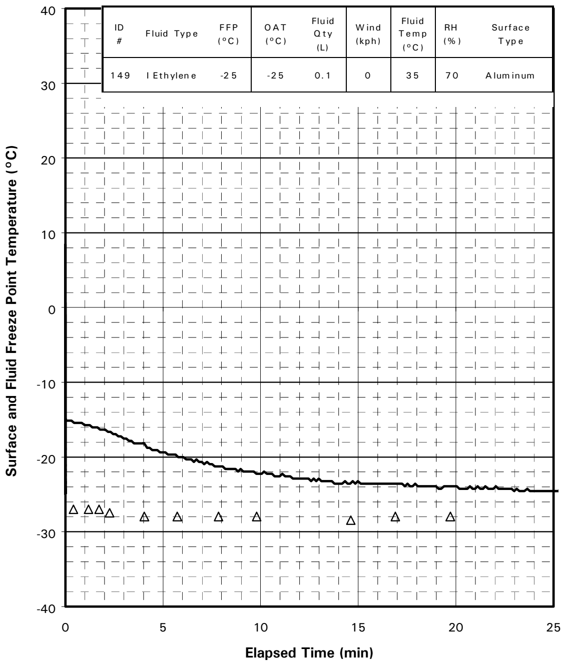
ID# 148



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
148	1 Ethylene	-25	-25	0.1	0	50	70	Aluminum

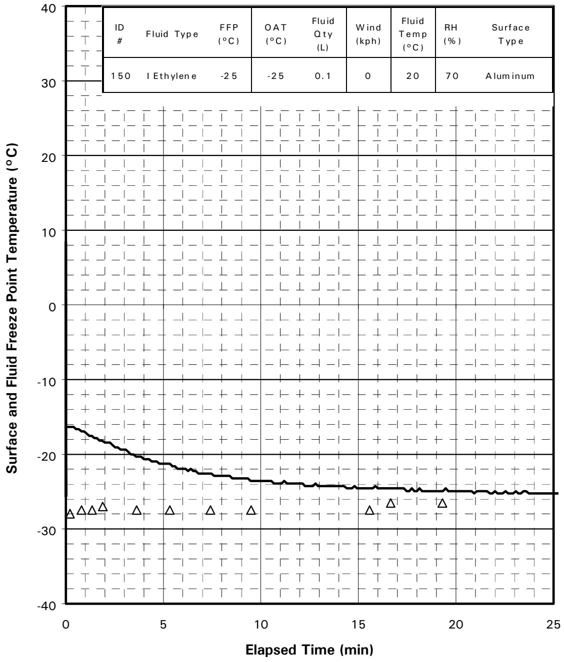
Fluid Freeze Point and Surface Temperature Profile

ID# 149



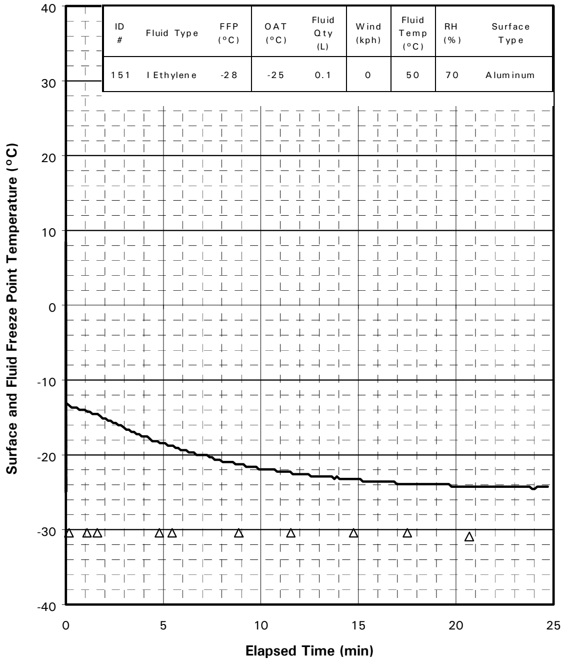
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
149	I Ethylene	-25	-25	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 150



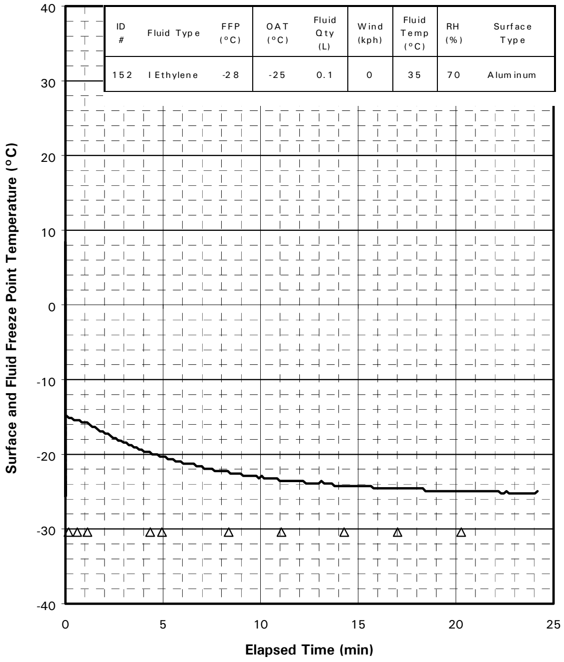
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
150	I Ethylene	-25	-25	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 151



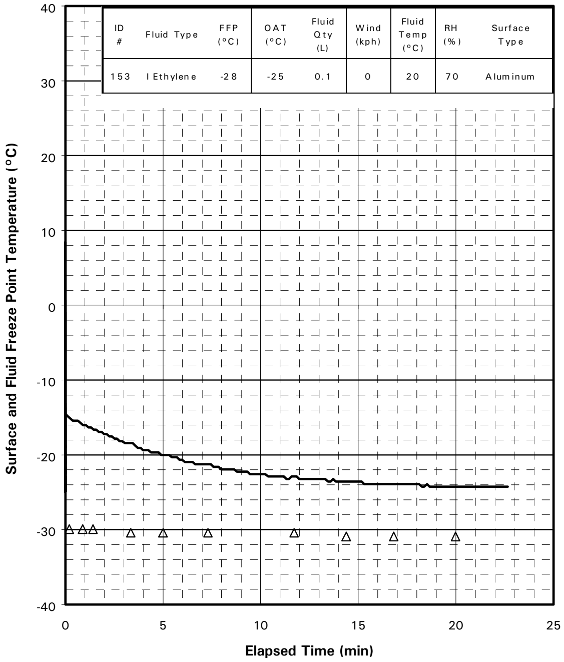
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
151	I Ethylene	-28	-25	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 152



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
152	I Ethylene	-28	-25	0.1	0	35	70	Aluminum

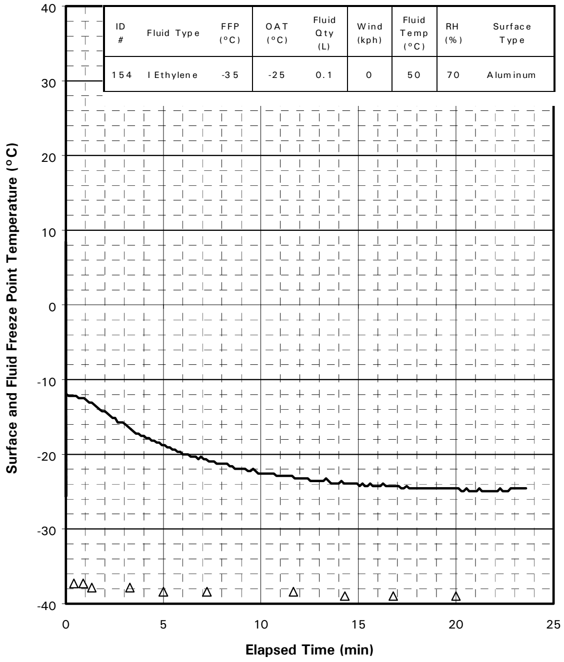
Fluid Freeze Point and Surface Temperature Profile
ID# 153



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
153	I Ethylene	-28	-25	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

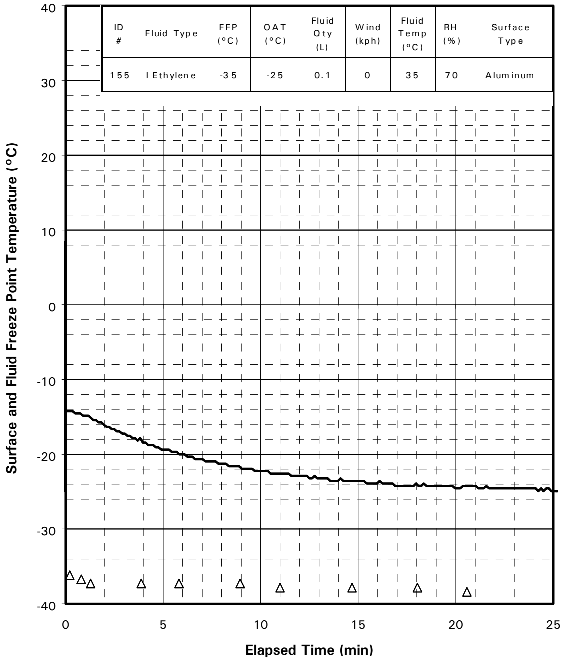
ID# 154



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
154	I Ethylene	-35	-25	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

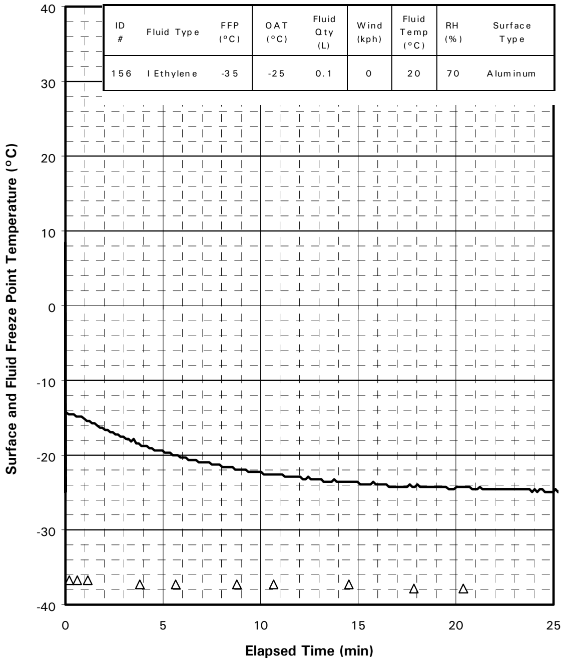
ID# 155



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
155	I Ethylene	-35	-25	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

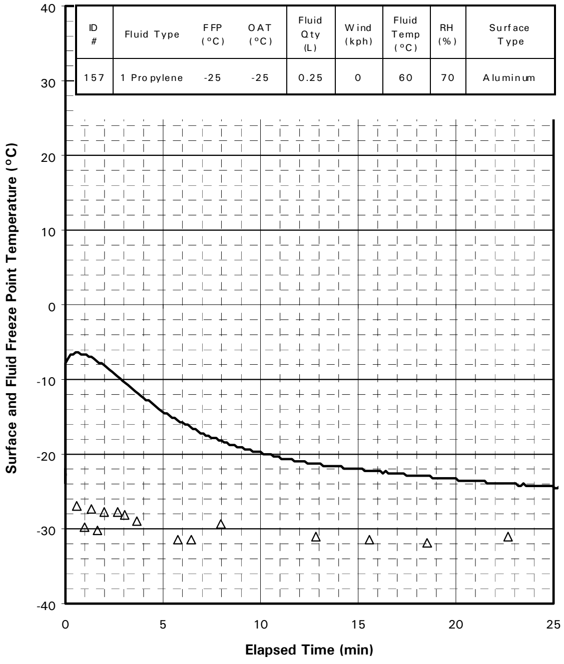
ID# 156



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
156	I Ethylene	-35	-25	0.1	0	20	70	Aluminum

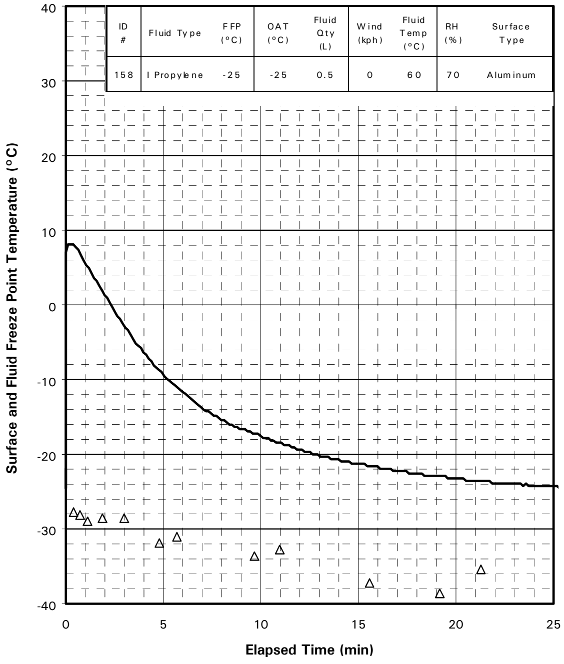
Fluid Freeze Point and Surface Temperature Profile

ID# 157



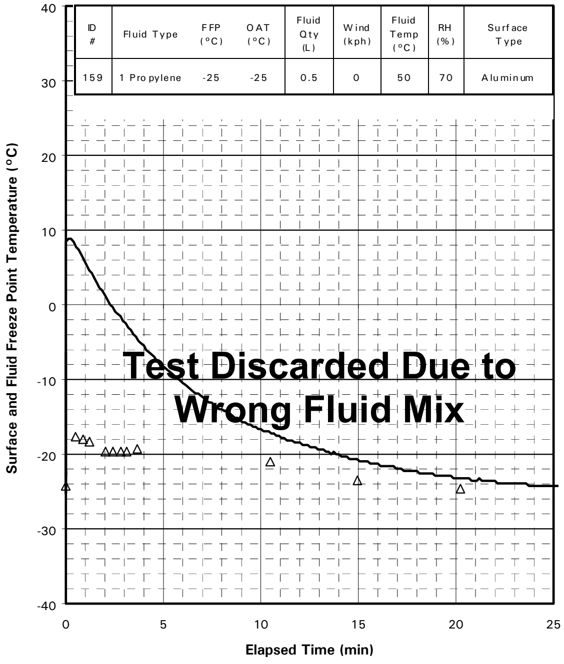
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
157	1 Propylene	-25	-25	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 158



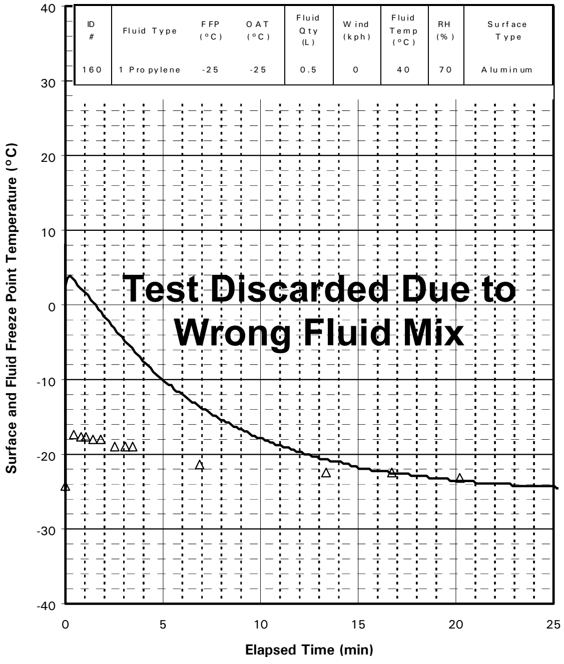
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
158	I Propylene	-25	-25	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 159



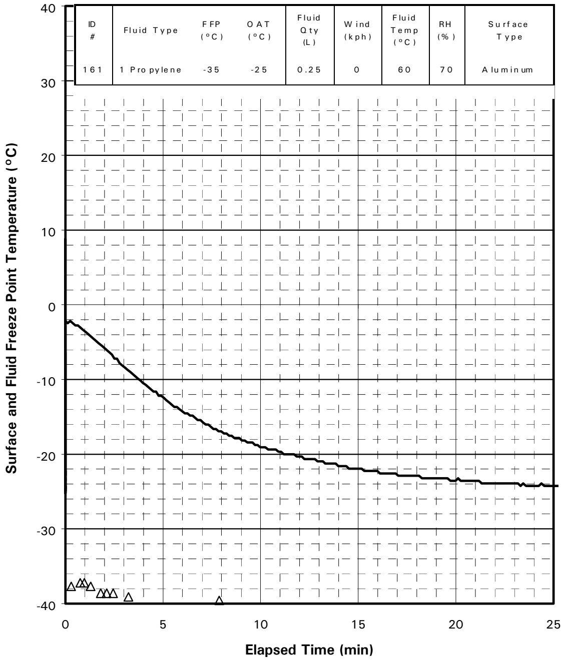
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
159	1 Propylene	-25	-25	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 160



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
160	1 Propylene	-25	-25	0.5	0	40	70	Aluminum

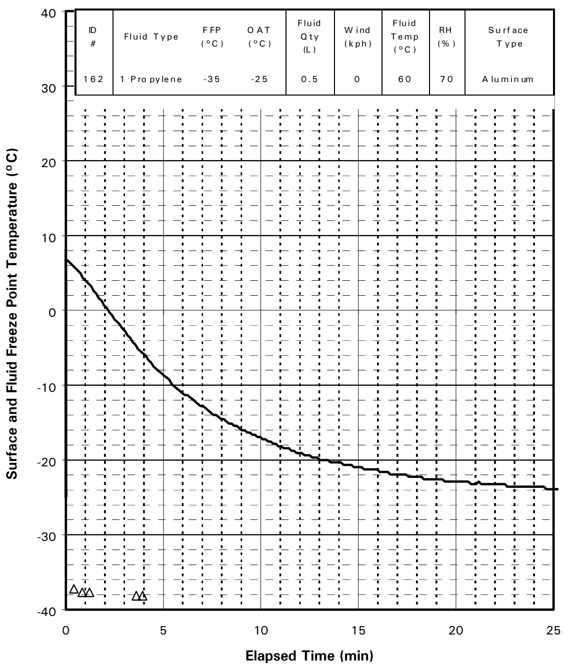
Fluid Freeze Point and Surface Temperature Profile
ID# 161



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
161	1 Propylene	-35	-25	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

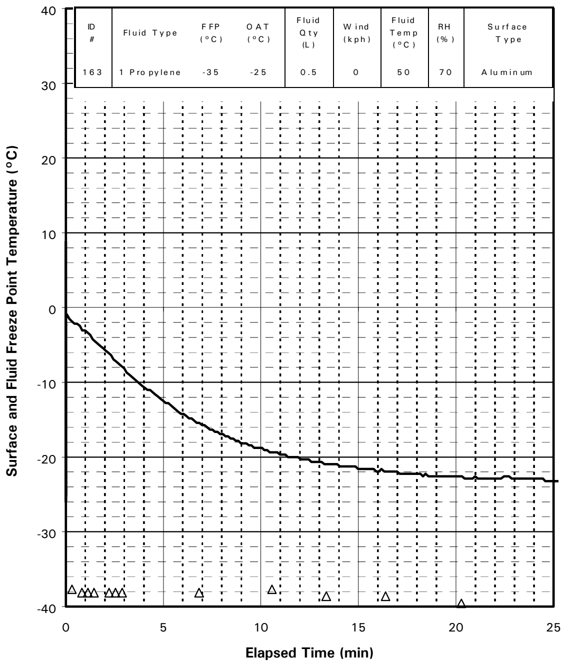
ID# 162



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
162	1 Propylene	-35	-25	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

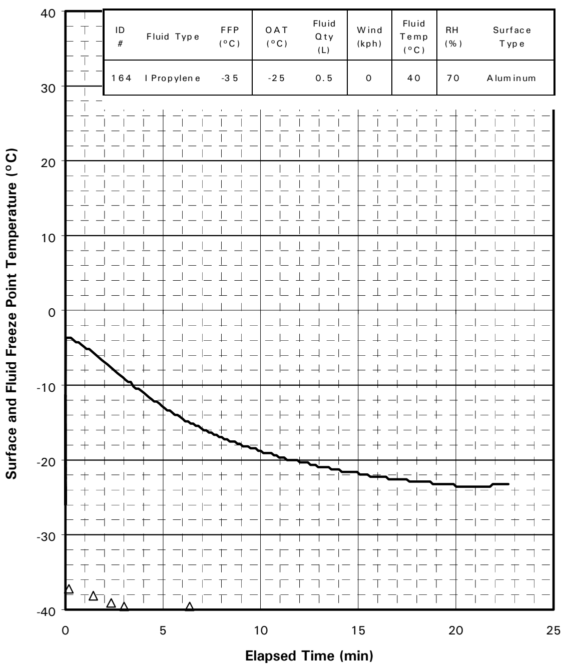
ID# 163



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
163	1 Propylene	-35	-25	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

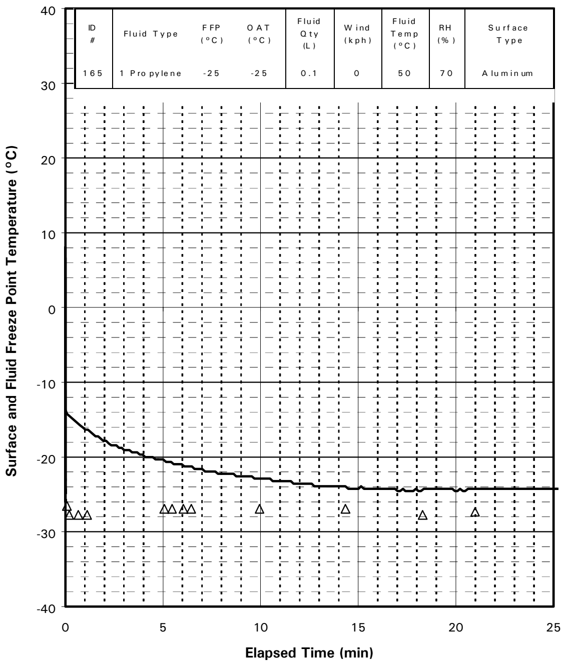
ID# 164



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
164	I Propylene	-35	-25	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

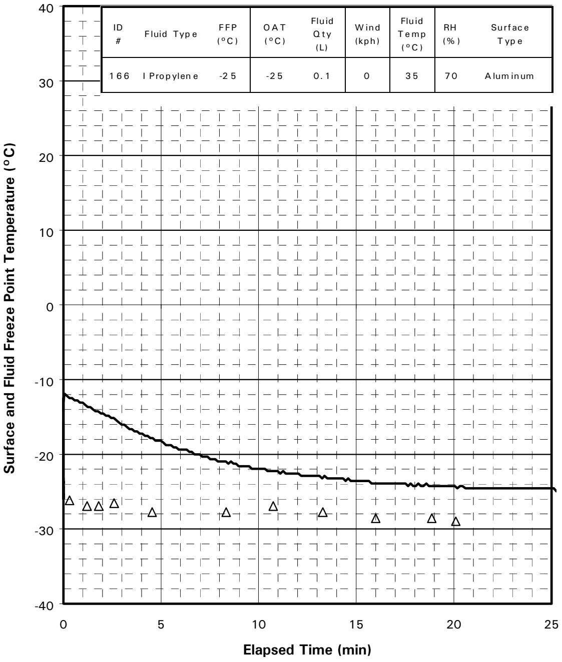
ID# 165



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
165	1 Propylene	-25	-25	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

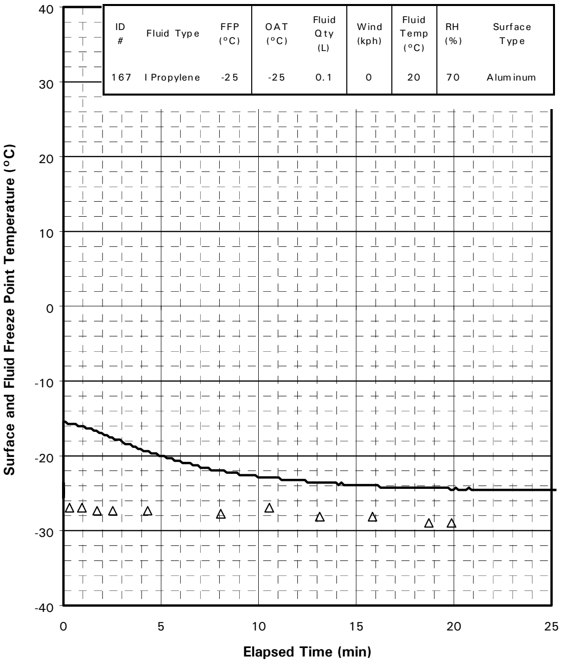
ID# 166



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
166	I Propylene	-25	-25	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

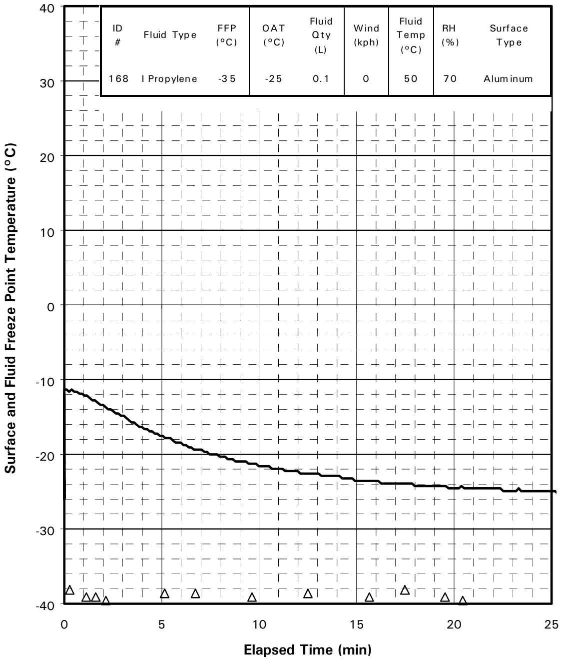
ID# 167



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
167	I Propylene	-25	-25	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

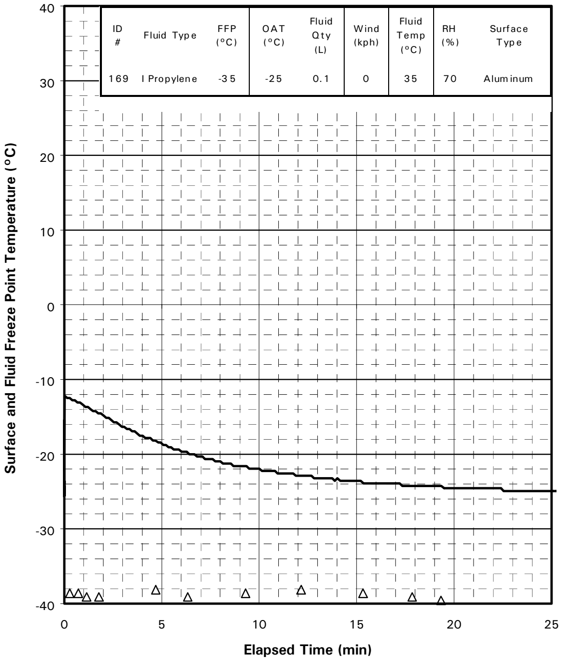
ID# 168



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
168	I Propylene	-35	-25	0.1	0	50	70	Aluminum

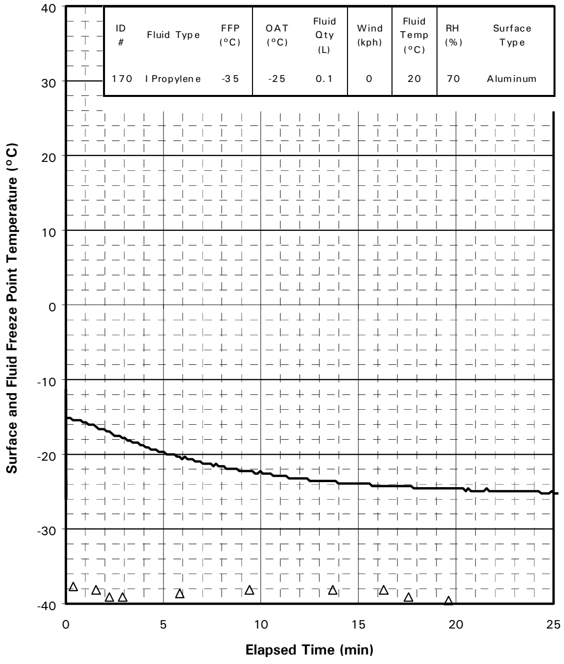
Fluid Freeze Point and Surface Temperature Profile

ID# 169



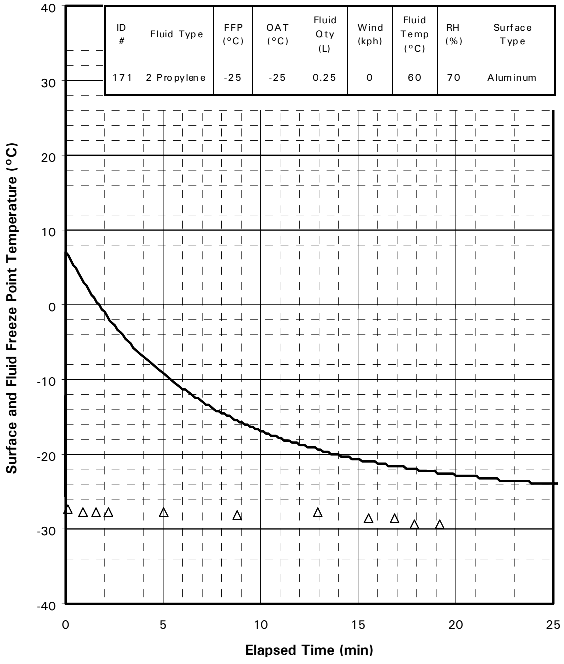
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
169	I Propylene	-35	-25	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 170



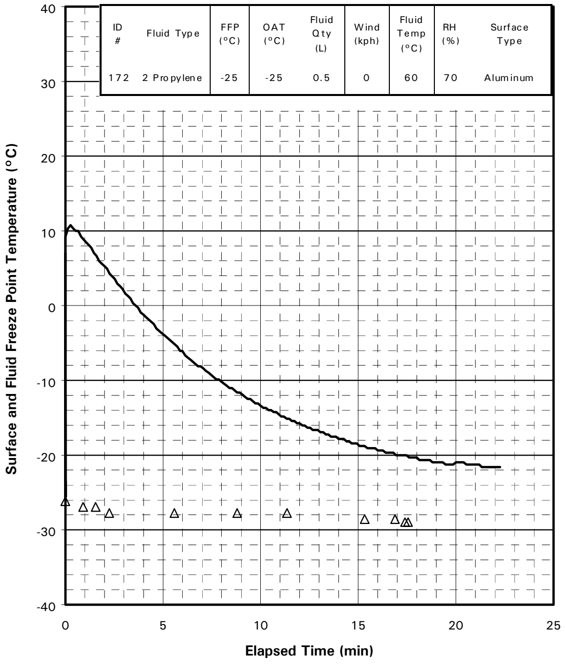
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
170	I Propylene	-35	-25	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 171



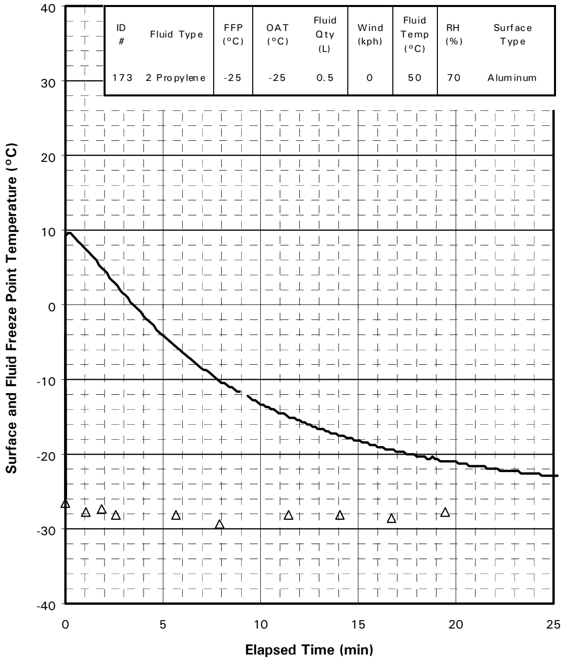
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
171	2 Propylene	-25	-25	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 172



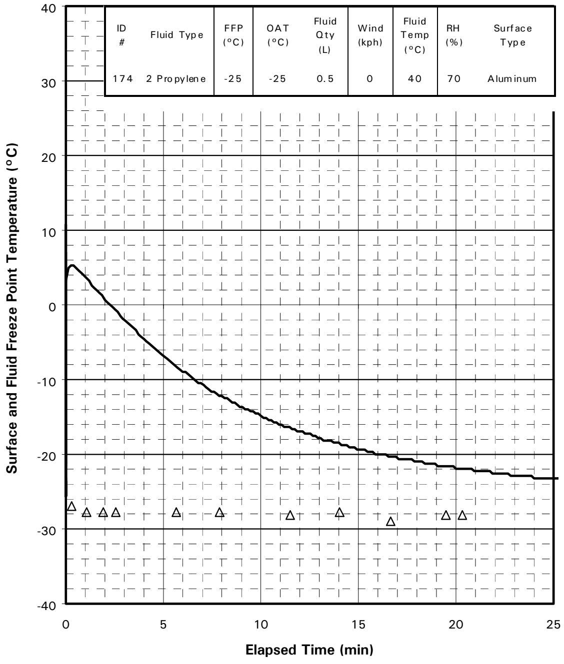
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
172	2 Propylene	-25	-25	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 173



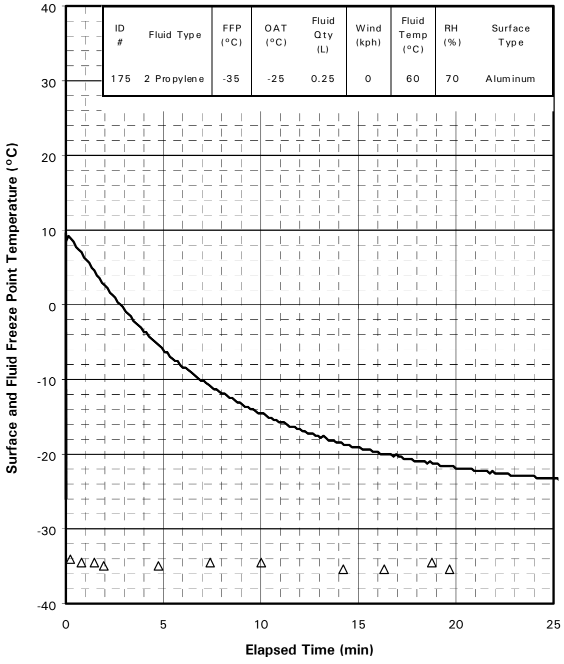
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
173	2 Propylene	-25	-25	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 174



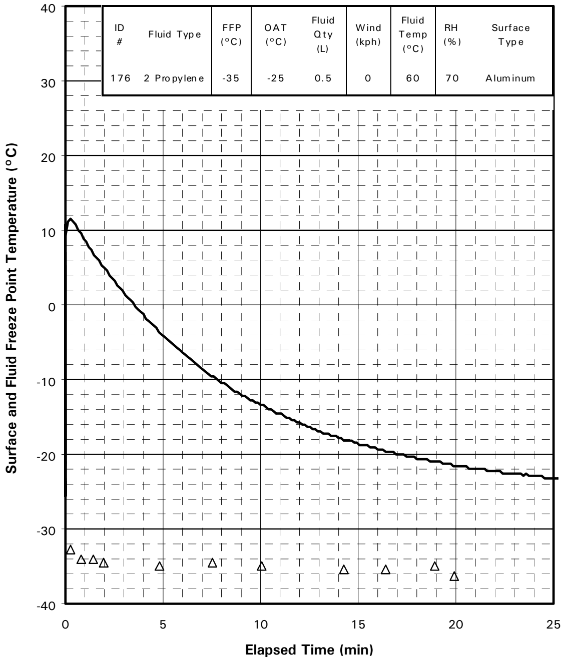
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
174	2 Propylene	-25	-25	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 175



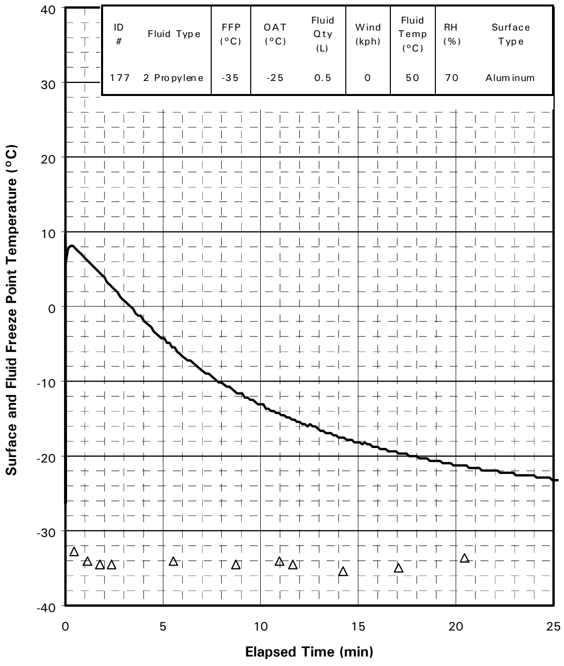
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
175	2 Propylene	-35	-25	0.25	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 176



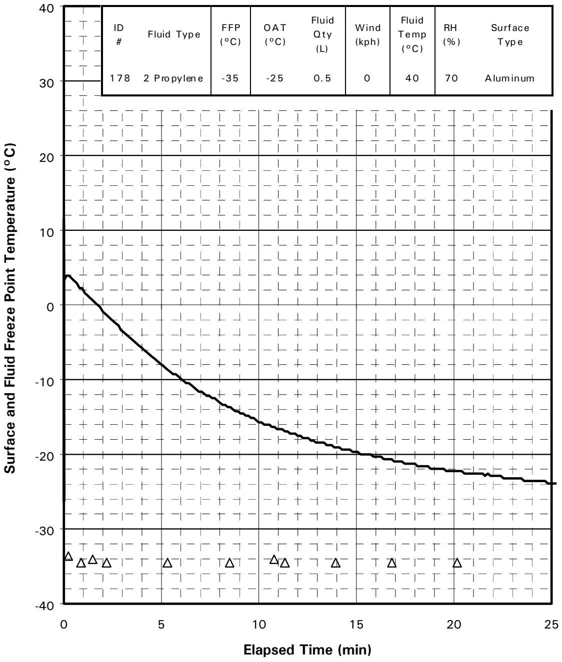
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
176	2 Propylene	-35	-25	0.5	0	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 177



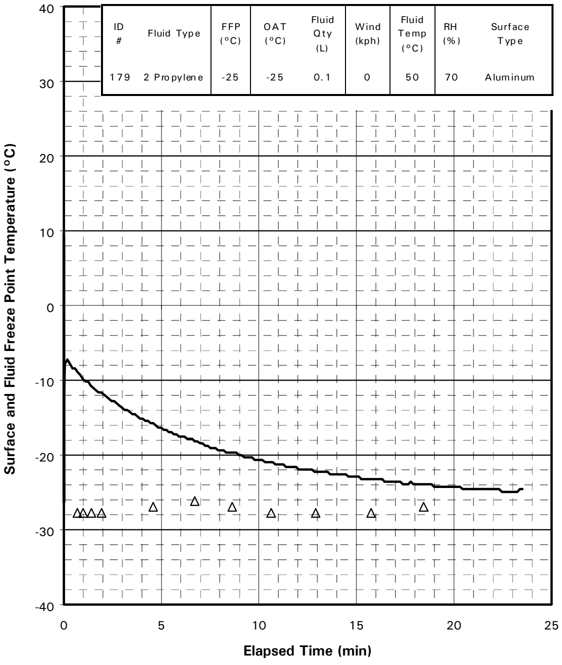
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
177	2 Propylene	-35	-25	0.5	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 178



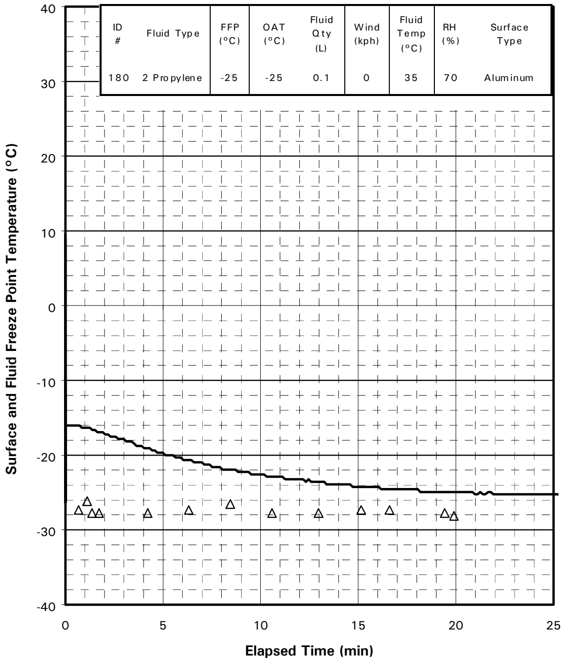
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
178	2 Propylene	-35	-25	0.5	0	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 179



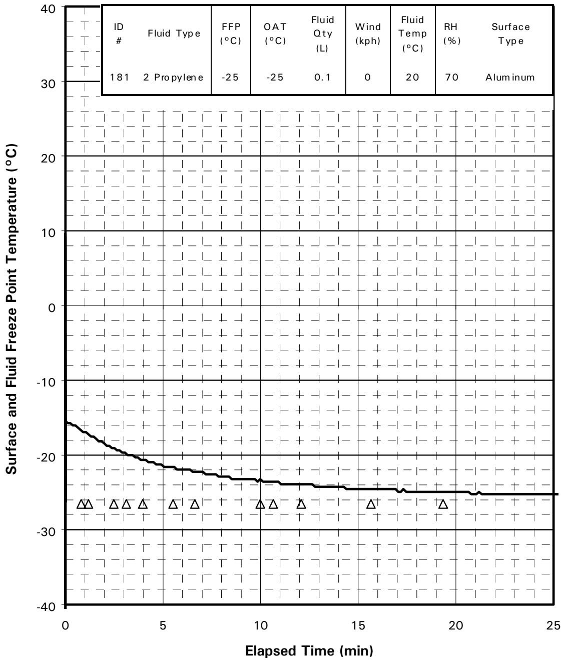
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
179	2 Propylene	-25	-25	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 180



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
180	2 Propylene	-25	-25	0.1	0	35	70	Aluminum

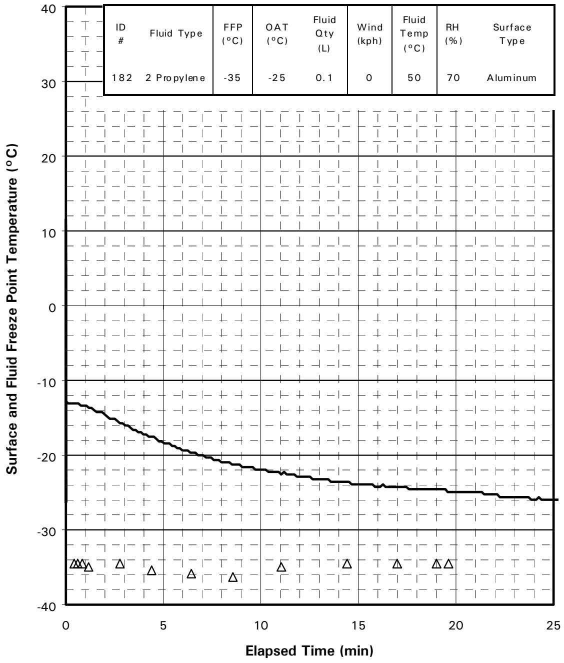
Fluid Freeze Point and Surface Temperature Profile
ID# 181



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
181	2 Propylene	-25	-25	0.1	0	20	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

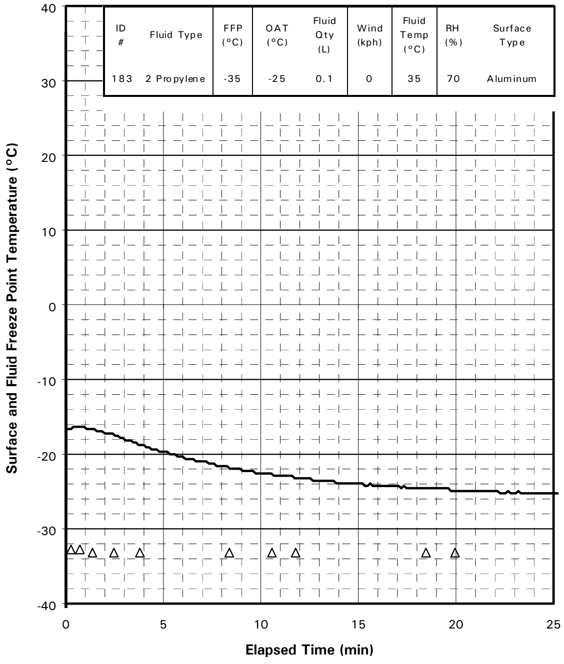
ID# 182



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
182	2 Propylene	-35	-25	0.1	0	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

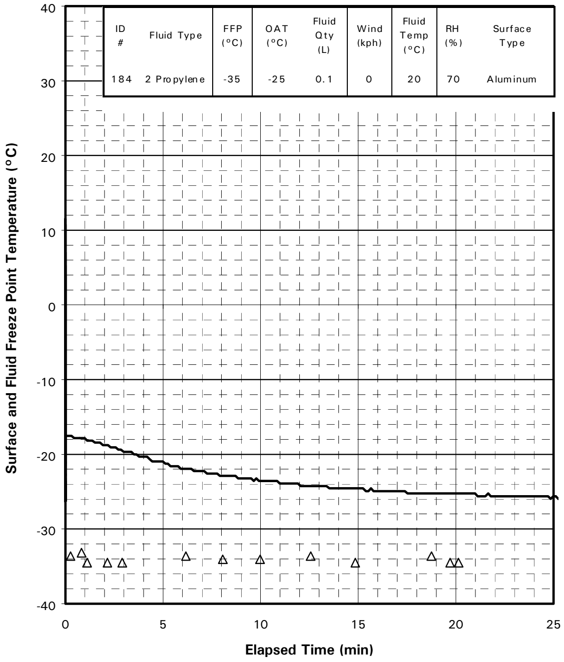
ID# 183



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
183	2 Propylene	-35	-25	0.1	0	35	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

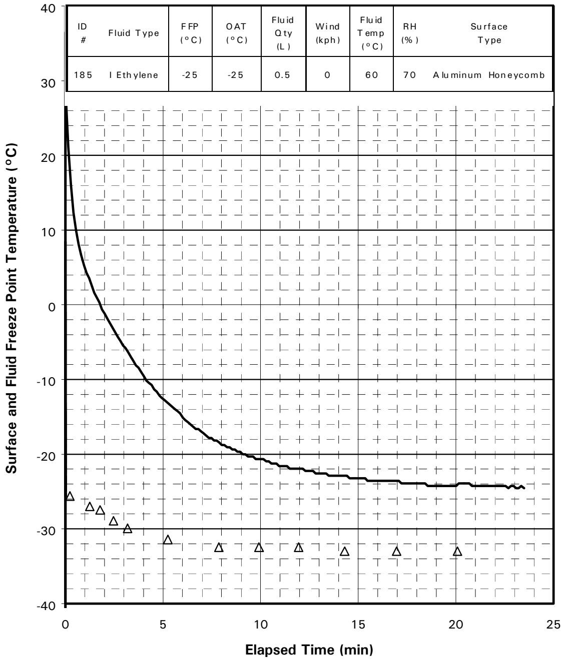
ID# 184



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
184	2 Propylene	-35	-25	0.1	0	20	70	Aluminum

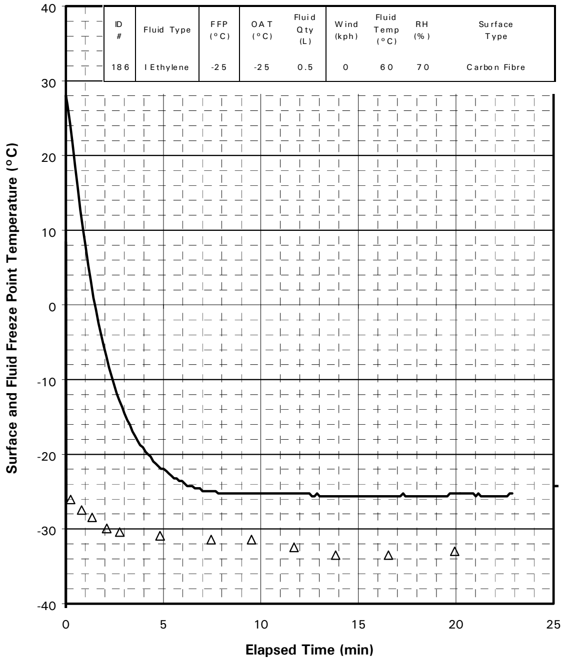
Fluid Freeze Point and Surface Temperature Profile

ID# 185



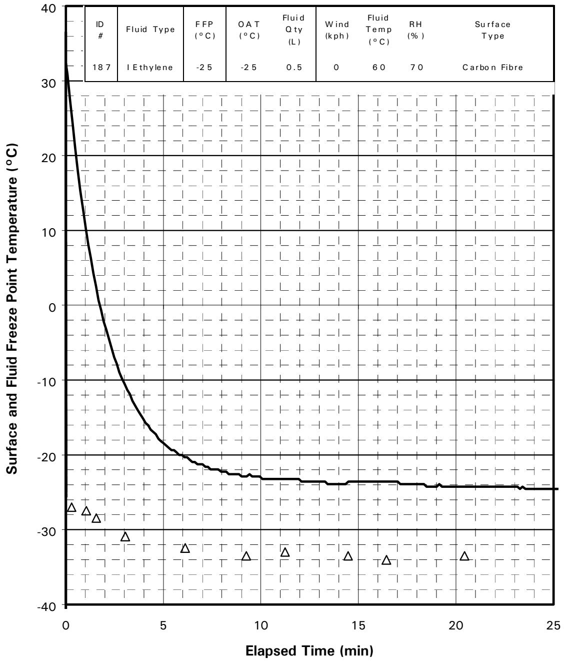
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
185	I Ethylene	-25	-25	0.5	0	60	70	Aluminum Honeycomb

Fluid Freeze Point and Surface Temperature Profile
ID# 186



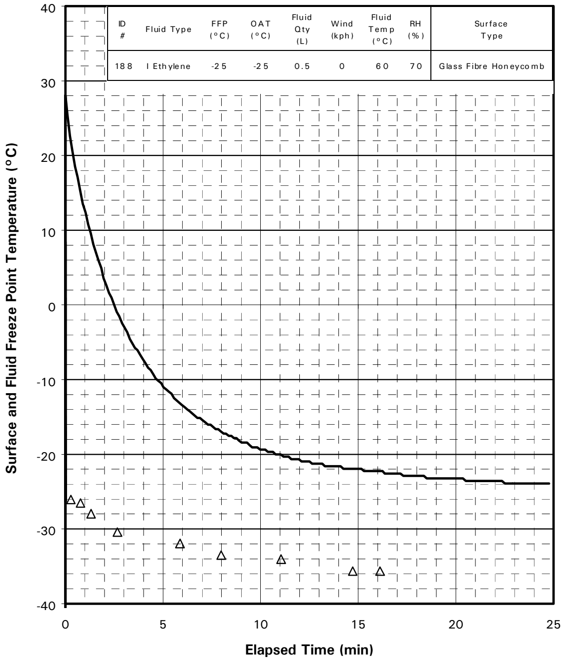
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
186	I Ethylene	-25	-25	0.5	0	60	70	Carbon Fibre

Fluid Freeze Point and Surface Temperature Profile
ID# 187



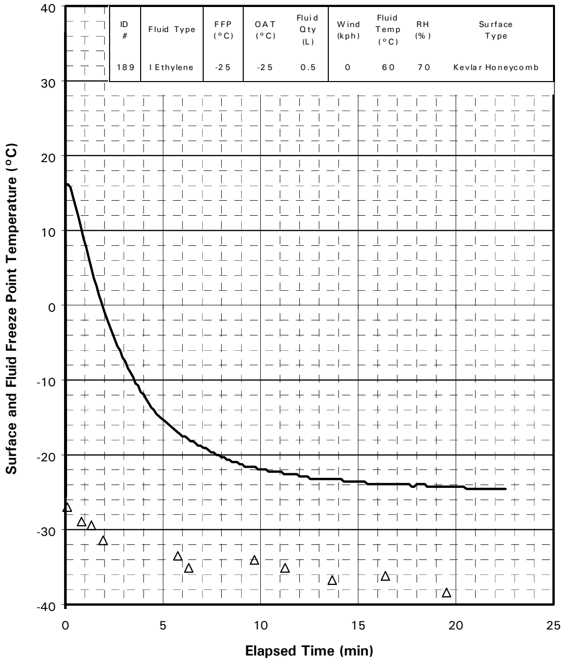
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
187	I Ethylene	-25	-25	0.5	0	60	70	Carbon Fibre

Fluid Freeze Point and Surface Temperature Profile
ID# 188



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
188	I Ethylene	-25	-25	0.5	0	60	70	Glass Fibre Honeycomb

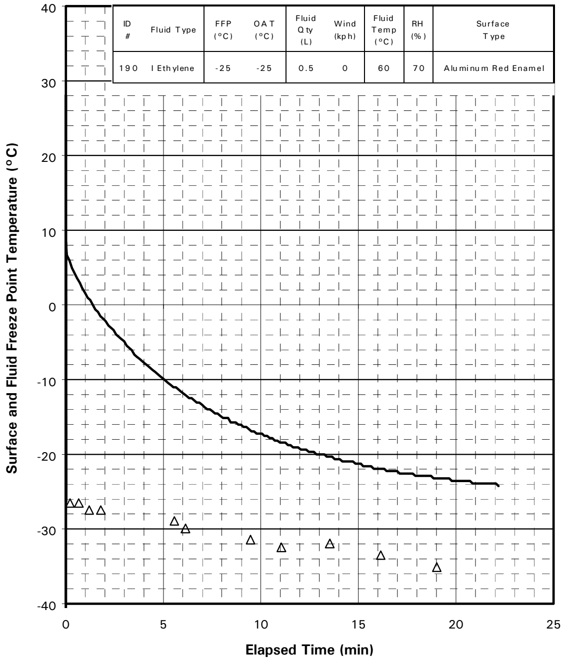
Fluid Freeze Point and Surface Temperature Profile
ID# 189



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
189	I Ethylene	-25	-25	0.5	0	60	70	Kevlar Honeycomb

Fluid Freeze Point and Surface Temperature Profile

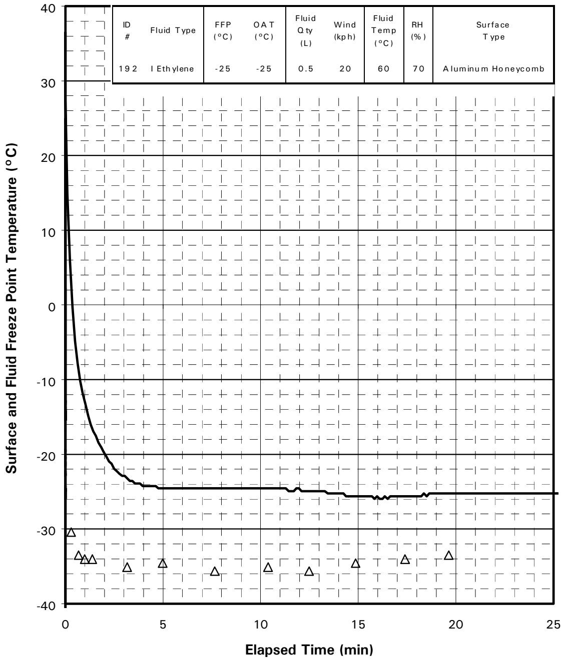
ID# 190



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
190	I Ethylene	-25	-25	0.5	0	60	70	Aluminum Red Enamel

Fluid Freeze Point and Surface Temperature Profile

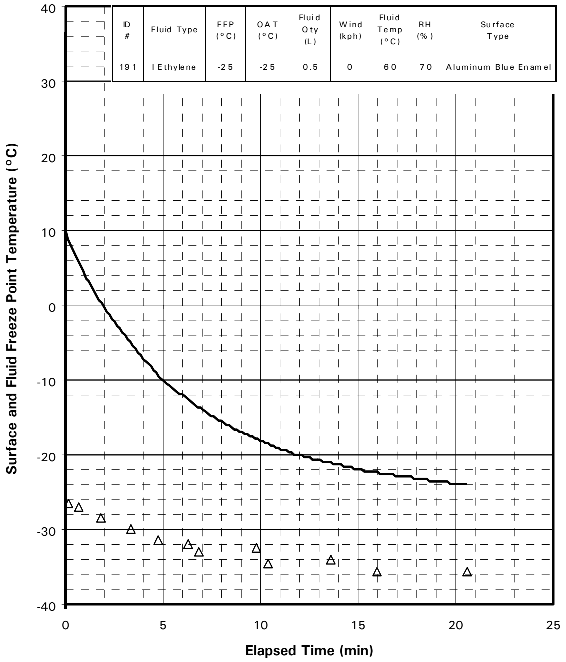
ID# 192



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
192	I Ethylene	-25	-25	0.5	20	60	70	Aluminum Honeycomb

Fluid Freeze Point and Surface Temperature Profile

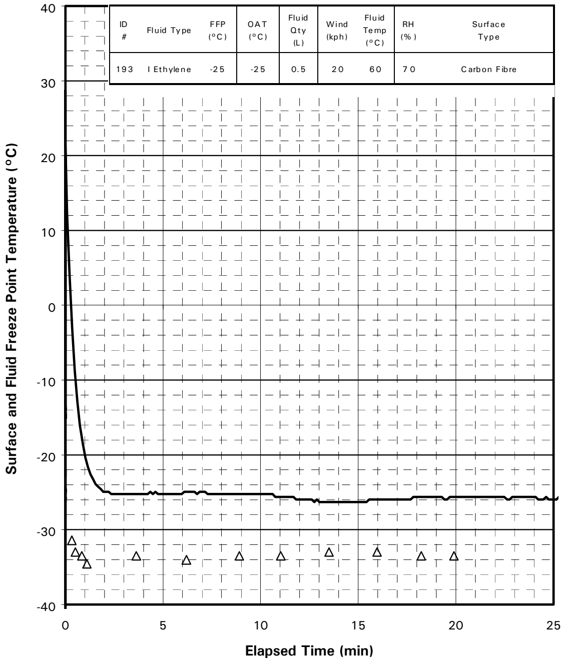
ID# 191



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
191	I Ethylene	-25	-25	0.5	0	60	70	Aluminum Blue Enamel

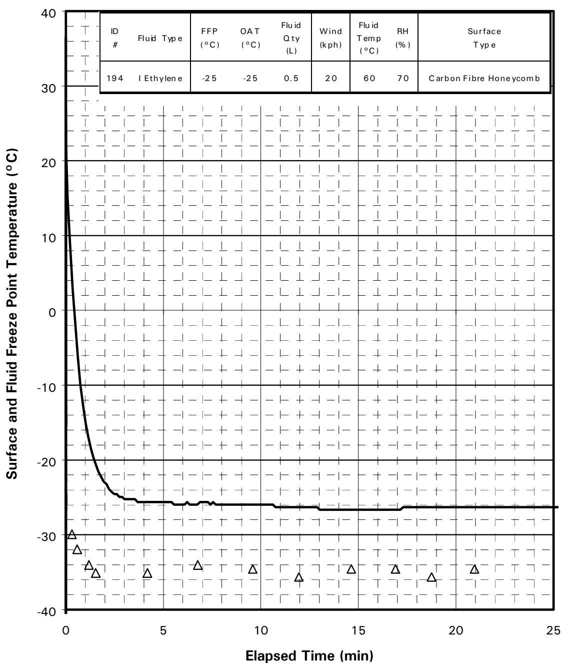
Fluid Freeze Point and Surface Temperature Profile

ID# 193



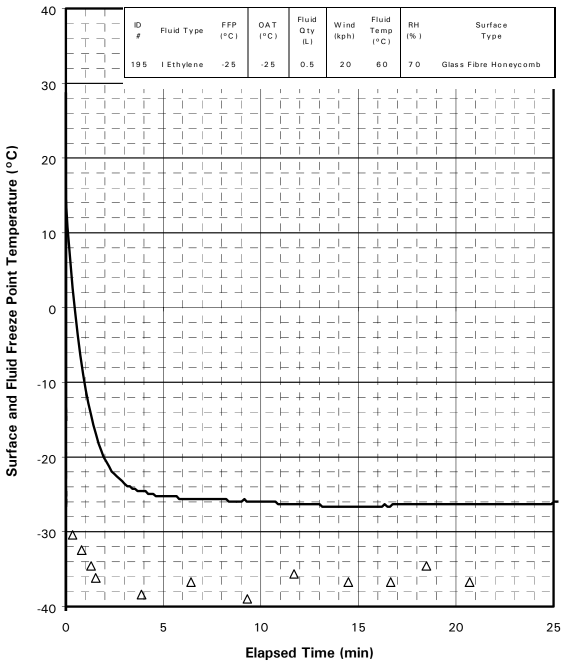
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
193	I Ethylene	-25	-25	0.5	20	60	70	Carbon Fibre

Fluid Freeze Point and Surface Temperature Profile
ID# 194



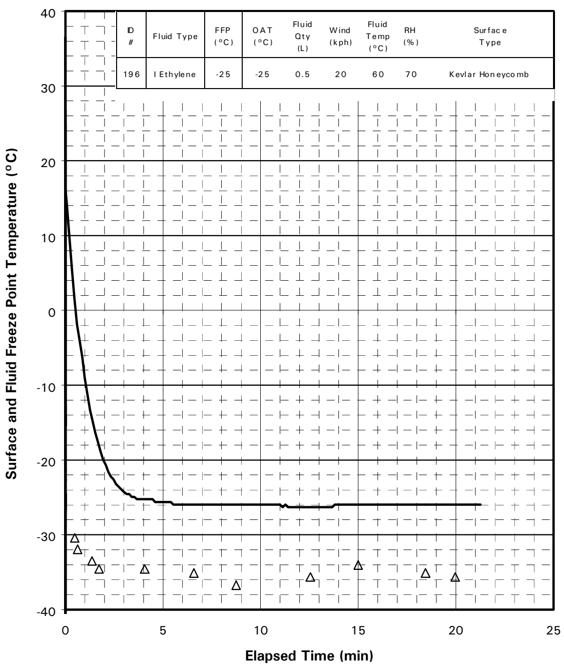
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
194	I Ethylene	-25	-25	0.5	20	60	70	Carbon Fibre Honeycomb

Fluid Freeze Point and Surface Temperature Profile
ID# 195



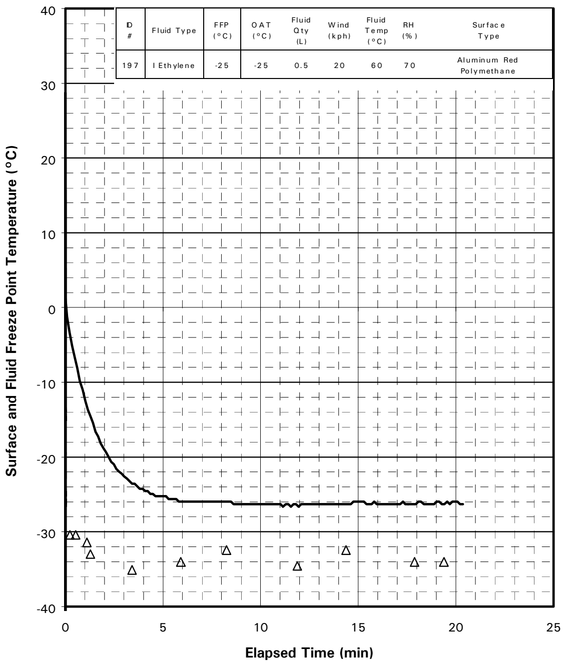
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
195	I Ethylene	-25	-25	0.5	20	60	70	Glass Fibre Honeycomb

Fluid Freeze Point and Surface Temperature Profile
ID# 196



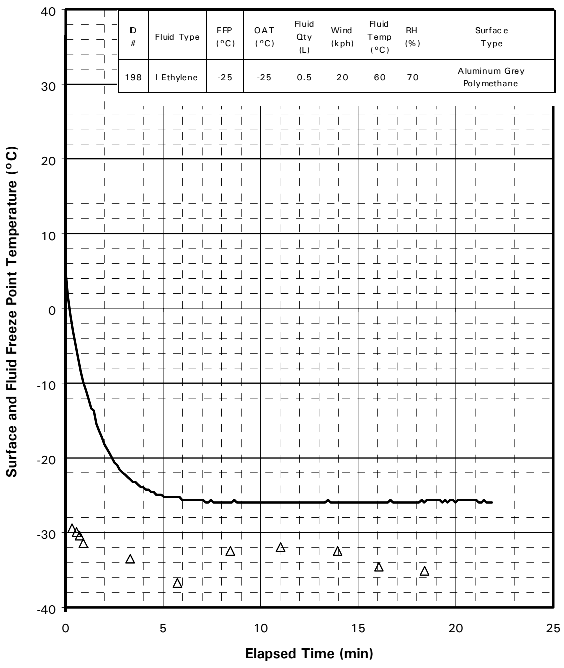
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
196	I Ethylene	-25	-25	0.5	20	60	70	Kevlar Honeycomb

Fluid Freeze Point and Surface Temperature Profile
ID# 197



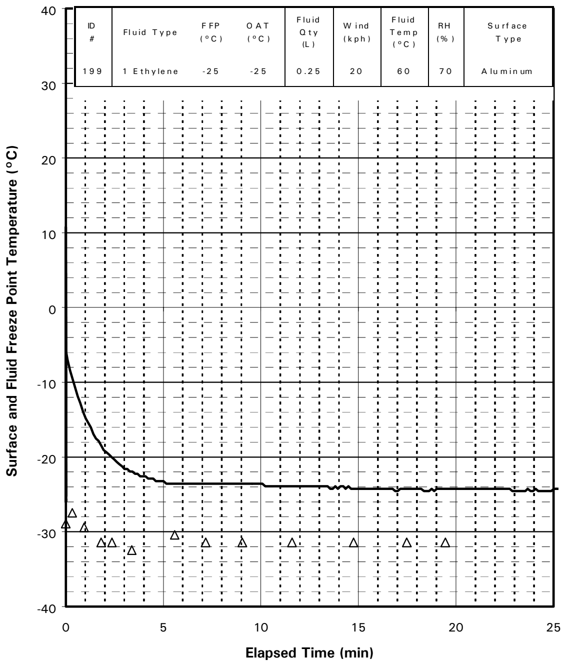
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
197	I Ethylene	-25	-25	0.5	20	60	70	Aluminum Red Polymethane

Fluid Freeze Point and Surface Temperature Profile
ID# 198



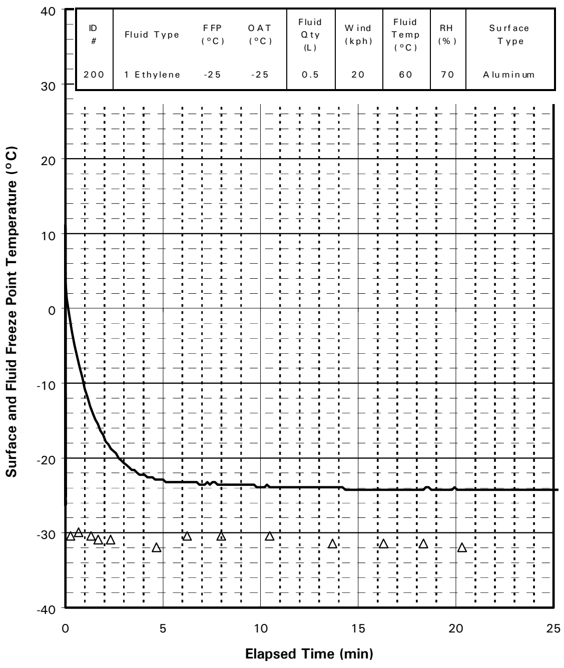
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
198	I Ethylene	-25	-25	0.5	20	60	70	Aluminum Grey Polymethane

Fluid Freeze Point and Surface Temperature Profile
ID# 199



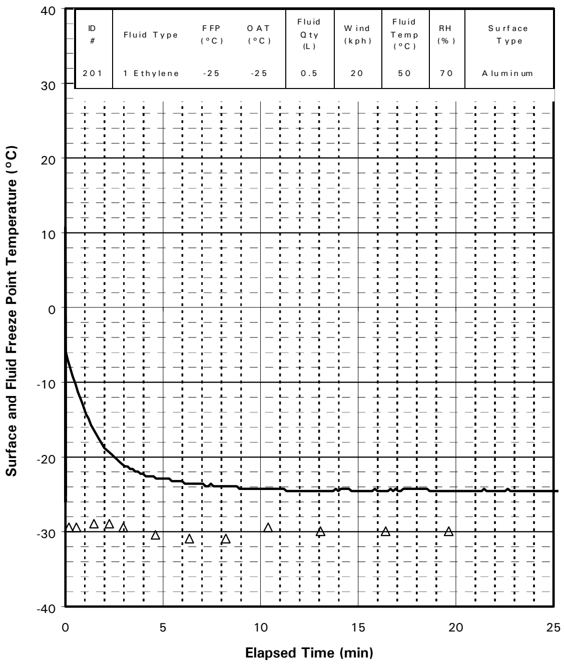
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
199	1 Ethylene	-25	-25	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 200



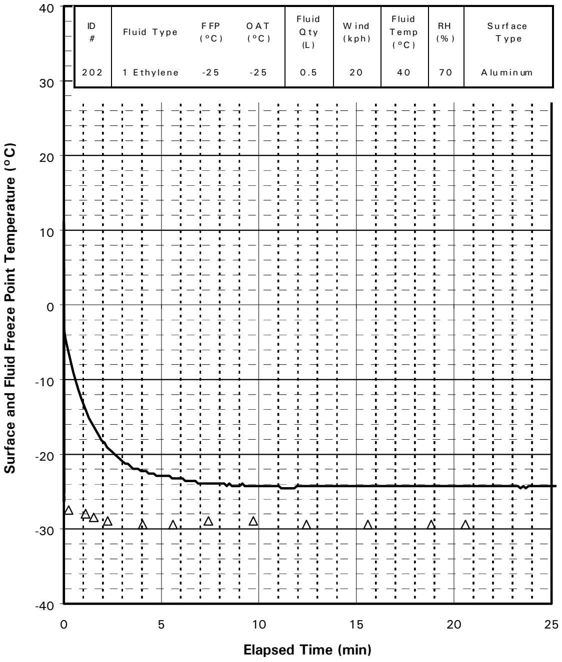
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
200	1 Ethylene	-25	-25	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 201



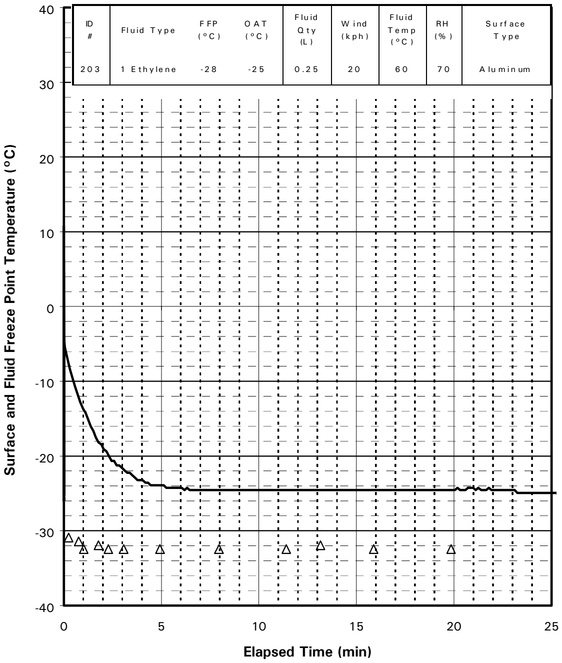
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
201	1 Ethylene	-25	-25	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 202



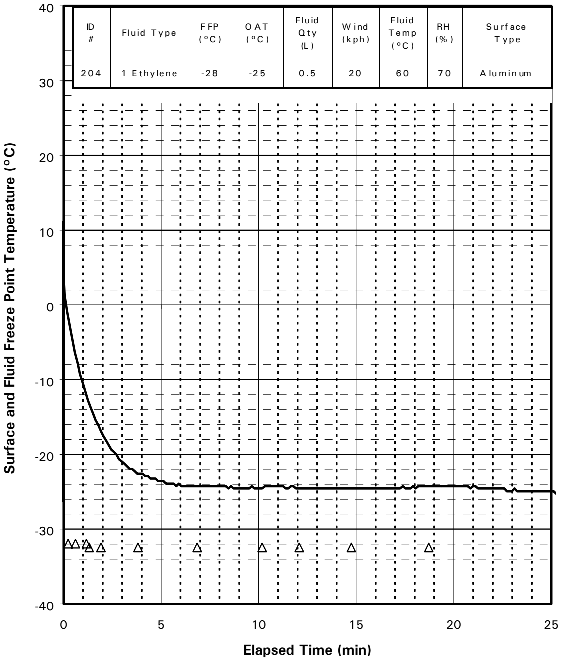
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
202	1 Ethylene	-25	-25	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 203



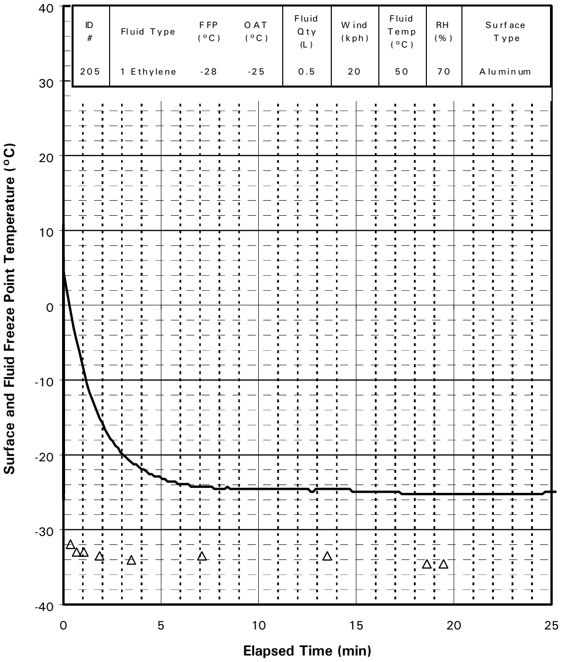
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
203	1 Ethylene	-28	-25	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 204



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
204	1 Ethylene	-28	-25	0.5	20	60	70	Aluminum

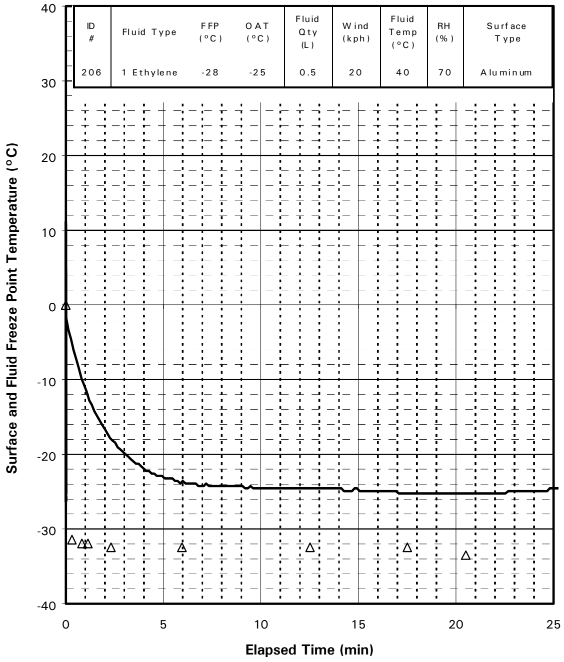
Fluid Freeze Point and Surface Temperature Profile
ID# 205



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
205	1 Ethylene	-28	-25	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

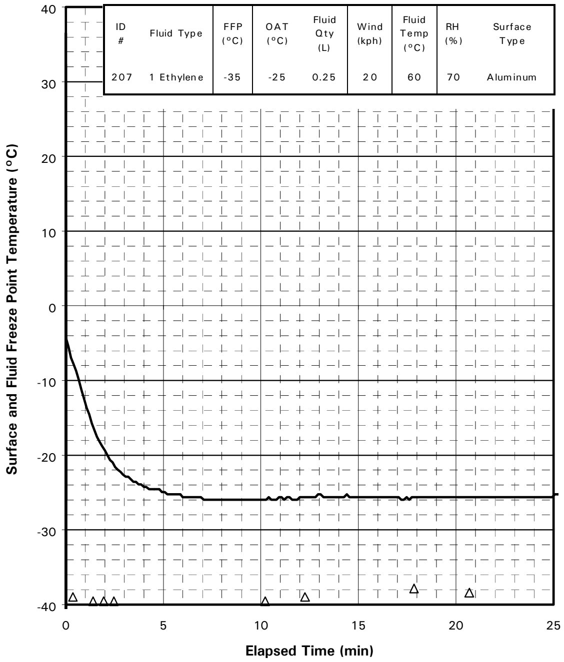
ID# 206



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
206	1 Ethylene	-28	-25	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

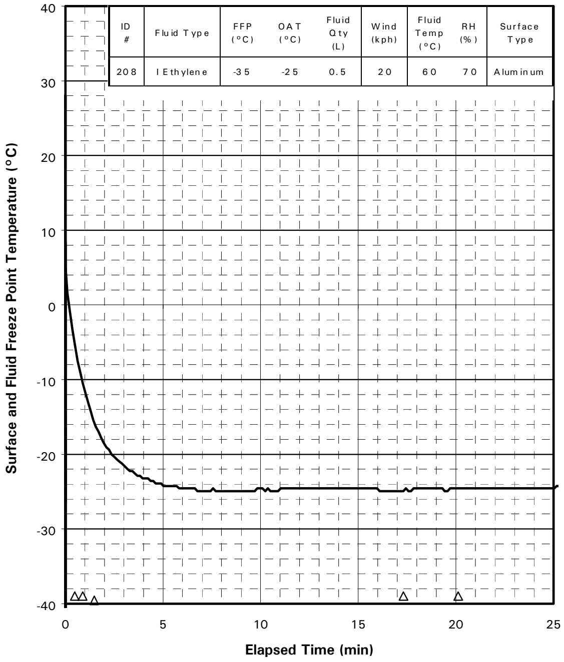
ID# 207



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
207	1 Ethylene	-35	-25	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

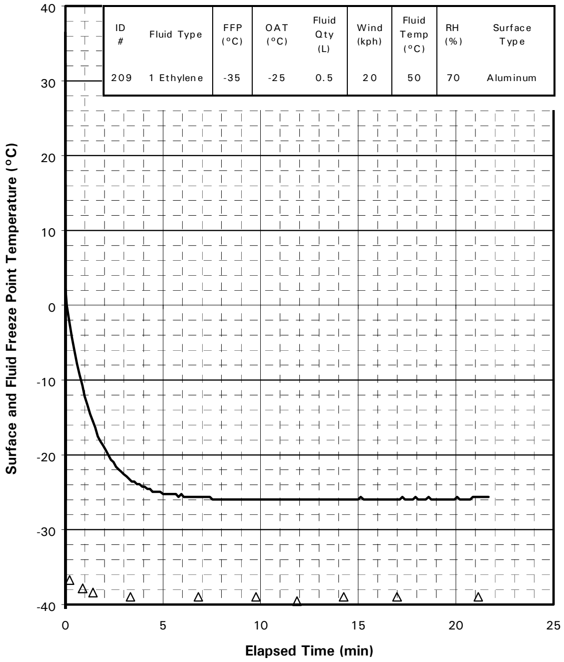
ID# 208



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
208	I Ethylene	-35	-25	0.5	20	60	70	Aluminum

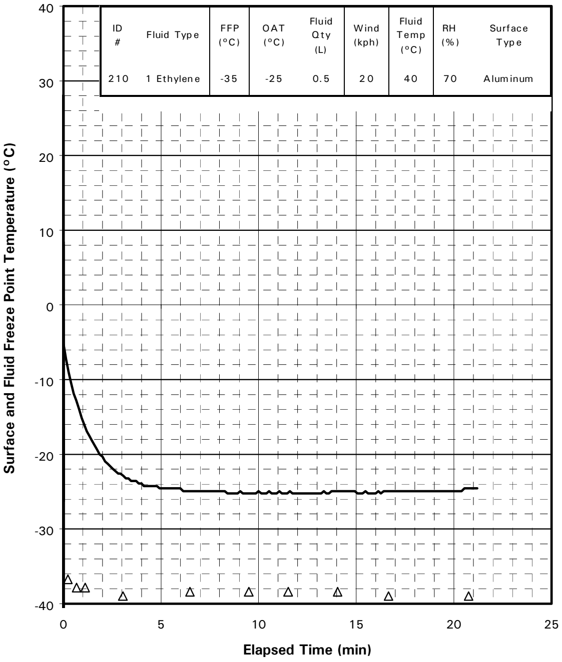
Fluid Freeze Point and Surface Temperature Profile

ID# 209



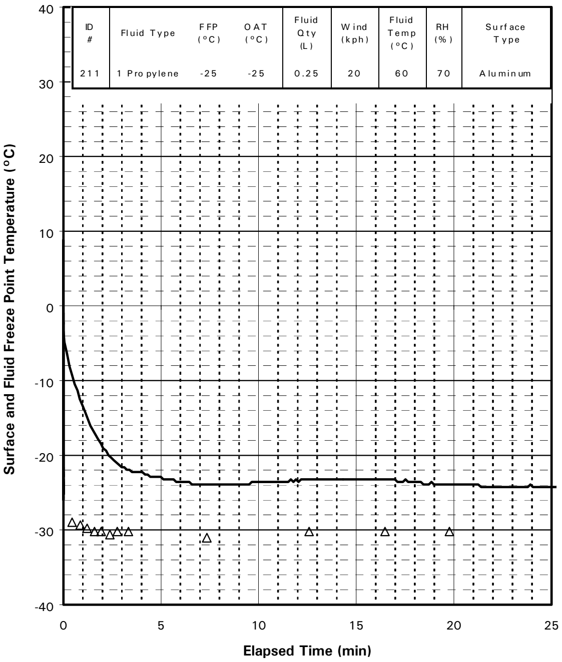
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
209	1 Ethylene	-35	-25	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 210



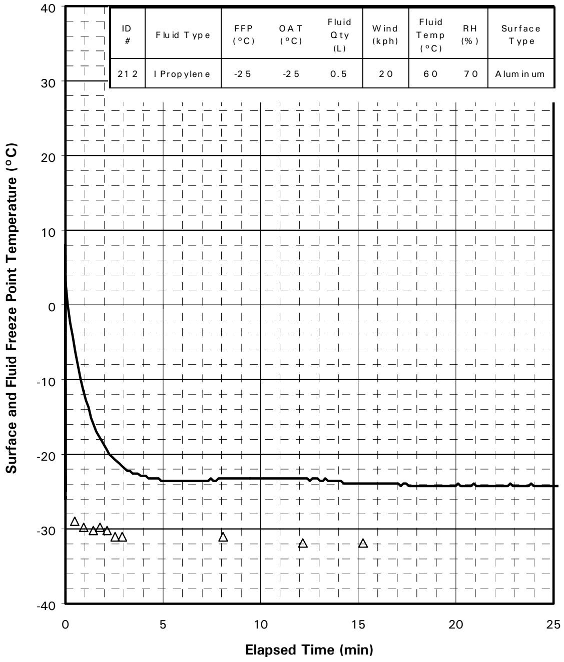
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
210	1 Ethylene	-35	-25	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 211



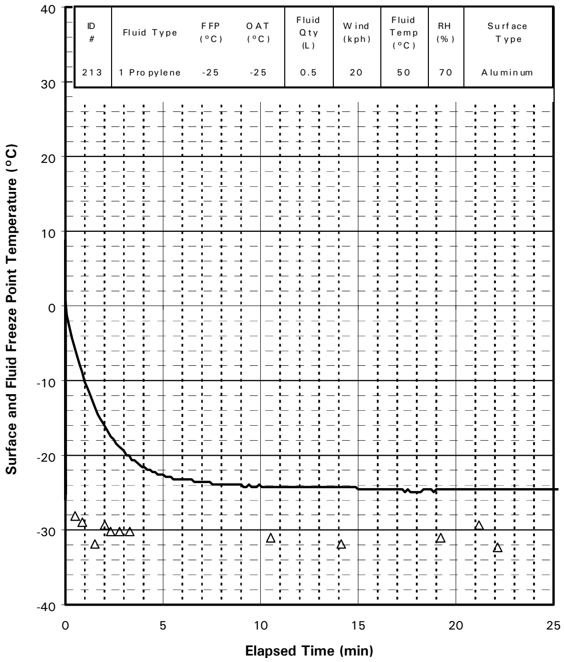
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
211	1 Propylene	-25	-25	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 212



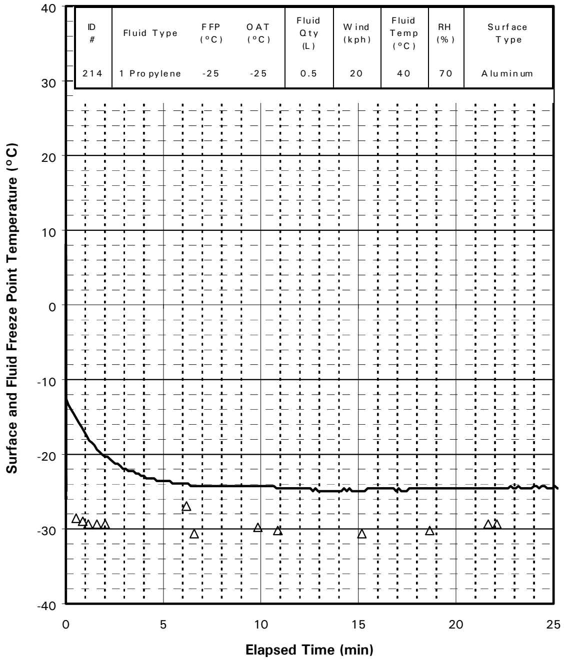
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
212	1 Propylene	-25	-25	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 213



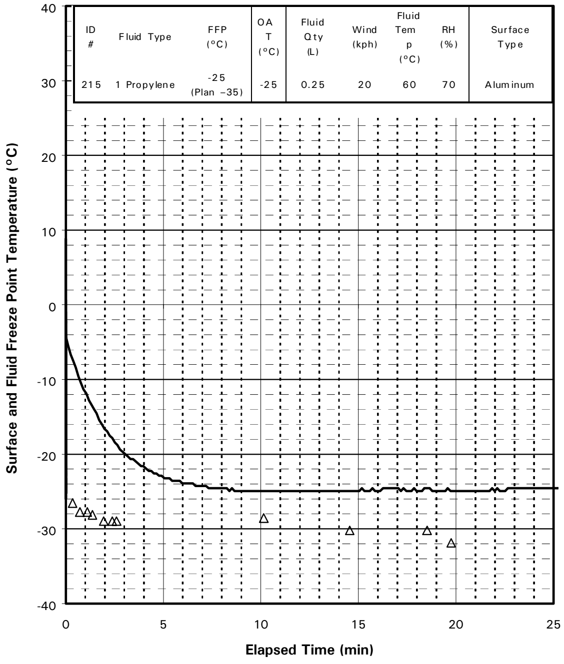
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
213	1 Propylene	-25	-25	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 214



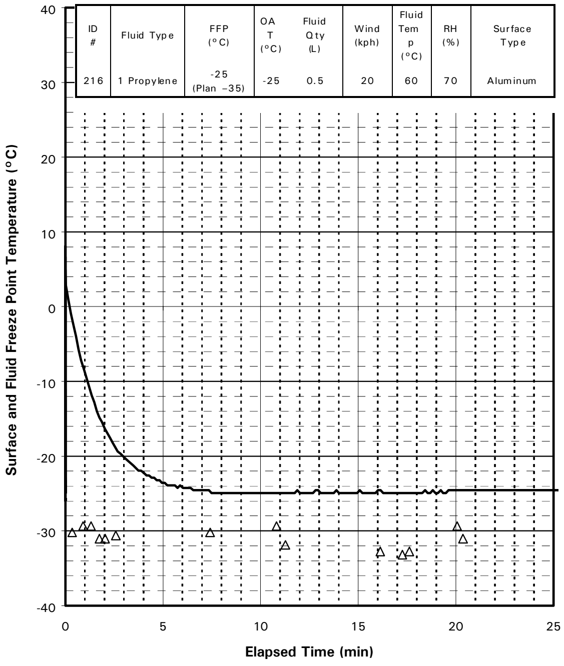
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
214	1 Propylene	-25	-25	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 215



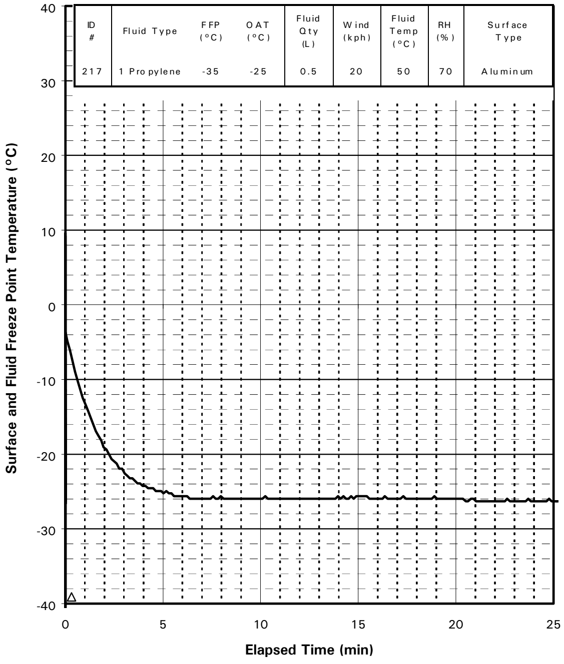
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
215	1 Propylene	-25 (Plan -35)	-25	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 216



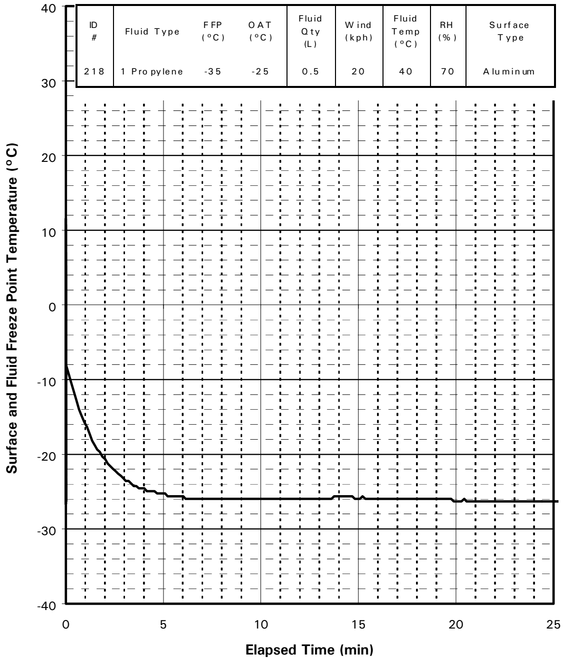
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
216	1 Propylene	-25 (Plan -35)	-25	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 217



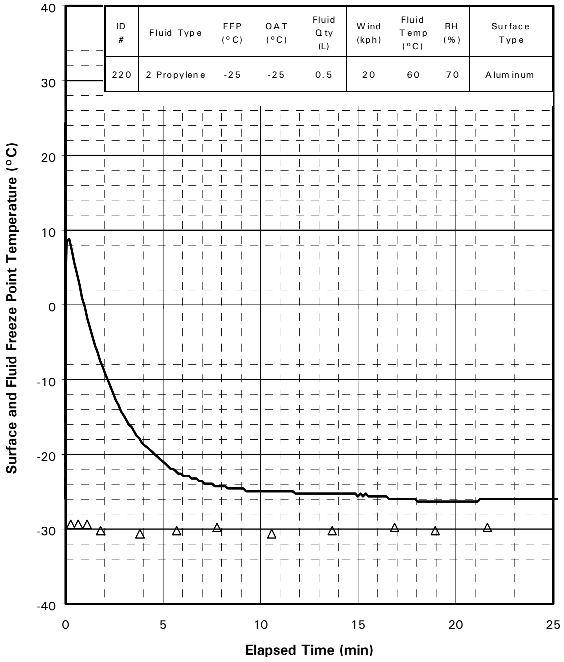
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
217	1 Propylene	-35	-25	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 218



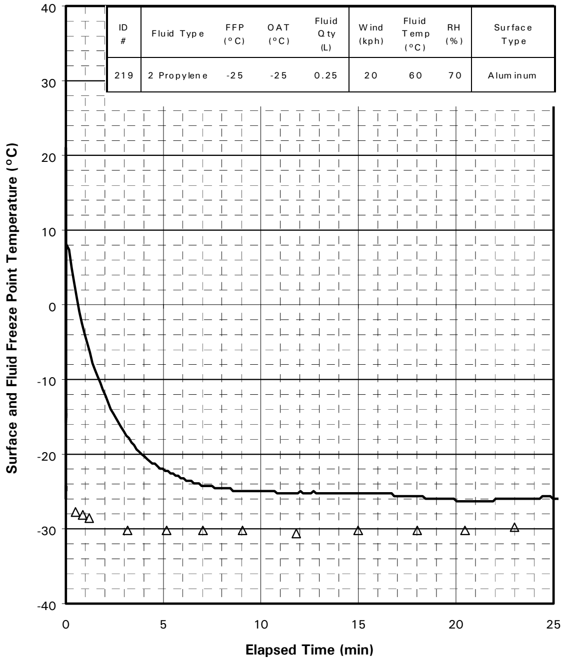
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
218	1 Propylene	-35	-25	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 220



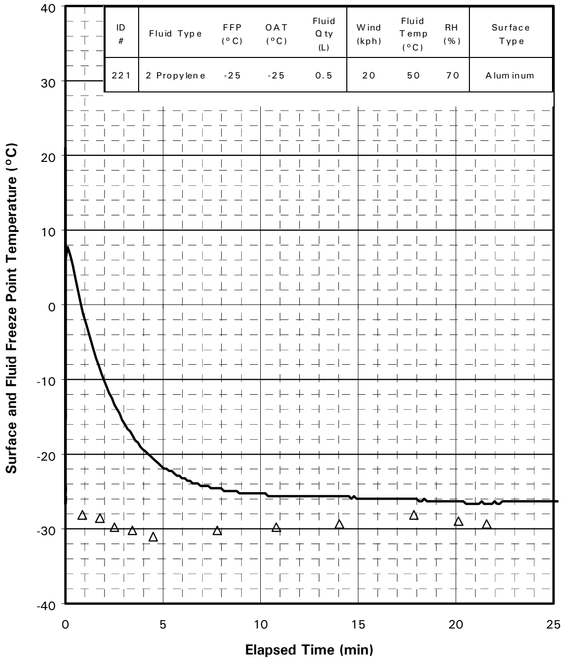
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
220	2 Propylene	-25	-25	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 219



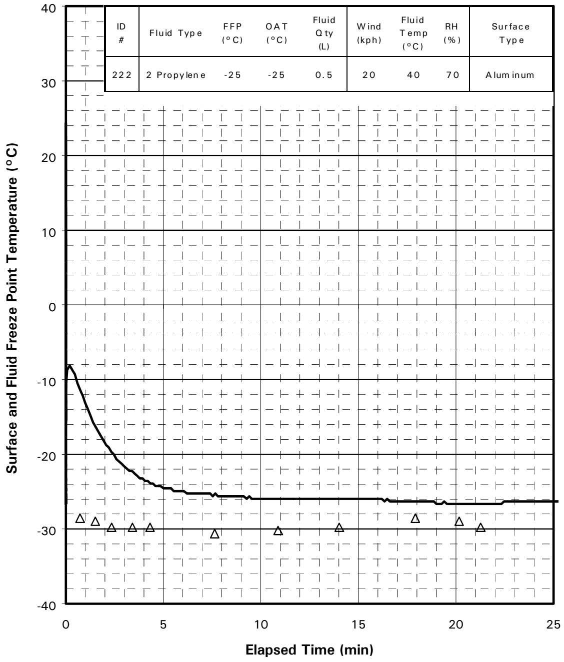
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
219	2 Propylene	-25	-25	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 221



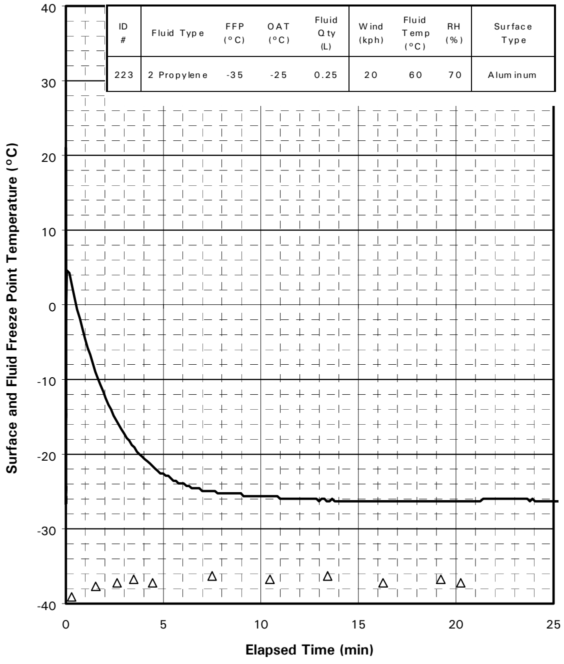
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
221	2 Propylene	-25	-25	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 222



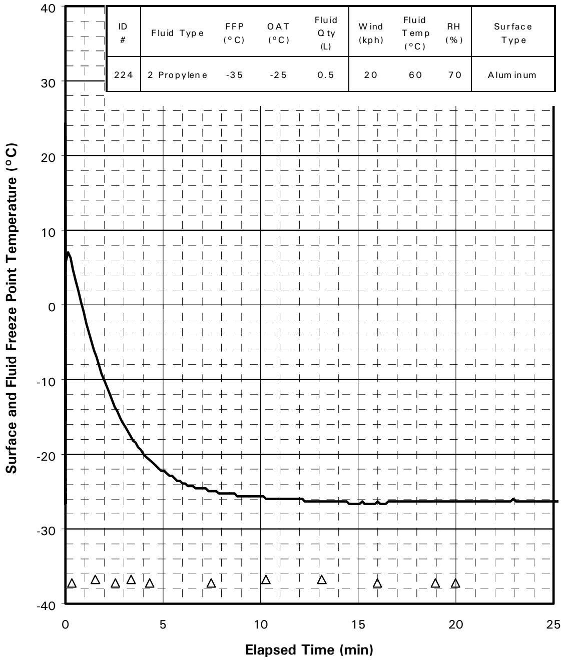
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
222	2 Propylene	-25	-25	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 223



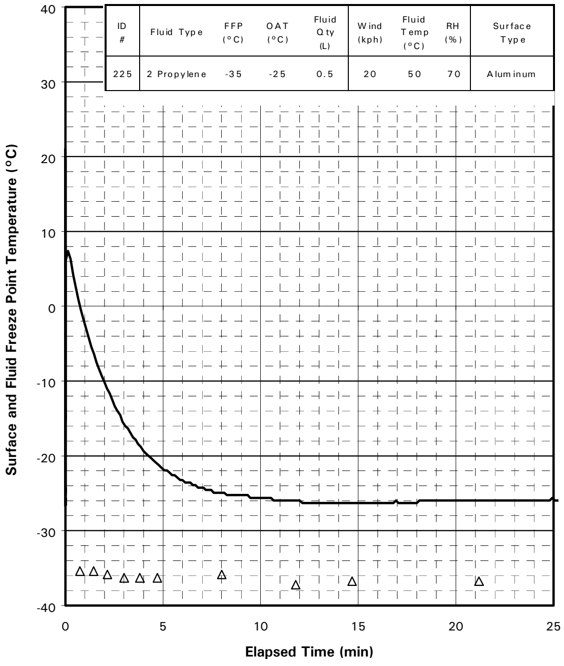
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
223	2 Propylene	-35	-25	0.25	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 224



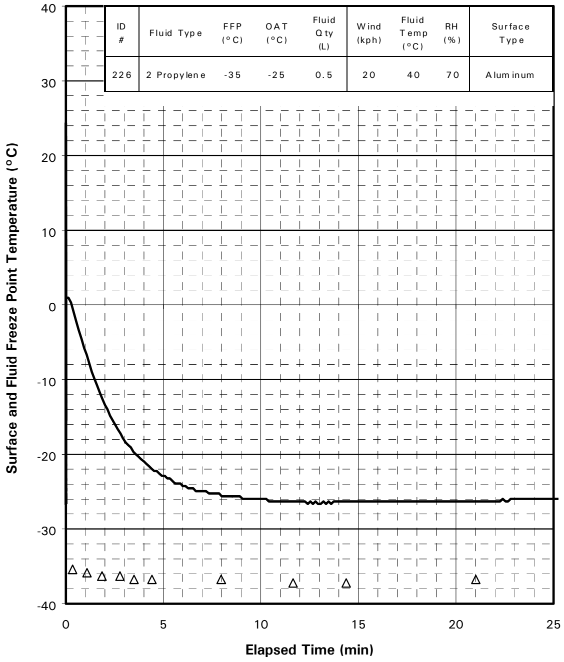
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
224	2 Propylene	-35	-25	0.5	20	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 225



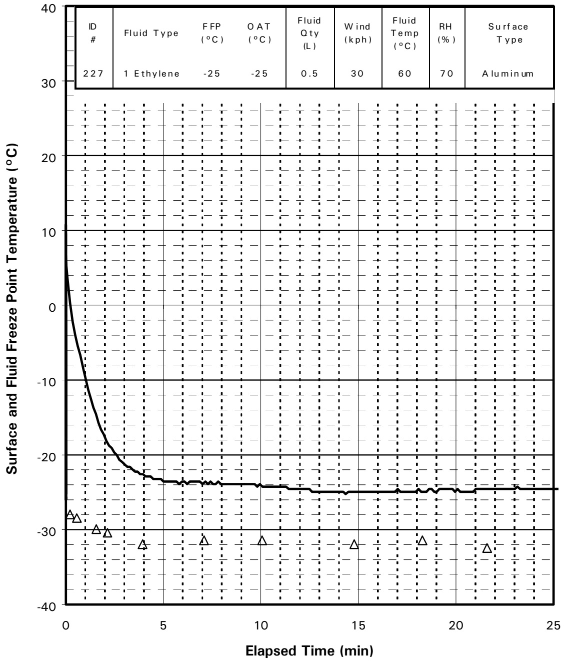
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
225	2 Propylene	-35	-25	0.5	20	50	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 226



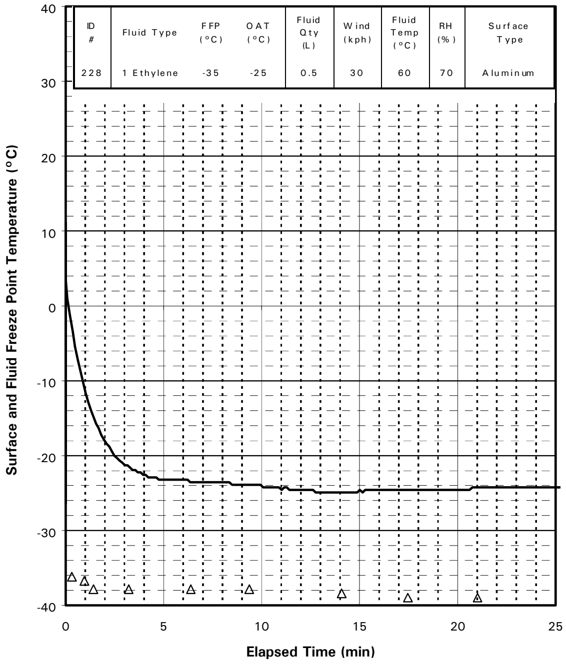
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
226	2 Propylene	-35	-25	0.5	20	40	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 227



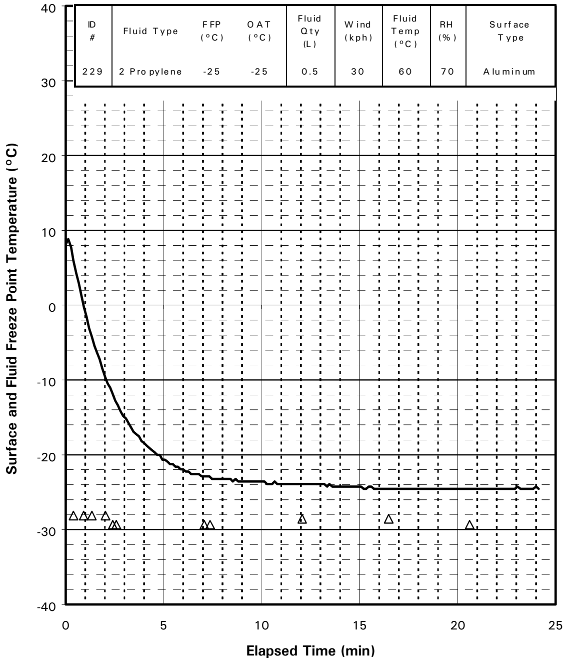
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
227	1 Ethylene	-25	-25	0.5	30	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 228



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
228	1 Ethylene	-35	-25	0.5	30	60	70	Aluminum

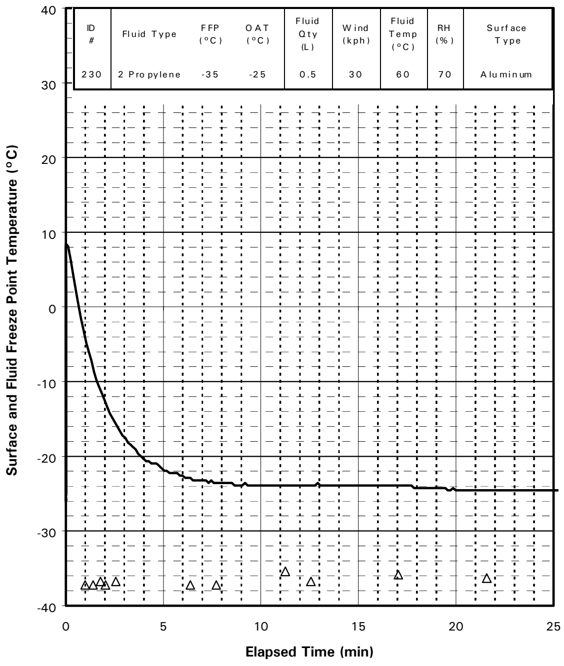
Fluid Freeze Point and Surface Temperature Profile
ID# 229



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
229	2 Propylene	-25	-25	0.5	30	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

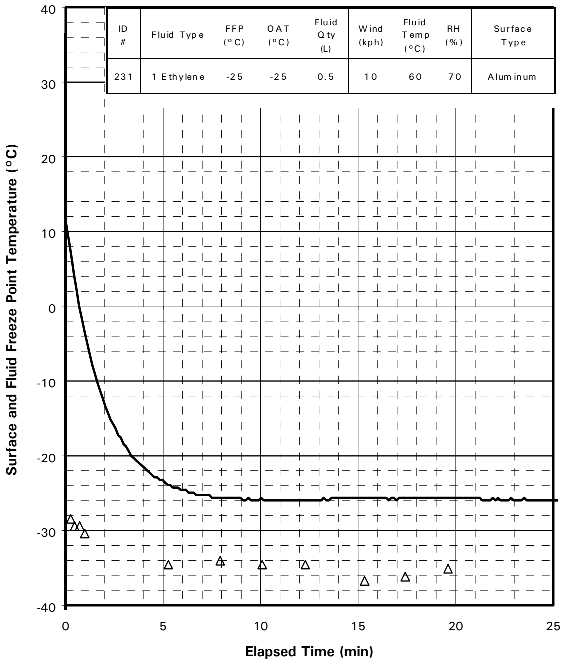
ID# 230



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
230	2 Propylene	-35	-25	0.5	30	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

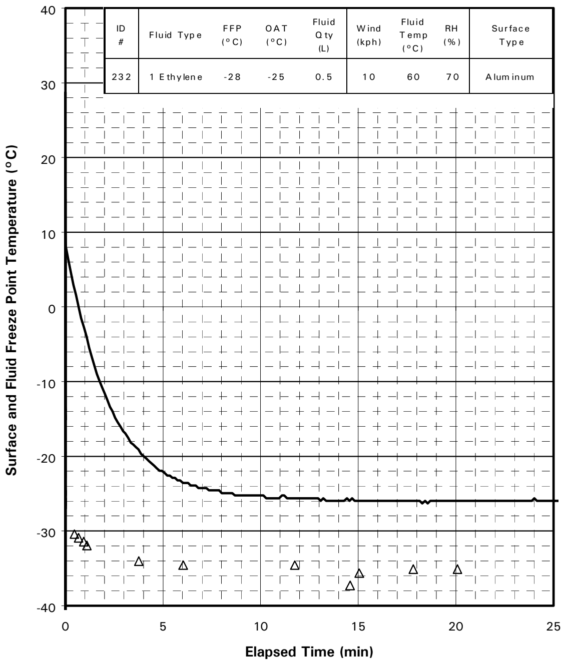
ID# 231



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
231	1 Ethylene	-25	-25	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

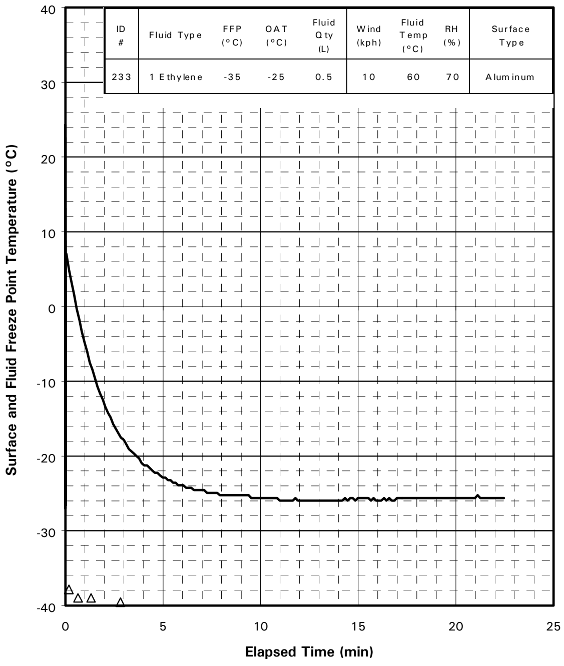
ID# 232



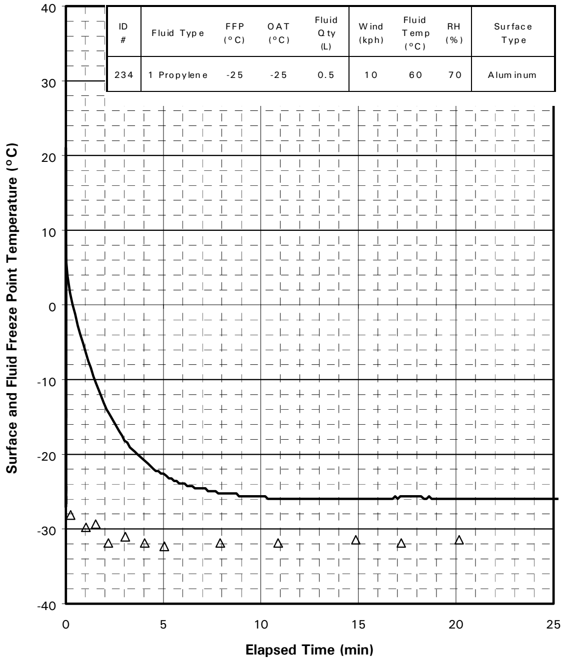
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
232	1 Ethylene	-28	-25	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile

ID# 233



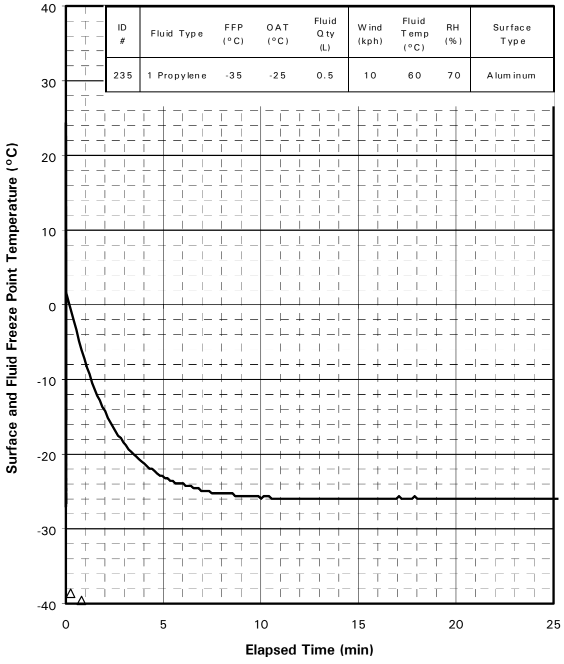
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
233	1 Ethylene	-35	-25	0.5	10	60	70	Aluminum



Fluid Freeze Point and Surface Temperature Profile

ID# 234

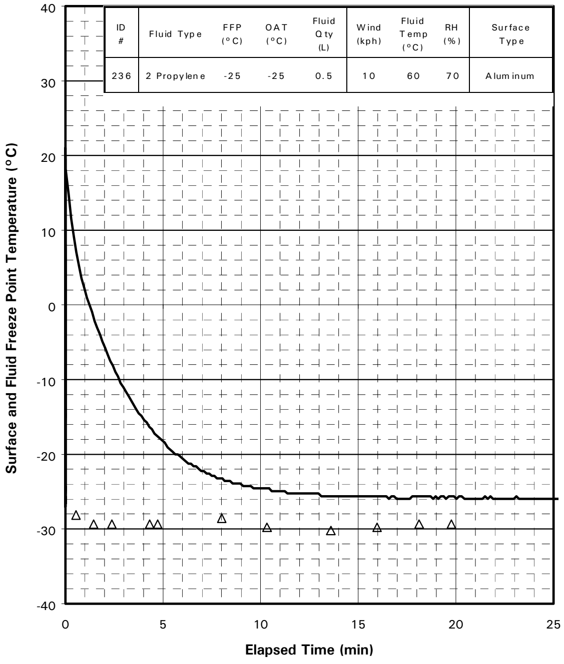
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
234	1 Propylene	-25	-25	0.5	10	60	70	Aluminum



Fluid Freeze Point and Surface Temperature Profile

ID# 235

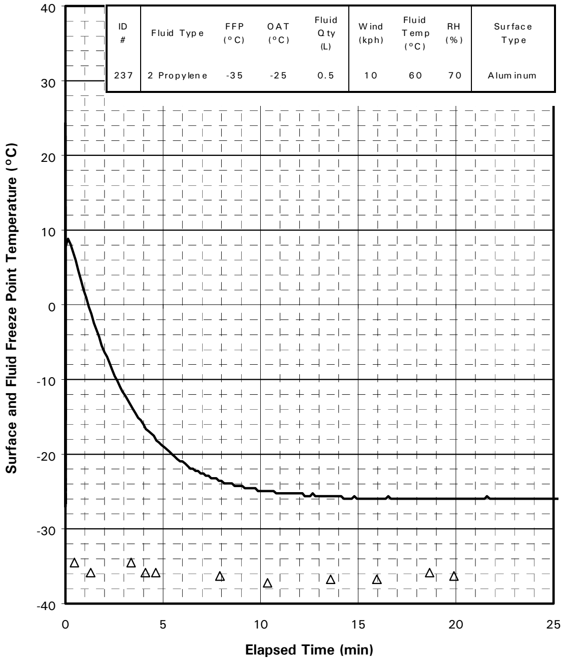
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
235	1 Propylene	-35	-25	0.5	10	60	70	Aluminum



Fluid Freeze Point and Surface Temperature Profile

ID# 236

ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
236	2 Propylene	-25	-25	0.5	10	60	70	Aluminum

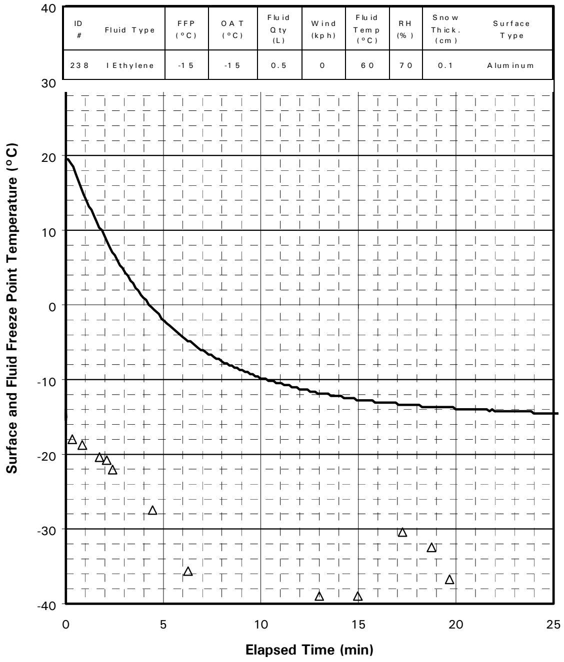


Fluid Freeze Point and Surface Temperature Profile

ID# 237

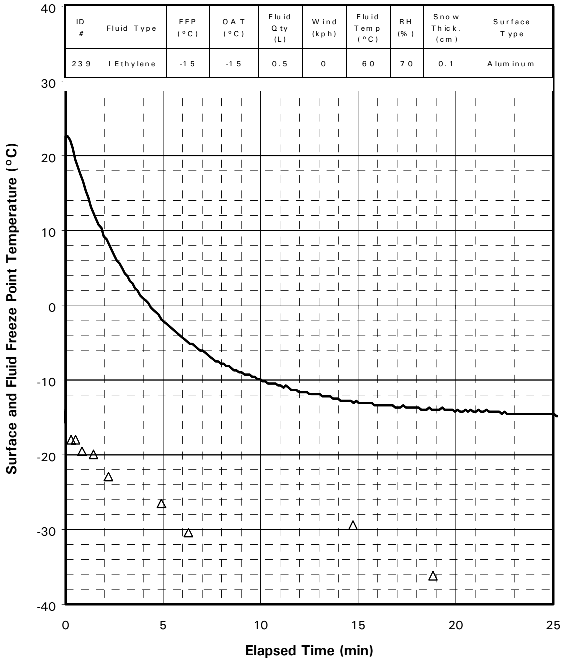
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
237	2 Propylene	-35	-25	0.5	10	60	70	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 238



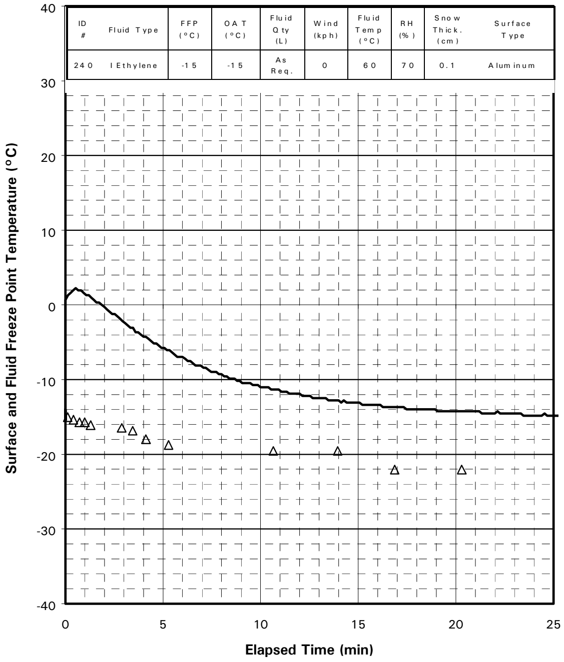
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
238	I Ethylene	-15	-15	0.5	0	60	70	0.1	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 239



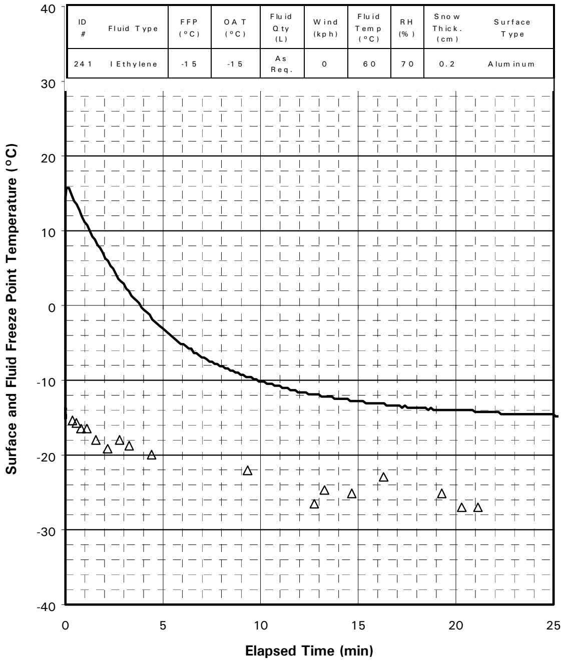
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
239	I Ethylene	-15	-15	0.5	0	60	70	0.1	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 240



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
240	I Ethylene	-15	-15	As Req.	0	60	70	0.1	Aluminum

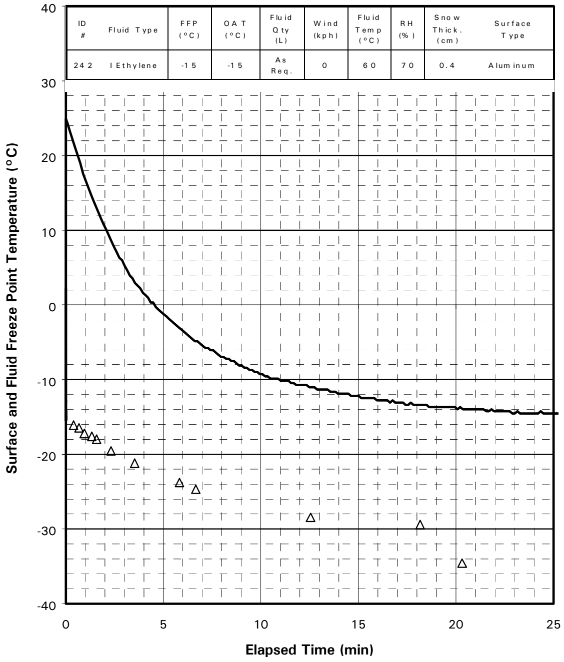
Fluid Freeze Point and Surface Temperature Profile
ID# 241



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
241	I Ethylene	-15	-15	As Req.	0	60	70	0.2	Aluminum

Fluid Freeze Point and Surface Temperature Profile

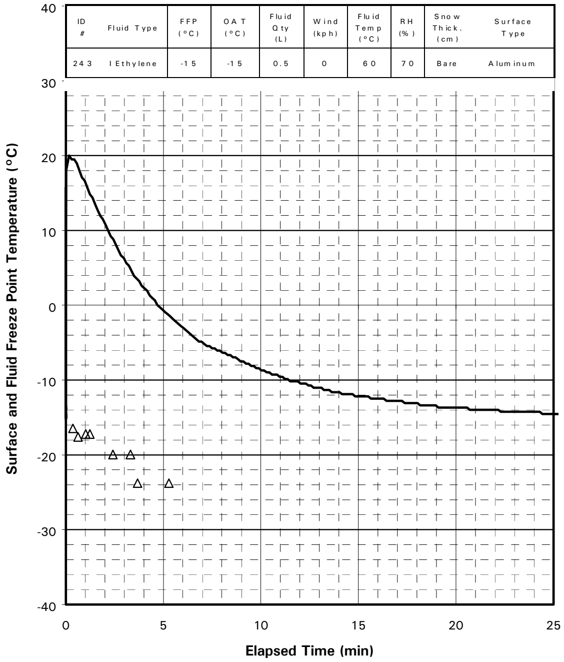
ID# 242



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
242	I Ethylene	-15	-15	As Req.	0	60	70	0.4	Aluminum

Fluid Freeze Point and Surface Temperature Profile

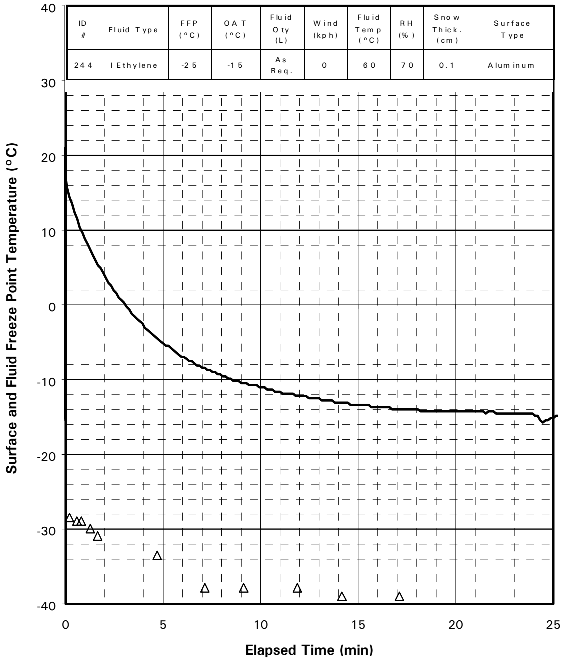
ID# 243



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
243	I Ethylene	-15	-15	0.5	0	60	70	Bare	Aluminum

Fluid Freeze Point and Surface Temperature Profile

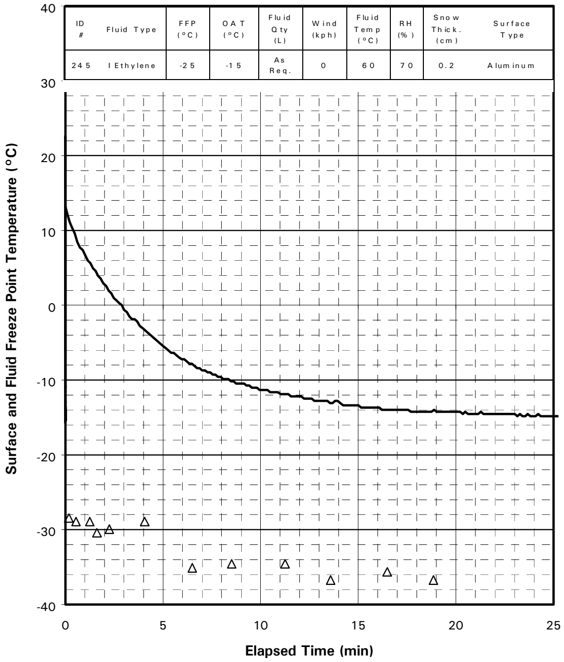
ID# 244



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
244	I Ethylene	-25	-15	As Req.	0	60	70	0.1	Aluminum

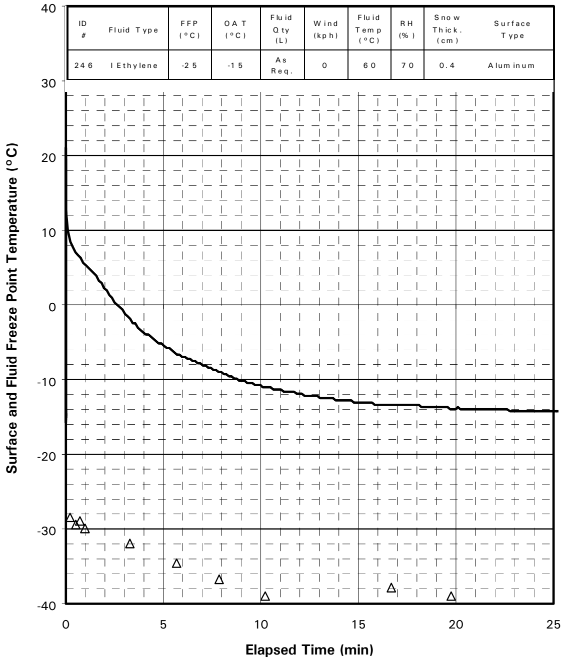
Fluid Freeze Point and Surface Temperature Profile

ID# 245



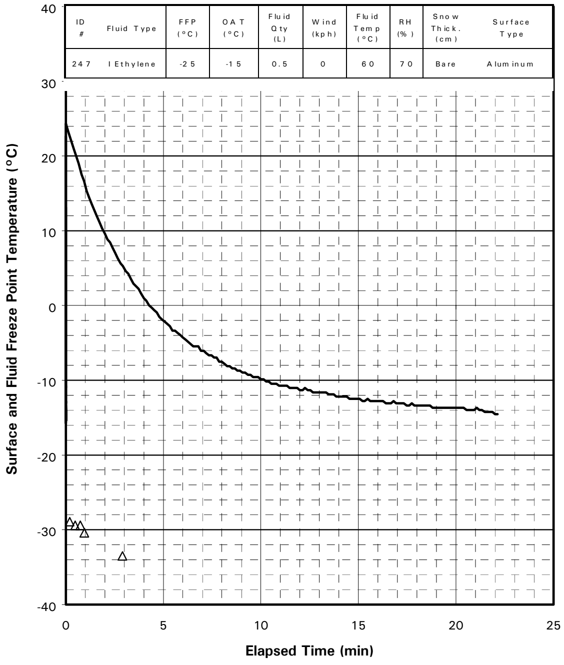
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
245	I Ethylene	-25	-15	As Req.	0	60	70	0.2	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 246



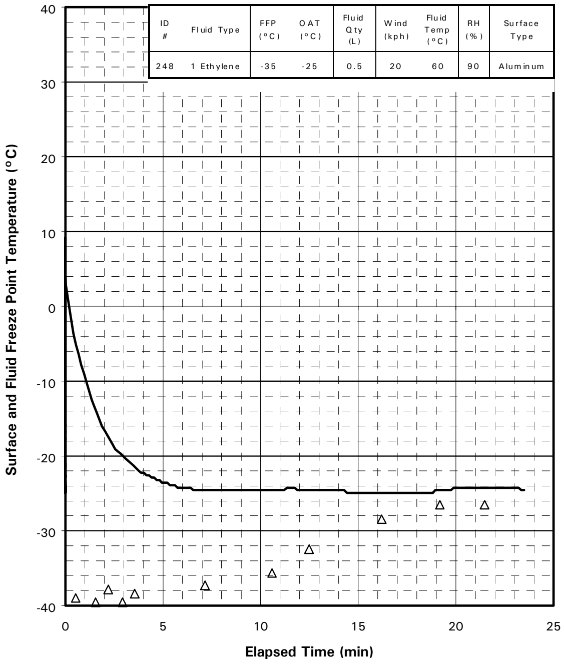
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
246	I Ethylene	-25	-15	As Req.	0	60	70	0.4	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 247



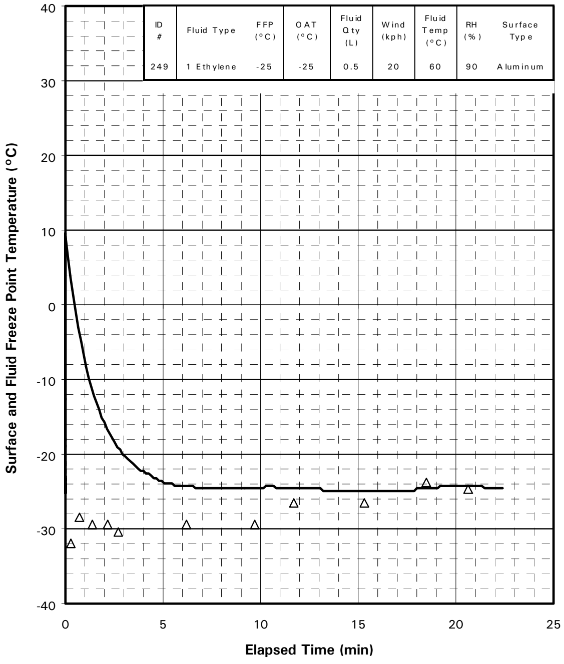
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Snow Thick. (cm)	Surface Type
247	I Ethylene	-25	-15	0.5	0	60	70	Bare	Aluminum

Fluid Freeze Point and Surface Temperature Profile
ID# 248



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
248	1 Ethylene	-35	-25	0.5	20	60	90	Aluminum

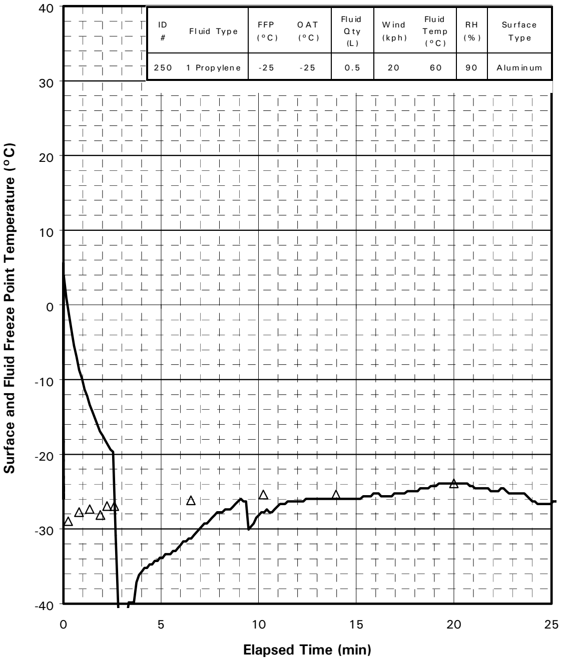
Fluid Freeze Point and Surface Temperature Profile
ID# 249



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
249	1 Ethylene	-25	-25	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile

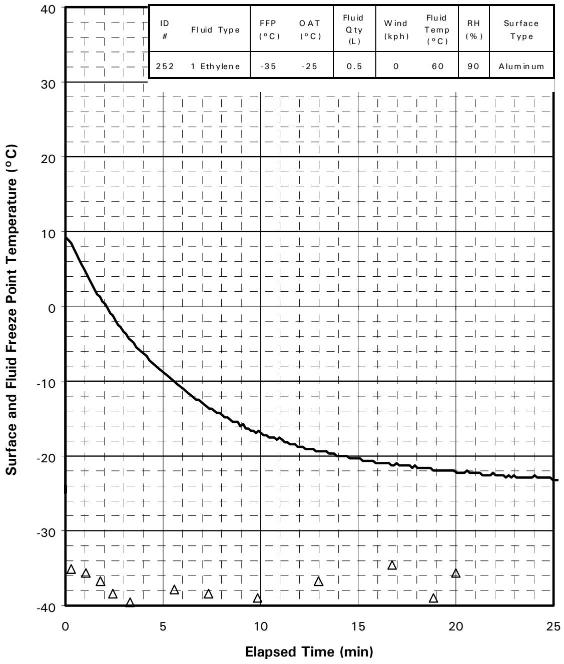
ID# 250



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
250	1 Propylene	-25	-25	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile

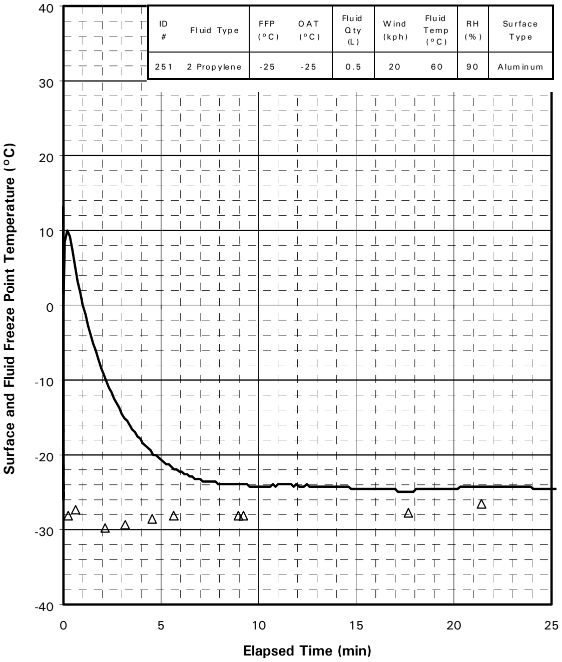
ID# 252



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
252	1 Ethylene	-35	-25	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile

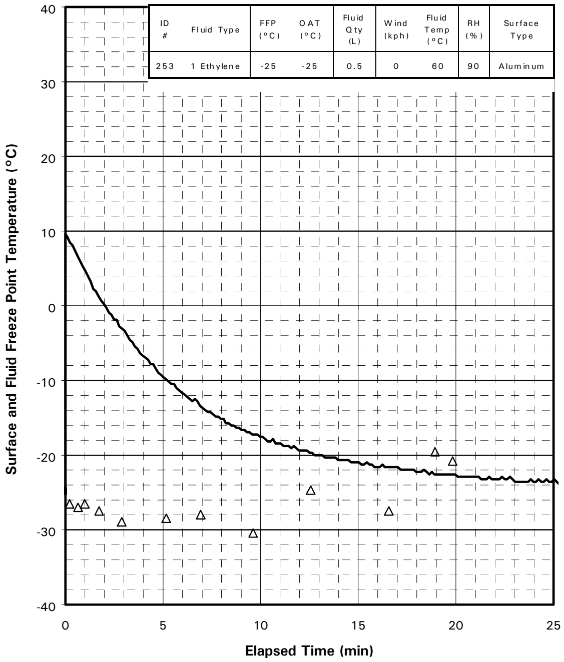
ID# 251



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
251	2 Propylene	-25	-25	0.5	20	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile

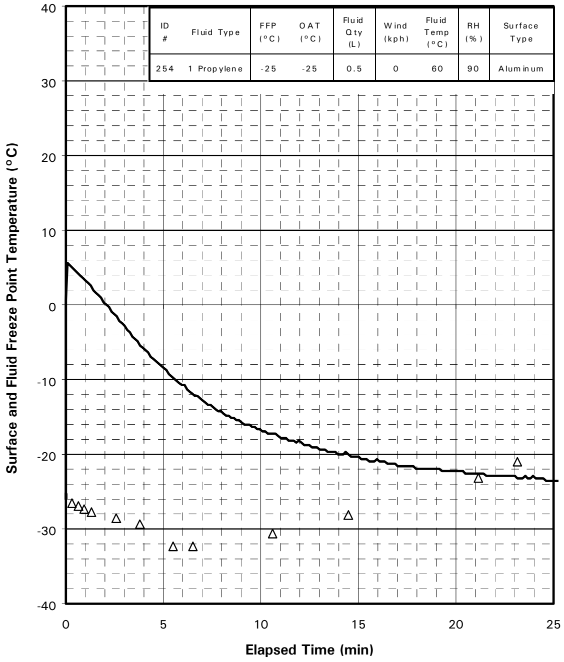
ID# 253



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
253	1 Ethylene	-25	-25	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile

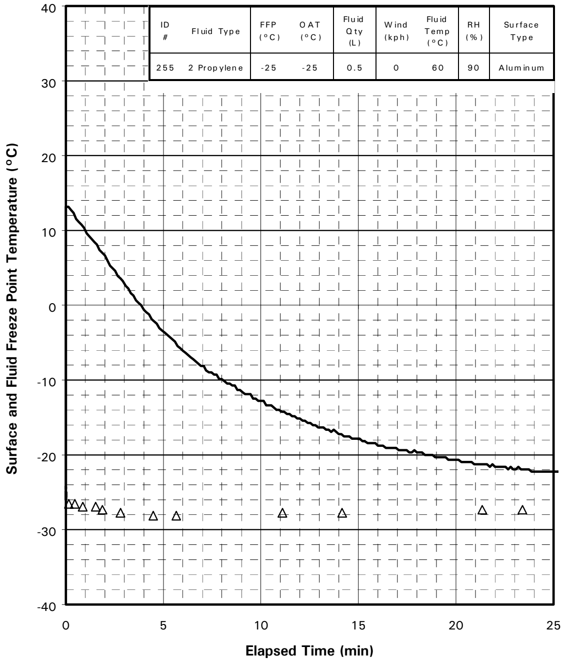
ID# 254



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
254	1 Propylene	-25	-25	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile

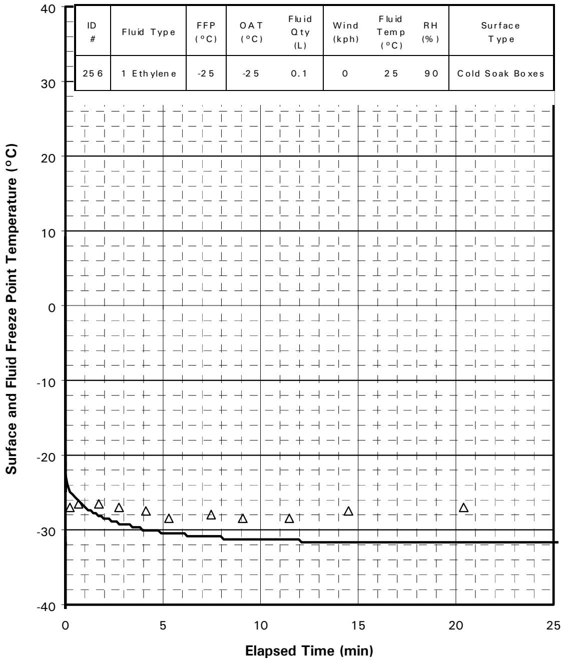
ID# 255



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
255	2 Propylene	-25	-25	0.5	0	60	90	Aluminum

Fluid Freeze Point and Surface Temperature Profile

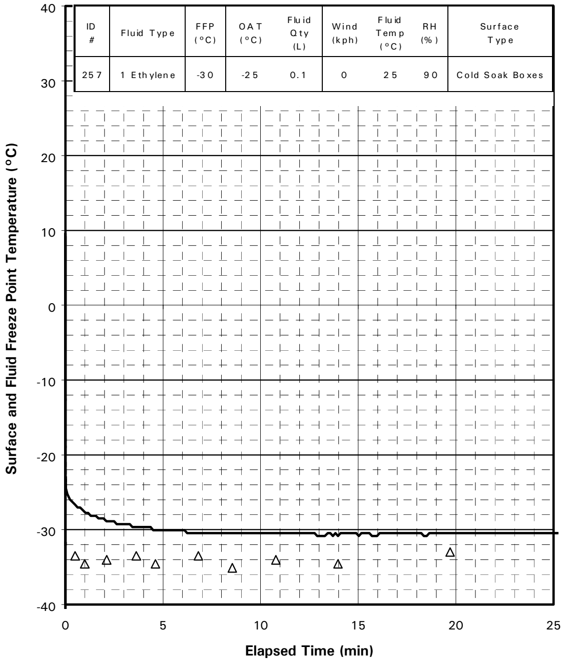
ID# 256



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
256	1 Ethylene	-25	-25	0.1	0	25	90	Cold Soak Boxes

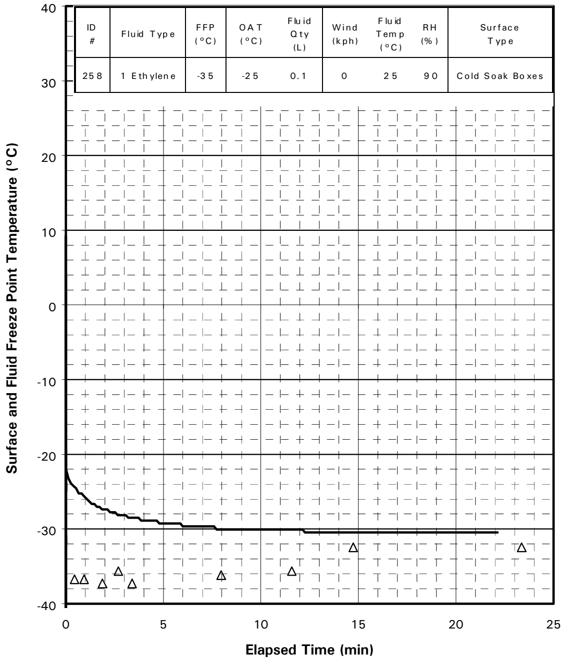
Fluid Freeze Point and Surface Temperature Profile

ID# 257



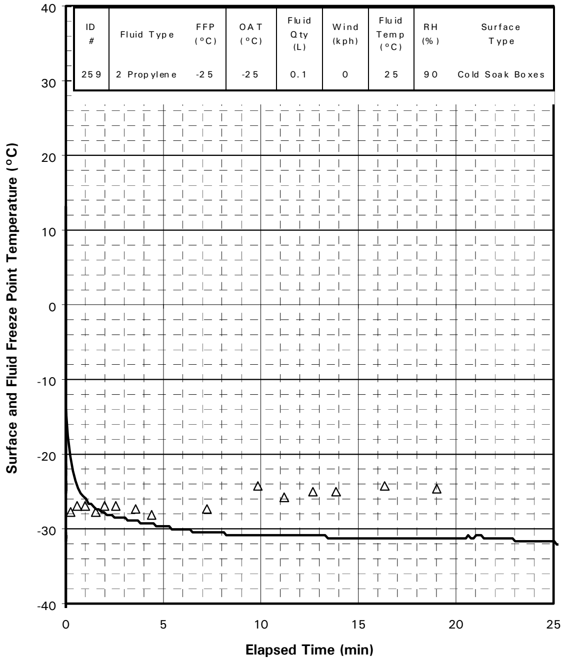
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
257	1 Ethylene	-30	-25	0.1	0	25	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 258



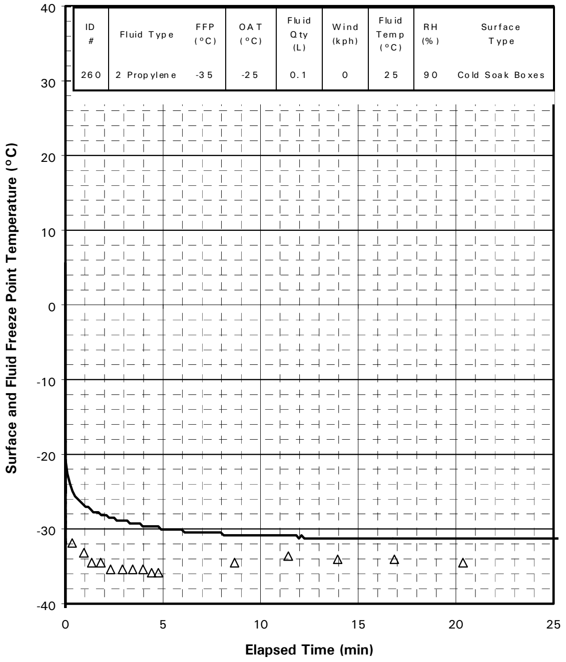
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
258	1 Ethylene	-35	-25	0.1	0	25	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 259



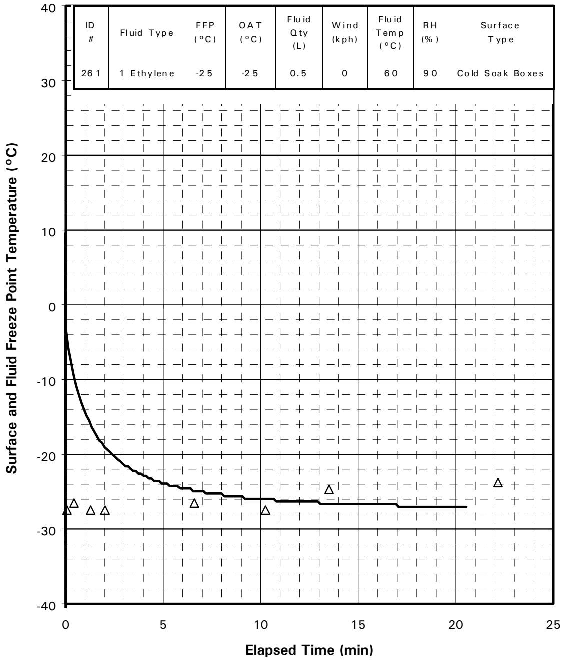
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
259	2 Propylene	-25	-25	0.1	0	25	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 260



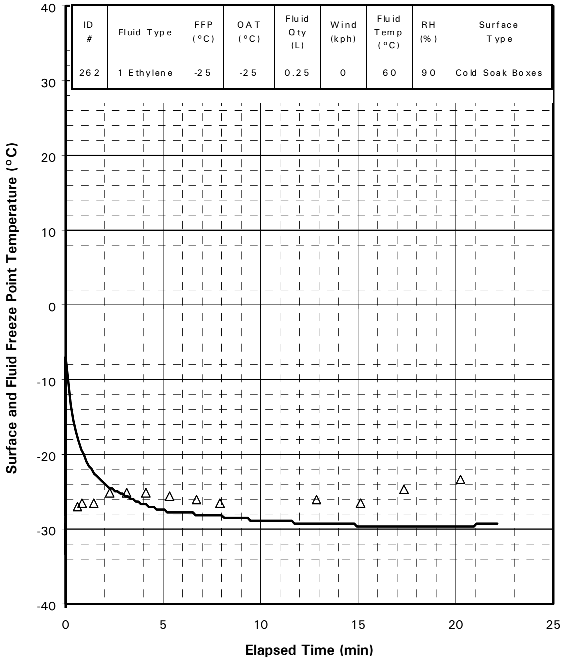
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
260	2 Propylene	-35	-25	0.1	0	25	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 261



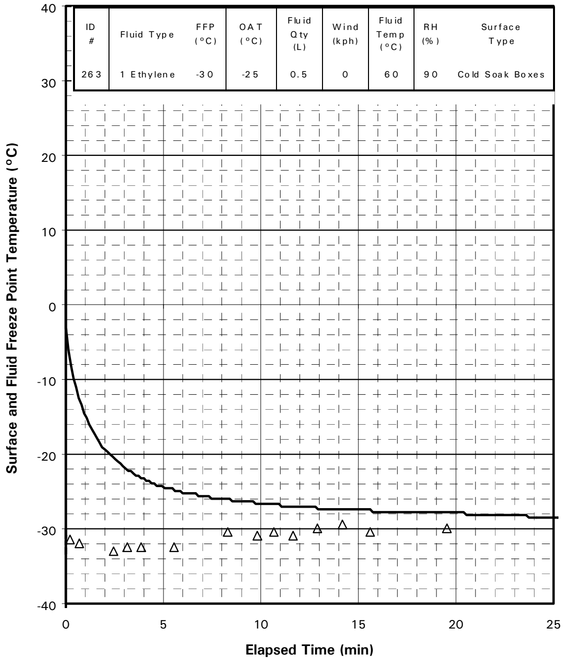
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
261	1 Ethylene	-25	-25	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 262



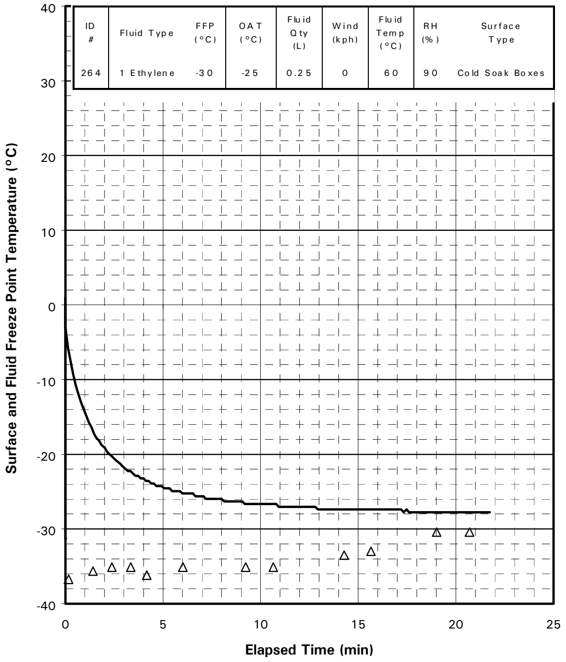
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
262	1 Ethylene	-25	-25	0.25	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 263



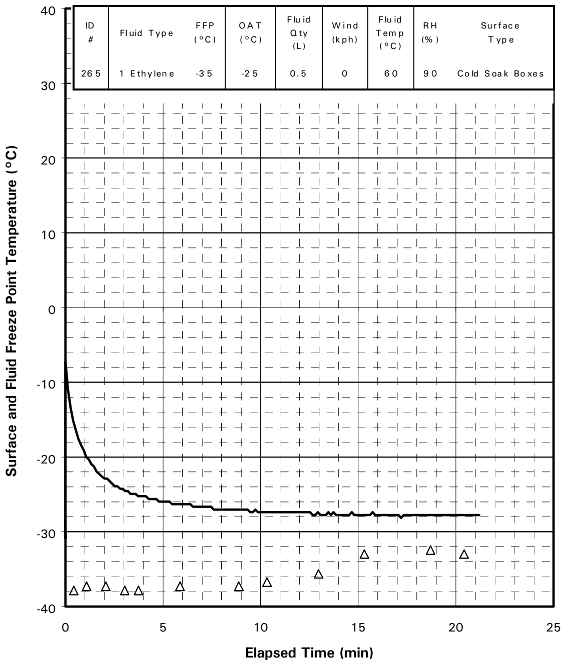
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
263	1 Ethylene	-30	-25	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 264



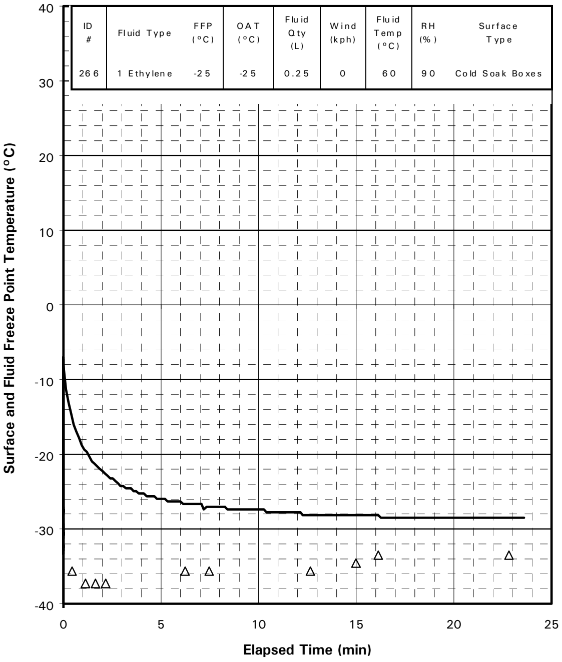
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
264	1 Ethylene	-30	-25	0.25	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 265



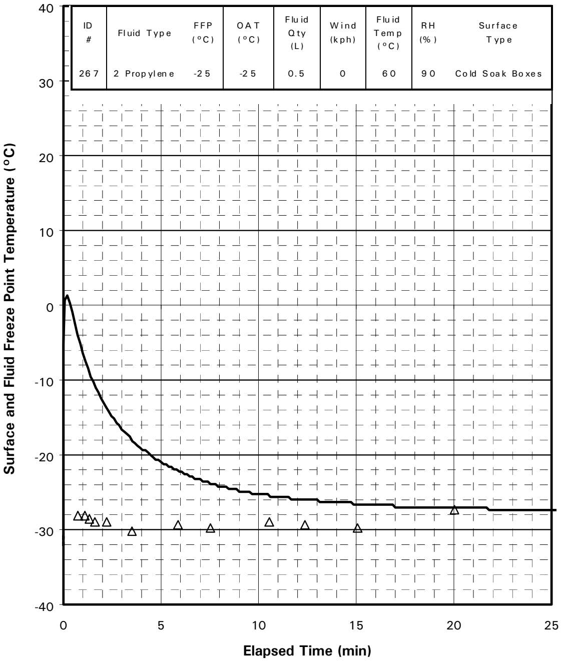
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
265	1 Ethylene	-35	-25	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 266



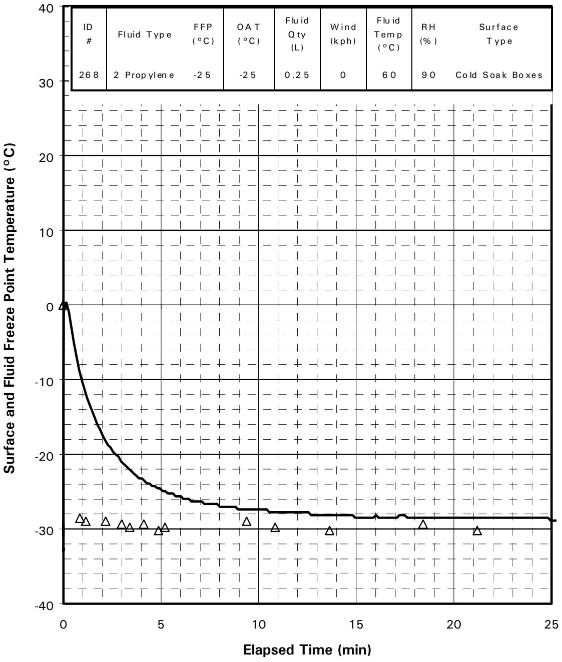
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
266	1 Ethylene	-25	-25	0.25	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 267



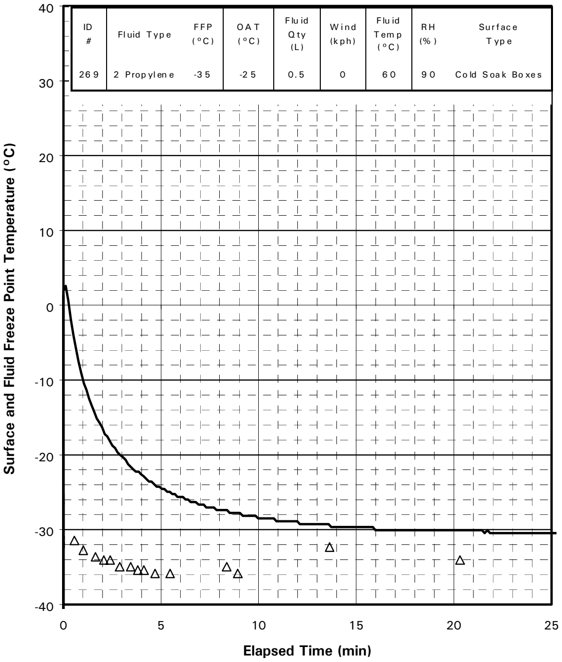
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
267	2 Propylene	-25	-25	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile
ID# 268



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
268	2 Propylene	-25	-25	0.25	0	60	90	Cold Soak Boxes

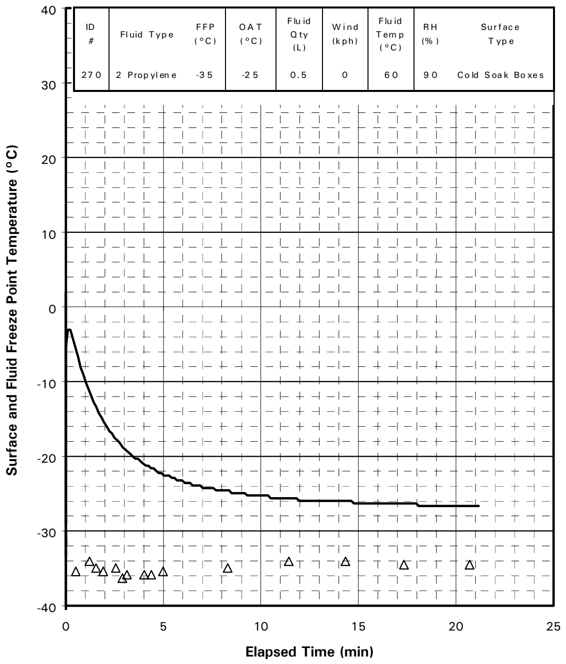
Fluid Freeze Point and Surface Temperature Profile
ID# 269



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
269	2 Propylene	-35	-25	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile

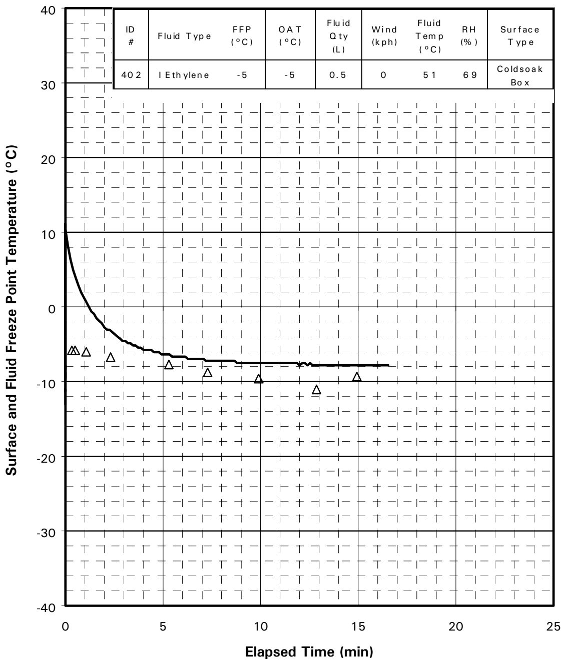
ID# 270



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
270	2 Propylene	-35	-25	0.5	0	60	90	Cold Soak Boxes

Fluid Freeze Point and Surface Temperature Profile

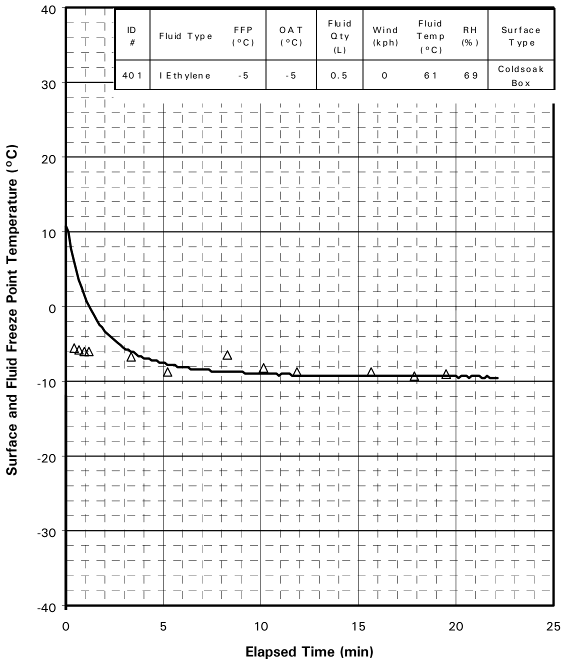
Cold Soaked Boxes - ID# 402



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
402	I Ethylene	-5	-5	0.5	0	51	69	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

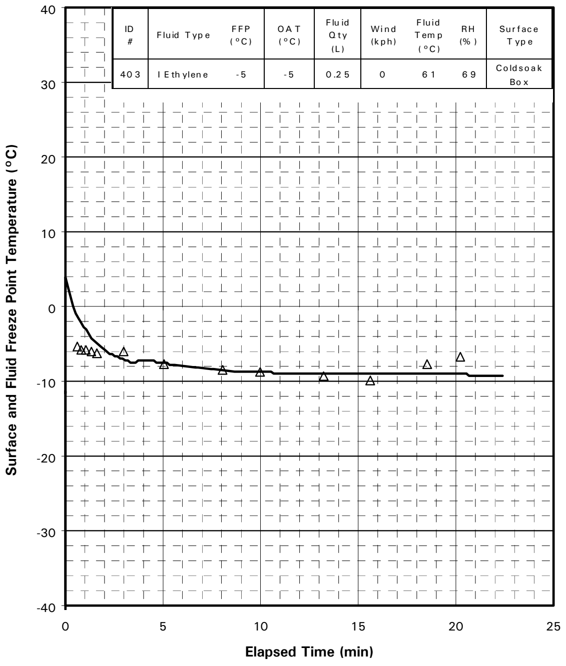
Cold Soaked Boxes - ID# 401



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
401	I Ethylene	-5	-5	0.5	0	61	69	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

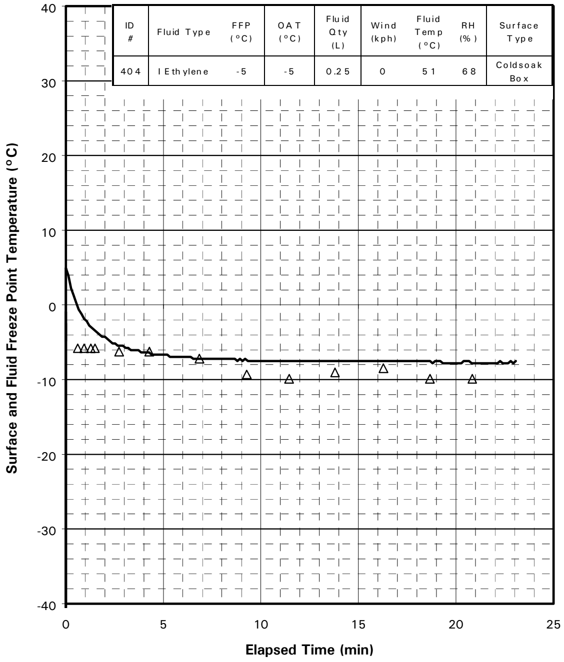
Cold Soaked Boxes - ID# 403



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
403	I Ethylene	-5	-5	0.25	0	61	69	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

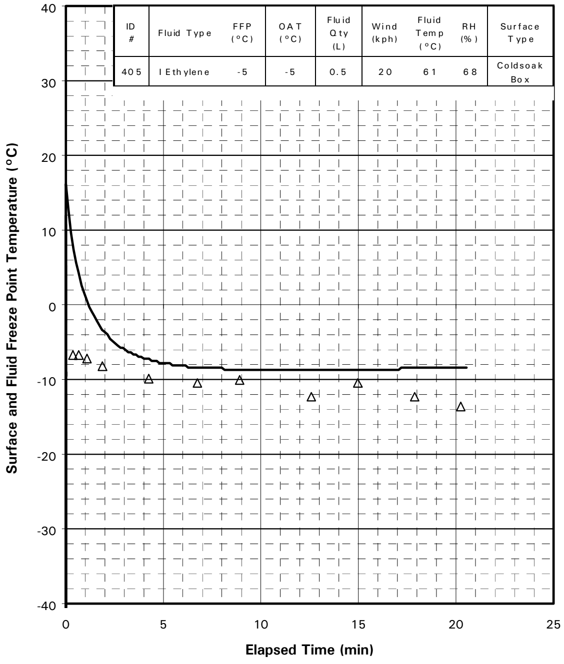
Cold Soaked Boxes - ID# 404



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
404	I Ethylene	-5	-5	0.25	0	51	68	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

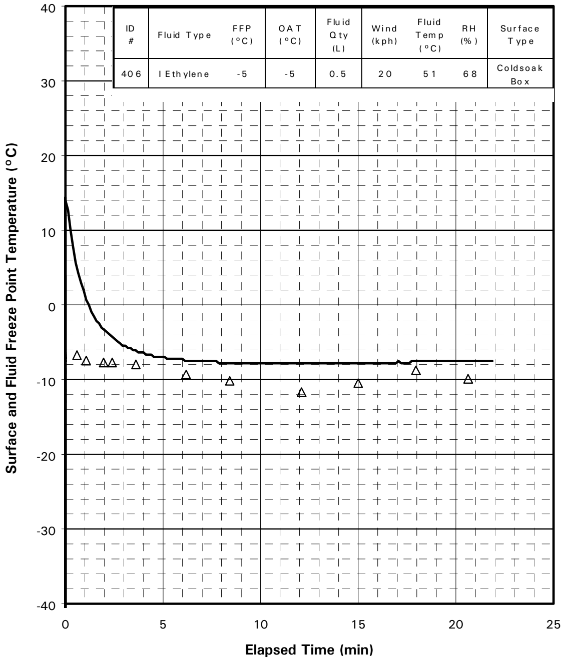
Cold Soaked Boxes - ID# 405



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
405	I Ethylene	-5	-5	0.5	20	61	68	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

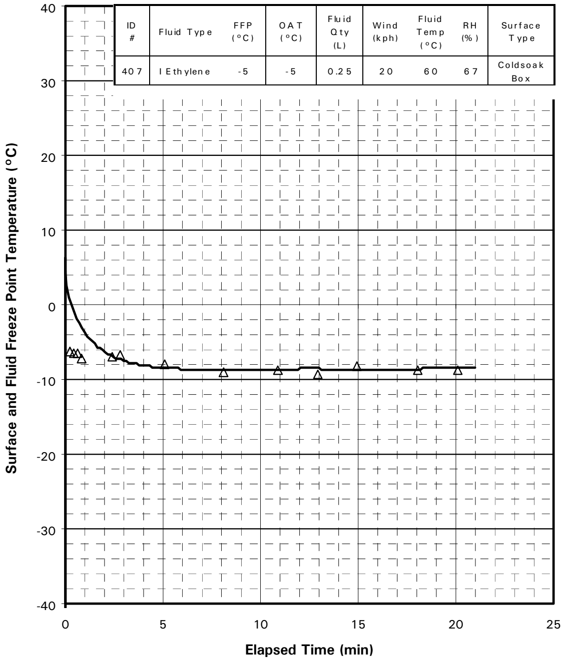
Cold Soaked Boxes - ID# 406



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
406	I Ethylene	-5	-5	0.5	20	51	68	Coldsoak Box

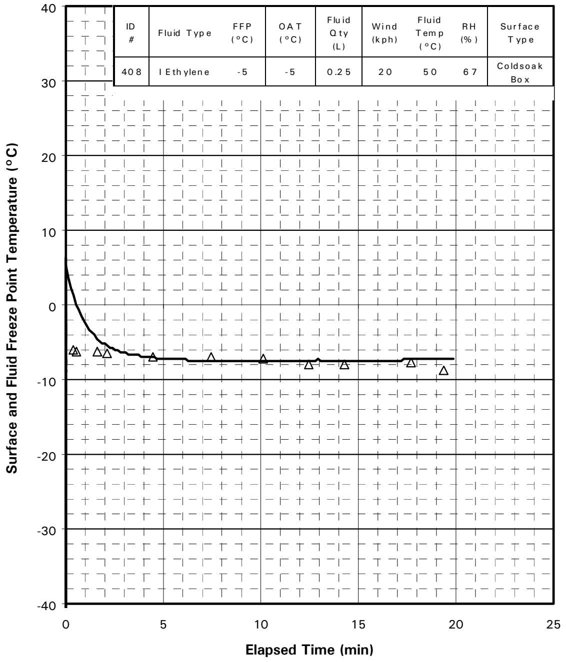
Fluid Freeze Point and Surface Temperature Profile

Cold Soaked Boxes - ID# 407



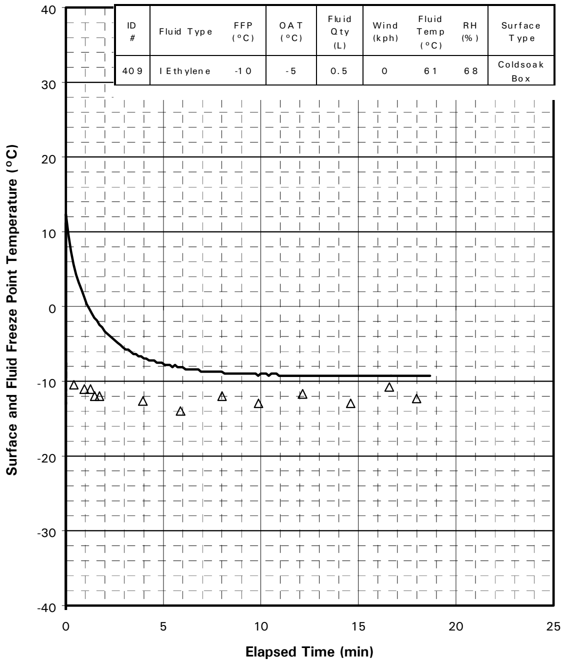
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
407	I Ethylene	-5	-5	0.25	20	60	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 408



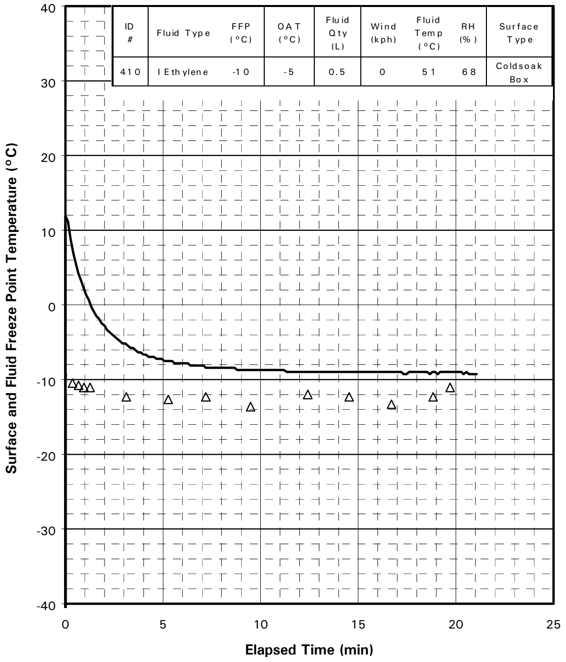
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
408	I Ethylene	-5	-5	0.25	20	50	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 409



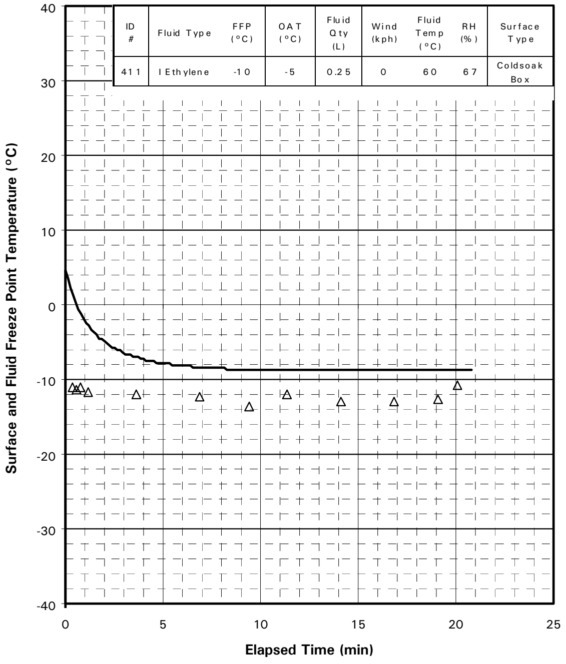
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
409	I Ethylene	-10	-5	0.5	0	61	68	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 410



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
410	I Ethylene	-10	-5	0.5	0	51	68	Coldsoak Box

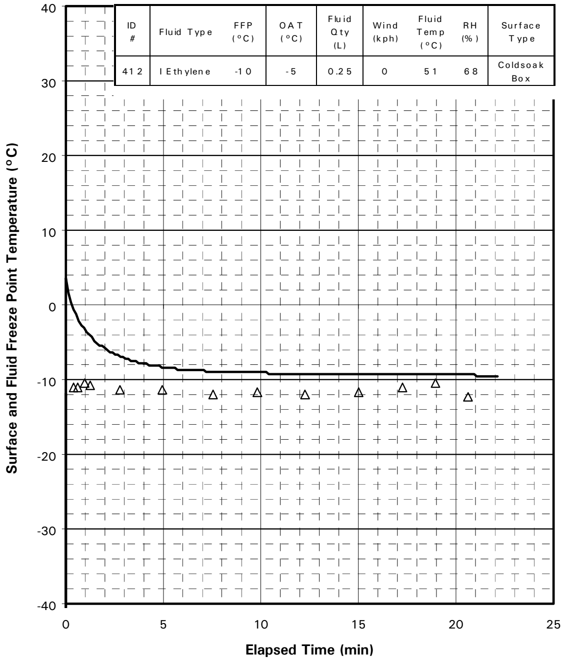
Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 411



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
411	I Ethylene	-10	-5	0.25	0	60	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

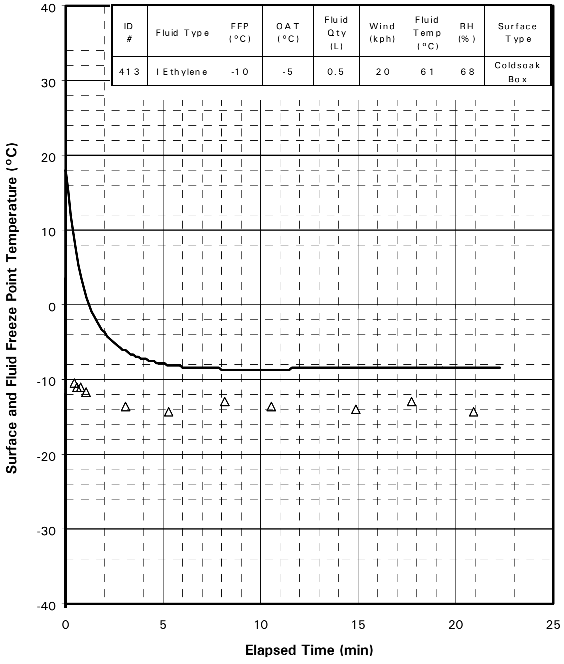
Cold Soaked Boxes - ID# 412



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
412	I Ethylene	-10	-5	0.25	0	51	68	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

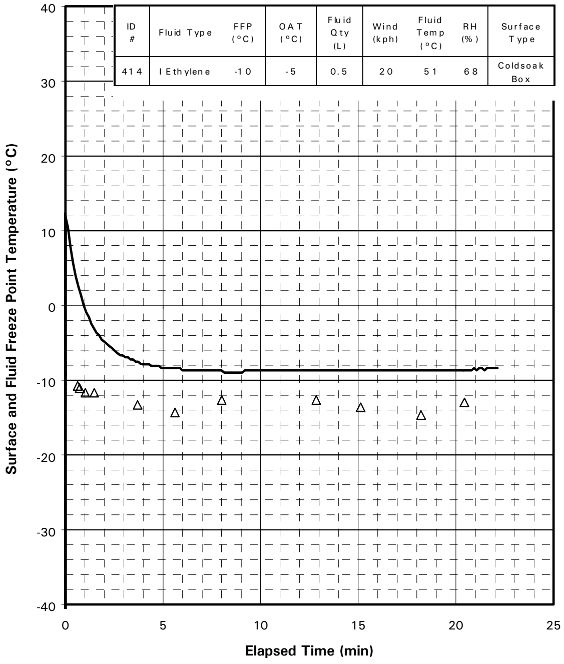
Cold Soaked Boxes - ID# 413



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
413	I Ethylene	-10	-5	0.5	20	61	68	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

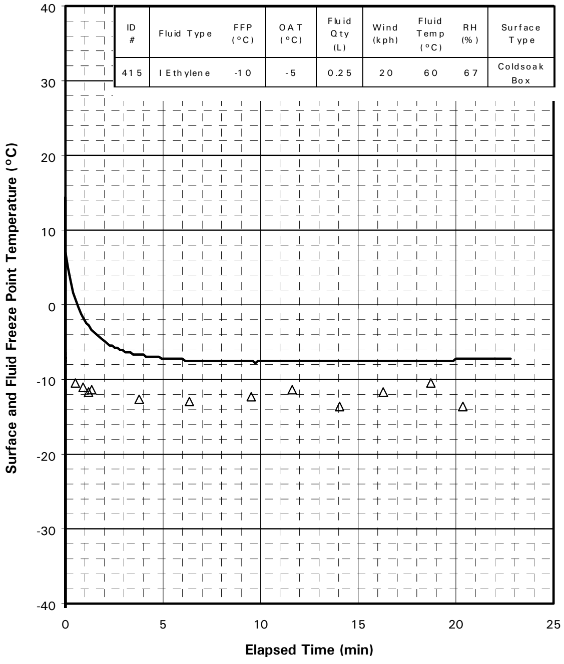
Cold Soaked Boxes - ID# 414



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
414	I Ethylene	-10	-5	0.5	20	51	68	Coldsoak Box

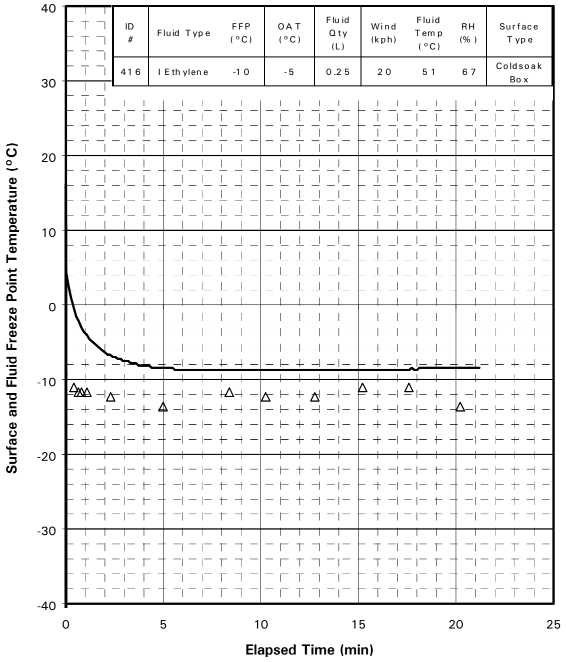
Fluid Freeze Point and Surface Temperature Profile

Cold Soaked Boxes - ID# 415



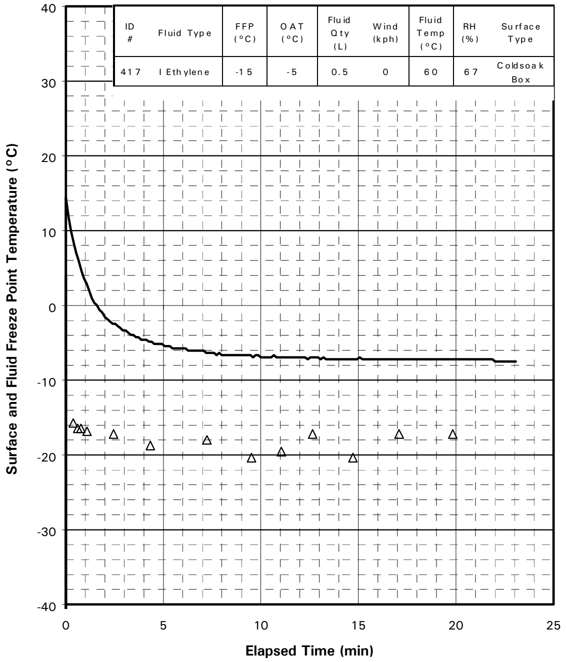
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
415	I Ethylene	-10	-5	0.25	20	60	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 416



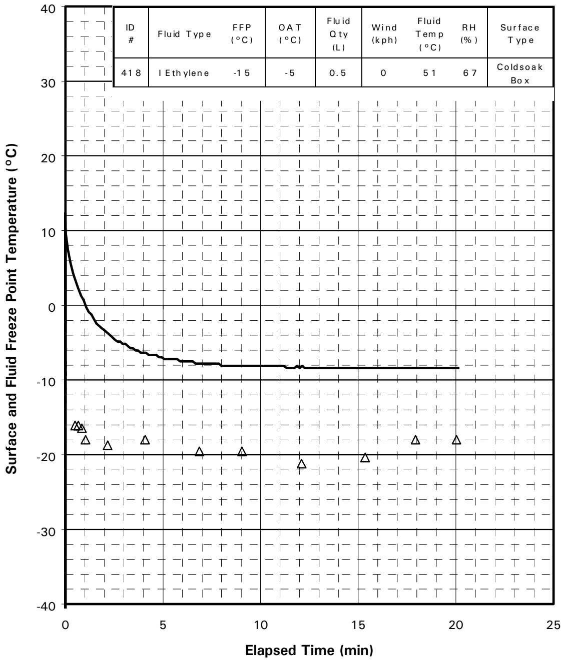
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
416	I Ethylene	-10	-5	0.25	20	51	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 417



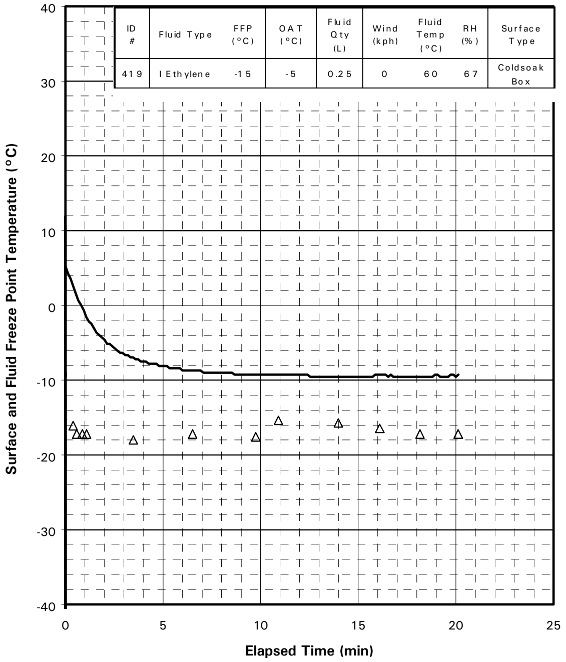
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
417	I Ethylene	-15	-5	0.5	0	60	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 418



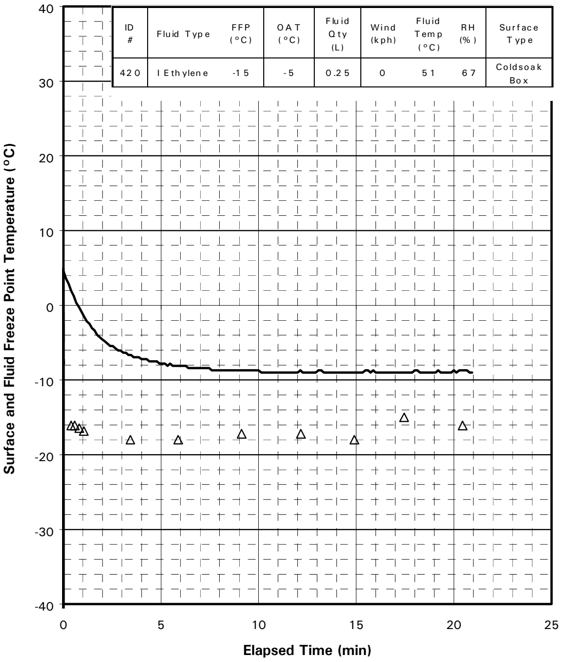
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
418	I Ethylene	-15	-5	0.5	0	51	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 419



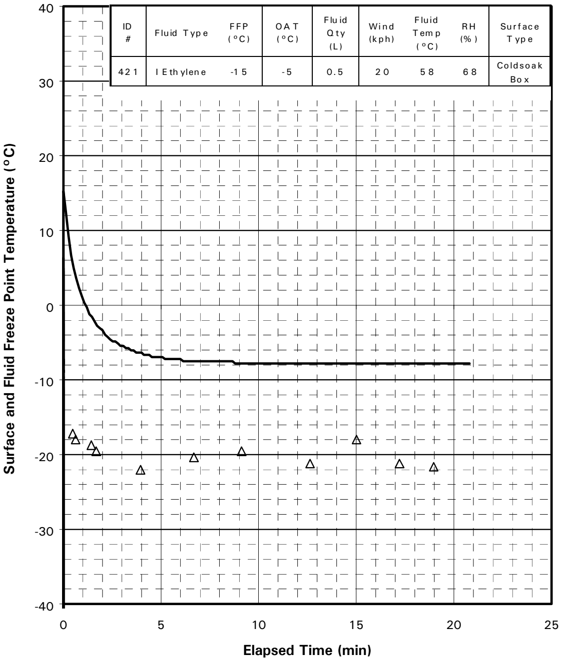
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
419	I Ethylene	-15	-5	0.25	0	60	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 420



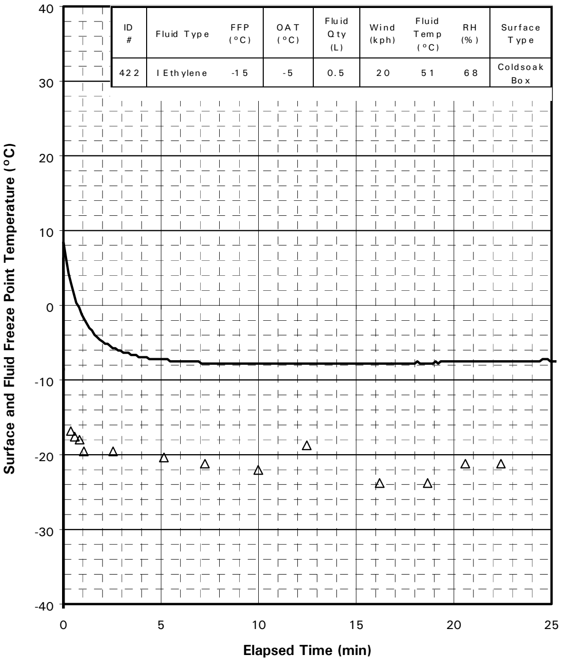
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
420	I Ethylene	-15	-5	0.25	0	51	67	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes ID# 421



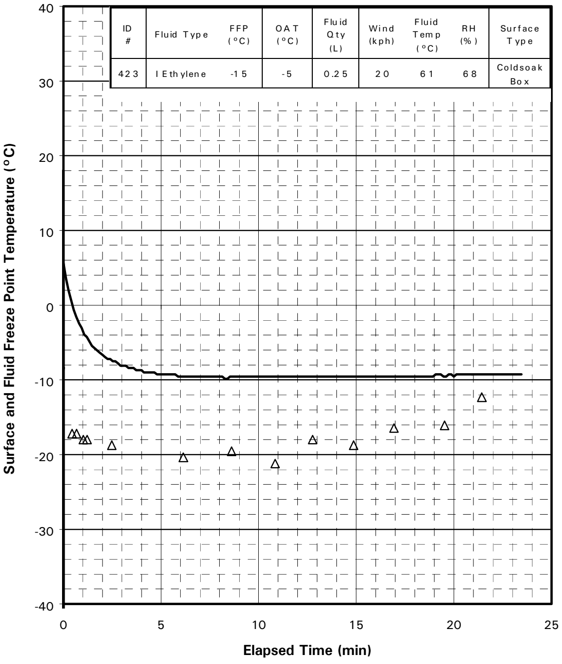
ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
421	I Ethylene	-15	-5	0.5	20	58	68	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 422



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
422	I Ethylene	-15	-5	0.5	20	51	68	Coldsoak Box

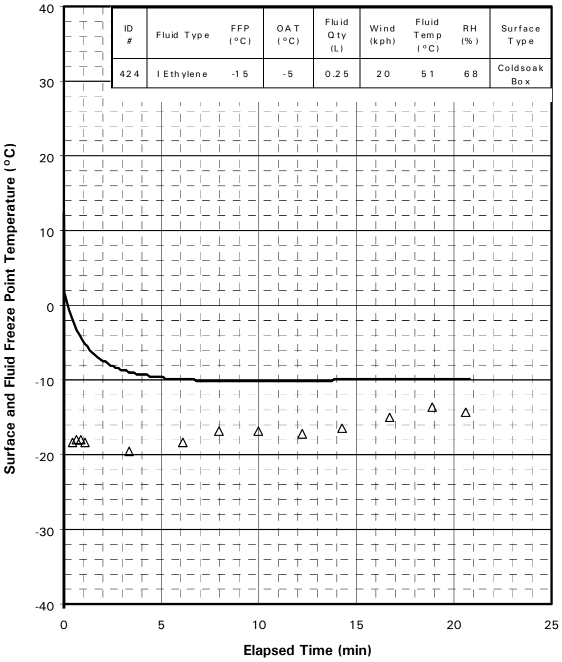
Fluid Freeze Point and Surface Temperature Profile
Cold Soaked Boxes - ID# 423



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
423	I Ethylene	-15	-5	0.25	20	61	68	Coldsoak Box

Fluid Freeze Point and Surface Temperature Profile

Cold Soaked Boxes ID# 424



ID #	Fluid Type	FFP (°C)	OAT (°C)	Fluid Qty (L)	Wind (kph)	Fluid Temp (°C)	RH (%)	Surface Type
424	I Ethylene	-15	-5	0.25	20	51	68	Coldsoak Box

APPENDIX F

AIRCRAFT DEICING/ANTI-ICING METHODS WITH FLUIDS

SAE The Engineering Society For Advancing Mobility Land Sea Air and Space®
INTERNATIONAL
400 Commonwealth Drive, Warrendale, PA 15096-0001

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 using heated deicing/anti-icing fluids (see 3.3.2). 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

APPENDIX A

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 A1 - Guidelines for the Application of SAE Type I Fluid Mixtures (Minimum Concentrations) as a Function of Outside Air Temperature (OAT)

APPENDIX G

ENVIRONMENTAL IMPACT ASSESSMENT

Environmental Impact Assessment
Waste disposal procedures for glycol-based products

1. INTRODUCTION

1.1 Objectives

The primary objectives of this study were to:

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

2. METHODOLOGY

To assess the environmental impact of the use of glycol-based products and examine the waste disposal procedures, several deicing facility operators, airport authorities, regulatory agencies, and airlines were contacted. Primary contact with a number of organisations involved the use of the Internet and e-mail; however, all organisations were eventually contacted by phone. All values and information were obtained verbally over the phone.

3. DESCRIPTION AND PROCESSING OF DATA

3.1 Dorval (Montreal)

The Dorval Airport Authority, Aeroports de Montreal (ADM), and the new deicing facility operator, Aeromag 2000, agree that to their knowledge, there is no runoff and 100 percent of the deicing agents are collected within the facility. According to ADM and Montreal Urban Community (M.U.C) Environmental Department, the facility in Dorval has an agreement that allows them to send 20 t/day of waste solution (below 30 percent glycol) to the city of Dorval's treatment plant. The concentrations of the waste fluid are highly variable, as it depends on the type of deicing required. Concentrations of glycol can be 5 percent or lower; solutions over the 30 percent mark are kept in reservoir tanks in their warehouses.

Although these values are not foreseen to change, the M.U.C. is currently researching the issue to see if a change is necessary. In addition, recycling contracts are currently being discussed with Inland Technologies, because glycol concentrations at 25 percent and 30 percent are extremely valuable. The future goal of ADM is to send all waste fluid above 15 percent glycol to Inland Technologies for recycling. According to Aeromag 2000, the future use of non-glycol based deicing technologies would only be considered within the industry if these procedures work as well as current methods.

3.2 Mirabel (Montreal)

Mirabel Airport's deicing facility, also operated by Aeromag 2000, is older than Dorval's and consists of six 65 000 L recovery basins. These basins store waste fluids with glycol concentrations above 10 percent, which are eventually picked up and recycled by Inland Technologies. All waste fluids under the 10 percent glycol mark are sent to a local water treatment plant. No current daily disposal limit exists. These values are not expected to change in the near future.

3.3 Toronto

Pearson Airport's deicing facility is similar, on a larger scale, to that of the new Dorval Airport deicing facility, but with a few adjustments, including a staging bay. Consisting of 13.5 million L of underground storage, the facility is allowed to pump out 3500 kg/day of waste fluid to the treatment plant through the west side. Waste exiting the east side is shared with terminal 3, and has a limit of 10 500 kg/day. Trucks with a 34 000 L capacity are available to transport excess waste to the sanitary plants. It should be noted that these amounts must be below 10 percent glycol. Glycol concentrations are variable and depend on the operation being performed. It is estimated that the majority of waste fluids are below 3 percent glycol. According to the Greater Toronto Airport Authority (GTAA), waste fluid with glycol concentrations of 10 percent or higher are taken by Inland Technologies to be recycled.

These values are not expected to change. Toronto's Pearson Airport is constantly looking for ways to address environmental concerns. Centralization of their deicing set-up was done in response to these needs. According to the GTAA, non-glycol based deicing methods are of interest, provided they meet the appropriate standards.

3.4 Vancouver

Waste fluids stored in storage lagoons are too dilute to be recycled. Regional laws forbid the local discharge of all glycol-based products. Currently, Inland Technologies is responsible for shipping the waste fluid (at 3 percent or lower glycol concentrations) to a Seattle-based treatment plant. Inland's role is strictly one of transportation, because it is not cost-effective to recycle such a dilute fluid. Furthermore, Hudson General is having difficulty finding enough trucks to meet the demand.

The current situation is not expected to change in the near future. The industry is skeptical that a new method of freeze depressant will ever perform up to the standards of glycol. Glycol is readily available but expensive to recover. However, new alternatives must meet biological oxygen demand (B.O.D.) concerns as well as function to the level of glycol-based deicing methods, if the industry is to switch over.

3.5 United States

U.S. federal regulations allow airports to discharge 5000 pounds/24 hours, of ethylene glycol-based deicing fluid. This value includes all forms of discharge (land, air, and waterways), and is based purely on weight and not on the glycol concentration of the discharged solution. Airports must obtain a permit for all their discharges. Certain specifications, such as concentrations and B.O.D. limits of discharged solutions, will vary from airport to airport under these permits. According to US Airways and the Environmental Protection Agency (EPA), under the C.E.R.C.L.A. laws (Comprehensive Environmental Responsibilities Compensation Liability Act) all discharges exceeding the maximum weight/24 hours must be reported to the EPA.

The FAA (Federal Aviation Administration) discourages the use of open storage ponds, and strongly encourages the use of covered ponds, in an attempt to lower the possibility of problems associated with birds.

The values associated with the discharges of ethylene glycol-based products are not expected to change; however, it is predicted that similar regulations will eventually apply to propylene glycol-based products, which have a higher B.O.D. than ethylene glycol. At present, the United States EPA is researching the possibility of establishing effluent limit guidelines for all airports.

Although non glycol-based deicing techniques such as infrared heat and hot air have had limited success, most efforts in the United States focus on the containment, recovery, and recycling of the current deicing fluids.

4. CONCLUSIONS

Airports in Toronto and Vancouver were found to have similar regulations regarding glycol disposal procedures. Regional regulations in Vancouver stipulate that all glycol waste must be disposed of outside the region. Toronto's Pearson Airport and Mirabel Airport outside of Montreal both recycle waste at 10 percent glycol and above, and send the remaining waste to local treatment plants. Montreal's Dorval Airport has the least strict regulations, allowing all waste below 30 percent glycol to be sent to the local treatment plant. The M.U.C. is currently doing research to determine whether the values at Dorval need to be adjusted. In addition, the ADM is presently negotiating a recycling contract with Inland Technologies.

U.S. federal regulations allow for airports to discharge 5000 pounds of ethylene glycol-based deicing fluids/24 hours. US Airways predicts that propylene glycol-based products will soon follow similar regulations.

Although the U.S. and Canada have tried alternative aircraft deicing procedures such as infrared heat and hot air, it appears unlikely that a new method will replace the current glycol-based deicing methods in the near future. The aircraft ground deicing industry seems content in focussing its attention on the containment, recovery, and recycling of glycol-based products.