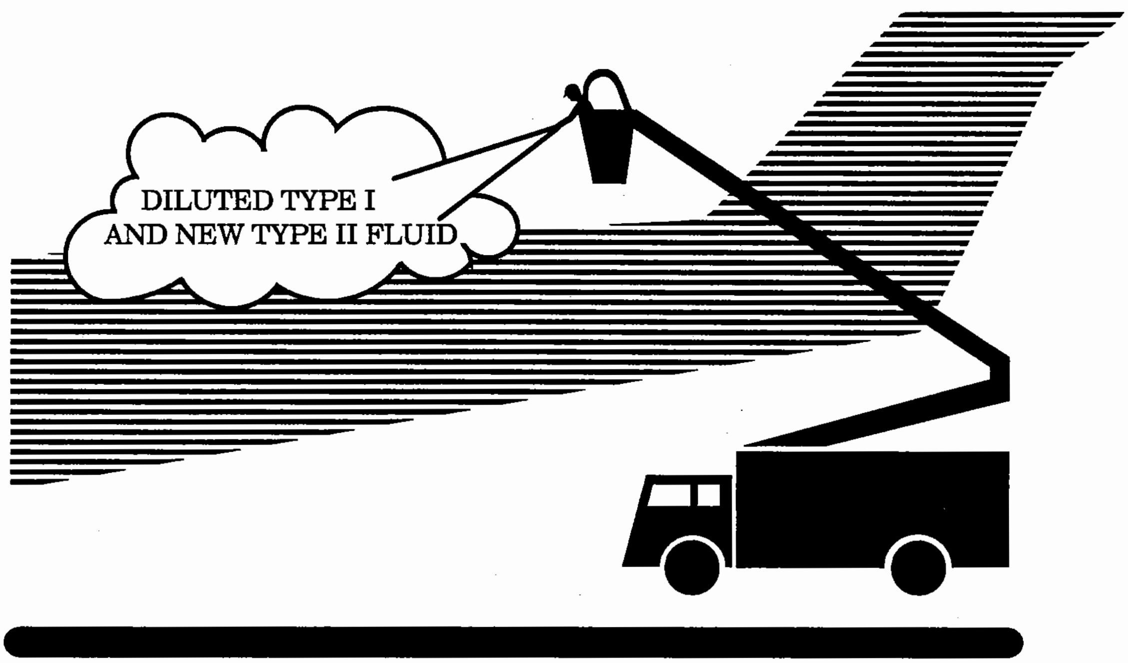
TP 12654E

Aircraft Ground De/anti-icing Fluid Holdover Time Field Testing Program for the 1994-1995 Winter



Prepared for

Transportation Development Centre
Safety and Security
Transport Canada

by

APS AVIATION INC.

John D'Avirro
Ziad Boutanios

December 1995

TP 12654E
CM1222.001

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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Dryden Commission Implementation Project of Transport Canada.

Un sommaire en français de ce rapport est inclus.

PREFACE

At the request of the Dryden Commission Implementation Program of Transport Canada, APS Aviation Inc. has undertaken a research program to further advance aircraft ground de-icing/anti-icing technology. Specific objectives of the overall program were:

- Substantiation of SAE/ISO Holdover Time Tables that define a de-icing fluid's ability to delay ice formation by conducting tests on flat plates under conditions of natural snow, simulated freezing drizzle, simulated light freezing rain, and simulated freezing fog for a range of fluid dilutions and temperature conditions;
- Development of data for "cold-soaked" wing conditions using cooled flat plates to simulate the conditions;
- Correlation of flat plate test data with the performance of various fluids on service aircraft by concurrent testing;
- Evaluation of the suitability of hot blown air equipment to remove frost at extreme low temperatures;
- Evaluation of the suitability of equipment which blows air to remove snow;
- Determination of the environmental limits for use of hot water as a de-icing fluid;
- Evaluation of a remote sensor to detect contamination on wing surfaces;
- Determination of the pattern of fluid run-off from the wing during take-off; and
- Determination of wing temperature profiles during and after the de-icing operation.

The research activities of the program conducted on behalf of Transport Canada during the 1994/95 winter season are documented in four separate reports. The titles of these reports are as follows:

- TP 12595E Aircraft Full-Scale Test Program for the 1994/95 Winter;
- TP 12653E Hot Water De-Icing Trials for the 1994/95 Winter;
- TP 12654E Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1994/95 Winter; and
- TP 12655E Forced Air De-Icing Trials for the 1994/95 Winter.

Three additional reports were produced as a part of this research program. The titles of these reports are as follows:

- TP 12676E Consolidated Fluid Holdover Time Test Data;
- TP 12677E Consolidated Research and Development Report; and
- TP 12678E Methodology for Simulating a Cold-Soaked Wing.

This report TP 12654E addresses the topics of substantiation of SAE/ISO Holdover Time Tables that define a de-icing fluid's ability to delay ice formation by conducting tests on flat plates under conditions of natural snow, simulated freezing drizzle, simulated light freezing rain, and simulated freezing fog for a range of fluid dilutions and temperature conditions; development of data for "cold-soaked" wings using cooled flat plates to simulate the conditions; and evaluation of a remote sensor to detect contamination on wing surfaces.

This program could not have been completed without the assistance of many individuals and organizations. APS would therefore like to thank the Dryden Commission Implementation Project, Transportation Development Centre, the Federal Aviation Administration, the National Research Council, Atmospheric Environment Services, Transport Canada and the fluid manufacturers for their contribution and assistance in the project. Special thanks are extended to Aeromag 2000, Aerotech International Incorporated, Air Atlantic, Air Canada, Calm Air, Canadian Airlines International, CanAir Cargo and United Airlines for their cooperation, personnel and facilities.

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Research reports produced on behalf of Transport Canada for testing during previous winters are available as follows: TP 11206E 1990/91; TP 11454E 1991/92; TP 11836E 1992/93; and 1993/94 Summary Report submitted to DCIP. Seven reports (including this report) were produced as part of this winter's research program: TP 12595E Full-Scale Tests; TP 12653E Hot Water; TP 12655E Forced Air; TP 12654E Holdover Time Substantiation; TP 12676E Consolidated Holdover Time Data; TP 12678E Methodology for Simulating a Cold-Soaked Wing; and TP 12677E Consolidated Research and Development.

16. Abstract

The objective of this study was to manage, conduct and analyse holdover time tests used to assess the time effectiveness of commercially produced de/anti-icing fluids with respect to the current SAE/ISO guidelines. Testing included: natural snow tests at Dorval; simulated freezing drizzle, light freezing rain and freezing fog tests at NRC facilities in Ottawa; and rain on cold-soaked surface tests, also conducted at the NRC. Test procedures consisted of pouring de/anti-icing fluids onto clean aluminium plates or on sealed cold-soaked boxes and recording the elapsed time to the end condition. Ice detection sensors were used to assist in the evaluation of fluid failure time. Standard and diluted Type I and Type II fluids, including UCAR Ultra, provided by five manufacturers, were tested. Variables measured included the elapsed time, total precipitation, temperature, wind speed and direction, and type of fluid.

A total of 425 natural snow, 94 freezing drizzle, 112 light freezing rain, 150 freezing fog, and 131 rain on cold-soaked surface tests were performed. Under natural snow and freezing fog, the Type I SAE/ISO HOT range was substantiated using diluted fluids with a 10°C buffer. New freezing drizzle and light freezing rain HOTs were developed in substitution of the freezing rain column in the SAE HOT table. When using Ultra for 1995/96 winter operations, the Type II HOTs were increased by 50% for the Neat concentration under all conditions except rain on cold-soaked wings. An experimental approach to represent rain on cold-soaked wings was developed. Preliminary test results show that the Type I and Type II 50/50 SAE/ISO HOTs for rain on cold-soaked wings may require a reduction.

The scope of future tests should focus on the new Type IV fluids for all forms of precipitation under all dilutions. Necessary procedural and equipment enhancements were recommended. Cold-soaked tests should be conducted to substantiate the SAE/ISO HOTs.

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Transports Canada a fait produire les rapports de recherche suivants sur les essais menés durant les hivers précédents : TP 11206E pour 1990-1991; TP 11454E pour 1991-1992; TP 11836E pour 1992-1993 et le sommaire pour l'année 1993-1994 présenté au Comité de mise en oeuvre de la Commission Dryden. Concernant le programme de recherche mené durant l'hiver de 1994-1995, les sept rapports suivants (y compris le présent) ont été produits : TP 12595E Full-Scale Tests; TP 12653E Hot Water; TP 12655E Forced Air; TP 12654E Holdover Time Substantiation; TP 12676E Consolidated Holdover Time Data; TP 12678E Methodology for Simulating a Cold-Soaked Wing et, enfin, TP 12677E Consolidated Research and Development.

16. Résumé

Le but de cette étude était d'organiser et de mener des essais visant à mesurer les durées d'efficacité des liquides dégivrants et antigivrage sur le marché, et de les comparer aux valeurs correspondantes des tables normalisées SAE/ISO. Les essais effectués étaient les suivants : sous neige naturelle à Dorval; simulation de précipitations verglaçantes (pluie fine, bruine et brouillard) et dans des conditions de sur-refroidissement sous pluie dans les installations du CNR à Ottawa. Le mode opératoire a consisté à verser un agent antigivre sur des plaques d'aluminium propres inclinées et à mesurer le temps écoulé jusqu'à l'apparition d'un état dit final. Des capteurs de givre ont également servi à mesurer les durées d'efficacité. Ont été mis en oeuvre des liquides de type I et II, standard ou dilués fournis par cinq fabricants, y compris Union Carbide qui a fourni le liquide de type IV. Les variables mesurées ont été les suivantes : temps écoulé, quantité totale de précipitation, température ambiante, vitesse et direction du vent et type de liquide.

Les essais ont permis de récolter le nombre suivant de mesures : 425 sous neige naturelle, 94 sous bruine verglaçante, 112 sous pluie fine verglaçante, 150 sous brouillard verglaçant et 131 dans des conditions de sur-refroidissement sous pluie. Sous neige naturelle et brouillard verglaçant, les durées d'efficacité SAE/ISO ont été jugées valables pour les liquides de type I dilués dont le point de congélation est inférieur par 10 °C au point de congélation ambiant. Sous bruine verglaçante et sous pluie fine verglaçante, de nouvelles valeurs sont proposées pour remplacer celles qui sont affichées sous la rubrique «pluie verglaçante» des tables SAE/ISO. Avec un liquide de type IV durant l'hiver de 1995-1996, les durées d'efficacité ont été augmentées de 50 p. 100 dans le cas d'un liquide de type IV pur et dans toutes les conditions météo excepté le sur-refroidissement sous pluie. Une méthode expérimentale a été mise au point pour la simulation des ailes sur-refroidies. Pour ce qui est des liquides de type I et II dilués 50/50, les premiers résultats montrent qu'il faudra probablement réviser à la baisse les valeurs extrêmes des intervalles de durée d'efficacité indiqués dans les tables SAE/ISO.

Les essais futurs devraient se concentrer sur les durées d'efficacité des liquides de type IV sous toutes formes de précipitation et à tous les degrés de concentration. Il faudra aussi améliorer les instruments et les procédures d'observations météorologiques, et mener des tests sur des plaques sur-refroidies pour confirmer les durées d'efficacité affichées dans les tables SAE/ISO.

17. Mots clés Aéronef, neige, brouillard, bruine, pluie, antigivrage, liquide, durée d'efficacité, précipitation, profil d'aile, plaque plane, dégivrage, givre, détecteur, sur-refroidissement	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

At the request of the Dryden Commission Implementation Program (DCIP) of Transport Canada (TC), APS Aviation Inc. (APS) undertook a research program to further advance aircraft ground de-icing/anti-icing technology. While a number of objectives of the test program are covered by other related reports, this document specifically addresses the topics of:

- Substantiation of SAE/ISO holdover time tables by conducting tests for a range of fluid dilutions and temperature conditions, on flat plates under conditions of natural snow, simulated freezing drizzle, simulated light freezing rain, and simulated freezing fog;
- Development of data for "cold-soaked" wing conditions using cooled flat plates; and
- Evaluation of a remote sensor to detect contamination on wing surfaces.

The project involved the participation of many de/anti-icing fluid manufacturers, DCIP, the Transportation Development Centre (TDC), TC, the National Research Council of Canada (NRC), and Atmospheric Environment Services (AES).

The bulk of testing consisted of pouring a range of de/anti-icing fluids onto clean, inclined flat aluminum plates, exposing the plates to various winter precipitation conditions and recording the elapsed time before the plates reached a defined end condition. The time that a tested fluid can delay ice formation, defines the specific holdover time or HOT. Some testing was also performed on a sealed box/plate section used for simulation of cold-soaking. In a number of tests, remote and surface ice detection sensors were used in the testing process.

This end condition was defined as the point when natural snow was no longer being absorbed or de-iced by the fluid. This occurred when snow was seen to be resting, or bridging, on top of the fluid and covering one-third of the plate. For the freezing fog, freezing drizzle, light freezing rain and rain on cold-soaked surface conditions, the "loss-of-gloss" type of failure point was used.

The variables which were measured included: total precipitation, failure time, ambient temperature, visibility, wind speed, wind direction, type of fluid and type of precipitation.

Data Collection

During the 1994/95 test season, data were collected for natural snow tests conducted at Dorval. Freezing drizzle, light freezing rain and freezing fog tests were conducted indoors in Ottawa, and rain on cold-soaked surface tests were also performed at NRC facilities in Ottawa.

For natural snow conditions, 425 usable tests were conducted. Of the 425 tests, 112 tests were with standard Type I de-icing fluids, 99 were with diluted Type I fluids, 128 were with Type II neat fluids, 28 were using Type II fluids diluted 50/50, and 58 were with Type II diluted 75/25 fluids. A number of the Type II fluid tests were performed with the new "next generation" Ultra fluid. A total of 94 simulated freezing drizzle tests and 112 light freezing rain tests were performed, again with both standard and diluted Type I and II fluids including Ultra. For simulated freezing fog, a total of 150 tests were conducted, primarily with standard and diluted Type I and neat Type II fluids. A total of 131 "rain on cold-soaked surface" tests were conducted with an approximately equal distribution of standard and diluted Type I fluids and neat and diluted Type II (including Ultra) fluids. Approximately one-half of the cold-soaked tests were performed with boxes having a depth of 7.5 cm and the remaining tests were with 15 cm deep boxes. The fluids were obtained from five manufacturers including Union Carbide's (UCAR) new Ultra fluid.

Meteorological Analysis

With the cooperation of the Atmospheric Environment Service (AES), APS was able to obtain relatively detailed meteorological information for the tests at the Dorval site. This cooperation included a Radar forecasting service which provided early warning for snowfalls and assisted in the planning of individual tests. The data provided by the AES instruments were automated and available on a minute-by-minute basis. This automated station (the Remote Environmental Automatic Data Acquisition Concept known as READAC) provided pertinent information such as total precipitation, wind speed and direction, visibility, and temperature.

The precipitation collection devices used at Dorval included plate pans and the READAC precipitation gauge. The comparison of these two methods for measurement of precipitation showed a good correlation. A plot of the average visibility measured by READAC compared to average plate pan collection rates showed a fair amount of scatter, even when segregating the data by the outside air temperature (OAT). The indication is that visibility is not directly related to precipitation rate.

Data Analysis

The primary focus of the 1994/95 winter testing program was to substantiate the existing Type I SAE/ISO holdover times, using test data resulting from diluted fluid mixtures and to compare the results of UCAR's Ultra Type II with conventional Type II fluids. Additional tests were completed to extend the SAE/ISO HOT range in freezing drizzle and light freezing rain from - 7°C to -10°C.

A statistical analysis was performed on the data. The primary purpose of this multi-variable regression analysis was to verify that the correct trends were present and to help to quickly identify any outlying points which required closer inspection.

Concluding Results

Under natural snow conditions, the current SAE/ISO HOT range for Type I fluids was substantiated using test data with diluted fluids having a 10°C freeze point (FP) buffer. Ultra neat was found to be more than 50% better than conventional neat Type II fluids. For 1995/96 winter operations, the Type II HOTs were increased by 50% for the neat concentration when using Ultra.

The freezing rain column in the SAE/ISO HOT tables was eliminated and replaced with two new columns: freezing drizzle and light freezing rain. New HOT ranges were determined based on flat plate testing at NRC's Climatic Engineering Facility. These new HOT ranges are applicable for temperatures as low as -10°C for most fluid types. The neat Type II HOTs were increased by 50% when Ultra is used.

For freezing fog, the diluted (10°C buffer) Type I tests showed that the SAE/ISO HOT range is substantiated, even at temperatures below -25°C. For Ultra, the neat Type II SAE HOTs were increased by 50%.

Preliminary results have shown that the SAE/ISO HOT ranges for rain on a cold-soaked wing may be adequate for neat Type II and Type II 75/25. For Type II 50/50 and diluted Type I fluids, the SAE/ISO HOT ranges may, subject to further testing, require a reduction.

Instrumar's C/FIMS and RVSIs ID-1 ice detection sensors when used, were found to generally correlate well with human observations of fluid failure.

Future Testing

Section 7 of this report outlines in detail the direction and scope for future testing, including recommendations on refining test procedures and future equipment enhancements. It is recommended that the scope of future tests should focus on the use of the new Type II (Type IV) fluids for all forms of precipitation under all dilutions (50/50, 75/25, and neat) and for a range of temperatures. Future cold-soaked tests should also be carried out with the new 2.5 cm boxes to further substantiate the SAE/ISO HOTs and set new values for the Type IV fluids.

SOMMAIRE

Mandatés par le Comité de mise en oeuvre de la Commission Dryden (CMOCD), mis sur pied par Transports Canada, les Services de planification en aviation Inc. (APS) ont lancé un programme de recherche visant à faire progresser la technologie de dégivrage/antigivrage des avions au sol. Certains des objectifs fixés à ce programme sont décrits dans plusieurs rapports connexes. Le présent rapport traite plus particulièrement des objectifs suivants :

- vérification des tables de durée d'efficacité selon SAE/ISO en menant des tests mettant en oeuvre des liquides purs ou diversement dilués, versés à des températures ambiantes variées sur des plaques planes sous neige naturelle ou une précipitation verglaçante simulée - pluie fine, bruine et brouillard;
- acquisition de données sur le sur-refroidissement par la simulation, en utilisant des plaques planes sur-refroidies;
- Évaluation d'un capteur détectant à distance l'état de contamination des ailes d'un avion.

Les chercheurs ont obtenu le concours des fabricants de liquides dégivrants et antigivrants, du CMOCD, du Centre de développement des transports (CDT), de Transports Canada, du Conseil national de recherches du Canada (CNR) et du Service de l'environnement atmosphérique (SEA).

Règle générale, les essais ont consisté à verser un liquide antigivre ou dégivrant sur des plaques d'aluminium propres inclinées, à exposer ces plaques à diverses formes de précipitation hivernale et à mesurer le temps écoulé jusqu'à l'apparition d'un état dit final. Le temps par lequel l'apparition du givre est repoussée grâce à l'action du liquide définit ce qui est appelé la durée d'efficacité de ce liquide. Des essais ont également été menés sur une boîte métallique fermée surmontée d'une plaque afin de simuler les conditions de sur-refroidissement. Dans un certain nombre d'essais, des capteurs de givre soit optiques, soit encastrés ont été utilisés.

Un état était dit final lorsque la neige naturelle cessait d'être absorbée par le liquide, c'est-à-dire lorsqu'on observait de la neige reposant sur la plaque, ou faisant le pont, au-dessus du liquide, jusqu'à concurrence du tiers de la surface de la plaque. Quant aux essais sous brouillard, bruine et pluie fine verglaçantes, et dans des conditions de sur-refroidissement sous pluie, l'état final correspondant était prononcé lorsque l'aspect «glacé» caractéristique des liquides disparaissait.

Les variables mesurées étaient les suivantes : quantité totale de précipitation, durée d'efficacité, température ambiante, vitesse et direction du vent, type de liquide et forme de précipitation.

Collecte de données

Au cours de la saison 1994-1995, les essais sous neige naturelle ont eu lieu à Dorval, les essais sous précipitations verglaçantes - brouillard, bruine et pluie fine - ont eu lieu par simulation à Ottawa et les essais dans des conditions de sur-refrodissement sous pluie dans les laboratoires du CNR à Ottawa.

Les essais sous neige naturelle ont permis de récolter 425 mesures exploitables, ventilées comme suit : 112 avec des liquides de type I standard et 99 avec des liquides de type I dilués; 128 avec des liquides de type II purs; 28 avec des liquides de type II à concentration 50/50 et 58 avec des liquides de type II à concentration 75/25. Pour un certain nombre des essais avec les liquides de type II, le nouveau liquide type IV a été utilisé. Les essais sous précipitation verglaçante simulée - bruine et pluie fine - ont donné 94 et 112 mesures, respectivement, avec des agents de type I, II et IV, standard et dilués. Les essais avec simulation de brouillard verglaçant ont donné 150 mesures, avec principalement des liquides de type I standard et dilués et de type II purs. Pour les 131 essais dans des conditions de sur-refroidissement sous pluie, on a utilisé des liquides de type I standard et dilué, de type II et IV purs et dilués, selon une distribution à peu près égale. Environ la moitié de ces derniers ont porté sur des boîtes de 7,5 cm de profondeur, et le reste sur des boîtes de 15 cm de profondeur. Les liquides testés ont été fournis par cinq fabricants, y compris Union Carbide qui a fourni le liquide de type IV.

Analyse des données météorologiques

Grâce à la collaboration du Service de l'environnement atmosphérique, les chercheurs ont pu obtenir des données météorologiques assez détaillées concernant le site d'essai à Dorval. Ils ont eu accès à des prévisions par radar sur les conditions de neige imminentes qui leur ont permis d'organiser la conduite des essais. En plus d'être automatiques, ces prévisions se faisaient sur une base permanente. Grâce au système télécommandé d'acquisition automatique de données environnementales (READAC), ils ont pu obtenir des informations utiles sur la quantité totale de précipitation, la vitesse et la direction du vent, la visibilité et la température.

Des bacs et le pluviomètre READAC étaient parmi les accessoires de mesure utilisés à Dorval. La corrélation des mesures fournies par ces deux procédés a été bonne. La recherche a montré que, en comparant le degré de visibilité donné par READAC au procédé du taux moyen d'accumulation dans les bacs, on obtient des résultats très dispersés, même après avoir départagé les données par tranches de température extérieure de l'air. La conclusion en est que la visibilité n'est pas directement liée au taux de précipitation.

Méthodes d'analyse

Le programme d'essais pour l'hiver de 1994-1995 avait pour objet principal de vérifier les tables de durée d'efficacité SAE/ISO pour les liquides de type I sur le marché, à la lumière des résultats des essais avec des liquides dilués, et aussi de comparer les durées du liquide de type IV avec celles des liquides de type II connus. D'autres essais ont été menés afin de déterminer les durées d'efficacité SAE/ISO dans des conditions de bruine verglaçante et de pluie fine verglaçante dans la gamme des -7 °C à -10 °C.

Les données récoltées ont été soumises à une analyse de régression à plusieurs variables, notamment pour s'assurer que les tendances qui se dégagent sont correctes et pour déceler les valeurs aberrantes méritant un examen plus approfondi.

Résultats de la recherche

La recherche montre que, sous neige naturelle, les durées d'efficacité des tables SAE/ISO sont valables pour les liquides de type I dilués dont le point de congélation est inférieur par 10 °C au point de congélation ambiant. Les durées procurées par le liquide de type IV ont été de moitié ou plus supérieures à celles des liquides de type II purs connus. Pour l'hiver 1995-1996, les durées d'efficacité du liquide type IV ont été obtenues en majorant de 50 p. 100 celles des liquides de type II purs.

La rubrique «pluie verglaçante» des tables SAE/ISO a été remplacée par deux autres, à savoir «bruine verglaçante» et «pluie fine verglaçante». De nouveaux intervalles de durées d'efficacité ont été déterminées à partir des résultats des essais sur plaques planes effectués dans les installations d'essais climatiques du CNR. Ces nouveaux intervalles sont bons pour la plupart des liquides et pour des températures allant jusqu'à -10 °C. Lorsqu'on utilise le type IV, les durées d'efficacité sont celles des liquides de type II purs majorées de 50 p. 100.

Sous brouillard verglaçant, les durées d'efficacité SAE/ISO des liquides de type I dilués (marge de 10 °C) sont valables, jusqu'à -25 °C et plus bas. Là encore, lorsqu'on utilise le type IV, les durées d'efficacité sont celles des liquides de type II purs majorées de 50 p. 100.

Dans des conditions de sur-refroidissement sous pluie, les durées d'efficacité SAE/ISO dégagées par les résultats préliminaires peuvent être valables lorsqu'on utilise un liquide type II pur ou dilué 75/25. Pour les liquides de type II dilués 50/50 et les liquides de type I dilués, il faudra probablement réviser à la baisse les valeurs extrêmes des intervalles de durée d'efficacité indiqués dans les tables SAE/ISO, sous réserve d'expérimentations plus poussées.

Les durées d'efficacité indiquées par les capteurs C/FIMS et RVSI ID-1 d'Instrumar montrent une bonne corrélation générale avec les observations visuelles.

Essais à venir

La partie 7 du présent rapport donne un aperçu détaillé de la portée et de l'orientation à donner aux essais à venir, ainsi que des recommandations pour améliorer les procédures ainsi que les équipements. Il est recommandé de concentrer les essais futurs sur les durées d'efficacité des liquides de type IV sous toutes formes de précipitation, à diverses températures, et à tous les degrés de concentration (50/50, 75/25 et pur), et de mener des tests sur des boîtes de 2,5 cm de profondeur pour confirmer les durées d'efficacité affichées dans les tables SAE/ISO, ainsi que celles pour les liquides de type IV.

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APPENDICES

FIGURE NUMBER | **PAGE NUMBER**

PHOTO NUMBER | **PAGE NUMBER**

TABLE NUMBER | **PAGE NUMBER**

LIST OF ACRONYMS

ADF	Aircraft De-icing Fluid
AES	Atmospheric Environment Services (Canada)
APS	APS Aviation Inc.
ARC	Aviation Research Corporation
ARP	Aerospace Recommended Practice
CAI	Canadian Airlines International
CEF	Climatic Engineering Facility
C/FIMS	Contaminant/Fluid Integrity Monitoring System
CWDS	Clean Wing Detection System
FAA	Federal Aviation Administration (USA)
FP	Freeze Point
FZD	Freezing Drizzle
HOT	Holdover Time
LFZR	Light Freezing Rain
NCAR	National Centre for Atmospheric Research
NRC	National Research Council
OAT	Outside Air Temperature
POSS	Precipitation Occurrence Sensing System
READAC	Remote Environmental Automatic Data Acquisition Concept
RVSI	Robotic Vision Systems Inc.
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre
UCAR	Union Carbide
UQAC	Université du Québec à Chicoutimi
WSET	Water Spray Endurance Test

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1. INTRODUCTION

1. INTRODUCTION

At the request of the Dryden Commission Implementation Program (DCIP) of Transport Canada (TC), APS Aviation Inc. (APS) undertook a research program to further advance aircraft ground de-icing/anti-icing technology. Objectives of the entire program and of the project described in this report were provided in the preface.

Aircraft ground de-icing has been the subject of concentrated industry attention over the past decade as a result of a number of fatal aircraft accidents. Much of this attention has been given to the abilities of de-icing fluids to provide an extended duration of protection against further snow or ice build up following initial de-icing. This has led to the development of fluid holdover time tables for use by aircraft operators and accepted by regulatory authorities. As well, new improved fluids have been developed with the specific objective of extending holdover times without impacting upon aerodynamic characteristics of the airfoil.

The upper times given in the current holdover time tables were originally established by European airlines based upon assumptions of fluid properties and previous data. The lower times of the HOT ranges (a fraction of the higher times) were determined by the SAE G-12 Committee based upon data from the 1990/91 winter tests. The extensive testing conducted by APS has been to determine the performance of fluids on standard flat plates in order to substantiate the times, or if warranted, to recommend changes.

Aircraft are de-iced using Type I de-icing fluids, which are sometimes diluted. While excellent for removing ice and snow which has already accumulated on the wings of aircraft, Type I fluids provide limited protection against further ice build up. The Type II fluids, being significantly more viscous, provide this kind of protection. Type III fluid (previously called Type 1.5) is a thickened fluid which has properties that lie between Types I and II. Its shearing and flow off characteristics are designed for aircraft with lower take-off speeds. Newer, longer lasting fluids are also in development. One such fluid which is commercially available is Union Carbide's Ultra Type II anti-icing fluid (possibly becoming Type IV in the future).

Following a series of meetings on holdover time, held in the late 1980's under SAE auspices, Air Canada and the Transportation Development Centre (TDC) took the initiative to develop a field test program for future years to determine fluid effectiveness under a variety of precipitation conditions. The results of the 1990/91 worldwide testing program, which concentrated on Type II fluids, were published by Aviation Planning Services (APS) Ltd. in the Transport Canada report TP 11206E, **"Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1990/91 Winter"**. The results of the 1991/92 test program, which concentrated on Type III fluids, were published by APS in the Transport Canada report TP 11454E, **"Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1991/92 Winter"**. Testing during the 1992/93 winter included not only testing of snow at Dorval, but also testing of freezing drizzle and freezing fog at NRC. The results of the 1992/93 test program, which focused on Type I fluids, were published by APS Aviation in the Transport Canada report TP 11836E, **"Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1992/93 Winter"**. The results of the 1993/94 test program, which focused on diluted Type II's, were published by APS Aviation in the report entitled **"Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1993/94 Winter"**.

The objectives (see Appendix H for the detailed work statement) of the flat plate tests during the 1994/95 winter were:

a) To conduct tests for the substantiation of the HOT tables for performance of diluted Type I fluids (with a 10°C buffer);

b) To supplement the substantiation of the HOT tables for performance of Type II and Type I fluids at low temperatures;

c) To conduct tests and compare the performance of UCAR Ultra Type II with other Type II fluids; and

d) To extend the operational temperature range of the freezing rain column from -7°C to -10°C.

Testing during the 1994/95 winter included natural snow tests at Dorval, freezing drizzle, rain and fog tests at the NRC Cold Chamber, as well as rain on cold-soaked surface tests also conducted at the NRC Chamber. The fluids tested for the 1994/95 winter season were primarily diluted Type I fluids and the new "next generation" Ultra Type II fluid.

As detailed in the table of contents, Section 2 of this report outlines testing procedures and equipment requirements. Subsequent sections describe the collected data and the meteorological conditions followed by the analysis of the data. The final sections provide conclusions and recommendations for future testing.

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2. METHODOLOGY

2.1 Holdover Time Tables and Definition of Weather Conditions

2.2 Test Sites

2.3 Test Conditions

2.4 Equipment

2.5 Test Procedures

2.6 Fluids

2.7 Personnel and Participants

2.8 Site Lighting and Video

2.9 Analysis Methodology

2. METHODOLOGY

This description of testing methods and assimilations is sub-divided into sections dealing with testing sites, test conditions, equipment, test procedures, fluids, personnel and participants, and analysis methodology.

2.1 Holdover Time Tables and Definition of Weather Conditions

Table 2.1 shows the Type I and Type II SAE/ISO holdover times which were used during the 1992/93 winter. This table was reproduced from the FAA Advisory Circular AC 120-58, 9/30/92. The holdover times are provided as a function of weather condition, fluid mixture and outside air temperature (OAT). The objective of the winter test program was to substantiate these holdover times or develop new ones based upon test data. This report addresses these questions.

Table D.1 in Appendix D provides the definitions of most weather conditions experienced in winter operations, including the criteria used to determine the precipitation intensity (light, moderate, heavy). This table was compiled by NCAR from the World Meteorological Organization Guide to Meteorological Instruments and Methods of Observation (1983), and from the American Meteorological Society, Glossary of Meteorology WSOH #7 MANOBS (3/94).

Table D.1 includes definitions for all weather conditions described in the holdover time table labelled 2.1 (frost, freezing fog, snow, freezing rain and rain). Definitions for freezing drizzle (including droplet size), snow pellets, snow grains, hail and ice pellets are also presented.

TABLE 2.1

1992/93 SAE/ISO HOLDOVER TIME TABLES

(REPRODUCTION FROM FAA ADVISORY CIRCULAR AC 120-58, 9/30/92)

Table 1. Guidelines for Holdover Times Anticipated by SAE Type II and ISO Type II Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION! THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY AND IT SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

OAT		Type II Fluid Concentration Neat-Fluid/Water (% by Volume)	Approximate Holdover Times Anticipated Under Various Weather Conditions (hours: minutes)				
°C	°F		FROST	FREEZING FOG	SNOW	FREEZING RAIN	RAIN ON COLD SOAKED WING
0 and above	32 and above	100/0	12:00	1:15-3:00	0:25-1:00	0:08-0:20	0:24-1:00
		75/25	6:00	0:50-2:00	0:20-0:45	0:04-0:10	0:18-0:45
		50/50	4:00	0:35-1:30	0:15-0:30	0:02-0:05	0:12-0:30
below 0 to -7	below 32 to 19	100/0	8:00	0:35-1:30	0:20-0:45	0:08-0:20	CAUTION! clear ice may require touch for confirmation
		75/25	5:00	0:25-1:00	0:15-0:30	0:04-0:10	
		50/50	3:00	0:20-0:45	0:05-0:15	0:01-0:03	
below -7 to -14	below 19 to 7	100/0	8:00	0:35-1:30	0:20-0:45		
		75/25	5:00	0:25-1:00	0:15-0:30		
below -14 to -25	below 7 to -13	100/0	8:00	0:35-1:30	0:20-0:45		
below -25	below -13	100/0 if 7°C (13°F) Buffer is maintained	A buffer of at least 7°C (13°F) must be maintained for Type II used for anti-icing at OAT below -25°C (-13°F). Consider use of Type I fluids where SAE or ISO Type II cannot be used.				

THIS TABLE DOES NOT APPLY TO OTHER THAN SAE OR ISO TYPE II FPD FLUIDS.

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER.

Table 2. Guidelines for Holdover Times Anticipated by SAE Type I and ISO Type I Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION! THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY AND IT SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

Freezing Point of Type I fluid mixture used must be at least 10°C (18°F) below OAT.

OAT		Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes)				
°C	°F	FROST	FREEZING FOG	SNOW	FREEZING RAIN	RAIN ON COLD SOAKED WING
0 & above	32 & above	0:18-0:45	0:12-0:30	0:06-0:15	0:02-0:05	0:06-0:15
below 0 to -7	below 32 to 19	0:18-0:45	0:06-0:15	0:06-0:15	0:01-0:03	CAUTION! Clear ice may require touch for confirmation
below -7	below 19	0:12-0:30	0:06-0:15	0:06-0:15		

THIS TABLE DOES NOT APPLY TO OTHER THAN SAE OR ISO TYPE I FPD FLUIDS.

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER.

2.2 Test Sites

In-situ natural snow testing for the 1994/95 winter was performed at Montreal's Dorval Airport, adjacent to the AES weather observation station. The location of the site at Dorval is shown on the plan view of the airport in Figure 2.1. Photo 2.1 was taken at the site and shows the RVSI remote sensor mounted on top of the test stand to the right and the trailer to the left. Photo 2.2 shows the AES meteorological equipment installation at Dorval airport. Some in-situ testing was also carried out by National Centre for Atmospheric Research (NCAR) at Denver. Some of their results from these tests were incorporated in this report.

Testing during the 1994/95 winter season for simulated freezing fog, rain on cold-soaked surface, freezing drizzle, and light freezing rain was carried out at NRC's indoor Climatic Engineering Facility (CEF). This is in contrast to previous years when freezing fog tests were conducted outdoors at NRC's helicopter icing facility. Due to an incident at this facility, the test rig is no longer functional.

In summary, the site locations as a function of condition tested is as follows:

- Freezing Fog: NRC CEF in 1995/95, and NRC Helicopter Icing Facility (outdoor) in 1992/93 and 1993/94;
- Natural Snow: Montreal, Dorval Airport by APS, and Denver, Colorado by NCAR;
- Freezing Drizzle and Light Freezing Rain: NRC CEF; and
- Rain on Cold-Soaked Surface: NRC CEF.

FIGURE 2.1

TEST SITE AT DORVAL AIRPORT

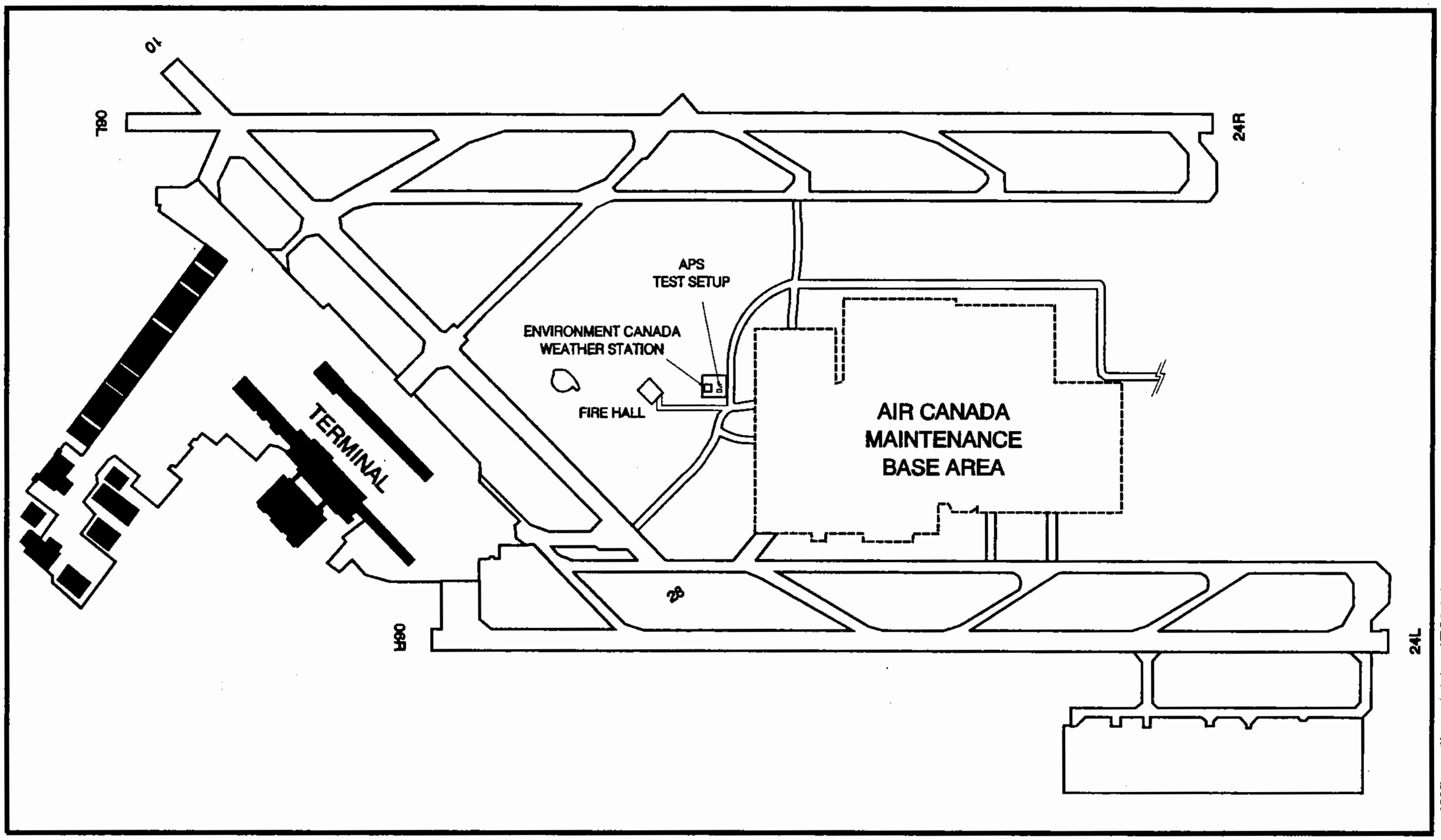


PHOTO 2.1
VIEW OF DORVAL TEST SITE AND ASSOCIATED EQUIPMENT

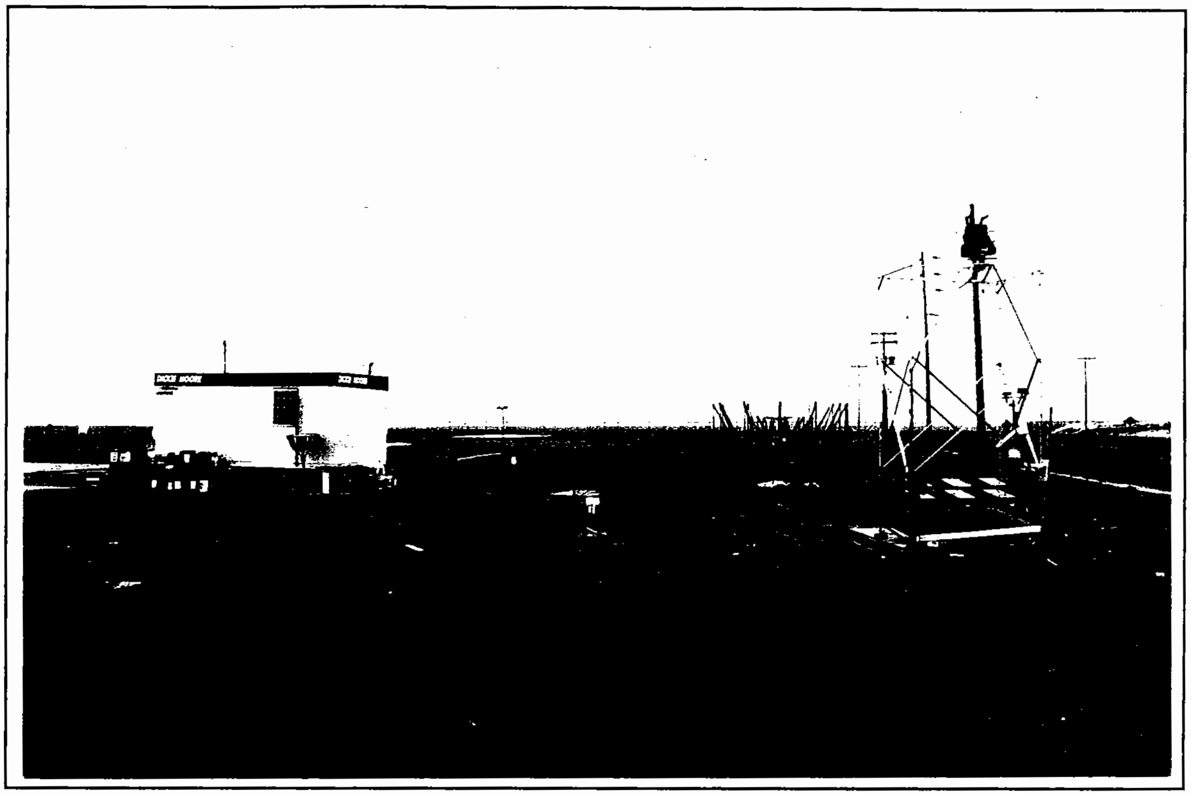


PHOTO 2.2
METEOROLOGICAL EQUIPMENT INSTALLATION (READAC)
AT DORVAL AIRPORT

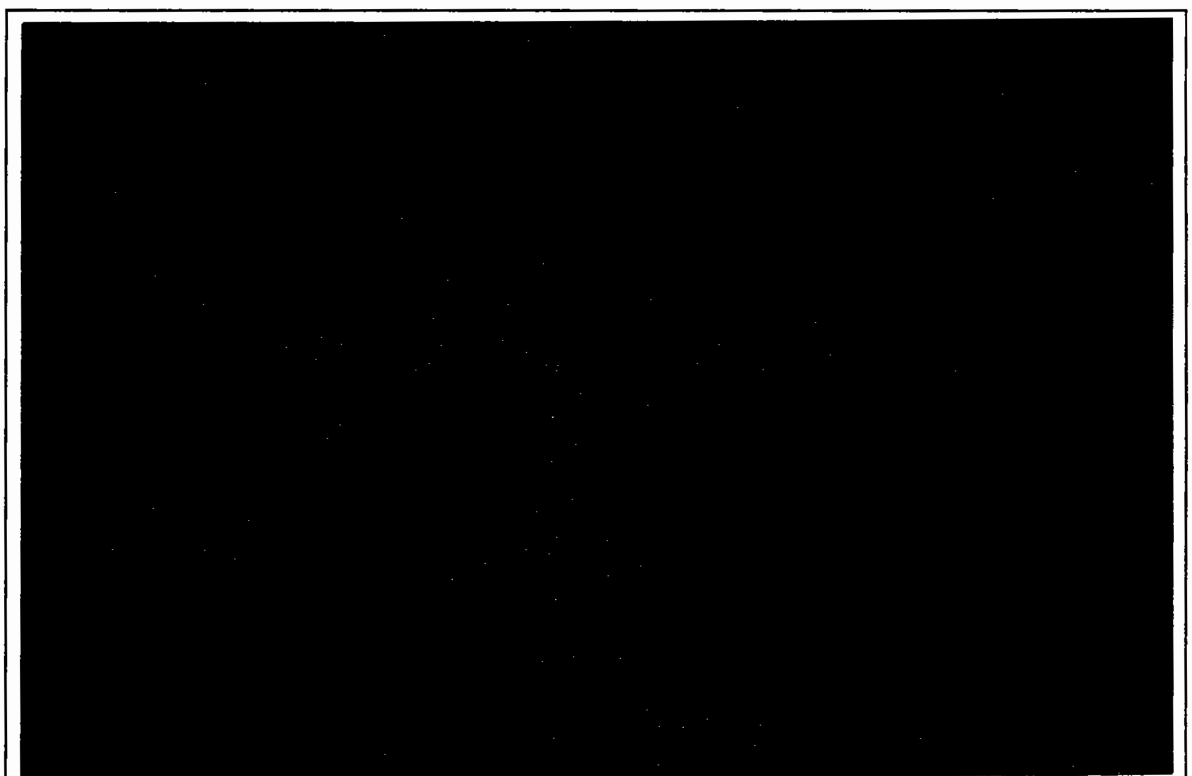


Photo 2.3 was taken inside the CEF and provides a general indication of the size of the facility. The facility was designed and built for the testing of locomotives. The characteristics of the CEF facility are described below.

- NRC Climatic Engineering Facility Characteristics:
  - Chamber size: 29.7 m (97 ft) long x 5.4 m (18 ft) wide x 5.8 m (19 ft) high;
  - Air temperature: 0 to -10°C for freezing drizzle and light freezing rain, 0 to -27°C for freezing fog; and
  - Two spray nozzles, with three degrees of freedom were used for simulating freezing drizzle and light freezing rain, and four wall bars with three spray nozzles per bar were used for freezing fog.

2.3 <u>Test Conditions</u>

Tests were conducted outdoors during natural precipitation conditions. To supplement these natural precipitation tests, simulations of freezing precipitation were also performed at NRC's Climatic Engineering Facility.

Described below is the set of test conditions at the Climatic Engineering Facility which were used for the acquisition of data under freezing drizzle, light freezing rain and freezing fog.

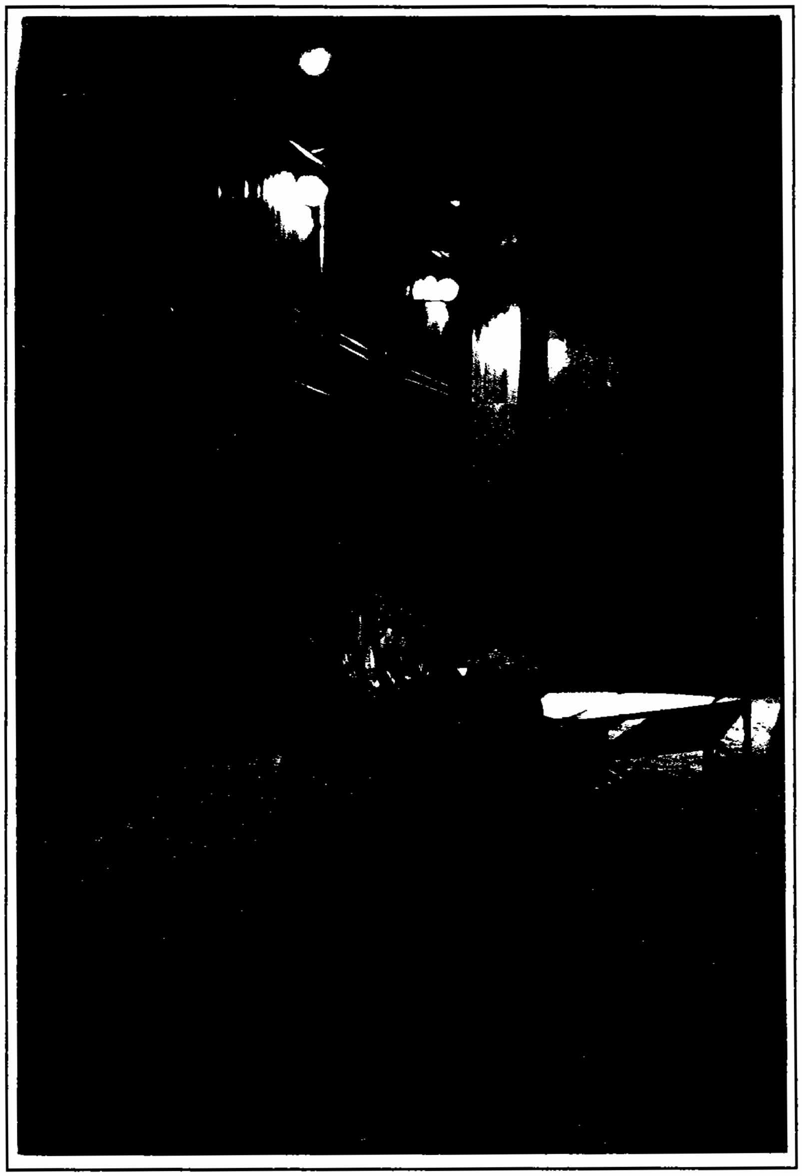
(i) Freezing Drizzle Characteristics During Tests

- Droplet median volume diameter: 600 µm;
- Precipitation Rate: less than 13 g/dm^2/hr; and
- Droplets produced with #24 hypodermic needle.

(ii) Light Freezing Rain Characteristics During Tests

- Droplet median volume diameter: 1500 µm;
- Precipitation Rate: 13 to 25 g/dm^2/hr; and
- Droplets produced with #20 hypodermic needle.

PHOTO 2.3
INSIDE VIEW OF NRC's CEF IN OTTAWA



(iii) Freezing Fog Characteristics During Tests

- Droplet median volume diameter: 30 to 60 μm; and
- Liquid water content: 0.2 to 0.6 gm^{-3}

(iv) Drizzle and Light Rain on Cold-Soaked Surface Characteristics

- Same as freezing drizzle and light freezing rain

2.4 Equipment

Figure 2.2 shows a schematic of the stand used for testing. Six test plates are mounted on the stand and these are inclined at a 10° slope. Figure 2.2 also depicts the size of a typical flat plate and markings on the flat plate.

The plates were marked with three parallel lines, 2.5 cm (1"), 15 cm (6") and 30 cm (12") from the top of the plate. The plates were also marked with 15 crosshairs. These crosshairs were used in determining whether end conditions (see next section for definition) were achieved.

Figure 2.3 shows the collection (plate) pan which is of the same size as a standard plate and used for measuring amounts of precipitation. The sealed boxes (15 cm and 7.5 cm deep) which were used for simulating a cold-soaked wing are also shown in Figure 2.3.

The detailed equipment list and specifications are included within the test procedures in Appendices A and B for the outdoor and indoor tests. The other major equipment required for the tests include:

FIGURE 2.2

FLAT PLATE TEST SET-UP

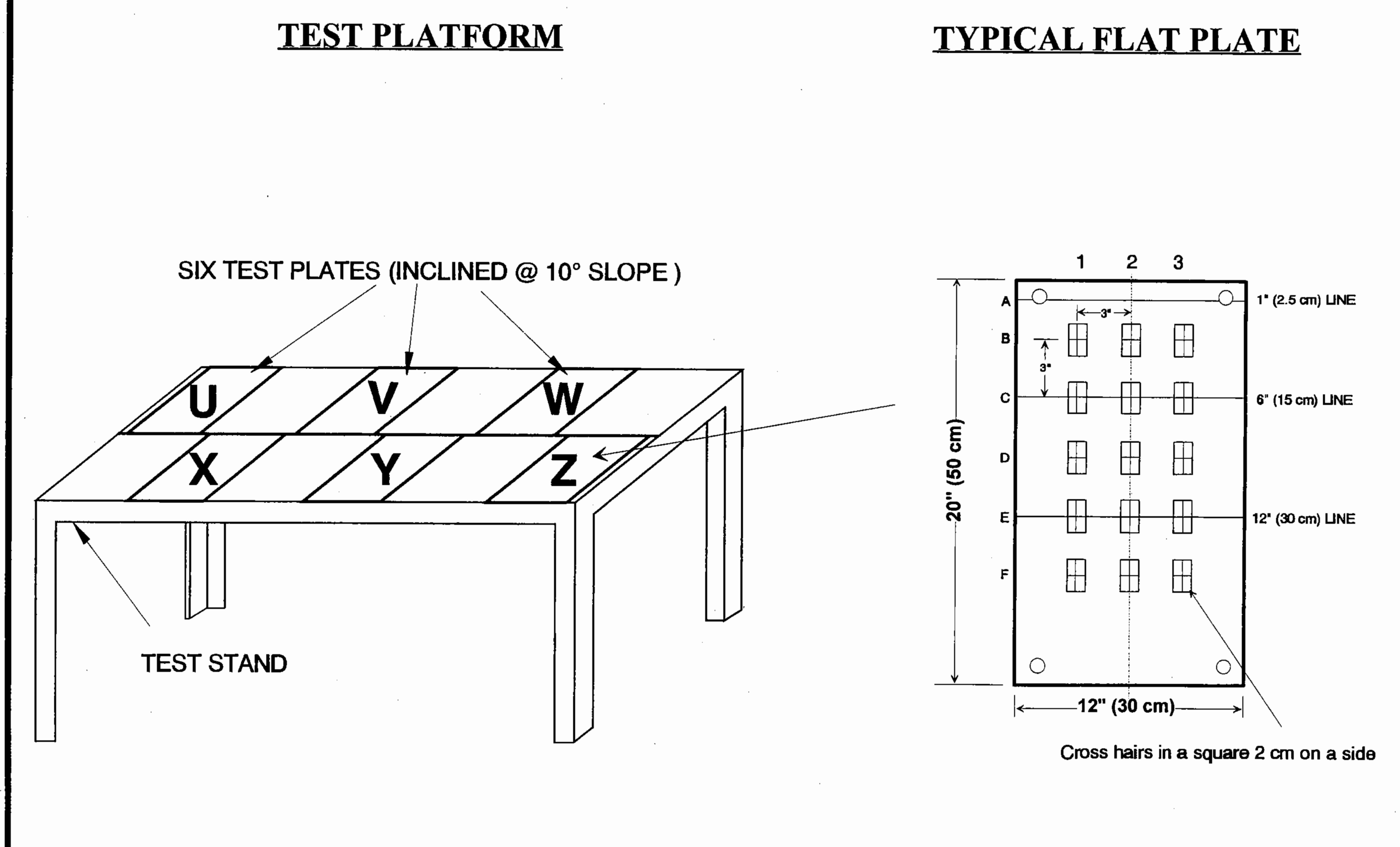
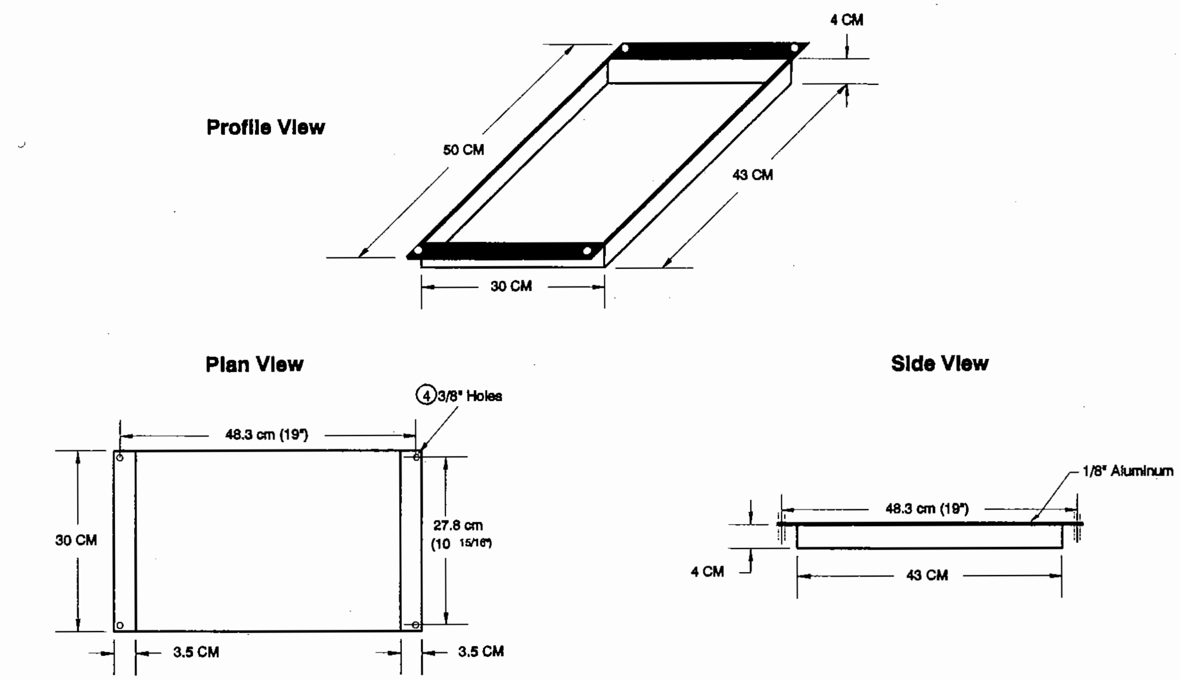


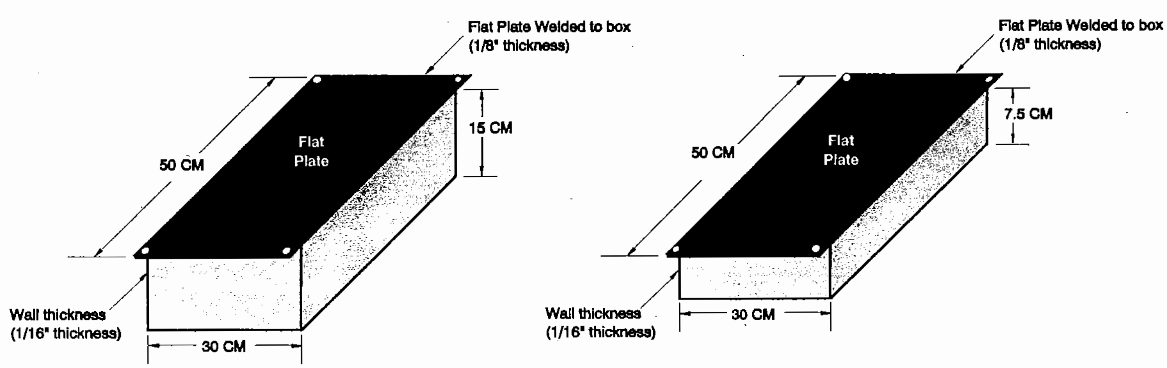
FIGURE 2.3

SCHEMATICS OF PLATE PAN AND SEALED BOXES

PLATE PAN



SEALED BOXES



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- Thermometer to record air temperature;
- Anemometer and wind vane to record wind speed and direction during the test. This equipment was installed at a 3 metre height;
- Plate pans, cake pans and snow gauges were used to measure precipitation during the test; and
- Remote sensors and plate surface ice sensors were used to assist in the determination of the end condition.

The ice sensors used in the 1994/95 season included two C/FIMS from Instrumar Ltd. of St. John's, Newfoundland and one external optical area sensor by RVSI of New York.

The rate of precipitation for freezing fog, light freezing rain and freezing drizzle, and rain on cold-soaked surface, as simulated at the NRC CEF, was measured using cake pans.

In addition to the equipment at the APS Dorval site, data from Environment Canada's automated weather observation equipment installed adjacent to APS' site was acquired. Appendix C shows a typical listing of the data provided by the Remote Environmental Automatic Data Acquisition Concept (READAC). This information was acquired from Atmospheric Environment Service (AES) on diskette on a minute-by-minute basis for the test events after January 1, 1995. The READAC equipment, most useful for the test program purposes, is described below:

a) Relative Humidity Gauge and Thermometer;

b) Anemometer and wind wane at a 10 metre height;

c) Precipitation Occurrence Sensing System (POSS):

The POSS system consists mainly of a Doppler radar set with a transmitter and a receiver as separate units (bi-static set-up). The system is aimed at an area a few centimetres above it where it measures the rate of fall of hydrometeors. The Doppler frequency shift of the returned signal provides the precipitation type, and the spectro power of the returned signal provides the intensity (light, moderate or heavy) and amount of precipitation. The output of the system consists of the start time, stop time, type, and intensity of precipitation.

d) Precipitation Gauge:

The READAC precipitation gauge is a modified Belfort weighing gauge. A bucket is attached to a spring balance and cable pulley arrangement connected to a rotating shaft. The degree of rotation of the shaft corresponds to the amount of accumulated precipitation in the bucket. The total amount of precipitation is the only value returned by the precipitation gauge arrangement. The gauge accuracy is subject to thermal expansion and contraction of the weighing mechanism. It is also affected by freezing precipitation accumulating on the sides of the gauge and melting later on, therefore resulting in a delayed and erroneous output. The gauge output resolution is 0.1 mm, liquid water equivalent.

e) Belfort Forward Scattermeter:

The Belfort Forward Scattermeter provides an estimate of visibility. The system consists of a Zenon bulb transmitter and a receiver both at an angle of 22°C below the horizontal aimed at a 0.02 m^3 sample volume of air 2.5 m above the ground. The transmitter illuminates the sample volume of air. The receiver measures the amount of light scattering off the aerosols present in the sample volume of air. This measure is inversely proportional to visibility. The output is given in units of miles.

2.5 Test Procedures

Generally, the testing consisted of pouring de/anti-icing fluids onto clean test panels (which were exposed to various winter precipitation conditions) and recording the elapsed time for each crosshair to fail before the test panels reached the end condition (see Section 2.5.1 below).

The test procedure for the natural snow flat plate tests was developed by the SAE G-12 Holdover Time Sub-Committee. The major steps are listed below. The complete details of the actual test procedures are provided in Appendix A:

- Synchronize all times;
- Clean panels;
- Apply fluids to test panels;
- Record crosshair end condition times;
- Continue testing until at least 5 crosshairs have reached the end condition on each test panel;
- Monitor weather conditions; and
- Clean panels and restart.

Appendix B contains the procedure used for testing at the CEF during freezing drizzle, light freezing rain, freezing fog and cold-soaked surface rain tests.

Rain on cold-soaked wing conditions cannot be tested using the conventional frosticator plate set-up. The cold fuel effect needs to be simulated to ensure that the results are representative of actual cold-soaked situations. The approach was to use a sealed rectangular aluminum box, 100% filled with a cold fluid and insulated all around except for the upper surface. The top of the box consists of a welded aluminum flat plate identical to the frosticator plate and used for fluid testing (see Section 2.4). The theoretical background and sizing for the boxes was based on the analysis contained in TC Report TP 12678E.

The cold-soak tests were performed at NRC's Climatic Engineering Facility. The same precipitation parameters used for light freezing rain and drizzle were used for cold-soaking. The ambient temperature was set at +2°C. The boxes were filled with glycol and cooled by a liquid nitrogen cooling unit. Insulation was attached on all sides of the boxes except the top to maintain cold temperatures. Plate temperatures on top of the box were recorded throughout the test using thermistors and/or hand-held temperature probes.

2.5.1 End Condition Definition

The procedure and the determination of the end condition evolved from the experiences of various test programs from previous winter seasons.

The plate failure time is that time required for the end conditions to be achieved. This occurs when the accumulating precipitation fails to be absorbed at any five of the crosshair marks on the panels.

A crosshair is considered failed if:

- There is a visible accumulation of snow bridging on top of the fluid at the crosshair when viewed from the front (i.e. perpendicular to the plate). There should be an indication that the fluid can no longer de-ice or absorb the precipitation at this point.

OR

- When precipitation or frosting produces a "loss of gloss" (i.e. dulling of the surface reflectivity) or a change in colour (dye) to grey or greyish appearance at any five crosshairs, or ice (or crusty snow) has formed on the crosshair (look for ice crystals). This condition is only applicable during freezing rain/drizzle, ice pellets, freezing fog, rain on cold-soaked surface or during a mixture of snow and freezing rain/drizzle and ice pellets.

Under conditions of moderate to heavy snow or hail, coverage may be very uneven; in this case, failure over about one-third of the panel should be measured.

2.6 Fluids

Type I and II fluids were tested and these were provided by Union Carbide (UCAR), Arco, Kilfrost, Octagon and Hoechst. The majority of tests conducted were with standard and diluted Type I fluids, and Neat Type II fluids, including UCAR's Ultra.

The volumetric concentrations for the Type I fluids as a function of freeze point were provided by the fluid manufacturers and are as follows:

Standard Type I Fluid Concentration (% glycol to % water):

- Fluid B-222 was 50/50
- Fluid B-213 was 57/43
- Fluid B-220 and Fluid B-221 were 63/37

Diluted Type I Fluid:

Fluid concentrations for diluted Type I fluids were determined based upon the OAT such that a 10°C buffer from the fluid freeze point (FP) was maintained. Table 2 in Appendix A shows the variation of fluid concentration as a function of OAT, for each fluid.

The fluid mixing operation at Dorval during the 1994/95 winter required considerable effort in order to get the mixtures with the required 10°C freeze point buffer for diluted Type I fluid tests. This operation was difficult due to many factors - the major ones are listed below:

- Most testers had to be trained since this new operation was required for most tests;

- The refractometer measurements were cumbersome since the reading had to be converted from °F to °C and attention needed to be given to whether the fluid was ethylene or propylene based. A further complication resulted from the fact that the temperature had to have a 10°C buffer;

- Completion of Table 2 in Appendix A took some time and multiple discussions with the fluid manufacturers;

- A temperature compensated brixometer was then purchased, however the mixing operation was still difficult and prone to errors;

- The trailer was too small to allow an efficient and simple fluid mixing operation, and was further complicated since a water outlet was not available in the trailer; and

- The OAT varied throughout the evening and sometimes during a long (Ultra) test. This often required a change in the glycol concentration over the course of one evening session.

To rectify and simplify some of the difficulties encountered, the procedure shown in Figure 2.4 was developed.

2.7 Personnel and Participants

The site at Dorval was staffed mainly by university students and supervised by the APS staff. This APS involvement was critical in giving the testers a thorough understanding of the intricacies and potential problems with the data collection process.

Figure 2.4
FLUID MIXING PROCEDURE FOR DILUTIONS

1) Pour exactly 2 litres of concentrate fluid into the "carboys" (gasoline containers).

2) Prior to test, determine the % glycol mixture with water required based on temperature (Table 2 of FPTP).

3) Use the formula below to compute the "volume of water to add" for the mixture in step 2. Add the water and shake the container.

4) Verify the mixture with the refractometer.

5) If the mixture is off by ± 1%, then adjust the mixture (use the formula again).

<u>To lower the Freeze Point</u>:

$$\text{Volume of Concentrate to add} = \frac{(\text{Desired Concentration} - \text{Current Concentration}) \times \text{Volume of fluid}}{100 - \text{Desired Concentration}}$$

<u>To raise the Freeze Point</u>:

$$\text{Volume of Water to add} = \frac{(\text{Current Concentration} - \text{Desired Concentration}) \times \text{Volume of fluid}}{\text{Desired Concentration}}$$

Example:

step 2: Suppose we need a 57% mixture of UCAR's Type I.

step 3: Vol. of water to add = $\frac{(100 - 57) \times 2}{57}$ = 1.5 litres

step 4: If the refractometer indicates a mix of 55%, then

step 5: Volume of concentrate to add = $\frac{(57 - 55) \times 3.5}{100 - 57}$ = 0.2 litre

2.8 Site Lighting and Video

Lighting is important since poor or badly positioned lighting equipment can affect results during night time sessions. Inadequate lighting was seen to cause glare which affected the human observation as well as the video filming operation.

Proper positioning of the panning video camera was of great importance to the filming operation as it affects the quality of the video. Ideally, the camera should be at the same level as the plates, pointing horizontally about 2 meters away. Proper focus should be ensured and zooming action should be avoided as much as possible since it was found to adversely affect the video quality. Further difficulty is experienced when the stand is rotated into the wind when trying to get the same camera position for all tests.

Hand-held camera filming proved to be extremely useful since it allowed special treatment and close inspection of failed fluids.

2.9 Analysis Methodology

Before all the collected data was analyzed, the raw data underwent verification to correct or remove any obvious errors. The individual data parameters and the units used in the final analysis are listed below.

- Precipitation rate - ($g/dm^2/hr$) averaged over test
- Total precipitation - (g/dm^2)
- Air temperature - (°C) averaged over test
- Wind speed - (kph) averaged over test

- Wind direction - (degrees from true north) averaged over test
- Platform angle - (degrees from true north)
- Time to failure of each crosshair - (minutes)

The analysis was performed in two stages. Analysis for the first stage was driven by the requirement to present results to the SAE G-12 Committee in Montreal, Amsterdam and Chicago, as well as presentation of the results to the Canadian Standing Committee on Operations under Icing Conditions in Ottawa. During the second stage, the data underwent further verification.

3. DESCRIPTION OF DATA

3.1 Dorval Natural Snow Tests

3.2 Simulated Freezing Drizzle and Light Freezing Rain

3.3 Simulated Freezing Fog Tests

3.4 Simulated Rain on Cold-Soaked Surface Tests

3. DESCRIPTION OF DATA

This section provides a summary of the number of data samples collected. Breakdowns are provided for quantity of data received, versus fluid type and distributions of basic weather parameters such as temperature, precipitation, wind speed and direction over the range of the tests collected. This is presented for the natural snow tests conducted at Dorval, and light freezing rain, freezing drizzle, freezing fog and cold-soaked tests conducted in Ottawa.

3.1 Dorval Natural Snow Tests

3.1.1 Usable Data

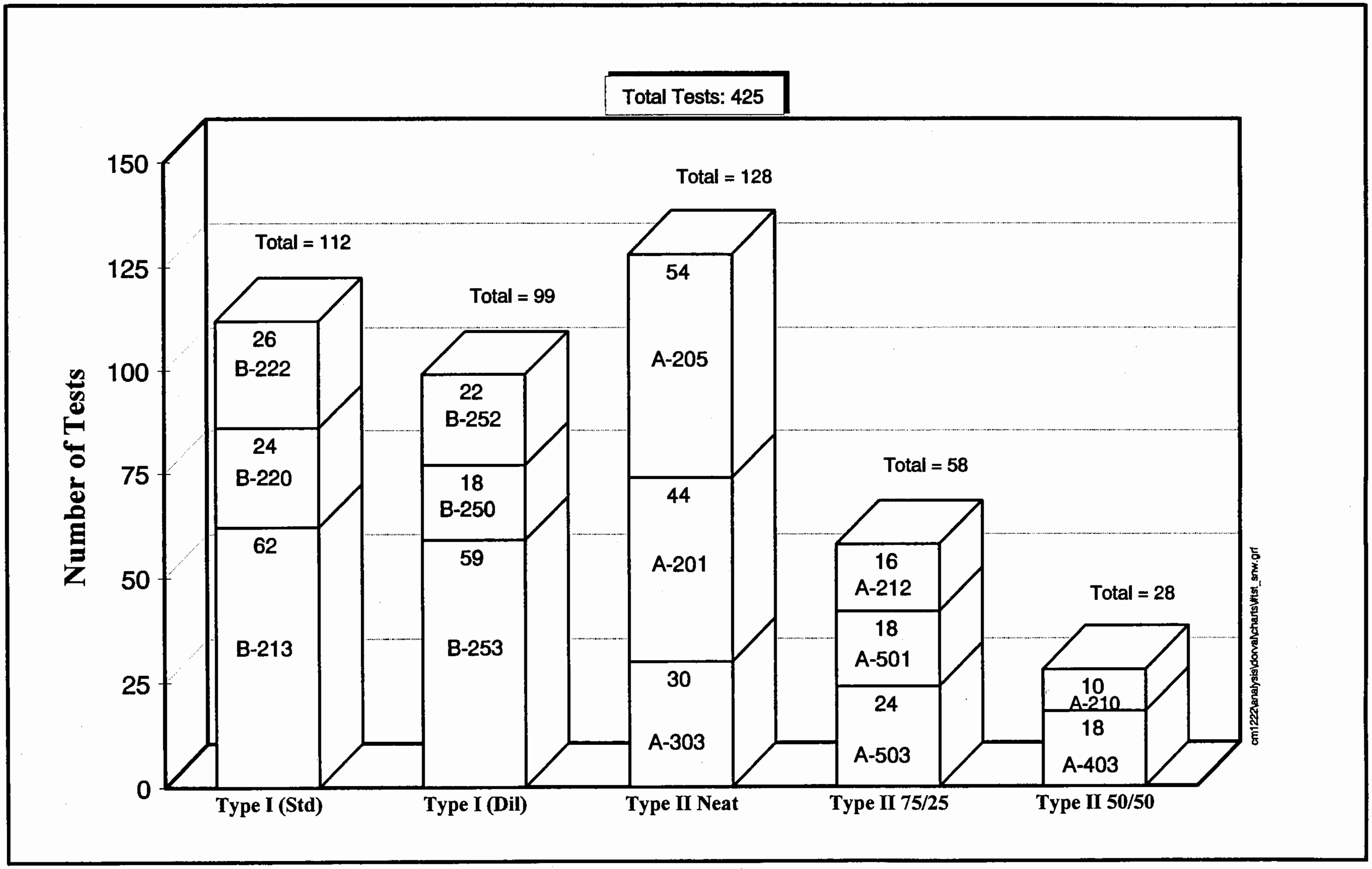
Section 2 provided a description of the test stand which contained six test plates, each plate representing a "flat plate test". During each "run" with six plates, the intent was to test three different fluids in duplicate.

During the 1994/95 test season, APS collected test data from 80 usable runs for the two stands located at Dorval. As shown in Figure 3.1, these data forms contained a total of 425 test points. The 425 tests occurred during natural snow conditions. There were 48 points removed from this group because freezing precipitation was mixed with snow. The data showed plate failure times greater than the current HOT's. Of the 425 usable tests, a total of 112 tests were of standard Type I, 99 were of diluted Type I, 128 were of Type II Neat, 28 were of Type II 50/50 and 58 were of Type II 75/25 fluids.

FIGURE 3.1

NUMBER OF NATURAL SNOW TESTS CONDUCTED

1994-1995 TEST SEASON AT DORVAL



3.1.2 Test Location and Fluids Tested

All 425 usable tests were carried out at Dorval. Tests were conducted with fluids from Octagon, Union Carbide, Hoechst, Kilfrost and Arco.

3.1.3 Distribution of Average Precipitation Rates

Figures 3.2 and 3.3 show the distribution of average precipitation rates measured at Dorval with plate pans for Type I and Type II fluids, respectively. The average rates were calculated by dividing the total precipitation recorded from the start of test to the time of failure, by the failure time.

3.1.4 Distribution of Other Meteorological Conditions

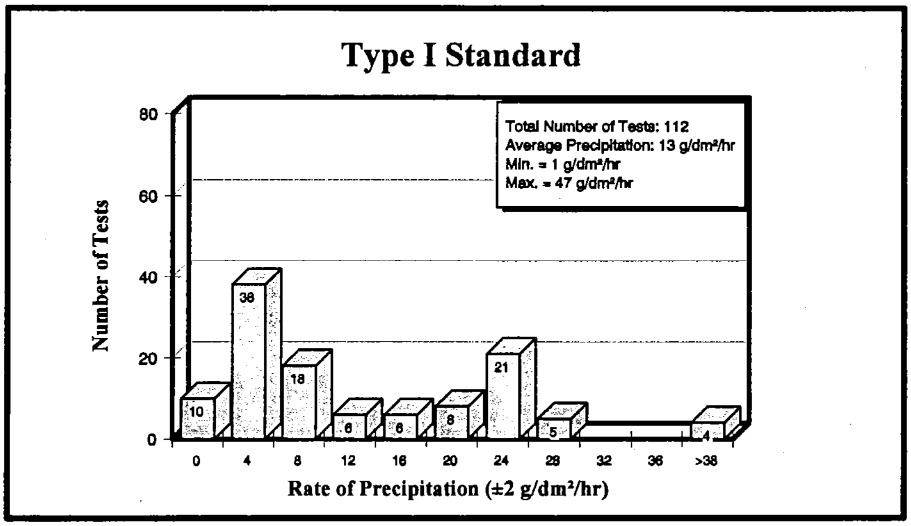
The distribution of meteorological parameters such as temperature, wind speed and wind direction is presented in Figures 3.4, 3.5, 3.6, 3.7 and 3.8, respectively.

FIGURE 3.2

DISTRIBUTION OF PRECIPITATION RATE

Natural Snow Tests

1994-1995



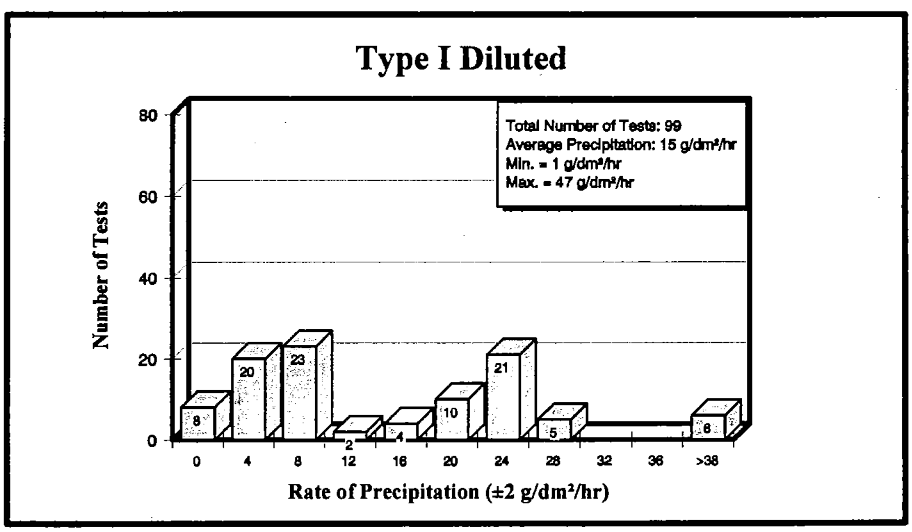


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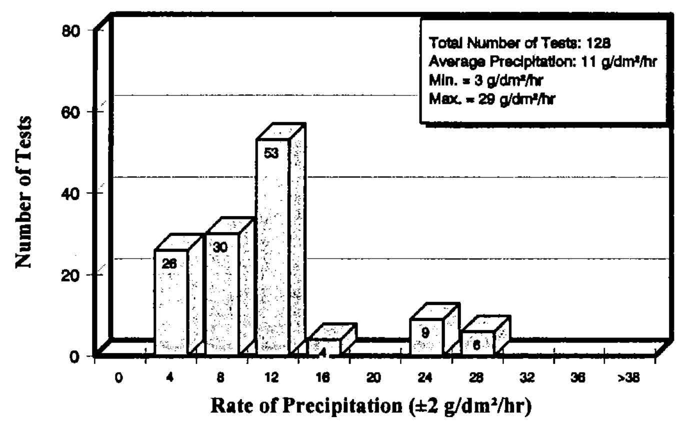
FIGURE 3.3

DISTRIBUTION OF PRECIPITATION RATE

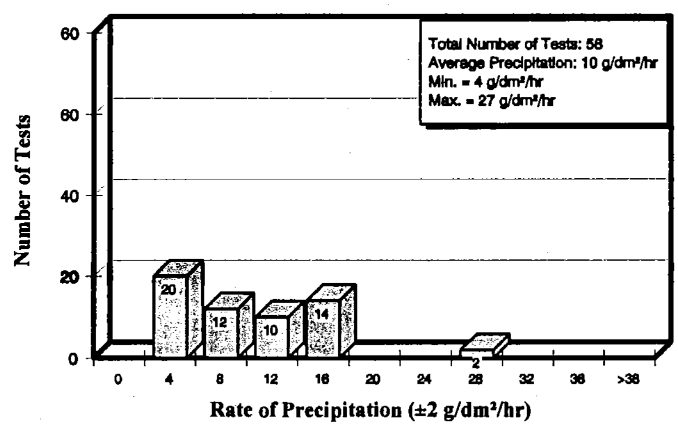
Natural Snow Tests

1994-1995

Type II Neat



Type II 75/25



Type II 50/50

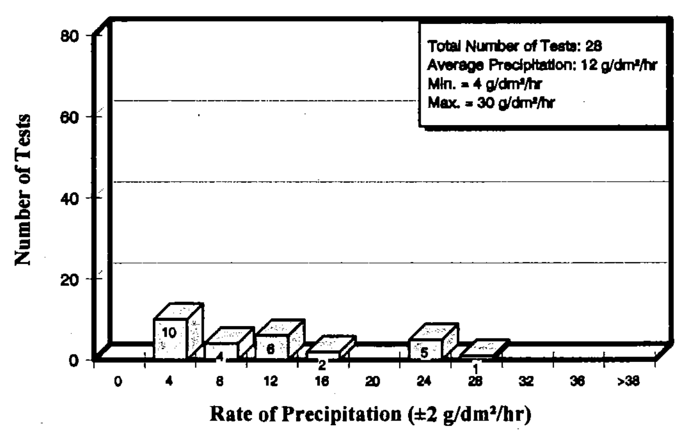


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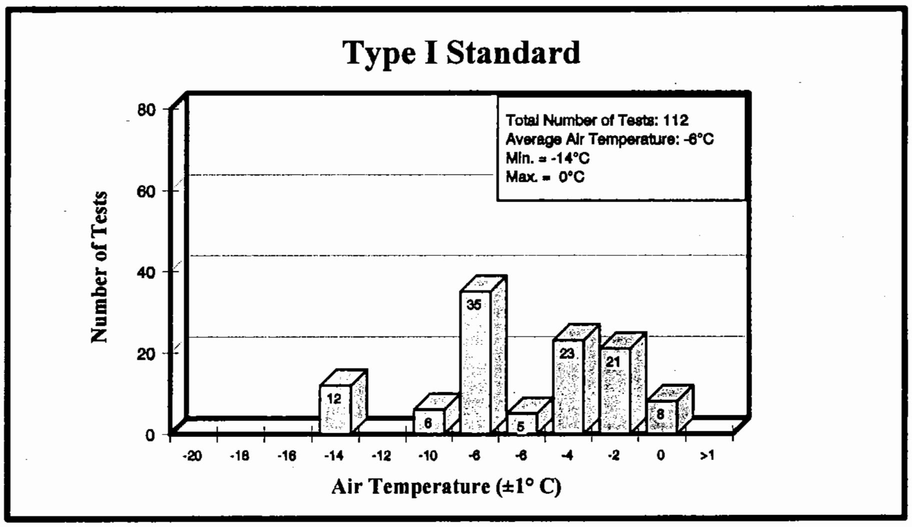
FIGURE 3.4

DISTRIBUTION OF AIR TEMPERATURE

Natural Snow Tests
1994-1995



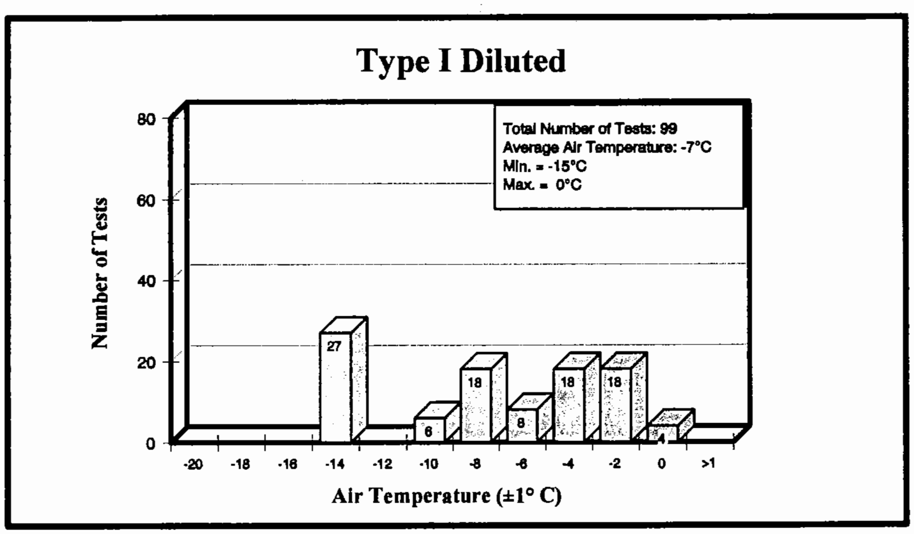


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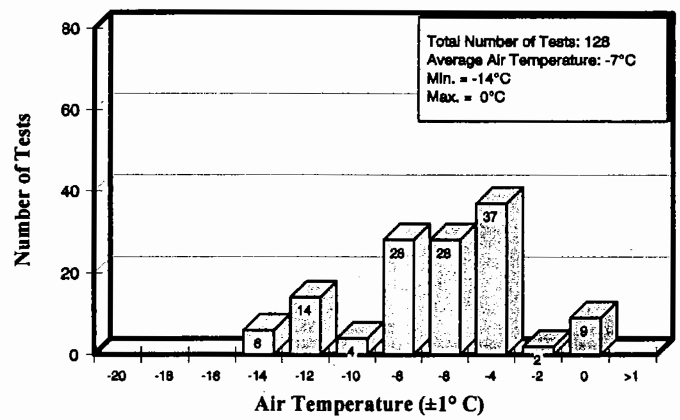
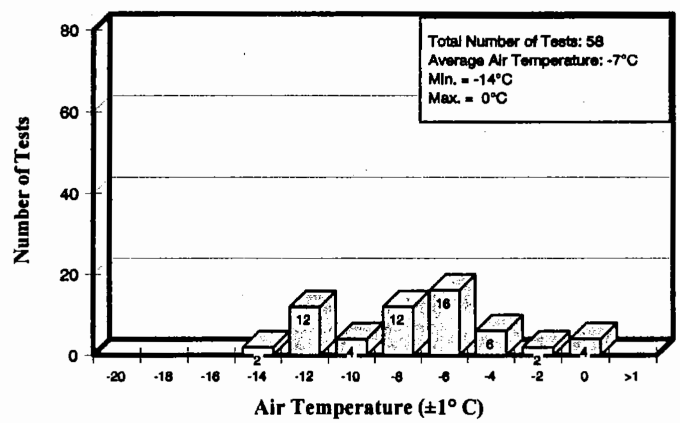
FIGURE 3.5
DISTRIBUTION OF AIR TEMPERATURE
Natural Snow Tests
1994-1995

Type II Neat



Type II 75/25



Type II 50/50

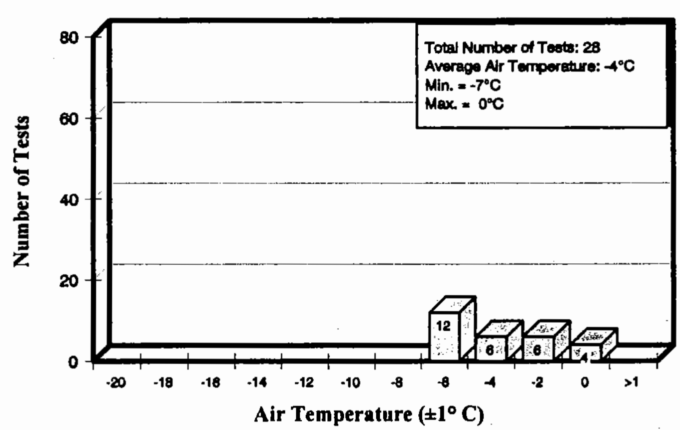


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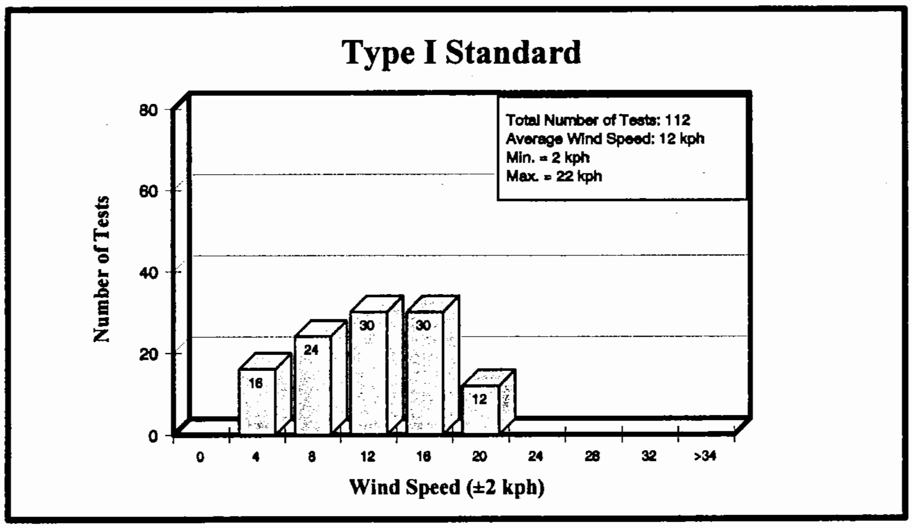
FIGURE 3.6

DISTRIBUTION OF WIND SPEED

Natural Snow Tests

1994-1995



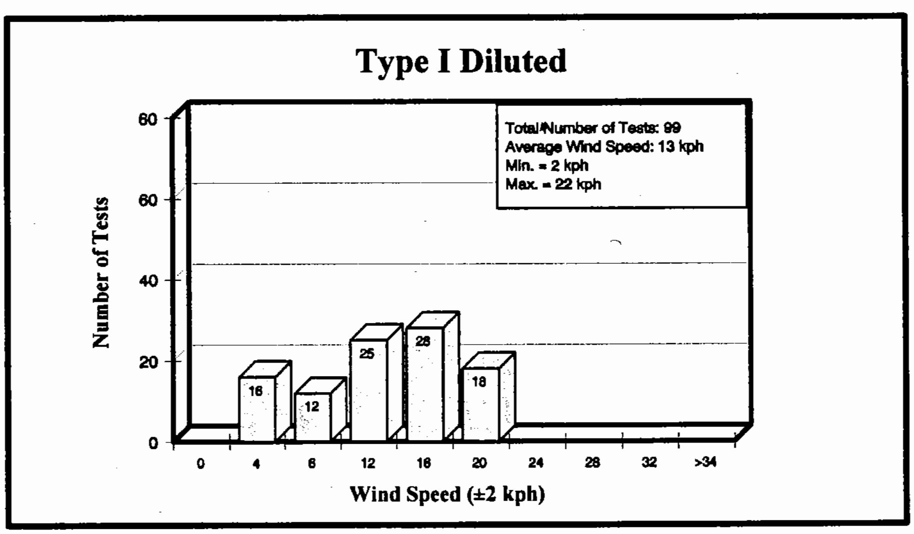


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FIGURE 3.7
DISTRIBUTION OF WIND SPEED
Natural Snow Tests
1994-1995

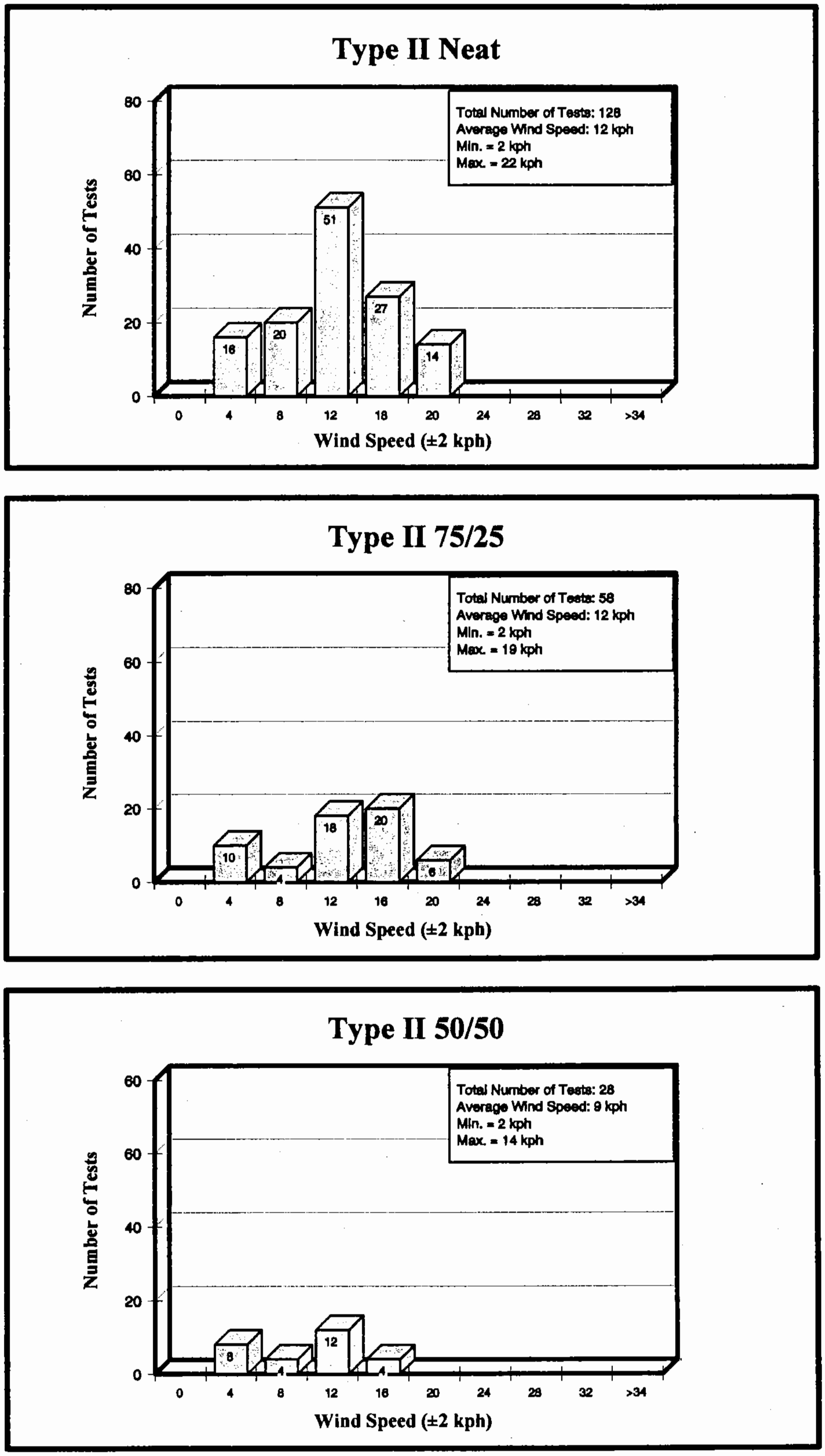

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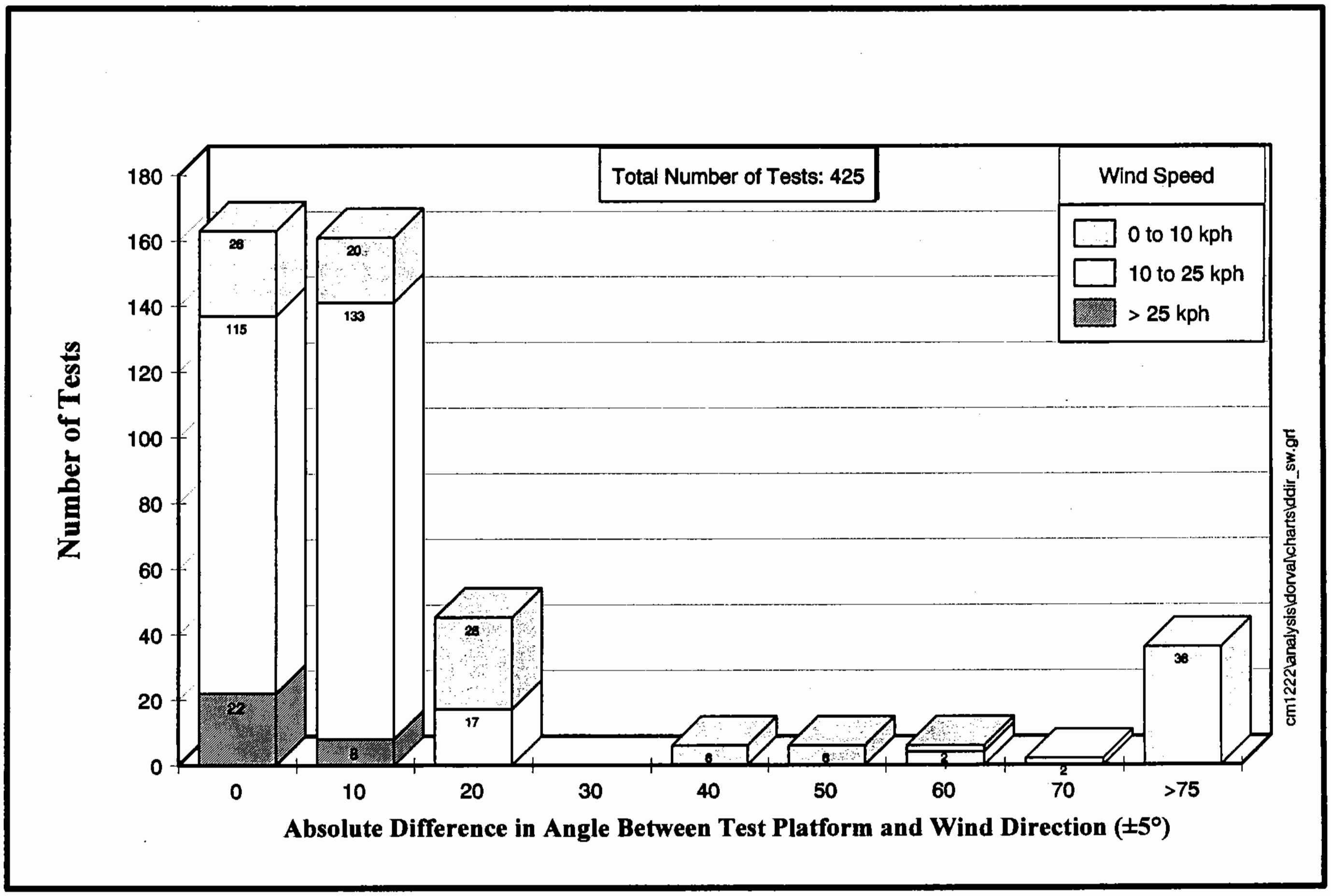
FIGURE 3.8
DISTRIBUTION OF WIND DIRECTION
Natural Snow Tests
1994-1995



3.2 Simulated Freezing Drizzle and Light Freezing Rain

3.2.1 Usable Data

APS collected data from 45 runs for the simulated freezing drizzle and light freezing rain tests in Ottawa. Almost every run contained data for six test plates. As shown in Figure 3.9, these runs contained a total of 206 usable test points, of which 94 points were during drizzle conditions and 112 were during light freezing rain.

3.2.2 Test Location and Fluids Tested

All of the 206 indoor usable tests were carried out at NRC's Climatic Engineering Facility in Ottawa. As with natural snow, the fluids used were from Union Carbide, Octagon, Hoechst, Kilfrost and Arco.

3.2.3 Distribution of Average Precipitation Rates

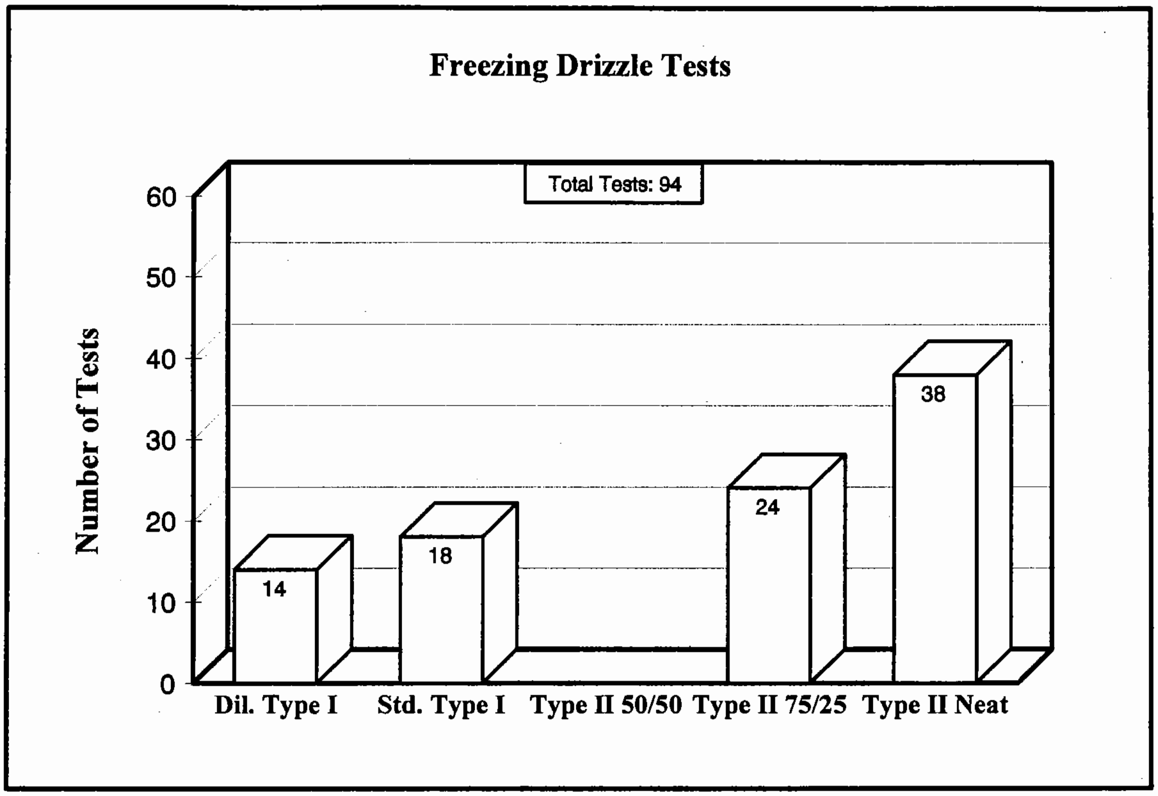
Figures 3.10 and 3.11 show the distribution of average precipitation rates recorded at NRC facilities. As described in Section 2, the average precipitation rates for freezing drizzle and light freezing rain were computed from weight measurements taken with the plate pans.

For all fluid types tested, precipitation rates for freezing drizzle were primarily in the 2 to 13 $g/dm^2/hr$ range, and for light freezing rain, in the 13 to 25 $g/dm^2/hr$ range.

FIGURE 3.9

NUMBER OF SIMULATED FREEZING DRIZZLE/RAIN TESTS

1994-1995 TEST SEASON



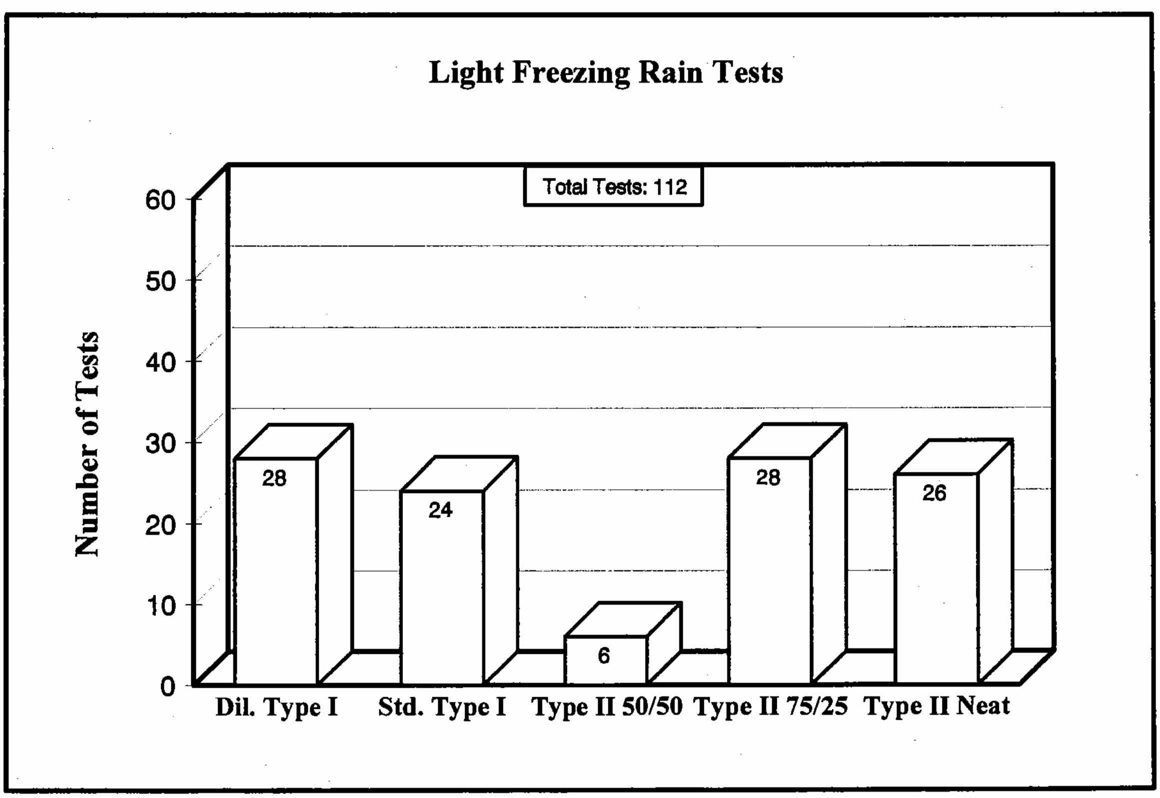


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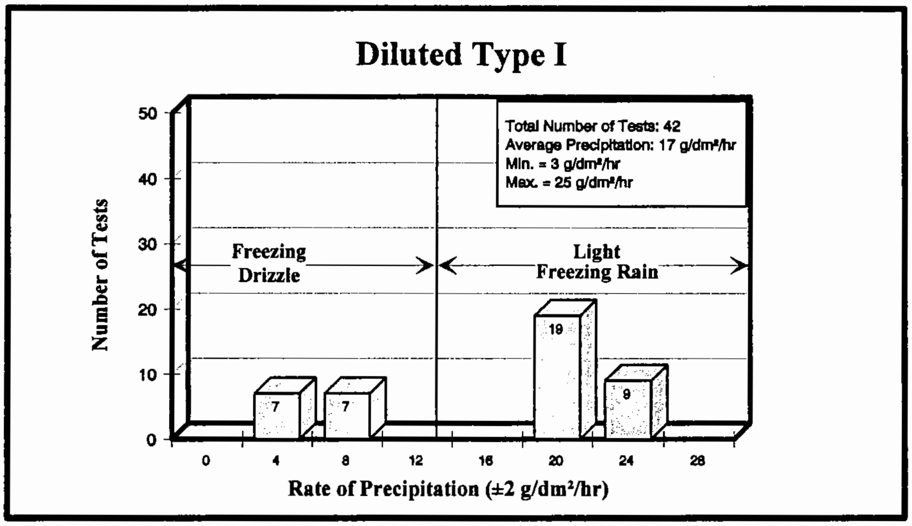
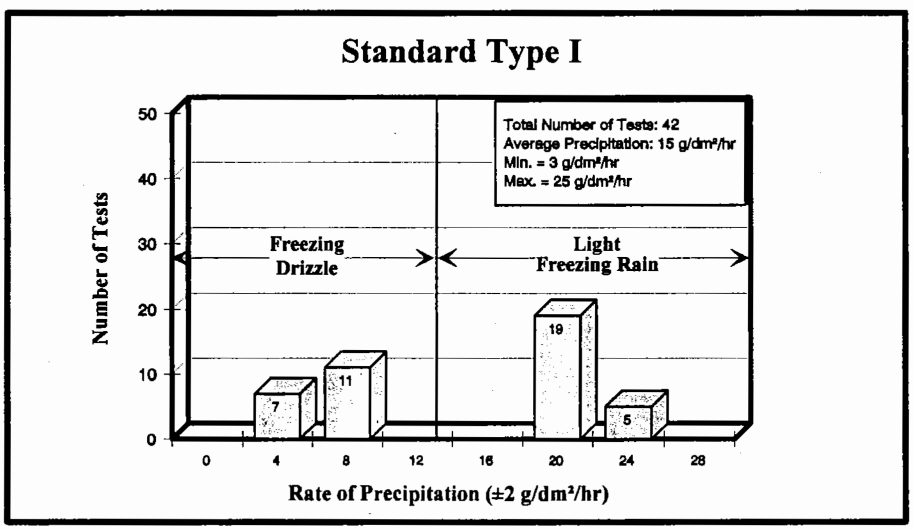
FIGURE 3.10

DISTRIBUTION OF PRECIPITATION RATE

Simulated Freezing Drizzle/Light Freezing Rain Tests
1994-1995





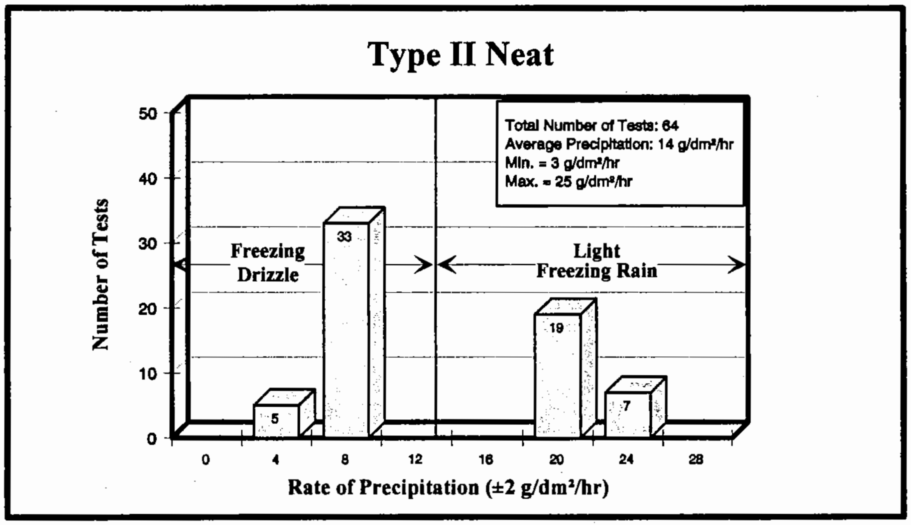
cm1222\analysis\frz_prec\charts\dpre_dr2.grf

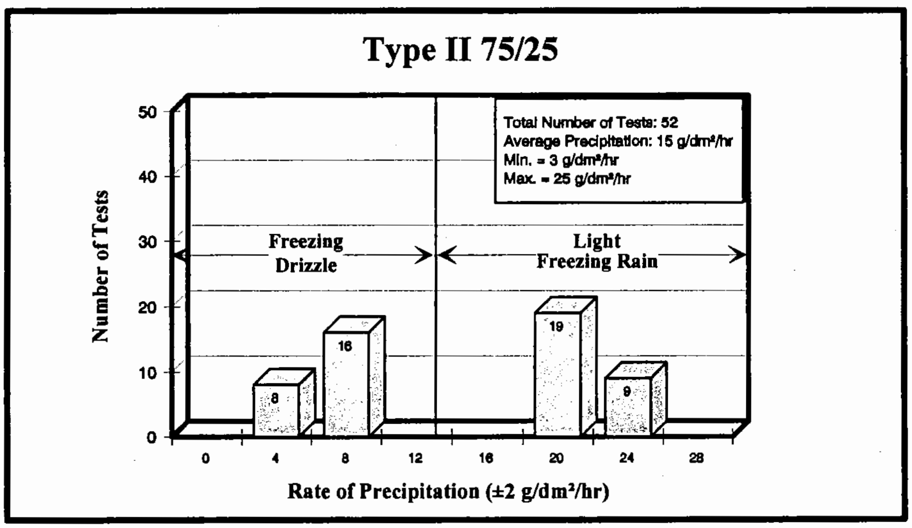
FIGURE 3.11

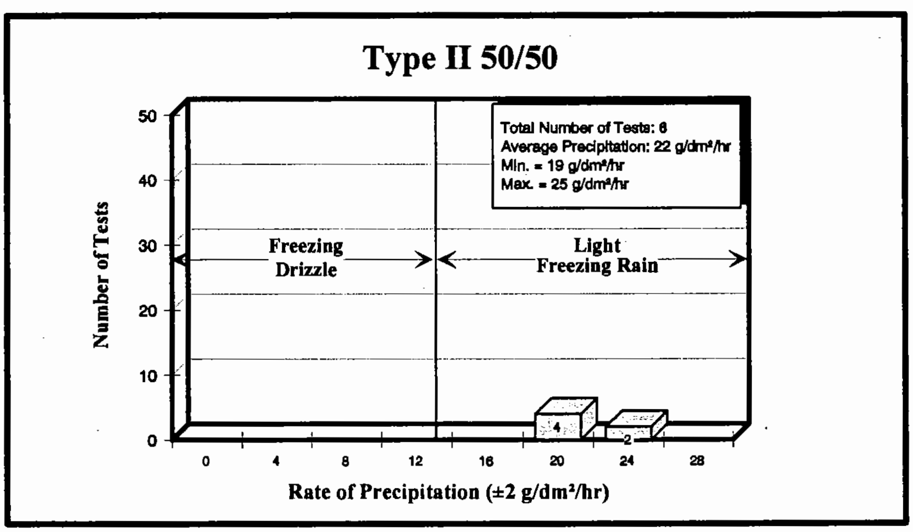
DISTRIBUTION OF PRECIPITATION RATE

Simulated Freezing Drizzle/Light Freezing Rain Tests

1994-1995





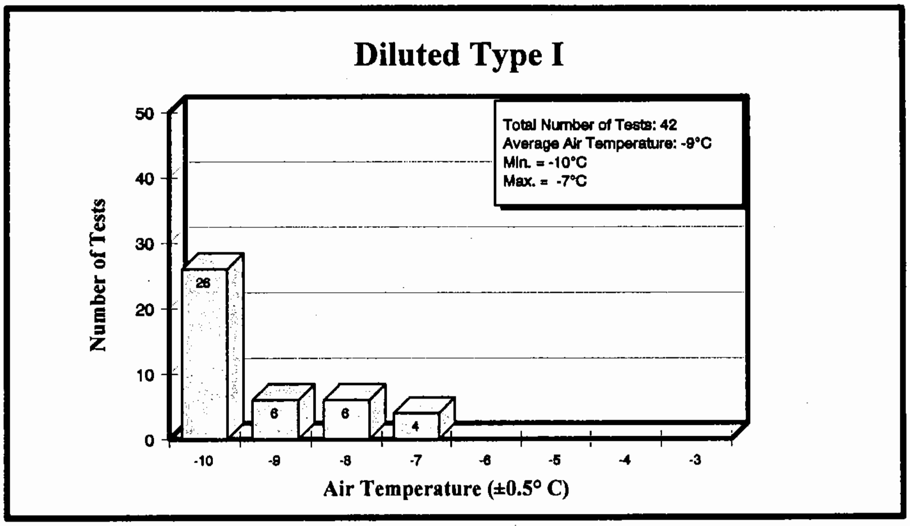


cm1222\analysis\frz_prec\charts\dpre_drz.grf

3.2.4 Distribution of Other Meteorological Conditions

The only other meteorological factor which was varied during the freezing drizzle and rain tests was air temperature. The distribution of the air temperatures is presented in Figures 3.12 and 3.13, which shows that the majority of the tests were conducted with air temperatures from -6°C to -10°C for Type I fluids and -5°C to -10°C for Type II fluids.

FIGURE 3.12
DISTRIBUTION OF AIR TEMPERATURE
Simulated Freezing Drizzle/Light Freezing Rain Tests
1994-1995



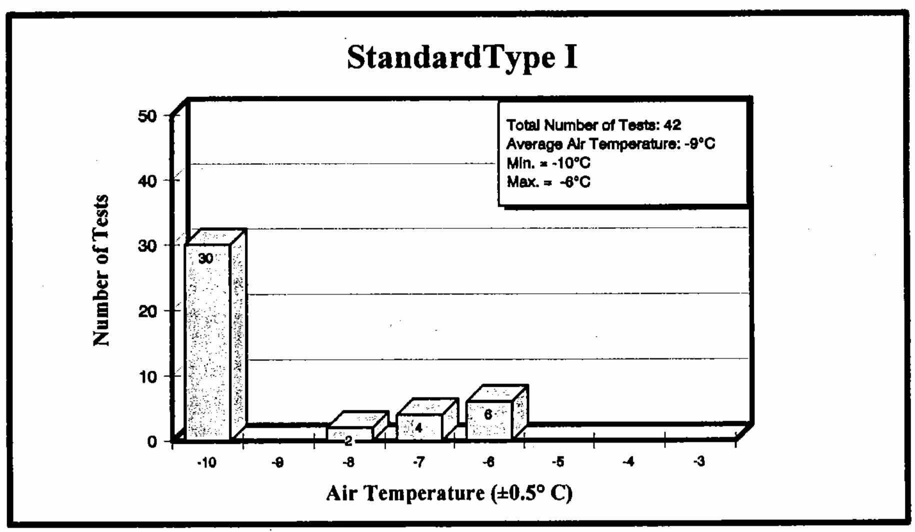


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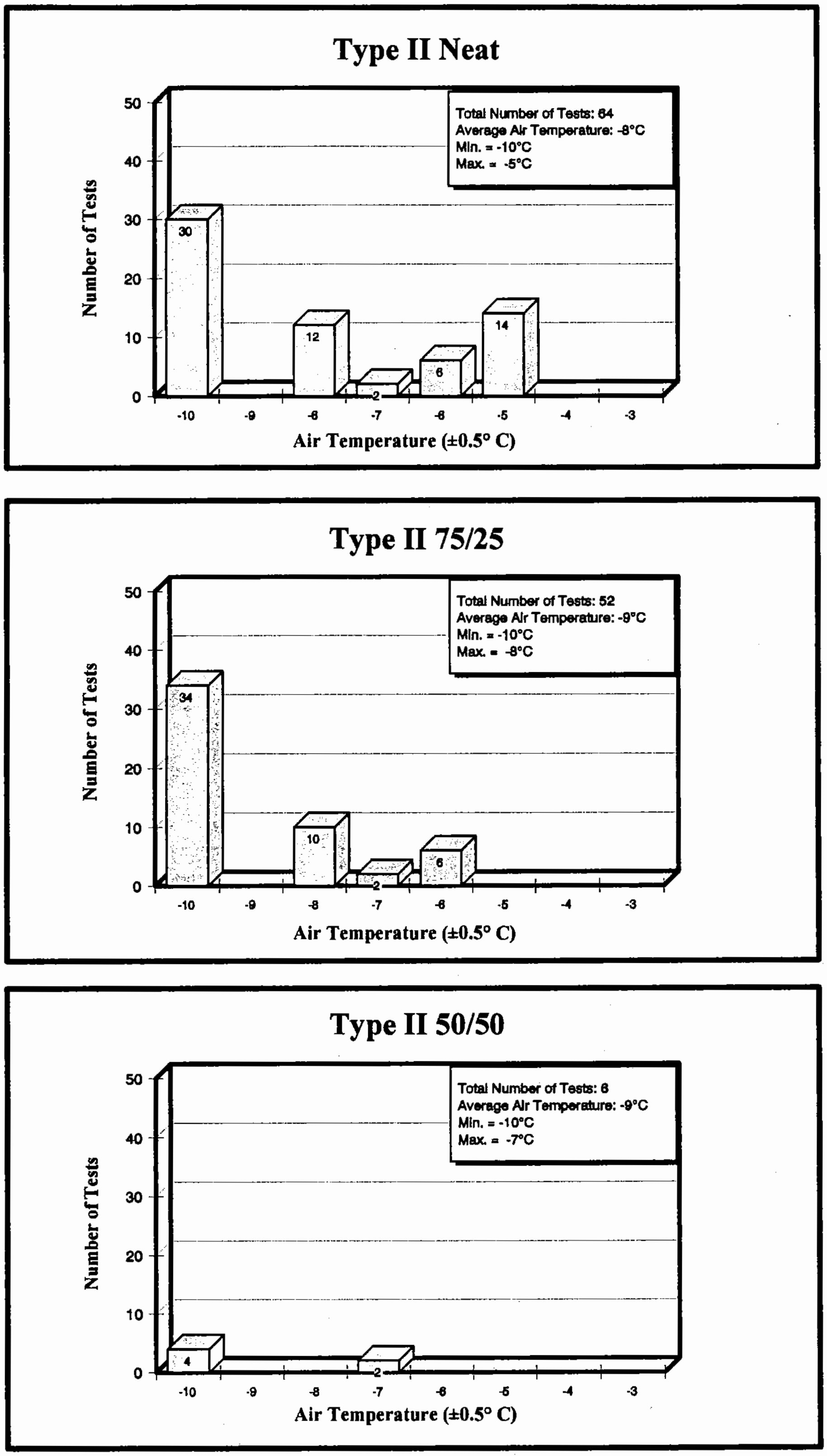
FIGURE 3.13

DISTRIBUTION OF AIR TEMPERATURE

Simulated Freezing Drizzle/Light Freezing Rain Tests

1994-1995



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3.3 Simulated Freezing Fog Tests

3.3.1 Usable Data

The breakdown of usable test data related to fluids tested was as follows (see Figure 3.14):

Fluid	**No. of data**
Type II Neat	68
Type II 75/25	11
Type II 50/50	12
Type I Standard	28
Type I Diluted	31
TOTAL	150

3.3.2 Test Location and Fluids Tested

As mentioned earlier, all of the 150 tests were carried out at NRC's indoor Climatic Engineering Facility in Ottawa. As for the freezing rain/drizzle tests and the natural snow tests, the fluids tested were from Union Carbide, Octagon, Hoechst, Kilfrost and Arco.

3.3.3 Distribution of Average Precipitation Rates

Figures 3.15 and 3.16 provide the distribution of average precipitation rates recorded at the NRC facility for Type I and Type II fluids, respectively. As previously mentioned, these rates were measured with a plate pan. It can be seen that the rates vary from about 2 to 16 $g/dm^2/hr$. However, only rates below 8 $g/dm^2/hr$ were used in the

FIGURE 3.14
NUMBER OF SIMULATED FREEZING FOG TESTS
1994-1995 TEST SEASON

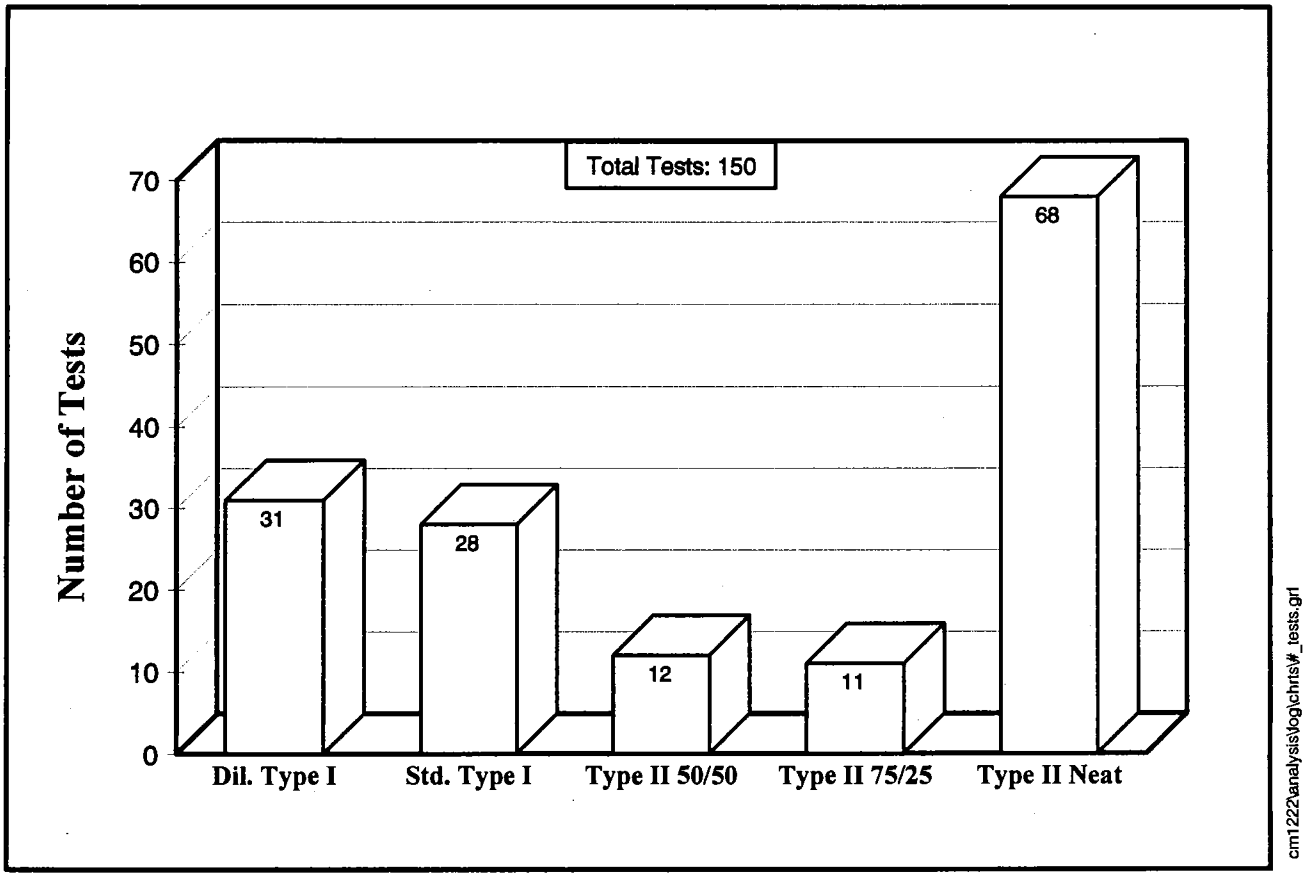
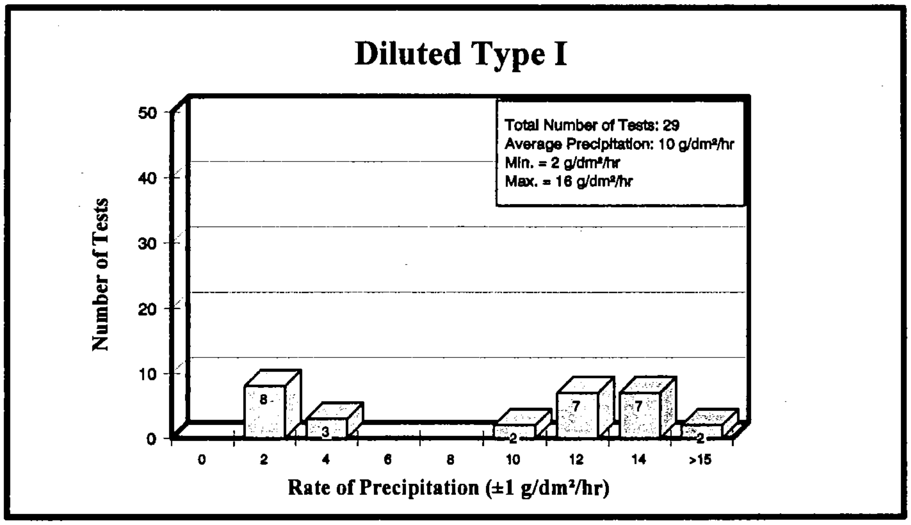


FIGURE 3.15
DISTRIBUTION OF PRECIPITATION RATE
Simulated Freezing Fog Tests
1994-1995



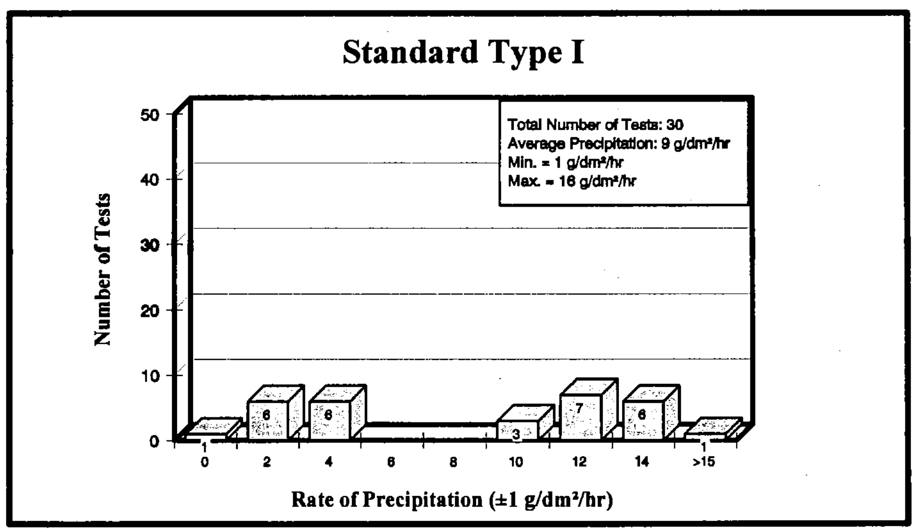


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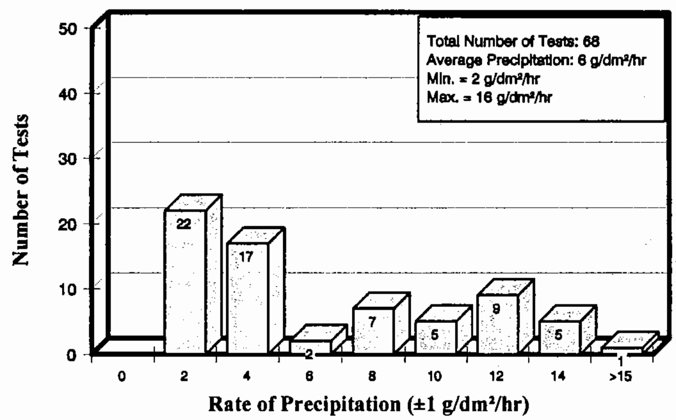
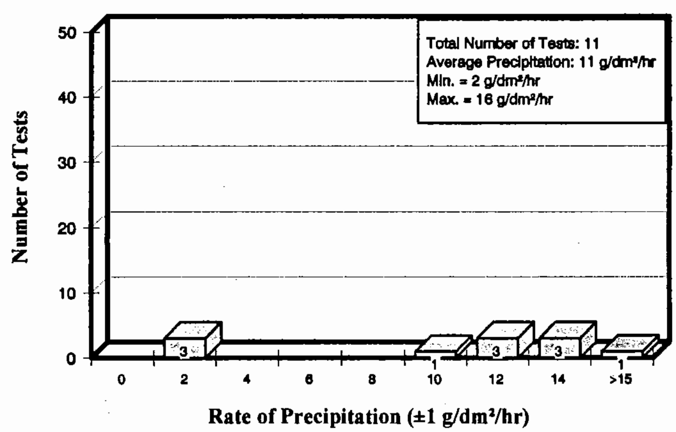
FIGURE 3.16
DISTRIBUTION OF PRECIPITATION RATE
Simulated Freezing Fog Tests
1994-1995

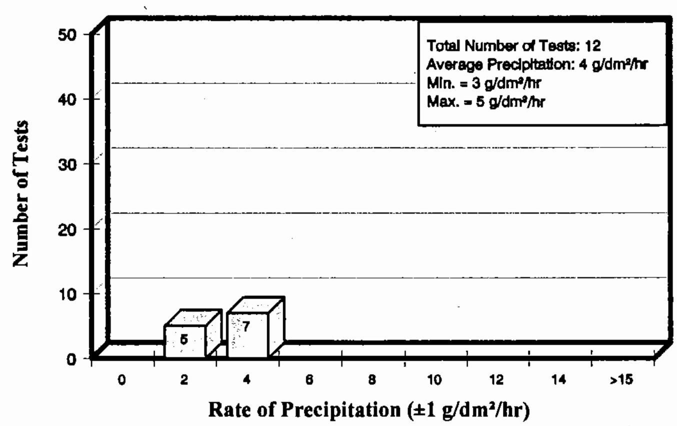
Type II Neat



Type II 75/25



Type II 50/50



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analysis since natural freezing fog is only known to occur at rates below 8 $g/dm^2/hr$.

3.3.4 Distribution of Other Meteorological Conditions

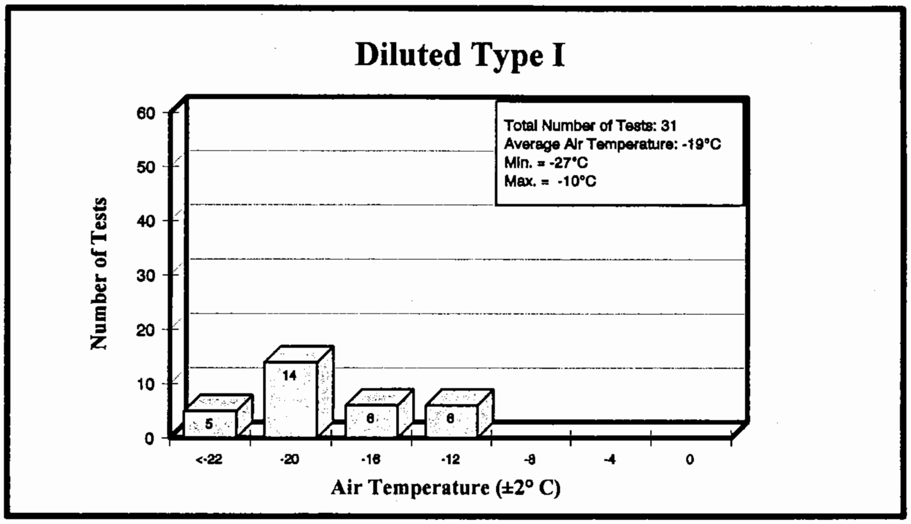
The only other meteorological factor which varied substantially during the freezing fog tests is temperature. The distribution of temperatures is presented in Figures 3.17 and 3.18, which shows that the test temperatures varied from about -10°C to -27°C for Type I fluids, and -11°C to -27°C for Type II fluids.

FIGURE 3.17

DISTRIBUTION OF AIR TEMPERATURE

Simulated Freezing Fog Tests

1994-1995



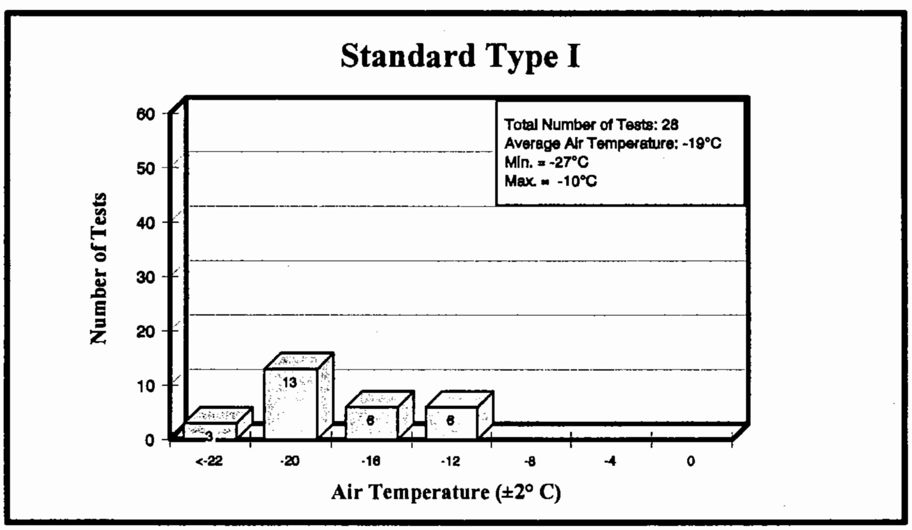


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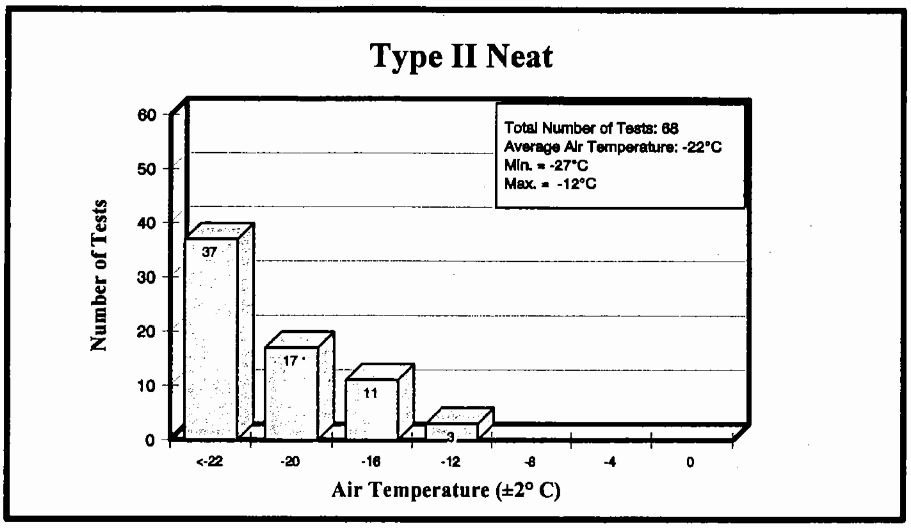
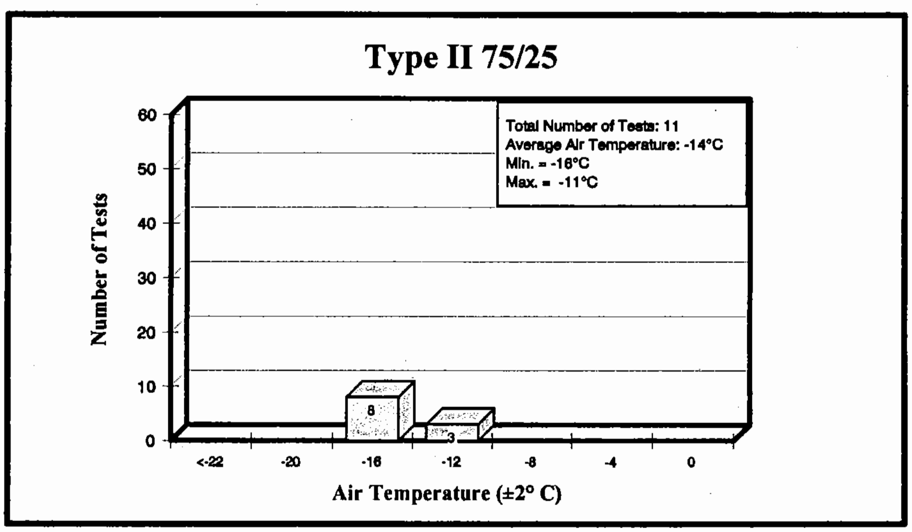
FIGURE 3.18

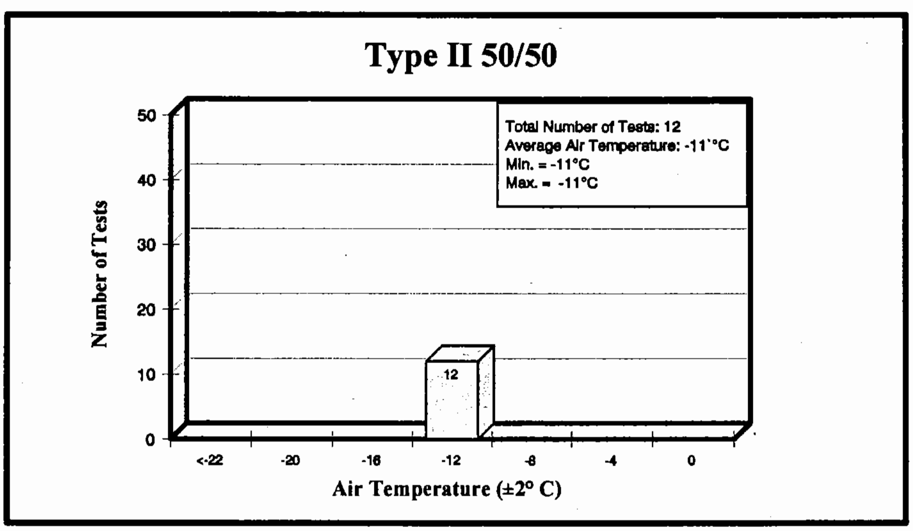
DISTRIBUTION OF AIR TEMPERATURE

Simulated Freezing Fog Tests

1994-1995







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3.4 Simulated Rain on Cold-Soaked Surface Tests

3.4.1 Usable Data

APS collected test data from 32 runs for the simulated rain on cold-soaked surface tests conducted at NRC's CEF in Ottawa. As shown in Figure 3.19, these runs contained a total of 131 usable test points for both sealed box sizes and all types of fluids used.

3.4.2 Test Location and Fluids Tested

All 131 usable tests were carried out at NRC's CEF in Ottawa. The fluids tested were from Union Carbide, Octagon, Hoechst, Kilfrost and Arco.

3.4.3 Distribution of Average Precipitation Rates

Figures 3.20 and 3.21 show the frequency distribution for the various rates of precipitation during the cold-soaked surface tests. The precipitation for the rain on cold-soaked surface tests was produced using the same apparatus as for the freezing drizzle and light freezing rain tests; as a result, the precipitation rate frequency distributions were the same.

3.4.4 Distribution of Average Surface Skin Temperature

The ambient air temperature was set to +2°C during the rain on cold-soaked surface tests, and the box skin temperature was varied

FIGURE 3.19
NUMBER OF COLD-SOAKED TESTS
1994-1995 TEST SEASON

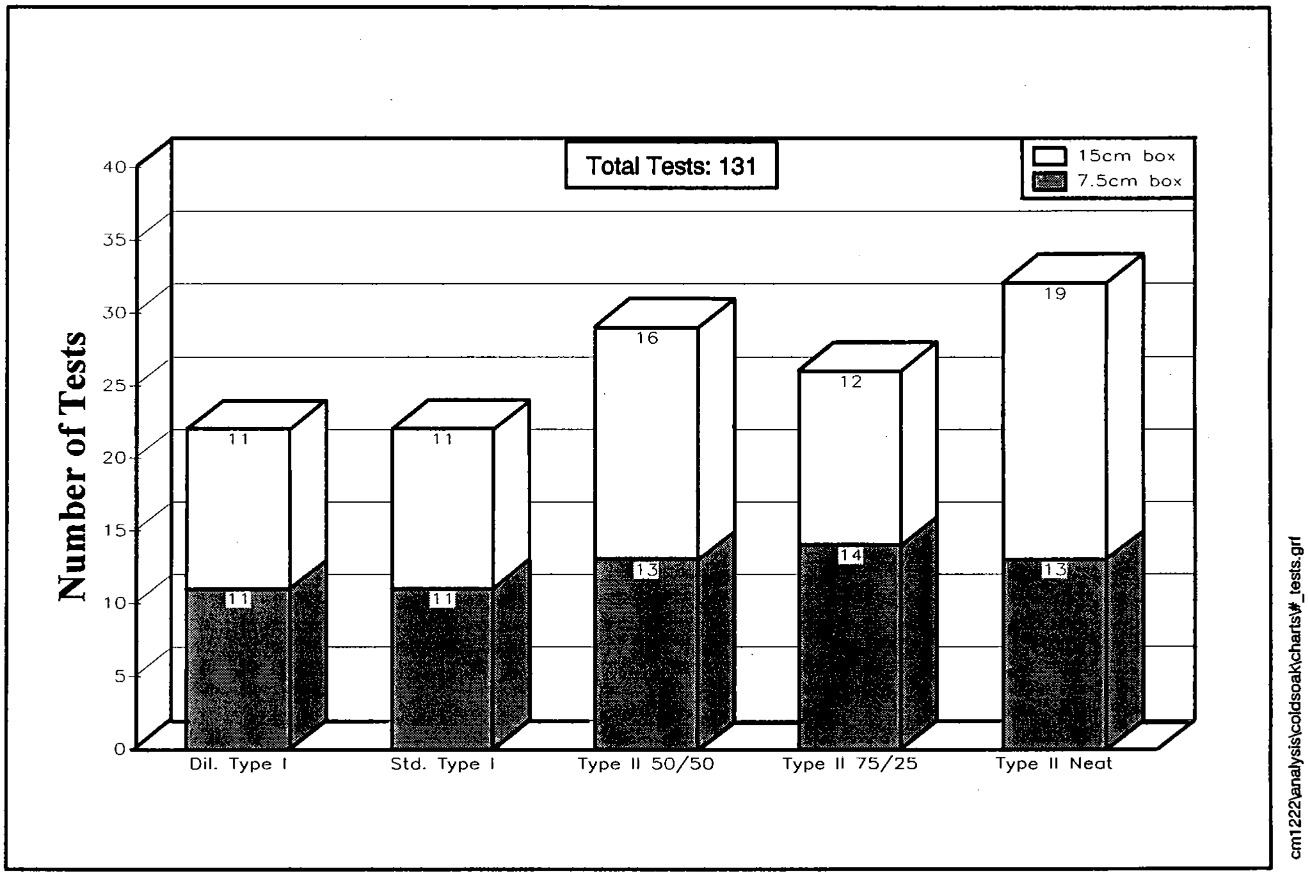
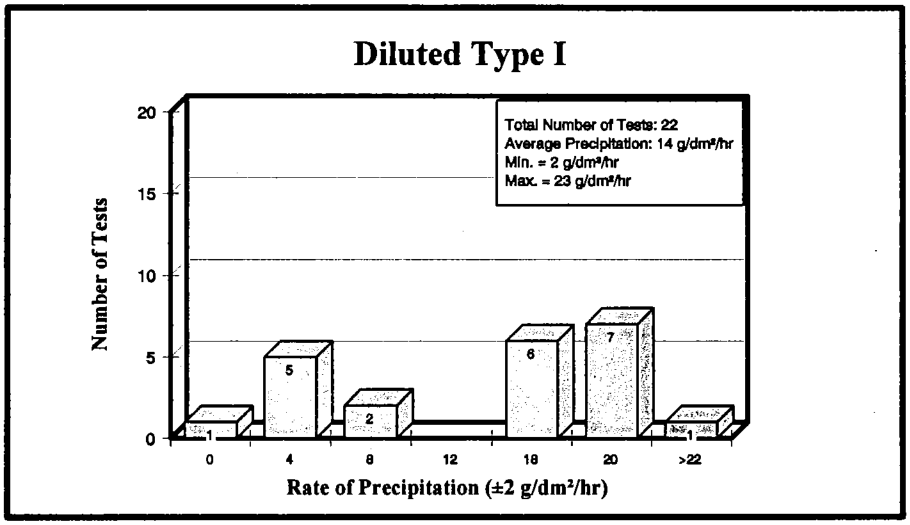


FIGURE 3.20
DISTRIBUTION OF PRECIPITATION RATE
Cold-Soaked Box Tests
1994-1995



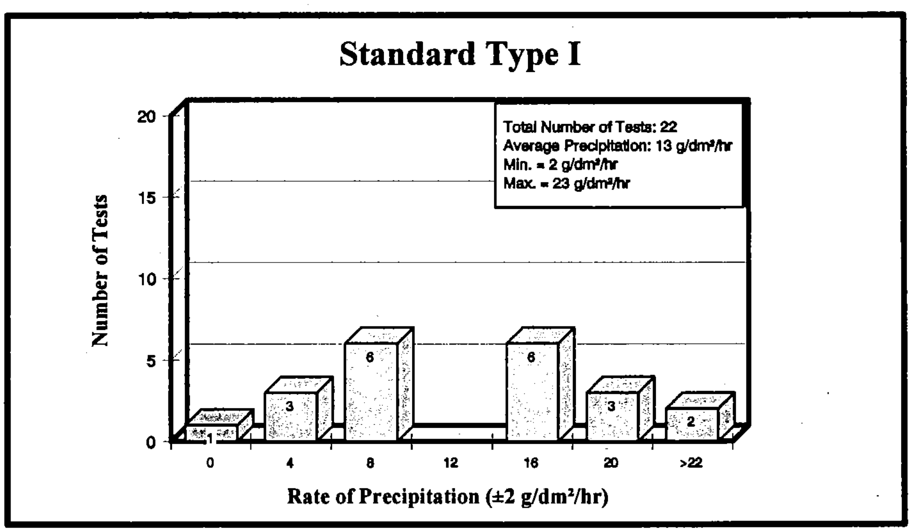


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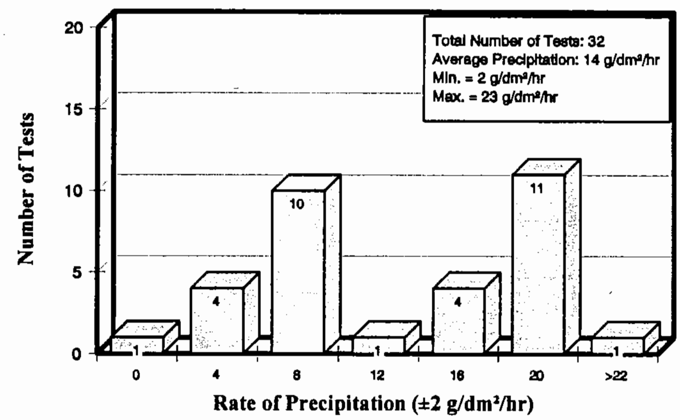
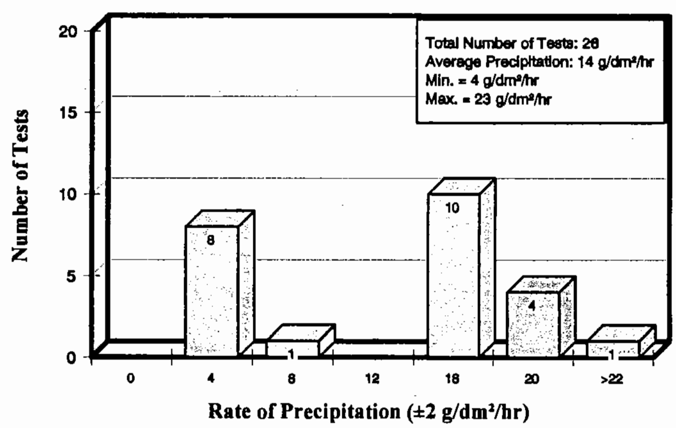
FIGURE 3.21
DISTRIBUTION OF PRECIPITATION RATE
Cold Soaked Box Tests
1994-1995

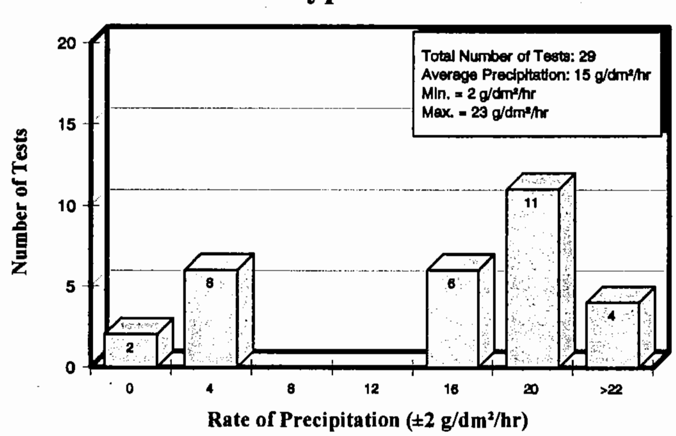
Type II Neat



Type II 75/25



Type II 50/50



cm1222\analysis\coldsoak\charts\dpre_box.grf substantially from test to test for all fluid types. Figures 3.22 and 3.23 show the average skin temperature distribution for each fluid type. The skin temperature ranged from -1°C to -13°C for Type I fluids, and -2°C to -10°C for Type II fluids.

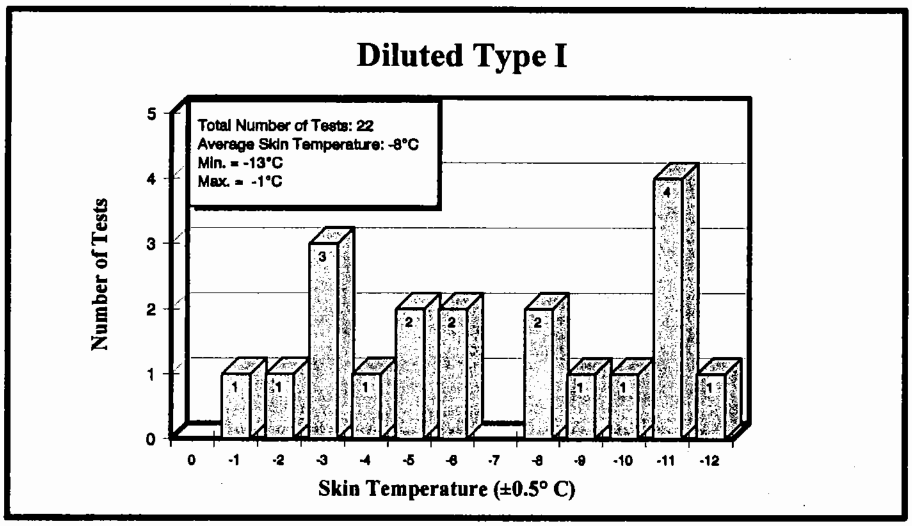
For each test, temperatures recorded were the average of measurements taken by hand-held temperature probes or thermistor sensors. The thermistors were mounted on the top surface of each box over a crosshair marking located 22.5 cm (9 in.) from the top of the box.

FIGURE 3.22

DISTRIBUTION OF SKIN TEMPERATURE

Cold-Soaked Box Tests

1994-1995



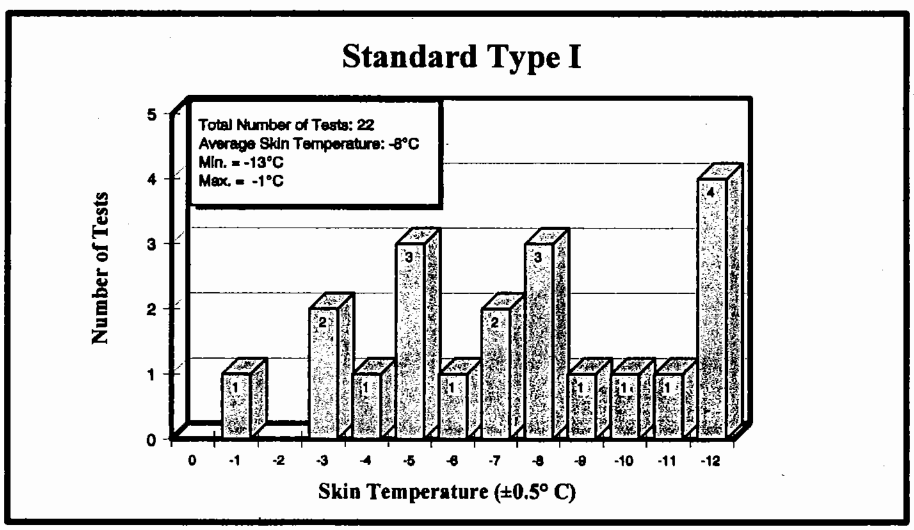


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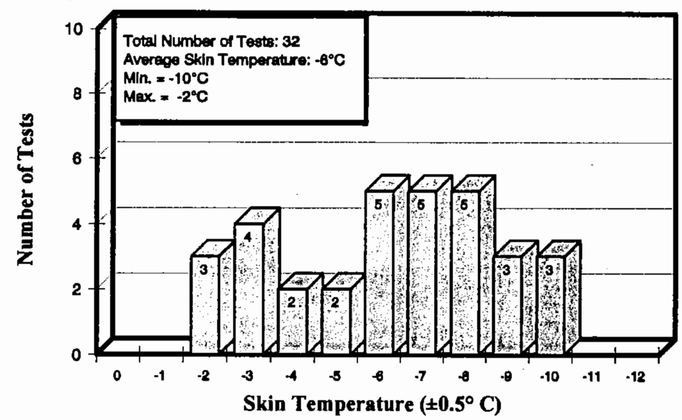
FIGURE 3.23

DISTRIBUTION OF SKIN TEMPERATURE

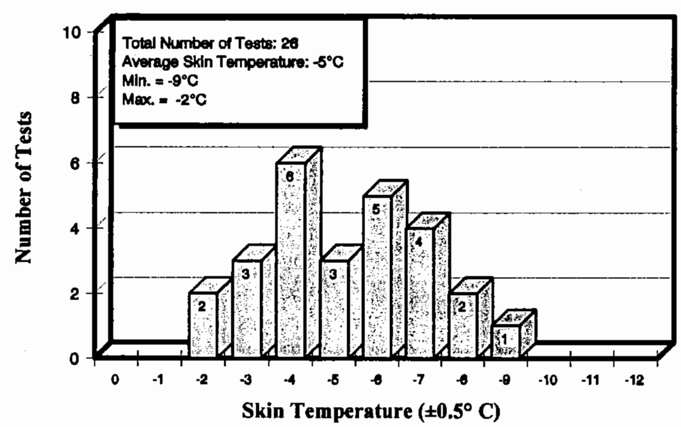
Cold-Soaked Box Tests

1994-1995

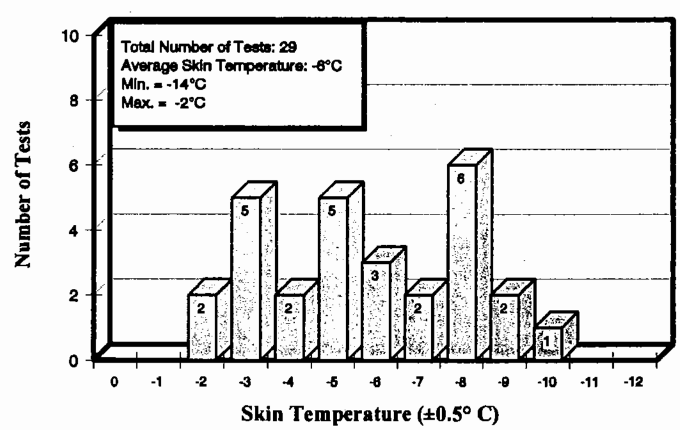
Type II Neat



Type II 75/25



Type II 50/50



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4. METEOROLOGICAL ANALYSIS

4.1 AES Radar Forecast Service

4.2 Comparison of Precipitation Collection Devices at Dorval

4.3 Visibility versus Rate of Precipitation

4.4 Comparison of Meteorological Measurements

4. METEOROLOGICAL ANALYSIS

The following sub-sections examine in detail meteorological instruments including precipitation collection devices, and provide a comparison of the Dorval site equipment with that of AES. This winter, the data collection at the AES site was automated. It was referred to as Remote Environmental Automatic Data Acquisition Concept (READAC).

4.1 AES Radar Forecast Service

The AES "Radar Forecasting" service was installed in the trailer at Dorval in order to provide early warning for snowfalls and allow the test staff to be prepared for each test. The Radar Forecasting service consisted of a wireless receiver which was linked to a printer. The radar system, located at McGill University, transmitted weather data every 60 minutes which was available as a printout at the site. The printout provided detailed predictions one hour at a time for 5 minute intervals at 19 different locations in Quebec including the Dorval airport. The predictions included the type of precipitation expected, the precipitation intensity, expected accumulation and forecast reliability. Table 4.1 shows a typical Radar service printout for January 11, 1995 at 20:35.

The sample Dorval forecast in Table 4.1 indicates that there is an excellent probability of light snow for 15 to 25 minutes starting at 20:45. This would change to moderate and then to heavy snow (F) at 21:20 for about 15 minutes. The projection indicated that snow would stop at about 21:55. AES uses 2 cm/hr or greater as an indicator of heavy snow. This equates to about 20 $g/dm^2/hr$, assuming a 10 to 1 snow to water equivalence.

TABLE 4.1
TYPICAL RADAR FORECAST FROM WEATHERCOPY (AES)

BULLETIN #116: PFCA.112040

ENVIRONNEMENT CANADA
PREVISION DE PRECIPITATION

SERVICE CHASSE-NEIGE / PREVISIONS RADAR D'HEURE EN HEURE
PREVISION EMISE A 20H35 HNE, MERCREDI LE 11 JANVIER 1995
VALIDES DE 20H45 A 21H45 HNE AVEC UN APERCU POUR L'HEURE SUIVANTE.

ENDROIT	PREVISIONS												PN/PX	APERCU						FIAB.
	20H45						21H15					21H40		21H45					22H35	
DORVAL	L	L	L	M	L	M	M	F	F	F	M	M	1/ 1	M	L	.	.	.	.	EXCL
GRANBY	.	.	L	L	L	L	L	L	L	L	L	L	T/ T	L	M	M	M	M	M	P/F
JOLIETTE	.	.	L	L	M	L	L	.	.	.	.	.	0/ T	.	.	.	.	.	.	EXCL
LACHINE	L	L	M	L	M	M	M	M	F	F	M	M	T/ 1	M	L	.	.	.	.	EXCL
LE POUCE VERT	L	L	L	L	M	M	M	M	M	M	M	M	T/ 1	M	M	M	M	.	.	EXCL
LONGUEUIL	.	L	L	L	L	L	L	M	M	F	F	M	1/ 1	M	M	L	.	.	.	EXCL
MTG IBERVILLE	L	L	L	L	L	M	M	L	M	M	M	M	T/ 1	M	M	M	M	.	.	EXCL
MIRABEL	.	.	L	M	M	M	M	M	M	M	M	L	T/ 1	.	.	.	.	.	.	EXCL
MONTREAL	L	L	L	L	L	L	L	M	M	F	F	M	1/ 1	M	M	L	.	.	.	EXCL
MONTREAL-NORD	L	L	L	L	L	L	M	M	F	F	M	M	T/ 1	M	L	.	.	.	.	EXCL
MTL-BOUT-DE-L'ILE	.	.	.	L	L	.	L	M	M	M	M	M	T/ T	M	M	L	.	.	.	EXCL
MTL-COMMUNE	L	L	L	L	L	L	L	M	M	F	F	M	1/ 1	M	M	L	.	.	.	EXCL
MTL-DES CARRIERES	L	L	L	L	L	L	M	M	F	F	F	M	T/ 1	M	M	L	.	.	.	EXCL
MTL-MADISON	L	L	L	L	M	M	L	M	F	F	F	M	1/ 1	M	M	.	.	.	.	EXCL
MTL-POINCARE	L	L	L	L	L	L	M	M	F	F	M	M	1/ 1	M	L	.	.	.	.	EXCL
SAINT-HUBERT	.	L	L	L	L	L	L	L	M	M	F	F	T/ 1	M	M	M	.	.	.	EXCL
SAINT-JEAN	L	L	L	L	M	M	M	M	M	M	M	M	T/ 1	M	M	M	M	.	.	EXCL
ST-LUC	L	L	L	L	L	M	M	M	M	M	M	M	T/ 1	F	M	M	L	.	.	EXCL
VERDUN	L	L	L	L	L	M	L	M	M	F	F	F	1/ 1	M	M	.	.	.	.	EXCL
	20H45						21H15					21H40		21H45					22H35	

TAUX DE PRECIPITATIONS:
- . : PAS DE PRECIPITATIONS.
- L : LEGER. ENTRE 0.1 ET 0.5 CM/HR.
- M : MODERE. ENTRE 0.5 ET 1.9 CM/HR.
- F : FORT. 2 CM/HR. ET PLUS.
- N : DONNEES NON DISPONIBLES.

ACCUMULATIONS:
- PN : HAUTEUR MINIMUM DE NEIGE PREVUE EN CM.
- PX : HAUTEUR MAXIMUM DE NEIGE PREVUE EN CM.
- T : TRACE. ACCUMULATION PREVUE DE MOINS DE 0.1 CM.

FIABILITE:
- EXCL : EXCELLENT.
- TBON : TRES BON.
- BON : BON.
- P/F : PEU FIABLE [1].

[1] PRECIPITATIONS DETECTEES MAIS DEPLACEMENT ERRATIQUE OU PRECIPITATIONS TRES ISOLEES. LA PREVISION NE PEUT ETRE FAITE AVEC CERTITUDE.

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The system allowed the test site leader to prepare for the tests and scheduling tests for different fluid types according to the occurrence and intensity of snowfalls.

4.2 Comparison of Precipitation Collection Devices at Dorval

The measurement of precipitation in previous winters was made using a European ombrometer, plate pans, and collection devices used by the City of Montreal. Previous analysis has shown that the amount of precipitation collected by the plate pans correlated well with the shielded gauges used by the City of Montreal. For the 1994/95 winter season, Environment Canada had available a shielded collection device (see Section 3) which was part of the READAC station, and was similar to the instruments used by the City of Montreal.

Figure 4.1 shows a typical plot of the total cumulative precipitation over time from the READAC precipitation gauge installed at Dorval. The measurements shown in Figure 4.1 were taken on March 8, 1995 while tests on both stands were in progress. The sensitivity of the instrument is 1 g/dm^2 and measurements were recorded every minute. While the chart shows a substantial amount of "noise", mostly caused by vibrations due to wind, the measurements over a test period (usually in excess of 10 to 15 minutes) have small errors. For shorter test periods, usually during high precipitation rates, the relative amount of "noise" was less.

Figure 4.2 shows the comparison of the precipitation rate computed from the READAC equipment with that of the plate pans. The comparison was carried out for some tests and shows a very good correlation between the two measurements.

FIGURE 4.1

READAC PRECIPITATION GAUGE
TOTAL CUMULATIVE PRECIPITATION @ DORVAL

MAR 08/95, FORM 96 & 97

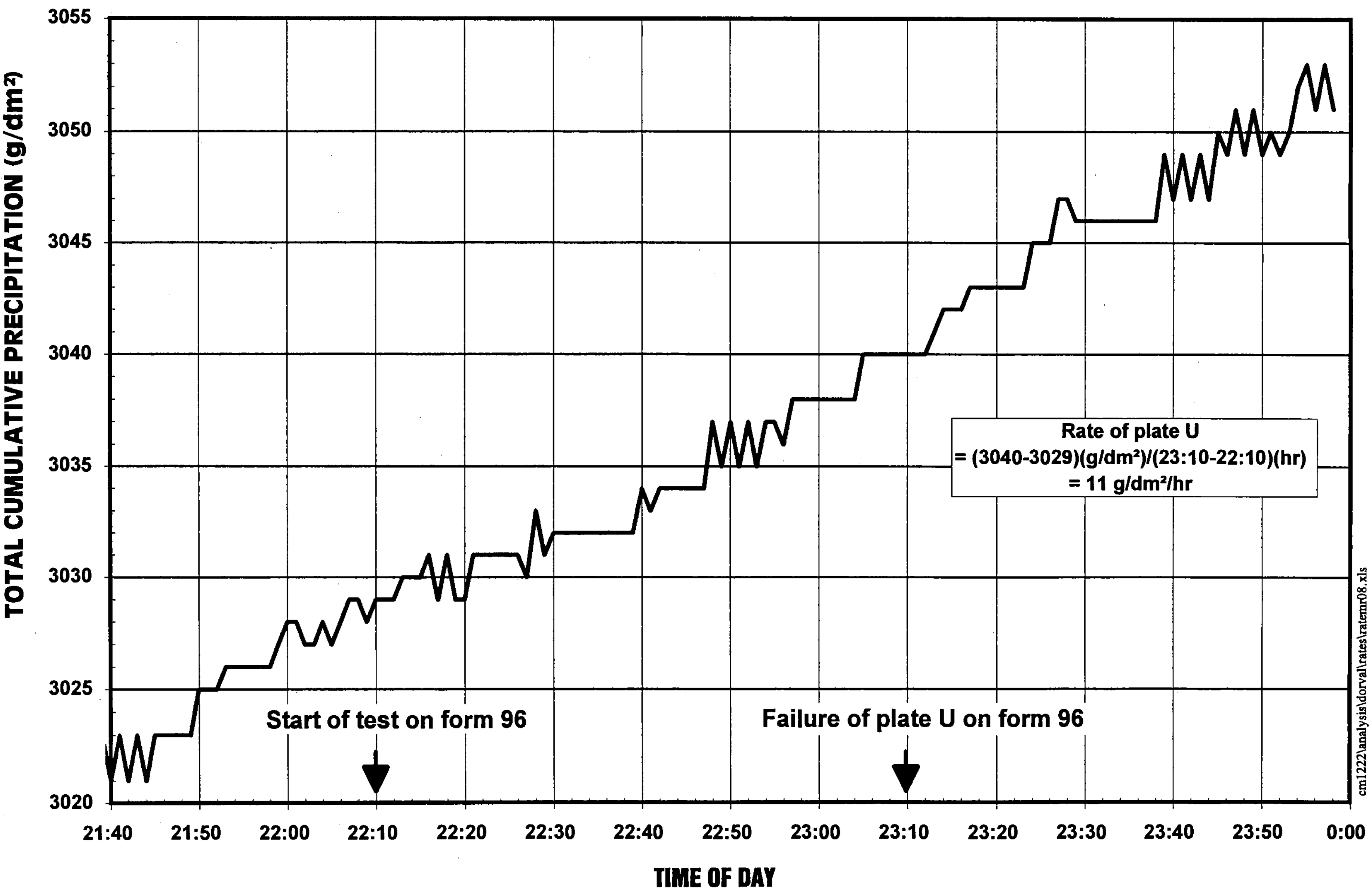
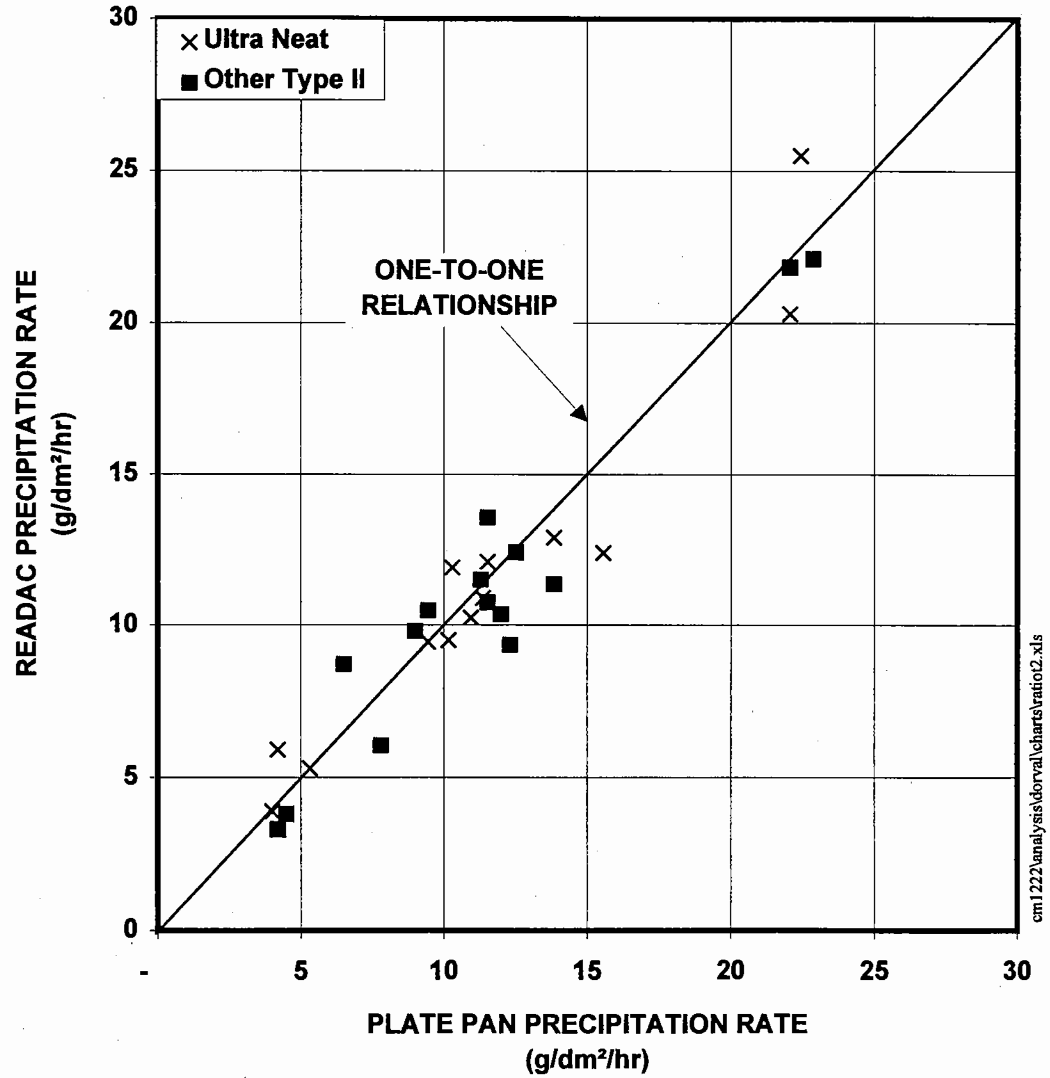


FIGURE 4.2
COMPARISON OF READAC AND PLATE PAN PRECIPITATION RATES
NATURAL SNOW TESTS
1994/1995



Any future testing should be conducted with the plate pans and data from the READAC station should also be acquired.

4.3 Visibility versus Rate of Precipitation

Figure 4.3 illustrates relationships between visibility in miles for various rates of precipitation, as a function of temperature. The visibility data was obtained from measurements from the READAC station at Dorval airport. The data points represent the average plate pan precipitation rates for all 1994/95 snow tests versus the average visibility during the time of testing. The plot shows a fair amount of scatter and no real trend with temperature. Graph plots with shorter time intervals should be made using the READAC visibility and precipitation rate data, as a function of temperature.

4.4 Comparison of Meteorological Measurements

Figure 4.4 represents test site wind speed measurements versus Environment Canada's READAC wind speed measurements. In both cases, wind speed is computed to be the average wind speed over the duration of the test. The test site measurements were about 65% of those from READAC. The READAC measurement is made at 10 metres above ground where as the wind is measured 3 metres above the test site to approximate wind flow over the test stands.

Figure 4.5 shows the comparison of wind direction from the APS test site instrument and from the READAC. The chart shows that, if the standard 16° variation between Magnetic and True North was applied, the correlation between the two instruments is excellent.

Figure 4.6 shows the comparison of temperature data. Again, it can be seen that there is an excellent correlation between the two instruments.

FIGURE 4.3

VISIBILITY vs RATE OF PRECIPITATION

NATURAL SNOW TESTS 1994-1995

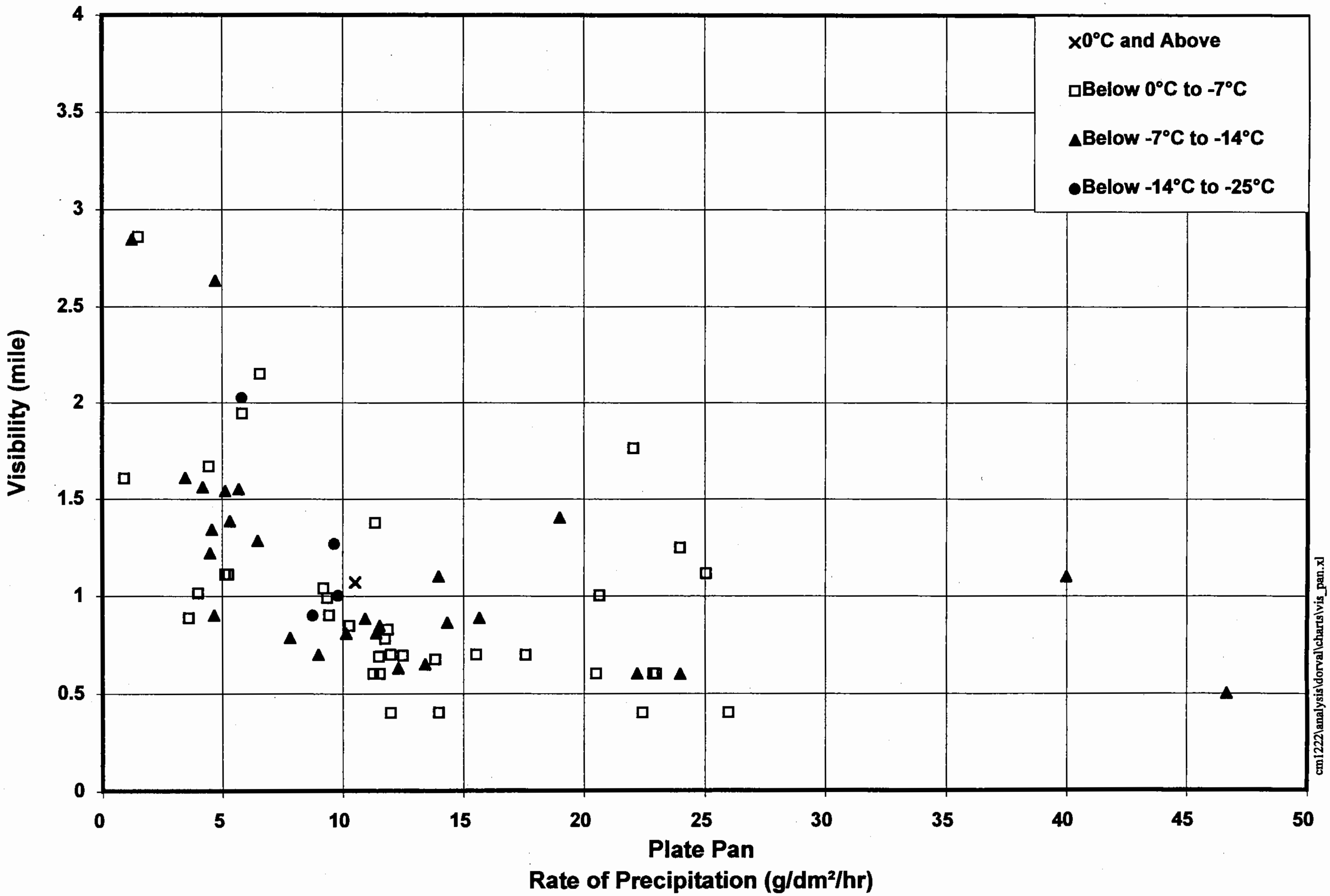


FIGURE 4.4
COMPARISON OF WIND SPEED DATA
APS DATA vs. READAC DATA
1994 - 1995

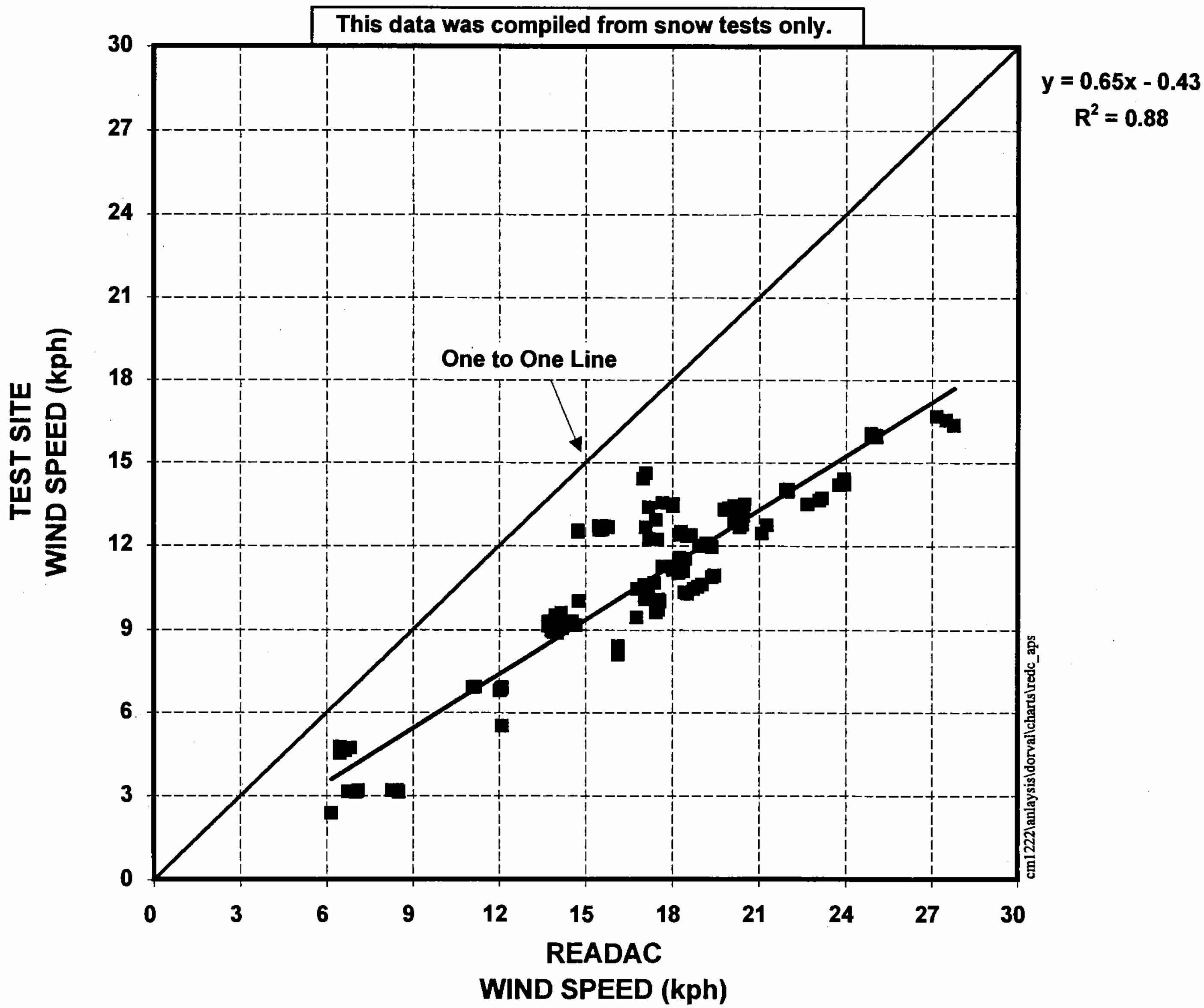


FIGURE 4.5

COMPARISON OF WIND DIRECTION DATA

APS DATA vs READAC DATA

1994 - 1995

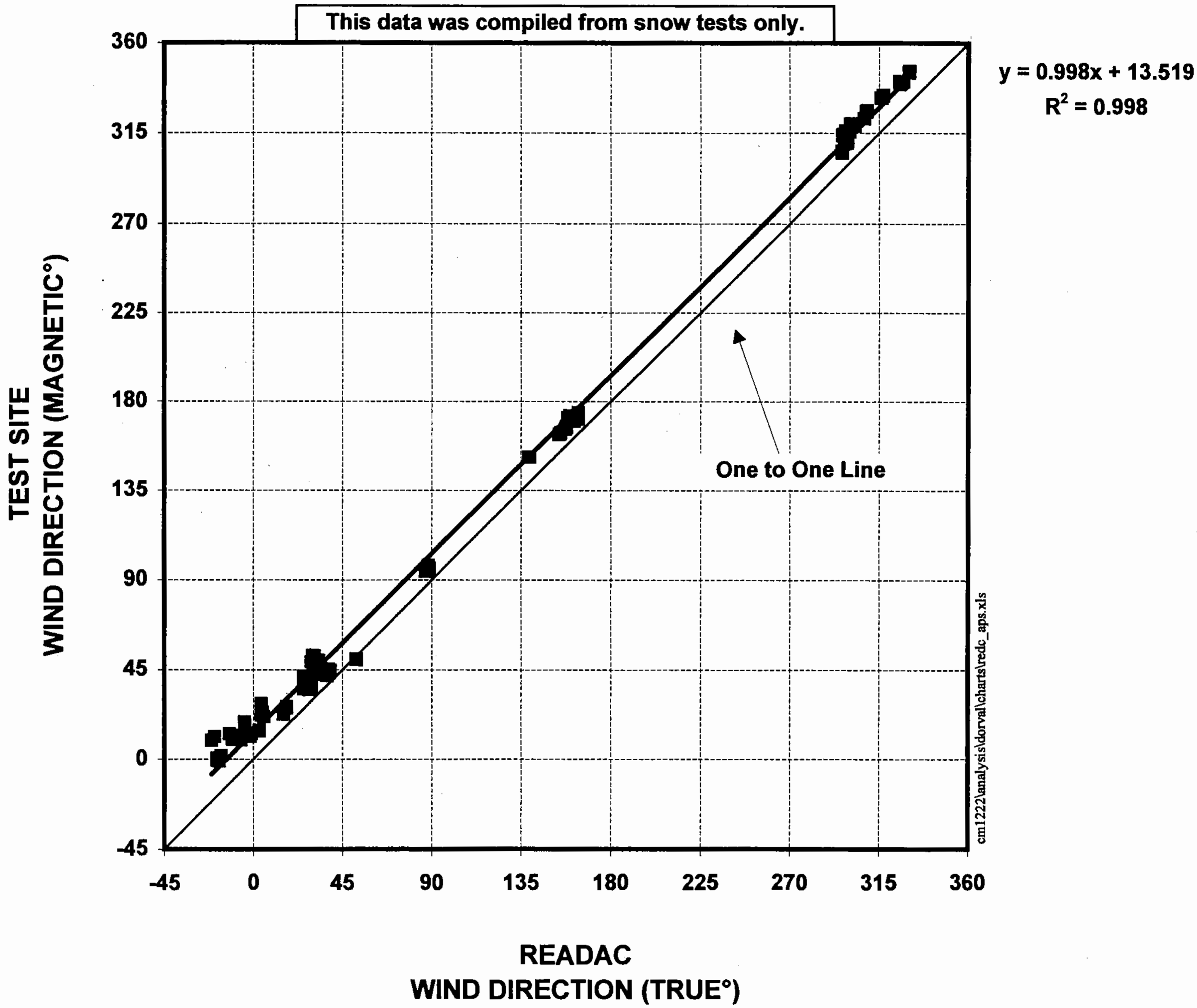
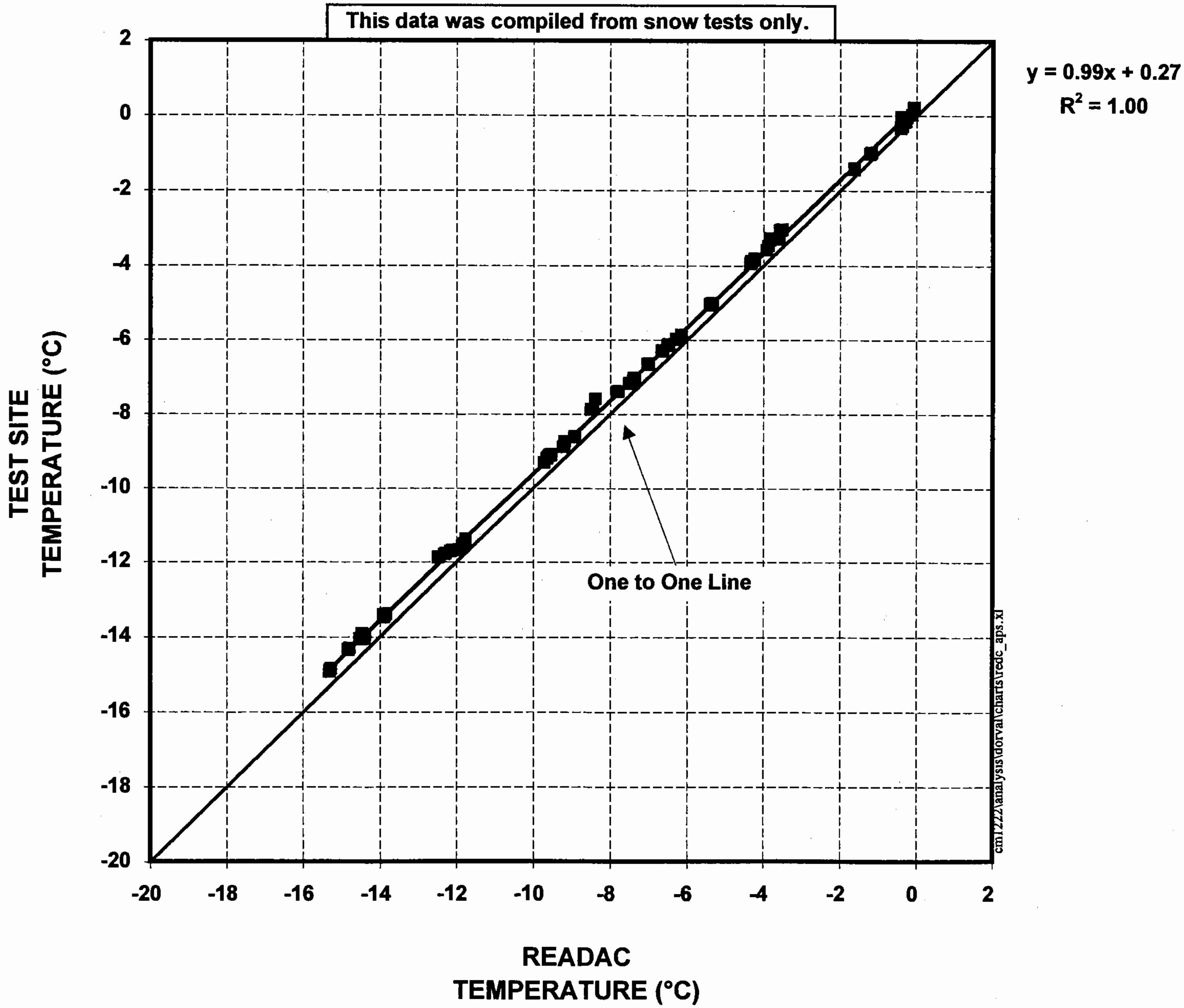


FIGURE 4.6
COMPARISON OF TEMPERATURE DATA
APS DATA vs READAC DATA
1994 - 1995



5. ANALYSIS

5.1 Flat Plate Tests

5.2 Ice Sensor Tests

5.3 Thickness of Ultra on Flat Plates

5. ANALYSIS

This section is divided into three sub-sections relating to flat plate tests, ice sensor tests, and thickness tests, respectively. The sub-section on flat plate tests provides the analysis of the data from tests conducted under natural snow, simulated freezing drizzle, light freezing rain, freezing fog and rain on cold-soaked surface. The sub-section on ice sensor tests contains a discussion of the C/FIMS and the RVSI ice sensors. The last sub-section contains the data from thickness measurements conducted on Ultra fluid.

5.1 Flat Plate Tests

The flat plate tests were conducted under four general categories of conditions:

- Natural snow;
- Simulated freezing drizzle and light freezing rain;
- Simulated freezing fog; and
- Simulated rain on cold-soak surfaces.

Each of these data sets are sub-divided into the fluid types, namely, standard Type I, diluted Type I, and Type II which are discussed separately.

A statistical analysis was performed on the data. This analysis consists of determining the variables of concern in the case of each fluid under different types of precipitation. The process starts by including all variables that are expected by experience to be of effect and then gradually eliminating those that turn out to be of no influence on the behaviour of the fluid at hand. The results of this analysis are included in Appendix I.

The primary purpose of the statistical analysis was to assess the data and to verify what trends were present. For example, a positive coefficient for temperature designates that failure time decreases with decreasing temperatures. A negative coefficient for rate of precipitation indicates that failure time decreases with increasing water content. The statistical analysis also provided an indication of the outlying points, which were then studied in more detail. The regression analysis showed that Type I fluid is less predictable than Type II fluid, particularly for freezing drizzle and light freezing rain. Type II fluid is also less predictable in snow than it is in freezing drizzle and light freezing rain.

The SAE/ISO HOT tables used prior to the current 1994/95 winter season were shown in Section 2.1. The proposed tables based upon the 1994/95 winter testing are shown in Section 6 of this report. The data to support the proposed changes is provided in this section.

5.1.1 Natural Snow Conditions

The natural snow tests were performed at the Dorval test site. The following parameters were recorded throughout the tests:

- Ambient temperature;
- Relative humidity;
- Wind speed and direction;
- Type of precipitation;
- Amount of precipitation; and
- End condition.

The regression analysis was performed for all fluid types by concentration and fluid manufacturer. The basic parameters listed above were used for the regression, and the degree to which they affected the failure time, varied from fluid to fluid.

5.1.1.1 Standard Type I Fluids under Natural Snow

Figure 5.1 shows the effect of rate of precipitation and fluid type on fluid failure time. As seen in previous years, the failure time generally decreases with increasing rate of precipitation. The failure times of the three Type I fluid types tested are not significantly different. The six points circled in Figure 5.1 that are above the others, resulted from warm ambient temperatures (-2°C to 0°C) and relatively high wind speed (>15 kph).

Figures 5.2 and 5.3 show the effect of temperature and rate of precipitation on Type I fluids. All but five points (fluid on two or more plates may have failed at the same time) fall between or above the

FIGURE 5.1

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON STANDARD TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

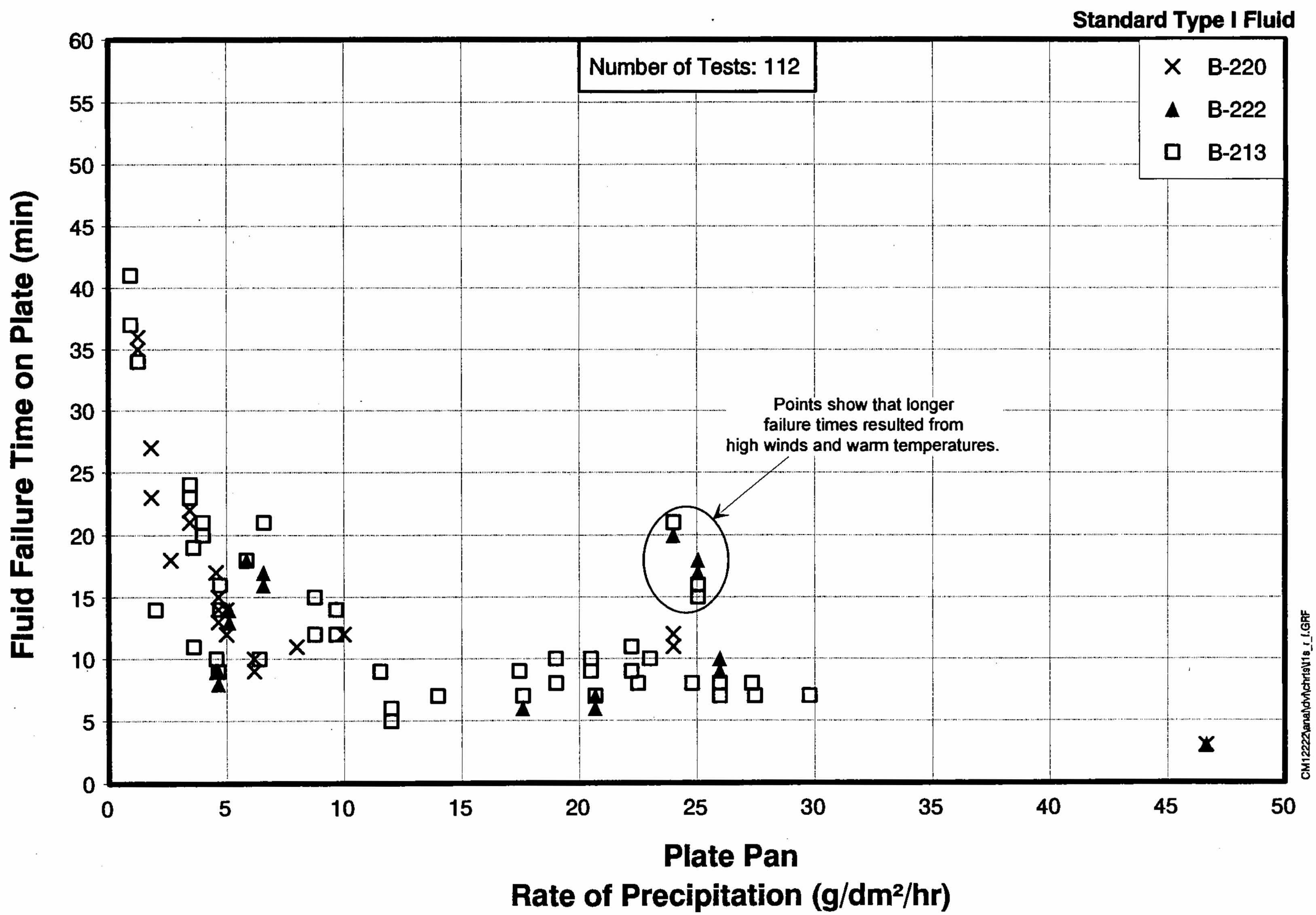


FIGURE 5.2

EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON STANDARD TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

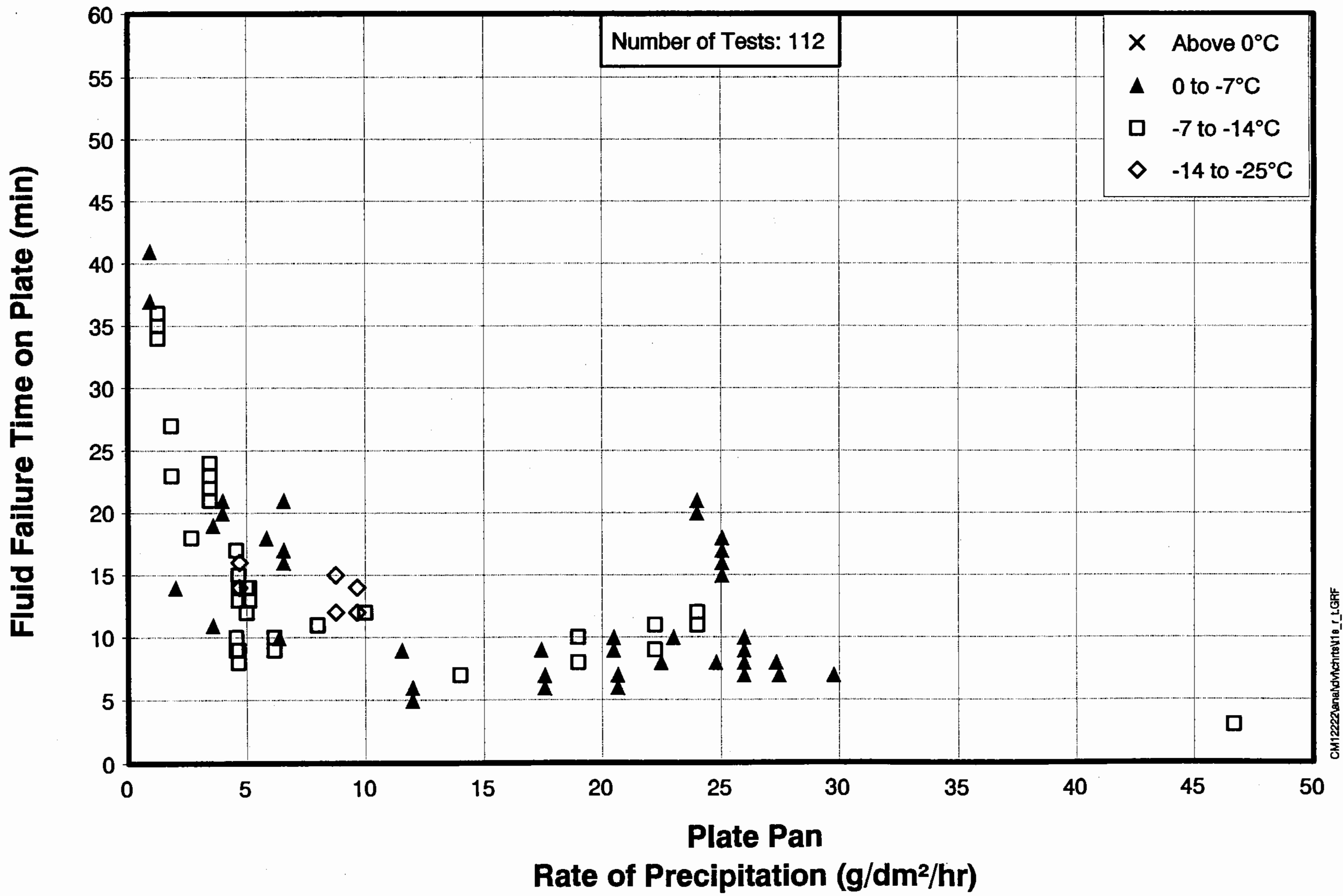
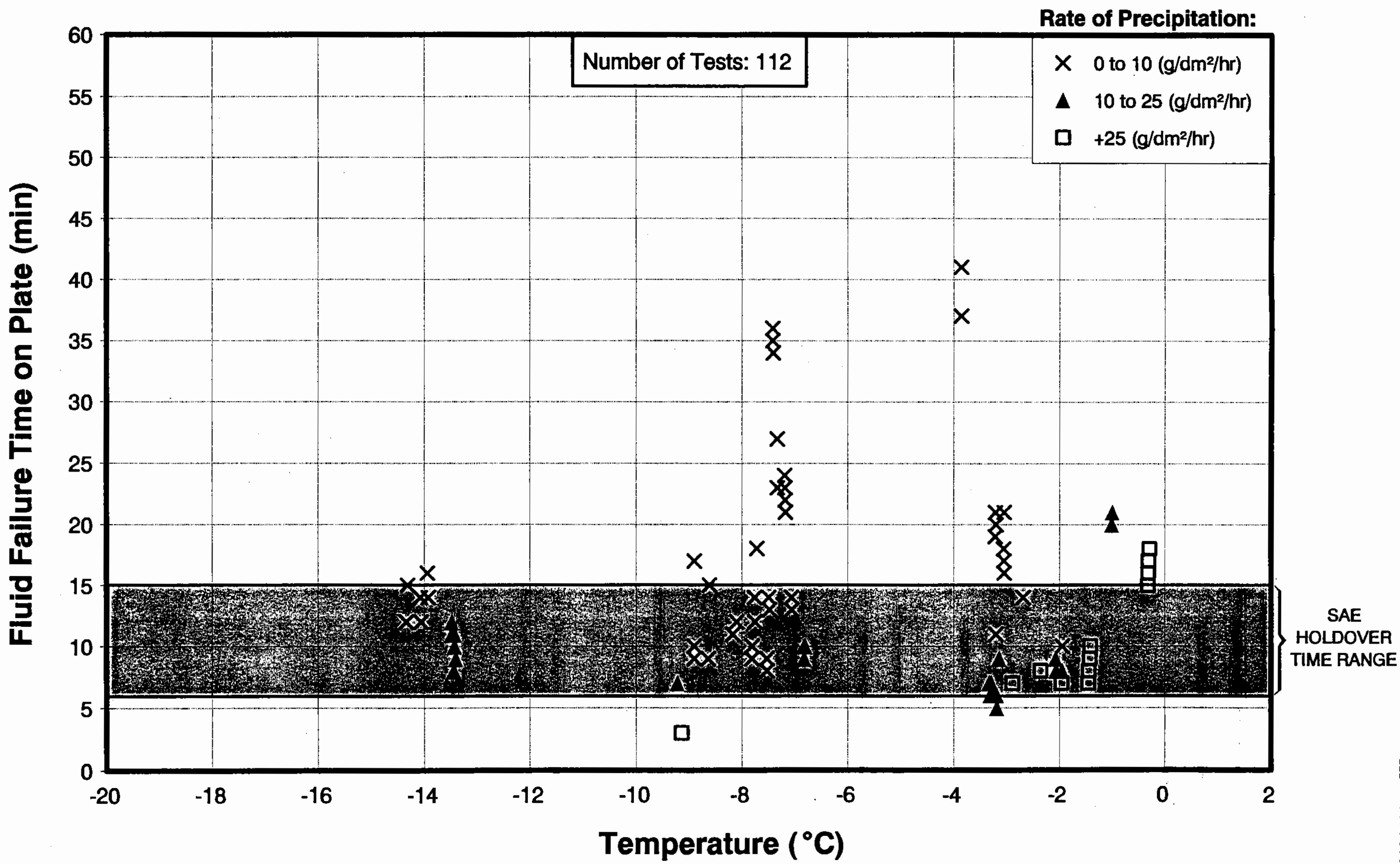


FIGURE 5.3

RESULTS OF STANDARD TYPE I NATURAL SNOW TESTS AS A FUNCTION OF TEMPERATURE AND RATE OF PRECIPITATION



SAE/ISO HOT range of 6 to 15 minutes (see Figure 5.3) for standard Type I fluids under natural snow conditions. Four of the five failing tests occurred at a very high rate (>45 g/dm²/hr) during snow squall conditions; the other occurred at a moderate rate of precipitation and the failure time (5 minutes) was just below the lower limit of 6 minutes.

5.1.1.2 Diluted Type I Fluids under Natural Snow

One objective of this winter's test program was to test the diluted Type I's, diluted in accordance with the Type I holdover time table. This requires that the fluid be diluted such that the freezing point of the glycol/water mix is 10°C below the outside air temperature (OAT), thereby providing a 10°C buffer. The glycol/water mixtures, as a function of OAT, are presented in Table 5.1 for all the tested fluids.

The diluted Type I's behave similarly to the standard Type I's, as indicated by Figure 5.4 which shows a plot of failure time versus rate of precipitation for different diluted Type I's. Comparison with Figure 5.1 shows similar trends; the four diluted Type I points which failed above the rest (at a rate of 25 g/dm²/hr), resulted from tests during high winds and warm temperatures.

TABLE 5.1

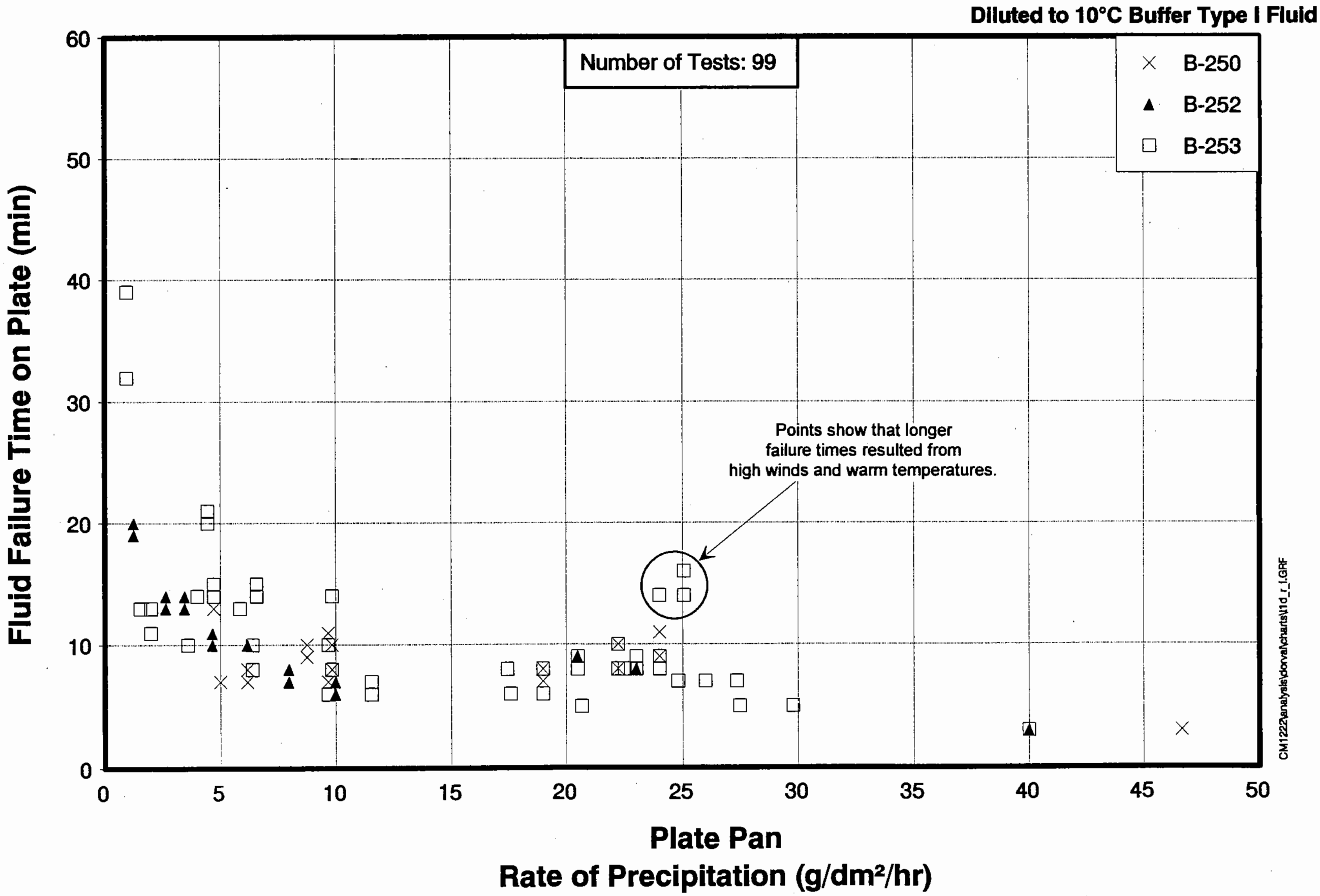
PERCENTAGE OF GLYCOL MIXTURE WITH WATER (%) AS A FUNCTION OF OAT USED FOR DILUTED TYPE I TESTS TO ACHIEVE A 10°C BUFFER

Outside Air Temperature (°C) OAT	Fluid Freeze Point (°C)	B-250 (Dilution) (% Glycol in water mix)	B-251 (Dilution) (% Glycol in water mix)	B252 (Dilution) (% Glycol in water mix)	B-253 (Dilution) (% Glycol in water mix)	B-253 (Brix)
0 °C	-10 °C	28%	28%	31%	23%	14
-2 °C	-12 °C	31%	31%	35%	26%	16
-4 °C	-14 °C	35%	34%	39%	29%	18
-6 °C	-16 °C	37%	37%	42%	31%	19.7
-8 °C	-18 °C	40%	40%	45%	34%	21.2
-10 °C	-20 °C	42%	42%	48%	36%	22.5
-14 °C	-24 °C			50%**		24.8
-15 °C	-25 °C	47%	48%	53%	41%	25.5
-20 °C	-30 °C	52%	52%	58%	46%	27.9
-25 °C	-35 °C	56%	57%	63%	50%	30
-30 °C	-40 °C	60%	TBD	67%	54%	32
-33 °C	-43 °C		TBD		57%**	33
-35 °C	-45 °C	63%**	63%**			33.7

** Standard mixture recommended by manufacturer.

FIGURE 5.4

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON DILUTED (10°C BUFFER) TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS



The bar chart in Figure 5.5 shows a comparison of the average failure times of diluted Type I and standard Type I as a function of OAT. Each set of bars represents the average failure time during one test. It can be seen that the standard Type I is generally superior to the diluted Type I, but only by a small margin. This indicates that rate of precipitation has a greater effect than temperature in that the precipitation quickly dilutes the fluid thereby raising its freeze point. The large difference between the standard and diluted set of bars in Figure 5.5 at -7°C resulted from a significant decrease in the precipitation rate at the end of the test.

Figure 5.6 shows a plot of the diluted Type I failure times as a function of OAT and rate of precipitation. Note that one of the objectives was to acquire test data at very cold temperatures, however the conditions did not permit this to happen. Based on the tests shown in Figure 5.6, it can be seen that the variation of failure time with temperature is negligible compared to its variation with rate of precipitation. All the points fall within or above the SAE/ISO HOT range, with the exception of eleven points which fall below the range; two points were just below (5 minutes) the lower limit of 6 minutes, and nine tests involved extreme weather conditions. The ***caution*** note in the HOT table of the Aerospace Recommended Practice ARP 4737 indicates that the HOT's will be shortened in heavy weather conditions. Based on the above, the HOT range for Type I fluids is substantiated, provided the weather conditions are not heavy.

FIGURE 5.5

COMPARISON OF AVERAGE FAILURE TIME BETWEEN STANDARD TYPE I AND DILUTED TYPE I FLUIDS TESTED AT THE SAME TIME ON THE SAME STAND DURING NATURAL SNOW CONDITIONS

1994/1995

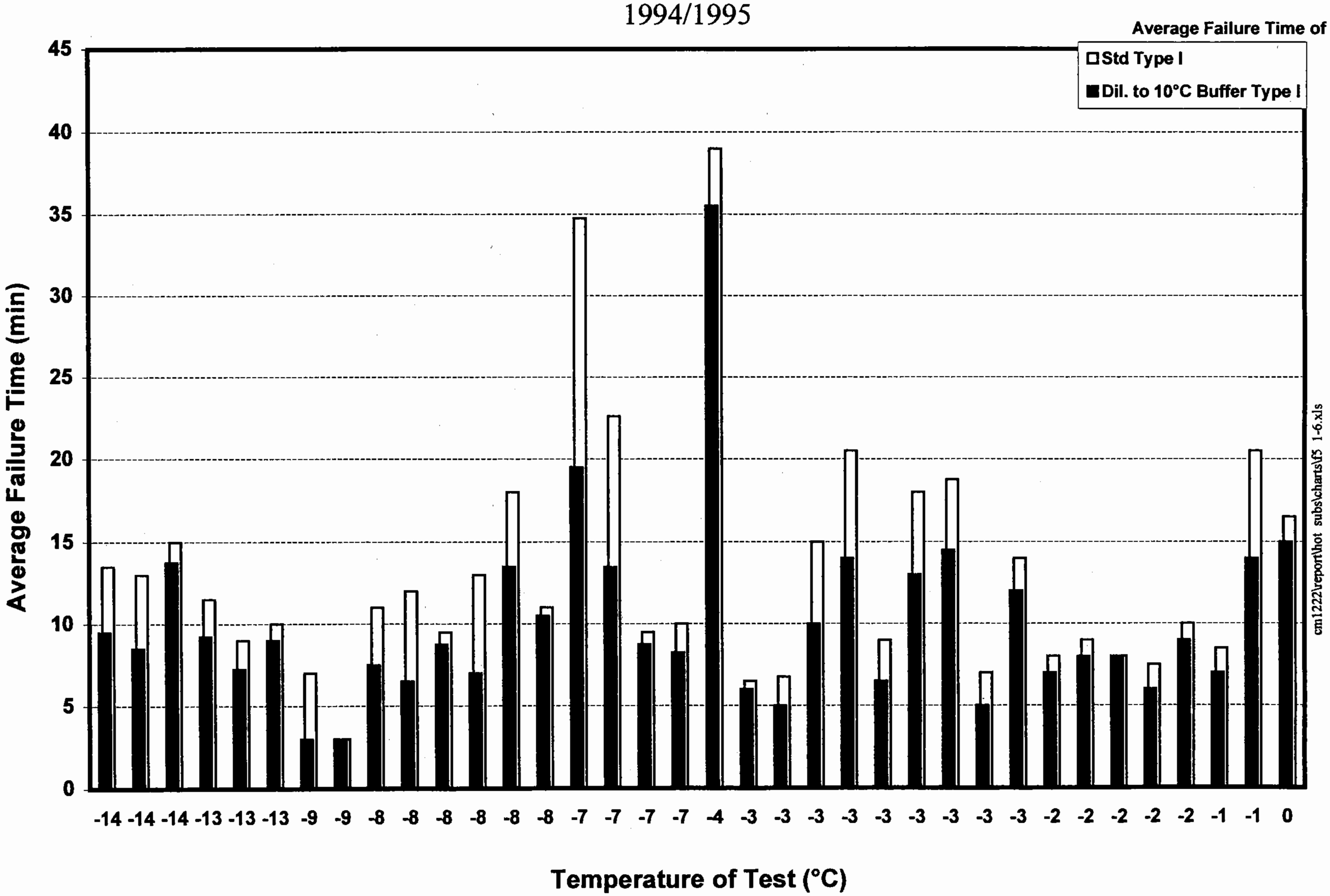
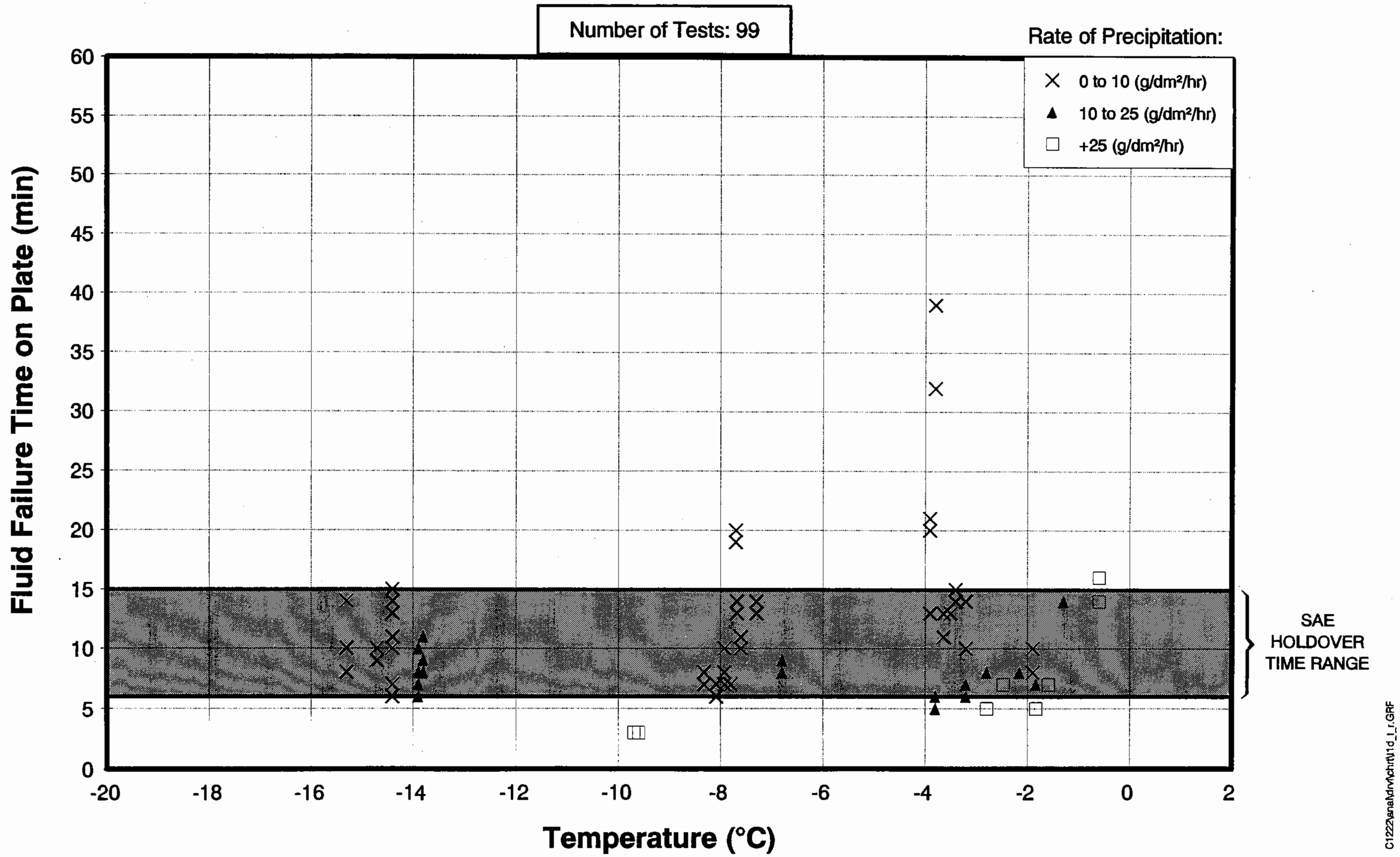


FIGURE 5.6

RESULTS OF DILUTED TYPE I NATURAL SNOW TESTS AS A FUNCTION OF TEMPERATURE AND RATE OF PRECIPITATION

1994 - 1995



5.1.1.3 Type II Neat Fluids under Natural Snow

One of the objectives of this year's test program was to test new long life Type II fluids (UCAR Ultra) and compare them to other Type II fluids. Figure 5.7 shows a plot of failure time versus rate of precipitation for regular Type II Neat fluids as well as the new UCAR Ultra Neat. The chart clearly indicates that Ultra is a superior fluid to regular Type II Neat fluids and that rate of precipitation has a strong influence on fluid failure time.

A second objective of this year's test program was to try to conduct as many Neat Type I and Type II tests as possible at the colder temperatures. Figure 5.8 shows the results of the Type II Neat plate failure times as a function of temperature and fluid type. Also shown on the chart is the current SAE/ISO HOT range as a function of temperature. Tests during cold temperatures occurred on only a few occasions during the 1994/95 winter. Furthermore, the chart shows that the current 1994/95 data supports the previous year conclusions which stated that the SAE/ISO HOT range was substantiated for all temperatures ranges. Table 5.2 shows a summary of the tests which were conducted by APS with Ultra and other Type II's on the same stand at the same time. The right hand side of the table shows if these tests have sensors available. In the case where these were available, the read-outs of the sensor outputs were plotted. Figure 5.9 shows a bar chart comparison of the average failure time of Ultra Neat and the other Type II fluids tested at the same time on the same stand. The average Ultra fluid rate of precipitation during the test is shown on the horizontal scale. The

FIGURE 5.7
EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II NEAT FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

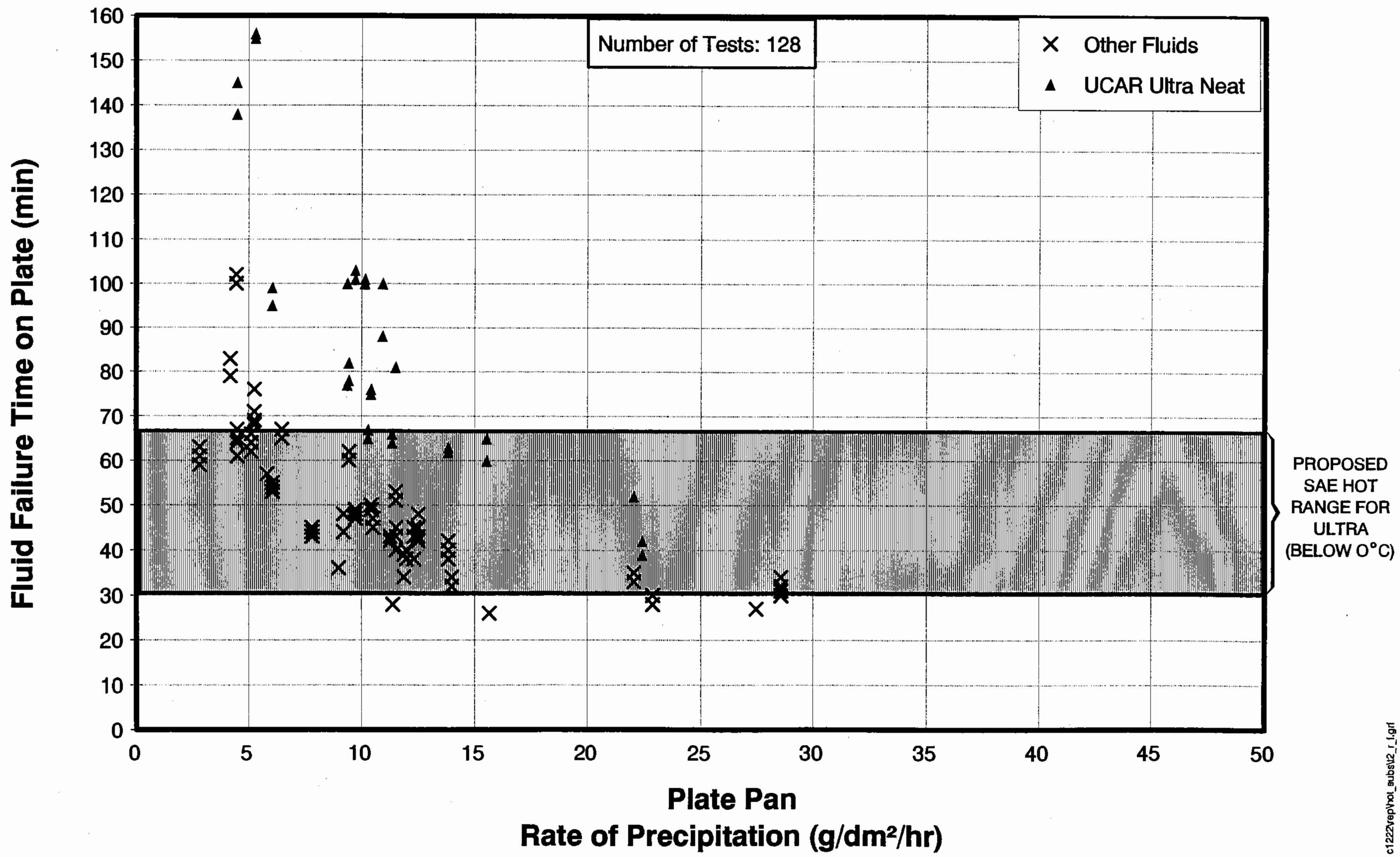


FIGURE 5.8

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II NEAT FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

1994 - 1995

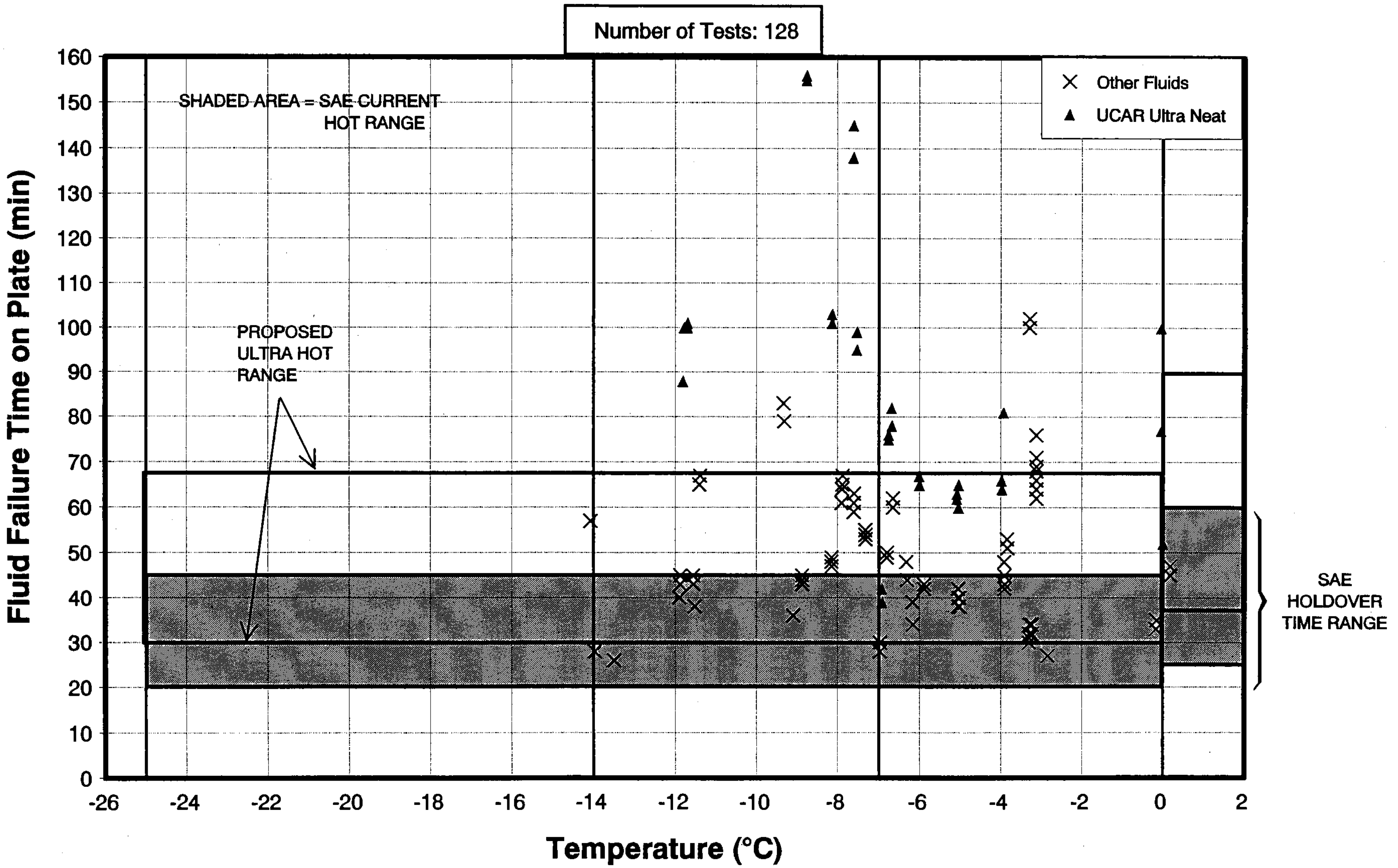


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TABLE 5.2

Summary of Ultra Comparison Tests

Ultra vs Other Type II

Run #	Ultra Avg Fail (min)	Other Avg Fail (min)	Precipitation Rates: ULTRA RATE READAC Rate ($g/dm^2/h$)	ULTRA RATE Pan Rate ($g/dm^2/h$)	OTHER TYPE II RATE READAC Rate ($g/dm^2/h$)	OTHER TYPE II RATE Pan Rate ($g/dm^2/h$)	Avg Temp (°C)	Avg Wind (kph)	Failure Time *RATIO (Ultra/Other TII's)*	*AVAILABILITY* RVSI	Ultra w/CFIMS	Other TII w/C
42	142	64	n/a	4	4	4	-8	14	2.2	y	n/a	y2
48	76	50	n/a	10	n/a	10	-7	16	1.5	y	n/a	y2
50	97	54	n/a	6	n/a	6	-7	20	1.8	y	n/a	y2
54	102	48	n/a	10	n/a	10	-8	21	2.1	y	n/a	y2
57*	108	62	n/a	3	n/a	3	-8	9	1.8	n/a	n/a	n/a
59	156	44	5	5	6	8	-9	9	3.6	n/a	n/a	n/a
62*	108	81	3	4	3	4	-9	10	1.3	y	n/a	n/a
64*	99	36	6	4	10	9	-9	5	2.8	y	n/a	n/a
71	52	34	20	22	22	22	0	14	1.6	n/a	n/a	n/a
77	94	43	10	11	11	12	-12	11	2.2	n/a	n/a	n/a
79	101	41	10	10	9	12	-12	13	2.5	n/a	n/a	y
81*	190	66	4	4	9	6	-11	13	2.9	n/a	n/a	n/a
86	41	29	26	22	22	23	-7	14	1.4	n/a	y	n/a
93	81	53	12	12	14	12	-4	10	1.5	n/a	n/a	n/a
94	65	45	11	11	12	13	-4	10	1.5	n/a	y	y
96	63	39	12	16	10	12	-5	13	1.6	n/a	n/a	n/a
97	63	40	13	14	11	14	-5	13	1.6	n/a	n/a	n/a
98	66	43	12	10	12	11	-6	14	1.6	n/a	n/a	n/a
101	80	61	9	9	10	9	-7	11	1.3	n/a	y	y

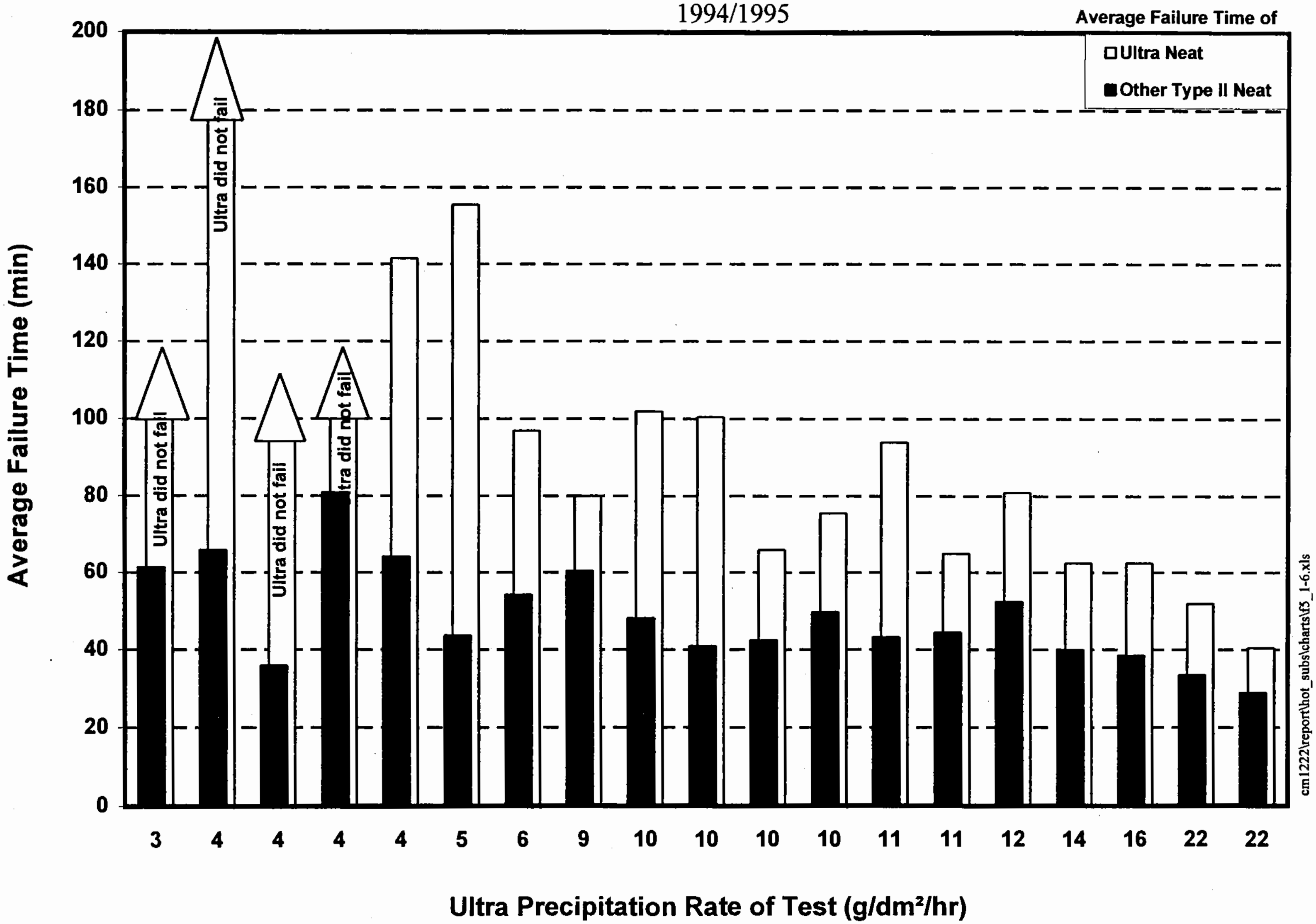
*Ultra did not fail. For these tests, the failure time given for Ultra is computed by subtracting the start time from the time the test was ended. This often occured when the precipitation stopped.

cm1222\analysis\dorval\charts\RATIOT2.XLS
Observed Data, 06/02/96

FIGURE 5.9

COMPARISON OF AVERAGE FAILURE TIME BETWEEN ULTRA NEAT TYPE II AND OTHER NEAT TYPE II FLUIDS TESTED AT THE SAME TIME ON THE SAME STAND DURING NATURAL SNOW CONDITIONS

1994/1995



ratio of the average failure time of Ultra divided by the other Type II's is shown in Figure 5.10. It was observed from the test data that Ultra Neat is usually more than 50% better than the other Neat Type II fluids. It can also be seen that the performance of Ultra, when compared to other Type II's, generally diminishes as the rate of precipitation increases. Only three points fall below the ratio of 1.5 (i.e. at 9.5, 11.4, 22.4 g/dm^2/hr). If, however, the current HOT range (20 to 45 minutes) is multiplied by 1.5 for Ultra Neat, the resulting HOT's[1] would range from 30 to 67 minutes (see Figure 5.8). These three points, with HOT's of 80, 65 and 40 minutes, will still fall within or above the new proposed range.

Some data were also obtained by NCAR in order to establish new HOT's for the new Type II fluids; these data are shown in Appendix E, where the failure time ratios are illustrated in a bar chart. The NCAR data imply that a ratio of 2.0 is more suitable for Ultra. Figure 5.11 shows a plot of failure times of Ultra and regular Type II's versus rate of precipitation for the NCAR and APS data combined.

Also shown on the chart are best fit curves - note that the circled points were removed from the determination of the best fit curves since they are outliers. The following observations could be made.

1 A factor of 1.5 on the current Type II HOT's has been proposed by the SAE G-12 Committee to be used for the 1995/96 winter. This factor is to be used during snow conditions for the Neat concentration on the new Type II (Type IV) fluids with WSETs >80 minutes.

FIGURE 5.10

COMPARISON OF AVERAGE FAILURE TIME BETWEEN ULTRA AND OTHER NEAT TYPE II FOR TESTS CONDUCTED AT THE SAME TIME ON THE SAME STAND DURING NATURAL SNOW CONDITIONS

1994/1995

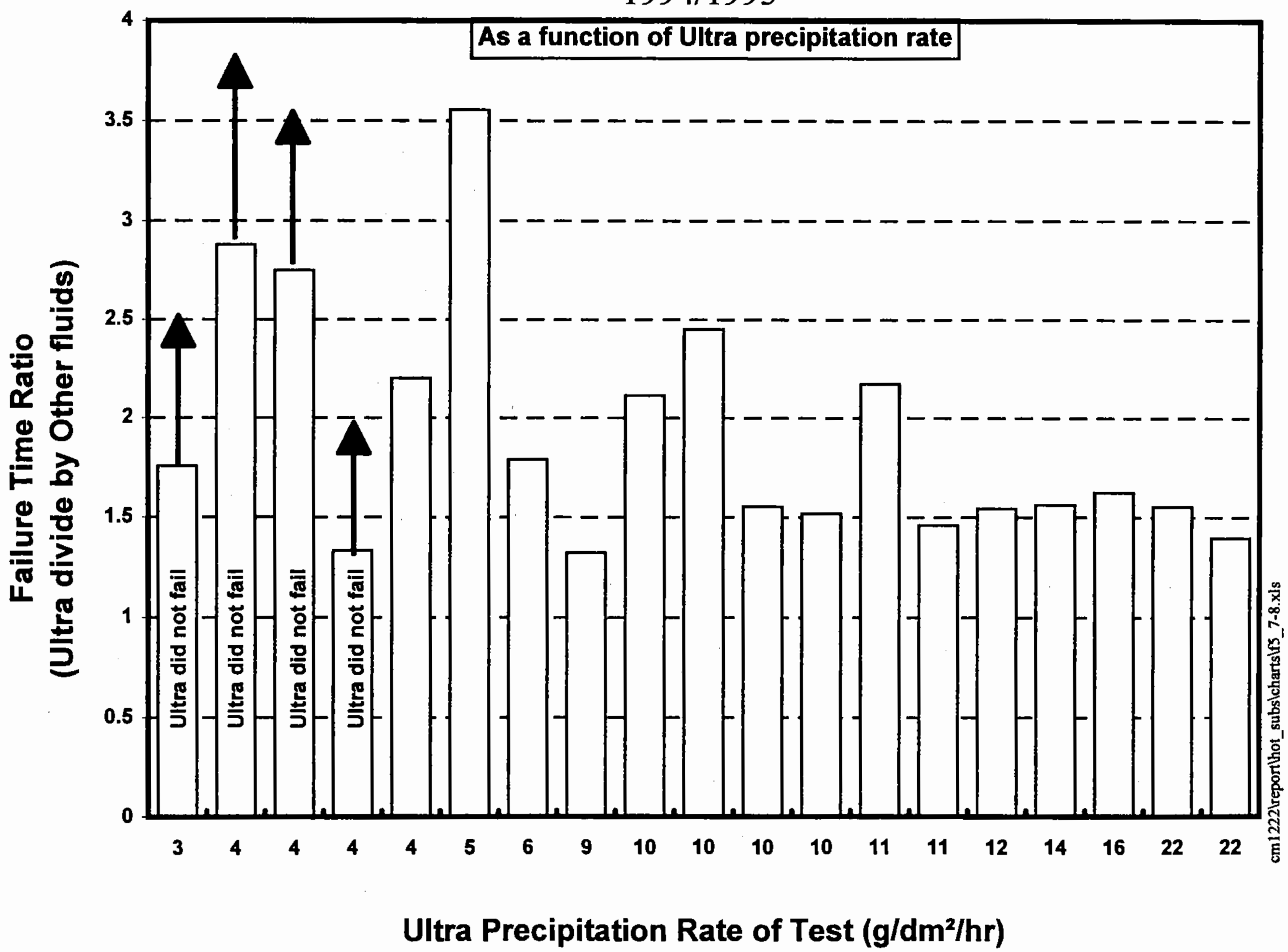
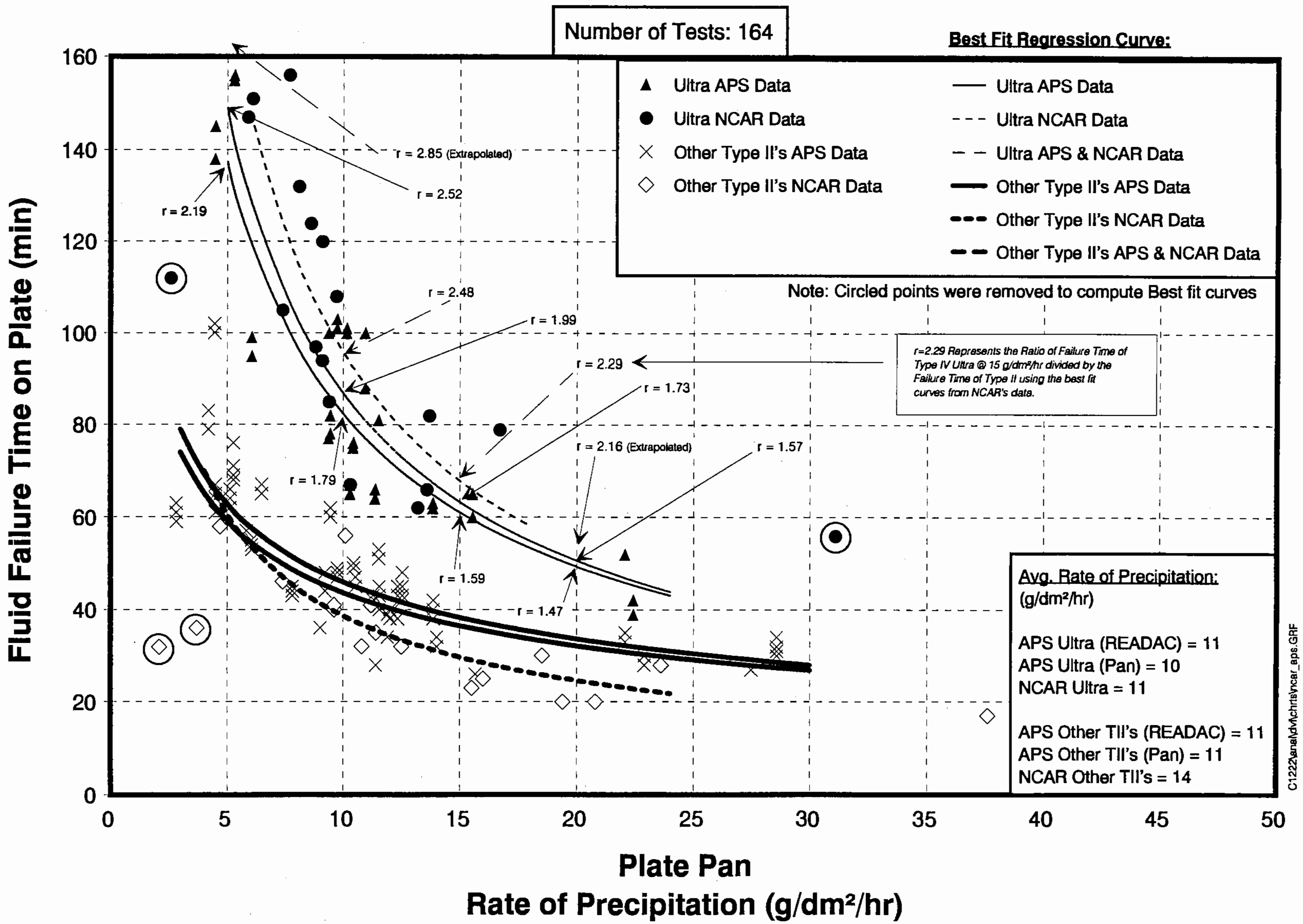


FIGURE 5.11

COMPARISON OF ULTRA TYPE II NEAT AND OTHER TYPE II NEAT FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS NCAR AND APS DATA COMBINED



i) In general, the APS and NCAR Ultra points appear to follow similar trends. A few NCAR points may be higher since many of the temperatures during their tests were above freezing.

ii) The average rate of precipitation of NCAR's other Type II tests was 14 $g/dm^2/hr$, and for Ultra it was 11 $g/dm^2/hr$. This is one explanation for NCAR's higher ratios.

iii) There is a greater difference between the APS and NCAR other Type II points.

iv) Based on NCAR video records, it appears that the failure calls by NCAR are somewhat earlier then those by APS. The end condition definition given in Section 2, is:

A visible accumulation of snow resting or bridging on top of the fluid on 5 of 15 crosshairs, or

Ice has formed on 5 crosshairs. This is typically referred to as "loss of gloss", and is usually applicable during other freezing precipitation.

NCAR in the video often refers to the occurrence of "slush" and "plate failure" as if they were the same. Based upon the definition, the failure call by NCAR appears premature.

v) It can be argued that a similar and consistent failure call (other than Type II compared to Ultra) is more important than the absolute time. Figure 5.12 shows that, on average (from APS' tests) the failure time ratio of Ultra over other Type II's is higher for failures at the 1" (2.5 cm) line in comparison to failures at the 6" (15 cm) line. Therefore, premature failure calls will likely have a tendency to result in higher ratios. This is further explained by Figure 5.13 which shows profiles of fluid thickness on a 10° flat plate. These profiles were determined using a painter's thickness gauge and demonstrate that the thickness ratio of Ultra compared to a standard Type II at the 1" (2.5 cm) line is greater than at the 6" (15 cm) line - hence premature calls will result in higher time ratios.

Based upon the observations above, the lower, more conservative ratio of 1.5 should be applied for the 1995/96 winter season.

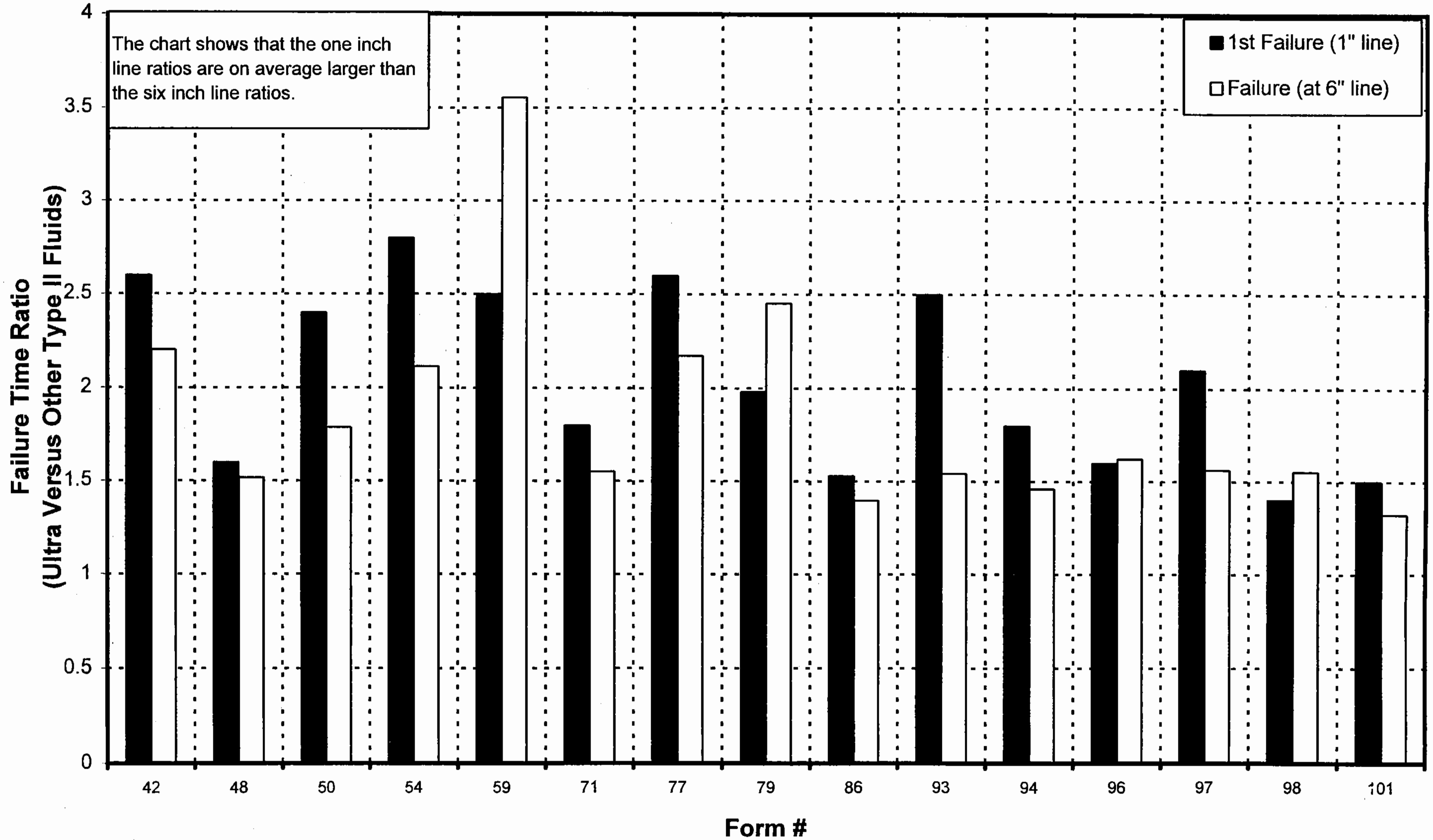
To further support this recommendation, Figure 5.11 shows that:

- the NCAR and APS best fit Ultra curves have a tendency to approach a value of 30 minutes as rates increase above 25 $g/dm^2/hr$; and
- the ratio of failure time appears to decrease with increasing precipitation rate.

FIGURE 5.12

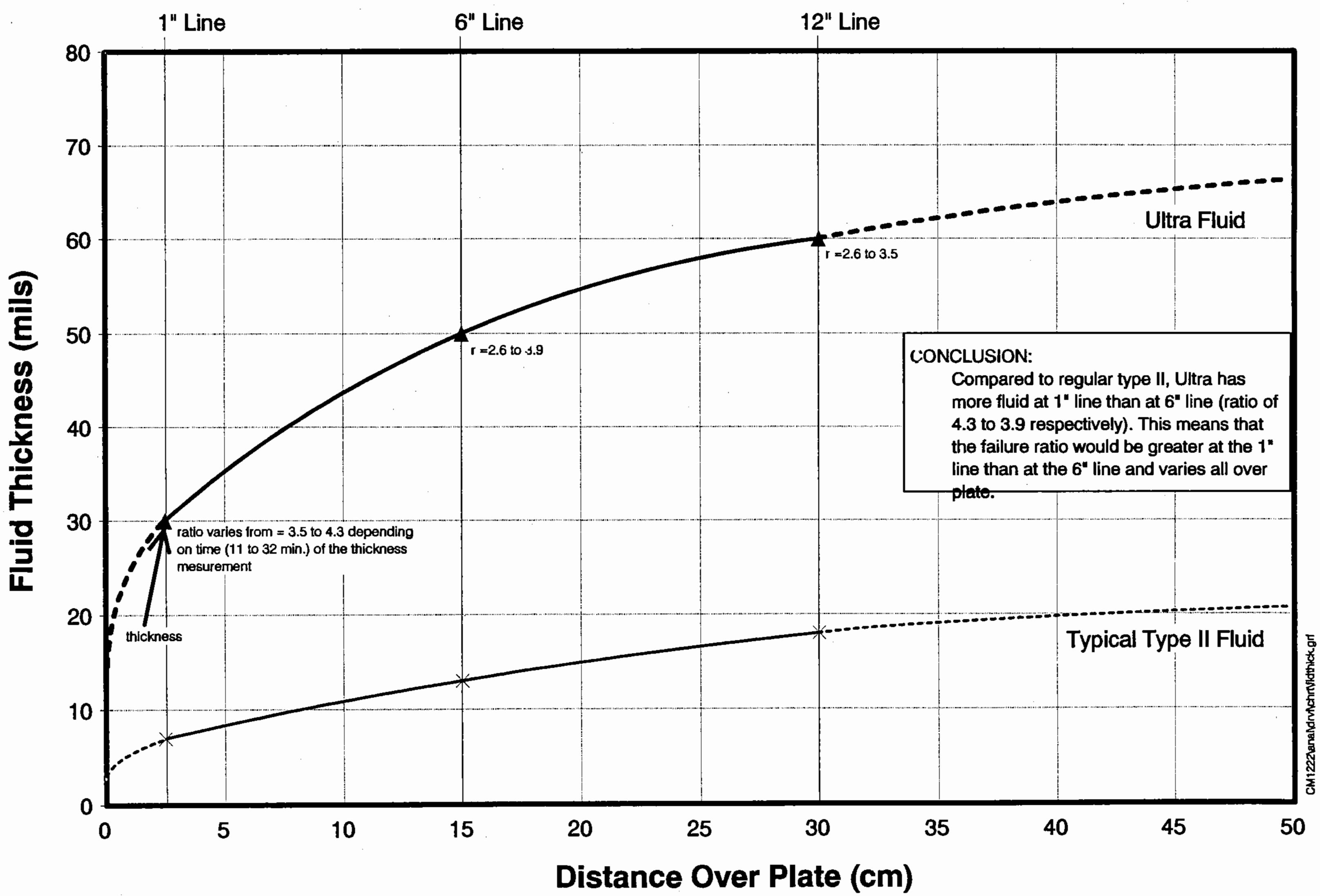
ULTRA VERSUS TYPE II FAILURE TIME RATIOS DURING NATURAL SNOW CONDITIONS

1994/1995



cm1222\analysis\dorval\charts\ratiot2.xls, 1st & 6" Line Fai
04/06/96

FIGURE 5.13
ULTRA AND TYPE II NEAT FLUID THICKNESS PROFILES AT 30 MINUTES INTO THE TEST



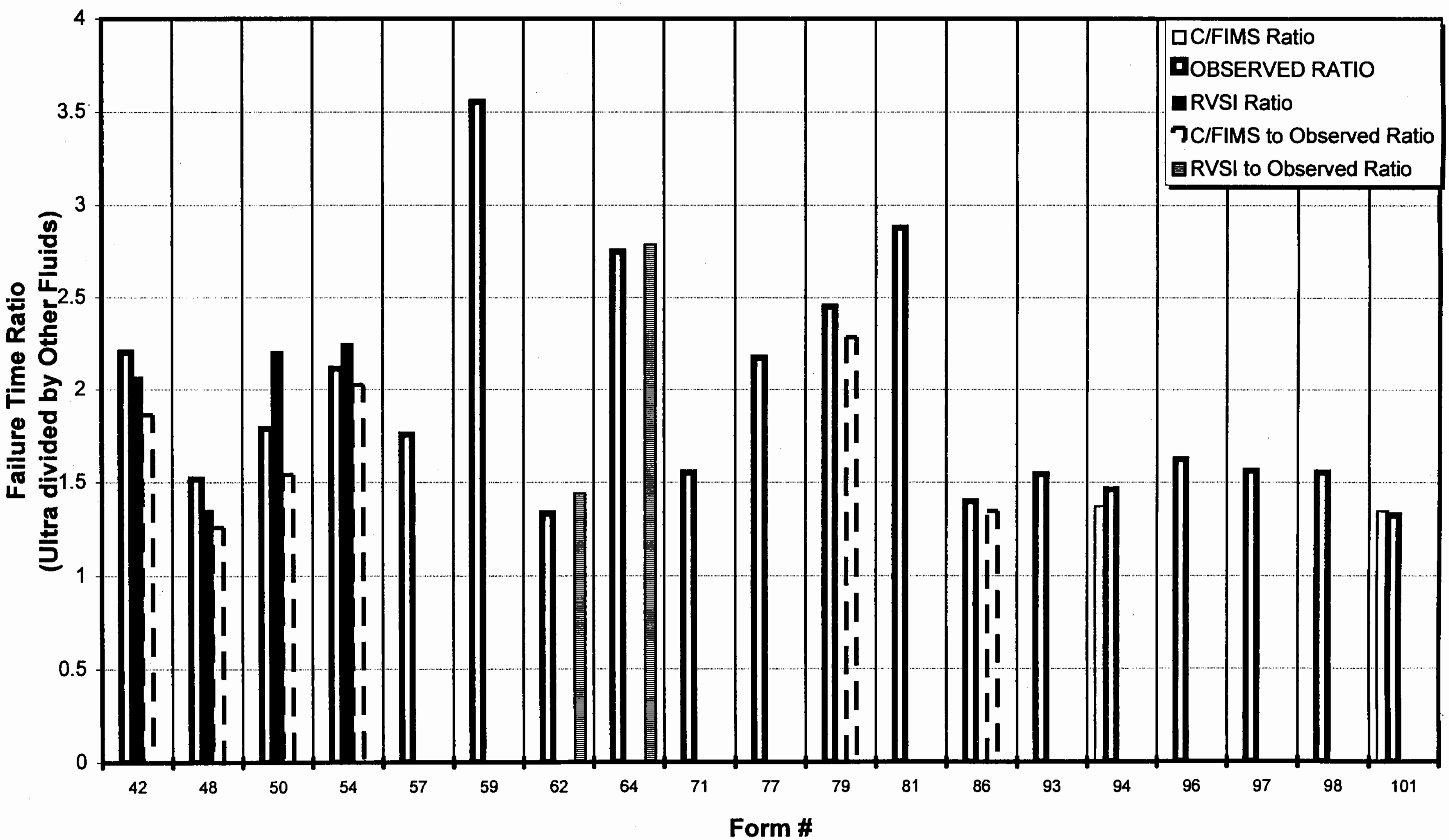
When available, the sensor data was plotted and compared to the observer failure calls (see Table 5.2). Figure 5.14 shows the ratio of the failure times between Ultra Neat and other Type II fluids for 19 test sessions (by Form #). Five modes of display are presented. The first bar (on the left side) was computed by taking the failure times from the C/FIMS; the second bar was computed from the human observer calls of failure; the third bar used data from the RVSI sensor to establish failure; the fourth bar used data from the C/FIMS for one failure time and the human observer call for the other failure time; and the fifth bar used data from the RVSI for one failure time and the human observer call for the second failure time.

The chart shows that, when sensors were available, the ratios obtained with the instruments were not significantly different from the observer ratios. For example, Figure 5.15 shows the RVSI ID-1 sensor traces (Form 48) for two Ultra plates and two other Type II plates. The chart shows that depending on the degree of contamination (RHO value), the ratio of Ultra over other Type II failure time varies from about 1.6 to 1.4. This supports the APS conclusions.

FIGURE 5.14

RATIO OF C/FIMS AND ID-1 SENSOR FAILURE TIME BETWEEN ULTRA NEAT TYPE II AND OTHER TYPE II FLUIDS DURING NATURAL SNOW CONDITIONS

1994/1995



Sensor Ratio, 28/05/96
cm1222\analysis\dorval\charts\ratiot2.xls

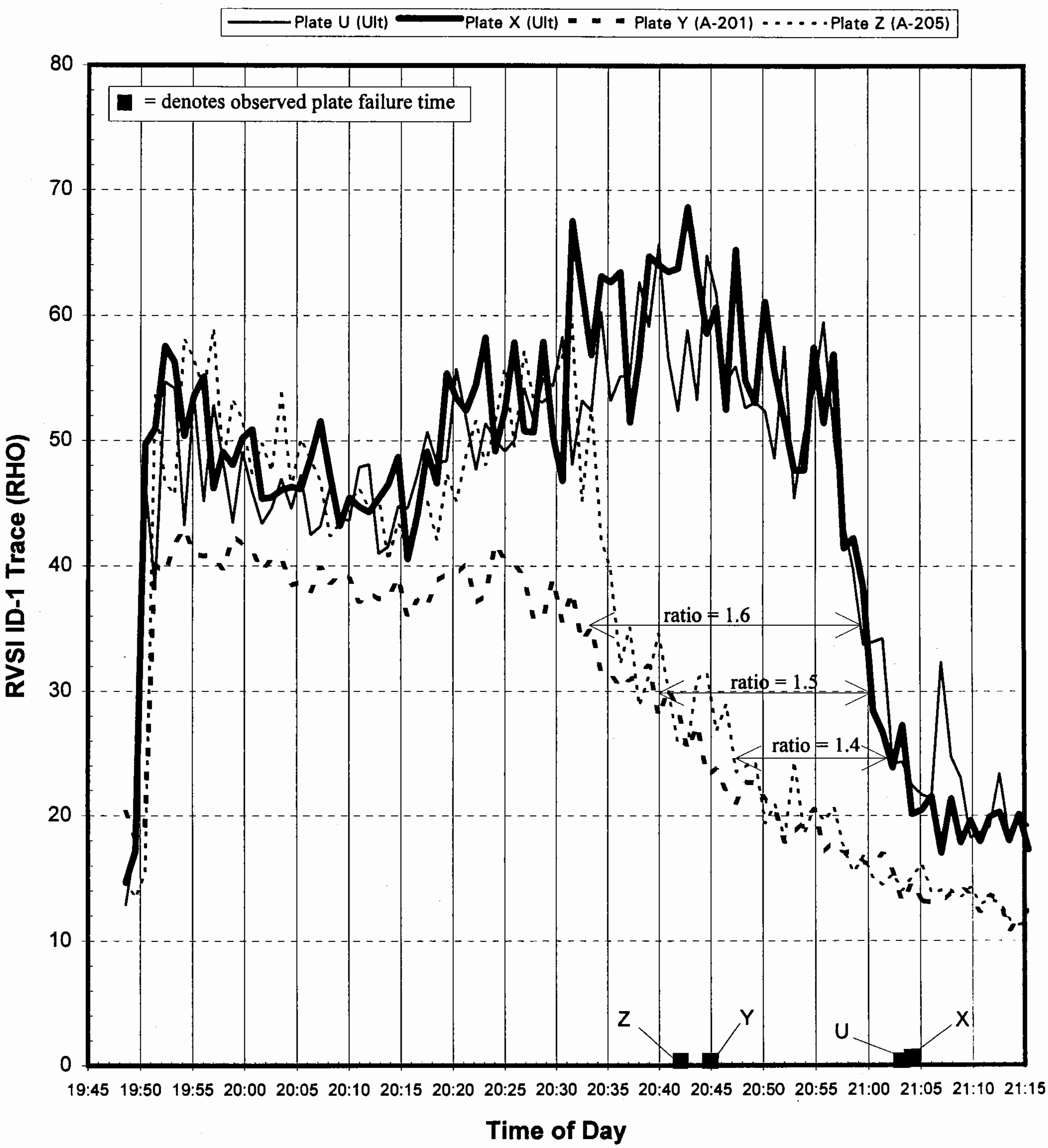
FIGURE 5.15

NATURAL SNOW

RVSI ID-1 SENSOR TRACE

Type II Neat

Feb. 04, 1995



C1222\anal\drvl\cfimd1\FB04F48.XLS

RVSI ID-1 (all plt)

5.1.1.4 Type II 75/25 Fluids under Natural Snow

A total of 58 tests were carried out for Type II 75/25 fluids during the 1994/95 winter. Figure 5.16 shows the failure times versus rate of precipitation of regular Type II 75/25 for both the 1993/94 and 1994/95 winter season and UCAR Ultra 75/25 for the 1994/95 season. It was observed that Ultra 75/25 is only slightly superior to other Type II 75/25 fluids at low and moderate rates of precipitation. No tests were carried out at higher rates due to lack of natural precipitation and priority given to Type I and Neat Type II fluids. The present data does not justify the introduction of a time factor for Ultra 75/25 in comparison to conventional Type II 75/25's. The 1994/95 data does support the previous winter data which showed that the SAE/ISO HOT's were substantiated. Figure 5.17 is shown here for record purposes and provides the results of this winter's testing as a function of temperature.

FIGURE 5.16

COMPARISON OF ULTRA TYPE II 75/25 AND OTHER TYPE II 75/25 FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

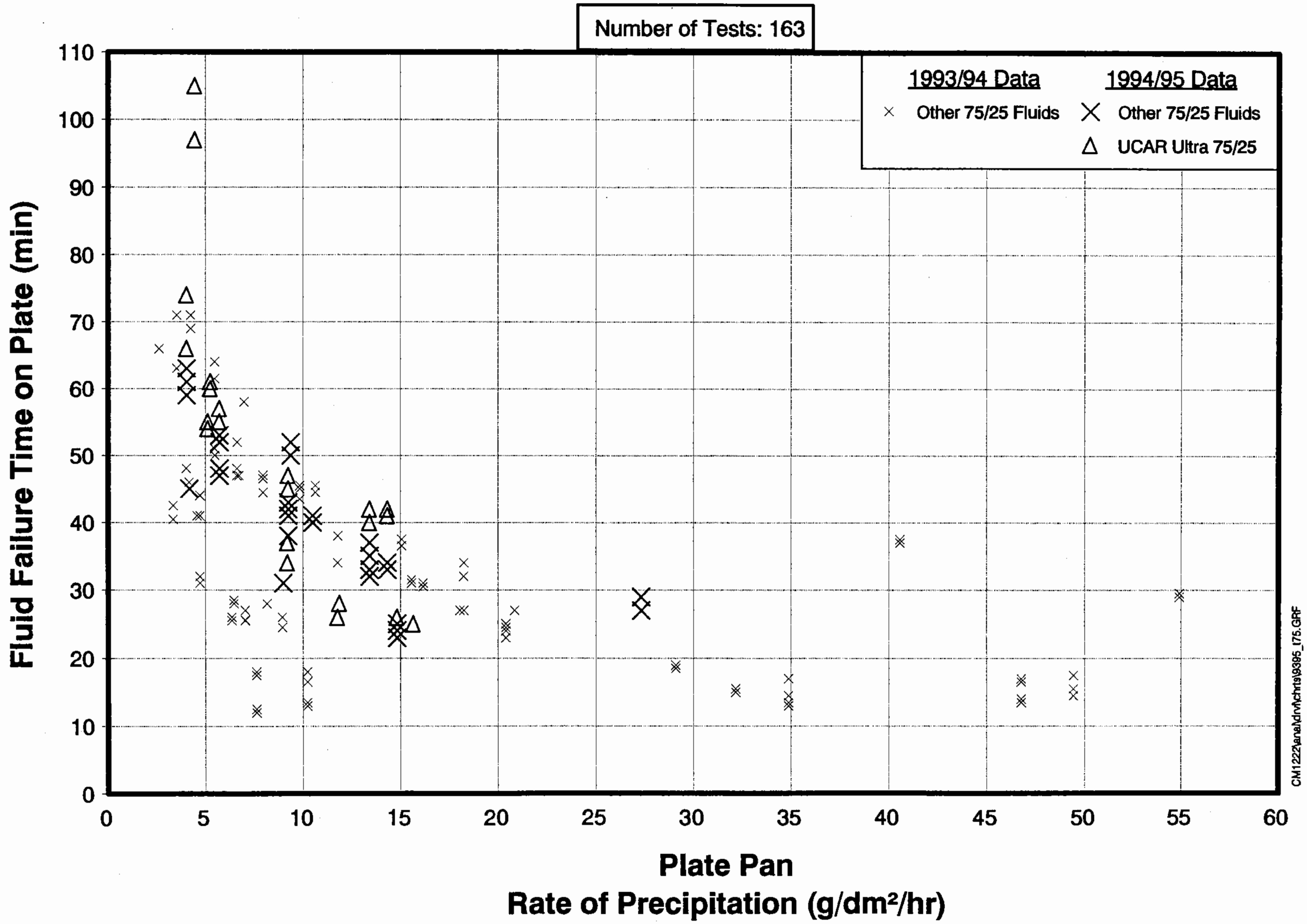
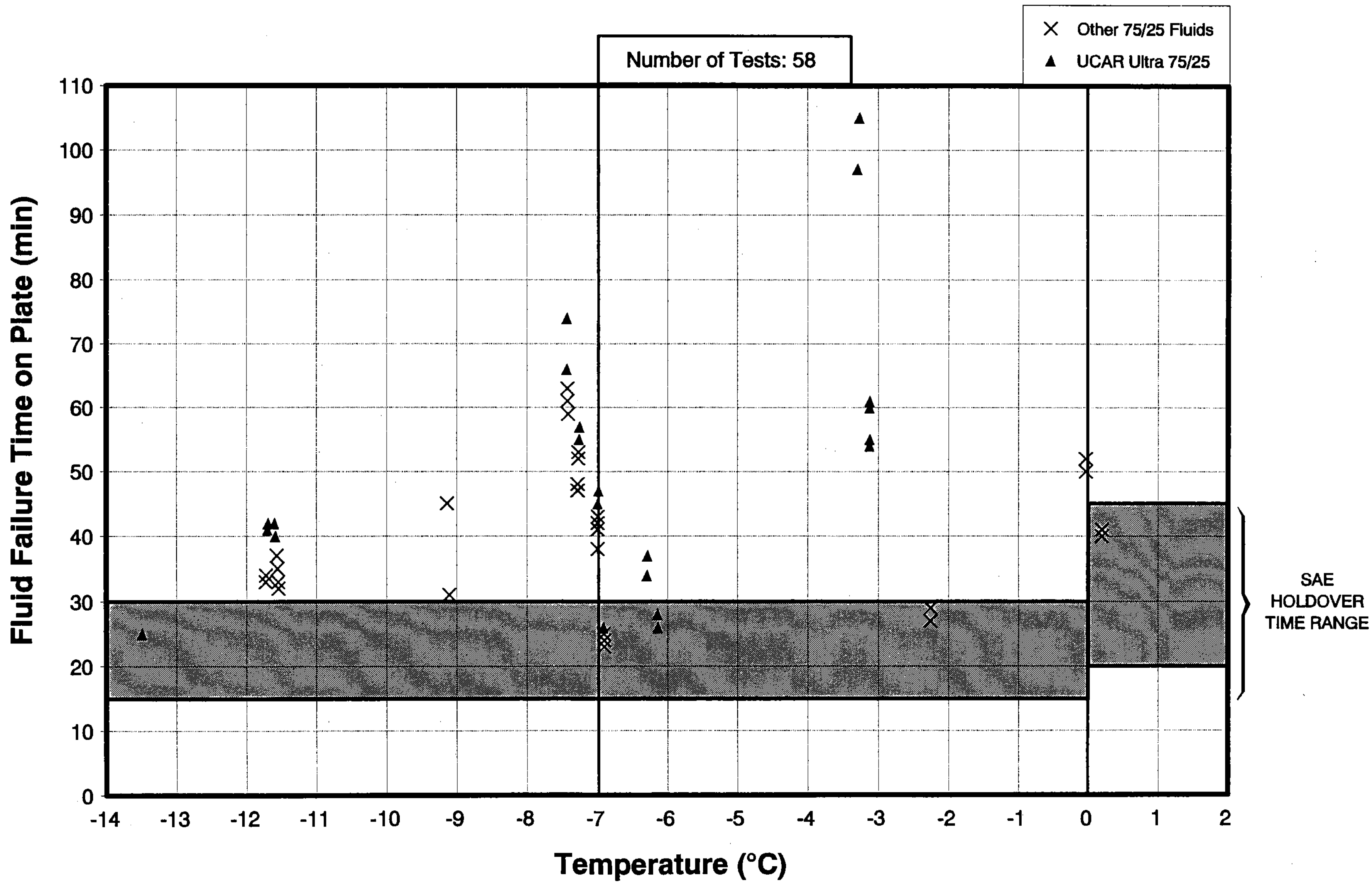


FIGURE 5.17

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II 75/25 FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

1994 - 1995



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5.1.1.5 Type II 50/50 Fluids under Natural Snow

A total of 28 tests were conducted for Type II 50/50 fluids during the 1994/95 winter. These tests were mostly done to compare Type II Ultra 50/50 to other Type II 50/50 fluids. Figure 5.18 shows the failure time versus the rate of precipitation for this winter's Type II 50/50 tests with last year's regular Type II 50/50 tests. The tests show that the Type II 50/50 from both years behave similarly and the points still fall within the SAE/ISO HOT range. The tests did not show any improvement of the UCAR Ultra Type II 50/50 over the conventional Type II 50/50 points, and as a result a time factor was not introduced for Ultra Type II 50/50. Figure 5.19 is shown for record purposes and provides the results of this winter's testing as a function of temperature.

FIGURE 5.18
COMPARISON OF ULTRA TYPE II 50/50 AND OTHER TYPE II 50/50 FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

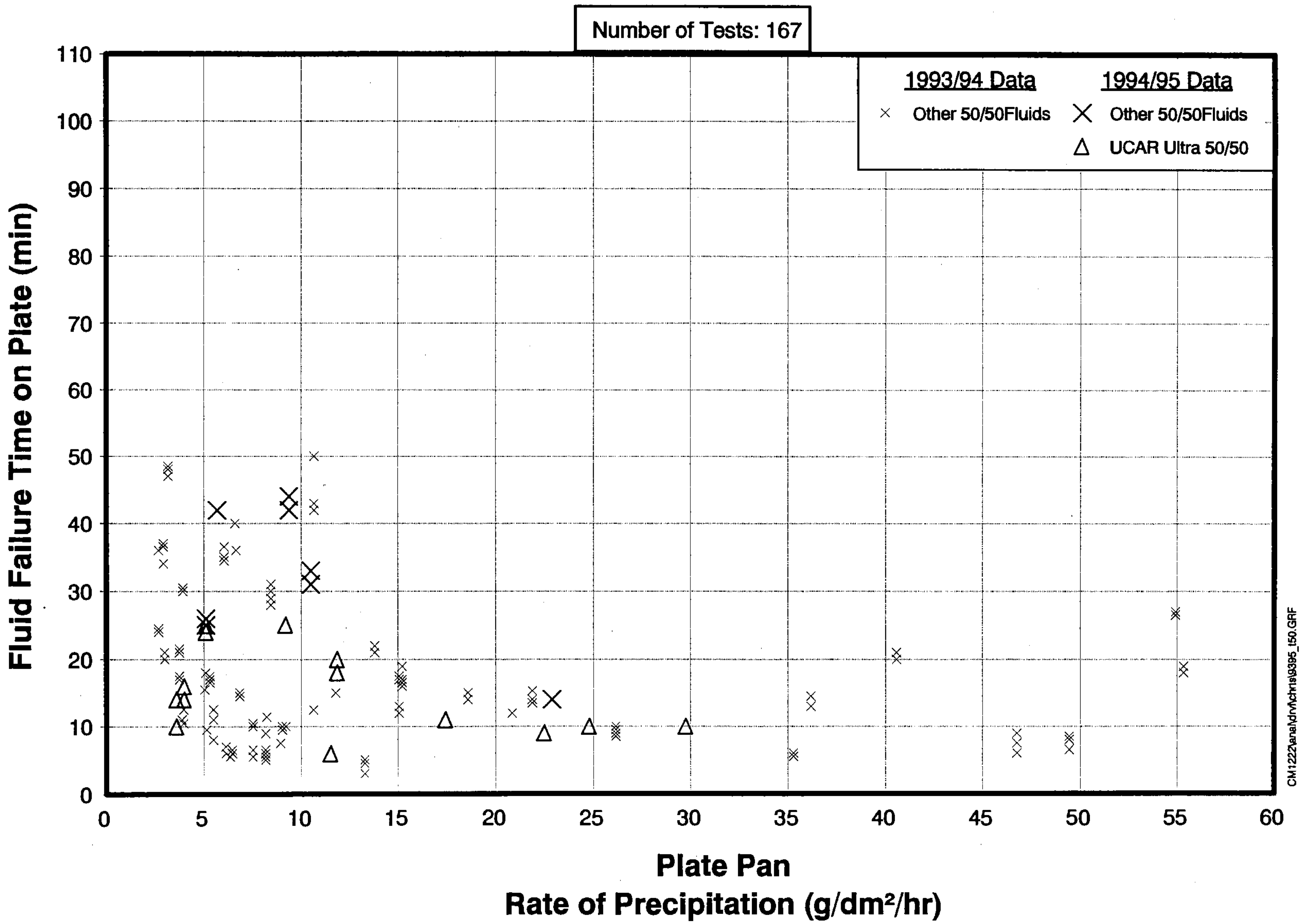
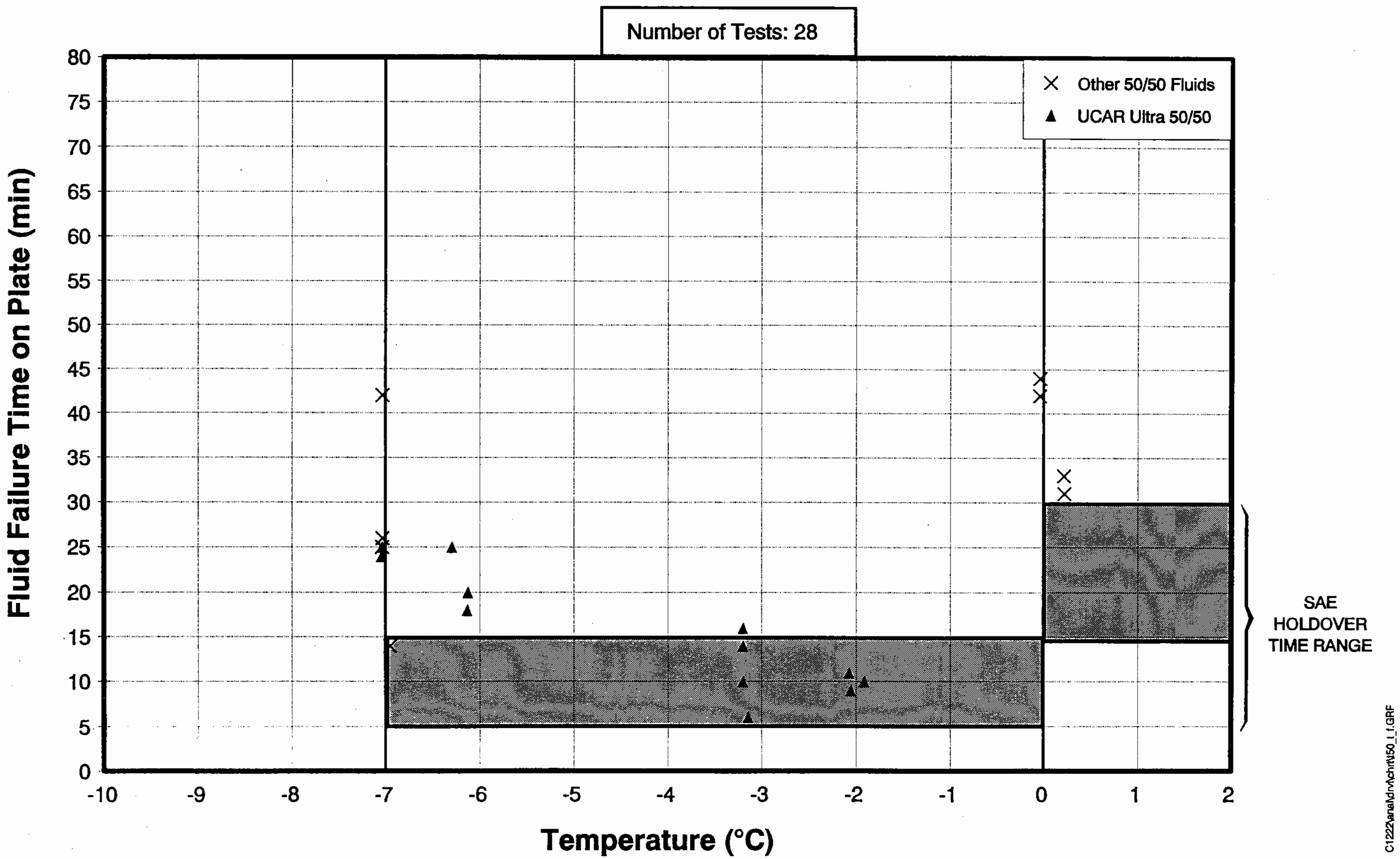


FIGURE 5.19

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II 50/50 FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

1994 - 1995



5.1.2 Simulated Freezing Drizzle and Light Freezing Rain

Simulated freezing drizzle and light freezing rain experiments were carried out at NRC's Climatic Engineering Facility (CEF) at Ottawa. Past experience at APS and NRC helped set the parameters for the precipitation as defined in Section 2.3: rates for freezing drizzle ranged from 2 to 13 $g/dm^2/hr$ with a mean droplet diameter of 600 μm, whereas for light freezing rain, the rates ranged from 13 to 25 $g/dm^2/hr$ and the mean droplet diameter was 1500 μm. This year's data is systematically presented with last year's since both sets were produced according to the same parameters.

The appearance of the plates during the time of failure under both freezing drizzle (FZD) and light freezing rain (LFZR) was observed to be as described below. In all test cases under both FZD and LFZR, the condition of the fluid on the plate goes through the following phases:

- Phase I: glossy fluid; to
- Phase II: loss of gloss - opaque/dull slushy surface; to
- Phase III: a clear ice surface.

APS reports failure at the onset of the loss of gloss (Phase II).

<u>For Type I fluid tests</u>: The difference in appearance of the failed fluid between FZD and LFZR around the time of failure is not significant. It is believed that this results since the time to go from Phase II to Phase III is short in both FZD and LFZR.

For Type II fluid tests: During LFZR, the transition from Phase II to Phase III happens much faster than under FZD, and as a result, this gives the impression that failures under FZD are more apparent and opaque than under LFZR.

Regression equations were developed for freezing drizzle and light freezing rain for the different types of fluids tested and these equations are reported in Appendix I. The only exception is for Type II 50/50 fluids for which only six points were available including Ultra 50/50 data (which performs about the same as other Type II's at this dilution). No regression equations were developed for this group.

Figure 5.20 shows the failure time versus rate of precipitation for three sets of data: natural precipitation (APS), CEF simulated precipitation and UQAC WSET simulated precipitation. The purpose of this figure is to verify the validity of the APS simulation. UQAC provided B-250 Type I fluid data at glycol concentrations of 75% and 50%. An average was taken to represent the 63% dilution which is equivalent to the B-250 fluid at its standard concentration. The best fit curves for UQAC and APS are very close and have good agreement. The failure times for natural precipitation are longer than those for the simulated precipitation, which indicates that the simulated precipitation data is conservative. However the natural precipitation data is subject to more errors than the simulated precipitation data; for example wind effects in outdoor tests generally result in longer holdover times; furthermore longer failure times can arise from uncertainty on the part of the human observer in calling the end condition, particularly when snow or ice pellets may be mixed with freezing rain.

FIGURE 5.20
EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON STANDARD TYPE I FLUID FAILURE TIME IN FREEZING PRECIPITATION CONDITIONS

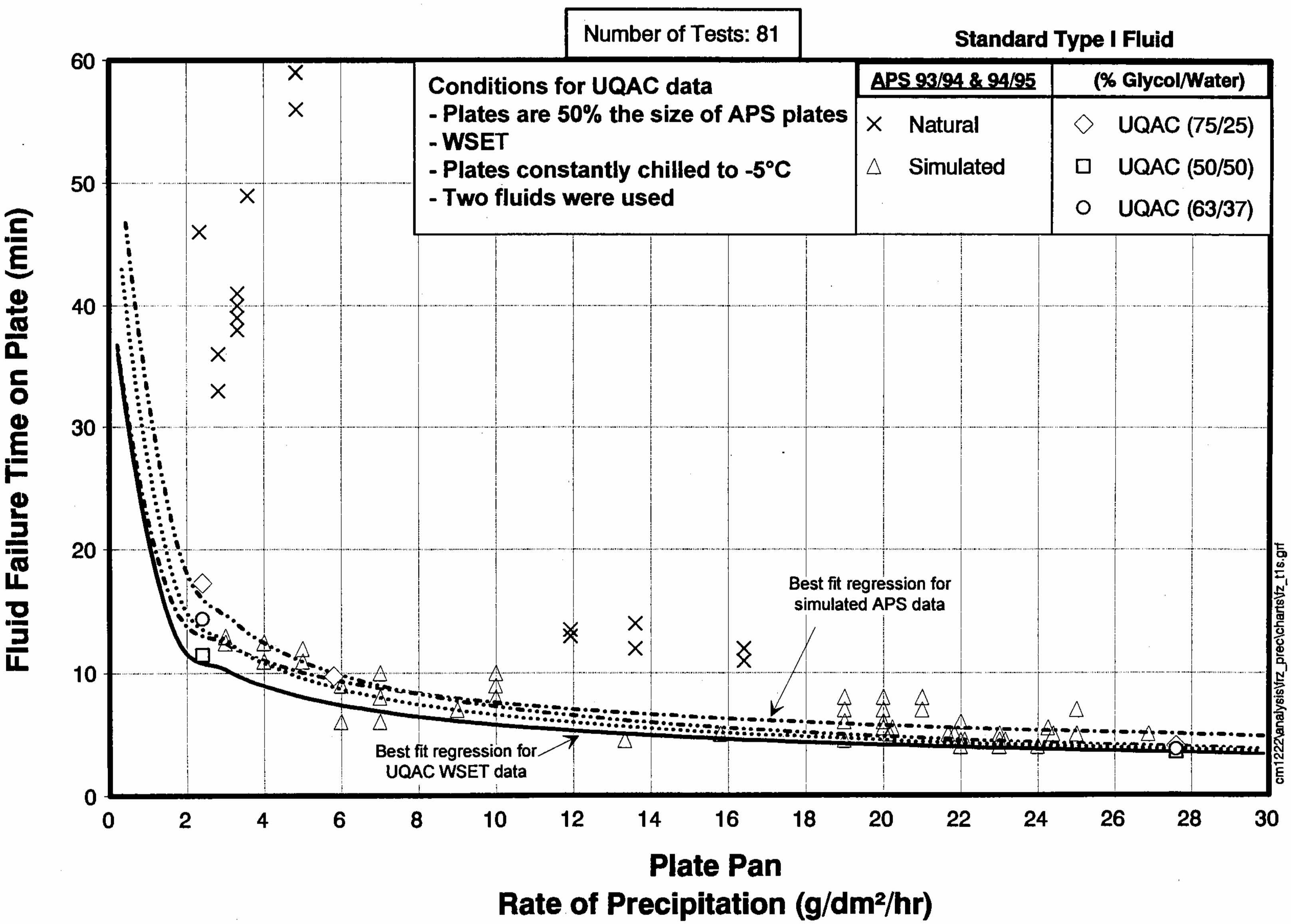


Figure 5.21 shows a similar plot of the results as was shown in Figure 5.20, however this time for Type II 75/25 fluids. This chart also shows that the UQAC and APS data are in agreement.

The data will be presented and discussed according to fluid type and concentration.

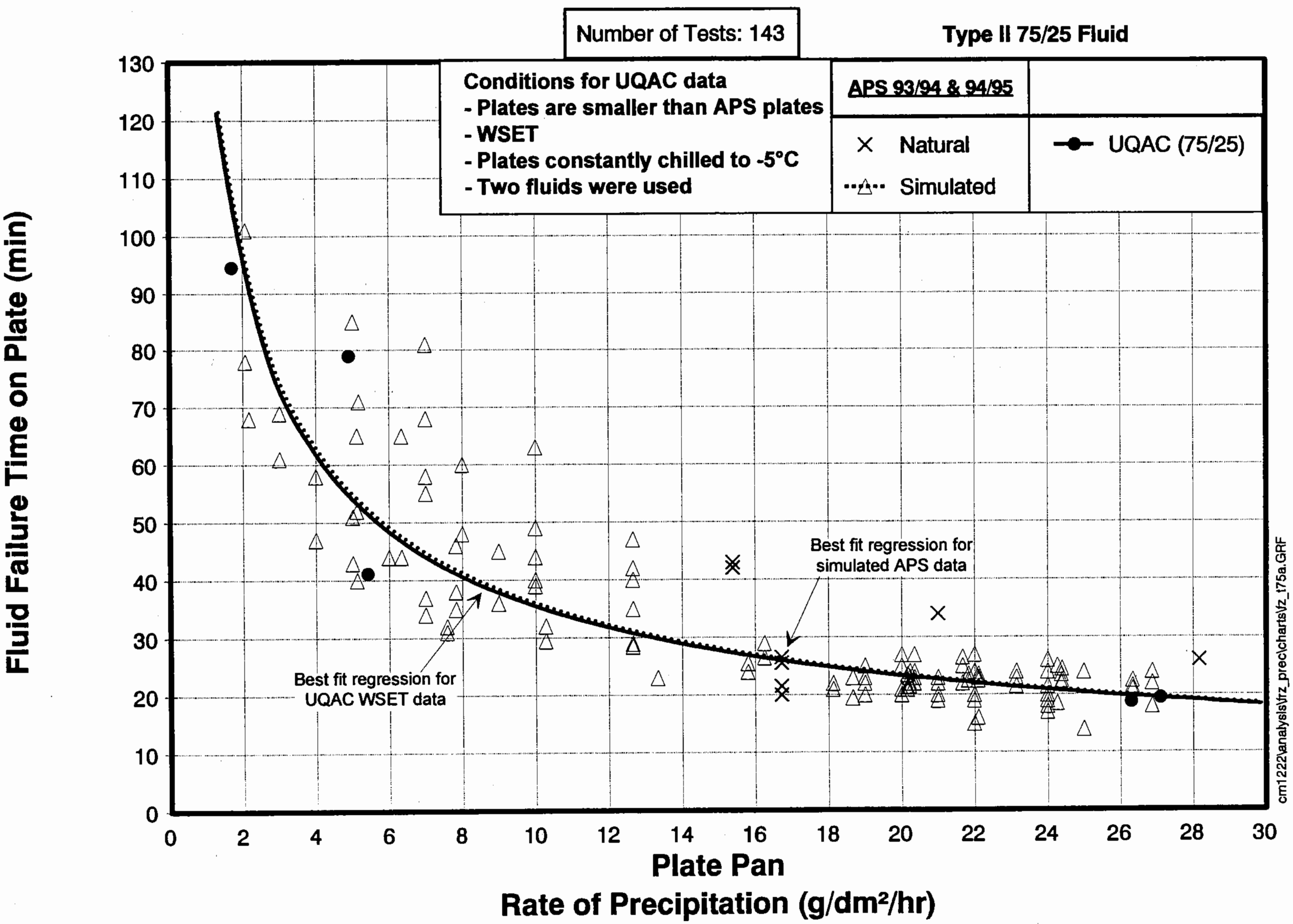
The analysis presented in the subsequent section follow discussions and resolutions which resulted from the SAE G-12 HOT Sub-Committee meetings in Montreal, Amsterdam and Chicago in 1995. Of particular importance, the current freezing rain column in the HOT Tables was changed and expanded to two columns, freezing drizzle and light freezing rain, and the new HOT's reflect the testing conducted by APS. It is important to note that these new HOT ranges were determined by the entire Sub-Committee based upon the APS data. The methodology used by the SAE Sub-Committee in determining the new range of HOT's in each cell of the tables was as follows:

<u>Lower HOT Number</u>: Selecting either the lowest data point (failure time) or a more conservative time obtained by inspection. Consideration was given to the values consistent with the adjacent cells of the HOT table.

<u>Upper HOT Number</u>: Selecting the time when most or all of the data points fall below this number. (Based on the above, it is important that the operators and training personnel express ***caution*** to the pilots in the utilization of the upper number).

FIGURE 5.21

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II 75/25 FLUID FAILURE TIME IN FREEZING PRECIPITATION CONDITIONS



5.1.2.1 Standard Type I Fluids under Simulated Freezing Drizzle and Light Freezing Rain

Figure 5.22 shows the failure times of the standard Type I data versus rate of precipitation as a function of fluid type. The chart was compiled based upon data collected from both 1993/94 and 1994/95 and is further subdivided as a function of freezing drizzle and light freezing rain. The points fall above the current SAE/ISO holdover time range for freezing rain. Figure 5.23 shows the failure time versus temperature of the same data. Once again this data is further subdivided by freezing drizzle (FZD) and light freezing rain (LFZR) as well as the year in which it was tested.

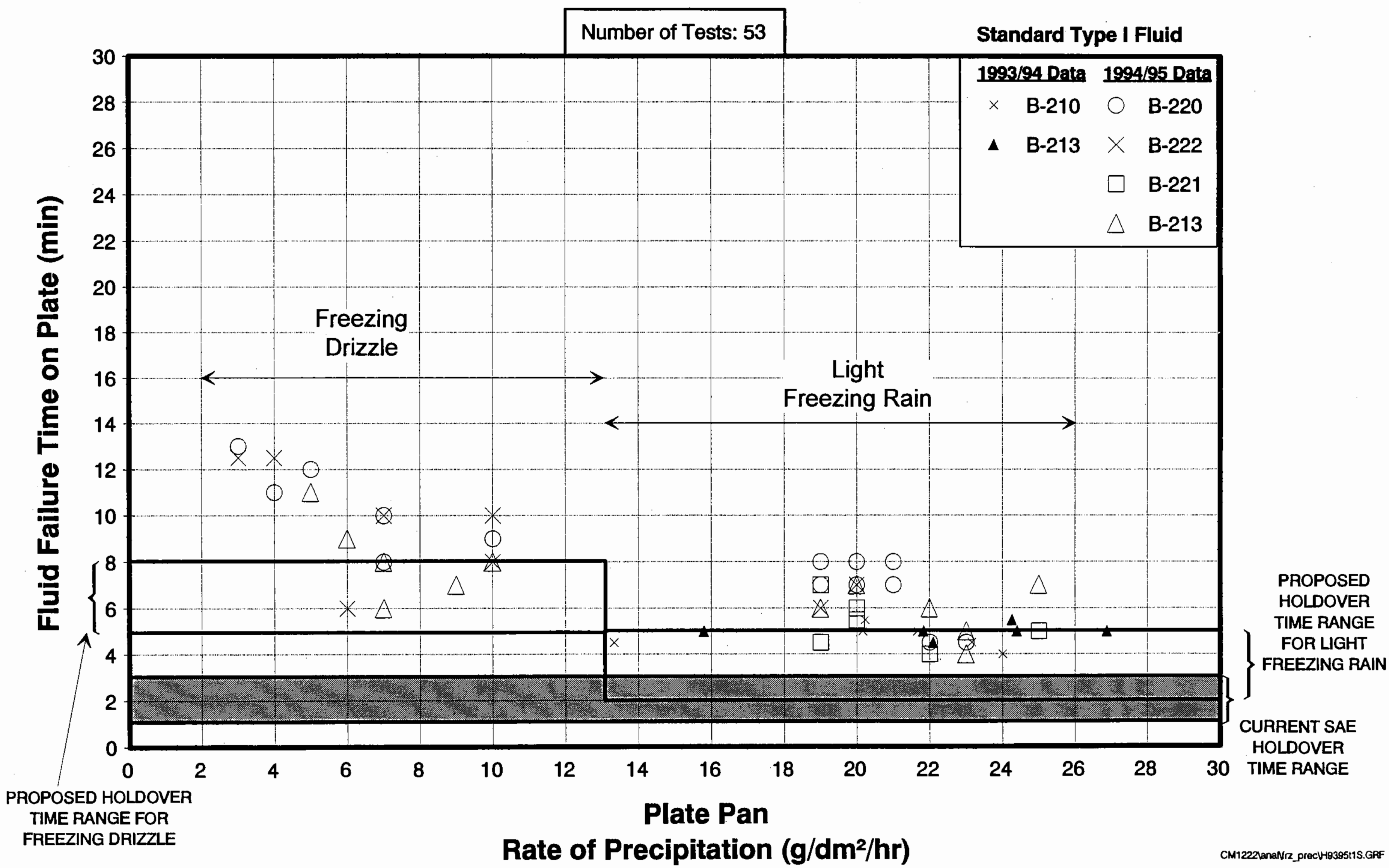
5.1.2.2 Diluted Type I Fluids under Simulated Freezing Drizzle and Light Freezing Rain

Figures 5.24 and 5.25 show the failure times of Diluted Type I fluids as functions of rate of precipitation and temperature, respectively. They show the current and proposed HOT's for both FZD and LFZR. It was suggested that the current HOT range of 1 to 3 minutes be increased to 2 to 5 minutes and that the column heading be changed to light freezing rain. A new column was also suggested under the name of freezing drizzle, with a HOT range of 5 to 8 minutes be ascribed to it.

One of the objectives for the 1994/95 winter testing was to extend the freezing rain column down to temperatures of -10°C.

FIGURE 5.22

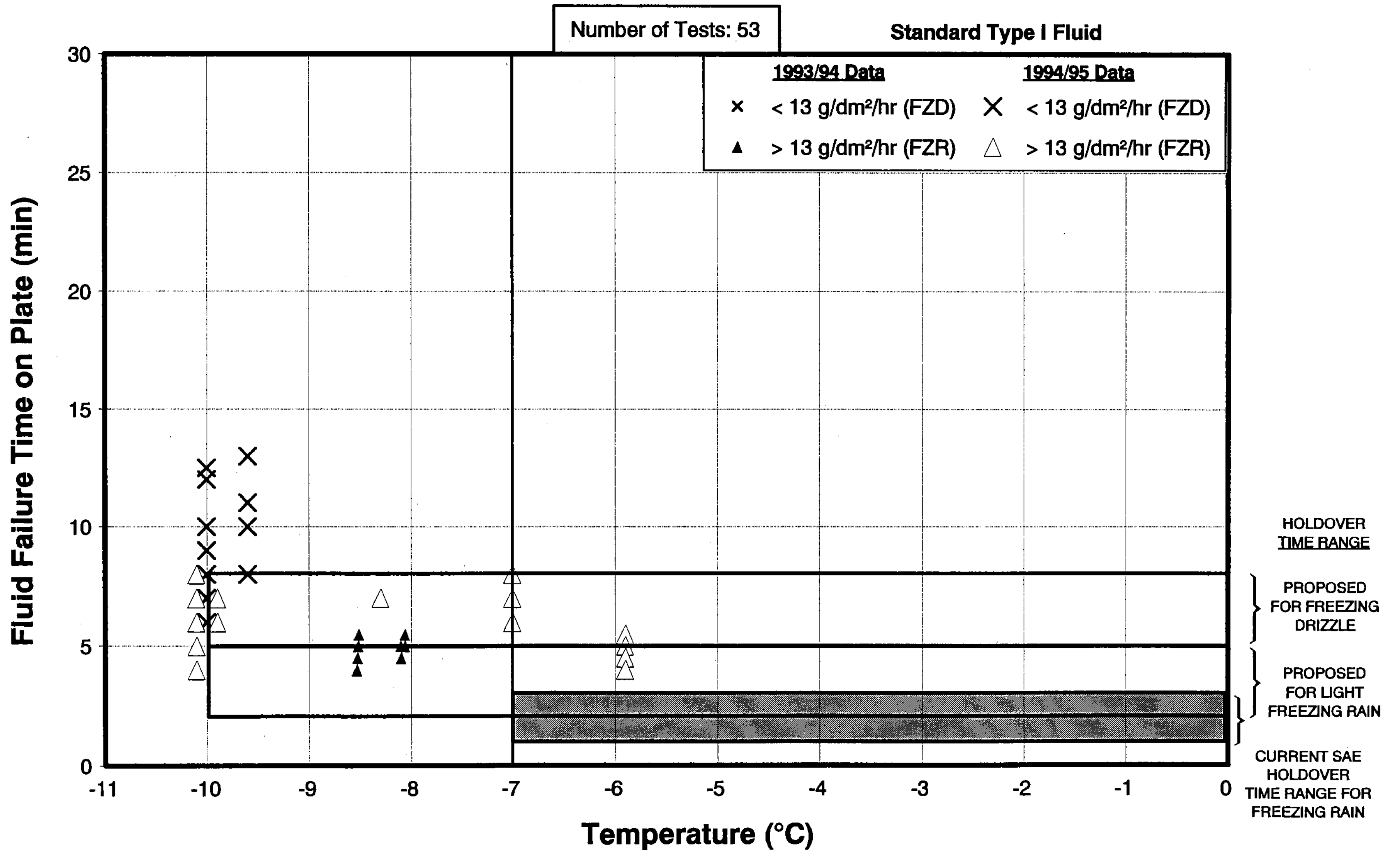
EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON STANDARD TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE AND LIGHT FREEZING RAIN CONDITIONS



CM1222\ana\frz_prec\H9395t1S.GRF

FIGURE 5.23

EFFECT OF RATE OF PRECIPITATION AND TEMPERATURE ON STANDARD TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE AND LIGHT FREEZING RAIN CONDITIONS



CM1222\anal\frz_prec\charts\T9395I1s.(

FIGURE 5.24

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON DILUTED TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE AND LIGHT FREEZING RAIN CONDITIONS

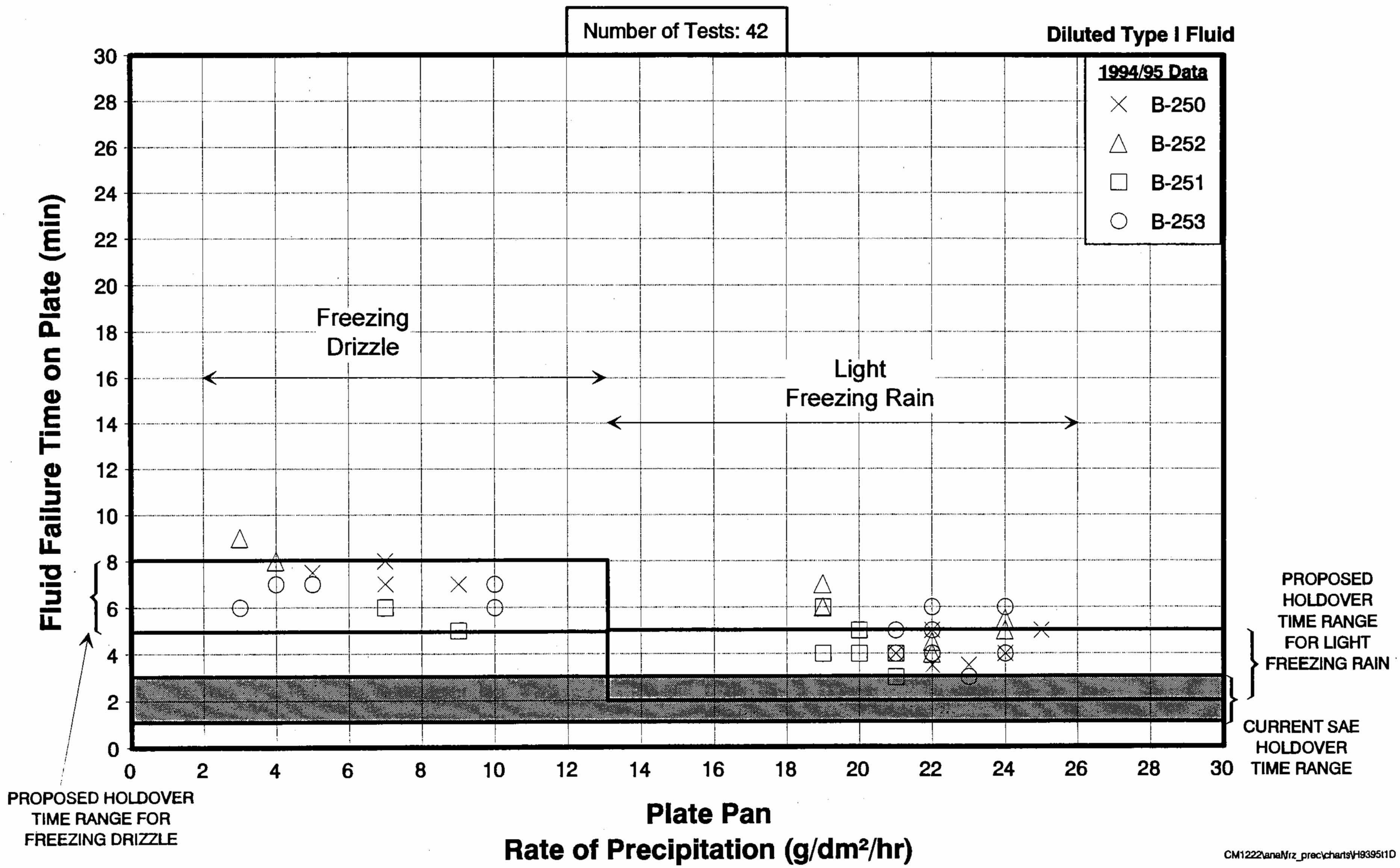
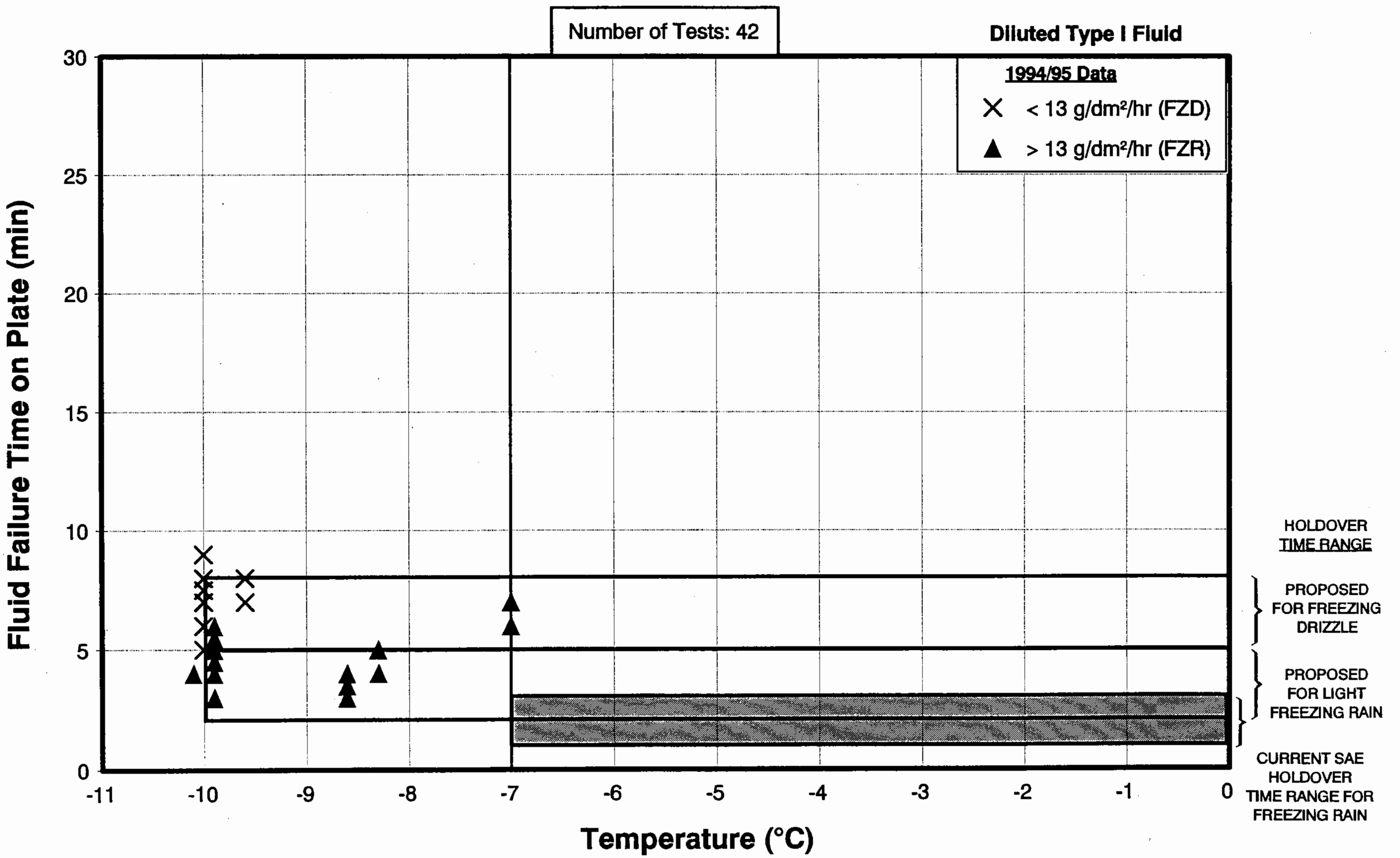


FIGURE 5.25

EFFECT OF RATE OF PRECIPITATION AND TEMPERATURE ON DILUTED TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE AND LIGHT FREEZING RAIN CONDITIONS



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As a result, the proposed changes to the HOT tables are applicable for temperatures between -7°C and -10°C for both diluted and standard Type I fluids.

5.1.2.3 Type II Neat Fluids under Simulated Freezing Drizzle and Light Freezing Rain

Figure 5.26 shows the failure time versus rate of precipitation of Type II Neat fluids including UCAR Ultra. Again, the fluids show longer times than the current SAE Holdover Time range of 8 to 20 minutes. A new HOT range of 30 to 60 minutes for freezing drizzle was proposed for the conventional Type II fluids, and 15 to 30 minutes was proposed for light freezing rain. Figure 5.27 shows the freezing drizzle data and Figure 5.28 shows the light freezing rain data as a function of temperature. These charts also show that the new proposed HOT ranges are applicable for temperatures down to -10°C.

Part of this year's Cold Chamber testing was to compare UCAR Ultra to other conventional Type II fluids. Flat plate tests show that Ultra has longer holdover times than conventional Type II fluids and exceeds both current and proposed HOT ranges for conventional fluids. Figure 5.26 shows that this occurs under both freezing drizzle and light freezing rain. Based on APS' data, Transport Canada supported an increase in the HOT range for Ultra Neat under all temperature conditions by a factor of 50% over the conventional Type II's, for operations during the 1995/96 winter season. The factor of 1.5 is consistent with the natural snow factor, and when applied to Figure 5.26, the

FIGURE 5.26

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II NEAT FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE AND LIGHT FREEZING RAIN CONDITIONS

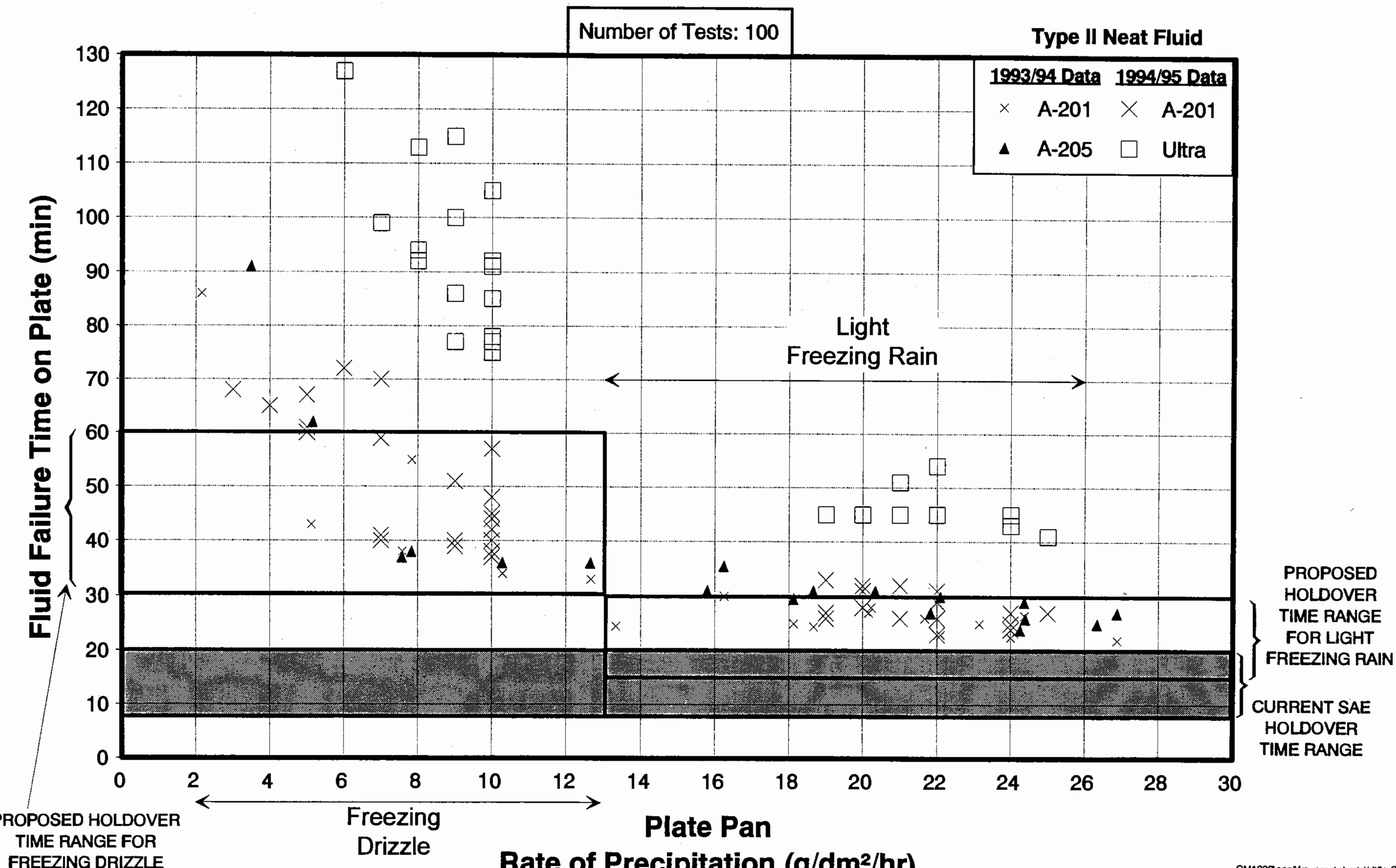

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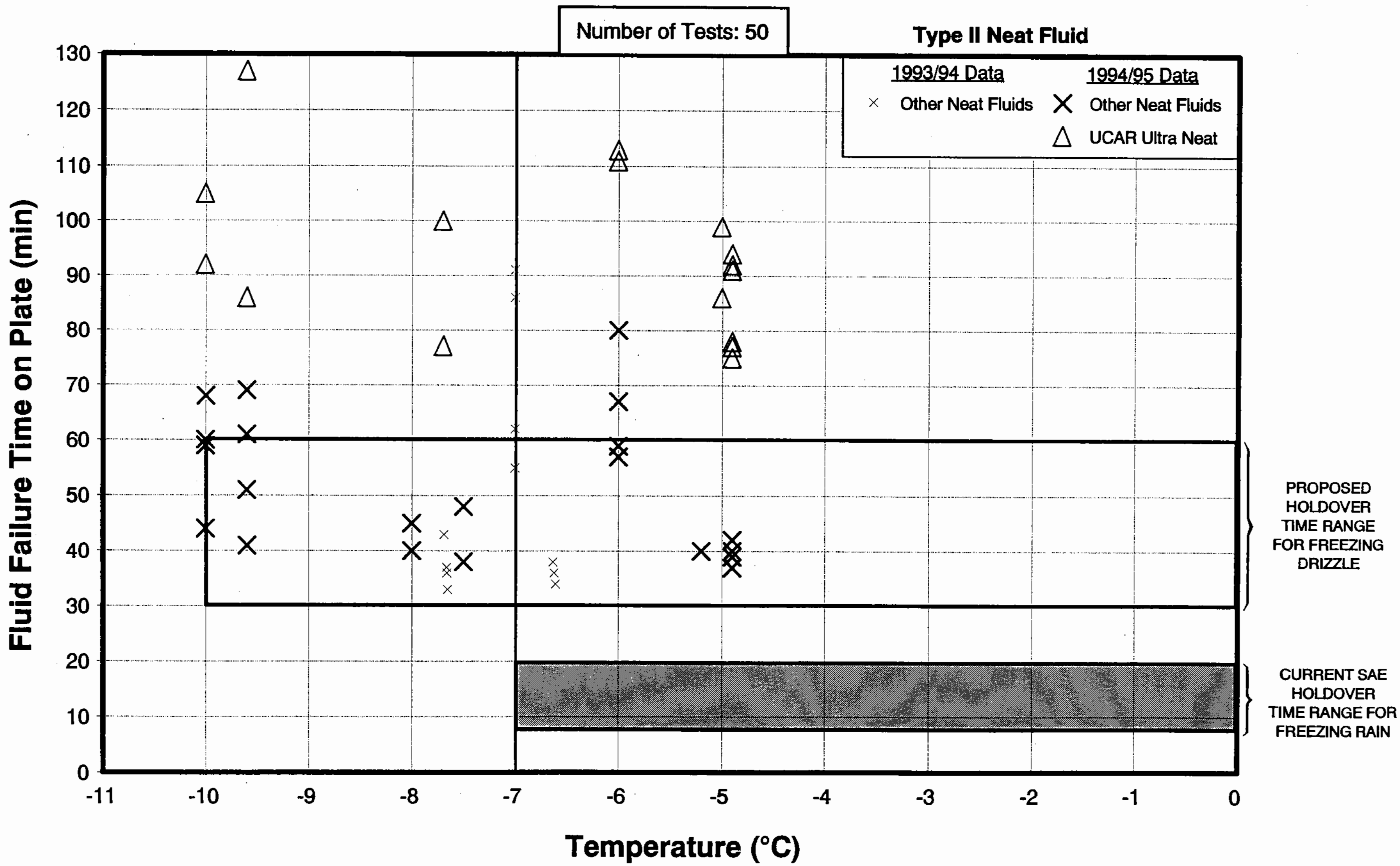
FIGURE 5.27

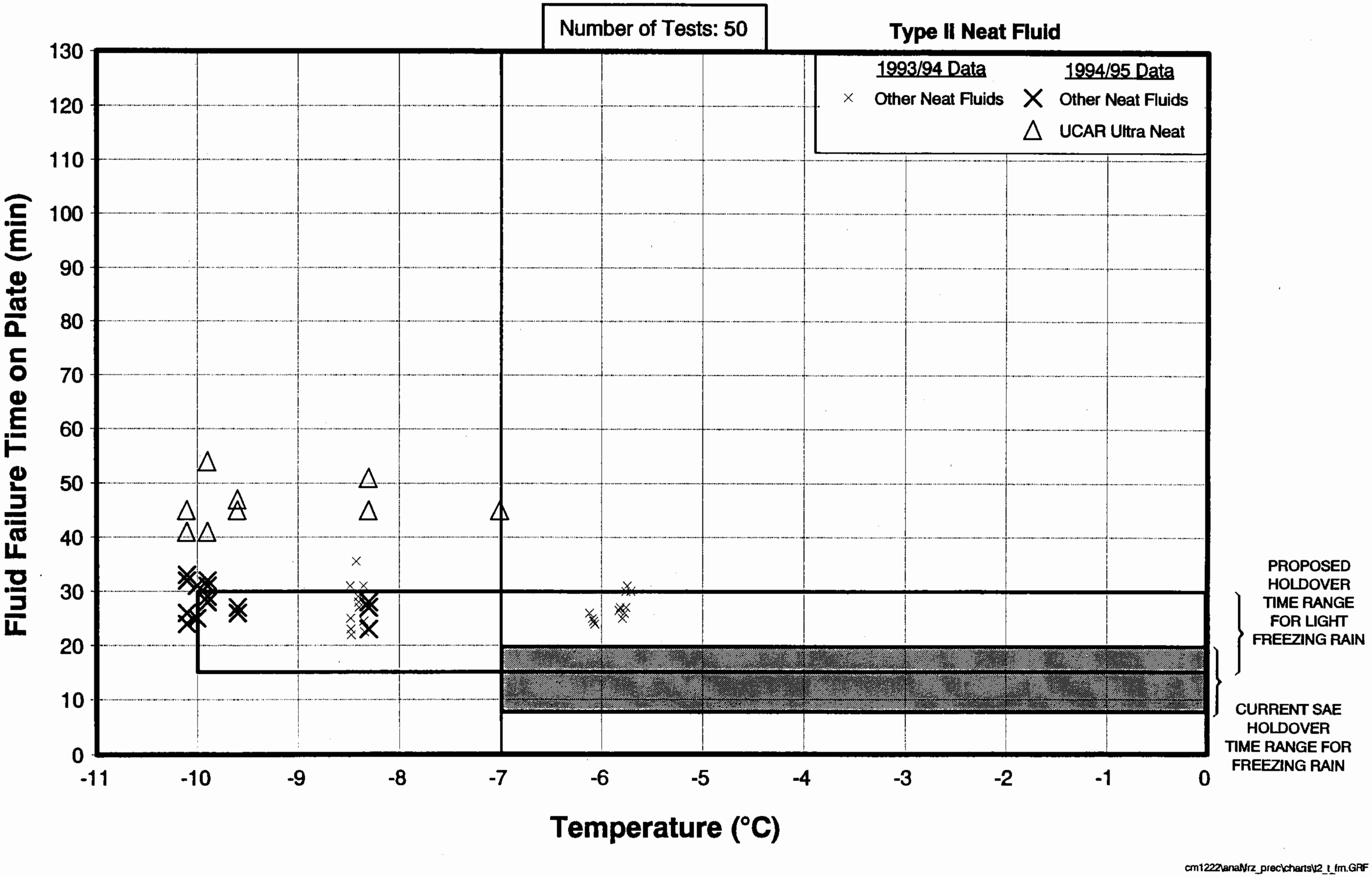
EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II NEAT FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS



cm1222\anal\frz_prec\chrts\t2_t_fdz.GRF

FIGURE 5.28

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II NEAT FAILURE TIME IN SIMULATED LIGHT FREEZING RAIN CONDITIONS



proposed range for FZD is 45 to 90 minutes and 22.5 to 45 minutes for LFZR. The Ultra Neat test data supports the new proposed ranges. As a result of these developments by Canada, the SAE HOT Sub-Committee in Chicago agreed and proposed use of this factor under these conditions for the 1995/96 winter.

5.1.2.4 *Type II 75/25 Fluids under Simulated Freezing Drizzle and Light Freezing Rain*

Figure 5.29 shows the failure time versus rate of precipitation of Type II 75/25 conventional and new long life fluids under freezing drizzle and light freezing rain. Once again, the failure times exceed the current SAE HOT range. The new proposed HOT range under freezing drizzle is 20 to 45 minutes, and for light freezing rain 10 to 25 minutes was recommended by the Committee. Figure 5.30 and Figure 5.31 show the failure times plotted as a function of temperature. The proposed HOT changes are applicable for temperatures down to -10°C.

For the Type II 75/25 case, Ultra shows slightly superior behaviour only in the freezing drizzle category. The Ultra data suggests a HOT range of 30 to 70 minutes, which translates to a ratio of 1.5 between the conventional fluid HOT and the Ultra HOT, however this was not adopted by the SAE. For light freezing rain, Ultra behaved identically to the conventional Type II fluids.

FIGURE 5.29

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II 75/25 FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE AND LIGHT FREEZING RAIN CONDITIONS

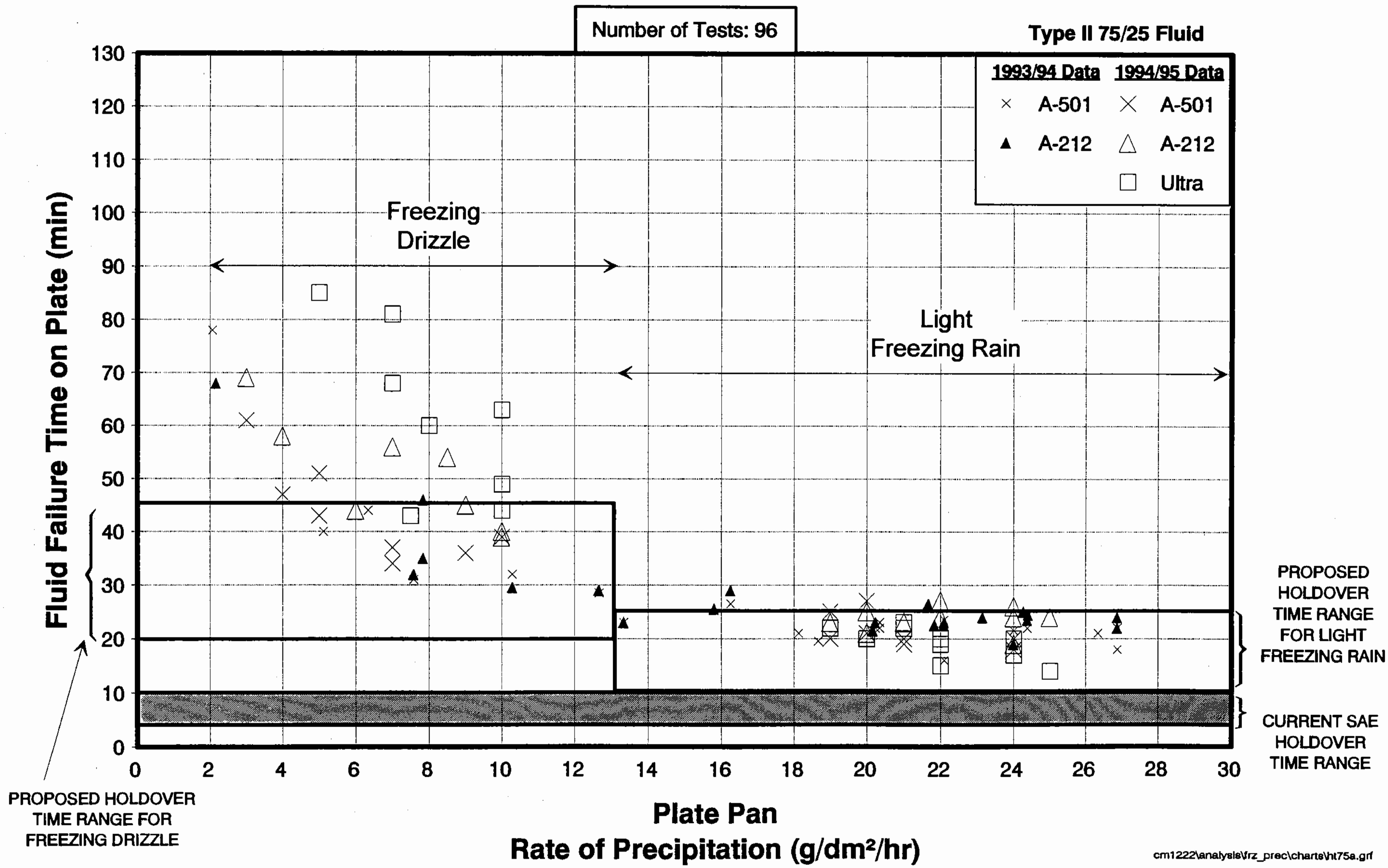


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FIGURE 5.30
EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II 75/25 FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS

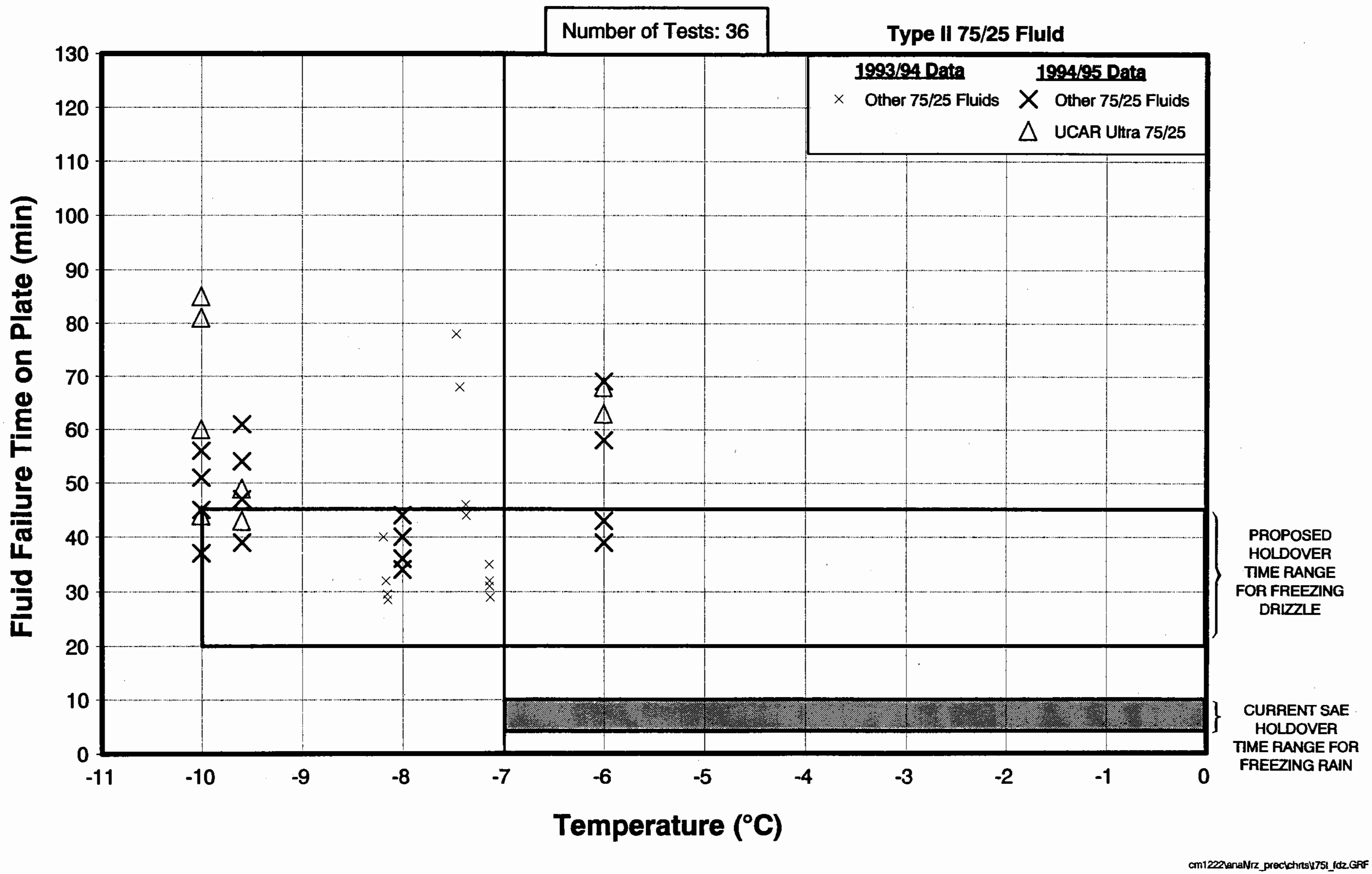
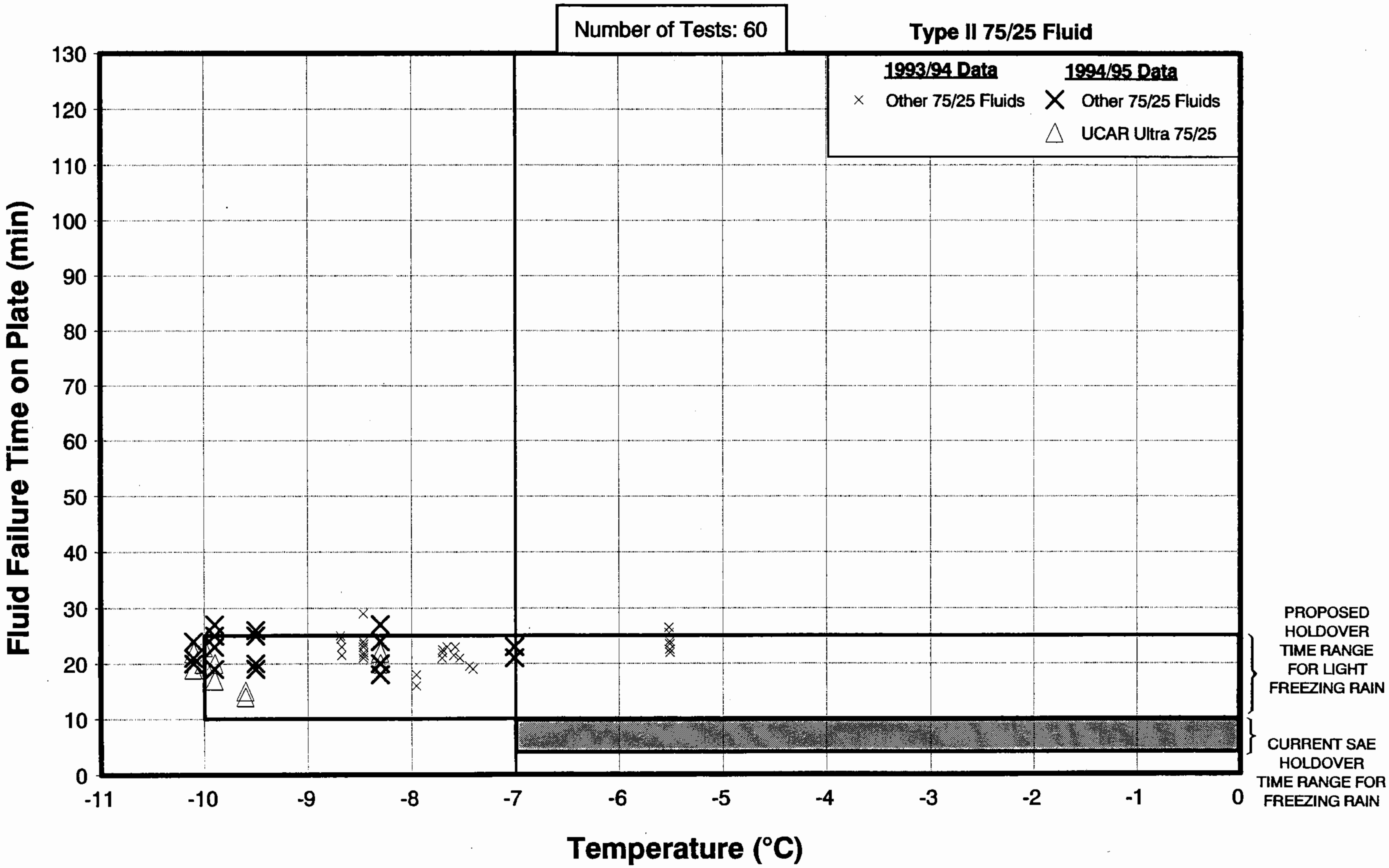


FIGURE 5.31

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II 75/25 FAILURE TIME IN SIMULATED LIGHT FREEZING RAIN CONDITIONS



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5.1.2.5 Type II 50/50 Fluids under Simulated Freezing Drizzle and Light Freezing Rain

Figure 5.32 shows the failure time of Type II 50/50 fluids versus rate of precipitation, as well as the new proposed HOT's of 15 to 35 minutes for freezing drizzle and 5 to 15 minutes for light freezing rain. Figure 5.33 and Figure 5.34 show the failure times versus temperature under FZD and LFZR conditions, respectively.

FIGURE 5.32

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II 50/50 FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE AND LIGHT FREEZING RAIN CONDITIONS

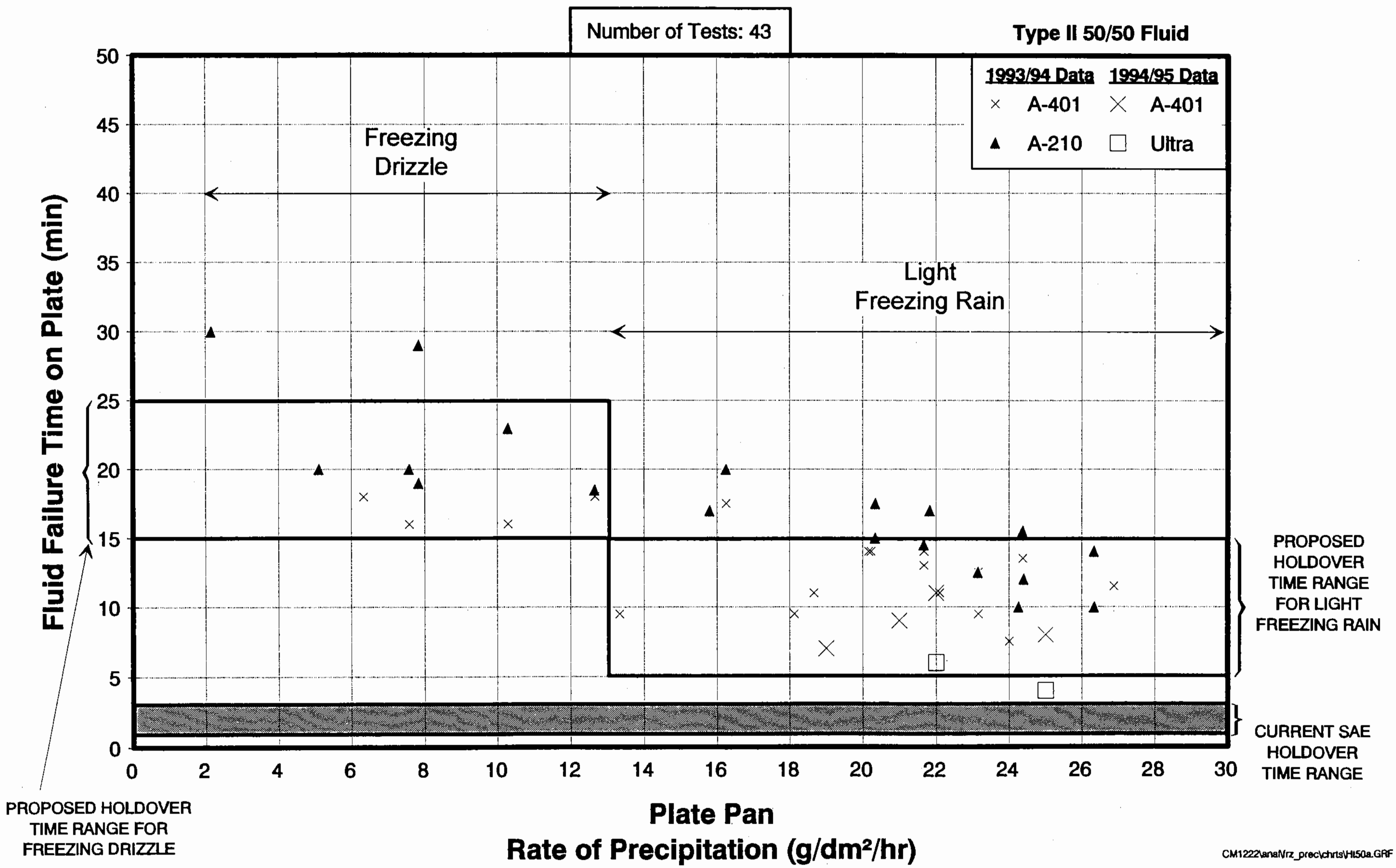
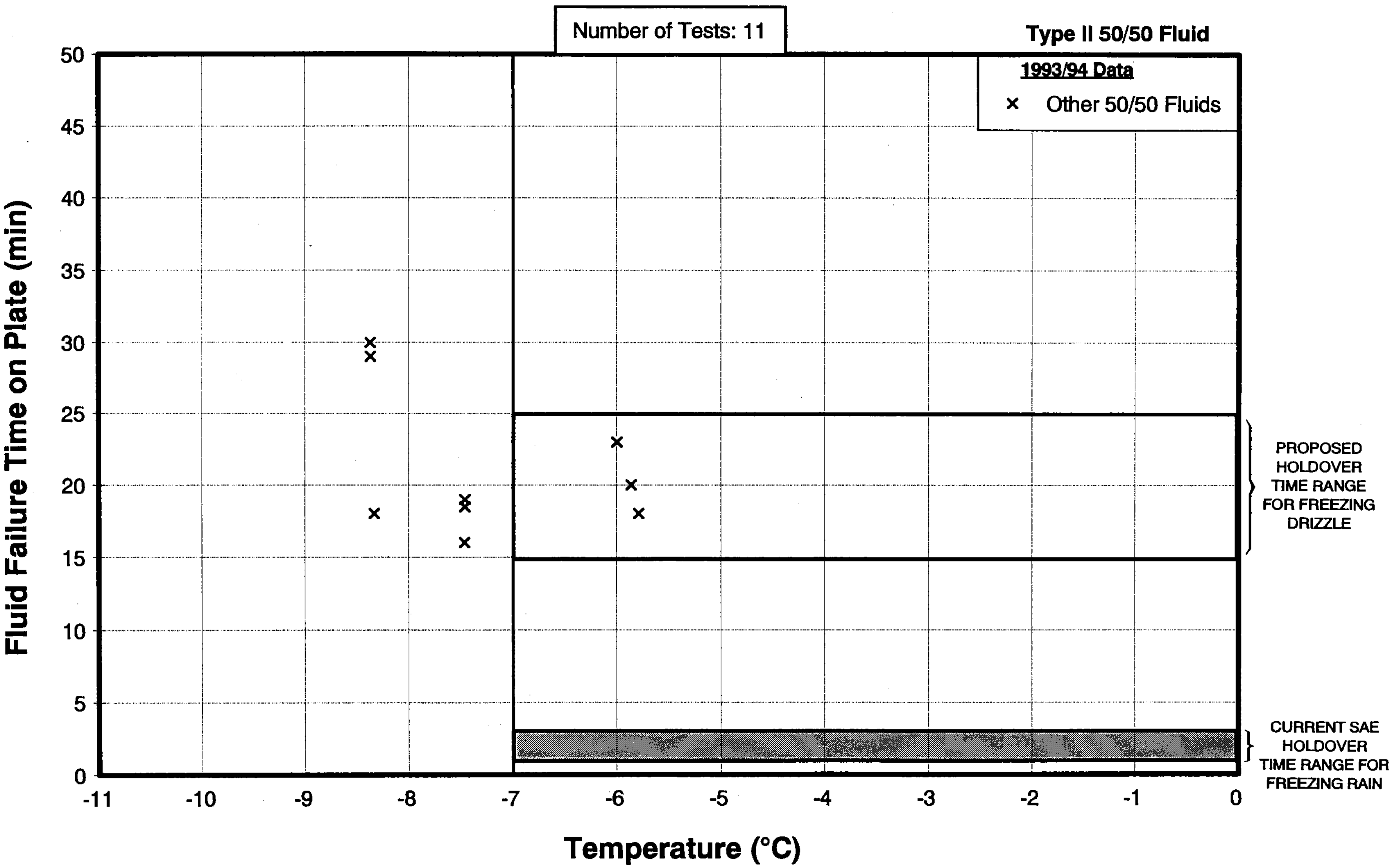


FIGURE 5.33

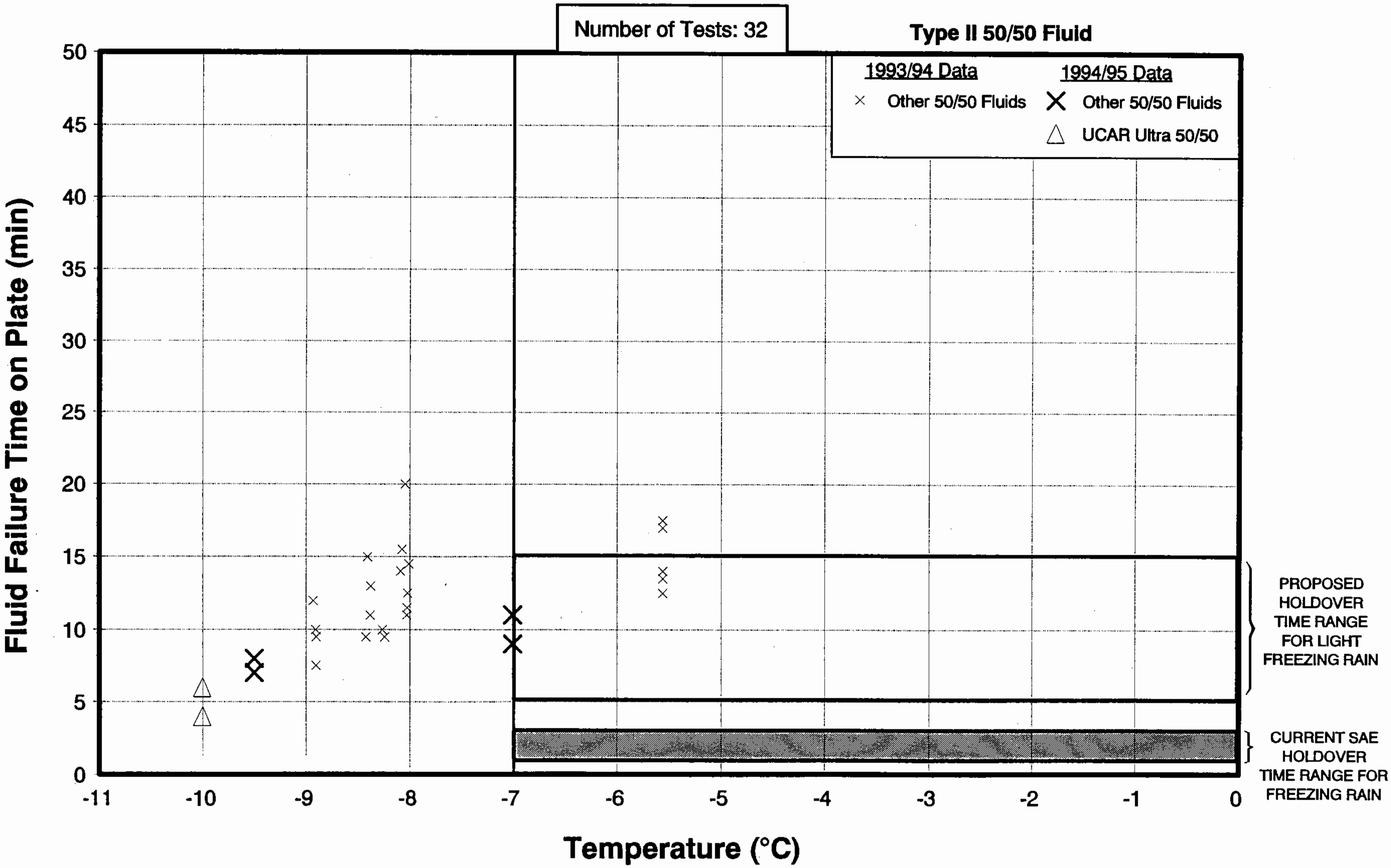
EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II 50/50 FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS



cm1222\anal\frz_prec\chrts\t50t_fdz.GRF

FIGURE 5.34

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II 50/50 FAILURE TIME IN SIMULATED LIGHT FREEZING RAIN CONDITIONS



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5.1.3 Simulated Freezing Fog

The 1994/95 winter simulated freezing fog experiments were performed at NRC's CEF. NRC have indicated that natural freezing fog generally produces deposition rates ranging from 2 to 8 $g/dm^2/hr$ and this varies with wind speed. Some testing was conducted at higher rates (11 to 16 $g/dm^2/hr$) as part of the calibration of the chamber and in order to provide better insight of the fluid performance. The reference average particle size for the indoor test was less than 50 µm and the testing temperature range was from below -7°C to -27°C. Regression equations were developed for different fluids under freezing fog precipitation and they are presented in Appendix I. The data was analyzed based on fluid type.

5.1.3.1 Standard Type I Fluids under Simulated Freezing Fog

Four different Type I fluids were tested under simulated freezing fog at their standard concentrations. Figure 5.35 shows the 1994/95 data plotted as a function of rate of precipitation and fluid type. These new points satisfy the current SAE HOT range for standard Type I Fluids under freezing fog, even at the higher rates (8 to 16 $g/dm^2/hr$). Figure 5.36 shows the same data combined with the 1992/93 outdoor data under the same format. The two data sets complement each other on the 2 to 16 $g/dm^2/hr$ rate range. It was generally observed that both the indoor and outdoor tests produced similar results. As has been shown for other fluids and conditions, the data suggests an exponential decay of failure time with precipitation rate for standard Type I under freezing fog conditions.

FIGURE 5.35
EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON STANDARD TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

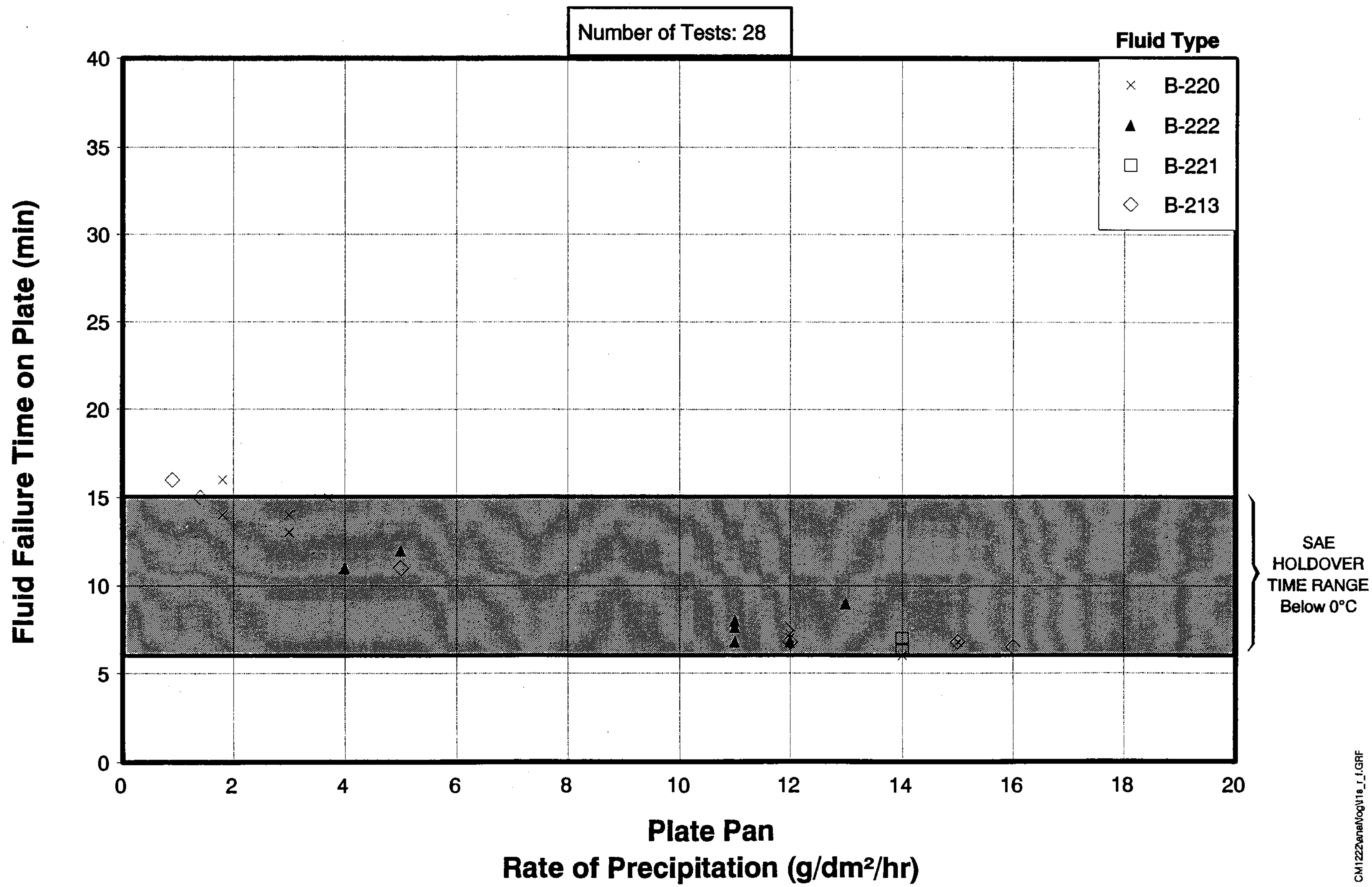
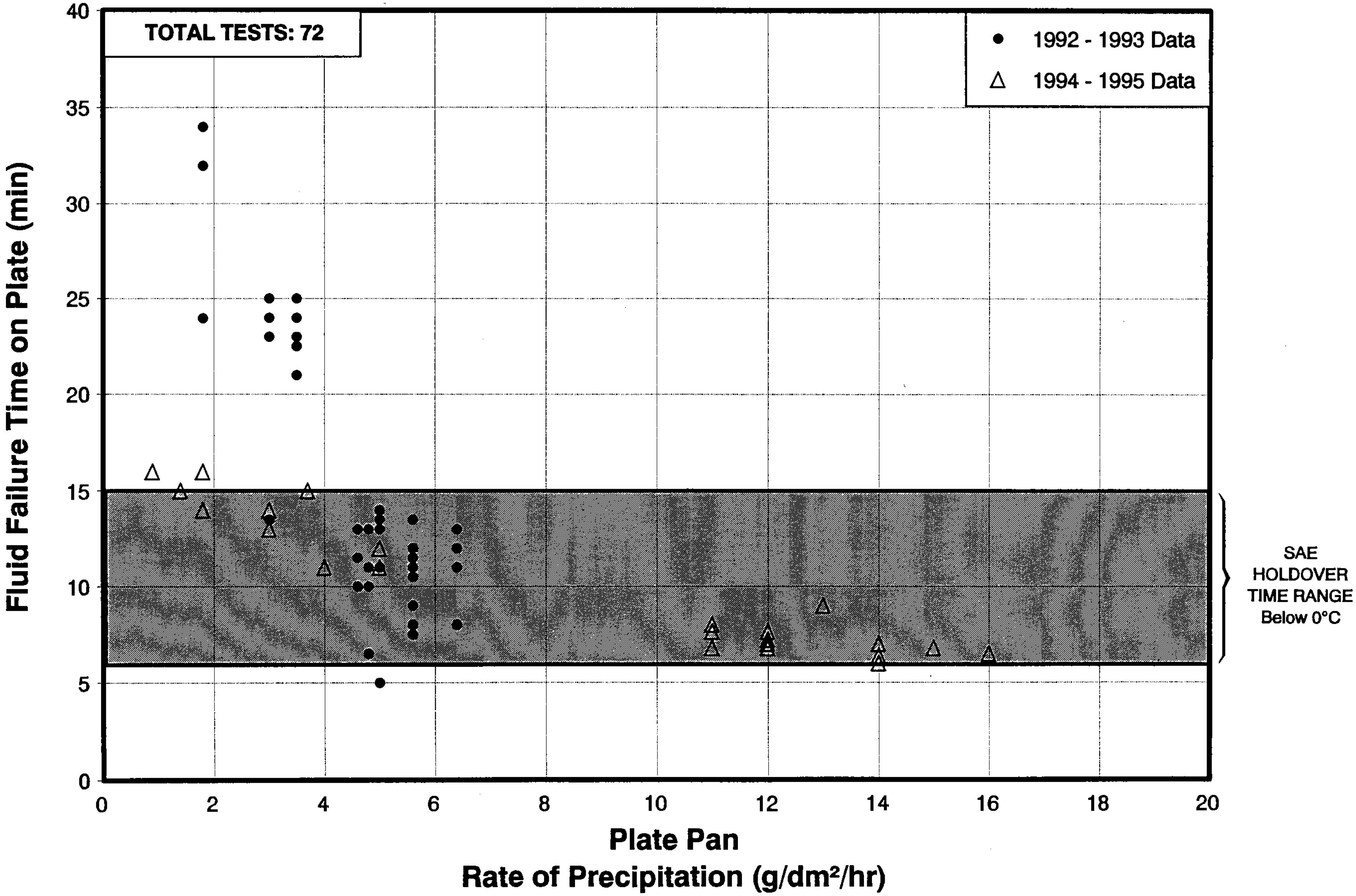


FIGURE 5.36

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1992 - 1995



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The failure time data for 1992/93 and 1994/95 are shown versus temperature in Figure 5.37 and they indicate that the HOT range is substantiated at temperatures as low as -27°C.

5.1.3.2 Diluted Type I Fluids under Simulated Freezing Fog

Diluted Type I fluids were also tested under simulated freezing fog at the same conditions as the standard Type I fluids. A total of 31 tests were conducted indoors at the CEF in 1994/95. Figure 5.38 shows the failure times of diluted Type I fluids versus rate of precipitation. Of the 29 points, 28 lie within the SAE/ISO HOT range. The one point below the range occurred at high rates where natural freezing fog would not likely occur, and where visibility would be limited. Figure 5.39 presents the same data plotted as a function of temperature.

The chart does not show a major effect of temperature on failure time which indicates that the behaviour of diluted Type I's is somewhat standardized at all temperatures due to the 10°C buffer.

Figure 5.39 indicates that the current SAE/ISO HOT Range of 6 to 15 minutes is substantiated for diluted Type I fluids. This is applicable for temperatures during freezing fog conditions as low as -27°C.

FIGURE 5.37

EFFECT OF FLUID TYPE AND TEMPERATURE ON STANDARD TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1992/93 & 1994/95 TEST SEASON

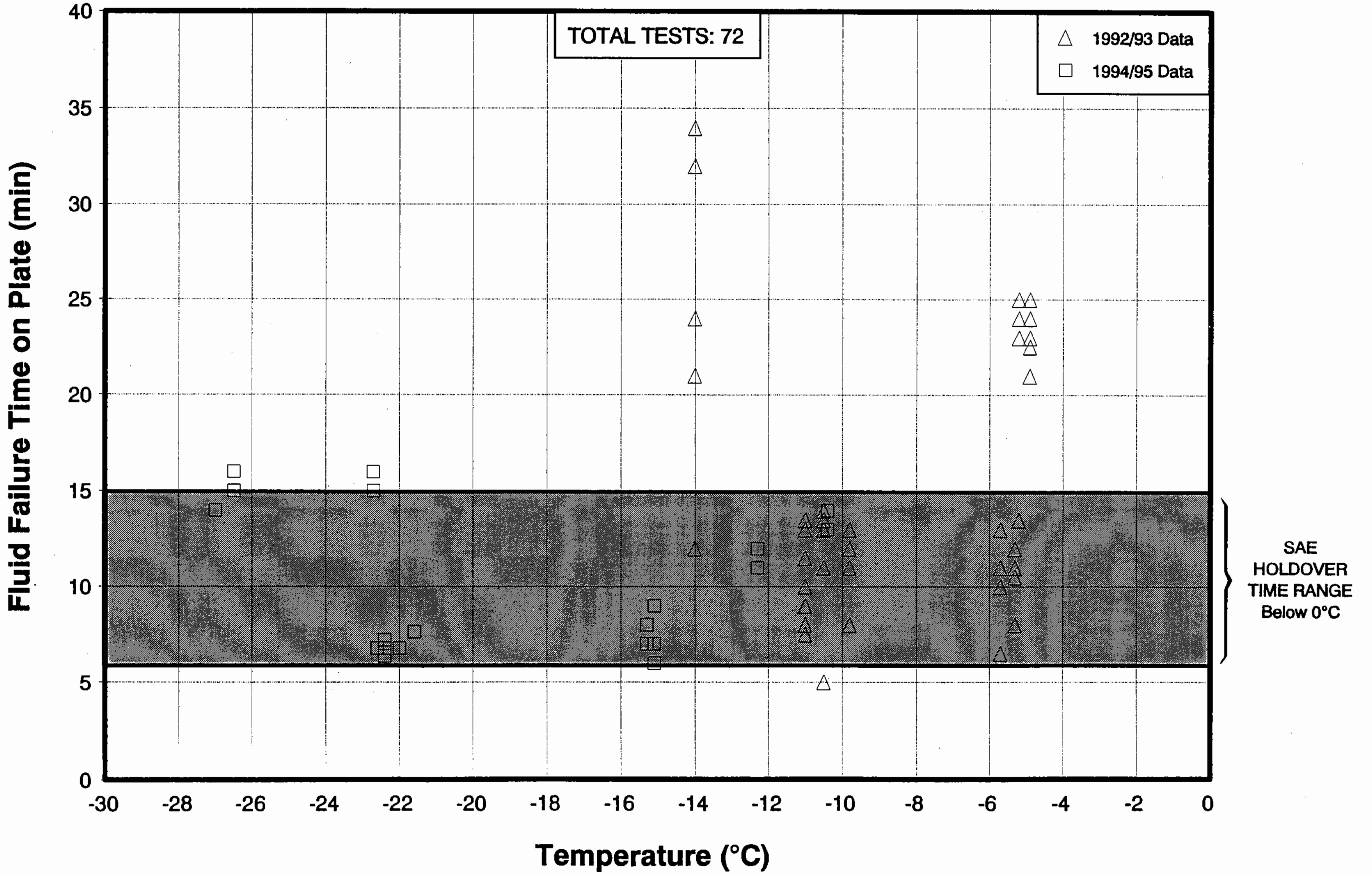


FIGURE 5.38

RESULTS OF DILUTED TYPE I FREEZING FOG TESTS AS A FUNCTION OF FLUID TYPE AND RATE OF PRECIPITATATION

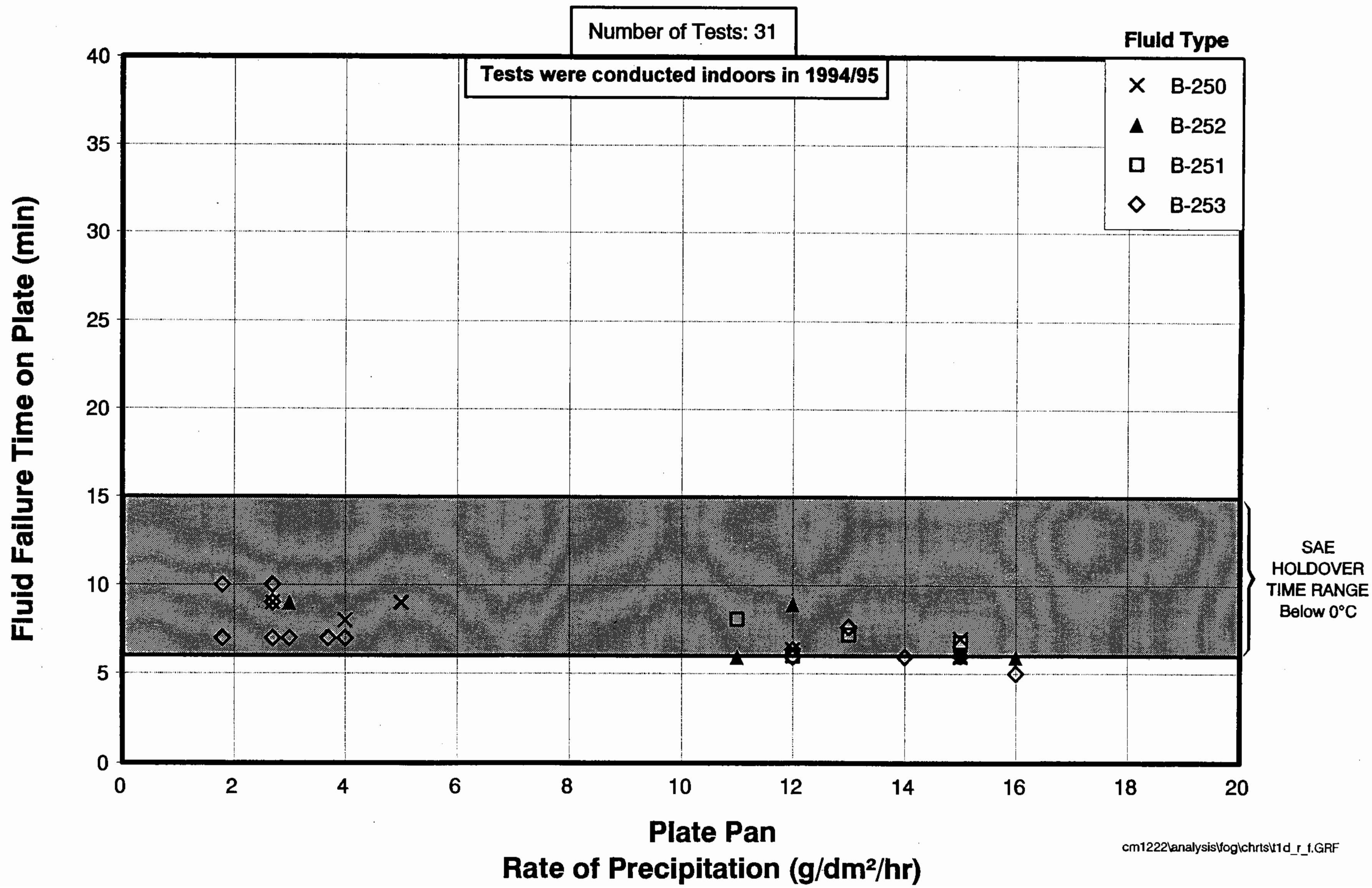
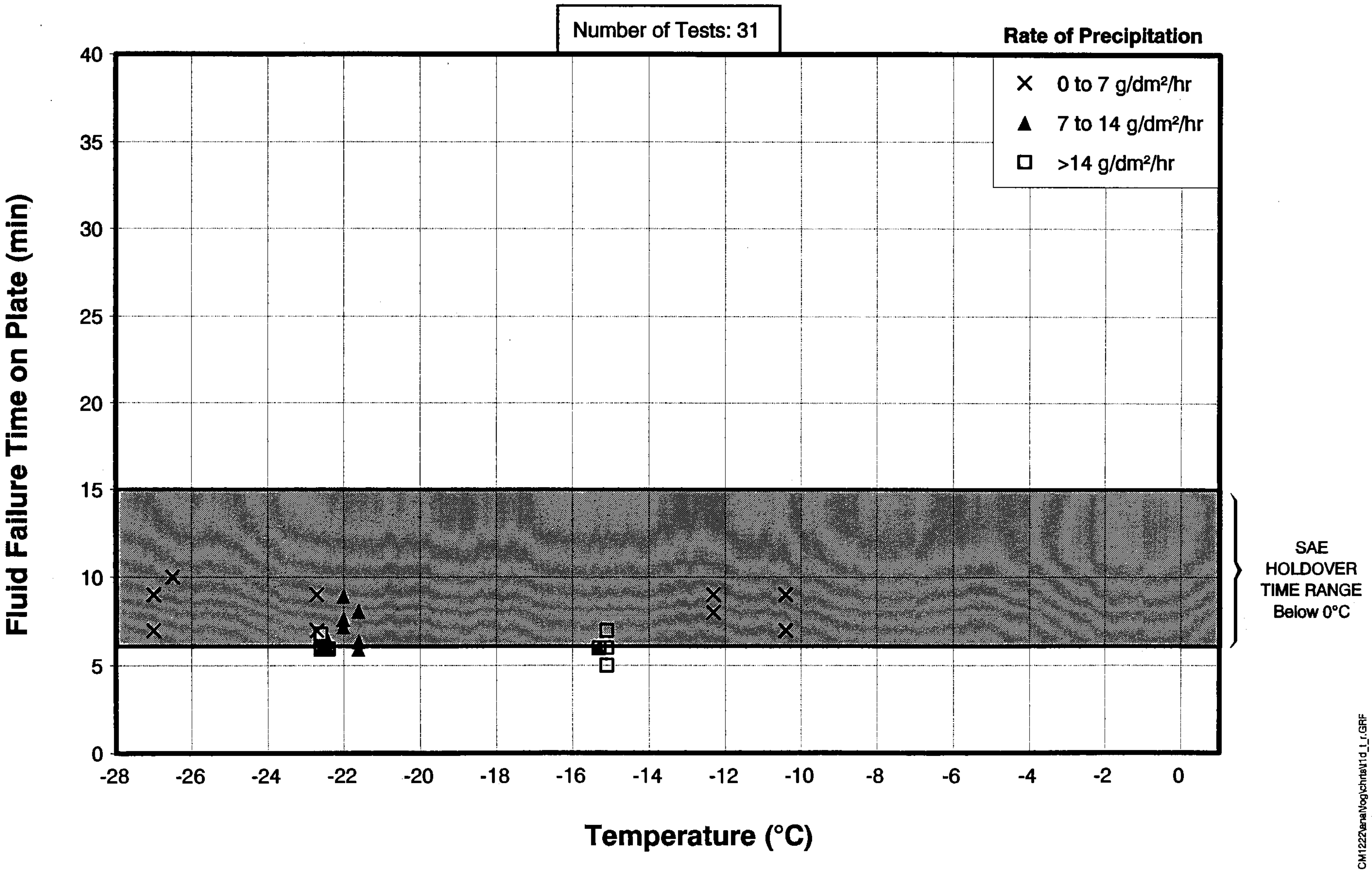


FIGURE 5.39
EFFECT OF RATE OF PRECIPITATION AND TEMPERATURE ON DILUTED TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS



5.1.3.3 Type II Neat Fluids under Simulated Freezing Fog

Figure 5.40 shows the failure time versus rate of precipitation for freezing fog data from 1993/94 outdoor and 1994/95 indoor tests. The 1994/95 data was further sub-divided in Figure 5.40 into Type II Neat fluids and Ultra Neat data. The test points with a rate of precipitation greater than 8 $g/dm^2/hr$ were obtained during the chamber calibration tests with four rather than two sets of nozzles. However, freezing fog at these levels is not realistic and therefore these points were removed from the analysis. Figure 5.41 shows the resulting data together with the SAE/ISO HOT range.

Figure 5.42 shows the same data as Figure 5.41 in a failure time versus temperature format; these data support the conclusion from last winter that the SAE/ISO HOT range is substantiated and extends the validity down to temperatures as low as -27°C.

Figure 5.41 and 5.42 show that the Ultra Neat fluid is superior to the other Type II Neat fluids. Based on this data, Transport Canada increased the HOT range for Ultra Neat under all temperature conditions by a factor of 50% over the conventional Type II's, for operations during the 1995/96 winter season. The factor of 1.5 is consistent with the factor for snow, freezing drizzle and light freezing rain. When this factor is applied to the current range of 35 to 90 minutes, the new proposed range becomes 52.5 to 135 minutes. These developments in Canada prompted the SAE Hot Sub-Committee to propose the use of the

FIGURE 5.40

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II NEAT FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1993 - 1995

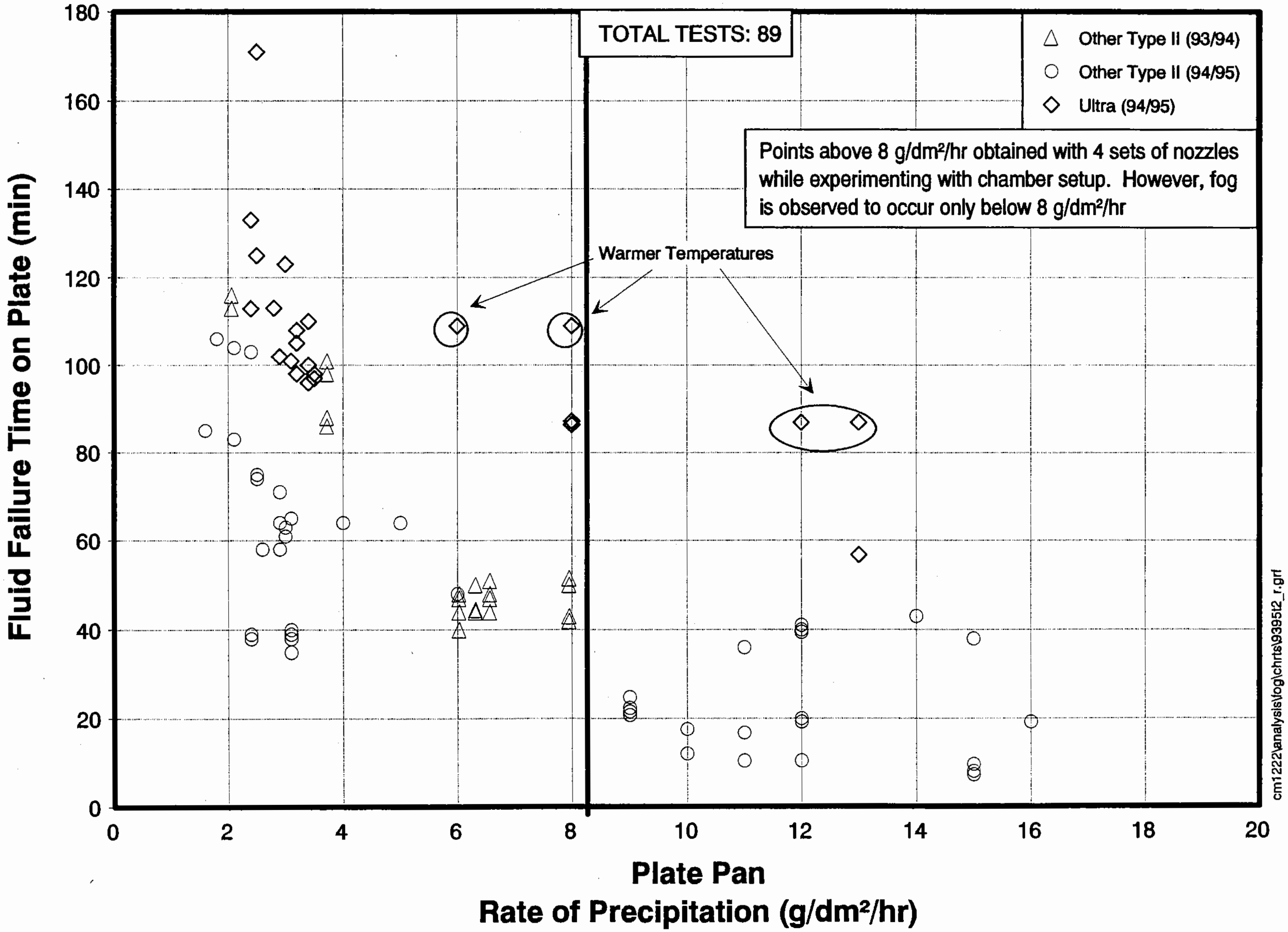
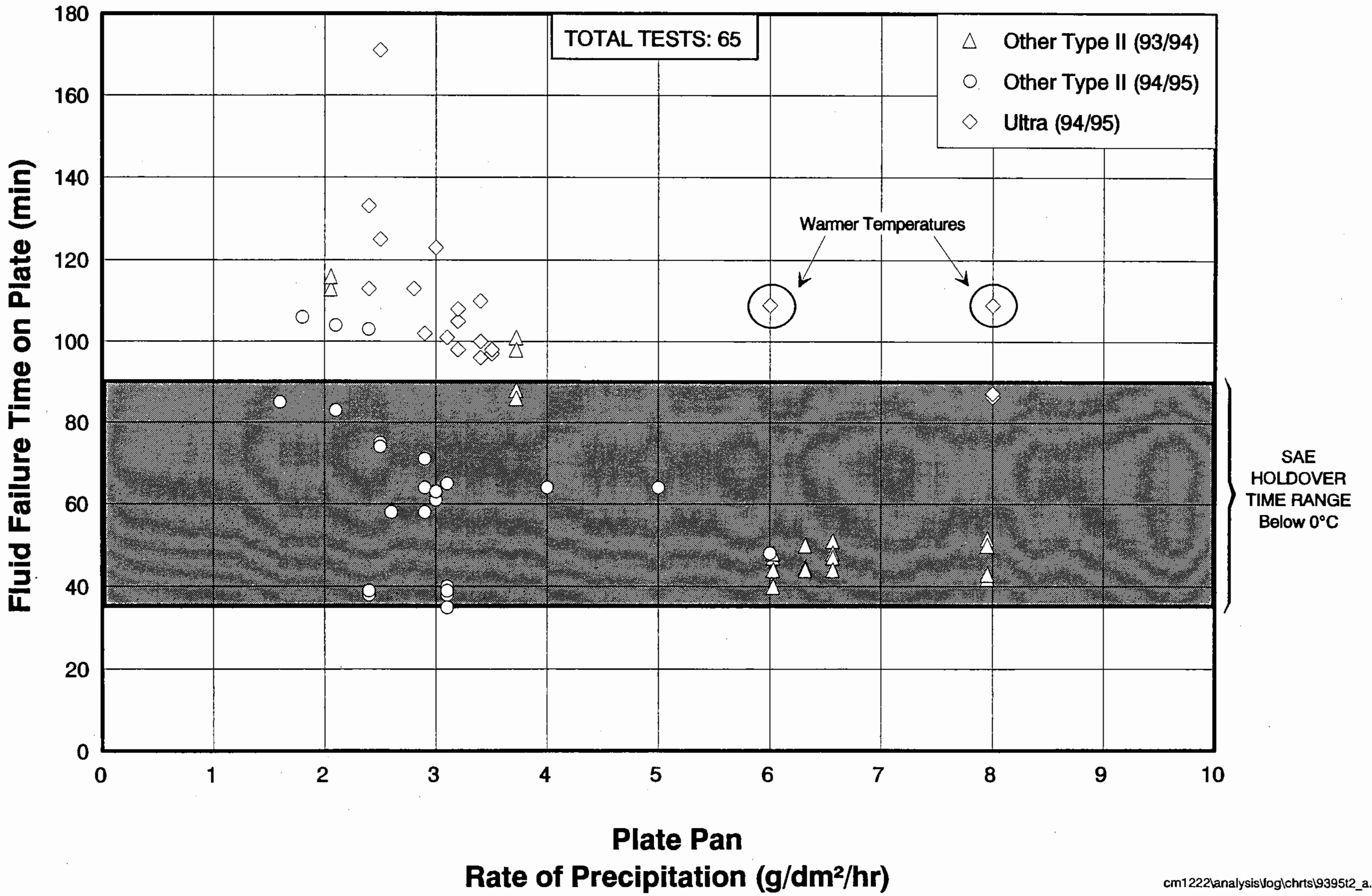


FIGURE 5.41

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II NEAT FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1993 - 1995

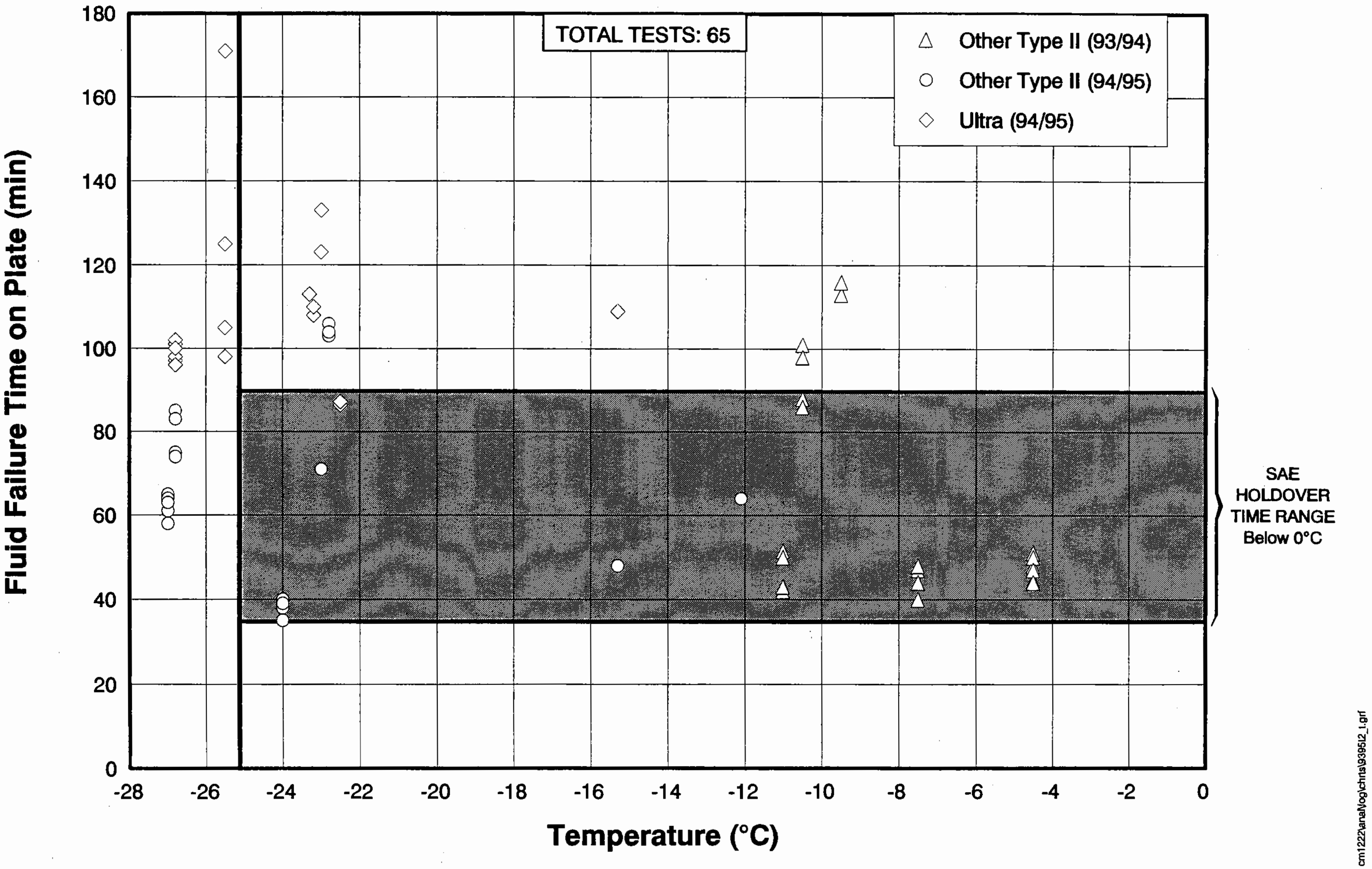


cm1222\analysis\fog\chrts\9395t2_a.grf

FIGURE 5.42

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II NEAT FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1993 - 1995



1.5 factor when using a new full certified Type IV fluid during freezing fog conditions for the 1995/96 winter.

5.1.3.4 Type II 75/25 Fluids under Simulated Freezing Fog

Figure 5.43 shows the effect of fluid type and rate of precipitation on Type II 75/25 fluid failure times in simulated freezing fog conditions. The test points designated by triangles were collected during outdoor tests in 1993/94 at NRC's Helicopter Icing Facility, and the remaining points in 1994/95 were obtained at NRC's indoor CEF. Figure 5.43 shows that rate of precipitation has a strong effect on plate failure time, and that the indoor and outdoor data appears to follow similar trends.

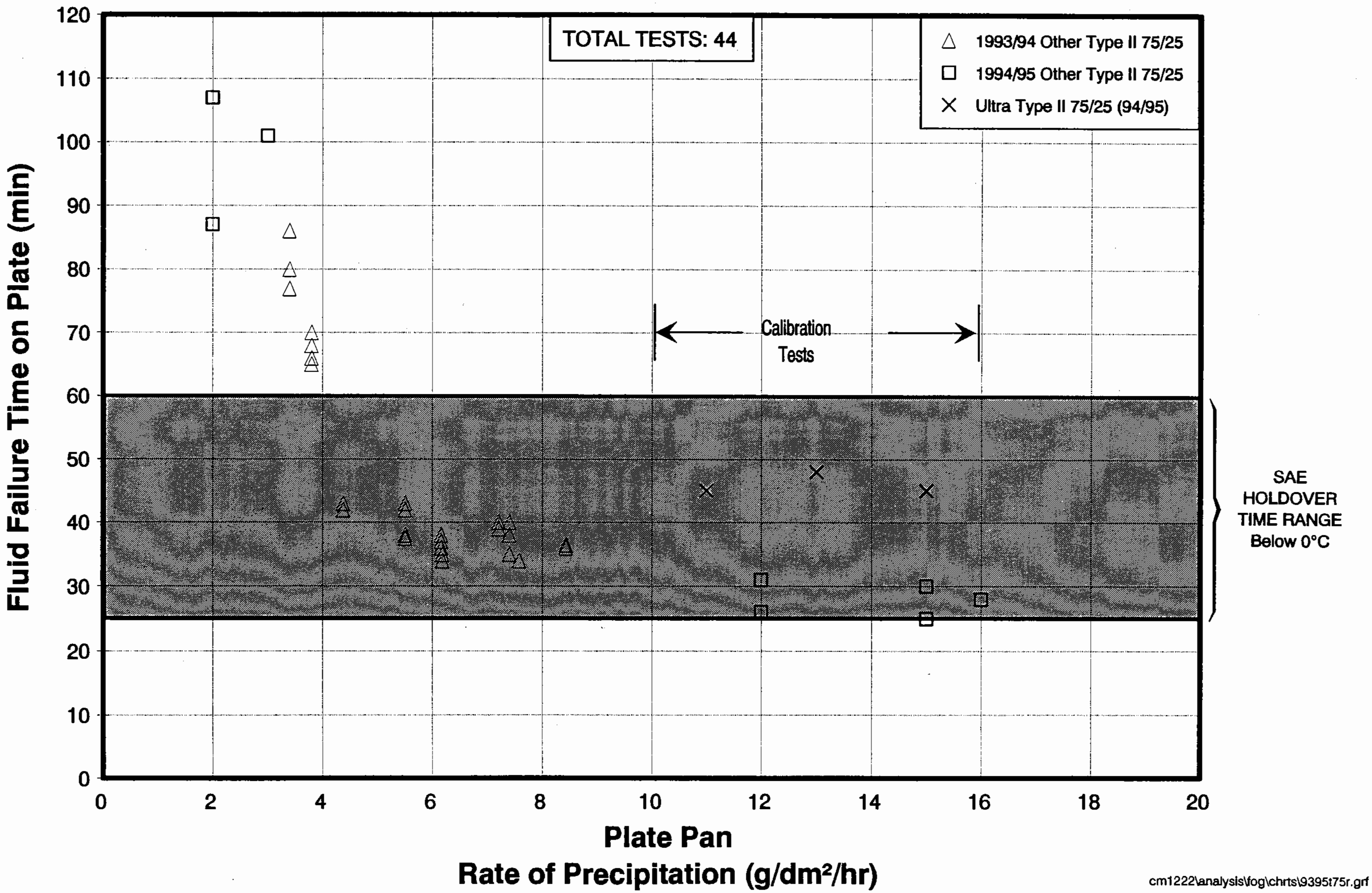
Figure 5.44 shows the same data plotted as a function of temperature. The chart shows that all the data falls within or above the SAE/ISO HOT range of 25 to 60 minutes, and therefore supports previous conclusions regarding substantiation.

The two figures also show the improved performance of UCAR Ultra 75/25 during the calibration tests. These calibration tests were conducted at low temperatures (-15°C) and very high deposition rates (freezing fog does not normally occur at rates greater than 10 g/dm^2/hr). While the three tests show that a factor of 1.5 would be suitable, more tests at the lower, more realistic deposition rates and higher temperatures are required.

FIGURE 5.43

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II 75/25 FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1993 - 1995

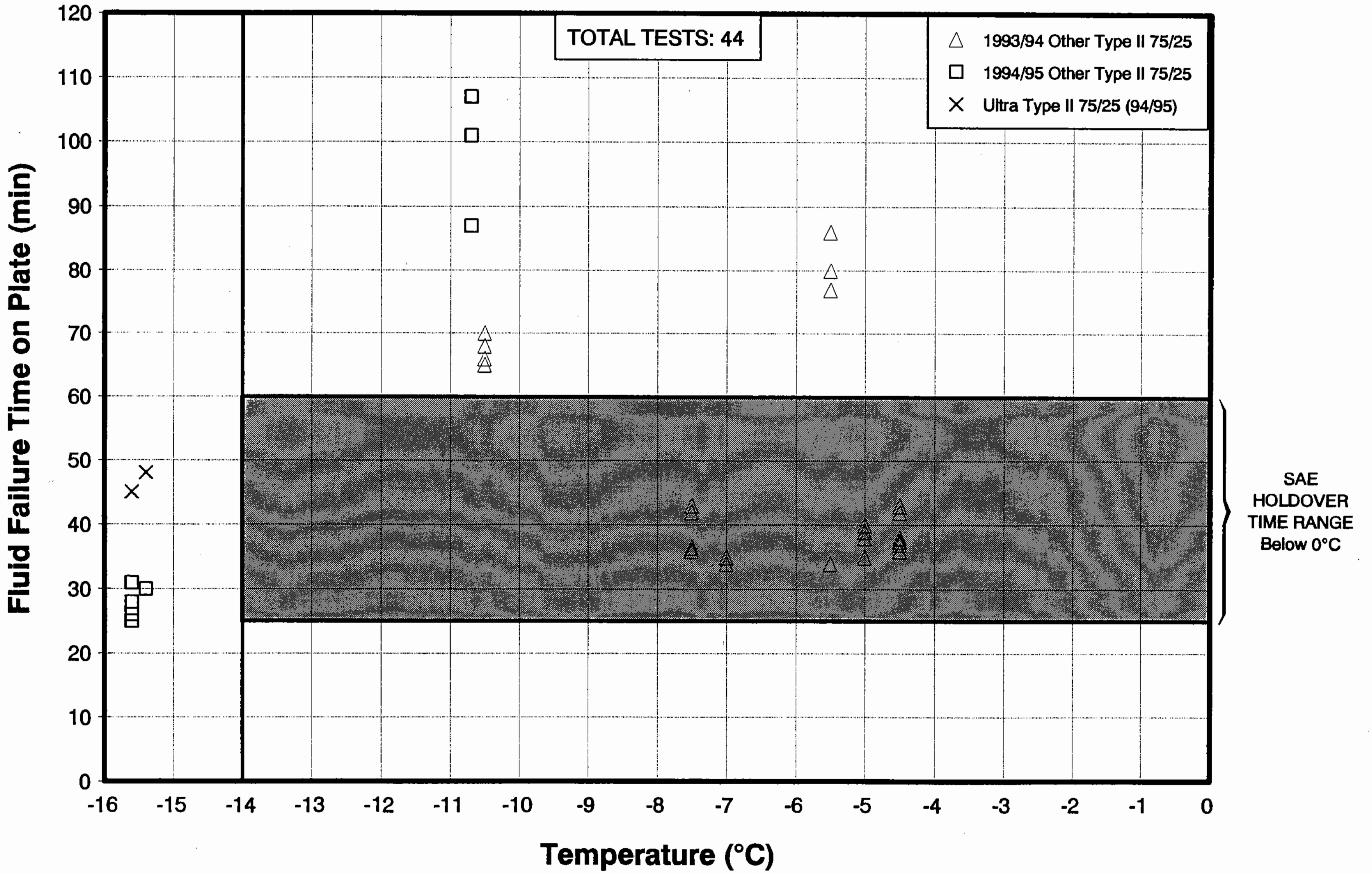


cm1222\analysis\fog\chrts\9395t75r.grf

FIGURE 5.44

EFFECT OF FLUID TYPE AND TEMPERATURE ON TYPE II 75/25 FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1993 - 1995



cm1222\analysis\fog\chrts\9395t75t.grf

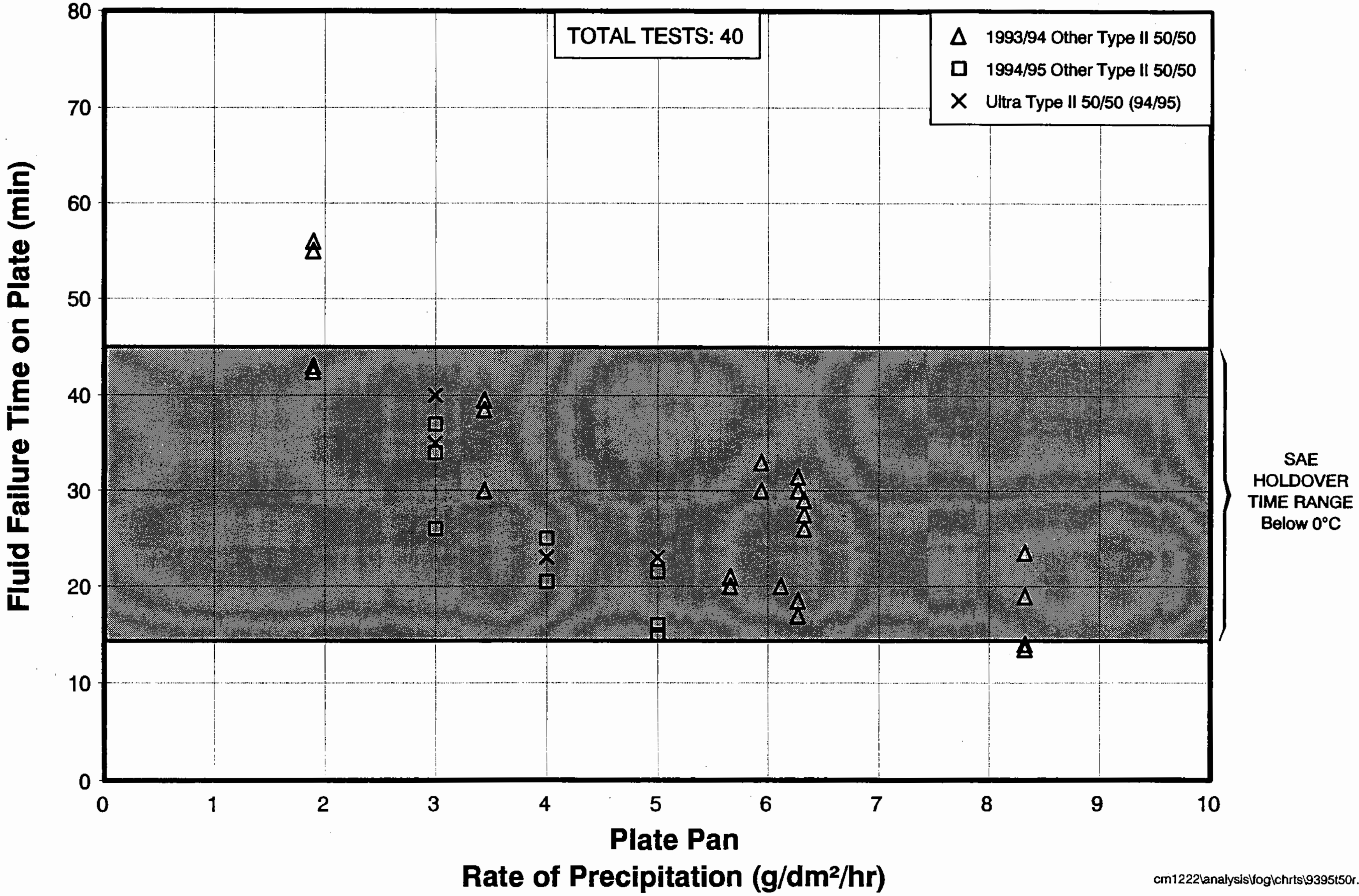
5.1.3.5 Type II 50/50 Fluids under Simulated Freezing Fog

Figure 5.45 shows the effect of rate of precipitation on Type II 50/50 fluid failure time in simulated freezing fog conditions. Tests from 1993/94 and 1994/95 are shown by different symbols. Twelve tests were conducted at NRC's indoor CEF in 1994/95. The tests confirmed that the SAE/ISO HOT lower limit needed the reduction from 20 minutes to 15 minutes. These tests also showed that the diluted Ultra Type II 50/50 was not significantly different than the other diluted Type II 50/50 fluids.

FIGURE 5.45

EFFECT OF FLUID TYPE AND RATE OF PRECIPITATION ON TYPE II 50/50 FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS

1993 - 1995



cm1222\analysis\fog\chrts\9395t50r.grf

5.1.4 Rain on Cold-Soaked Surface

The objective of the rain on cold-soaked box tests was to substantiate the current SAE/ISO HOT's for both Type I and Type II fluids. This section provides a brief description of the methodology followed by the presentation of the data collected.

A cold-soaked surface is defined as one that is colder than the OAT and several degrees below the freeze point. This can occur when the outside air temperature (OAT) is greater than zero if the fuel in the wing is at low temperatures (below 0°C). Ice formation will occur on the wing following the freezing of rain drops on an unprotected wing surface. This problem usually occurs in the immediate area of the fuel tank and is most likely for "wet" wings (where the fuel touches the wing). In many cases, de-icing followed by anti-icing will be required, which puts an aircraft in a holdover time situation.

Tests were performed on the boxes, as in flat plate tests, and fluid failure times for different fluids on both boxes were obtained. The two boxes used were of similar dimensions except for the depths. One box was 15 cm deep and the other 7.5 cm deep.

The method used in relating the two boxes to a representative aircraft wing surface is provided in a related Transport Canada Report TP 12678E.

5.1.4.1 Data Analysis

5.1.4.1.1 Type II Neat

Figure 5.46 shows the effect of box size and rate of precipitation on Type II Neat (including Ultra) fluid failure time in cold-soak conditions. Figure 5.47 shows the same points plotted as a function of the box skin temperature.

Appendix I shows regression equation results for standard Type II Neat fluid failure (excluding Ultra) under cold-soak conditions for each of the two boxes. Figure 5.48 shows the plot of the regression equations of 7.5 cm box and the 15 cm box along with the data points (excluding Ultra). These curves are drawn for box skin temperatures of -10°C. The data shows that higher precipitation and lower temperatures shorten failure times. A curve corresponding to the projected Canadair RJ wing failure time is also shown, and was obtained by multiplying the time of the 7.5 cm box by 1.33 (see Transport Canada Report TP 12678E). The related Transport Canada Report TP 12678E indicates that a more accurate way to obtain an aircraft wing HOT would be to test a box with a matching time constant, or two boxes with time constants above and below that of the aircraft wing.

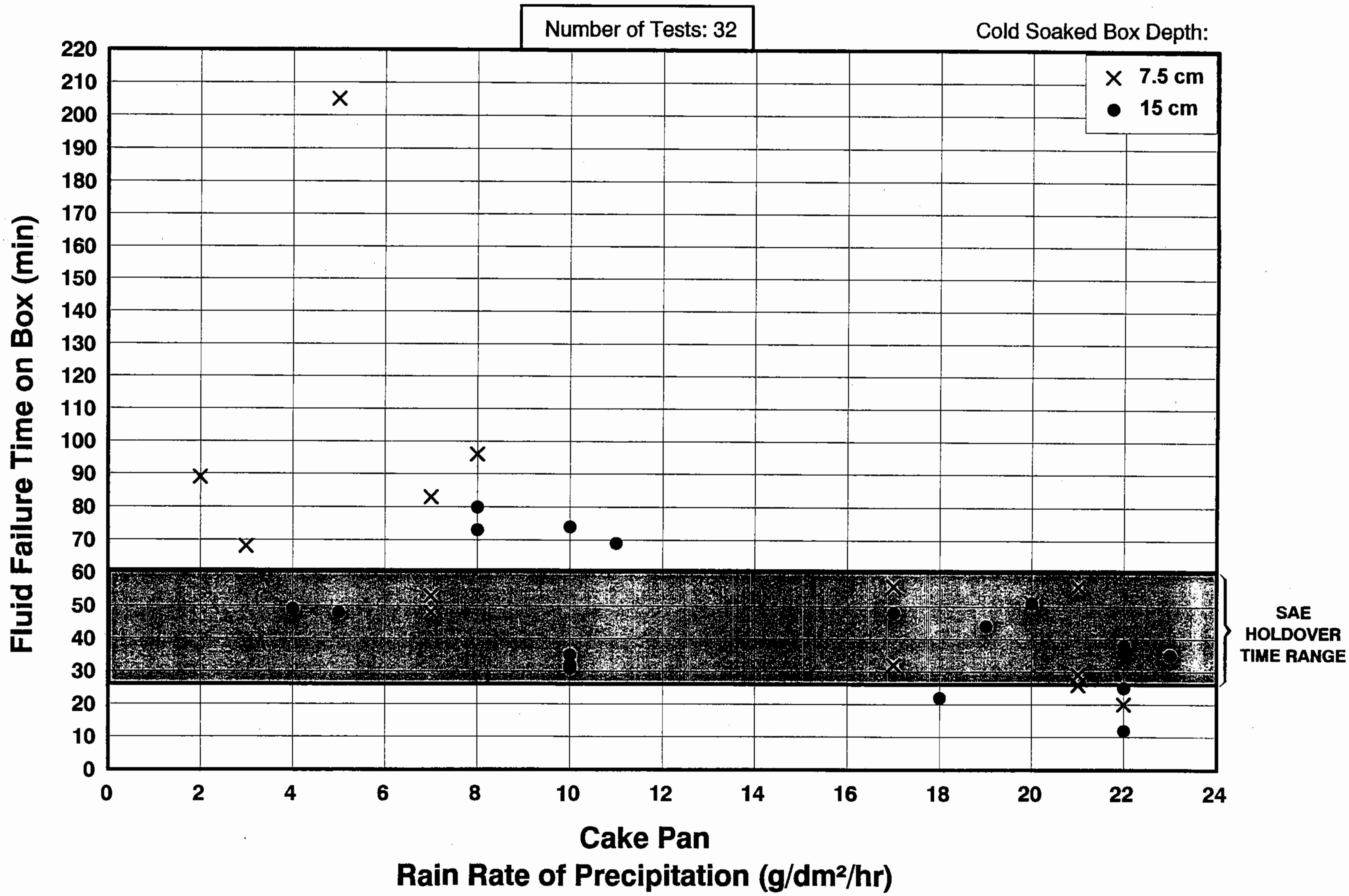
Figure 5.48 also shows the current SAE/ISO HOT range. The results from the tests show that the HOT range is "somewhat substantiated" for the Canadair RJ wing. Further testing[2] is required to study the effects of higher rates of precipitation and other wing types.

[2] The temperature data from testing conducted by Aviation Research Corporation needs to be integrated into this analysis. This would provide an indication of what the lower limit for temperature would be.

FIGURE 5.46

EFFECT OF BOX SIZE AND RATE OF PRECIPITATION ON TYPE II NEAT FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995

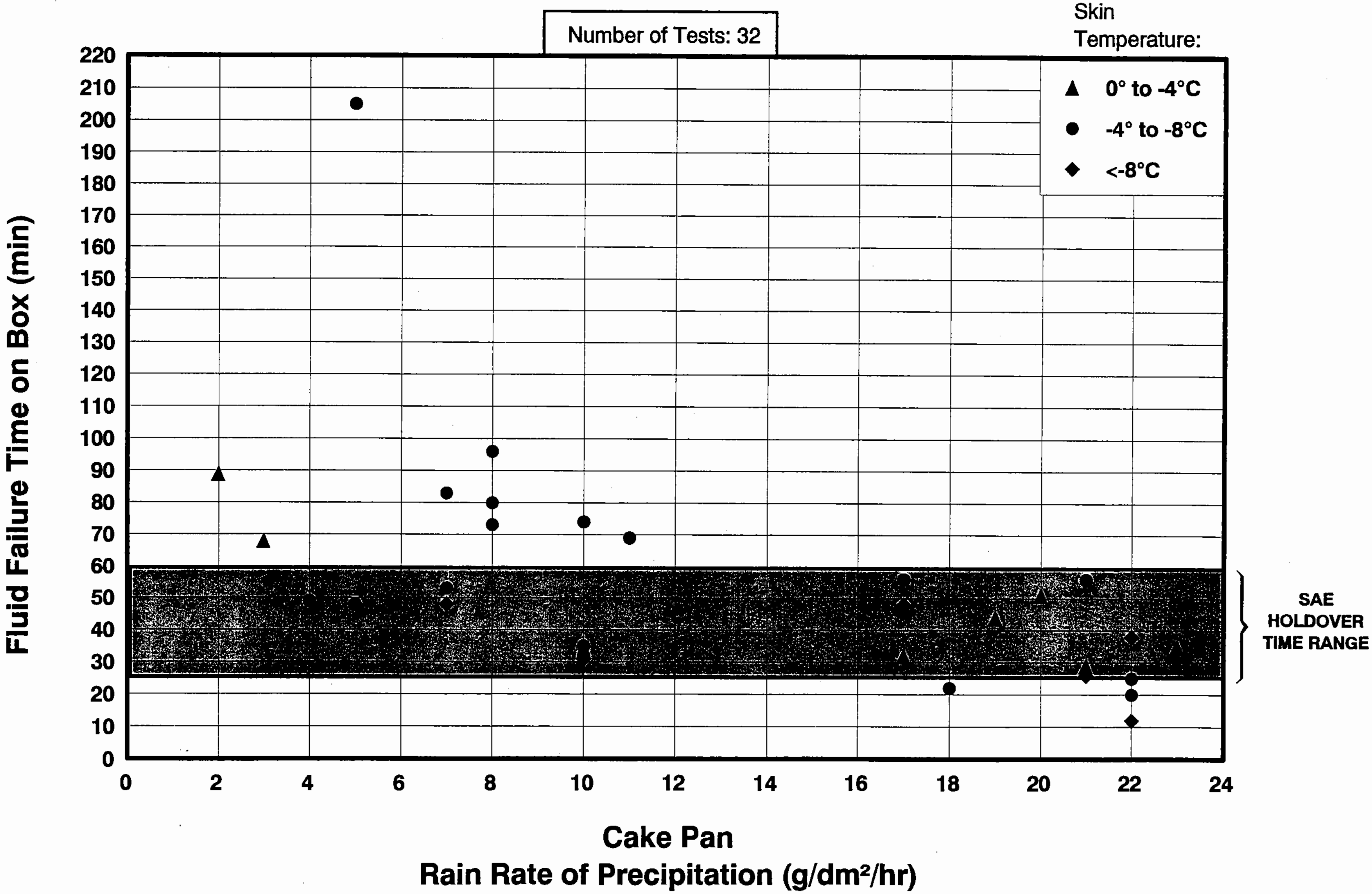


C1222\report\hot_subs\charts\coldsoak\2_r_b.GRF

FIGURE 5.47

EFFECT OF SKIN TEMPERATURE AND RATE OF PRECIPITATION ON TYPE II NEAT FLUID FAILURE TIME IN COLD SOAK CONDITIONS

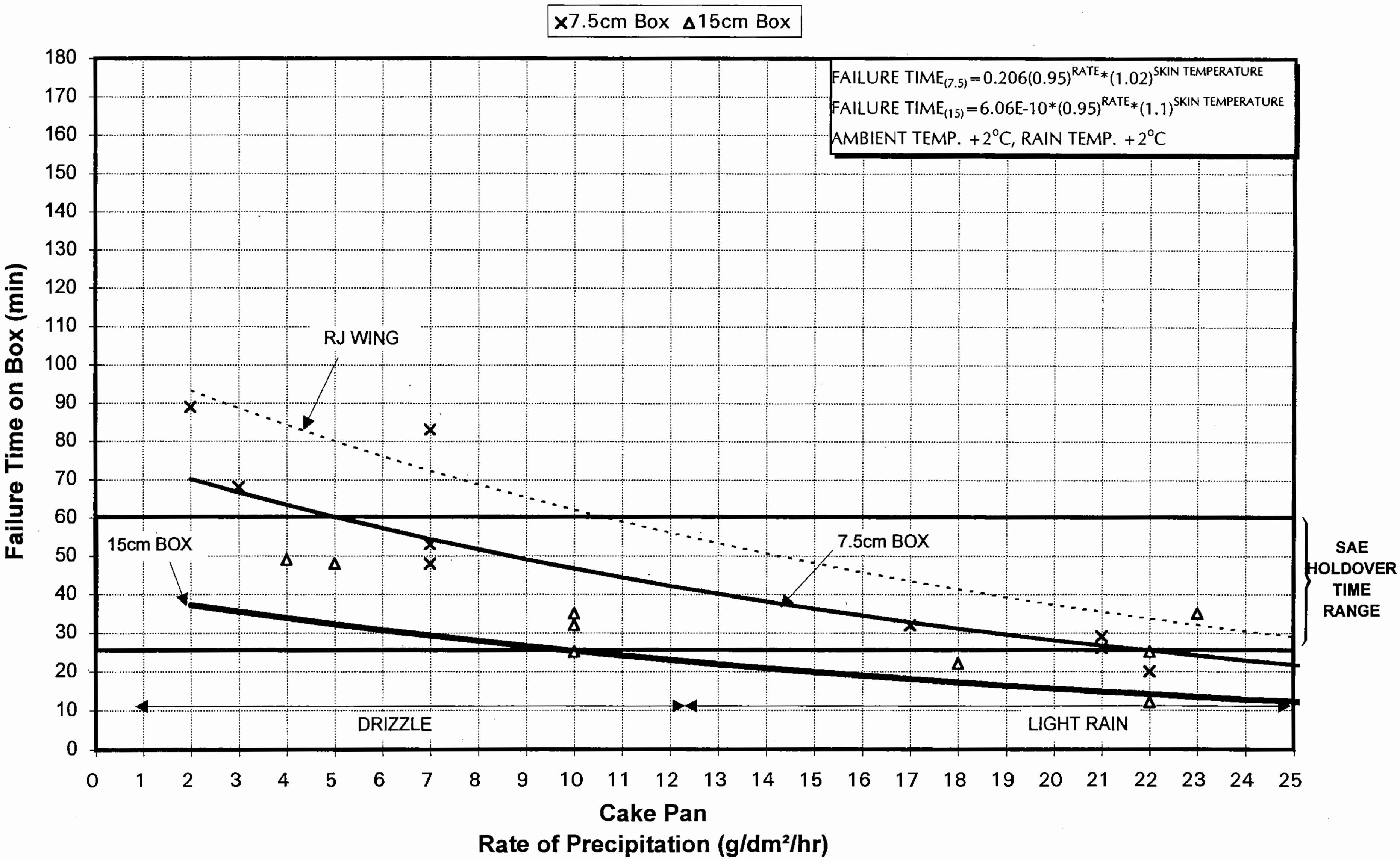
1994 - 1995



C1222\report\hot_subs\charts\coldsoak\t2_r_l.GRF

FIGURE 5.48

PROJECTED RJ FAILURE TIME CURVE FOR STANDARD TYPE II NEAT FLUID



cm1222\report\hot_subs\charts\coldsoak\3C_T2.XLS
T2 neat (with pts)

Ultra was tested concurrently with conventional Type II fluids under various rates of precipitation and at several box skin temperatures. In general, Ultra was found to be superior to conventional Type II fluids when applied on cold-soaked surfaces at full strength. Ultra failure times were found to exceed conventional Type II fluid failure times by a ratio of 1.5 to 2.5 for both box sizes depending on the rate of precipitation and box skin temperature.

5.1.4.1.2 Other Fluids

The previous subsection showed the results of Neat Type II fluids. This section shows the data from Type II 75/25, Type II 50/50 and Type I tests. The charts, listed below, show the results of fluid failure time on the box versus the rate of precipitation for the tests conducted at the CEF during the 1994/95 winter. Each chart shows the associated current SAE/ISO HOT range.

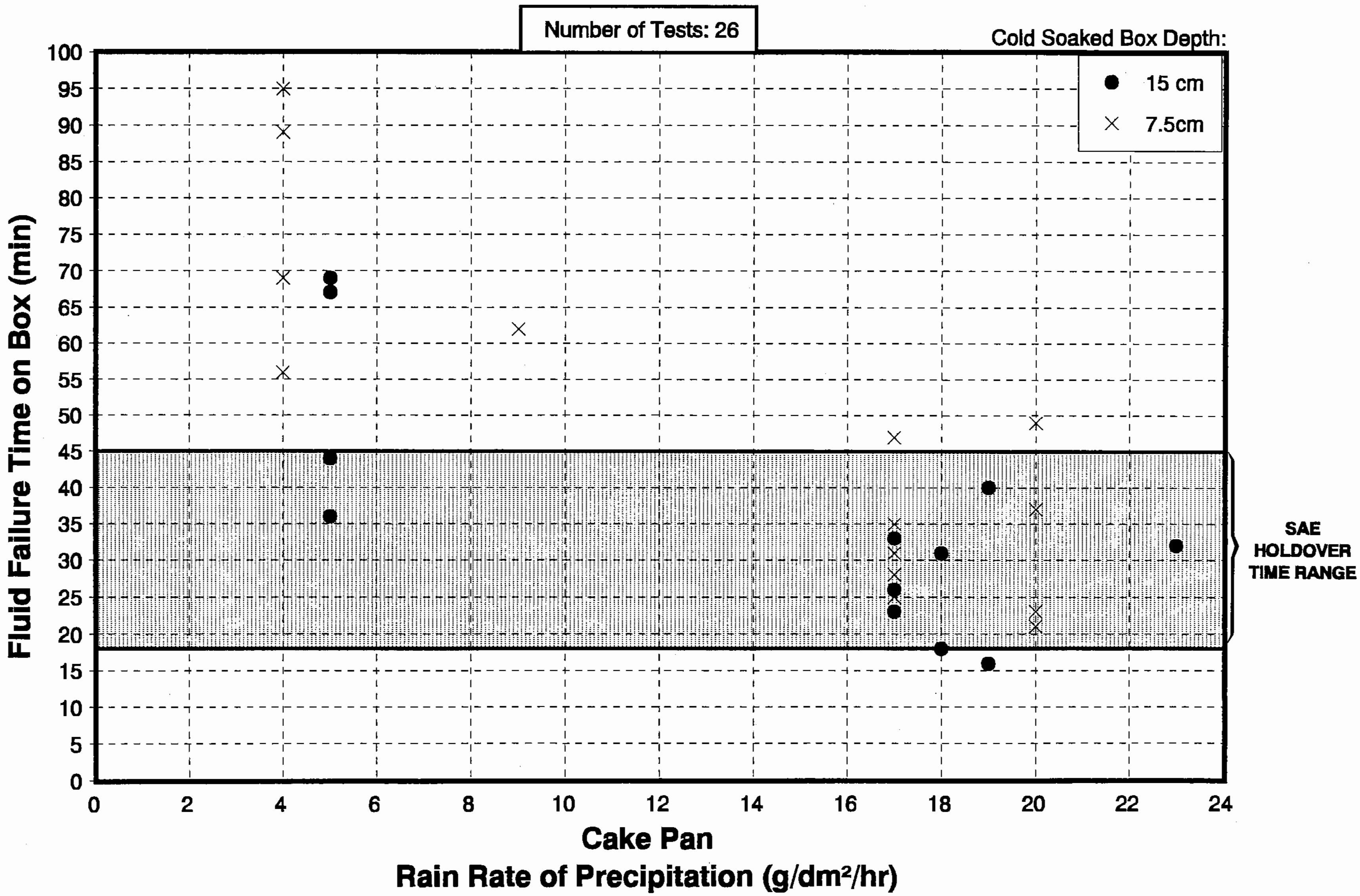
Figure 5.49	Type II 75/25	Effect of box depth
Figure 5.50	Type II 75/25	Effect of skin temperature
Figure 5.51	Type II 50/50	Effect of box depth
Figure 5.52	Type II 50/50	Effect of skin temperature
Figure 5.53	Type I diluted	Effect of box depth
Figure 5.54	Type I diluted	Effect of skin temperature
Figure 5.55	Type I standard	Effect of box depth
Figure 5.56	Type I standard	Effect of skin temperature

In the previous sub-section, a scale factor of 1.33 was applied to the test results of the small box to get the projected results of a full-scale wing. If this factor was applied to the Type II 75/25 fluid tests, Figures 5.49 and 5.50 show that the SAE/ISO HOT range for Type II 75/25 is "somewhat substantiated". Figures 5.51 to 5.54 show that the SAE/ISO

FIGURE 5.49

EFFECT OF BOX SIZE AND RATE OF PRECIPITATION ON TYPE II 75/25 FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995



cm1222\analysis\coldsoak\charts\75_r_b.GRF

FIGURE 5.50

EFFECT OF SKIN TEMPERATURE AND RATE OF PRECIPITATION ON TYPE II 75/25 FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995

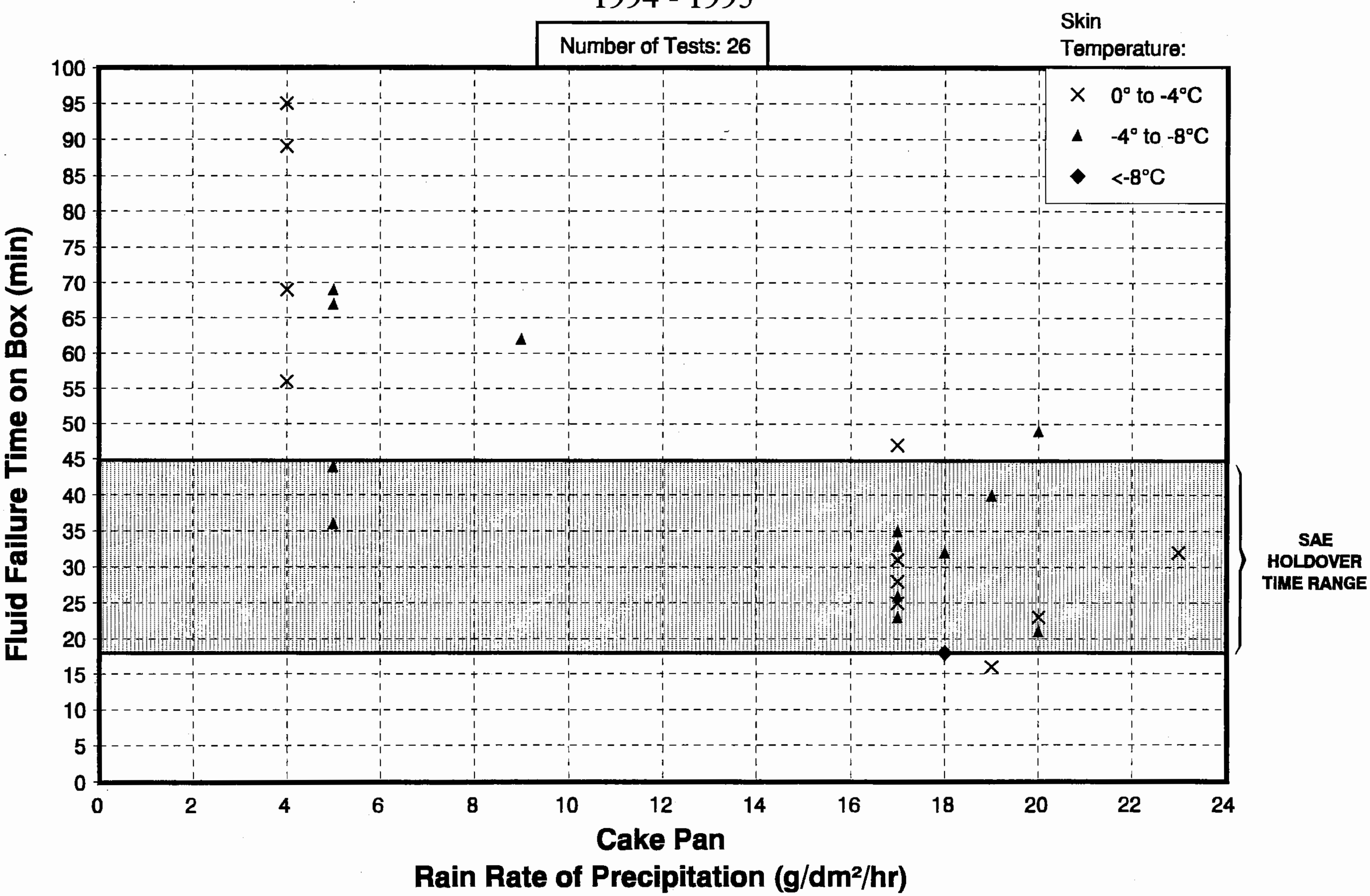
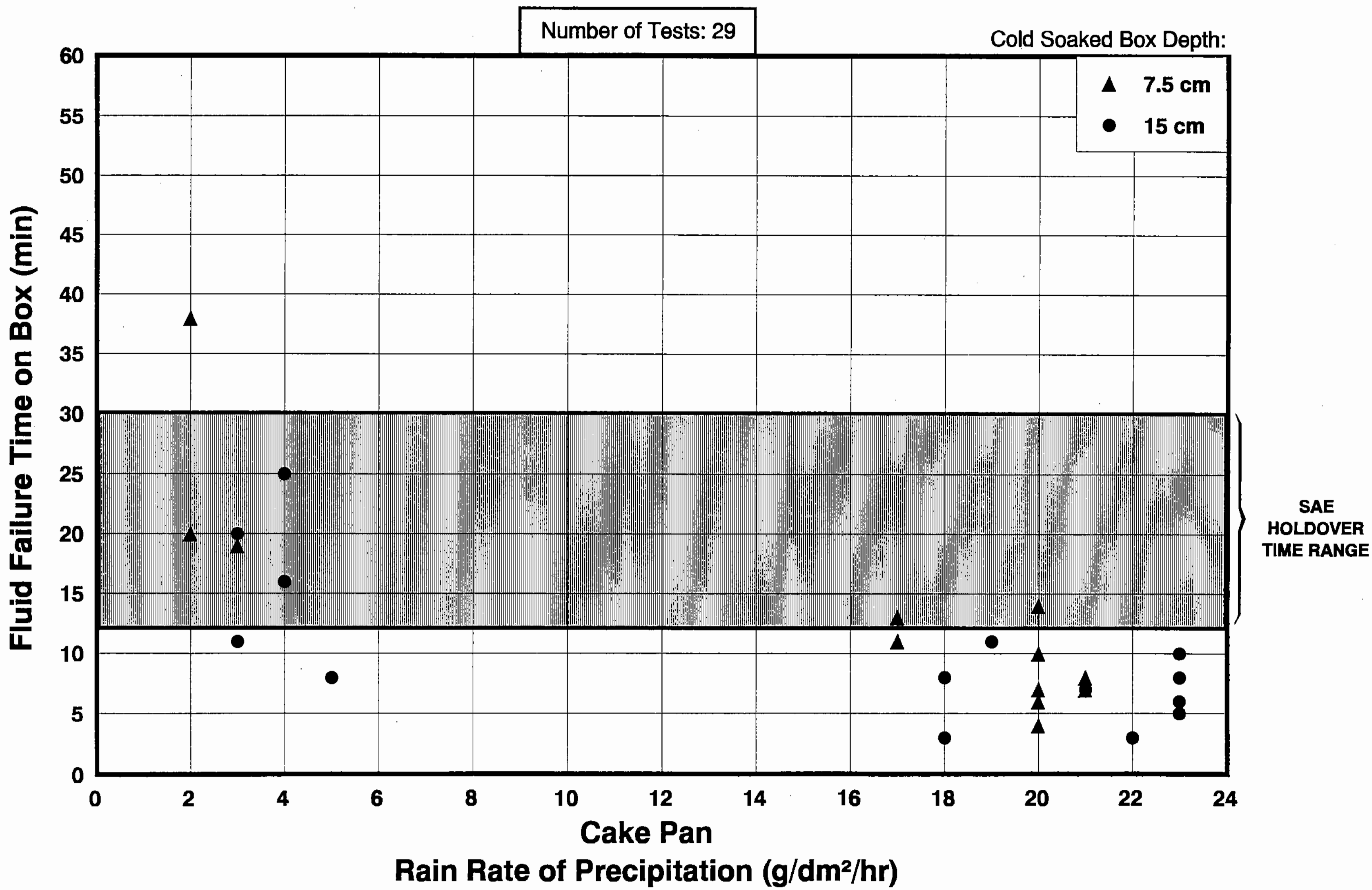


FIGURE 5.51

EFFECT OF BOX SIZE AND RATE OF PRECIPITATION ON TYPE II 50/50 FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995

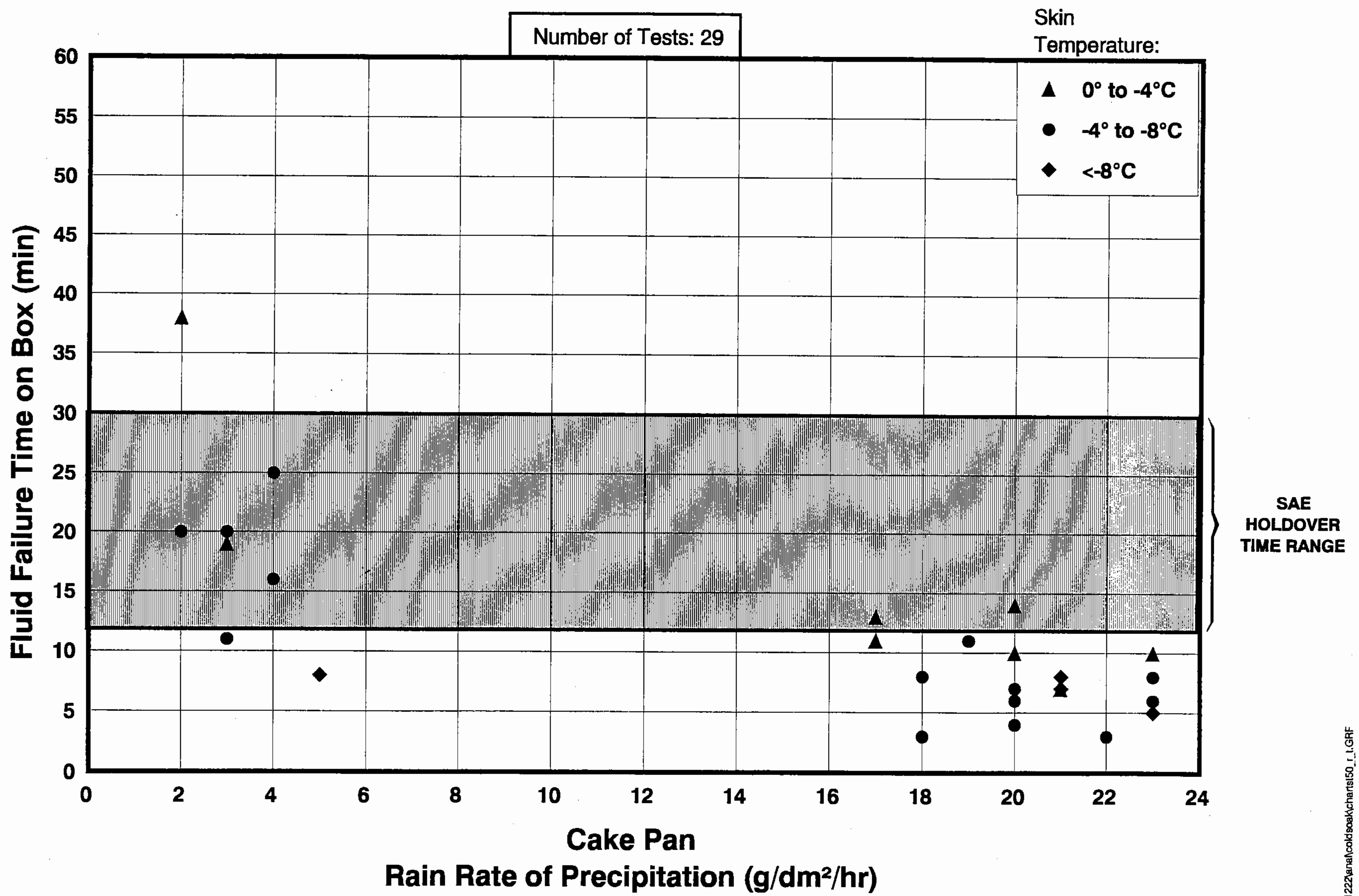


cm1222\anal\coldsoak\charts\50_r_b.GRF

FIGURE 5.52

EFFECT OF SKIN TEMPERATURE AND RATE OF PRECIPITATION ON TYPE II 50/50 FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995

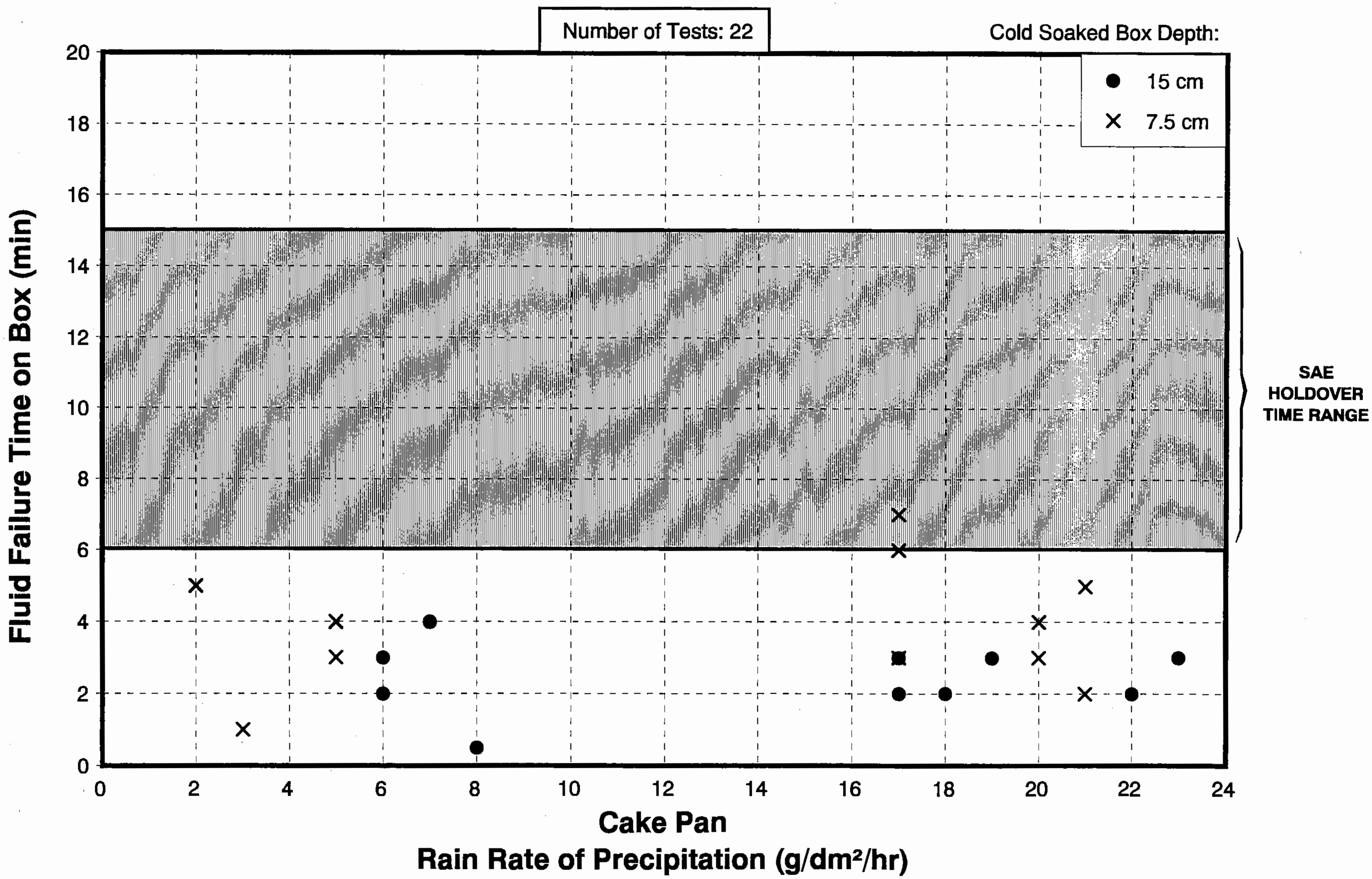


cm1222\anal\coldsoak\charts\50_r_I.GRF

FIGURE 5.53

EFFECT OF BOX SIZE AND RATE OF PRECIPITATION ON DILUTED TYPE I FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995

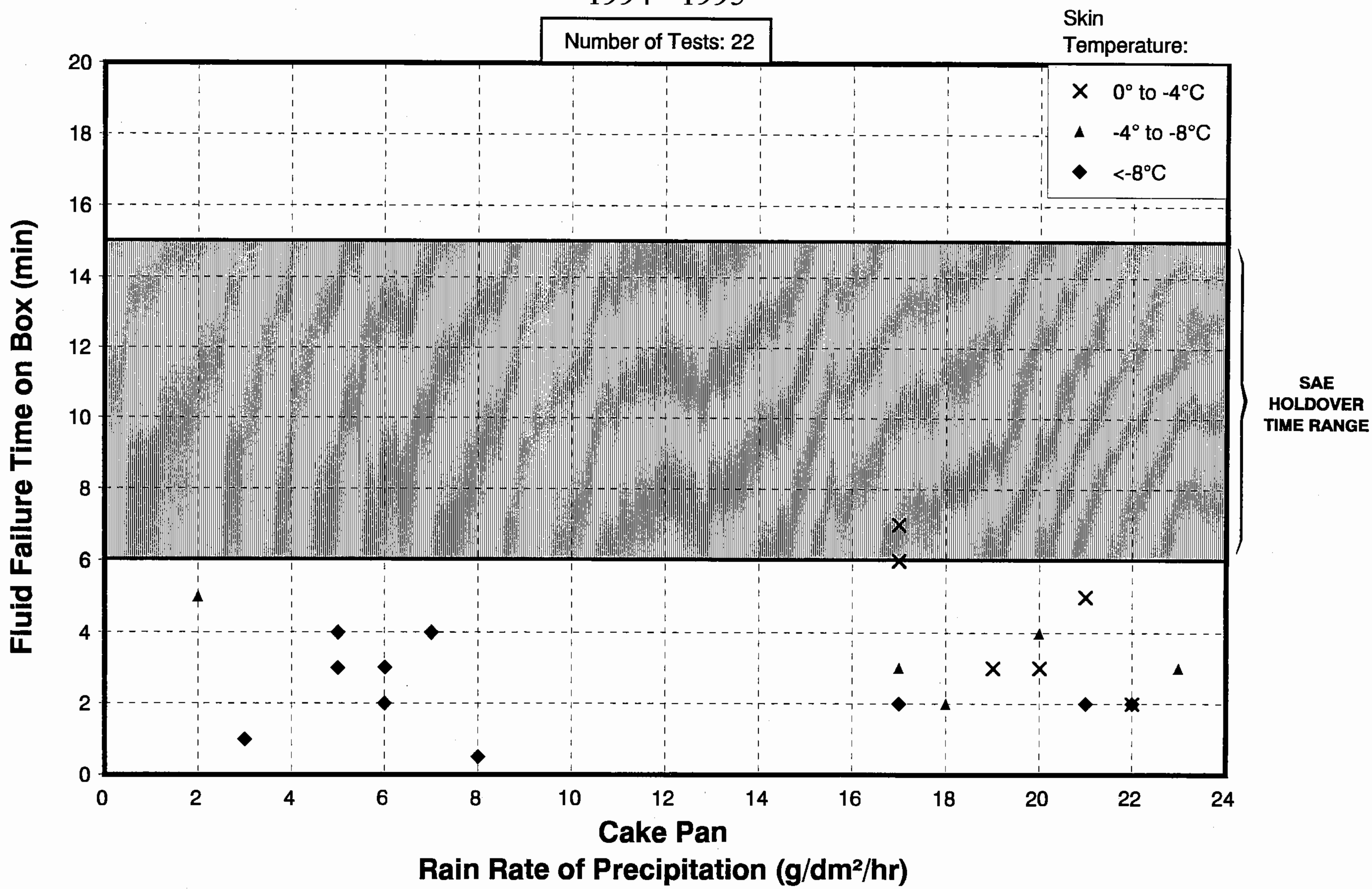


cm1222\ana\coldsoak\charts\1d_r_b.GRF

FIGURE 5.54

EFFECT OF SKIN TEMPERATURE AND RATE OF PRECIPITATION ON DILUTED TYPE I FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995

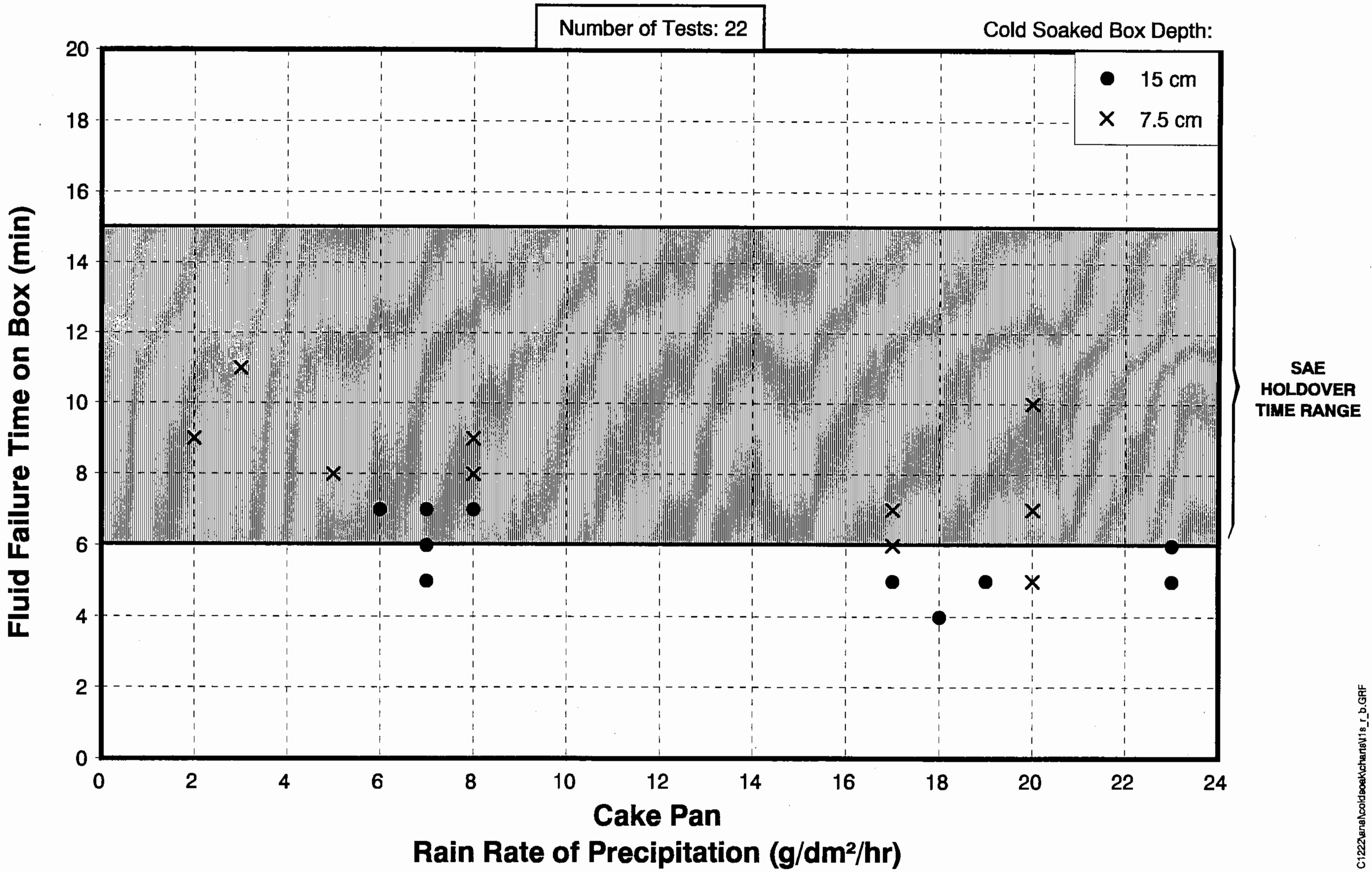


C1222\ans\coldsoak\charts\t1d_r_l.GRF

FIGURE 5.55

EFFECT OF BOX SIZE AND RATE OF PRECIPITATION ON STANDARD TYPE I FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995

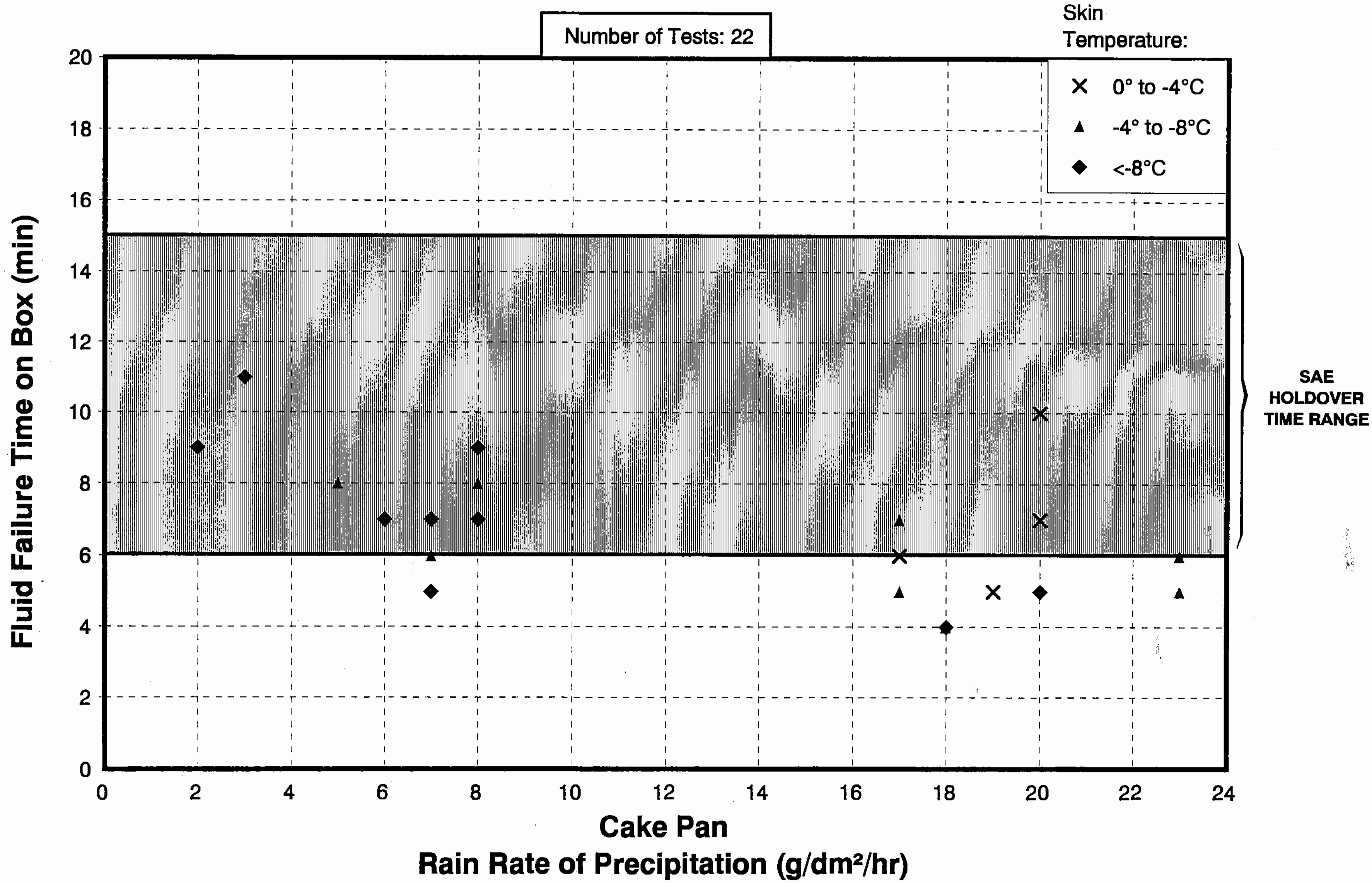


C1222\ena\coldsoak\charts\1s_r_b.GRF

FIGURE 5.56

EFFECT OF SKIN TEMPERATURE AND RATE OF PRECIPITATION ON STANDARD TYPE I FLUID FAILURE TIME IN COLD SOAK CONDITIONS

1994 - 1995



HOT range for Type II 50/50 and diluted Type I fluids may require a slight reduction. Figures 5.55 and 5.56 show that the standard Type I would be a more appropriate Type I fluid under rain on cold-soaked wing conditions. Alternately, diluted Type I should only be used as a de-icing agent in a two-step procedure using standard Type I in the second step.

5.2 Ice Sensor Tests

For the 1994/95 winter program, ice sensors were used to assist and support testing conducted on flat plates as well as aircraft. The Transport Canada Report TP 12595E, **"Aircraft Full-Scale Test Program for the 1994/95 Winter"** contains the results from a test conducted to determine the pattern of fluid flow on a wing during taxi and take-off, as well as the results from the temperature history tests. These tests were conducted on full-scale aircraft and the appropriate parameters were measured using aircraft wing flush-mounted C/FIMS sensors.

This report includes a discussion of the results from the use of C/FIMS on flat plates tested at Dorval and from the use of RVSI's ID-1 remote sensor. One ID-1 was mounted on the flat plate test stand at Dorval, and a second sensor was initially used in Cold Chamber tests at NRC in Ottawa and then mounted on a Canadian Airlines de-icing vehicle in Toronto.

The ice sensor tests are primarily flat plate tests with Instrumar's C/FIMS and RVSI's ID-1 ice sensor. Instrumar's sensors are point sensors mounted on the flat plate at the 6 inch (15 cm) line, where failure is normally reported. RVSI's sensor can view the area of a large surface, and was mounted for viewing an area of 1.2 x 2.4 metres (4 x 8 feet). A more detailed description of the two sensors is provided in the subsequent sections.

5.2.1 C/FIMS Sensor Analysis

The Instrumar C/FIMS sensor has been used extensively through APS' past and present testing activities. The sensor results usually correlated well with the visual end condition calls made by the human observer.

Figure 5.57 shows the C/FIMS impedance trace for its three channels A, B and C for a test conducted at Dorval. The outside observer (o) fluid failure point is indicated by a solid line at 15:02 or 67 minutes into the test. Four arrows were marked on the chart and designate the times that four different observers (1, 2, 3, 4) independently determined the fluid failure point after inspection of the curves. One of these observers was from Instrumar, and the three other observers were from APS. The curve inspection failure times range from 74 to 80 minutes into the test. This indicates that the failure time judgements are comparable.

Figure 5.58 shows the failure determinations from all of the observers in bar chart format for 14 different tests, including the one shown in Figure 5.57. Again, it can be seen that the independent failure determinations are comparable with each other. The failure time determinations by the four observers were averaged and this value was plotted in Figure 5.59 against the corresponding outside observer failure time. The plot shows that the points do not deviate much from the one-to-one relationship line. The circled points show the largest deviation from the one-to-one line. These may have been called prematurely by the outdoor observer due to the increase in snowfall rate just prior to failure time. Overall, there was a good correlation between the C/FIMS sensor judgement of failure by observation of the curves and the failure call by the outside observer.

FIGURE 5.57

C/FIMS #17 SENSOR TRACE

NATURAL SNOW

Fluid A-201, Type II Neat

Feb 04/95, Form 42 (Run #1), Plate V

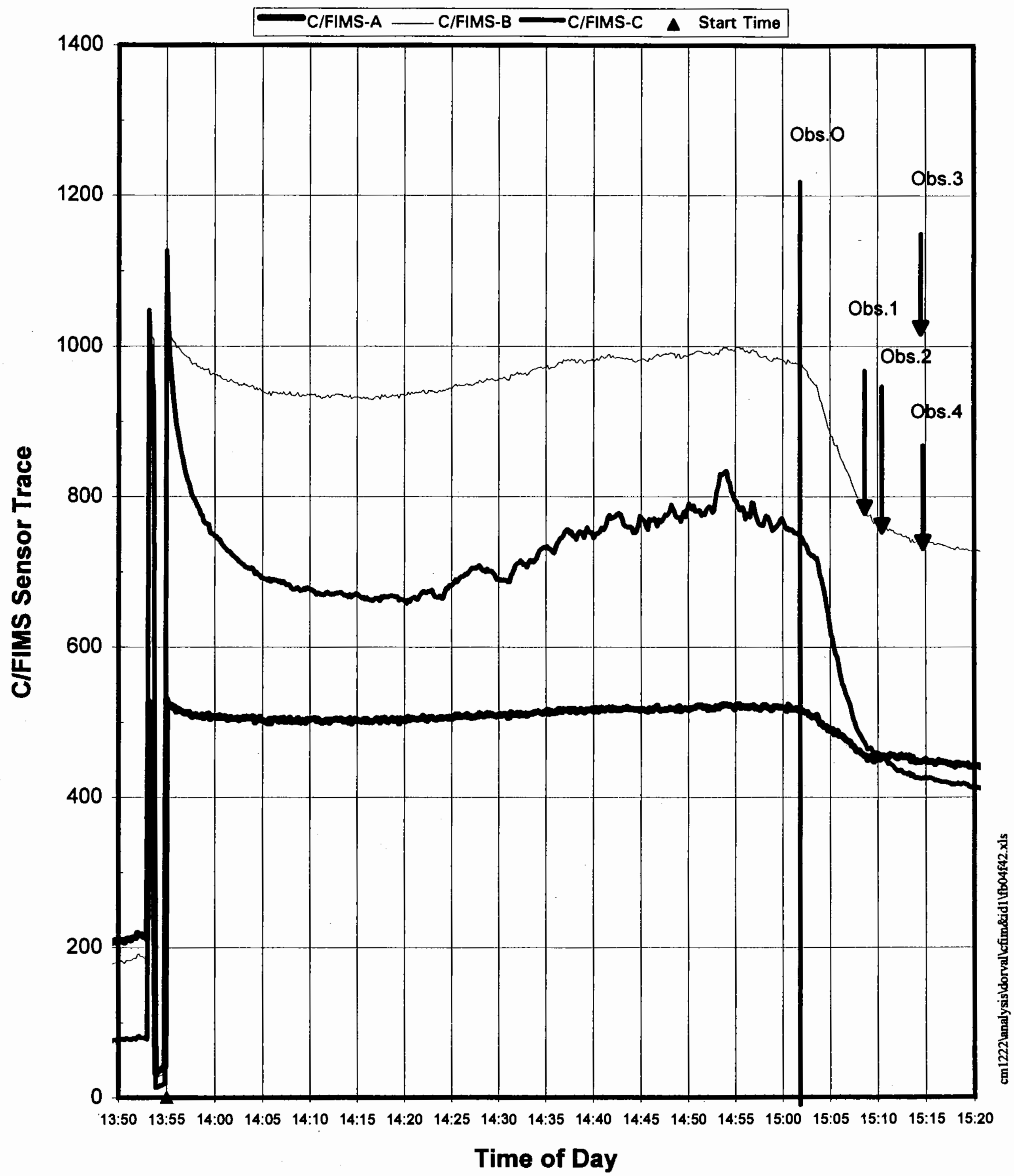
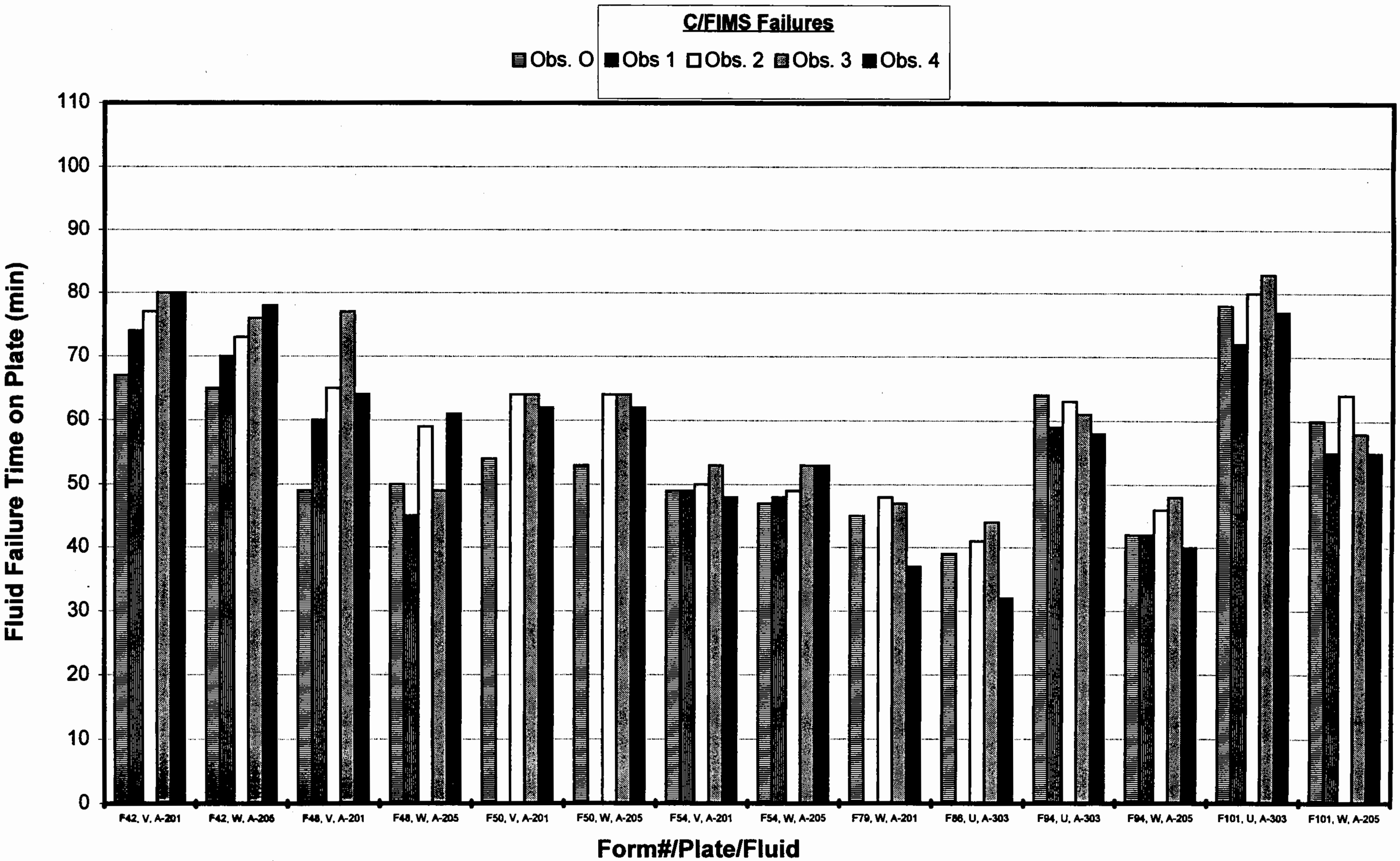


FIGURE 5.58

COMPARISON OF OBSERVED AND C/FIMS SENSOR FAILURE TIME DURING NATURAL SNOW CONDITIONS

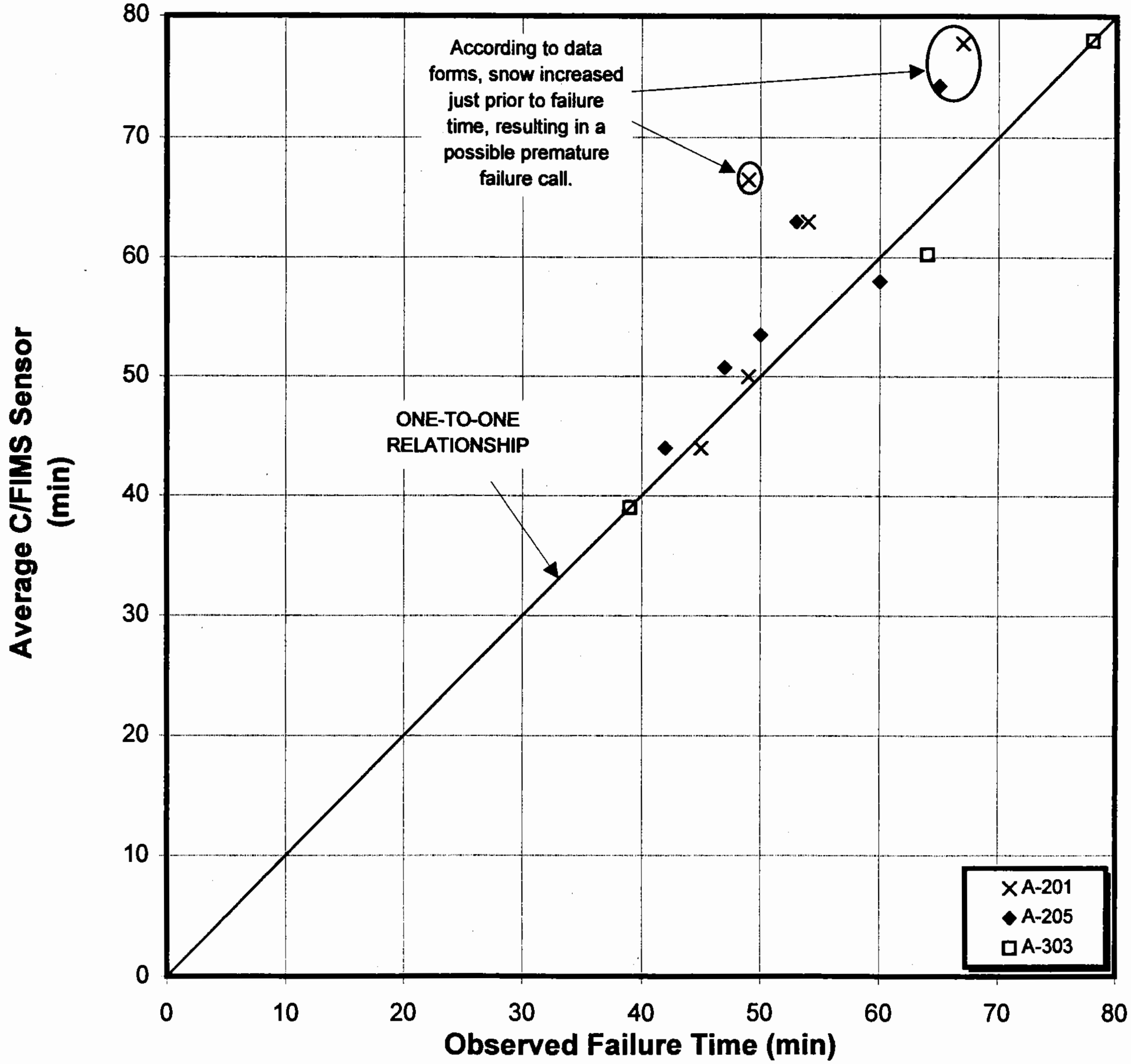
1994/1995



CFIMS Time, 29/05/96
cm1222\analysis\dorval\charts\ratiot2.xls

FIGURE 5.59

COMPARISON BETWEEN FLUID FAILURE TIMES OF OBSERVER AND AVERAGE C/FIMS SENSOR DURING NATURAL SNOW CONDITIONS 1994/1995



cm1222\analysis\dorval\charts\RATIOT2.XLS
CFIMS vs Obs (1 to 1), 28/05/96

5.2.2 RVSI'S ID-1 Tests

The RVSI ID-1 external ice detection sensor was purchased from RVSI for testing at Dorval. An additional sensor was leased and installed on a de-icing vehicle at Pearson International Airport to be used during the full-scale tests. Due to the lack of snow in Toronto during overnight hours, it was only used for the single test event.

RVSI's technology detects ice by electro-optical means and can help verify the safe condition of entire aircraft surfaces in a short time. The ID-1 was designed to provide inspection of critical surfaces in adverse winter conditions on large commercial jets or small commuters. It is claimed that the technology can be adapted to both ground-based and airborne ice detection systems and is expected to have significant safety, economic, and environmental benefits.

The ID-1 unit at Dorval is mounted on the test stand as shown in Figure 5.60, and because it is a visual system with video display capabilities, it can show results of the scanned image on an indoor computer monitor instantaneously. The Toronto RVSI unit was installed on the bucket of the de-icing truck (see Photo 5.1) with the scanned image being returned through the monitor screen on the unit or on the monitor in the cab (see Photo 5.2). The Toronto unit was initially tested at the CEF in Ottawa. Details relating to the installation and operation of the RVSI unit are provided in Appendix F.

Tests were also conducted with the ID-1 mounted on the stand during indoor CEF tests in Ottawa under simulated freezing fog, drizzle, light freezing rain and cold-soak tests.

FIGURE 5.60
RVSI ID-1 SENSOR MOUNTING

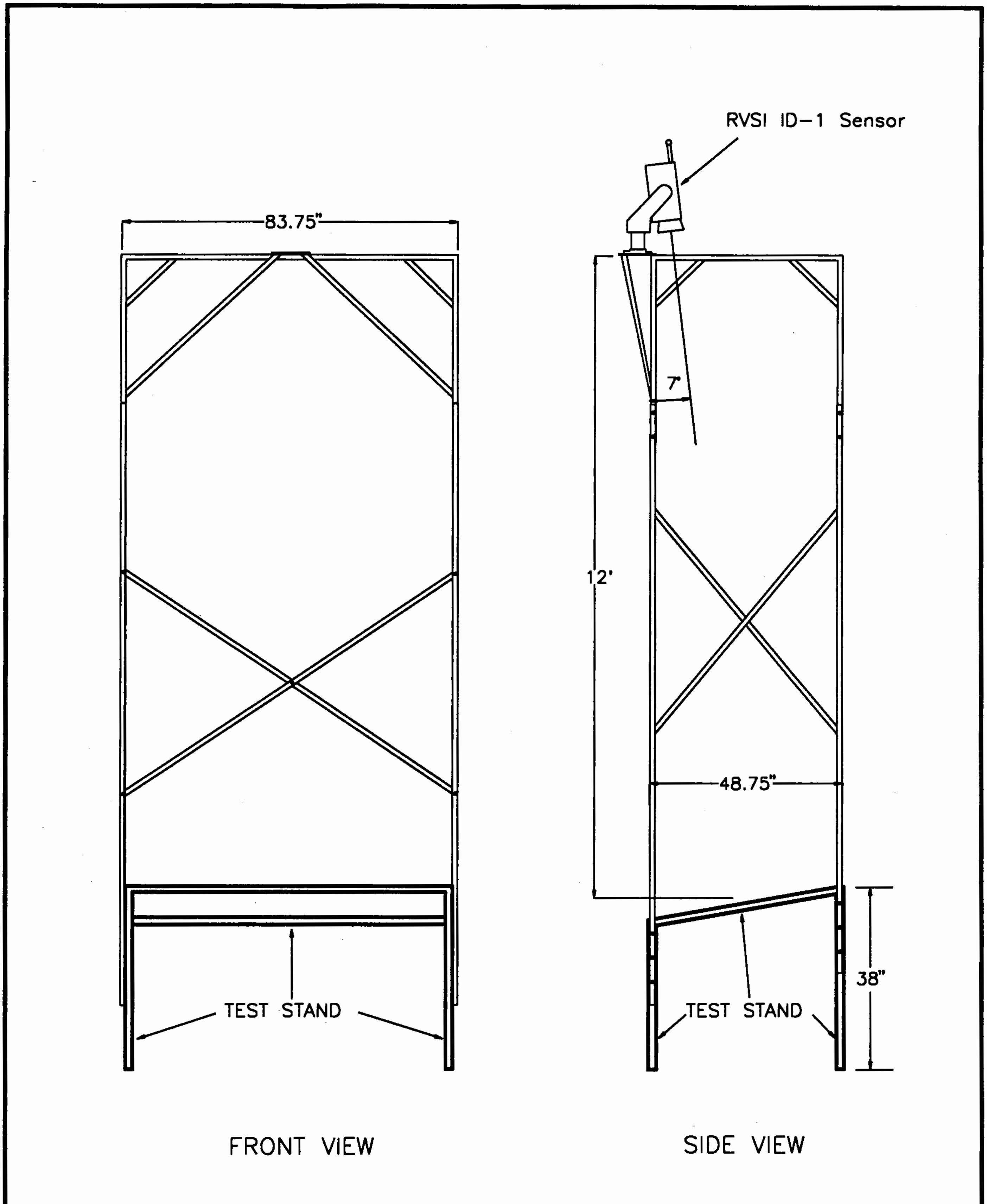
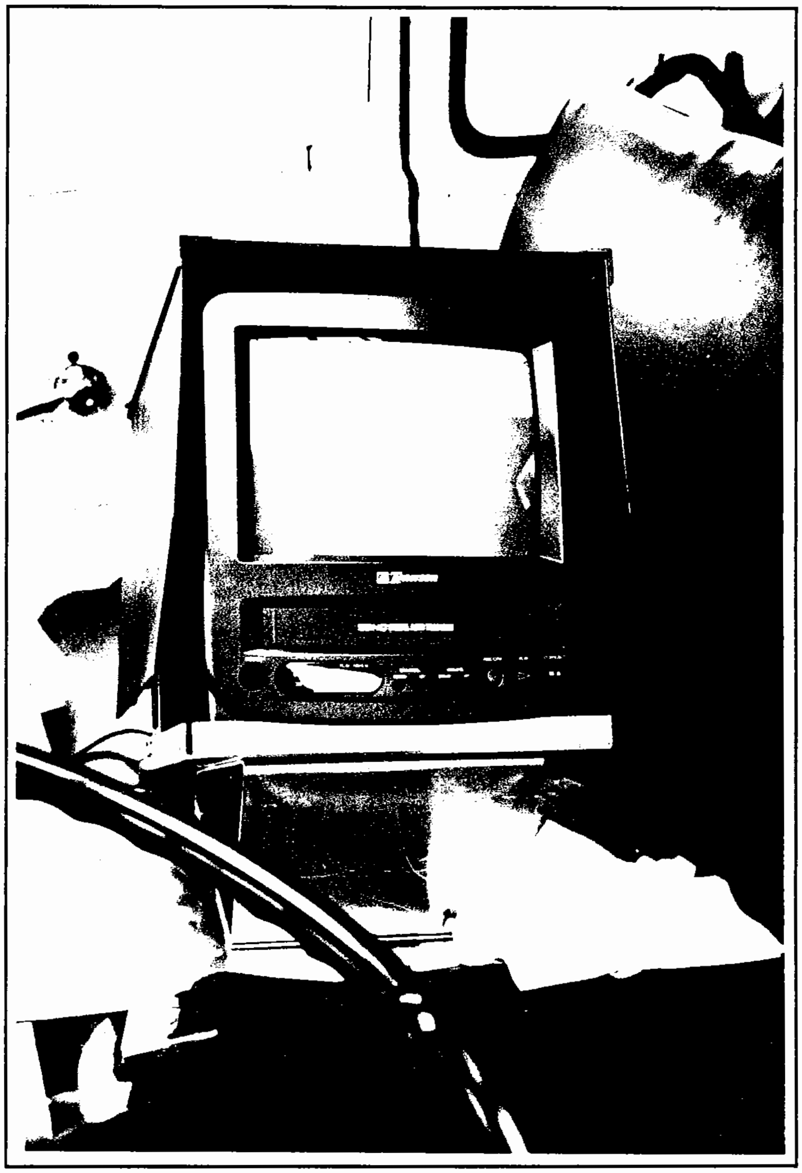


PHOTO 5.1
INSTALLATION OF RVSI ID-1 REMOTE ICE DETECTION SYSTEM ON CAI's DE-ICING VEHICLE

PHOTO 5.2
VIDEO DISPLAY IN CABIN OF DE-ICING VEHICLE



5.2.2.1 ID-1 Position Tests at the CEF

The objectives of the RVSI ID-1 position tests were to verify the performance and suitability of the sensor prior to field use. The conditions which were examined included the effect of lighting on the test panels, positioning of the sensor with respect to the plates, and temperature in the chamber. The experimental plan for these tests is included as Appendix G.

As part of these tests, C/FIMS sensors were mounted on the plates to ensure that consistent conditions and precipitation rates were experienced from one test to another when assessing the effect of various conditions on RVSI's ID-1. The C/FIMS signatures were verified and these showed consistent results.

The ID-1 can display the ice intensity level for each of the 60000 pixels in its image. For analysis purposes, the scanned images can be replayed with up to eight colour resolutions showing differing ice contamination intensities (or ice confidence levels) (see Appendix F). Approximately 26 tests were conducted to study the effect of fluid type, fluid concentration, position and illumination. For each test, the ice intensity level corresponding to the observed failure of the 5th crosshair was determined.

The results of the tests are summarized below (see Appendix F for details):

- The response of the ID-1 was not affected when the angle between the vertical axis and the sensor was less than 23°. At larger angles a difference between the observer and the sensor was noticed;

- The ID-1 showed slightly different ice intensity levels when compared to the human observer in the testing of fluid concentration and fluid type;

- The performance of the ID-1 was not affected by illumination.

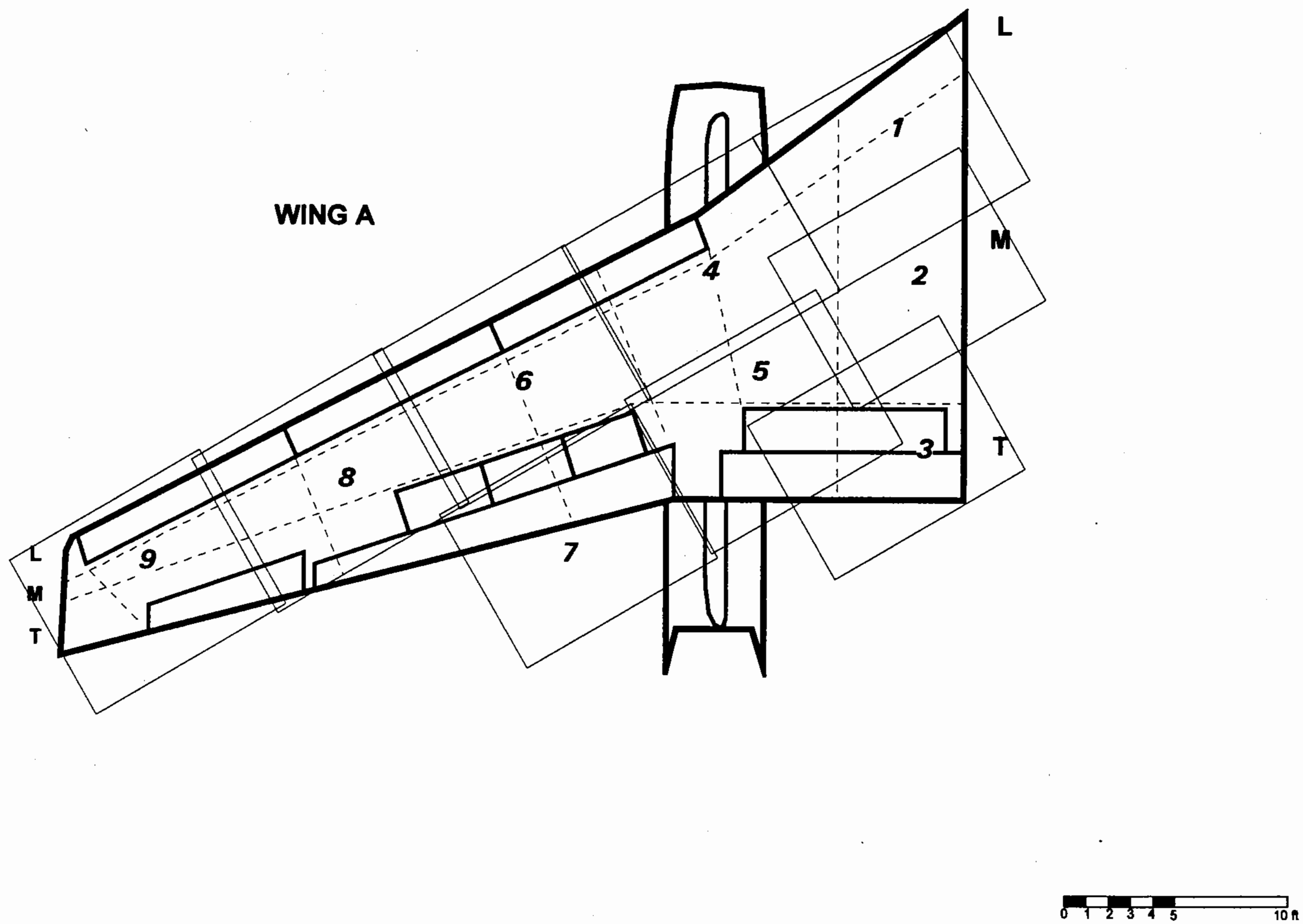
5.2.2.2 Full-Scale Test of Type I Fluid at Pearson International Airport (YYZ)

The ID-1 was installed in the bucket of a CAI de-icing vehicle. Due to the lack of snow at Toronto Pearson International Airport after January, between midnight and 05:00 am, only the one test session was possible. The unit was tested on a B-737 wing during a full-scale test at Toronto Pearson International Airport. Only a few images were taken during this test, since the CAI operator of the bucket and Zephyr North's (an APS sub-contractor) ID-1 operator were familiarizing themselves with this operation. The snow tapered off after this test and eventually stopped.

Most of the failures on occurred at the trailing edge on the flaps and ailerons which are of composite material. During this full-scale test, difficulty was experienced by the Zephyr North operator in identifying contamination on the painted and composite sections of the B-737. Unpainted metallic surfaces did not present any difficulty.

A grid structure for the wing was devised for the ID-1 operator to follow in scanning the wing. An example of this grid is provided in Figure 5.61. While the wing division grid was found to be useful for the scanning of the wing, it was difficult to locate the frames while conducting the analysis. An improved scanning plan for working with the wing would be useful for future tests.

FIGURE 5.61
BREAKDOWN OF B737-200 FOR RVSI ID-1 IMAGING



cm1222\procedur\drawings\rvsi-737.drw

5.3 Thickness of Ultra on Flat Plates

Thickness tests on flat plates were performed on March 23, 1995 on the new Ultra Type II Neat fluid. The ambient air temperature was -2°C and the wind speed was 5 kph with the wind blowing up the plates. The tests were conducted in the evening under overcast conditions with no precipitation. The general objective of the test was to determine whether fluid thickness is affected by the amount of fluid poured and by applying fluid a second time. For this purpose, six thickness measurement tests were conducted as follows:

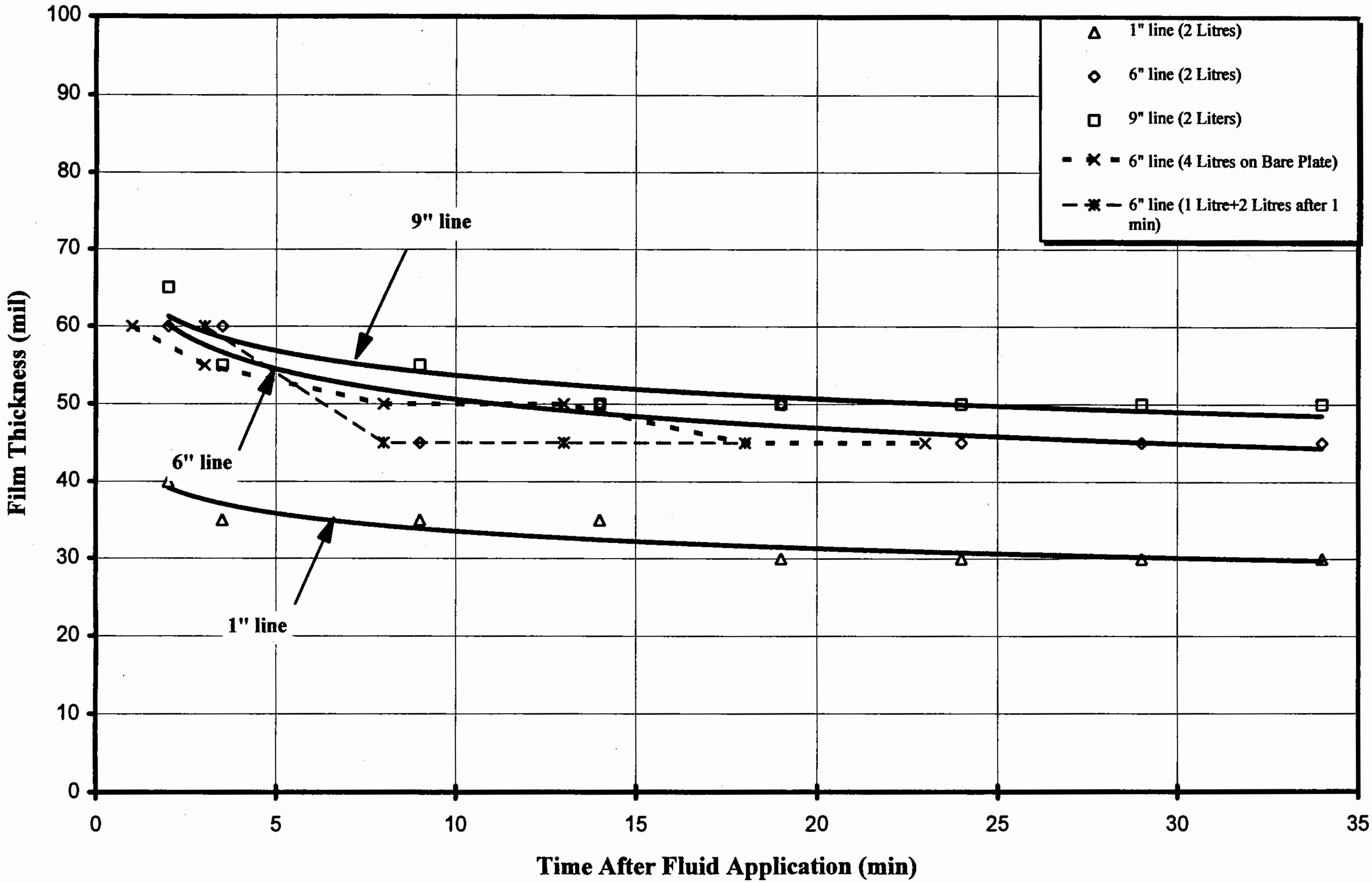
- 1 litre poured on bare plate;
- 2 litres poured on bare plate;
- 4 litres poured on bare plate;
- 1 litre followed by 2^{nd} application of 1 litre after 1 minute;
- 1 litre followed by 2^{nd} application of 2 litres after 1 minute;
- 1 litre followed by 2^{nd} application of 4 litres after 1 minute.

The stabilized thicknesses at the 15 cm (6") line were found to be similar in all cases. The stabilized fluid thickness from the application of 2 litres was found to be 30 mils at the 2.5 cm (1") line, 45 mils at the 15 cm (6") line and 50 mils at the 22.5 cm (9") line (see Figure 5.62).

FIGURE 5.62

FILM THICKNESS DECAY ON FLAT PLATE @ AES SITE (94/95)

Ultra Type II Neat on Bare Plate



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6. CONCLUSIONS

6.1 Test Procedures and Equipment

6.2 Meteorological Analysis

6.3 Flat Plate and Cold-Soak Tests

6.4 Ice Sensor Tests

6. CONCLUSIONS

As is apparent when comparing the analysis contained in this report with that included in previous reports, relationships between the failure times of the de/anti-icing fluids and the meteorological parameters are far more evident than was the case in the past. Improvements in meteorological data collection contributed greatly to this result. This winter's program consisted mainly of testing conventional Type II Neat fluids, Type I diluted and standard fluids and the new Ultra fluid which is the first of the new long life fluids. Flat plate testing was conducted under natural snow at the AES Dorval test site, simulated freezing fog, drizzle and light freezing rain at the NRC Cold Chamber at Ottawa. Cold-Soaked tests were also carried out at the NRC Cold Chamber.

The conclusions from this year's testing and analysis are presented in point form as they pertain to: test procedures and equipment; meteorology; flat plate tests and ice sensor tests.

6.1 Test Procedures and Equipment

- The end condition is still subjective in nature, although perhaps less so than in the past. It was still possible for different individuals to make different determinations as to the time the end condition was reached.

- Preparation and mixing of diluted Type I fluids proved to be a lengthy and confusing operation at times. During the testing season, it became evident that if fluids were not prepared before the start of the test, then fluid mixing would easily interfere with the testing.

- Data from the READAC station at Dorval was found to be useful and should be acquired for future testing. The Radar forecasts were found to be useful for test planning as well as manpower planning.

- Appropriate lighting and correct positioning of the panning camera is required to properly record the tests.

- Hand-held camera filming proved to be extremely useful since it allowed for special treatment and close inspection of failed fluids.

6.2 Meteorological Analysis

- Comparison of the precipitation rate measurements from the plate pans with the precipitation gauge from the READAC station showed a good correlation between the two instruments.

- A relationship between average visibility and precipitation rate as a function of temperature was not apparent.

- Comparison of wind, humidity, and temperature from the test site to the READAC data showed good correlation.

6.3 Flat Plate and Cold-Soak Tests

The flat plate tests were conducted under a variety of precipitation conditions. Tables 6.1 to 6.3 provide the current status of the SAE/ISO HOT's as they have been proposed by the SAE G-12 Committee. These are the tables which are being proposed for use in the 1995/96 winter in Canada and the United States. Table 6.1 is for Type I, Table 6.2 is for Type II and Table 6.3 is for the new

TABLE 6.1

CURRENT SAE/ISO HOLDOVER TIME TABLE FOR TYPE I FLUIDS TO BE USED IN 1995/96

TABLE 2. Guidelines for Holdover Times Anticipated by SAE Type I and ISO Type I Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION: THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY AND IT SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

TYPE I

Freezing Point of Type I Fluid Mixture used must be at least 10°C (18°F) below OAT.

OAT		Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes)					
					PROPOSED		
°C	°F	FROST	FREEZING FOG	SNOW	FREEZING DRIZZLE	LIGHT FRZ RAIN	RAIN ON COLD SOAKED WING
0 & above	32 & above	0:18-0:45 **S**	0:12-0:30 **NS**	0:06-0:15 **S**	0:05-0:08 **S**	0:02-0:05 **S**	0:06-0:15 **NS**
below 0 to -7	below 32 to 19	0:18-0:45 **S**	0:06-0:15 **S**	0:06-0:15 **S**	0:05-0:08 **S**	0:02-0:05 **S**	CAUTION! clear ice may require touch for confirmation
below -7	below 19	0:12-0:30 **S**	0:06-0:15 **S**	0:06-0:15 **S**	** **S**	*** **S**	

This table does not apply to other than SAE or ISO Type I FPD fluids.

The responsibility for the application of these data remains with the user.

** Approximate Holdover Time for Freezing Drizzle is between 5 to 8 min below -7°C to -10°C.

*** Approximate Holdover Time for Light Freezing Rain is between 2 to 5 min below -7°C to -10°C.

S = Substantiated

NS = Not substantiated

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with Proposed 11/15/95

TABLE 6.2

CURRENT SAE/ISO HOLDOVER TIME TABLE FOR TYPE II FLUIDS TO BE USED IN 1995/96

TABLE 1. Guidelines for Holdover Times Anticipated by SAE Type II and ISO Type II Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION: THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY AND IT SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

TYPE II

OAT		Type II Fluid Concentration Neat-Fluid/Water (% by volume)	Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes)					
						PROPOSED		
°C	°F		FROST	FREEZING FOG	SNOW	FREEZING DRIZZLE	LIGHT FRZ RAIN	RAIN ON COLD SOAKED WING
0 and above	32 and above	100/0	12:00 S	1:15-3:00 NS	0:25-1:00 S	0:30-1:00 S	0:15-0:30 S	0:24-1:00 NS
		75/25	6:00 S	0:50-2:00 NS	0:20-0:45 S	0:20-0:45 S	0:10-0:25 S	0:18-0:45 NS
		50/50	4:00 S	0:35-1:30 NS	0:15-0:30 S	0:15-0:25 S	0:05-0:15 S	0:12-0:30 NS
below 0 to -7	below 32 to 19	100/0	8:00 S	0:35-1:30 S	0:20-0:45 S	0:30-1:00 S	0:15-0:30 S	CAUTION! clear ice may require touch for confirmation
		75/25	5:00 S	0:25-1:00 S	0:15-0:30 S	0:20-0:45 S	0:10-0:25 S	
		50/50	3:00 S	0:15-0:45 S	0:05-0:15 S	0:15-0:25 S	0:05-0:15 S	
below -7 to -14	below 19 to 7	100/0	8:00 S	0:35-1:30 S	0:20-0:45 S	A S	C S	
		75/25	5:00 S	0:25-1:00 S	0:15-0:30 S	B S	D S	
below -14 to -25	below 7 to -13	100/0	8:00 NS	0:35-1:30 S	0:20-0:45 S			
below -25	below -13	100/0 if 7°C (13°F) Buffer is maintained	A buffer of at least 7°C (13°F) must be maintained for Type II used for anti-icing at OAT below -25°C (-13°F). Consider use of Type I fluids where SAE or ISO Type II cannot be used. NS	NS				

This table does not apply to other than SAE or ISO Type II FPD fluids.

The responsibility for the application of these data remains with the user.

A - Approximate Holdover Time for Type II Neat in Freezing Drizzle is between 30 to 60 min below -7°C to -10°C.

B - Approximate Holdover Time for Type II 75/25 in Freezing Drizzle is between 20 to 45 min below -7°C to -10°C.

C - Approximate Holdover Time for Type II Neat in Light Freezing Rain is between 15 to 30 min below -7°C to -10°C.

D - Approximate Holdover Time for Type II 75/25 in Light Freezing Rain is between 10 to 25 min below -7°C to -10°C.

S = Substantiated

NS = Not substantiated

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with Proposed 11/15/95

TABLE 6.3

CURRENT HOLDOVER TIME TABLE FOR ULTRA FLUID TO BE USED IN 1995/96

TABLE 1. Guidelines for Holdover Times Anticipated by SAE Type II and ISO Type II Fluid Mixtures as a Function of Weather Conditions and OAT.

CAUTION: THIS TABLE IS FOR USE IN DEPARTURE PLANNING ONLY AND IT SHOULD BE USED IN CONJUNCTION WITH PRETAKEOFF CHECK PROCEDURES.

ULTRA

OAT °C	OAT °F	Ultra Fluid Concentration Neat-Fluid/Water (% by volume)	Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes): FROST	FREEZING FOG	SNOW	PROPOSED: FREEZING DRIZZLE	PROPOSED: LIGHT FRZ RAIN	RAIN ON COLD SOAKED WING
0 and above	32 and above	100/0	18:00 S	1:52-4:30 NS	0:37-1:30 S	0:45-1:30 S	0:22-0:45 S	0:24-1:00 NS
		75/25	6:00 NS	0:50-2:00 NS	0:20-0:45 NS	0:20-0:45 NS	0:10-0:25 NS	0:18-0:45 NS
		50/50	4:00 NS	0:35-1:30 NS	0:15-0:30 NS	0:15-0:25 NS	0:05-0:15 NS	0:12-0:30 NS
below 0 to -7	below 32 to 19	100/0	12:00 S	0:52-2:15 S	0:30-1:07 S	0:45-1:30 S	0:22-0:45 S	CAUTION! clear ice may require touch for confirmation
		75/25	5:00 NS	0:25-1:00 NS	0:15-0:30 NS	0:20-0:45 NS	0:10-0:25 NS	
		50/50	3:00 NS	0:15-0:45 NS	0:05-0:15 NS	0:15-0:25 NS	0:05-0:15 NS	
below -7 to -14	below 19 to 7	100/0	12:00 S	0:52-2:15 S	0:30-1:07 S	A S	C S	
		75/25	5:00 NS	0:25-1:00 NS	0:15-0:30 NS	B NS	D NS	
bel** -14 to -30	bel** 7 to -22	100/0	12:00 S	0:52-2:15 S	0:30-1:07 S			

This table does not apply to other than Ultra FPD fluids.

The responsibility for the application of these data remains with the user.

A - Approximate Holdover Time for Ultra Neat in Freezing Drizzle is between 45 to 90 min below -7°C to -10°C.

B - Approximate Holdover Time for Ultra 75/25 in Freezing Drizzle is between 20 to 45 min below -7°C to -10°C.

C - Approximate Holdover Time for Ultra Neat in Light Freezing Rain is between 22 to 45 min below -7°C to -10°C.

D - Approximate Holdover Time for Ultra 75/25 in Light Freezing Rain is between 10 to 25 min below -7°C to -10°C.

**** - Below -30°C, consider use of Type I fluid.**

Based on the Ultra Flat Plate test results, the Type II neat HOT's were increased by 50% in all conditions except rain on cold-soaked wing.

S = Substantiated

NS = Not substantiated

CM1222\PRESENTA\OTT_OC95\HO1_TBU.XLS
with Proposed 11/15/95

Ultra fluid. For each table, in each block, an indicator on the current status is provided. "S" designates that the times for the specific condition and fluid are substantiated, and "NS" indicates that they are not substantiated.

6.3.1 Natural Snow

- The current Type I SAE/ISO holdover time range was substantiated for diluted Type I fluids. The few points that lie below the SAE/ISO range occurred during extreme weather conditions.

- Type I standard mix fluids were only slightly superior to diluted Type I fluids diluted to the strength appropriate for a 10°C temperature buffer.

- Ultra Neat was found to be more than 50% better than conventional Neat Type II fluids. The Neat Type II SAE HOT's were increased by 50% for use with Ultra. The performance of Ultra, when compared to the other Type II's, generally diminishes as the precipitation rate increases.

- Higher winds generally tend to prolong failure times. This is believed to occur because the fluid is kept on the plate longer by the wind blowing up the sloped plate.

- Higher rates of precipitation and colder temperatures tend to reduce failure times for both indoor and outdoor testing.

- Fluids from different manufacturers even within the same type category generally have different failure times.

6.3.2 Freezing Drizzle and Light Freezing Rain

- The freezing rain column in the SAE/ISO HOT tables was eliminated and replaced with two new columns: freezing drizzle and light freezing rain. These two precipitation types were differentiated because their respective rates of precipitation, droplet sizes and holdover times were notably different.

- Comparison of the UQAC WSET data at low rates of precipitation to APS' freezing drizzle data, and comparison of the WSET data at higher rates of precipitation to APS' light freezing rain data, showed that the data from UQAC and APS were in agreement.

- New HOT ranges were determined based on the NRC CEF flat plate tests for all fluid types. These new HOT ranges are applicable for temperatures down to -10°C for all fluid types except Type II 50/50. For Type II 50/50, the new HOT range is applicable down to -7°C.

- For Ultra, the Neat Type II SAE HOT's were increased by 50%.

6.3.3 Freezing Fog

- The current SAE/ISO HOT range is substantiated for diluted Type I fluids.

- The few tests conducted with Type I and Type II fluids at temperatures below -25°C showed that the current SAE/ISO HOT's are still substantiated for these low temperatures.

- For Ultra, the Neat Type II SAE HOT's were increased by 50%.

6.3.4 Rain on Cold-Soaked Surface

- Preliminary results have shown that the SAE/ISO HOT ranges may be adequate for Neat Type II and Type II 75/25. For Type II 50/50 and diluted Type I fluids, the SAE/ISO HOT ranges may require a reduction.

6.4 Ice Sensor Tests

- The RVSI ID-1 and C/FIMS sensor observations at the Dorval test site were found to correlate well with human failure observations.

- The RVSI ID-1 was easily installed in the chamber and on the de-icing vehicles. With proper training the unit was simple to operate. Improvements to the unit with respect to size, weight and manoeuvrability would enhance its operation.

- The RVSI ID-1 must be optimally positioned with respect to the target to ensure correct ice detection.

- When scanning painted or composite surfaces on an aircraft wing, the display on the monitor showed that these surfaces were contaminated, when in fact they were not.

7. RECOMMENDATIONS ON FUTURE TESTING

7.1 Test Procedures and Equipment

7.2 Flat Plate Testing

7.3 Ice Detection Instruments

7. RECOMMENDATIONS ON FUTURE TESTING

This section outlines the direction and scope for future testing. Future testing should be undertaken on the basis that a plan is in place to refine the data even further and to continue the substantiation and development of the HOT tables.

7.1 Test Procedures and Equipment

- Modify the standard flat plate testing procedure to allow more frequent plate pan precipitation rate measurements during the experiments.

- Acquire and install at Dorval the same ETI snow gauge being used by NCAR in Denver.

- Acquire data from the READAC weather station at Dorval. Consider acquisition of the Radar forecasting service.

- Analyse visibility versus rate of precipitation on a minute-by-minute basis from the READAC data for the 1994/95 winter snow events. Plot as a function of temperature.

- Define tester responsibilities to optimize the outdoor testing operations, particularly since the new Type IV fluids last longer.

- Determine the type of precipitation during the tests and in particular whether it is ice pellets, snow grain, etc. Devise a methodology to determine whether snow is wet or dry.

- Devise a fluid mixing and preparation procedure. Such a procedure would facilitate the Type I and II fluid mixing operation and ensure the required amounts of fluids are available prior to the beginning of each test occasion.

- The lighting and panning video camera positions should be positioned to provide the best video quality possible. Special care should be given to glare and focus and also to maintain reasonable camera temperature.

- Film all tests using a hand-held video camera. The camera operator should coordinate operation with the tester calling the failures on the plates. The hand-held camera provides better definition and detail than the panning video camera and allows a close inspection of arbitrary points on any plate. Ensure that plates are identified with big letters to facilitate reviewing.

- C/FIMS sensors should be adapted and the software modified to be used for calling fluid failure.

- The C/FIMS sensor data should be automatically saved even if the system fails during a test.

- The RVSI and C/FIMS software should allow a fast and efficient retrieving of the data as it is a tedious task.

7.2 Flat Plate Testing

7.2.1 Natural Snow

- Test conventional and new Type II, standard and diluted Type I fluids at very cold temperatures (T<-14°C).

- Run tests with new Type II fluids at all temperatures and all concentrations. As part of the test, conventional Type II's should be included to provide a "benchmark"

- Conduct flat plate thickness measurement tests for new Type II fluids.

7.2.2 Freezing Drizzle/Light Freezing Rain/Freezing Fog

- Run new Type II fluid tests at all concentrations and temperatures. Include conventional Type II fluids for comparison.

- Test the effect on HOT of consecutive application of Type II fluids (new and conventional) on clean and contaminated Type I fluids.

7.2.3 Rain on Cold-Soaked Surface

- Provide more data with 7.5 cm and new 2.5 cm sealed boxes for conventional Type II and Type I fluids to improve the quality of the analysis.

- Simulate rain at high rates of precipitation for all tests.

- Conduct tests with new Type II (Type IV) fluids.

- Conduct full-scale aircraft cold-soak experiments in order to verify the analytical HOT's and to verify the time constant assumptions.

7.3 Ice Detection Instruments

7.3.1 Surface

- Conduct future testing with as many C/FIMS as is practical.

- Determine the reliability of the C/FIMS sensor company developed algorithm for determining fluid failures in a systematic fashion (during site testing).

7.3.2 Remote

- Use the RVSI or other remote sensor to determine the end condition for the flat plates.

- Continue the evaluation of existing remote ice detection sensors (RVSI, SPAR, etc.).

APPENDIX A

FLAT PLATE TEST PROCEDURE

CM1222.001

EXPERIMENTAL PROGRAM
FOR DORVAL NATURAL PRECIPITATION FLAT PLATE TESTING
1994 - 1995

APS Aviation Inc.

January 31, 1995
Version 1.2

EXPERIMENTAL PROGRAM
FOR DORVAL NATURAL PRECIPITATION FLAT PLATE TESTING
1994 - 1995

This document provides the detailed procedures and equipment required for the conduct of natural precipitation flat plate tests at Dorval for the 1994/95 winter season.

1. OBJECTIVE

To complete the substantiation of the existing SAE Holdover Time Tables and proposed table extensions by conduct of tests on standard flat plates as follows:

- Type I and Type II fluids under conditions of natural snow at the lowest temperature ranges.
- Type I fluids at dilutions for which a buffer of approximately 10°C from the fluid freeze point is maintained.
- At least two samples of a new family of "long-life" fluids will be tested to establish the holdover times over the full range of HOT Table conditions for this potential new fluids category.

2. TEST REQUIREMENTS (PLAN)

Attachment I provides the list (not in any order) of tests to be conducted at the Dorval test site located adjacent to AES. These tests shall be conducted during natural precipitation conditions.

3. EQUIPMENT

Test equipment required for the flat plate tests was determined in the last four years in association with the SAE working group. This equipment is listed in Attachment II.

4. PERSONNEL

One test site supervisor and at least two testers per stand are required to conduct a test.

5. PROCEDURE

The modified test procedure is also included in Attachment II. This procedure was developed more than four years ago and was modified over the years to incorporate discussions at the SAE working group meetings.

6. DATA FORM

A data form is included with Attachment II.

ATTACHMENT I

NATURAL PRECIPITATION TEST PLAN

RUN #	TEMP DEG C	NUMBER OF PLATES TESTED	TYPE 1* (De-icing)						TYPE II (Anti-icing)											
			HOECHST		ARCO PLUS		UCAR		OCT			OCT-NEW			KIL ABC-3/ARCO ABC-3			UCAR-ULTRA		
			50/50	DIL	63/37	DIL	XL54	DIL	NEAT	75/25	50/50	NEAT	75/25	50/50	NEAT	75/25	50/50	NEAT	75/25	50/50
1	>0	6				2	2	2												
2	>0	6			2		2	2												
3	>0	6			2	2		2												
4	>0	6	2	2				2												
5	>0	6				2		2			2									
6	>0	6											2	2					2	
7	>0	6									2			2						2
8	>0	6											2	2					2	
9	>0	6								2					2	2				
10	>0	6							2	2					2					
11	>0	6										2			2			2		
12	>0	6							2			2						2		
13	>0	6										2			2			2		
14	>0	6										2			2			2		
15	>0	6								2				2						2
16	0 TO -7	6								2				2						2
17	0 TO -7	6											2	2					2	
18	0 TO -7	6									2			2						2
19	0 TO -7	6											2	2					2	
20	0 TO -7	6				2	2	2												
21	0 TO -7	6			2		2	2												
22	0 TO -7	6			2	2		2												
23	0 TO -7	6	2	2				2												
24	0 TO -7	6		2		2		2												
25	0 TO -7	6							2			2						2		
26	0 TO -7	6							2			2						2		
27	0 TO -7	6										2			2			2		
28	0 TO -7	6										2			2			2		
29	0 TO -7	6									2	2						2		
30	-7 TO -14	6				2	2	2												
31	-7 TO -14	6			2		2	2												
32	-7 TO -14	6			2	2		2												
33	-7 TO -14	6	2	2				2												
34	-7 TO -14	6		2		2		2												
35	-7 TO -14	6											2			2			2	
36	-7 TO -14	6									2		2						2	
37	-7 TO -14	6							2			2						2		
38	-7 TO -14	6							2			2						2		
39	-7 TO -14	6										2			2			2		
40	-7 TO -14	6										2			2			2		
41	-7 TO -14	6							2			2						2		
42	-14 TO -25	6				2	2	2												
43	-14 TO -25	6			2		2	2												
44	-14 TO -25	6			2	2		2												
45	-14 TO -25	6	2	2				2												
46	-14 TO -25	6							2			2			2					
47	-14 TO -25	6							2			2			2					
48	-14 TO -25	6										2			2			2		
49	-14 TO -25	6							2						2			2		
50	-14 TO -25	6							2						2			2		
51	<-25	6				2	2	2												
52	<-25	6			2		2	2												
53	<-25	6			2	2		2												
54	<-25	6	2	2				2												
55	<-25	6							2			2			2					
56	<-25	6							2			2			2					
57	<-25	6										2			2			2		
58	<-25	6							2						2			2		
59	<-25	6							2						2			2		
TOTAL		354	10	14	20	26	20	46	30	8	10	40	12	16	38	4	0	40	12	8

* The dilutions should be based upon Table 2. XL54 (57% - 43%) and ARCO PLUS (63% - 37%) are commonly used in Canada.

Note: Type I fluid should be applied at Indoor Temperatures, while Type II fluids should be at Outside Air Temperatures.

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ATTACHMENT II
FLAT PLATE FIELD TEST EQUIPMENT AND PROCEDURE
1994 - 1995

This field test procedure has been developed by the Holdover Time Working Group of the SAE Committee on Aircraft Ground De/Anti-icing as part of an overall testing program that includes laboratory tests, field tests and full-scale aircraft tests, which is aimed at substantiating the holdover time table entries for freezing point depressant (FPD) fluids known as de/anti-icing fluids.

1. SCOPE

This procedure describes the equipment and generalized steps to follow in order to standardize the method to be used to establish the time period for which freezing point depressant (FPD) fluids provide protection to test panels during inclement weather such as freezing rain or snow.

2. EQUIPMENT

2.1 Rain/Snow Gauge

The following equipment or equivalent are recommended:

2.1.1 Tipping Bucket

2.1.1.1 Electrically Heated Gauge - Weathertronics Model 6021-B

collector orifice	200 mm diameter
sensitivity	1 tip/0.1 mm accuracy 0.5% @ 13 mm/hr
output	0.1 sec switch closure
voltage	115 v (model -D 230 v)
switch	A reed mercury wetted

2.1.1.2 Electromechanical Event Counter Option

Event counter (112 V DC # 115 V AC) Weathertronics Model 6422

2.1.1.3 Digital Display Option

(A) Event Accumulator range 0-1000 counts linearity 0.05%	- Weathertronics Model 1600
(B) Power Supply & Enclosure	- Weathertronics Model 1020
(C) LCD Digital Display	- Weathertronics Model 1991

2.1.1.4 Ombrometer

Thies Model 5.4031.11.000, resolution 0.005 mm, maximum rate 2 mm/min (24 V DC). To be used with associated wind protection element.

2.1.1.5 PC Interface Option

(A) Event Accumulator	- Weathertronics Model 1600
(B) Power Supply & Enclosure	- Weathertronics Model 1025
(C) PC Interface module	- Weathertronics Model 1799

2.1.1.6 Fisher and Porter with Nipher Shield

This model, used at many Canadian airports, has a resolution of 0.1mm.

2.1.2 Manual Gauge

A manual standard rain and snow gauge can be used provided that the diameter of the gauge be as close as possible to 208 mm. This may not be possible in Europe therefore the diameter of the gauge must be reported with all tests results.

2.1.3 Cake Pan or Plate Pan

A large low cakepan (6"x6"x2" minimum) may be used to collect and weigh snow. A plate pan (the same area as a flat plate and 4 cm deep) may be preferable since it lies like the flat plates at a 10° incline. A schematic of the plate pan is provided as Figure 0.

Note: When this method is used the bottom and sides of the pan MUST BE WETTED (before each pre-test weighing) with de/anti-icing fluid to prevent blowing snow from escaping the pan.

2.2 Temperature Gauge

T or K type thermocouple thermometer capable of measuring outside air and panel temperatures to an accuracy of 0.5 degrees C (1 degree F) over the range +10 to -30 C (+50 to -20 F).

2.3 Test Stand

A typical test stand is illustrated in Figure 1; it may be altered to suit the location and facilities, but the angle for the panels, their arrangement and markings must all conform to Figures 1 and 2.

There shall be no flanges or obstructions close to the edges of the panels that could interfere with the airflow over the panels.

2.4 Test Panels

2.4.1 Material and Dimensions

Alclad Aluminum 2024-T6 or 5052-H32 polished standard roll mill finish 30x50x0.32 cm, for a working area of 25x40 cm. Thicker aluminum stock may be needed when an instrument is mounted on the plate.

2.4.2 Markings

Each panel shall be marked as shown in Figure 2 with lines at 2.5 and 15 cm from the panel top edge, with fifteen cross-hair points and with vertical lines 2.5 cm from each side; this marks off a working area of 25 x 45 cm on each panel. All marks shall be made using a 1/8" thick black marker or silk screen process, which does not come off with application of the test fluids or any of the cleaning agents. Remarking of the plates will be required as the markings fade because of the cleaning actions.

2.4.3 Attachment

For attachment to the test stand, at least four holes shall be made, spaced along the two sides of each panel; the holes shall be within 2 cm from the panel edge.

2.5 Fluid Application

The fluid should be poured onto the plates from a manageable container, until the entire test section surface is saturated.

2.6 Film Thickness Gauge

Film thickness at the six inch line can be measured (this is optional). Painter's wet paint film thickness gauge. 1-08 mil gauge or equivalent is available from Paul N. Gardner Company Inc. Pompano Beach Florida.

2.7 Video recording

Where feasible a video recorder should be mounted to record salient events during testing. Care must be taken that the camera and any lighting do not interfere with the airflow or ambient temperatures.

2.8 Anemometer

Wind Minder Anemometer Model 2615 or equivalent. Available from Qualimetrics Inc. Princeton New Jersey.

2.9 Wind Vane

Model 2020 Qualimetrics or equivalent

2.10 Relative Humidity Meter

Cole Parmer RH/Temperature Indicator P/N N-032321-00 with remote probe P/N N-03321030. Temperature limits -30 to 60°C RH range 20 to 100% accuracy ± 7% (20-30%); = -5% (30-100%); or equivalent. Available from Cole Parmer Instrument Company Chicago Illinois.

2.11 Signal Conditioning Modules

Qualimetrics:

Enclosure/Power Supply Model 1020 (115 V AC)
Ombrometer Module Model 1600
Anemometer Module Model 1202
Temperature Module Model 1419-A
Relative Humidity Module Model 1500
Wind Vane Module

2.12 Computer Interface

Qualimetrics Model 1799-A, RS-232, 1 to 10 channels, 10 sec. to 1 hr. sampling rate.

2.13 Additional Equipment

- Squeegee
- Extension power cords
- Stopwatch
- Flood lights (2 x 500 watts)
- Pressurized space pens and water repellent paper
- PC to record meteorological data

3. DE/ANTI-ICING FLUIDS

3.1 Test Fluids

Only fluids that have been certified will be included in tests. Fluid suppliers shall submit to the test coordinating organization proof of certification for the fluids they provide.

3.2 Certification

Type II fluids shall be sheared by each manufacturer to that viscosity which would have been obtained by subjecting their fluids to the shear Stability Test found in the AEA Material specification revision C (October 1, 1988) paragraph 4.2.8.2.2.

Each manufacturer shall provide samples and a certificate of compliance showing the viscosity of their test sample of fluid before and after the Shear Stabile Test. Test verifications of each fluid may be made at the University of Quebec at Chicoutimi (UQAC).

3.3 Dye

Fluids will be supplied for certification and for testing in the form to be used on aircraft.

3.4 Dilution of Type I Fluids

Type I fluids must be diluted as a function of outside air temperature according to Table 2. These concentrations were determined based upon information provided by the fluid manufacturers for which a buffer of 10°C from the fluid freeze point is maintained. When preparing the mixtures, verify with a refractometer that the percentage concentrations are accurate. Union Carbide products are based on Ethylene Glycol, while the Octagon and Arco products are composed of Propylene Glycol.

4. PROCEDURE

4.1 Setup

4.1.1 Panel Test Stand

If there is any wind, orient the test fixture such that the aluminum holdover test panels top surfaces are facing into the wind direction at the beginning of the test such that the wind is blowing up the panels

i.e. ----> /
wind panel

If the wind shifts during the test do not move the fixture; simply note it on the data sheet.

4.1.2 Rain Gauge

Place the Rain Gauge as close as possible to the test fixture. Ensure that the interior level is used to indicate that the bucket is level. Ensure that the gauge is not shadowed by an object which would interfere with the collection for the snow or the freezing rain. If there is drifting snow it may be necessary to raise the snow gauge above the drift level but no higher than the test panel. The snow gauge measurements should be started as early as feasible and continue throughout the duration of all tests to provide a continuous record of precipitation.

4.1.3 Manual Cake Pan or Plate Pan Method

Add ¼ inch de/anti-icing fluid to the bottom of the pan as well as wetting the inner sides of the pan. Weigh the wetted pan prior to testing to the nearest gram. Weigh again after test completion to determine the true water content reading of the snow.

Use of more than one cake or plate pan is recommended to provide multiple readings through the course of the test period; mounting the pans on the test stand at the same orientation of the plates is recommended.

When using plate pans to measure precipitation rate, ensure that two plate pans are used. Care must be taken to ensure that snow or ice does not fall into the pans when transporting them into the trailer.

4.2 Test Panel Preparation

4.2.1 Before the start of each day's testing, ensure the panels are clean.

4.2.2 Place the panels on the fixture and attach to the frame screws with flat bolts (wing nuts will make attaching and removal easier in poor weather)

4.2.3 Allow the panels to cool to outside air temperature.

4.3 Fluid Preparation and Application

4.3.1 Fluid Temperature

Except for Type I fluids, all fluids should be kept outside (cold-soaked to ambient temperature conditions) before tests start.

4.3.2 Cleaning Panels

Before applying test fluid to a panel, squeegee the surface to remove any precipitation or moisture.

4.3.3 Order of Application

Apply the fluid to the panels, commencing at the upper edge of the test panel and working downwards to the lower edge. Ensure complete coverage by applying the fluid in a flooding manner. Start with the top left panel U, then cover panel X in the second row with the same fluid, load the second test fluid on panel V followed by panel Y, etc. (see Figure 0).

4.4 Holdover Time Testing

4.4.1 Set the **timer on** as the first fluid application (plate u and x) is completed. Note the time when fluid application is completed on the remaining panels.

4.4.2 Commence recording the test with a video recorder until the test reaches the END CONDITION (see Section 5).

4.4.3 Record the elapsed time (holdover time) required for the precipitation to achieve the test END CONDITION.

4.4.4 In heavy precipitation, continue the test until the precipitation reaches the bottom of the panel. Record the time for this event.

5. END CONDITIONS

The plate failure time is that time required for the end conditions to be achieved.

This occurs when the accumulating precipitation fails to be absorbed at any five of the crosshair marks on the panels.

A crosshair is considered failed if:

- There is a visible accumulation of snow (not slush, but white snow) on the fluid at the crosshair when viewed from the front (i.e. perpendicular to the plate). You are looking for an indication that the fluid can no longer accommodate or absorb the precipitation at this point.

OR

- This condition is <u>only</u> applicable during freezing rain/drizzle ice pellets, freezing fog or during a mixture of snow and freezing rain/drizzle and ice pellets. When precipitation or frosting produces a "loss of gloss" (i.e. a dulling of the surface reflectivity) or a change in colour (dye) to grey or greyish appearance at any five crosshairs, or ice (or crusty snow) has formed on the crosshair (look for ice crystals).

As these determinations are subjective in nature, the following is **<u>very important</u>**:

- Whenever possible, have the same individual make the determination that a crosshair has failed.
- When making such a determination, ensure consistency in the criteria used to call the end of a test.
- Under light snow conditions, snow may sometimes build up on the fluid and then be absorbed later as the fluid accommodates (absorbs) for it. If this occurs, record the first time snow builds up and note (in the comments sections) that there was an "un-failure" at a specific crosshair.

Under conditions of moderate to heavy snow or hail, coverage may be very uneven; this measure should indicate failure over about one-third of the panel.

6. END OF TEST

Record the type and extent of contamination on the control plate. For example note if the plate is covered in a light fluffy snow, or light ice, or any other distinguishing features of the contamination. Record the type of snow according to the classification in Figure 3.

Once the test has ended, wipe the plates and cleanse with isopropyl alcohol and/or pure glycol. Restart the testing procedure and continue as long as the weather conditions warrant.

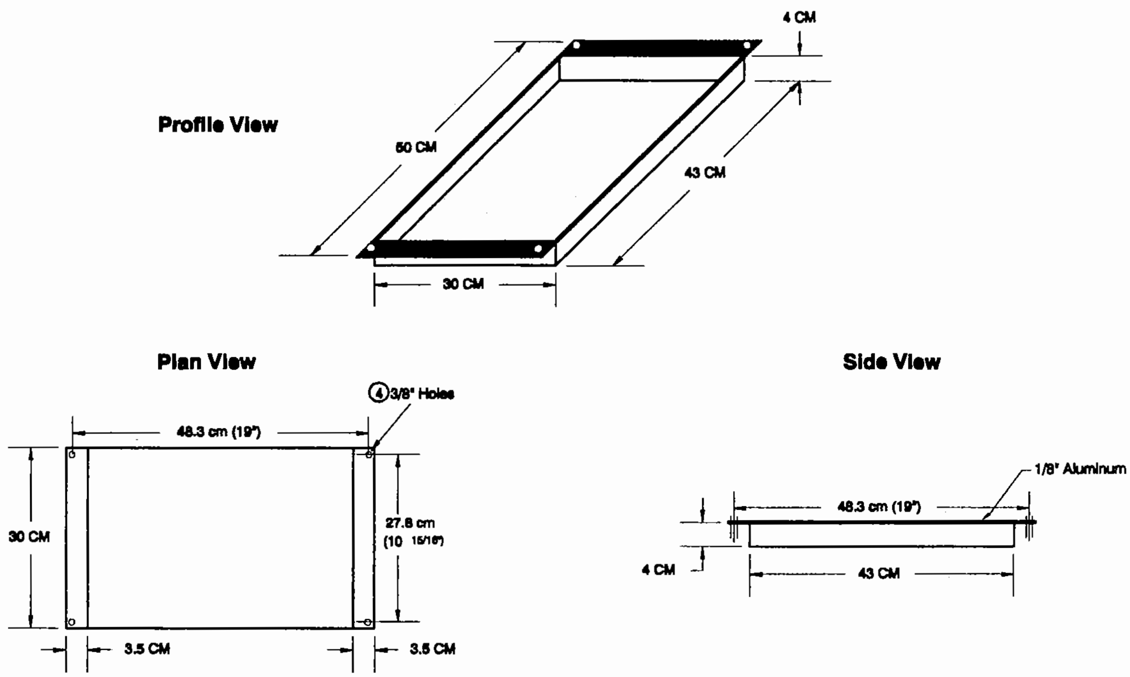
7. REPORTING & OBSERVATIONS

Calculate and record test data, observations and comments in the format of Table 1. Each test must be conducted in duplicate. Detailed definitions and descriptions of meteorological phenomena are available in the Manual of Surface Weather Observation (MANOBS).

FIGURE 0

SCHEMATICS OF PLATE PAN AND TEST STAND

PLATE PAN



TEST STAND

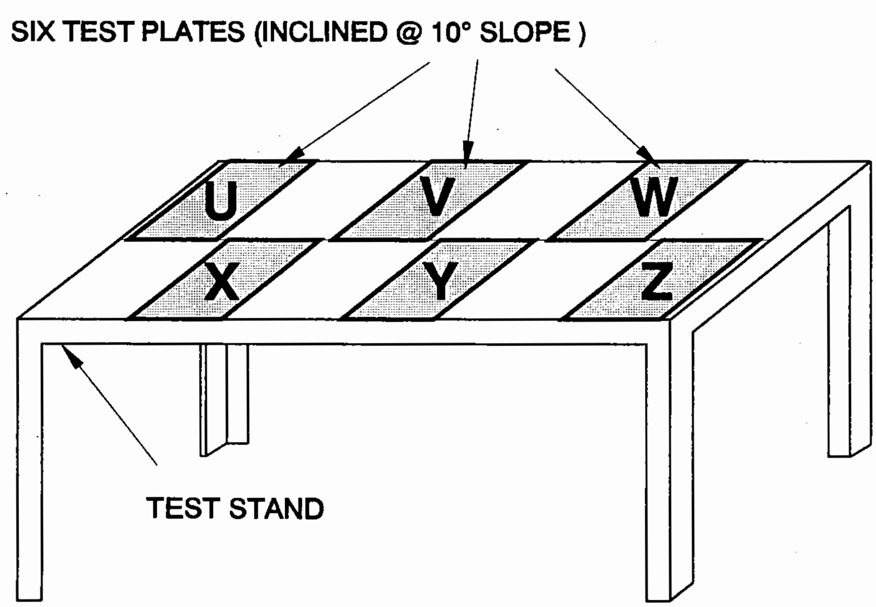


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FIGURE 1
TEST STAND

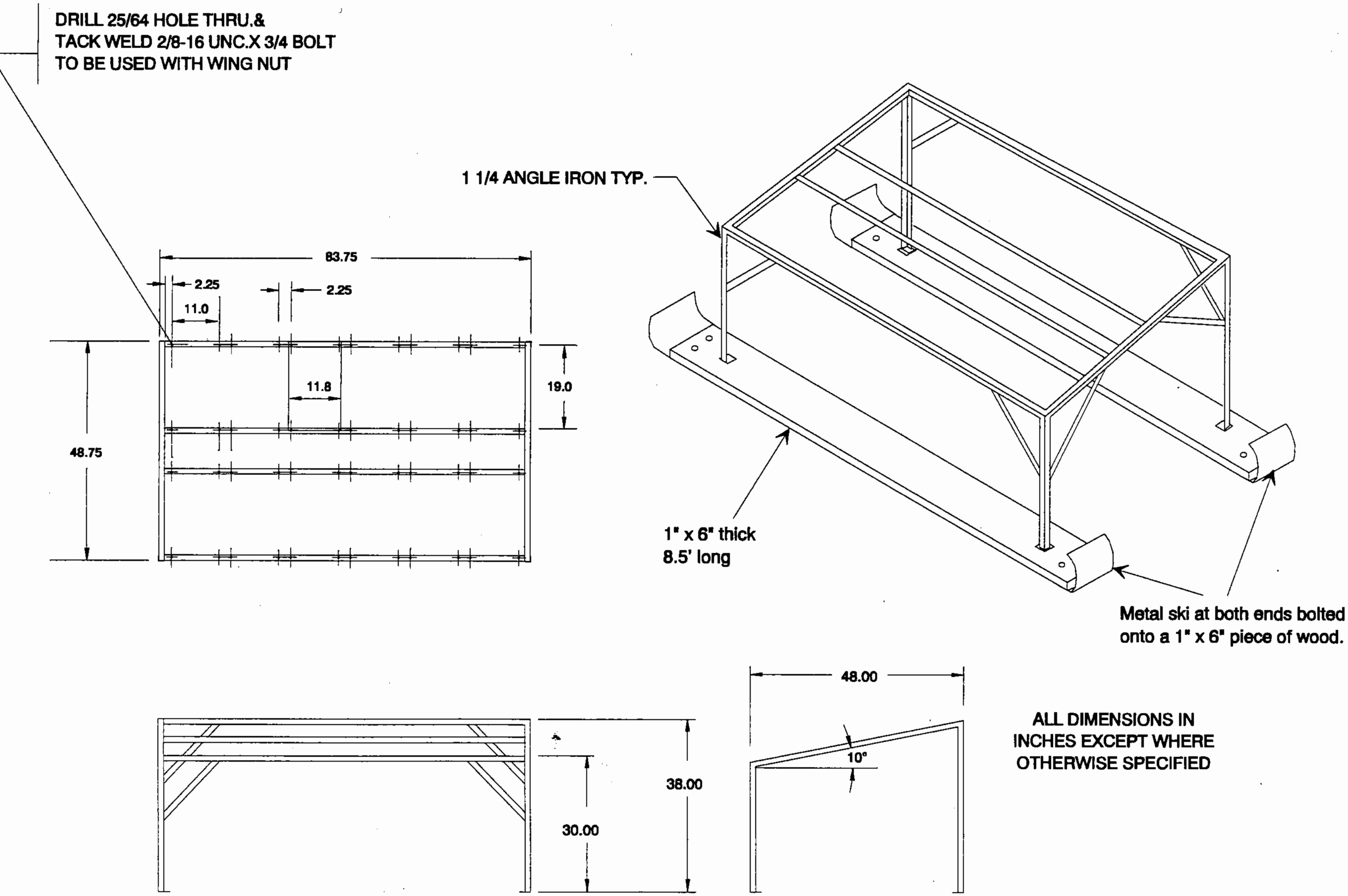

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FIGURE 2

FLAT PLATE MARKINGS

TYPICAL PLATE

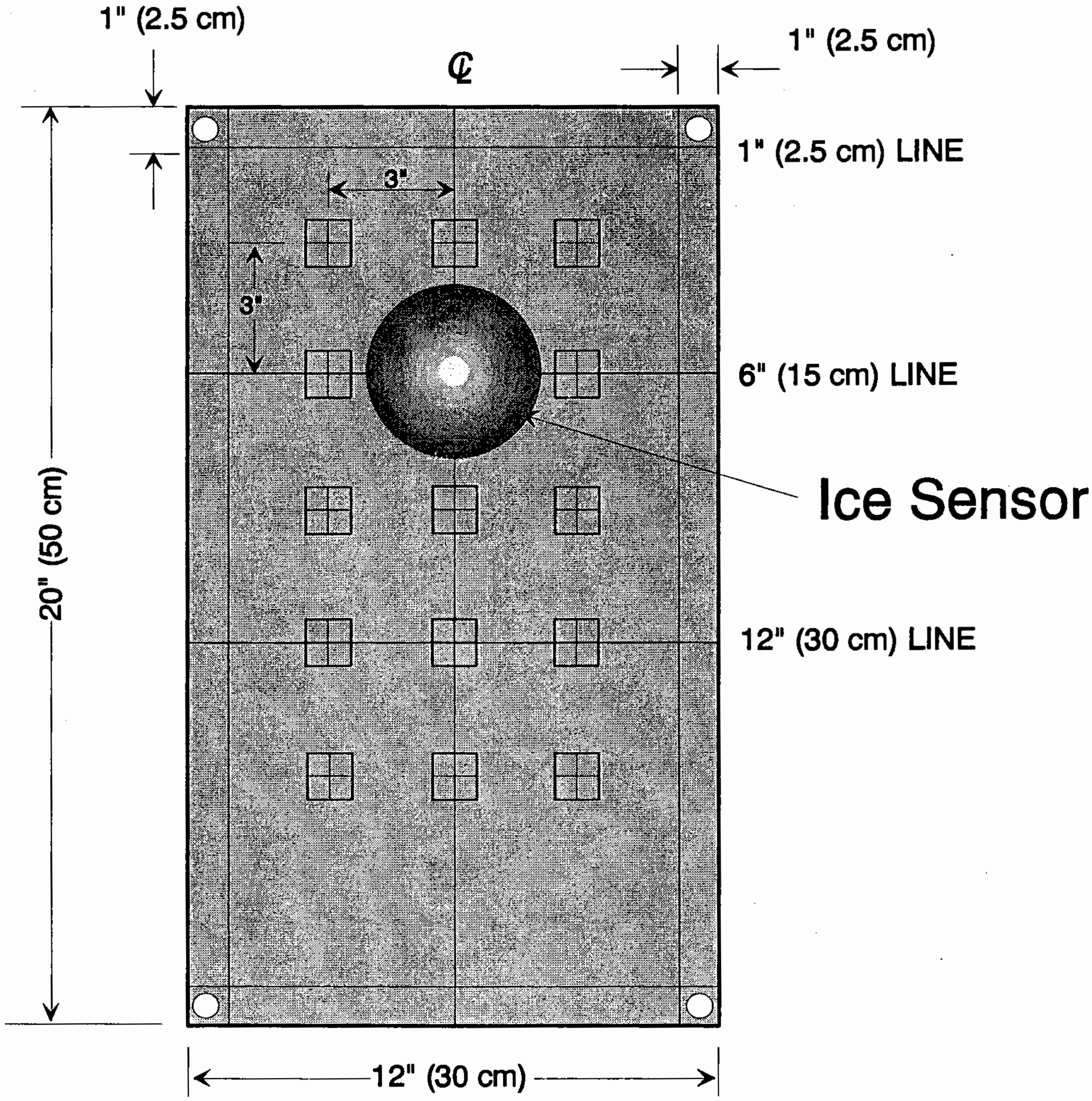

TABLE 1

REMEMBER TO SYNCHRONIZE TIME

DE/ANTI-ICING DATA FORM

VERSION 2.2 Winter 94/95

LOCATION: DATE: RUN NUMBER: STAND # : CIRCLE SENSOR PLATE: u v w x y z

Time After Fluid Applied to Plates U and X: am / pm SENSOR NAME:

RVSI Series # : ____________ Frame # : ____________

COLLECTION PAN: PAN # ________ PAN # ________

	Before	After	Before	After
Weight of Pan (g)				
Collection Time (min)				

DIRECTION OF STAND:

CONTROL PLATE COMMENTS:

PRECIP: ZR ZL S SW IP IC BS SP ++ + - --

SNOW/RAIN CATEGORIES (use velvet & classification):

OTHER COMMENTS (Fluid Batch, etc):

FAILURES CALLED BY :

HAND WRITTEN BY :

ASSISTED BY:

* To Compare to previous years of testing, subtract "Time of Fluid Aplication".

***TIME (After Fluid Application) TO FAILURE FOR INDIVIDUAL CROSSHAIRS (MINUTES)**

Time of Fluid Application: ⟶ ______ mins (V & Y) ______ mins (W & Z)

	Plate U			Plate V			Plate W		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA									
TIME OF SLUSH FORMATION ON SENSOR HEAD	1st	½	Full	1st	½	Full	1st	½	Full

	Plate X			Plate Y			Plate Z		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA									
TIME OF SLUSH FORMATION ON SENSOR HEAD	1st	½	Full	1st	½	Full	1st	½	Full

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TABLE 2

PERCENTAGE OF GLYCOL MIXTURE WITH WATER (%) AS A FUNCTION OF OAT USED FOR DILUTED TYPE I TESTS TO ACHIEVE A 10°C BUFFER

Outside Air Test Temperature (°C) OAT	Fluid Freeze Point (°C)	B-250* (Dilution) (% Glycol in water mix)	B-251* (Dilution) (% Glycol in water mix)	B252* (Dilution) (% Glycol in water mix)	B-253* (Dilution) (% Glycol in water mix)	B-253* (Brix)
0 °C	-10 °C	28%	28%	31%	23%	14
-2 °C	-12 °C	31%	31%	35%	26%	16
-4 °C	-14 °C	35%	34%	39%	29%	18
-6 °C	-16 °C	37%	37%	42%	31%	19.7
-8 °C	-18 °C	40%	40%	45%	34%	21.2
-10 °C	-20 °C	42%	42%	48%	36%	22.5
-14 °C	-24 °C			50%**		24.8
-15 °C	-25 °C	47%	48%	53%	41%	25.5
-20 °C	-30 °C	52%	52%	58%	46%	27.9
-25 °C	-35 °C	56%	57%	63%	50%	30
-30 °C	-40 °C	60%	TBD	67%	54%	32
-33 °C	-43 °C		TBD		57%**	33
-35 °C	-45 °C	63%**	63%**			33.7

* Based on a 10°C buffer. If Based on a 10°C buffer. If verifying the glycol concentration/freeze point with a refractometer, note that the freeze point will be 10°C lower.

** Brix for UCAR Ultra is 37 (Brix for UCAR Ultra is 37 (min: 35, max: 38)

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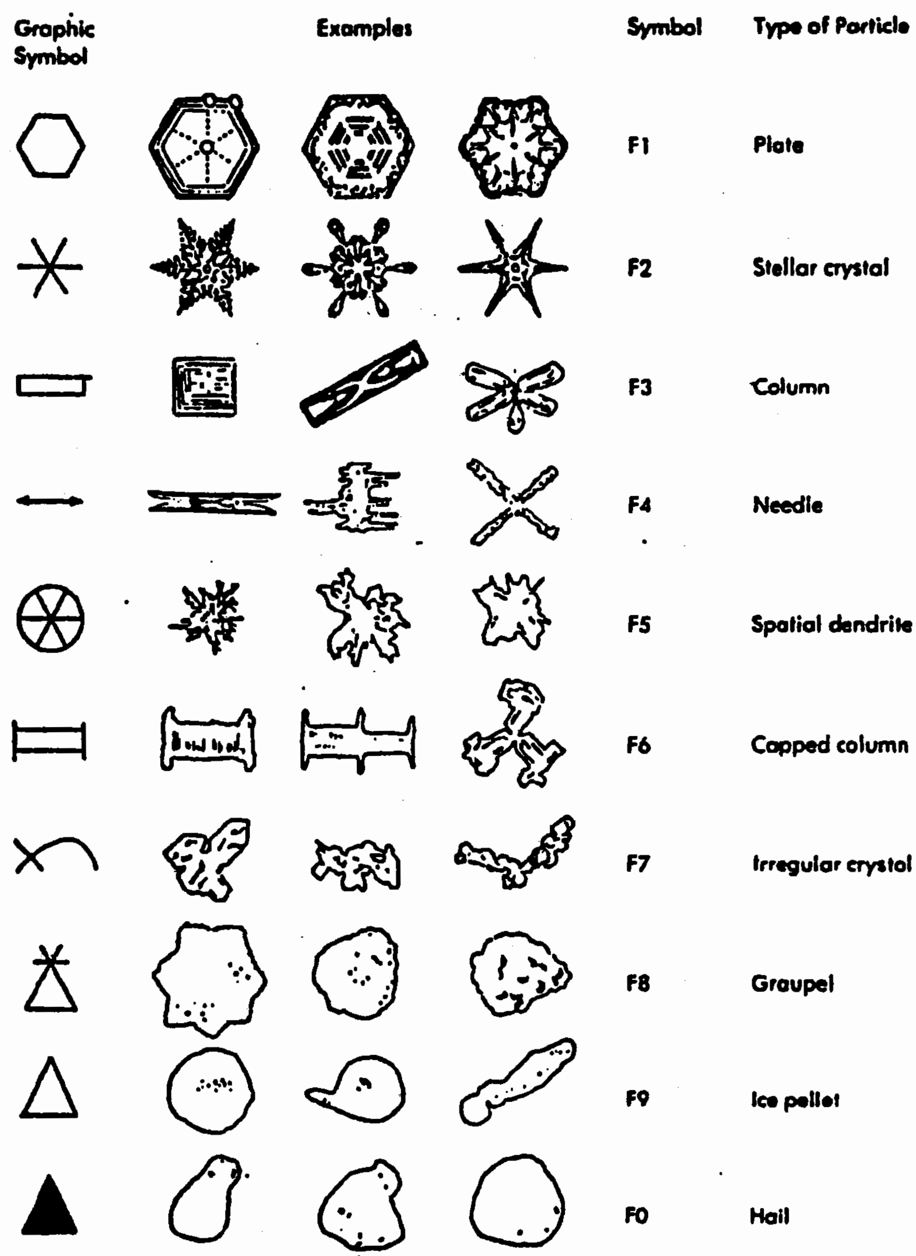
INTERNATIONAL CLASSIFICATION FOR SOLID PRECIPITATION



4. A pictorial summary of the International Snow Classification for solid precipitation. This classification applies to falling snow.

Source: *International Commission on Snow and Ice, 1951*

APPENDIX B
SIMULATED FREEZING PRECIPITATION TEST PLAN AND PROCEDURES

CM1222.001

DETAILED PLAN OF NRC COLD CHAMBER TESTING

1994 - 1995

- Freezing Fog
- Freezing Rain/Drizzle
- Rain on a Cold-soaked surface

APS Aviation Inc.

March 31, 1995
Version 1.2

This document provides the detailed procedures and equipment required for the conduct of simulated freezing fog, freezing drizzle/rain and rain on a cold-soaked surface tests. These tests will be conducted at NRC's Climatic Engineering Facility (CEF) in Ottawa the week of April 3rd and April 10, 1995.

1. OBJECTIVES

1.1 Freezing Fog

The objectives of the freezing fog cold chamber tests are the following:

a) Provide data for the completion of the substantiation of HOT tables for Neat Type II (old and new) and Type I fluids from -25°C to -30°C.

b) Same as a) at a range of -7°C to -14°C.

c) Same as b) for Type II 75/25 fluids, to complete its substantiation and compare Ultra 75/25 with regular Type II 75/25.

d) Same as a, b, c) at 0°C to -7°C. Complete substantiation of HOT for Type II 50/50 and comparison of regular Type II 50/50 with Ultra 50/50.

A sub-objective of the tests is to try to correlate between RVSI ID-1, C/FIMS sensors and human visual failure calling criteria.

1.2 Freezing Rain/Drizzle

The objectives of these tests are the following:

a) Continue the comparison of new Type II fluids (Neat, 75/25, 50/50) with old Type II fluids (Neat, 75/25, 50/50) at 0°C to -7°C..

b) Provide data for substantiation of Type II fluids at -7°C to -10°C (neat, 75/25) both old and new.

c) Provide data for substantiation of standard and diluted Type I (with 10°C buffer) at 0°C to -7°C.

d) Provide some data for Type I standard and diluted at -7°C to -10°C.

1.3 Cold-soaked conditions

The objectives of the cold-soaked testing are the following:

a) To substantiate the HOT tables for Type II fluids old and new at 0°C and above (Neat and diluted).

b) To substantiate the HOT tables for Type I fluids (standard and diluted with 10°C buffer) at 0°C and above.

2. PERSONNEL

Three (3) testers will be required for the CEF testing at all times. Testers 1 and 5 will be required occasionally over the two week period. Duties will be shared as follows:

Tester 1 (HF) - Setting up C/FIMS and RVSI equipment.
- Setting up video equipment.
- Operating and running previously mentioned equipment.

Tester (MH)
- Prepare sealed boxes and coolant fluid for cold soaked testing.
- Weigh plate pans.
- Perform experiments and mix fluids

Tester 3 (ZB) - General set up.
- Prepare plates and pans for each run (sealed boxes as well).
- Perform experiment.
- Responsible for the entire experiments.

Tester 4 (GT)
- General set up.
- Mixing fluids.
- Prepare plates and pans for each run (sealed boxes as well).
- Perform experiment.
- Determine end condition.

Tester 5 (DB/JM)
- Video of set up and selected tests.

3. PROCEDURES

The procedures for most tests is the same as per the FPTP. The data form (attached) will be the same as the one used for the FPTP. The exceptions are the following:

a) Run numbers followed by a, b or c (sub-run) refer to tests conducted on Ultra neat stands at the place of other regular Type II's or Type I's that have already failed.

b) Freezing fog tests (runs #1 - 12) will use two stands. The test will start with one stand, then the other after 30 minutes to be able to coordinate in between two stands. The second stand will preferably be started as first batch of Type I's have failed on the first stand and the precipitation rates are being measured.

c) Measurement of precipitation rates will be done concurrently with tests having six (6) plates or less (runs #17 - 33) at six locations between the plates. For runs having sub-runs, the rates will be measured for 10 minutes before the sub-run and ten minutes after the sub-run. Each test will have its own precipitation rate form to be filled in every test. (Precipitation Rate Measurement @ CEF data form).

d) The sealed boxes for cold soaked testing will have to be prepared in advance by T4 who will have to run the cooling unit (ie T4 will have to be familiar with unit in advance). T4 will fill the boxes with cold glycol, empty them from warm glycol using either a manual or motor pump.

e) A video record of most tests will be collected using the time lapse video camera with panning capability. Hand-held video of the facility and of selected tests will be taken over the two week period. APS will advise Image Projection of these tests.

4. TEST PLAN AND EQUIPMENT LIST

Tables I and II provide a testing equipment list and a day by day test schedule respectively.

Day I is equivalent to Monday April 3, 1995. The APS team will be at the Ottawa cold chamber on Friday March 31, 1995 to set up the equipment.

TABLE II

CEF TEST PLAN

SEQ. #	RUN #	TEMP DEG C	NUMBER OF PLATES TESTED	TYPE 1* (De-Icing)						TYPE II (Anti-Icing)														
				HOECHST		ARCO PLUS		UCAR		OCT			KIL ABC-3/ARCO ABC-3			UCAR-ULTRA								Proj Time
				50/50	DIL	63/37	DIL	XL54	DIL	NEAT	75/25	50/50	NEAT	75/25	50/50	NEAT	75/25	50/50	Objectives	Rate	Prec.type	Nozzle	Day	hr:min
1	1	<-25	12	1	1	1	1	1	1	2			2			2			a	2 to 10	FZF	TBD	1	1:30
2	1a	<-25	6	1	1	1	1	1	1										a	2 to 10	FZF	TBD	1	
3	2	<-25	12	1	1	1	1	1	1	2			2			2			a	2 to 10	FZF	TBD	1	1:30
4	2a	<-25	6	1	1	1	1	1	1										a	2 to 10	FZF	TBD	1	
5	3	-7 TO -14	12	1	1	1	1	1	1	2			2			2			b	2 to 10	FZF	TBD	2	1:30
6	3a	-7 TO -14	6								2			2			2		c	2 to 10	FZF	TBD	2	
7	4	-7 TO -14	12	1	1	1	1	1	1	2			2			2			b	2 to 10	FZF	TBD	2	1:30
8	4a	-7 TO -14	6								2			2			2		c	2 to 10	FZF	TBD	2	
9	5	0 TO -7	12	2		2		2		2			2			2			d	2 to 10	FZF	TBD	2	2:00
10	5a	0 TO -7	6									2			2			2	d	2 to 10	FZF	TBD	2	
11	6	0 TO -7	12		2		2		2		2			2			2		d	2 to 10	FZF	TBD	2	1:00
12	6a	0 TO -7	6									2			2			2	d	2 to 10	FZF	TBD	2	
13	7	-7 TO -10	12							2	2		2	2		2	2		b	14 to 30	FZR	20	3	1:00
14	7a	-7 TO -10	8		2		2	2	2										d	14 to 30	FZR	20	3	
15	8	-7 TO -10	12							2	2		2	2		2	2		b	14 to 30	FZR	20	3	1:00
16	8a	-7 TO -10	8	2	2	2			2										d	14 to 30	FZR	20	3	
17	9	-7 TO -10	12							2	2		2	2		2	2		b	14 to 30	FZR	20	3	1:00
18	9a	-7 TO -10	8	2		2	2	2											d	14 to 30	FZR	20	3	
19	10	-7 TO -10	12							2	2		2	2		2	2		b	14 to 30	FZR	20	3	1:00
20	10a	-7 TO -10	8		2		2	2	2										d	14 to 30	FZR	20	3	
21	11	0 TO -7	12								2		2		2	2	2	2	a	14 to 30	FZR	20	3	
22	11a	0 TO -7	8		2	2		2	2										c	14 to 30	FZR	20	3	
23	12	-7 TO -10	12							2	2		2	2		2	2		b	2 to 13	FZD	24	4	1:40
24	12a	-7 TO -10	8	2		2		2	2										d	2 to 13	FZD	24	4	
25	13	-7 TO -10	12							2	2		2	2		2	2		b	2 to 13	FZD	24	4	1:10
26	13a	-7 TO -10	8	2	2		2		2										d	2 to 13	FZD	24	4	
27	14	-7 TO -10	12							2	2		2	2		2	2		b	2 to 13	FZD	24	4	1:10
28	14a	-7 TO -10	8		2	2	2	2											d	2 to 13	FZD	24	4	
29	15	-7 TO -10	12							2	2		2	2		2	2		b	2 to 13	FZD	24	4	1:10
30	15a	-7 TO -10	8	2		2		2	2										d	2 to 13	FZD	24	4	
31	16	0 TO -7	12							2		2		2		2	2	2	a	2 to 13	FZD	24	4	1:30
32	16a	0 TO -7	8	2	2		2		2										c	2 to 13	FZD	24	4	
33	16b	0 TO -7	8		2	2	2	2											c	2 to 13	FZD	24	4	
34	16c	0 TO -7	8	2		2	2		2										c	2 to 13	FZD	24	4	
34a	16y	0 TO -7	12							2	2		2	2		2	2		a	2 to 13	FZD	24	4	
34b	16z	0 TO -7	8							2	2		2	2					a	2 to 13	FZD	24	4	
35	17	>0	6								2		2			2			a	2 to 13	D	24	5	1:00
36	18	>0	6							2		2		2					a	2 to 13	D	24	5	0:30
37	19	>0	6										2			2	2		a	2 to 13	D	24	5	1:00
38	20	>0	6								2				2			2	a	2 to 13	D	24	5	0:30
39	21	>0	6		2	2		2											b	2 to 13	D	24	6	0:15
40	22	>0	6	2			2		2										b	2 to 13	D	24	6	0:15
41	23	>0	6		2	2		2											b	2 to 13	D	24	6	0:15
42	24	>0	6	2			2		2										b	14 to 30	R	20	6	0:15
43	25	>0	6		2	2		2											b	14 to 30	R	20	6	0:15
44	26	>0	6	2			2		2										b	14 to 30	R	20	6	0:15
45	27	>0	6		2	2		2											b	14 to 30	R	20	6	0:15
46	28	>0	6							2			2			2			a	14 to 30	R	20	6	1:00
47	29	>0	6								2			2			2		a	14 to 30	R	20	6	0:30
48	30	>0	6									2			2			2	a	14 to 30	R	20	7	0:15
49	31	>0	6							2			2			2			a	14 to 30	R	20	7	1:00
50	32	>0	6								2			2			2		a	14 to 30	R	20	7	0:30
51	33	>0	6									2			2			2	a	14 to 30	R	20	7	0:15
52	34	>0	6							2			2			2			a	14 to 30	R	20	7	1:00
53	35	>0	6								2			2			2		a	14 to 30	R	20	7	0:30
54	36	>0	6									2			2			2	a	14 to 30	R	20	7	0:15
55	37	>0	6					1	1	1		1		1		1			a	14 to 30	R	20	7	1:00
TOTAL			470	28	32	32	30	33	33	41	38	15	42	37	14	43	36	16						

* The dilutions should be based upon Table 2. XL54 (57% - 43%) and ARCO PLUS (63% - 37%) are commonly used in Canada.

Note: Type I fluid should be applied at Indoor (non-chamber) Temperatures, while Type II fluids should be at Ambient (chamber) Air Temperatures.

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TABLE I

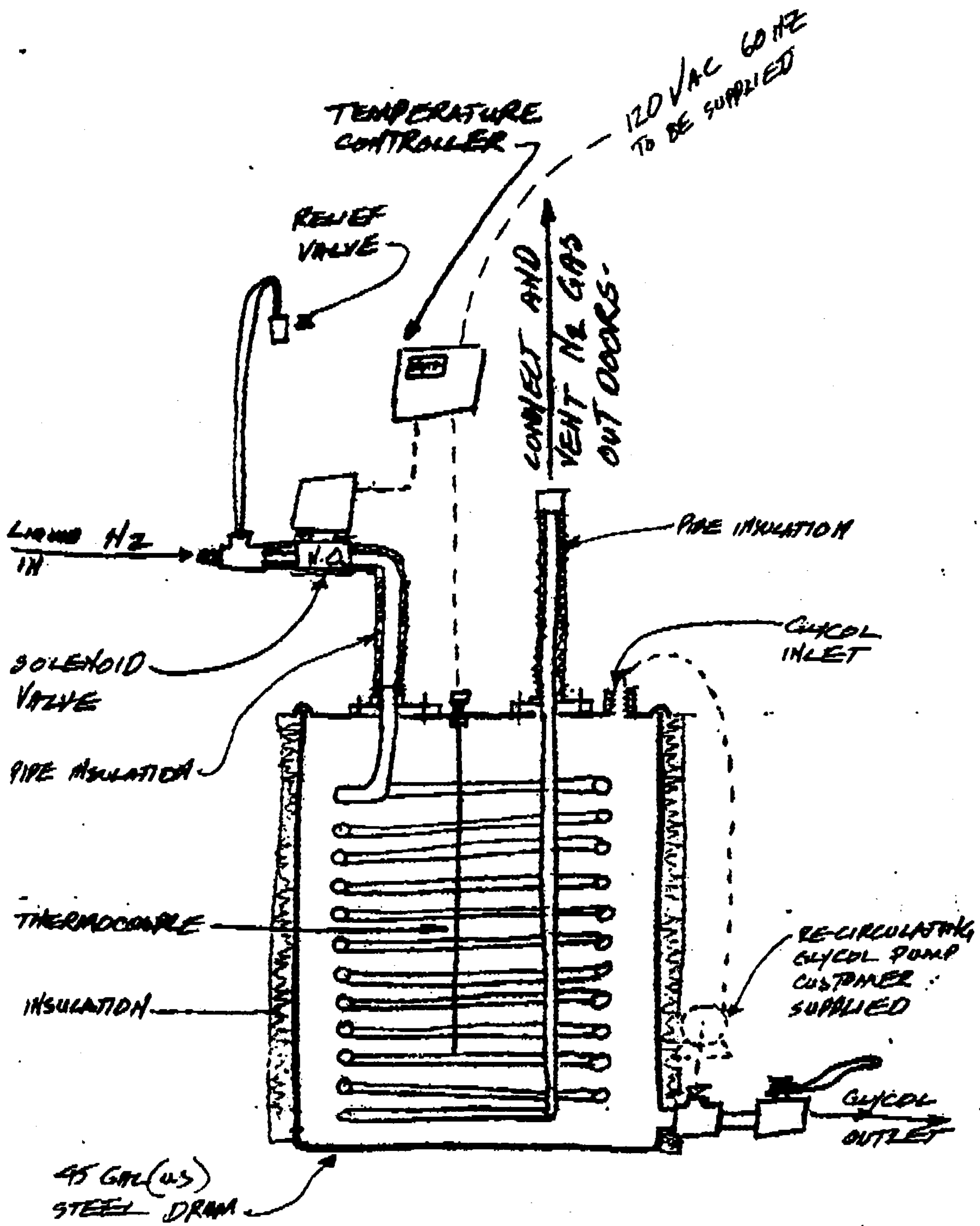
NRC COLD CHAMBER TESTS

TEST EQUIPMENT CHECKLIST

TASK	NRC Cold Chamber	
	Resp.	Status
Logistics for Every Test		
Make Hotel reservations	DD	
Rent Van	ZB	
Rent Car	HF	
Call Site Personnel	ZB	
Call RVSI Personnel	JD	
Test Equipment		
Stand X 2, #2 (TBD)	ZB\MH	
C/FIMS Equipment X 2	ZB\HF	
Still Photo Camera	ZB	
Tape Recorder with Mic.(voice)	ZB	
Weigh Scale	ZB	
Stand Video Camera	HF	
VCR for Video Camera	HF	
T.V. for Video Camera	HF	
Pole for Video Camera	ZB	
Video Camera X 1 (Surf & Snow)	HF	
Thickness Gauge - optional	GT	
Reg. Plates (wing nuts) X 12+12	GT	
Data Forms for plates and cold-soaked boxes	HF	
Precipitation rate Data Form	ZB	
Reports + Tables	ZB	
Cake Pans X 12	GT	
Video Tapes	GT	
Isopropyl alcohol	GT	
Type I Fluids	ZB	
Type II Fluids	ZB	
Clipboards X 3	GT	
Space pens X 6	GT	
Paper Towels	GT	
Rubber squeegees	GT	
Plastic Refills for Fluids and funnels	GT	
Electrical Extension Cords	GT	
Lighting X 2	GT	
Tools	GT	
Box Plate Model X 12	ZB	
Cooling Unit for Box Coolant	ZB	
Coolant Fluid	ZB	
Insulation Jacket for Cold-Soaked Box X 12	ZB	
Stop watches X 4	GT	
Clock Timer for stand x 2	GT	
RVSI Equipment	HF	
Storage bins for small equipment	GT	
Temperature Probe x 8 (P.Dawson's unit)	HF	
Protective clothing	GT	
Refractometer	GT	
Tie wraps	GT	
Tags (Labels) for Fluid designation on stand	MH	
Scrapers	GT	

CHKLS_CC.XLS
3/29/95
4:30 PM

COOLING UNIT DIAGRAM

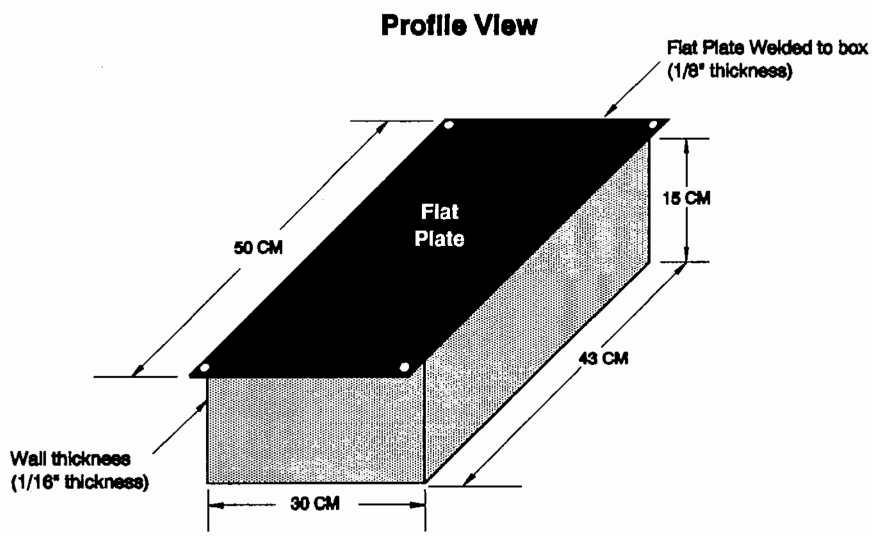


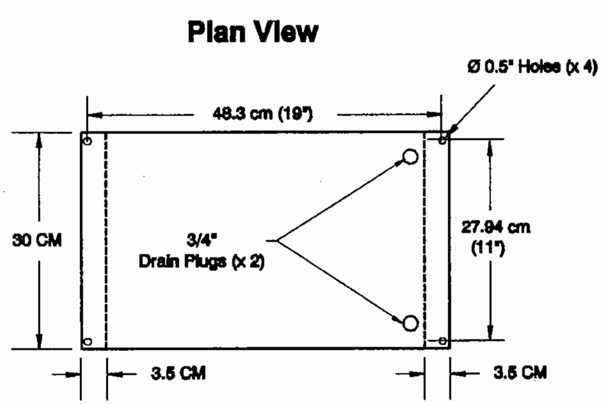
GLYCOL CHILLER

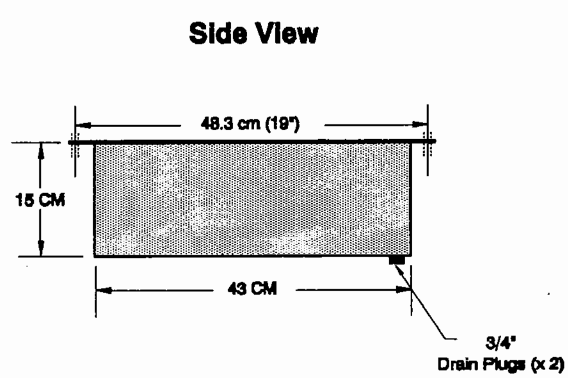
95.03.17

SCHEMATICS OF SEALED BOX
DEPTH OF 15 CM

SEALED BOX







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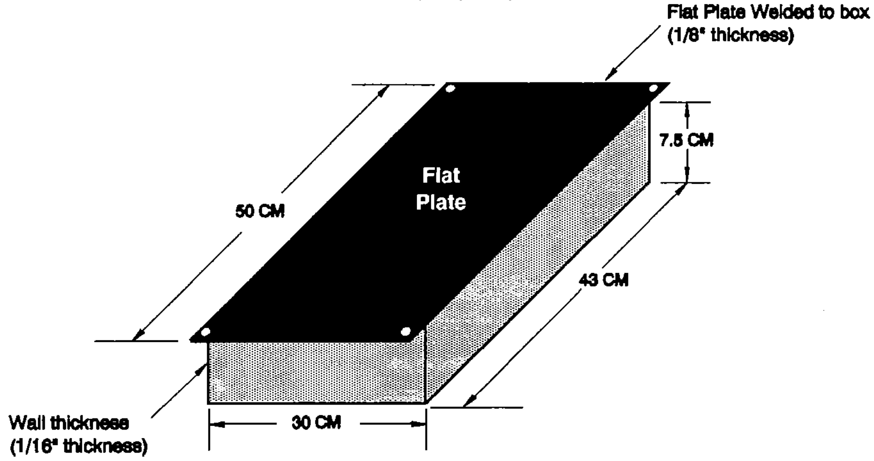
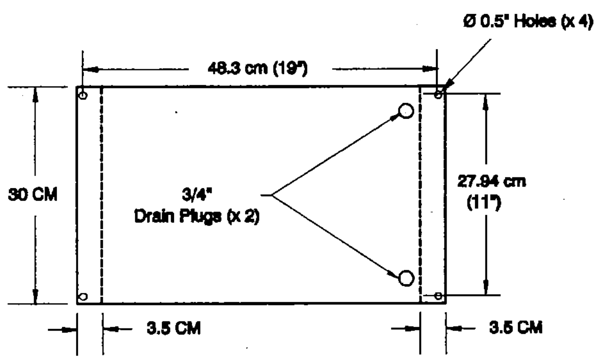
SCHEMATICS OF SEALED BOX
DEPTH OF 7.5 CM

SEALED BOX

Profile View



Plan View



Side View

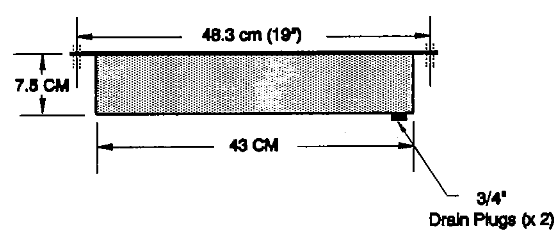


TABLE 1

DE/ANTI-ICING DATA FORM

REMEMBER TO SYNCHRONIZE TIME — VERSION 2.2 — Winter 94/95

LOCATION: **DATE:** **RUN NUMBER:** **STAND # :** **CIRCLE SENSOR PLATE:** u v w x y z

Time After Fluid Applied to Plates U and X: am / pm **SENSOR NAME:**

RVSI Series # : ________ **Frame # :** ________

COLLECTION PAN:	**PAN #**		**PAN #**	
	Before	**After**	**Before**	**After**
Weight of Pan (g)				
Collection Time (min)				

DIRECTION OF STAND:

CONTROL PLATE COMMENTS:

PRECIP: ZR ZL S SW IP IC BS SP ++ + - --

SNOW/RAIN CATEGORIES (use velvet & classification):

OTHER COMMENTS (Fluid Batch, etc):

FAILURES CALLED BY :

HAND WRITTTEN BY :

ASSISTED BY:

***TIME (After Fluid Application) TO FAILURE FOR INDIVIDUAL CROSSHAIRS (MINUTES)**

Time of Fluid Application: → ________ mins (V & Y) ________ mins (W & Z)

	Plate U			**Plate V**			**Plate W**		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA									
TIME OF SLUSH FORMATION ON SENSOR HEAD	1st	½	Full	1st	½	Full	1st	½	Full

	Plate X			**Plate Y**			**Plate Z**		
FLUID NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA									
TIME OF SLUSH FORMATION ON SENSOR HEAD	1st	½	Full	1st	½	Full	1st	½	Full

* To Compare to previous years of testing, subtract "Time of Fluid Apllication".

PFORM2-2.XLS Printed: 3/29/95

PRECIPITATION RATE MEASUREMENT @ CEF IN OTTAWA

Date: ______________________

Start Time: ______________________ am/pm

Run # : ______________________

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

Pan Location:

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

Collection Pan:

Pan/ Cup #	Area of Pan (dm²)	Location	Weight of Pan (g) Before	After	Collection Time (min) Start	End
		U =				
		UU =				
		V =				
		VV =				
		W =				
		WW =				
		XX =				
		X =				
		YY =				
		Y =				
		ZZ =				
		Z =				

Comments: ______________________

Handwritten by: ______________________

Measured by: ______________________

Precipitation Rate = Δg/area (dm²)/hr

RATE_FRM.XLS
3/29/95

APPENDIX C

SAMPLE OF READAC INFORMATION

APPENDIX C

LEGEND OF READAC INFORMATION

YUL 020200 11SCT22OVC58OVC/9.+/C/M/-12.0/-20.9/26110G20/037//21010/42 9+/10255/-132-120/27011G020264241//3596-1/

YUL	Identification
020200	Date et heure d'observation
11SCT22OVC58OVC	Couches de Nuages
9.+	Visibilité
C	PCPN détectée par la POSS (Type (Valeurs possibles: C,L,R,S,A et P) + intensité)
M	Pression MSL (Toujours manquant)
-12.0	Température
-20.9	Point de Rosée
26110G20	Direction et vitesse des vents (Moyenne de 2 minutes)
037	Calage Altimétrique (30.37)
21010	Opacité cumulative pour chaque couche de nuages (20% pour la première couche) (100% pour les deux premières couches) (100% pour les trois premières couches)
42 9+	Visibilté Min et Max des 10 dernières minutes
10255	Pression de la station (1025.5 mb)
-132 -120	Température Min et Max de la dernière heure
27011	Direction et vitesse des vents (Moyenne 10 minutes)
G020	Rafale durant les 10 dernières minutes
26424	Direction et vitesse du plus haut vent de la dernière heur
1	Unités de la moyenne de vent de deux minutes
//	Données de verglas (intmt Z/./Z intmt/,/Z/ ou rien)
3596	Quantité PCPN dans la collecteur (359.6 mm)
-1	PCPN totale dans la dernière heure (0.1 mm)

File:g:\cm1222\data\readac\WEATHER.XLS

APPENDIX C

SAMPLE OF READAC INFORMATION

RA/ZUL/SA/062137/AUTO/19OVC/9.+/S-/M/-3.8/-9.2/18403/979//10/509+/10047/-43-37/19004G00000000//3864-0/

RA/ZUL/SA/062138/AUTO/19OVC/9.+/S-/M/-3.7/-9.1/18503/979//10/809+/10047/-43-37/19004G00000000//3864-0/

RA/ZUL/SA/062139/AUTO/19OVC/9.+/S-/M/-3.8/-9.1/18503/979//10/709+/10047/-43-37/19004G00000000//3864-0/

RA/ZUL/SA/062141/AUTO/19OVC/9.+/S-/M/-3.8/-9.2/19303/979//10/709+/10047/-43-37/19004G00000000//3864-0/

RA/ZUL/SA/062142/AUTO/19OVC36OVC/9.+/S-/M/-3.8/-9.1/20002/979//1010/609+/10047/-43-37/19004G00000000//
O

RA/ZUL/SP/062143/AUTO/19OVC37OVC/9.+/S--/M/-3.7/-9.1/20502/980//1010/609+/10048/-43-37/19003G00000000/
g

RA/ZUL/SA/062144/AUTO/19OVC/9.+/S--/M/-3.8/-9.0/00000/980//10/609+/10048/-42-37/19003G00000000//3863-0/
5

RA/ZUL/SA/062145/AUTO/19OVC/9.+/S--/M/-3.7/-9.0/00000/980//10/609+/10048/-42-37/19002G00000000//3865-0/

RA/ZUL/SA/062146/AUTO/19OVC/9.0/S--/M/-3.7/-8.8/00000/980//10/609+/10048/-42-37/19002G00000000//3863-0/

RA/ZUL/SP/062147/AUTO/19OVC/9.0/S-/M/-3.7/-8.8/22002/980//10/509+/10049/-42-37/20002G00000000//3865-0/

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RA/ZUL/SA/062152/AUTO/20OVC/8.0/S-/M/-3.6/-8.9/22104/980//10/409+/10051/-41-36/22002G00000000//3863-0/

RA/ZUL/SA/062153/AUTO/21OVC/8.0/S-/M/-3.5/-8.9/22003/980//10/409+/10051/-41-35/22002G00000000//3865-0/

RA/ZUL/SA/062154/AUTO/20OVC/8.0/S-/M/-3.5/-8.8/22904/981//10/409+/10051/-40-35/22003G00000000//3863-0/

RA/ZUL/SA/062156/AUTO/20OVC/8.0/S-/M/-3.6/-8.8/24304/981//10/409+/10051/-40-35/23003G00000000//3863-0/

RA/ZUL/SA/062159/AUTO/17OVC/5.0/S-/M/-3.6/-8.8/23904/980//10/159+/10051/-39-35/23004G00000000//3864-0/

RA/ZUL/SA/062200/AUTO/17OVC/5.0/S-/M/-3.6/-8.8/24804/981//10/159+/10051/-39-35/24004G00000000//3864-0/

RA/ZUL/SA/062201/AUTO/11SCT17OVC/4.0/S-/M/-3.6/-8.9/24804/981//010/159+/10052/-39-35/24004G00000000//3
p

RA/ZUL/SA/062202/AUTO/11SCT17OVC/3.5/S-/M/-3.7/-8.9/25004/981//110/159+/10052/-39-35/24004G00000000//3

RA/ZUL/SP/062203/AUTO/11OVC/2.9V/S-/M/-3.7/-8.8/24704/981//10/15V9+/10052/-39-35/24004G00000000//3864-0

RA/ZUL/SA/062204/AUTO/11OVC/2.7V/S-/M/-3.7/-8.7/24705/981//10/15V9+/10053/-39-35/25004G00000000//3864-

RA/ZUL/SA/062205/AUTO/11OVC/2.5V/S-/M/-3.7/-8.7/25006/981//10/15V80/10053/-39-35/25005G00000000//3864-0

APPENDIX D

DEFINITIONS OF WEATHER PHENOMENON

TABLE D.1

DEFINITIONS OF WEATHER PHENOMENON

Weather Phenomenon*	Definition*
FROST	Ice crystals that form from ice-saturated air at temperatures below 0°C (32°F) by direct sublimation on the ground or other exposed objects.
FREEZING FOG (F)	A suspension of numerous minute water droplets which freezes upon impact with ground or other exposed objects, generally reducing the horizontal visibility at the earth's surface to less than 1 km (5/8 mile).
SNOW (S)	Precipitation of ice crystals, most of which are branched, star-shaped, or mixed with unbranched crystals. At temperatures higher than about -5°C (23°F), the crystals are generally agglomerated into snowflakes.
FREEZING DRIZZLE (ZL)	Fairly uniform precipitation composed exclusively of fine drops [diameter less than 0.5 mm (0.02 in.)] very close together which freezes upon impact with the ground or other exposed objects.
FREEZING RAIN (ZR)	Precipitation of liquid water particles which freezes upon impact with the ground or other exposed objects, either in the form of drops of more than 0.5 mm (0.02 in.) or smaller drops which, in contrast to drizzle, are widely separated.
RAIN (R)	Precipitation of liquid water particles either in the form of drops of more than 0.5 mm (0.02 in.) diameter or of smaller widely scattered drops.
SNOW PELLETS (SP):	Precipitation of white and opaque grains of ice. These grains are spherical or sometimes conical; their diameter is about 2-5 mm (0.1-0.2 in.). Grains are brittle, easily crushed; they bounce and break on hard ground.
SNOW GRAINS (SG):	Precipitation of very small white and opaque grains of ice. These grains are fairly flat or elongated; their diameter is less than 1 mm (0.04 in.). When the grains hit hard ground, they do not bounce or shatter.
HAIL (A):	Precipitation of small balls or pieces of ice with a diameter ranging from 5 to > 50 mm (0.2 to 2.0 in.) falling either separately or agglomerated.
ICE PELLETS (IP):	Precipitation of transparent or translucent pellets of ice, which are spherical or irregular, and which have a diameter of 5 mm (0.2 in.) or less. The pellets of ice usually bounce when hitting hard ground.

Intensity Criteria**

Snow (S) and Freezing Drizzle (ZL)

Estimated Intensity	Horizontal Visibility (statute mile)
Light (-)	If visibility is 5/8 mi (1.0 km) or more
Moderate	If visibility is less than 5/8 to 5/16 mi (1.0 to 0.5 km)
Heavy (+)	If visibility is less than 5/16 mi (0.5 km)

Note: Horizontal visibility is only an <u>estimation</u> of snow and freezing drizzle intensity. Measurements and observations have shown that visibility and precipitation intensity are <u>not</u> <u>always</u> directly correlated.

<u>Drizzle Intensity (ZL):</u>

Light(-): From a trace to 0.01 inch/hr (0.254 mm or 2.54 $gr/dm^2/hr$)
Moderate From 0.01 to 0.02 inch/hr (<0.508 mm or 5.08 $gr/dm^2/hr$)
Heavy(+): More than 0.02 inch/hr (>0.508 mm or 5.08 $gr/dm^2/hr$)

Rain (R) and Freezing Rain (ZR)

Light (-)	Measured Intensity	Up to 0.10 in/hr (2.5 mm or 25 $gr/dm^2/hr$); Maximum 0.01 inch in 6 minutes
	Estimated Intensity	From scattered drops that, regardless of duration, do not completely wet an exposed surface up to a condition where individual drops are easily seen.
Moderate	Measured Intensity	0.11 in to 0.30 in/hr (7.6 mm or 76 $gr/dm^2/hr$); more than 0.01 to 0.03 inch in 6 minutes
	Estimated Intensity	Individual drops are not clearly identifiable; spray is observable just above pavement and other hard surfaces.
Heavy (+)	Measured Intensity	More than 0.30 in/hr (7.6 mm or 76 $gr/dm^2/hr$); more than 0.03 inch in 6 minutes
	Estimated Intensity	Rain seemingly falls in sheets; individual drops are not identifiable; heavy spray to height of several inches is observed over hard surfaces.

<u>Conversions for Water</u>

1 mm = 0.03937 in = 10 gr/dm^2
1 in = 25.4 mm = 254 gr/dm^2

*From World Meteorological Organization Guide to Meteorological Instruments and Methods of Observation (1983)
** From American Meteorological Society, Glossary of Meteorology WSOH #7 MANOBS (3/94)

Compiled by Jeff Cole and Roy Rasmussen of NCAR/RAP: Feb 01, 1996

APPENDIX E

NCAR 1994/95 WINTER HOT TESTS

Results of NCAR Winter 1994/1995
Holdover Time Tests - Marshall Test Site

START TIME	FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	HT Ratio	WC Ratio
January 28, 1995:									
1721	II-X	23.6	28	Snow	39	6.7	56		
	II-Y	13.7	82	Snow	39	6.7	56	2.9	1.7
1854	II-X	7.4	46	Snow	39	8.9	46		
	II-Y	9.7	108	Snow	39	8.9	46	2.4	3.1
2048	II-X	9.6	40	Snow	35	8.9	73		
	II-Y	8.1	132	Snow	35	8.9	73	3.3	2.8
February 10, 1995:									
1741	II-X	19.4	20	Snow	25	12.3	84		
	II-Y	8.6	124	Snow	25	12.3	84	6.2	2.7
1955	II-X	9.6	41	Snow	20	13.4	90		
	II-Y	6.1	151	Snow	20	13.4	90	3.8	2.4
March 6, 1995:									
0700	II-X	4.7	58	Snow	31	3.4	98		
	II-Y	9.1	120	Snow	31	3.4	98	2.1	4.0
0810	II-X	11.4	35	Snow	30	4.5	98		
	II-Y	9.4	85	Snow	30	4.5	98	2.4	2.0
April 10, 1995:									
0755	II-X	3.7	36	Snow	24	22.0	96		
	II-Y	2.6	112	Snow	24	22.0	96	3.1	2.2
0952	II-X	2.1	32	Snow	22	11.0	96		
	II-Y	9.1	94	Snow	22	11.0	96	2.9	3.7
1130	II-X	15.5	23	Snow	21	11.2	94		
	II-Y	10.3	67	Snow	21	11.2	94	2.9	1.9
1237	II-X	20.8	20	Snow	19	10.1	94		
	II-Y	13.6	66	Snow	19	10.1	94	3.3	2.2
1408	II-X	12.5	32	Snow	21	6.7	94		
	II-Y	7.4	105	Snow	21	6.7	94	3.3	1.9
April 17, 1995:									
1841	II-X	11.2	41	Snow	39	14.6	82		
	II-Y	5.9	147	Snow	39	14.6	82	3.6	1.9
April 18, 1995:									
1145	II-X	18.5	30	Snow	28	0	96		
	II-Y	16.7	79	Snow	28	0	96	2.6	2.4
1310	II-X	16.0	25	Snow	30	0	96		
	II-Y	13.2	62	Snow	30	0	96	2.5	2.1
April 19, 1995:									
0218	II-X	10.8	32	Snow	32	5.6	98		
	II-Y	8.8	97	Snow	32	5.6	98	3.0	2.5
April 21, 1995:									
0729	II-X	37.6	17	Snow	34	6.7	94		
	II-Y	31.1	56	Snow	34	6.7	94	3.3	2.7
0830	II-X	10.1	56	Snow	34	5.6	96		
	II-Y	7.7	156	Snow	34	5.6	96	2.8	2.1

UNITED AIRLINES 1994 WSET
CLIMATIC CHAMBER TEST RESULTS (HOLDOVER TIME)

CHAMBER Y

FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	H2O (g/min)	TEMP (degF)	WIND (mph)	R.H. (%)	HT Ratio
Test One: Application of 100/0 Type II to clean test plate							
II-X	5.0	31.8	0.083	23	0.5	Nm	
II-Y	5.0	100	0.083	23	0.5	Nm	3.1
Test Two: Applied hot 50/50 Ty I; then 100/0 Type II							
II-X	5.0	30.8	0.083	23	0.5	Nm	
II-Y	5.0	110	0.083	23	0.5	Nm	3.6
Test Three: Application of dyed 100/0 Type II							
II-X	5.0	31.8	0.083	23	0.5	Nm	
II-Y	5.0	102	0.083	23	0.5	Nm	3.2
Test Four: Application of 100/0 Type II to clean test plate							
II-X	20.0	12	0.333	23	0.5	Nm	
II-Y	20.0	39.8	0.333	23	0.5	Nm	3.3
Test Five: Application of dyed 100/0 Type II							
II-X	20.0	11	0.333	23	0.5	Nm	
II-Y	20.0	36.5	0.333	23	0.5	Nm	3.3
Test Six: Applied 50/50 Type I; then 100/0 Type II							
II-X	5.0	12	0.083	2.3	0.5	Nm	
II-Y	5.0	31	0.083	2.3	0.5	Nm	2.6

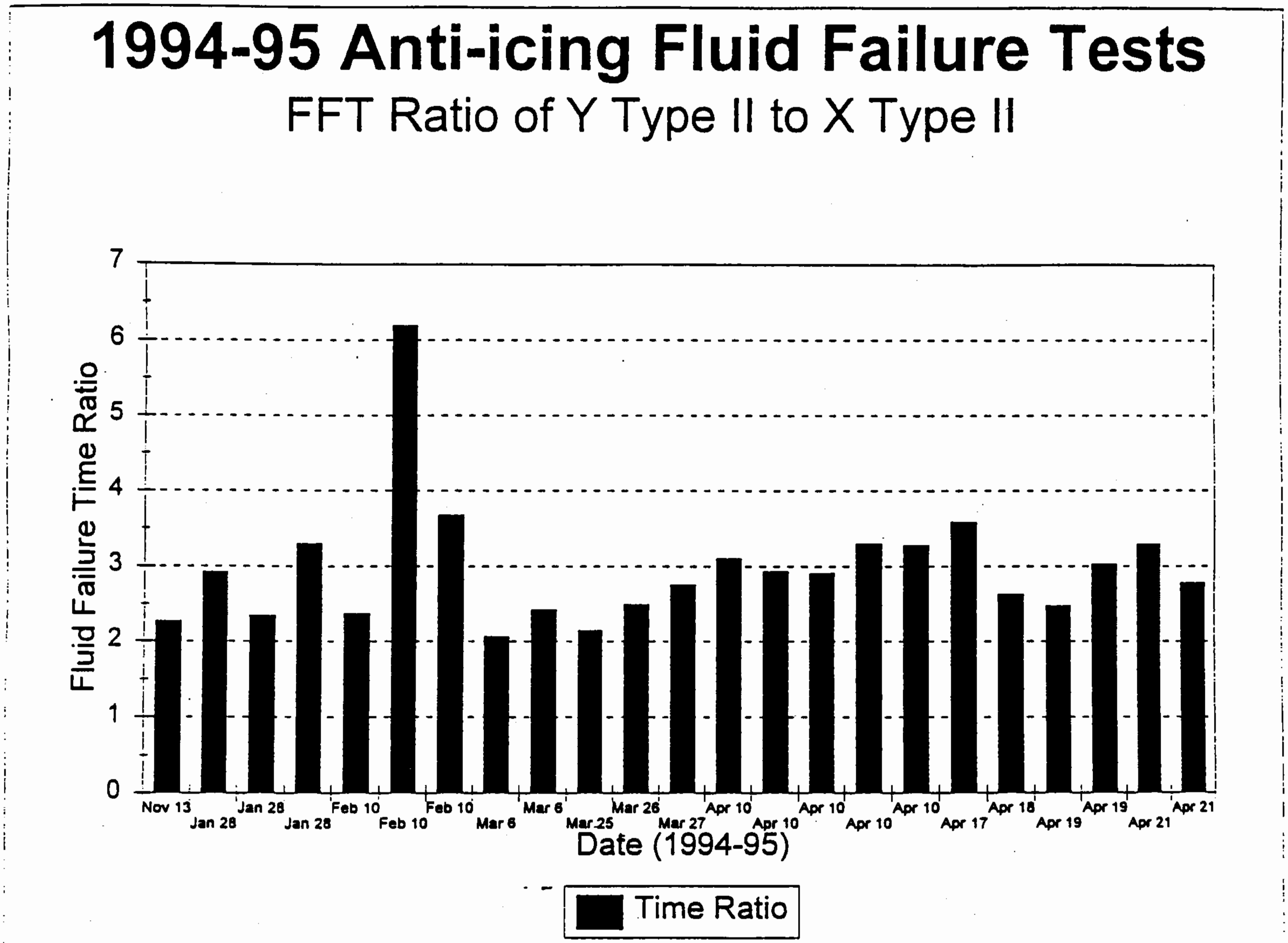
CHAMBER X

FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	H2O (g/min)	TEMP (degF)	WIND (mph)	R.H. (%)	HT Ratio
Test One: Application of 100/0 Type II to clean test plate							
II-X	7.1	33	0.118	23	0.5	Nm	
II-Y	6.4	>120	0.108	23	0.5	Nm	3.6
Test Two: Application of 100/0 Type II to clean test plate							
II-X	10.9	22	0.182	23	0.5	Nm	
II-Y	13.9	70	0.232	23	0.5	Nm	3.2
Test Three: Application of 100/0 Type II to clean test plate							
II-X	13.1	20	0.218	23	0.5	Nm	
II-Y	13.9	85	0.232	23	0.5	Nm	4.2

NOTES:
1. Fluid holdover time (HOLD TIME) specified in minutes
2. H2O is grams/minute deposited over a square decimeter area
3. HT Ratio = Holdover time ratio of Fluid Y to Fluid X

ILLUSTRATES THAT IN A CLIMATIC CHAMBER, REAL WORLD WEATHER CAN BE SIMULATED AND A RELATIONSHIP OF HOLDOVER TIMES CAN BE MEASURED BETWEEN FLUID X AND FLUID Y

5/8/95 MHK



1994-95 Anti-icing Fluid Failure Tests
FFT Ratio of Y Type II to X Type II
Fluid Failure Time Ratio
0
1
2
3
4
5
6
7
Nov 13
Jan 28
Jan 28
Jan 28
Feb 10
Feb 10
Feb 10
Mar 6
Mar 6
Mar 25
Mar 26
Mar 27
Apr 10
Apr 10
Apr 10
Apr 10
Apr 10
Apr 17
Apr 18
Apr 19
Apr 19
Apr 21
Apr 21
Date (1994-95)
Time Ratio

Results of NCAR Winter 1994/1995 Holdover Time Tests - Marshall Test Site

NOTES:

1. Fluid holdover time (HOLD TIME) specified in minutes.
2. HT Ratio = Holdover time ratio of Fluid Y to Fluid X
3. WC Ratio = Snow Pan water content (grams) ratio of Fluid Y to Fluid X at end of protection time
4. Temperature, Wind Speed and Relative Humidity values are average conditions during the time of the test
5. Water content value is the average of the storm precipitation water content calculated over the test time

ILLUSTRATES THAT UNDER SNOW CONDITIONS, A RELATIONSHIP OF HOLDOVER TIMES CAN BE INFERRED BETWEEN FLUID X AND FLUID Y

Data Reduction - United Airlines
5/7/95 - MHK

Results of NCAR Winter 1994/1995
Holdover Time Tests - Marshall Test Site
SNOW CONDITIONS

PLOTTED ON A SPECIFIC FLUID, DECREASING STORM WATER CONTENT BASIS

START TIME	FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	H2O (g/min)	TEMP (degF)	WIND (mph)	R.H. (%)	TEST DATE
0729	II-X	37.6	17	0.627	34	6.7	94	4/21/95
1721	II-X	23.6	28	0.393	39	6.7	56	1/28/95
1237	II-X	20.8	20	0.347	19	10.1	94	4/10/95
1741	II-X	19.4	20	0.323	25	12.3	84	2/10/95
1145	II-X	18.5	30	0.309	28	0	96	4/18/95
1310	II-X	16.0	25	0.267	30	0	96	4/18/95
1130	II-X	15.5	23	0.258	21	11.2	94	4/10/95
1408	II-X	12.5	32	0.208	21	6.7	94	4/10/95
0810	II-X	11.4	35	0.190	30	4.5	98	3/6/95
1841	II-X	11.2	41	0.187	39	14.6	82	4/17/95
0218	II-X	10.8	32	0.179	32	5.6	98	4/19/95
0830	II-X	10.1	56	0.169	34	5.6	96	4/21/95
2048	II-X	9.6	40	0.160	35	8.9	73	1/28/95
1955	II-X	9.6	41	0.159	20	13.4	90	2/10/95
1854	II-X	7.4	46	0.123	39	8.9	46	1/28/95
0700	II-X	4.7	58	0.078	31	3.4	98	3/6/95
0755	II-X	3.7	36	0.061	24	22.0	96	4/10/95
0952	II-X	2.1	32	0.035	22	11.0	96	4/10/95

START TIME	FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	H2O (g/min)	TEMP (degF)	WIND (mph)	R.H. (%)	TEST DATE
0729	II-Y	31.1	56	0.518	34	6.7	94	4/21/95
1145	II-Y	16.7	79	0.278	28	0	96	4/18/95
1721	II-Y	13.7	82	0.228	39	6.7	56	1/28/95
1237	II-Y	13.6	66	0.226	19	10.1	94	4/10/95
1310	II-Y	13.2	62	0.220	30	0	96	4/18/95
1130	II-Y	10.3	67	0.172	21	11.2	94	4/10/95
1854	II-Y	9.7	108	0.162	39	8.9	46	1/28/95
0810	II-Y	9.4	85	0.157	30	4.5	98	3/6/95
0952	II-Y	9.1	94	0.152	22	11.0	96	4/10/95
0700	II-Y	9.1	120	0.152	31	3.4	98	3/6/95
0218	II-Y	8.8	97	0.146	32	5.6	98	4/19/95
1741	II-Y	8.6	124	0.143	25	12.3	84	2/10/95
2048	II-Y	8.1	132	0.135	35	8.9	73	1/28/95
0830	II-Y	7.7	156	0.128	34	5.6	96	4/21/95
1408	II-Y	7.4	105	0.123	21	6.7	94	4/10/95
1955	II-Y	6.1	151	0.102	20	13.4	90	2/10/95
1841	II-Y	5.9	147	0.099	39	14.6	82	4/17/95
0755	II-Y	2.6	112	0.043	24	22.0	96	4/10/95

ILLUSTRATES DECREASING WATER CONTENT, INCREASING HOLD TIME; WIND AND TEMPERATURE INFLUENCE

Data Reduction -United Airlines
5/5/95 MHK

Results of NCAR Winter 1994/1995
Holdover Time Tests - Marshall Test Site

PLOTTED ON AN INCREASING TEMPERATURE BASIS

START TIME	FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	HT Ratio	WC Ratio
1237	II-X	20.8	20	Snow	19	10.1	94		
	II-Y	13.6	66	Snow	19	10.1	94	3.3	2.2
1955	II-X	9.6	41	Snow	20	13.4	90		
	II-Y	6.1	151	Snow	20	13.4	90	3.8	2.4
1130	II-X	15.5	23	Snow	21	11.2	94		
	II-Y	10.3	67	Snow	21	11.2	94	2.9	1.9
1408	II-X	12.5	32	Snow	21	6.7	94		
	II-Y	7.4	105	Snow	21	6.7	94	3.3	1.9
0952	II-X	2.1	32	Snow	22	11.0	96		
	II-Y	9.1	94	Snow	22	11.0	96	2.9	3.7
0755	II-X	3.7	36	Snow	24	22.0	96		
	II-Y	2.6	112	Snow	24	22.0	96	3.1	2.2
1741	II-X	19.4	20	Snow	25	12.3	84		
	II-Y	8.6	124	Snow	25	12.3	84	6.2	2.7
1145	II-X	18.5	30	Snow	28	0	96		
	II-Y	16.7	79	Snow	28	0	96	2.6	2.4
0810	II-X	11.4	35	Snow	30	4.5	98		
	II-Y	9.4	85	Snow	30	4.5	98	2.4	2.0
1310	II-X	16.0	25	Snow	30	0	96		
	II-Y	13.2	62	Snow	30	0	96	2.5	2.1
0700	II-X	4.7	58	Snow	31	3.4	98		
	II-Y	9.1	120	Snow	31	3.4	98	2.1	4.0
0218	II-X	10.8	32	Snow	32	5.6	98		
	II-Y	8.8	97	Snow	32	5.6	98	3.0	2.5
0729	II-X	37.6	17	Snow	34	6.7	94		
	II-Y	31.1	56	Snow	34	6.7	94	3.3	2.7
0830	II-X	10.1	56	Snow	34	5.6	96		
	II-Y	7.7	156	Snow	34	5.6	96	2.8	2.1
2048	II-X	9.6	40	Snow	35	8.9	73		
	II-Y	8.1	132	Snow	35	8.9	73	3.3	2.8
1721	II-X	23.6	28	Snow	39	6.7	56		
	II-Y	13.7	82	Snow	39	6.7	56	2.9	1.7
1841	II-X	11.2	41	Snow	39	14.6	82		
	II-Y	5.9	147	Snow	39	14.6	82	3.6	1.9
1854	II-X	7.4	46	Snow	39	8.9	46		
	II-Y	9.7	108	Snow	39	8.9	46	2.4	3.1

APPENDIX F

INSTALLATION, OPERATION AND RESULTS OF RVSI TESTS

INSTALLATION, OPERATION AND RESULTS OF RVSI TESTS

This appendix provides an overview of the installation, operation and results from testing conducted with RVSI's ID-1 ice detection sensor.

F.1 Installation of Portable ID-1 at CEF

Two sensors manufactured by RVSI were tested in the 1994/95 winter. One sensor was installed on a platform above the test stand at Dorval. The installation and the operation of the second leased ID-1 unit had to be simple since it had to be used for the full-scale tests in Toronto. For security reasons in Toronto, the unit had to be stored in the trailer after every event. Prior to the installation on a de-icing vehicle at Toronto, the unit was tested in the NRC Climatic Engineering Facility (CEF) at Ottawa. As part of the tests conducted at the CEF in Ottawa, one of the objectives was to become familiar with the installation and the operation of the unit.

Installation/Teardown

The ID-1 unit was easily installed onto a scissor-lift using a clamp fastened to the personnel safety rail. The clamp was attached to the camera via a folding swing-arm which assisted in the positioning the entire unit. The unit was installed using two people. One person cradled the camera, swing-arm, and half the clamp, and a second person adjusted the camera position and tightened four (4) lock-nuts of the half-clamp to the railing. Instrument removal was accomplished in the same way, although in reverse. The installation of the mounting bracket took less that 1/2 hour, and the attachment of the ID-1 took about 5 minutes.

Ease of Positioning

The ID-1 unit was supported on a folding swing-arm. This allowed for horizontal panning-type motions. The fork-mount housing allowed the unit to be tilted up or down. Both degrees of freedom permit easy manoeuvrability in most desired angles. There was some restriction of motion in the upwards direction due to the ergonomics of the fork-mount housing and the camera unit itself which limited the distance between the camera and the subject to be imaged. For far away subjects, the angling of the unit was more difficult. It took about one minute to align the ID-1 with the plates, but with some practice this time would be reduced. The vertical motion control and the swing-arm should have the ability to be variably damped and locked into a fixed position.

F.2 Installation of ID-1 at Toronto

The installation of the portable ID-1 unit in Toronto was completed by the end of January 1995. The unit was mounted on the bucket of a Canadian Airlines de-icing vehicle by RVSI, with the assistance of APS and its sub-contractor Zephyr North. Photo 5.1 in Section 5.2 shows the installation of this unit on the CAI vehicle. A display of the results is provided on a video monitor in the cab of the truck (see Photo 5.2 in Section 5.2) and to the ID-1 operator in the bucket.

Training on operation of the unit was provided to Zephyr North and consisted of an explanation and demonstration of the equipment over three metal plates on the floor of CAI's Ground Support Equipment Hangar.

A practice session was conducted in mid-February to gain practice and trouble-shoot usage of the RVSI ice detection system, in an outside, over-wing, dry run situation. The session was attended by Transport Canada, APS and Zephyr North with the assistance of CAI. Practice was gained using the ID-1 over a B-737 and A-320 wing. Slight frost existed on the panels but could not be easily detected by the Zephyr North observer when frost was present over the painted surfaces. Positioning of the ID-1 for optimum view was difficult due to the limited range of the truck boom movement.

F.3. RVSI ID-1 Test Results

The ID-1 can provide a display showing up to eight ice intensity levels, in the shaded mode, for each of the 200 x 300 pixels in its image. This works out to between 5 and 10 pixels per square inch (or per cross-hair) on the standard 10° flat plate. In the binary mode, only two levels are available. A schematic showing a comparison of the two modes follows.

Binary Mode

Green	White

A

← clear surface → | ← contaminated → surface

Shaded Mode

← ice intensity level ("bin number") →

1	2	3	4	5	6	7	8
Gr							Wh

For each test, the observed end condition time (⅓ of the plate) coincided with an ice intensity level when ⅓ of the plate was covered. For example, in the Binary mode, the observer may have called failure when the RVSI monitor was at position A (less than

1/3 of plate is shown as white on RVSI). In the shaded mode, this corresponds to ice intensity level 3 or 4. Ice intensity level 3 or 4 would imply that the plate has less failure than if it was called at a later time corresponding to level 6 or 7. This ice intensity level will be referred to as a "bin number" (one of the eight bin numbers shown above). The bin numbers corresponding to fluid failure were analyzed to assess the ID-1's performance.

A series of tests were performed at the NRC Cold Chamber in January 1995 in order to assess the ID-1's sensitivity with respect to position over the plates. Different ID-1 positions were used throughout the tests under different precipitation conditions and temperatures. Table F.1 contains the information pertaining to the position tests used in the analysis. Figure F.1 shows a schematic of the cold chamber with the stand location and the directional system of coordinates used to locate the ID-1 unit. The data is presented by fluid type in Sections 3.1, 3.2 and 3.3. Within each section, a discussion pertaining to the ID-1 position and temperature effect is included. Subsequent sections (3.4 and 3.5) include a discussion pertaining to the fluid type, concentration effect and lighting.

F.3.1 Type II Neat Fluids

a) Position Sensitivity

Experiments 6, 5, and 7 were scanned from positions (0,0,12), (5,0,12), and (12,0,12), respectively for a Type II Neat fluid under simulated light freezing rain. The bin numbers corresponding to failure on 1/3 of the plate were 7, 7 and 8 for experiments 6, 5, and 7. The ID-1 was unaffected by forward distance to the plates for experiments 6 and 5 where the inclinations of the sensor from the vertical Z axis were 0° and

TABLE F.1

SUMMARY OF ID-1 POSITION TESTS

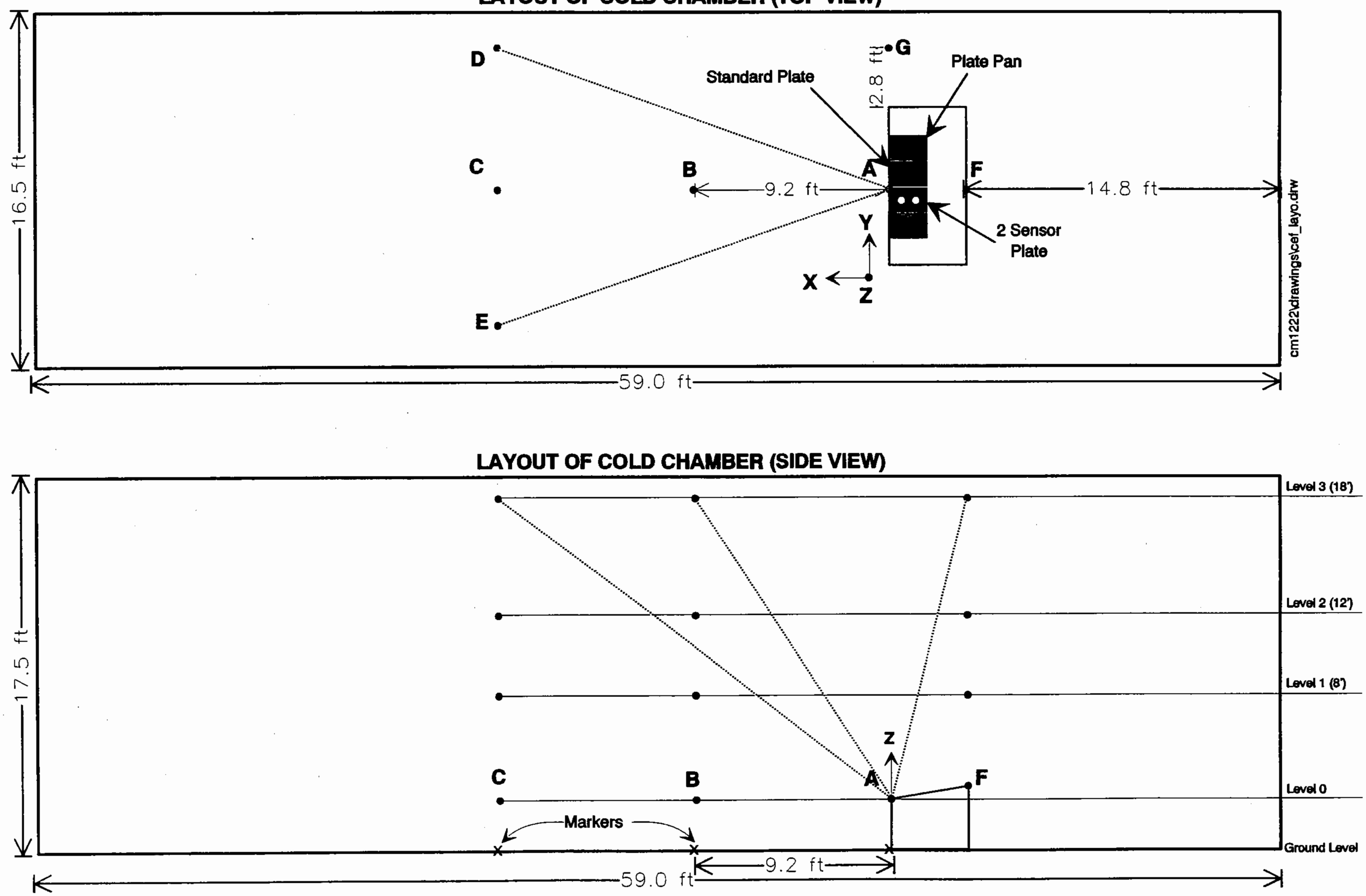
EXPERIMENT #	ID-1 SEQUENCE #	PLATE	FLUID	TEMPERATURE (Celsius)	PRECIPITATION (Type)	ID-1 (x,y,z) POSITION (ft.)	BIN # FOR 1/3 OF THE PLATE
5	6	X	II 100/0	-10	ZR	(5,0,12)	7
6	7	X	II 100/0	-10	ZR	(0,0,12)	7
7	8	X	II 100/0	-10	ZR	(12,0,12)	8
11	13	Z	II 50/50	-10	ZR	(5,0,12)	7
12	14	Z	II 50/50	-10	ZR	(5,0,12)	7
13	15	X	II 50/50	-10	ZR	(-4,0,12)	7
14	16	X	I STD	-10	ZR	(-4,0,12)	6
15	18	Y	I STD	-5	ZR	(-4,0,12)	5
16	19	Y	I STD	-5	ZR	(-4,0,8)	4
17	20	X	I STD	-5	ZR	(12,-4,8)	8
18	21	X	I STD	-5	ZR	(12,-4,12)	8
20	24	X	II 50/50	-15	ZF	(0,0,8)	5
23	28	Z	II 100/0	-25	ZF	(3,0,8)	8
25	31	X	II 50/50	-10	ZF	(2,0,8)	6
26	32	X	II 100/0	-10	ZF	(2,0,8)	7

09/05/96
CM1222\ANALYSIS\ID1_POS\TABL_LOG.XLS

FIGURE F.1

POSITION OF RVSI'S ID-1

LAYOUT OF COLD CHAMBER (TOP VIEW)



22.6°, respectively. For experiment 7 where the inclination was 45°, a slight effect was noticed since the bin number attributed to 1/3 of the plate at observed failure was 8 compared to 7 for the other two tests.

b) Temperature Sensitivity

Experiments 23 and 26 were both conducted for a Type II Neat fluid under simulated freezing fog from positions of (2, 0, 8) and (3, 0, 8). The one foot difference in the X coordinate is not believed to have any effect since it is roughly equal to operational position accuracy. The bin numbers corresponding to the observed failure are 8 and 7 for the two experiments. The two experiments had identical rates of precipitation but different temperatures (-25°C for experiment 23 and -10°C for experiment 26). The -25°C test had an observed failure corresponding to a bin number of 8 compared to 7 for the -10°C test. This implies earlier failure indication at lower temperatures by the ID-1 under simulated freezing fog. This could be explained by the larger amount of condensed and frozen water particles in the air at lower temperatures. This higher concentration of condensed and frozen water particles per volume of air could be causing the ID-1 to indicate early failure.

F.3.2 Type II 50/50 Fluids

a) Position Sensitivity

Experiments 11 and 13 were conducted for Type II 50/50 fluids under similar simulated light freezing rain and temperature conditions but from positions (5, 0, 12) and (-4, 0, 12). The corresponding inclinations from the vertical axis were 22.6° and -18.4°. The bin number for the observed failure was 7 for both tests, indicating, no effect for these positions.

F.3.3 Type I Standard Fluids

a) Position Sensitivity

Experiments 15, 16, 17 and 18 were conducted with standard Type I fluid under simulated light freezing rain at -5°C and identical rates of precipitation. The position of the ID-1 was (-4, 0, 12), (-4, 0, 8), (12, -4, 8) and (12, -4, 12) for each test. The ID-1 inclination angle off the vertical at the plates was 18°, 27°, 58° and 47°, respectively. Test 15 was conducted with the ID-1 at the same X & Y position as test 16, but 4 feet higher. Test 18 was conducted with the ID-1 at the same position as test 17, but again 4 feet higher. Tests 17 and 18 were conducted at more shallow angles than tests 15 and 16.

The bin numbers matching observed failure on 1/3 of the plates were 5 and 4 for tests 15 and 16. Again, there is indication of a threshold inclination angle between 18° and 27° where the ID-1 looses sensitivity. This is consistent with previous results.

The bin number matching the observed failure was 8 for both test 17 and 18 and these were done at inclination angles of 58° and 47°. With such high inclination angles, the ID-1 detected high levels of ice formation on the plates for both tests but that detection was present from the very beginning of the tests when failure was not yet observed. This indicates that large distances from a target, associated with large inclination angles, can result in erroneous operation.

F.3.4 Fluid Concentration and Type Sensitivity

a) Fluid Concentration Sensitivity

Tests 5 and 11 were done at the same position under similar environmental conditions for Type II Neat and 50/50 under simulated light freezing rain. The bin number matching the observed failure on 1/3 of the plate was 7 in both cases, giving no indication of fluid concentration effect on the ID-1 operation under light freezing rain.

Some effect was observed for Type II Neat and 50/50 fluids under simulated freezing fog in tests 26 and 25. The bin number matching observed failure on 1/3 of the plates was 6 for test 25 and 7 for test 26.

b) Fluid Type

Tests 13 and 14 were conduct at the same position under similar environmental conditions for Type II 50/50 and standard Type I under simulated light freezing rain. The bin number corresponding to observed failure on 1/3 of the plate was 7 for test 13 and 6 for test 14 which indicates a slight fluid type effect on the ID-1 operation under simulated freezing rain.

F.3.5 Illumination Effect

Tests 11 and 12 were done for Type II 50/50 fluids under similar environmental conditions and identical rates of precipitation of simulated light freezing rain. The difference was the illumination which was increased for test 12. Both tests had bin numbers of 7 matching failure on 1/3 of the plate, which indicates that illumination has no effect on the ID-1's performance.

APPENDIX G

TEST PROGRAM FOR ID-1 POSITION TESTS

CM1222.001

EXPERIMENTAL PROGRAM FOR RVSI's ID-1 POSITION TESTS
1994 - 1995

To be conducted the week of
January 9, 1995 at CEF, NRC, Ottawa

APS Aviation Inc.

January 6, 1995

Version 1.2

EXPERIMENTAL PROGRAM
FOR RVSI's ID-1 POSITION TESTS
1994 - 1995

1. OBJECTIVES

a) To evaluate the response of RVSI's ID-1 when viewing the flat plate and airfoil from various positions and angles in the cold chamber.

b) To compare the response of the Instrumar C/FIMS and RVSI's ID-1 during the same flat plate test in the cold chamber.

c) To assess the installation of RVSI's ID-1 on a lift vehicle and its maneuverability once it is installed.

2. TEST REQUIREMENTS (PLAN)

Attachment 1a provides the list of test to be conducted at CEF, Ottawa during freezing drizzle and snow simulation tests. **Figure 1** shows the layout of ⅔ of the cold chamber.

3. EQUIPMENT

Test equipment required for the RVSI's ID-1 Position Tests is provided in Attachment II. Details and specifications for some of the equipment is provided in the experimental plan developed for Dorval's flat plate testing "Experimental Program for Dorval Natural Precipitation Testing 1994/95 (FPTP)".

4. PERSONNEL

Up to three personnel are required to conduct tests for each experiment.

Personnel, P1 is responsible for setup, C/FIMS computer, taking data.
Personnel, P2 is responsible for setup, C/FIMS computer, taking data.
Personnel, P3 is responsible for setup, preparation of fluids, plate pans and taking notes.

5. TEST PROCEDURE

Pre-test set-up (day 1)

1. Layout working area with points A, B, C ... (see Figure 1)
2. Set-up stand @ A (0, 0, 0) as per FPTP.
3. Ensure proper illumination.
4. Set-up computers (C/FIMS & RVSI ID-1).
5. Connect computers to sensors (C/FIMS & RVSI ID-1).
6. Install RVSI ID-1 onto lift vehicle.
7. Note the time to install RVSI's ID-1 and any installation problems.

Assess the RVSI's ID-1 for the following:

8. Moveability and functionality.
9. Tilt and pan.
10. Ease of operation.
11. Alignment (view finding).
12. Control Mechanism.
13. Ease of mounting and dismounting.

Pre-test

Ensure precipitation of light freezing rain and snow @ approximately $25g/dm^2/hr$

1. Place RVSI's ID-1 into the required position.
2. Synchronize computers and wrist watches.
3. Prepare fluids for pouring.
4. Attach clip with fluid name and type.
5. Prepare and weigh plate pans.
6. Fill all revelent information into data sheet.
7. Set (LRU) on-off - on.
8. Ensure video camera is ready.
9. Set timer to '0'.

Execution of Test

1. Start computers (C/FIMS and RVSI).
2. Clean plates using fluid and squeegee.
3. Apply fluids to plates and/or airfoil and note time.
4. Set timer - on
5. Place plate pans on stand and note time.
6. Occasionally record the test with video camera until test reaches the end condition.
7. Record the elapsed time (holdover time) required for the precipitation to reach the end condition.

6. DATA FORMS

Table 1 from the FPTP.
Table 2 Airfoil de/anti-icing data form.

ATTACHMENT Ia

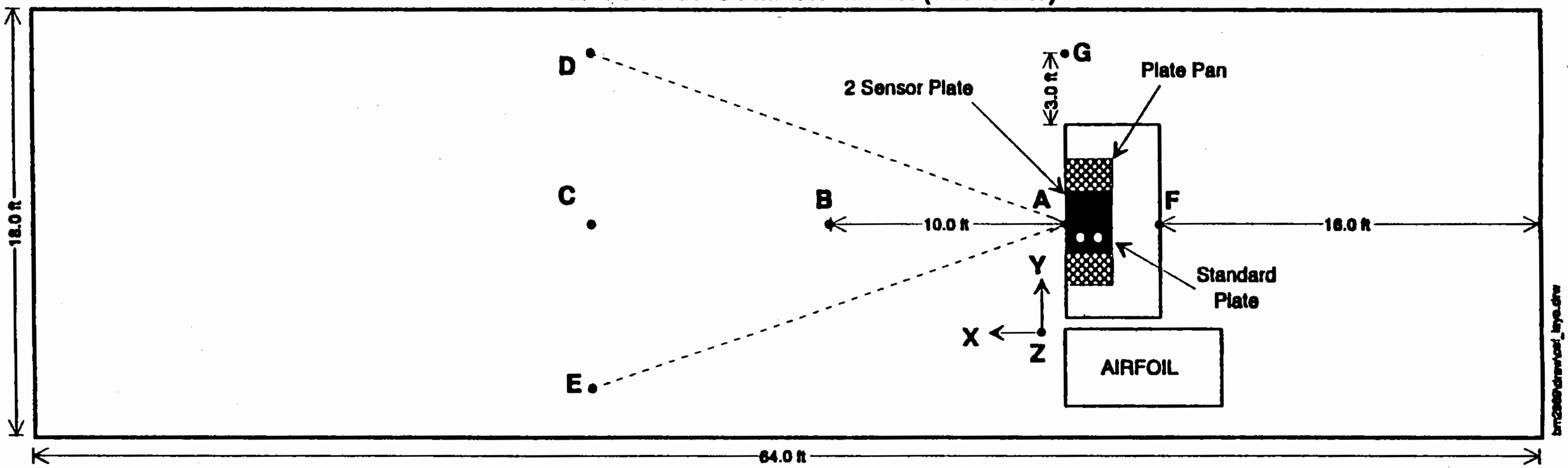
RVSI's ID-1 POSITION TEST (Cold Chamber)

Run #	Temp °C	Precipitation	Fluid	Point	Coordinates (ft)			Test Day				
					X	Y	Z	1	2	3	4	5
1	-10	Freezing Drizzle	Oct/(50/50)/Type II	C	20	0	18		X			
2	-10	Freezing Drizzle	Oct/(50/50)/Type II	C	20	0	12		X			
3	-10	Freezing Drizzle	Oct/(50/50)/Type II	C	20	0	8		X			
4	-10	Freezing Drizzle	Oct/(50/50)/Type II	C	20	0	0		X			
5	-10	Freezing Drizzle	Oct/(50/50)/Type II	C	20	0	12		X			
6	-10	Freezing Drizzle	Oct/(50/50)/Type II	B	10	0	12		X			
7	-10	Freezing Drizzle	Oct/(50/50)/Type II	A	0	0	12		X			
8	-10	Freezing Drizzle	Oct/(50/50)/Type II	F	-4	0	12		X			
9	-10	Freezing Drizzle	Oct/(50/50)/Type II	G	0	7	18		X			
10	-10	Freezing Drizzle	Oct/Neat/Type II	G	0	7	18		X			
11	-15	Snow/Ice Pellet	Oct/Neat/Type II	C	20	0	12			X		
12	-15	Snow/Ice Pellet	Oct/Neat/Type II	B	10	0	12			X		
13	-15	Snow/Ice Pellet	Oct/Neat/Type II	A	0	0	12			X		
14	-15	Snow/Ice Pellet	Oct/Neat/Type II	F	-4	0	12			X		
15	-30	Snow/Ice Pellet	Oct/Neat/Type II	C	20	0	12			X		
16	-30	Snow/Ice Pellet	Oct/Neat/Type II	B	10	0	12			X		
17	-30	Snow/Ice Pellet	Oct/Neat/Type II	A	0	0	12			X		
18	-30	Snow/Ice Pellet	Oct/Neat/Type II	F	-4	0	12			X		
19	-5	Freezing Drizzle	Oct/Neat/Type II	C	20	0	8				X	
20	-5	Freezing Drizzle	Oct/Neat/Type II	B	10	0	8				X	
21	-5	Freezing Drizzle	Oct/Neat/Type II	A	0	0	8				X	
22	-5	Freezing Drizzle	Oct/Neat/Type II	F	-4	0	8				X	
23	-5	Freezing Drizzle	Oct/Neat/Type II	D	20	7	8				X	
24	-10	Freezing Drizzle	UCAR/XL54/Type I	C	20	0	18				X	
25	-10	Freezing Drizzle	UCAR/XL54/Type I	B	10	0	18				X	
26	-10	Freezing Drizzle	UCAR/XL54/Type I	A	0	0	18				X	
27	-10	Freezing Drizzle	UCAR/XL54/Type I	F	-4	0	18				X	
28	-15	Snow	Oct/Neat/Type II	C	20	0	12					X
29	-15	Snow	Oct/Neat/Type II	B	10	0	12					X
30	-15	Snow	Oct/Neat/Type II	A	0	0	12					X
31	-15	Snow	Oct/Neat/Type II	F	-4	0	12					X
32	-5	Snow	UCAR/XL54/Type I	C	20	0	8					X
33	-5	Snow	UCAR/XL54/Type I	B	10	0	8					X
34	-5	Snow	UCAR/XL54/Type I	A	0	0	8					X

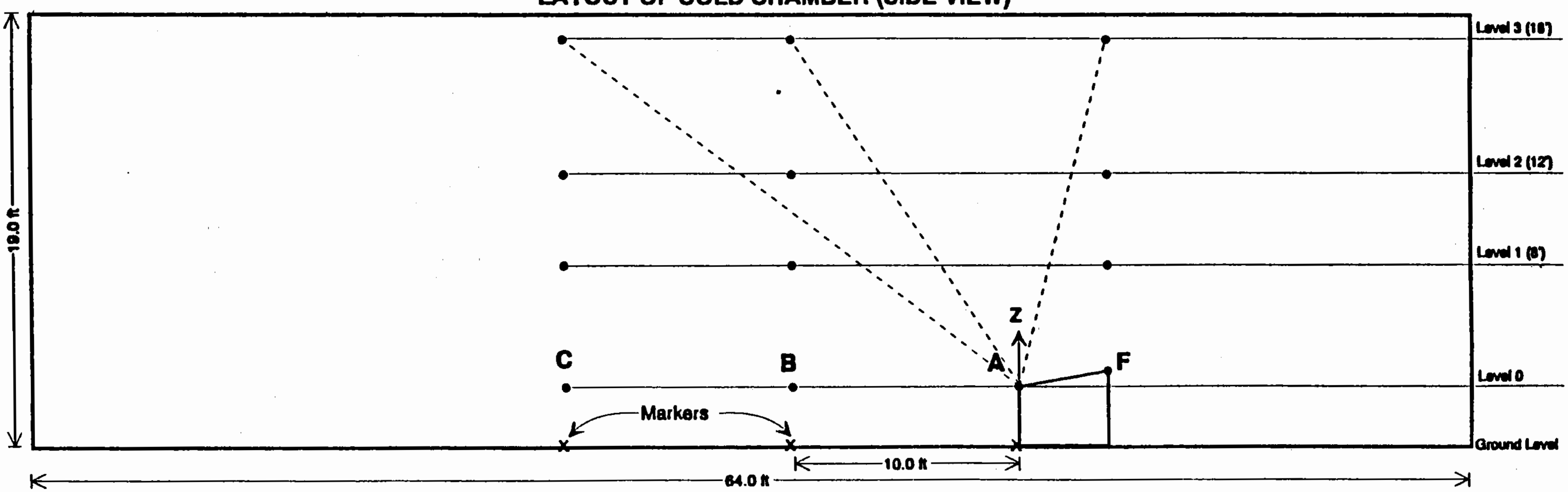
FIGURE 1

POSITION OF RVSI'S ID-1

LAYOUT OF COLD CHAMBER (TOP VIEW)



LAYOUT OF COLD CHAMBER (SIDE VIEW)



ATTACHMENT 2

RVSI's ID-1 POSITION TEST

TEST EQUIPMENT CHECKLIST

TASK	*CEF, OTTAWA*	
	Resp.	**Status**
Logistics for Every Test		
Get confirmation from Oleskiw		
Personnel HF, GT, AP		
Hotel	APS	
Rent Van/Car	GT	
Test Plan	GT	
Test Equipment		
C/FIMS Equipment	HF	
- *Computer with Fastcom Card*	HF	
- *C/FIMS Sensor x 2*	HF	
- *C/FIMS Cables x 2*	HF	
- *LRU Box with cables*	HF	
- *Power bar*	HF	
Reg. Plates (wing nuts) X 2	AP	
1 Plate for 2 C/FIMS Sensor	AP	
2 Plates for 1 C/FIMS Sensor	AP	
XL 54 Fluid for plates	AP	
Ultra Fluid for plates	AP	
Plate Pan X 2	AP	
Tape measure	AP	
Clipboards X 2	AP	
Space pens X 2	AP	
Paper Towels	AP	
Rubber squeegee X1	AP	
Plastic Refills for Fluids and funnels X 2	AP	
Electrical Extension Cords X 4	AP	
Lighting X 2	AP	
Tools	AP	
Stop watches	AP	
Gas container	AP	
Storage bins for small equipment	AP	
Protective clothing	AP	
Tie wraps	AP	
Scrapers	AP	
1 VCR for RVSI (with cables)	GT	
1 TV monitor	GT	
1 Video Camera	GT	
Data Forms X 50	GT	
Hand Watch	GT	
Weigh Scale	NRC	
Mobile lift or Hoist	NRC	
Airfoil	NRC	
Stand	NRC	
Clamps/Bracket for RVSI ID-1	RVSI	
RVSI Equipment	RVSI	

DE/ANTI-ICING DATA FORM
FOR RVSI's ID-1 POSITIONING TEST

REMEMBER TO SYNCHRONIZE TIME

Winter 94/95

LOCATION: CEF, Ottawa DATE: RUN NUMBER: CIRCLE SENSOR PLATE: X Y

Time After Fluid Applied to Plates X and Y: am / pm SENSOR NAME:

RVSI Series # : ____________ Frame # : ____________

COLLECTION PAN: PAN # ________ PAN # ________

	Before	After	Before	After
Weight of Pan (g)				
Collection Time (min)				

CONTROL PLATE COMMENTS:

PRECIP: ZR ZL S SW IP IC BS SP ++ + - --

TIME (After Fluid Application) TO FAILURE FOR INDIVIDUAL CROSSHAIRS (MINUTES)

TIME OF FAILURE @ 6" (RVSI) ________ min

TIME OF FAILURE @ 12" (RVSI) ________ min

RVSI's ID-1 POSITION

Point	Coordinates (ft)		
	X	Y	Z

	Plate X			Plate Y		
FLUID NAME						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						

	1st	½	Full	1st	½	Full
TIME OF SLUSH FORMATION ON SENSOR #1						
TIME OF SLUSH FORMATION ON SENSOR #2						

SNOW/RAIN CATEGORIES (use velvet & classification):

COMMENTS (Assess maneuverability and alignment of RVSI's ID-1, etc):

COMMENTS (ILLUMINATION & LIGHTING):

FAILURES CALLED BY : ____________

HAND WRITTTEN BY : ____________

ASSISTED BY: ____________

RVSI_FRM.XLS Printed: 1/8/95

TABLE 2
AIRFOIL DE/ANTI-ICING DATA FORM

REMEMBER TO SYNCHRONIZE TIME

VERSION 1 Winter 94/95

LOCATION: CEF, Ottawa DATE: RUN # : FLUID TYPE:

Time After Fluid Application: am / pm

Fluid Film Thickness Time
(Time After Fluid Application): ________ min : sec

	SLUSH	FAILURE
1st Contamination Time :	________ min	________ min
Time on Centre of Sensor Head :	________ min	________ min

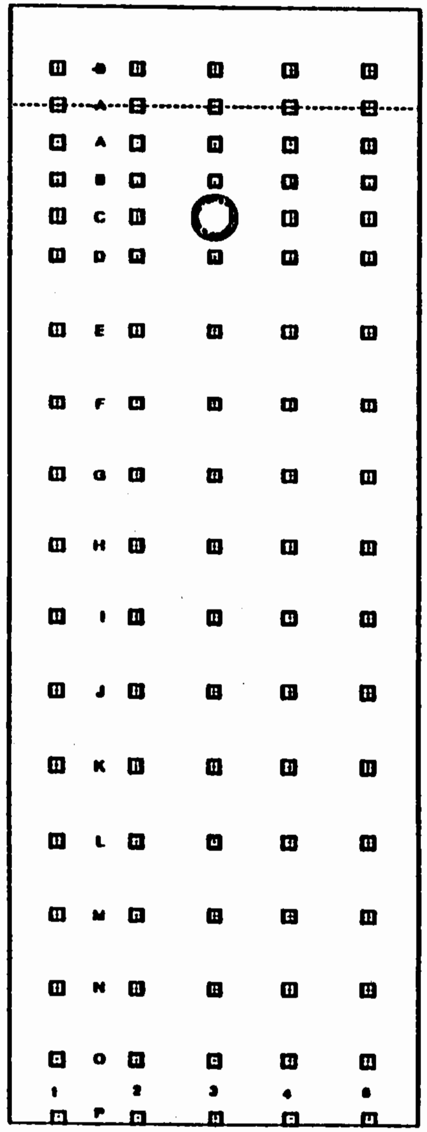
COMMENTS: ________

FAILURES CALLED BY: ________

ASSISTED BY: ________

TIME CONTOURS (min)*

SLUSH FORMATION

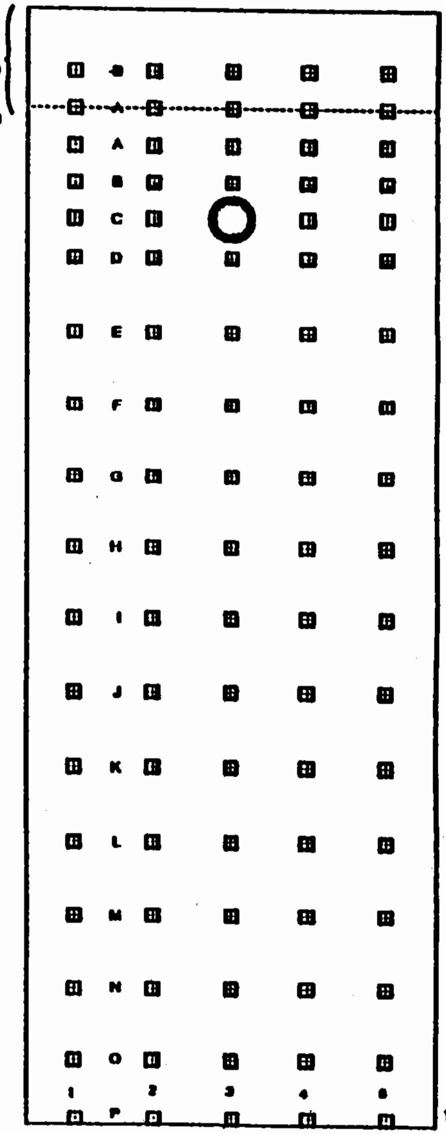


Underneath Leading Edge

Leading Edge

Trailing Edge

LOSS OF ABSORPTION CAPABILITY**
(Standard Failure)



18:1

* Inspect airfoil at 5 minute intervals (After Fluid Application) and draw time contours.
** For freezing fog/drizzle, use "Loss of Gloss" end condition.

AIRF_FRM.XLS
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APPENDIX H

TERMS OF REFERENCE - WORK STATEMENT

APPENDIX H

WORK STATEMENT

AIRCRAFT AND FLUID HOLDOVER TIME TESTS FOR WINTER 94/95
(Short Title: Winter Tests 94/95)

1 INTRODUCTION

The recommendations of the Dryden Inquiry in March 1992 and the setting up of the Dryden Commission Implementation Project Office (DCIP), were followed almost immediately by the La Guardia crash of a F-28, also in March 1992. This accident also had clear implications that ice on take-off was involved. As a result the FAA introduced Holdover Time regulations and requested that the SAE Committee on Aircraft Ground Deicing spearhead work on establishing holdover guidelines. This led to the formation of the holdover time working group, co-chaired by DCIP and FAA/ARC. A major test program was initiated building on an existing program which had been initiated by the Transport Development Centre (TDC) for the 90/91 winter season.

Transport Canada (DCIP) agreed to coordinate the expanded test program, and provide several Instrumar Clean Wing Detection Systems (CWDS) sensor units to be used at selected sites as a measure to better define fluid failure criteria.

Times given in Holdover Time Tables were established by European Airlines based on assumptions of fluid properties, and anecdotal data. The extensive testing conducted by DCIP has been to determine the performance of fluids on standard flat plates in order to substantiate the times, or if warranted, to recommend changes. The original DCIP program has been largely completed, however as a result of the program findings DCIP has agreed with the SAE to extend the Table coverage to the low temperatures encountered in North American operations, to substantiate Table values for 'rain on a cold soaked wing', and to consider a new class of 'longer life' fluids. These latter fluids presently qualify as Type II, but preliminary data suggests that their very long times to failure, under certain circumstances, might warrant a new classification to permit the Airlines to benefit accordingly. Finally the flat plate data has not, to date, been correlated with fluid performance on service aircraft on a systematic basis.

Canadian Airlines International Ltd. (CAI), and Air Canada have offered to cooperate with DCIP in order to promote winter operational safety by making aircraft and limited ground support staff available to facilitate the correlation of flat plate data with performance of fluids on aircraft.

DCIP plans to take advantage of these offers to undertake the outstanding Holdover Time work, and with crew and equipment mobilized, to 'piggy-back' additional tests:

To evaluate the suitability of hot air for de-icing as an alternative to heated de-icing fluids at low (e.g. -30°C and below) ambient temperatures. The hot air temperature must not exceed 85°C; time to de-ice, avoidance of re-freezing, and operational economics are factors to be considered. Similarly forced air will also be considered for removal of cold dry snow, and for 'warm' wet snow.

Use of hot water is presently permitted for de-icing down to -3°C. Past experience suggests that this could be extended to -7°C, or lower, though no quantitative data is available. The economic and environmental advantages are self-evident. Pertinent tests will therefore be conducted to address the effectiveness of hot (up to 85°C) water with consideration given not only to the de-icing operation proper, but also to the problem of ice formation on the ground.

Since instrumentation will be used to determine fluid failure on the aircraft the role and application of such instrumentation within the regulatory environment will be studied.

2 PROGRAM OBJECTIVE (MCR 16)

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

3 PROGRAM SUB-OBJECTIVES

Perform tests to record data which will subsequently be used to establish relationships between laboratory testing and real world experience in protecting aircraft surfaces. Develop reliable holdover time (HOT) guideline material based on test information for a wide range of winter weather operating conditions. Substantiate values in existing holdover time tables for type 1,type 2, and possibly type 3 fluids.

4 PROJECT OBJECTIVES

4.1 To complete the substantiation of the existing SAE HoldOver Time Tables and proposed Table extensions by conduct of tests on modified 'standard' flat plates, adapted to provide reference conditions for 'cold soaked' wings, for Type I and Type II fluids subjected to a controlled environment of rain.

4.2 To complete the substantiation of the existing SAE holdover time Tables and proposed table extensions by conduct of tests on standard flat plates as follows:

Type I and Type II fluids under conditions of natural snow, freezing drizzle and simulated freezing fog and freezing drizzle at the lowest temperature ranges for each condition of precipitation.

Type I fluids at dilutions for which a buffer of 10^{0} C from the fluid freeze point is maintained.

At least two samples of a new family of 'long-life' fluids will be tested to establish the holdover times over the full range of HOT table conditions for this potential new fluids category.

4.3 To correlate the flat plate test data used to substantiate the SAE HoldOver Time Tables with the performance of fluids on service aircraft, by concurrently testing de/anti-icing fluids on standard flat plates and service aircraft under conditions of natural freezing precipitation for Type I and Type II fluids during the 94/95 winter season.

4.4 To evaluate the suitability of hot air de-icing at low ambient temperatures as an alternative to heated de-icing fluids, and to evaluate the suitability of heated or unheated forced air for removal of cold dry snow, and/or wet snow.

4.5 To ascertain the evironmental limits for the use of hot water as a de-icing fluid.

4.6 To evaluate a remote sensor as an inspection device to detect contamination, under field conditions.

4.7 To determine the pattern of fluid run-off from the wing during take-off.

5. DETAILED STATEMENT OF WORK

The work shall be broken down into 7 distinct areas of activity consistent with the project objectives, together with activities for presentations and reporting at the completion of work. A detailed workplan, activity schedule, cash flow projection, project management control and documentation procedure shall be developed and delivered to the DCIP R&D Task Group project officer for approval within one week of effective start date.

5.1 "Cold soak' Test Program

5.1.1 Develop an experimental plan, prepare experiments, conduct tests, analyse results and prepare report for a program to substantiate the values given in the SAE HoldOver Time Tables for diluted and undiluted Type I and Type II fluids for "Rain on a Cold Soaked Wing".

5.1.2 Conduct tests at the Climatic Engineering Facility (CEF), of the National Research Council, Ottawa.

5.1.3 Supply all necessary equipment and fluids for conduct of the tests. This shall include a cooling system to maintain the test plate at constant temperature during the tests.

5.1.4 Schedule an array of tests, for review and approval by the DCIP project officer, covering a range of environmental temperatures from 0^oC to $+7^oC$, a range of plate temperatures from 0^oC to -15^oC, and a range of precipitation rates to be determined in consultation with personnel from AES and NRC. Coordinate the range of plate temperatures with data to be made available by DCIP from field measurements of wing temperatures on service aircraft.

5.1.5 Coordinate scheduling of tests with NRC. Give advance notice of all intended tests to DCIP project officer. Duration of tests shall be 5 working days, incuding set-up time. Complete tests no later than 31 March 1995.

5.2 Substantiation of HOT Tables

5.2.1 Develop experimental programs, for review and approval by the DCIP project officer, for testing of Type I fluids over the entire range of conditions covered by the HOT Tables. Test fluids at dilutions for which a buffer of 10^o C from the fluid freeze point is maintained. These programs shall include outside testing under conditions of natural precipitation, and laboratory testing in the NRC CEF for tests involving freezing fog and freezing drizzle.

5.2.2 Develop test programs for each applicable condition of precipitation, as specified by the SAE HOT Tables, for review and approval by the DCIP project officer:

(a) For testing of undiluted Type II fluids under conditions of natural snow and freezing drizzle at the lowest temperature ranges (i.e. below -14^{0}C).

(b) For testing of Type II fluids under conditions of simulated freezing fog and freezing drizzle at the lowest temperature ranges.

5.2.3 Develop a test program to test undiluted samples representative of the new 'long-life' fluids to establish holdover times over the full range of HOT table conditions for this potential new fluids category. Obtain samples from fluids producers. Conduct tests during periods of freezing precipitation concurrent with HOT Table substantiation tests of conventional fluids.

5.2.4 Establish a test site at Montreal, Dorval Airport for conduct of outside tests. Provide support services and appropriate facilities. Recruit and train local personnel. Repair and replace, as necessary, DCIP supplied equipment used for previous years' testing.

5.2.5 Conduct tests with simulated freezing fog and freezing drizzle in the NRC CEF facility, Ottawa. Provide materials and equipment necessary for tests, conduct tests, analyse results and report. Coordinate scheduling of tests with NRC. Give advance notice of all intended tests to DCIP R&D project officer. Duration of tests shall be 5 working days, incuding set-up time, and tests shall be completed no later than 31 March 1995.

5.2.6 Determine fluid failure by use of Instrumar C-FIMS instrument installed in at least one plate, by RVSI remote sensor set up to view a 'stand' of six standard test plates, and by visual observation.

5.2.7 Conduct ancilliary tests during outside tests at Dorval to collect visibility data during periods of freezing precipitation, and correlate measurements with concurrent meteorological data: precipitation rate, precipitation type, temperature, wind velocity and direction; and background lighting condition as appropriate. An NRC 'WIVIS' Visibility meter shall be obtained from AES in Toronto, where it will be calibrated, during early January 1995.

5.2.8 Program results and plans for completion shall be subject to a 'mid-term' review to be called by DCIP.

5.2.9 Videotape tests. Collect, analyse and report test results.

5.3 Correlation of performance of fluids on flat plates with performance on aircraft

Note: Availability of aircraft will be negotiated by DCIP. In general aircraft will be made available for testing outside regular service hours i.e. available between 11:00 hrs. and 06:00 hrs. Aircraft types to be used will be representative of those in common use by airlines in Canada. Test programs will be conducted at Toronto, Pearson international Airport, using aircraft made available by Canadian International Airlines Ltd. (CAI); at Montreal, Dorval International Airport, using aircraft made available by Air Canada; and in St. John's International Airport, Newfoundland using aircraft to be negotiated.

5.3.1 Develop experimental programs, for review and approval by the DCIP project officer, for concurrent comparison testing of Type I and Type II fluids under conditions of natural freezing precipitation on flat plates and on aircraft. Present the approved programs to the airlines involved prior to start of field tests.

5.3.2 Recruit and train local personnel who will conduct test work. Organize and conduct a 'Kick-off' meeting at each test site with all parties involved in the provision of services and conduct of tests .

5.3.3 Provide all fluids, equipment, an RVSI remote sensor, and all other instrumentation necessary for conduct of tests and recording of data. Ancilliary equipment shall include lighting fixtures as necessary, observation platforms, vehicles, storage facilities, office facilities and personnel rest accomodation for self-contained operations. Secure necessary approvals and passes for personnel and vehicle access and operation on airport airside property. Limit the number of personnel on site to the minimum necessary for execution of test programs: not more than eight persons under normal conditions, not more than ten persons maximum. Co-ordinate with all agencies involved to ensure that these limits are respected.

5.3.4 Include one 'dry run' at each test location prior to start of field tests, under conditions without precipitation, to ensure correct execution of tasks, simulated collection of all data required, and smooth co-ordination of functions.

5.3.5 Schedule tests to determine the comparative performance of Type I and Type II fluids on standard flat plates and aircraft on the basis of forecast significant-duration night-time periods of freezing precipitation. Give advance notice to the airline of the desired test set-up including aircraft orientation to the forecast wind direction, sequence of fluid applications, and any additional services requested. Fluids to be tested shall be from the range of fluids normally used by the airline. Application of different fluids may be requested for each wing in order to maximize test data. Application of fluids will be by airline personnel.

Record pattern of fluid failure. Record effect of aircraft orientation to wind as a variable over the series of tests conducted. The aircraft will in general not be re-oriented during conduct of a test.

5.3.6 Proposed test programs shall assume conduct of five (5) all night test sessions, subject to weather conditions. Additional tests may be requested subject to agreement by all parties involved. Perform tests following plans based on the following:

- A detailed statement of work for each of the participants.
- A specific plan of tests, for review by all parties, which shall include as a minimum:
    - schedule and sequence of activities
    - detailed list of responsibilities
    - complete equipment list
    - list of data, measurements, and observations to be recorded
    - detailed test procedures.
- Activities including:
    - Visual and Instrumented Data Logging.
    - Monitoring and recording environmental conditions, including:
        - -air temperature
        - -Wing surface temperature at selected locations
        - -wind velocity and direction
        - -precipitation type and rate
    - Record of Aircraft and Plate orientation to the wind.
    - Use of Instrumentation to determine condition of the fluid.
- Detailed and rigorous experimental procedures
- Acquisition of data from the tests to address:-
    - Identification of fluid failure criteria.
    - Location of first point of fluid failure on wing, and subsequent failure progression
    - Correlation of fluid failure time to environmental conditions.
    - Correlation of fluid failure times: flat plates and aircraft.
    - Behaviour of fluid on the 'representative' surface.

5.3.7 Anticipate availability at PIA, Toronto, of a Boeing 737 aircraft presently planned to be fitted with Allied Signal C-FIMS contamination sensors on the 'representative' surfaces. Incorporate data available from these sensors into the overall test results. Coordinate data collection activities with Allied Signal. Support visual observations, video records, and

C-FIMS records of fluids behaviour with output from the RVSI remote sensor.

5.3.8 Any equipment obtained from airlines for use during tests shall be returned to its original condition at the end of the test program.

5.3.9 Videotape records of all tests shall be made.

5.4 Forced Air as a de-icing and/or snow removal agent

Note: Hot air is not presently used for de-icing. Criteria for use will be availability of equipment/capital cost, time to de-ice, assurance that all frozen contamination is removed (re-freezing of melted precipitate does not occur), and overall cost effectiveness. Form of initial contamination may be a significant factor.

5.4.1 Conduct a preliminary overview to identify equipment potentially suitable for removal of frost at low (-33°C and lower) temperatures by hot air, and for removal of dry snow and/or wet snow by blown air. Review candidate technologies with personnel of DCIP and the participating Airlines.

5.4.2 Develop experimental programs, for review and approval by the DCIP project officer, for testing of the recommended technology(ies). A test location at Montreal Dorval Airport is anticipated. Recommend alternative test location(s) as appropriate. Arrange for availability of recommended equipment.

5.4.3 Establish test site(s) for conduct of tests. Review truck to be made available by CAIL as a potential mounting platform. Application of blown air will be by airline personnel. Provide support services and appropriate facilities. Recruit and train local personnel as necessary.

5.4.4 Schedule field tests on the basis of forecast weather conditions and plan and co-ordinate test activities in conjunction with airline personnel . Conduct tests under appropriate weather and contamination conditions:
- Aircraft with frost at -33°C or colder.
- Aircraft with accumulated cold dry snow at temperatures below 0°C
- Aircraft with accumulated wet snow at temperatures close to 0°C

5.4.5 Maintain a videotape record of tests. Collect analyse and report test results.

5.5 Hot Water as a de-icing agent

Note: Hot water has been in use as a de-icing agent for many years. Present restrictions limit its use to a minimum ambient air temperature of -3°C. Spent hot water run-off onto a cold-soaked de-icing pad surface will give rise to surface icing/hazards to operators. No anti-icing protection is afforded other than temperature rise of aircraft surfaces above 0°C. Substantiated limits to hot water use are not known. A test location at Montreal Dorval Airport is anticipated for work in conjunction with Air Canada.

5.5.1 Develop a test program to determine the minimum ambient (air and ground) temperature conditions under which hot water can be used for de-icing, for review and approval by the DCIP project officer and Air Canada.

5.5.2 Establish a test site at Montreal, Dorval Airport for conduct of tests. Application of blown air will be by airline personnel. Provide support services and appropriate facilities. Recruit and train local personnel as necessary.

5.5.3 Plan and co-ordinate field tests in conjunction with airline personnel on the basis of forecast weather conditions.

5.5.4 Maintain a video record of conduct of tests. Collect analyse and report test results.

5.6 The remote sensor as an inspection device to detect contamination, under field conditions.

Note: The ability of the RVSI sensor to detect and identify fluid failure on flat plates when exposed to freezing precipitation under field conditions was demonstrated during winter 1994/95 The technological application of the remote sensor, to be procured and installed in support of tests to ascertain the correlation of performance of fluids on flat plates with performance on aircraft, is still under development for application to aircraft inspection.

5.6.1 Develop an experimental program, for review and approval by the DCIP project officer, to verify in the NRC CEF cold chamber over a temperature range down to -30°C the performance and suitability of the sensor .

5.6.2 Develop an experimental program, for review and approval by the DCIP project officer, to verify the performance and suitability of the sensor for field use. Conditions to be examined shall include effect of background lighting; desirable distance of sensor from the wing surface and effective field of view; identification of the zone of the wing under inspection; potential need for scanning; and effects of meteorological conditions and presence of de/anti-icing fluids.

5.6.3 Define equipment requirements and design modifications necessary for mounting the sensor for field use.

5.6.4 Maintain a record of sensor video output with reference data. Collect, analyse and report test results.

5.7 The pattern of fluid run-off from the wing during take-off.

5.7.1 Arrange for de-icing/anti-icing the Boeing 737 aircraft using undiluted fluids during a period of without precipitation in the event that the C-FIMS sensors are installed. Record meteorological conditions; and thickness history of the fluid on each sensor from time of application to take-off, and after take-off if relevant and possible.

5.8 Presentations of test program results

5.8.1 Prepare and present preliminary findings of test programs involving field tests with aircraft to representatives of Transport Canada and the Airlines involved at end of the test season, but no later than April 30 1995.

5.8.2 Prepare and present, in conjunction with Transport Canada personnel, winter test program results at SAE G-12 Committee meetings in Chicago, and London, England.

5.9 Reporting

Reporting shall be in accordance with section 10 "Reporting", below.

5.9.1 Substantiation of HoldOver Time Tables
A final report shall be prepared covering all winter testing sponsored by TDC and DCIP, including that from previous winters, conducted to substatiate the SAE HOT Tables.

5.9.2 Reporting of Other Testing
Separate final reports shall be issued for each area of activity consistent with the project objectives.

APPENDIX I

STATISTICAL MULTI-VARIABLE REGRESSION ANALYSIS

STATISTICAL MULTI-VARIABLE REGRESSION ANALYSIS

A statistical analysis was performed on the data. This analysis consists of a stepwise multi-variable regression to determine the variables of concern in the case of each fluid under different types of precipitation. The process would start by including all variables that are expected by experience to be of effect and then gradually eliminating those that turn out to be of no influence on the behaviour of the fluid at hand. The quality of the regression fit is reflected by the R^2 value and the shape of the standardized residual distribution. The R^2 value is expressed in percentage and reflects the percentage of the data that can be described by the regression. The distribution of the standardized residuals should be as close as possible to a normal distribution and the standard error of the estimated fail time should be as small as possible to ensure a good prediction.

By dividing the sum of the squares of the residual by the degrees of freedom, one can obtain the error variance whose square root is the standard error reported in the regression analysis output. The standard error is a measure of the spread of the observations about the fitted regression line.

F probability test can be applied on each expression to determine if the obtained relationship is significant (i.e. whether or not the model is an adequate explanation of the true situation). The F value returned by the regression should be greater than the critical F value corresponding to the sample size and the regression's degrees of freedom. To determine whether a parameter is of effect on the fluid behaviour, the t statistic returned by the regression is compared to and should be greater than the critical t statistic corresponding to the sample's size and the regression's degrees of freedom. An alternate method to the t statistic consists of looking at the returned P value for each variable, which for a 95% confidence level, should be smaller than 0.05 (1 - 0.95 = 0.05).

The tables show the derived equations as well as the corresponding R^2, F statistic and standard error of the predicted fail time for the Type I and Type II tests conducted in the 1994/95 winter. The critical F statistic is also provided as well as the model's F statistic for each case.

TABLE I.1

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS
TYPE I FLUIDS IN NATURAL SNOW CONDITIONS

Dorvals Tests 1994-1995

Equation #	Fluid Type	No. of Tests	Equation	$F_{critical}$	F_{actual}	Std Err	R^2
1	All Std Type I	112	LOG t = -17.84 - 0.45 LOG(R) + 0.28 LOG(W) + 7.84 LOG (Tk) - 0.07(B-220)	2.5	49.3	0.140	64%
1a	B-222	24	LOG t = -87.06 - 0.42 LOG(R) + 36.44 LOG(Tk)	3.4	26.5	0.135	69%
1b	B-220	26	LOG t = 98.70 - 0.71 LOG(R) - 40.05 LOG(Tk)	3.4	127.3	0.075	91%
1c	B-213	62	LOG t = -11.78 - 0.45 LOG(R) + 0.26 LOG(W) + 5.35 LOG(Tk)	2.7	32.0	0.135	60%
2	All Dil Type I	99	LOG t = -54.26 - 0.45 LOG(R) + 0.22 LOG(W) + 23.13 LOG(Tk) + 1.96 LOG(C) + 0.20(B252) + 0.32(B-253)	2.2	29.8	0.123	64%
2a	B-250	20	LOG t = -175.80 - 0.36 LOG(R) + 73.05 LOG(Tk)	3.5	272.1	0.040	97%
2b	B-252	20	LOG t = 34.63 - 0.25 LOG(R) + 0.43 LOG(W) - 14.07 LOG(Tk)	3.1	25.3	0.077	79%
2c	B-253	59	LOG t = -52.59 - 0.46 LOG(R) + 0.23 LOG(W) + 22.54 LOG(Tk) + 1.78 LOG(C)	2.5	22.5	0.134	60%

Tk = kelvin (°C + 273.2)
W = wind speed (kph)
R = precipitation rate (g/dm²/hr)
C = concentration
t = failure time (min)

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TABLE I.2

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS
TYPE II FLUIDS IN NATURAL SNOW CONDITIONS

Dorval Tests 1994-1995

Equation #	Fluid Type	No. of Tests	Equation	$F_{critical}$	F_{actual}	Std Err	R^2
1	All Type II Neat	128	LOG t - 5.50 - 0.50 LOG(R) + 3.16 LOG(Tk) + 0.03(A-201) + 0.27(A-303)	2.2	149.7	0.071	82%
1a	A-201	44	LOG t = - 0.47 LOG(R) + 0.88 LOG(Tk)	3.2	46.2	0.074	66%
1b	A-205	54	LOG t = - 11.67 - 0.46 LOG(R) + 5.68 LOG(Tk)	3.2	92.9	0.057	78%
1c	A-303	30	LOG t = 22.83 - 0.67 LOG(R) - 0.16 LOG(W) - 8.30 LOG(Tk)	2.9	56.4	0.058	85%
2	All Type II 75/25	58	LOG t = 2.25 - 0.57 LOG(R) - 0.08 LOG(W)	3.2	84.3	0.077	74%
2a	A-501	18	LOG t = 2.01 - 0.44 LOG(R)	4.4	43.6	0.068	71%
2b	A-212	16	LOG t = 14.54 - 0.54 LOG(R) - 0.40 LOG(W) - 4.92 LOG(Tk)	3.2	71.0	0.033	93%
2c	A-503	24	LOG t = 2.32 - 0.72 LOG(R)	4.3	83.1	0.085	78%
3	All Type II 50/50	28	LOG t = 1.79 - 0.34 LOG(R) - 0.33(A-403)	3.3	16.2	0.176	53%
3a	A-210	10	LOG t = - 44.13 - 0.58 LOG(R) + 19.00 LOG(Tk)	4.1	13.8	0.096	74%
3b	A-403	18	LOG t = 125.42 - 51.20 LOG(Tk)	4.4	36.8	0.115	68%

Tk = kelvin (°C + 273.2)
W = wind speed (kph)
R = precipitation rate (g/dm²/hr)
t = failure time (min)

TABLE I.3

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS
TYPE I FLUIDS IN SIMULATED FREEZING DRIZZLE/LIGHT FREEZING RAIN

Dorval Tests 1994-1995

Equation #	Fluid Type	No. of Tests	Equation	$F_{critical}$	F_{actual}	Std Err	R^2
1	All Type I Std	42	LOG t = 1.27 - 0.38 LOG(R)	4.1	60.2	0.089	59%
1a	B-213	14	LOG t = 1.16 - 0.29 LOG(R)	4.6	10.7	0.083	43%
1b	B-220	14	LOG t = 49.4 - 0.27 LOG(R) - 19.9 LOG(Tk)	3.7	21.2	0.067	76%
1c	B-221	6	LOG t = 2.69 - 1.51 LOG(R)	6.0	3.8	0.080	36%
1d	B-222	8	LOG t = 1.23 - 0.32 LOG(R)	5.3	6.4	0.098	44%
2	All Type I Dil.	42	LOG t = 1.07 - 0.32 LOG(R)	4.1	46.0	0.088	52%
2a	B-250	10	LOG t = 1.24 - 0.46 LOG(R)	5.0	33.6	0.066	78%
2b	B-251	8	LOG t = 1.03 - 0.31 LOG(R)	5.3	3.0	0.091	22%
2c	B-252	8	LOG t = 1.08 - 0.27 LOG(R)	5.3	13.2	0.074	63%
2d	B-253	16	LOG t = 1.01 - 0.27 LOG(R)	4.5	12.8	0.096	44%

Tk = kelvin (°C + 273.2)
W = wind speed (kph)
R = precipitation rate ($g/dm^2/hr$)
t = failure time (min)

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TABLE I.4

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS
TYPE II FLUIDS IN SIMULATED FREEZING DRIZZLE/LIGHT FREEZING RAIN

Dorvals Tests 1994-1995

Equation #	Fluid Type	No. of Tests	Equation	$F_{critical}$	F_{actual}	Std Err	R^2
1	All Type II Neat	64	LOG t = 2.25 - 0.61 LOG(R) + 0.28(A-303)	3.2	275.5	0.064	90%
1a	A-201	38	LOG t = 2.17 - 0.54 LOG(R)	4.1	158.9	0.066	81%
1b	A-303	26	LOG t = 28.30 - 0.89 LOG(R) - 10.52 LOG(Tk)	3.4	207.6	0.039	94%
2	All Type II 75/25	52	LOG t = 2.29 - 0.69 LOG(R) - 0.09(A-201) - 0.01(A-205)	2.8	77.4	0.090	82%
2a	A-212	18	LOG t = 40.25 - 0.63 LOG(R) - 15.7 LOG(Tk)	3.6	103.3	0.049	92%
2b	A-501	16	LOG t = 2.04 - 0.53 LOG(R)	4.5	167.4	0.050	92%
2c	A-503	18	LOG t = 2.75 - 1.09 LOG(R)	4.4	220.6	0.072	93%

Tk = kelvin (°C + 273.2)
W = wind speed (kph)
R = precipitation rate ($g/dm^2/hr$)
t = failure time (min)

cm1222\analysis\dorval\eqn_tb2.xls

TABLE I.5

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS
TYPE I FLUIDS IN SIMULATED FREEZING FOG

Dorvals Tests 1994-1995

Equation #	Fluid Type	No. of Tests	Equation	$F_{critical}$	F_{actual}	Std Err	R^2
1	All Std Type I	28	LOG t = -4.13 - 0.37 LOG(R) + 2.25 LOG (Tk)	3.3	136.4	0.044	91%
1a	B-220	10	LOG t = 1.32 - 0.43 LOG(R)	5.0	105.2	0.048	92%
1b	B-222	8	LOG t = - 26.60 + 11.44 LOG(Tk)	5.3	37.3	0.039	84%
1c	B-213	8	LOG t = - 6.79 - 0.33 LOG(R) + 3.33 LOG(Tk)	5.3	182.9	0.023	98%
2	All Dil Type I	31	LOG t = 1.35 - 0.19 LOG(R) - 0.14 LOG(Tk)	3.3	18.0	0.055	53%
2a	B-250	7	LOG t = 1.06 - 0.22 LOG(R)	5.6	23.4	0.036	79%
2b	B-252	6	LOG t = 1.06 - 0.22 LOG(R)	6.0	5.2	0.071	46%
2c	B-253	14	LOG t = 0.97 - 0.17 LOG(R)	4.6	13.0	0.063	48%

Tk = kelvin (°C + 273.2)
W = wind speed (kph)
R = precipitation rate (g/dm²/hr)
t = failure time (min)

cm1222\analysis\dorval\eqn_tb1.xls

TABLE I.6

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS
TYPE II FLUIDS IN SIMULATED FREEZING FOG

Dorval Tests 1994-1995

Equation #	Fluid Type	No. of Tests	Equation	$F_{critical}$	F_{actual}	Std Err	R^2
1	All Type II Neat	68	LOG t - 62.74 - 0.69 LOG(R) + 27.14 LOG(Tk) - 0.54(A-201) - 0.34(A-205)	2.5	152.4	0.107	90%
1a	A-201	15	LOG t = - 106.38 + 44.77 LOG(Tk)	4.5	186.4	0.094	93%
1b	A-205	30	LOG t = - 58.31 - 0.76 LOG(R) + 25.18 LOG(Tk)	3.3	49.5	0.113	77%
1c	A-303	23	LOG t = - 23.02 - 0.38 LOG(R) + 10.52 LOG(Tk)	3.4	25.8	0.049	69%
2	All Type II 75/25	11	LOG t = -164.86 + 69.07 LOG(Tk) - 0.25(A-201) - 0.19(A-205)	3.6	388.8	0.022	99%
3	All Type II 50/50	12	LOG t = 799.73 - 330.01 LOG(Tk) - 0.15(A-201)	3.9	177.4	0.024	97%

Tk = kelvin (°C + 273.2)
W = wind speed (kph)
R = precipitation rate (g/dm²/hr)
t = failure time (min)

TABLE I.7

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR CONVENTIONAL TYPE II NEAT FLUIDS IN COLD SOAKED CONDITIONS

1994-1995

Box Size	No. of Tests	Equation	$F_{regression}$	$F_{critical}$	R^2	$(t_{15}/t_{7.5})_{Ts = -10°C}$
7.5 cm	9	$\text{FAILURE TIME}_{(7.5)} = 0.206(0.950)^{\text{RATE}} * (1.02)^{\text{SKIN TEMPERATURE}}$	16.4	4.3	85%	
15 cm	9	$\text{FAILURE TIME}_{(15)} = 6.06E\text{-}10(0.953)^{\text{RATE}} * (1.10)^{\text{SKIN TEMPERATUR}}$	8.8	4.3	74%	0.5

T_s = box skin temperature (kelvin = °C + 273.2)
R = precipitation rate (g/dm²/hr)
t = fluid failure time (min)