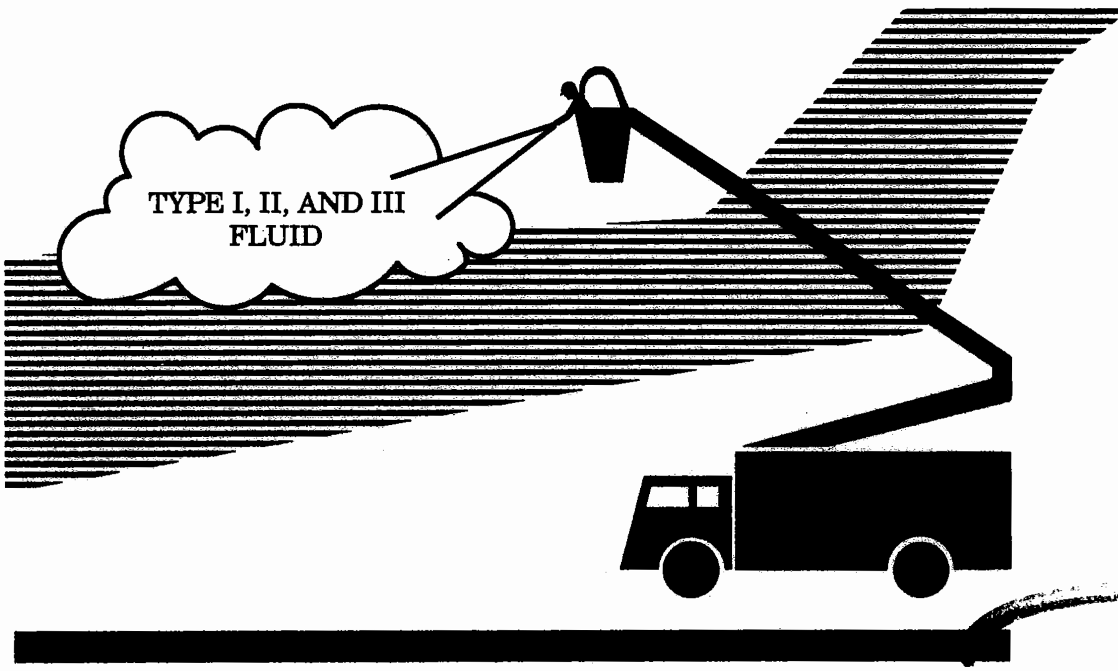
TP 11836E

Aircraft Ground De/Anti-icing Fluid Holdover Time Field Testing Program for the 1992-1993 Winter



Prepared for

Transportation Development Centre
Policy and Coordination
Transport Canada

by

APS Aviation Inc.

October 1993

TP 11836E
492-1100/C1127

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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 Transportation Development Centre of Transport Canada.

Un sommaire en français de ce rapport est inclus.

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16. Abstract

The objective of this study was to manage, conduct and analyze holdover time tests used to assess the time effectiveness of commercially produced de/anti-icing fluids with respect to the current SAE guidelines. Testing included: natural snow tests at Dorval; simulated freezing drizzle and freezing for tests at NRC facilities in Ottawa; and artificial snow tests at Mont Rigaud. Test procedures consisted of pouring de/anti-icing fluids onto clean aluminum plates and recording the elapsed time to the end condition. In order to correlate the flat plate tests with actual aircraft, a few simultaneous tests were carried out on various aircraft surfaces. Ice sensors were mounted on flat plates to evaluate their usefulness in the determination of fluid failure time. Type I, II and III fluids from five manufacturers were tested. Variables measured included total precipitation, failure time, temperature, humidity, wind speed and direction, fluid thickness, type of fluid and type of precipitation.

A total of 276 natural snow, 42 artificial snow, 58 freezing fog and 302 freezing drizzle usable test points were collected. A number of potentially significant relationships between fluid failure time and other variables have surfaced. Under snow conditions, a dimensional analysis yielded a regression equation, with an R^2 of 0.95, describing a typical Type II fluid failure. A statistical analysis showed that different fluids within each type category behave somewhat differently, and high rates of precipitation, low temperatures, high relative humidity, and low and high winds tend to lower the fluid effectiveness. Despite the high rates of precipitation, the freezing drizzle tests resulted in fluid failure times above the corresponding SAE lower limits. Analysis of the ice sensor tests showed sufficient promise for the use of these devices in future tests to determine the failure time of Type II and III fluids. Despite some scatter, a 1:1 relationship was found between the failure time on the flat plate and that on the aircraft surface.

The scope of future tests should focus on diluted Type II fluids to verify SAE holdover times. Necessary procedural and equipment enhancements were recommended, including a special test set-up using a wind shield; the use of ice sensors; and the use of improved meteorological instruments to measure the rate of precipitation. Additional aircraft surface tests to verify correlations with the flat plate must be conducted.

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16. Résumé

Le but de cette étude était d'organiser et de mener des essais visant à mesurer la durée d'efficacité des agents dégivrants et antigivrage sur le marché, et à les comparer aux valeurs correspondantes indiquées dans les lignes directrices de la SAE. Les essais effectués étaient les suivants : sous neige naturelle à Dorval; simulation de précipitations verglaçantes (pluie fine et brouillard) à Ottawa dans les installations du CNRC et sous neige artificielle au mont Rigaud (Québec). Les essais ont 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. Dans le but de corréler les résultats des essais sur des plaques planes avec ceux qui caractérisent les aéronefs, quelques essais ont eu lieu parallèlement sur diverses surfaces et gouvernes d'aéronefs. Des détecteurs de givre ont été par ailleurs fixés à des plaques planes afin de vérifier leur utilité dans le mesurage des durées d'efficacité. Ont ainsi été mis en oeuvre des fluides de type I, II et III fournis par cinq fabricants. Les variables mesurées comprenaient la quantité totale de précipitation, la durée d'efficacité, la température ambiante, l'humidité relative, la vitesse et la direction du vent, l'épaisseur de l'agent, la nature de celui-ci et la forme de précipitation.

Un total de 276 mesures exploitables a été obtenu sous neige naturelle, ainsi que 42 sous neige artificielle, 58 sous brouillard verglaçant et 302 sous pluie fine verglaçante. Un certain nombre de liens potentiellement intéressants ont pu être dégagées, entre durées d'efficacité, d'une part, et diverses variables, d'autre part. L'analyse dimensionnelle a permis d'esquisser des courbes de régression ($r^2 = 0,95$) décrivant les durées d'efficacité obtenues avec un agent de type II. L'analyse statistique a montré que, à l'intérieur de chaque type de fluide, il se trouve des agents qui se comportent quelque peu différemment des autres, et que leur durée d'efficacité tend à baisser lorsque les taux de précipitation et l'humidité relative sont élevés, que les températures sont faibles et que soufflent des vents de force ou faible ou élevée. Malgré des taux élevés de précipitation, les durées d'efficacité obtenues des essais sous pluie fine verglaçante ont été supérieures à la limite inférieure correspondante indiquée dans les lignes directrices de la SAE. Il est apparu lors des essais avec des détecteurs de verglas que ces dispositifs pourraient bien servir ultérieurement dans la détermination des durées d'efficacité des fluides de type II et III. Malgré une certaine dispersion des résultats, ceux-ci ont montré l'existence d'un rapport de 1 : 1 entre les durées d'efficacité sur surface portante d'aéronef et sur plaque plane.

Les essais futurs devraient porter sur l'emploi de fluides de type II dilués afin de vérifier les durées d'efficacité prescrites par la SAE à leur égard. Il faudra améliorer les instruments et les procédures d'observations météorologiques afin de pouvoir mesurer avec une précision accrue le taux d'absorption d'eau par les fluides, prévoir l'utilisation d'un banc d'essais comportant un écran contre le vent et vérifier l'utilité des détecteurs de givre. Enfin, il faudra vérifier par des essais complémentaires la corrélation qui a été constatée entre plaques planes et surfaces d'aéronefs.

17. Mots clés Aéronef, Neige, Brouillard, Pluie fine, Antigivrage, Fluide, Durée d'efficacité, Essai, Précipitations, Profil d'aile, Plaque plane, Données, Dégivrage, Glace, Détecteur.	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 Transportation Development Centre (TDC) of Transport Canada, APS Aviation Inc. (APS) undertook a study to manage, conduct and analyze holdover time tests used to assess the time effectiveness of commercially produced de/anti-icing fluids.

The project involved the participation of a number of de/anti-icing fluid manufacturers, the National Research Council of Canada (NRC), Atmospheric Environment Services (AES), TDC, Dryden Commission Implementation Project (DCIP), Transport Canada-Aircraft Services and Air Canada. This year's natural snow test site was relocated from the roof top of Air Canada's maintenance facility to the AES weather observation site at Dorval Airport in Montreal, Quebec. Testing of simulated freezing fog and drizzle were carried out at NRC's Helicopter Icing Facility and NRC's Climatic Engineering Facility in Ottawa, Canada. Some testing was also done under artificial snow conditions on a ski hill at Mont Rigaud, Quebec.

Generally, the testing consisted of pouring 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. Some testing was also performed on a wing section approximating the leading edge of an F-28, a horizontal stabilizer of a Beech King Air, a Beech King Air aircraft and a sealed box/plate section used for simulation of cold-soaking. In a number of tests, modified Instrumar IM 101 and FM 202 ice sensors were mounted on flat plates to investigate their possible use in the testing process.

The end condition was defined as the point when natural snow was no longer being absorbed or accommodated by the fluid. This was to be when snow was seen to be resting, or bridging, on top of the fluid, above a complete crosshair when viewed from the front of the test stand (perpendicular to the plates). For the freezing fog, freezing drizzle and artificial snow tests, the "loss-of-gloss" type of failure used in previous definitions of end conditions was used.

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

Data Collection

During the 1992-1993 test season, data was collected for natural snow tests conducted at Dorval, freezing drizzle and fog tests conducted in Ottawa, and artificial snow tests conducted at Rigaud. In addition, preliminary tests were conducted with various aircraft surfaces and the cold-soaked box section.

For the Dorval natural snow tests, a total of 76 test data forms were collected containing 151 Type I, 95 Type II and 30 Type III usable fluid data points; for the simulated freezing drizzle tests, a total of 51 data forms contained 121 Type I, 87 Type II, 32 diluted Type II and 62 Type III data points; and for simulated freezing fog, 17 data forms contained 44 Type I, 10 Type II and 4 Type III data points. A total of 42 usable artificial snow tests and 41 usable aircraft surface tests were conducted. From the above experiments, a total of 165 flat plate tests were performed with ice sensors; the majority of these were conducted in natural snow or simulated freezing drizzle.

The following general conclusions can be made regarding the classification of the data: the majority of the tests were conducted under natural snow and simulated freezing drizzle conditions; fluids were obtained from five manufacturers, however, the majority of the tests were conducted with fluids from three manufacturers; for the natural snow tests, the average rate of precipitation, air temperature, relative humidity, wind speed and wind direction were 20 $g/dm^2/hr$, -5°C, 77%, 18 kph and 0°, respectively.

Meteorological Analysis

With the assistance of Atmospheric Environment Services, the Consultants were able to obtain relatively detailed meteorological information for the site at Dorval. This data was used to determine days on which testing could have taken place. The actual days when testing was done were compared against these days. Results indicated not only improvements in coverage, but also an increase in testable days over previous years.

The precipitation collection devices used at Dorval included: a plate pan; a European ombrometer (unshielded); and Environment Canada's tipping bucket (shielded). The results of a comparative study showed that the shielded tipping bucket from Environment Canada provided the most complete data and the most realistic rates of precipitation.

Based on a relationship of visibility and precipitation rate developed by the NRC, and on the snow types observed as a function of precipitation rate, three snow categories were identified. These groups may be used, in the short term, to improve the holdover time information provided to pilots, but further research is required in this area.

Data Analysis

Two basic methods of analysis were performed on the data: a statistical analysis and a dimensional analysis. The statistical analysis primarily involved a linear and non-linear multi-variable regression to determine the existence (if any) of a relationship between the fluid failure time and various parameters such as fluid type, rate of precipitation, wind speed, temperature and relative humidity. The dimensional analysis was performed on the data obtained for Type II fluid tests under snow to establish a relationship based on known physical phenomena. The statistical analysis proved to be very useful in determining the factors influencing fluid failure time. The resulting R^2s for snow are generally higher than previous years'; Type II and Type III regressions, for instance, yielded R^2s ranging from 81% to 96%. The dimensional analysis yielded a regression equation (with an R^2 of 0.95) describing a typical Type II fluid failure as a function of the Reynolds' numbers for air and fluid flow, fluid concentration at failure and relative humidity. The applicability of the equation to any type of fluid should be investigated in future studies.

Under snow conditions, the relevant parameters were assessed to be fluid type, average wind speed, rate of precipitation, temperature and relative humidity. The analysis also shows that winds have an unusual effect on the failure time, in that high and low winds cause lower failure times than moderate winds for a given fluid, if other variables are kept constant. A number of fluids within each type category were found to behave somewhat differently, and high rates of precipitation, low temperatures and high relative humidity tend to lower the fluid effectiveness. Some tests on Type I and II fluids resulted in failure times lower than the corresponding SAE lower limit. These results were obtained during the severe snow storm of March 13, 1993 when, incidentally, the nearby Montreal International Airport remained operational.

Despite the qualitative and quantitative differences between the snow generated artificially and that occurring in nature, the artificial snow test data showed a reasonably good degree of correlation with natural snow data. Hence, artificial snow may possibly be suitable for use in future testing, particularly when natural snow is lacking.

Although the simulated freezing drizzle tests resulted in rates of precipitation well above those occurring in nature, the data shows a good correlation with previously collected data under natural conditions. Furthermore, it was found that the simulated freezing drizzle data correlates quite well with data obtained in the laboratory water spray endurance tests carried out by UQAC. In general, for a given fluid, the failure time under freezing drizzle conditions is governed by the rate of precipitation and the temperature. Despite the high rates of precipitation, the Type I, Type II and the diluted Type II (75/25, 50/50) tests resulted in failure times above the corresponding SAE lower limits.

Under freezing fog conditions, fluid type and rate of precipitation were identified as the two main parameters affecting the fluid effectiveness. The statistical analysis yielded a regression equation relating these parameters for a typical Type I fluid, with an R^2 of 0.93. Although a limited number of test points fell below the corresponding SAE lower limit, the corresponding rates of precipitation imply the presence of a very dense fog with reduced visibility such that the aircraft may not be able to take off in any case.

A limited number of tests were also performed in the absence of precipitation. They indicated that Type I fluids leave a thinner film than Type II or III fluids and stabilize two to three times faster.

The ice sensor tests show that these devices can be used in future tests to determine the failure time for Type II and III fluids only. However, in natural snow tests, the failure criteria will have to be changed from "loss of absorption capability" to "slush formation" if the sensors are to be used.

Although a high degree of scatter was observed, the test data on three curved surfaces (wing of a Beech King Air, a horizontal stabilizer, and the F-28 wing leading edge model) shows a 1:1 relationship between the aircraft surface and the flat plate, which is consistent with the results obtained by United Airlines on a large commercial jet aircraft.

Future Testing

Future tests should focus on the use of diluted (50/50 and 75/25) Type II fluids for all forms of precipitation in order to verify the holdover times prescribed by SAE for this type of fluid. Some concentrated Type I, II and III fluid tests should also be carried out, particularly under freezing fog, in which limited data is currently available. Furthermore, in order to investigate the effect of wind on fluid failure times, it is proposed to conduct some tests in a special test set-up (Wyoming shield), which is sheltered from the wind. More aircraft surface tests, especially under natural snow, are also recommended, to verify (to reduce the scatter) the 1:1 relationship obtained by APS and United Airlines. Cold-soaked tests should be designed and carried out based on the preliminary study conducted this year.

Monitoring of the test fluids, using a combination of ice sensor, video camera and an electro-optical external sensor, is recommended, to eliminate the subjectivity of the visual determination of the fluid failure. Improved meteorological instruments and procedures are required to determine more accurately the rate of water absorption by the fluid being tested. The rate measured with the ombrometer would be that which a pilot could obtain from the airport, and the rate measured from the plate pan is likely very representative of what is actually falling onto the plates. Improved accuracy in the measurement of precipitation rate can be achieved by the installation of a wind shield around the existing ombrometer, the use of a snow mass concentration measuring device or a Precipitation Occurrence Sensor System (POSS) to determine the terminal velocity of the precipitation, the use of plate pans for precipitation collection, and the observation and recording of snow type.

SOMMAIRE

Mandatés par le Centre de développement des transports (CDT) de Transports Canada, les Services de planification en aviation (SPA) ont entrepris d'organiser et de mener des essais visant à mesurer la durée d'efficacité des agents dégivrants et antigivrage sur le marché.

Les chercheurs ont fait appel à des fabricants d'agents dégivrants et antigivrage, au Conseil national de recherches Canada (CNRC), au Service de l'environnement atmosphérique (SEA), au Service des aéronefs de Transports Canada et à Air Canada. Le site des essais sous neige naturelle, jusqu'ici situé sur le toit du hangar d'entretien d'Air Canada, se trouve maintenant à la station d'observation météorologique du SEA à Dorval (Québec). Les essais de simulation des précipitations verglaçantes (pluie et brouillard) ont eu lieu dans les installations d'essai de givrage d'hélicoptères et d'ingénierie climatique relevant du CNRC à Ottawa. Certains autres essais sous neige artificielle ont eu lieu sur une pente de ski au mont Rigaud (Québec).

Règle générale, les essais ont consisté à verser un agent antigivre 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. Des essais ont également été faits sur un profil d'aile ayant la forme générale du bord d'attaque d'un F-28, sur l'empennage horizontal d'un Beech King Air, sur un avion Beech King Air et, pour la simulation des conditions de surrefroidissement, sur une boîte métallique fermée surmontée d'une plaque. Dans un certain nombre d'essais, des détecteurs de givre IM 101 et FM 202 modifiés ont été fixés à des plaques planes afin de vérifier leur utilité dans ce domaine.

Un état était dit final lorsque la neige naturelle cessait d'être absorbée par le fluide recouvrant une plaque, c'est-à-dire lorsqu'on observait de la neige reposant sur la plaque, ou faisant le pont, au-dessus d'une des croisées de fils marquées sur la plaque et vue perpendiculairement à celle-ci. Quant aux essais sous pluie et brouillard verglaçants et sous neige artificielle, l'état final correspondant était prononcé lorsque l'aspect «glacé» caractéristique des fluides disparaissait. Les variables mesurées étaient notamment les suivantes : la quantité totale de précipitation, la durée d'efficacité, la température ambiante, l'humidité relative, la vitesse et la direction du vent, l'épaisseur de l'agent, la nature de celui-ci et la forme de précipitation.

Collecte de données météorologiques

Au cours de la saison 1992-1993, les essais sous neige naturelle ont eu lieu à Dorval, les essais sous pluie et brouillard verglaçants à Ottawa et ceux sous neige artificielle à Rigaud. En outre, des essais préliminaires ont été effectués sur diverses surfaces portantes d'aéronefs et sur la plaque surrefroidie.

Les essais sous neige naturelle à Dorval ont permis de récolter un total de 276 procès-verbaux d'essai renfermant 151, 95 et 30 mesures exploitables avec des agents de type I, II et III, respectivement; les essais avec simulation de pluie fine verglaçante ont donné 51 procès-verbaux renfermant 121 et 87 mesures avec un agent de type I et II, respectivement, 32 avec un agent de type II dilué et 62 avec un agent de type III; quant aux essais avec simulation de brouillard verglaçant, les 17 procès-verbaux renfermaient 44, 10 et 4 mesures avec des agents de type I, II et III, respectivement. Un total de 42 mesures exploitables a été obtenu sous neige artificielle et 41 sur surfaces portantes. Parmi tous ces essais, un total de 165 ont été effectués sur plaques planes, utilisant des détecteurs de givre, la plupart se faisant sous neige naturelle ou sous pluie fine verglaçante.

Les modalités de la recherche peuvent être résumées comme suit : les essais ont eu lieu pour la plupart sous neige naturelle ou dans des conditions simulées de pluie fine verglaçante; les agents mis en oeuvre ont été fournis par cinq fabricants mais, dans la plupart des cas, ce sont les agents fournis par trois fabricants qui ont surtout servi; pour ce qui est des essais sous neige naturelle, les paramètres observés ont été les suivants : taux de précipitation 20 $g/dm^2/h$, température de l'air –5°C, humidité relative 77 p. 100, vitesse du vent 18 km/h et direction du vent 0°.

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. Elles ont permis de compter le nombre de jours durant lesquels des essais auraient pu être faits. À l'issue de la période d'essais, les chercheurs ont comparé ce nombre à celui durant lequel les essais avaient effectivement eu lieu. Les résultats ont montré une augmentation non seulement dans le nombre de jours couverts, mais aussi dans le nombre de jours se prêtant aux essais visés.

Parmi les accessoires de mesure utilisés à Dorval, on comptait les suivants : bac, micropluviomètre type européen (sans écran) et pluviomètre à auget basculeur (avec écran) d'Environnement Canada. Une étude comparative a montré que ce dernier a donné les résultats et indiqué les taux de précipitation les plus complets et les plus fiables.

À partir du rapport visibilité-taux de précipitation dégagé par le CNRC, et de celui entre structures de neige et taux de précipitation, les observations ont permis de déterminer trois grandes catégories de neige. Ces déterminations aideront à court terme les pilotes à mieux cerner la durée d'efficacité des agents utilisés; néanmoins, de plus amples recherches sont encore nécessaires.

Méthodes d'analyse

Deux méthodes d'analyse ont surtout été utilisées : l'analyse statistique et l'analyse dimensionnelle. La première, une analyse de régression linéaire et non linéaire à plusieurs variables, a permis de vérifier l'existence possible d'un lien entre durée d'efficacité et les divers autres paramètres tels que type de fluide, taux de précipitation, vitesse du vent, température et humidité relative. La seconde, appliquée aux résultats des essais avec des agents de type II sous neige naturelle, a servi à établir des liens fondés sur des phénomènes physiques connus. L'analyse statistique s'est révélée utile dans la détermination des facteurs d'influence sur la durée d'efficacité. Les indices de corrélation r^2 pour la neige ont été généralement plus élevés cette saison qu'antérieurement. Par exemple, dans le cas des agents de type II et III, des valeurs d'indice entre 81 et 96 p. 100 ont été observées. L'analyse dimensionnelle a permis, quant à elle, d'esquisser des courbes de régression ($r^2 = 0,95$) décrivant les durées d'efficacité obtenues avec un agent de type II en fonction du nombre de Reynolds relatif à l'écoulement de l'air et du fluide, du degré de concentration de celui-ci au moment de la cessation de l'effet et de l'humidité relative. De plus amples recherches seront nécessaires pour déterminer si ces courbes se vérifient dans le cas des autres types de fluide.

On a constaté que les paramètres significatifs en conditions neigeuses sont le type de fluide, la vitesse moyenne du vent, le taux de précipitation, la température et l'humidité relative. L'analyse a également montré que le vent a un effet inattendu sur la durée d'efficacité, à savoir que, pour un type de fluide donné, les vents forts et faibles abaissent la durée d'efficacité plus que ne le font les vents modérés, toutes autres variables demeurant égales. Il a été constaté que, à l'intérieur de chaque type de fluide, il se trouve des agents qui se comportent quelque peu différemment des autres, et que leur durée d'efficacité tend à baisser lorsque les taux de précipitation et l'humidité relative sont élevés et que les températures sont basses. À l'égard des fluides de type I et II, certains essais ont abouti à des durées d'efficacité tombant au-dessous de la limite inférieure correspondante indiquée dans les lignes directrices de la SAE. Ces constatations ont été faites après la forte tempête de neige qui s'est abattue sur Montréal le 13 mars 1993, alors que, curieusement, l'aéroport international de Montréal tout proche était resté ouvert.

Malgré les écarts tant qualitatifs que quantitatifs constatés entre la neige naturelle et artificielle, les résultats correspondants montrent une corrélation raisonnablement bonne. Il s'ensuit que la neige artificielle pourra peut-être convenir aux essais à venir, surtout si la neige naturelle venait à manquer.

Bien que la simulation des conditions de pluie fine verglaçante ait indiqué des taux de précipitation bien supérieurs à la réalité, les résultats montrent toutefois une bonne corrélation avec les résultats d'essais qui n'avaient pas été obtenus par la simulation. Par ailleurs, il a été constaté que les résultats de cette simulation montrent une assez bonne corrélation avec ceux des essais sur la tenue au brouillard d'eau pulvérisée, menés en laboratoire par l'Université du Québec à Chicoutimi. Règle générale, pour un type de fluide donné, la durée d'efficacité sous pluie fine verglaçante est conditionnée par le taux de précipitation et par la température. Malgré des taux élevés de précipitation, les durées d'efficacité constatées avec des agents de type I, II et type II dilué (75/25, 50/50) ont été supérieures à la limite inférieure correspondante indiquée dans les lignes directrices de la SAE.

Le type de fluide et le taux de précipitation ont été les principaux paramètres régissant la durée d'efficacité sous brouillard verglaçant. L'analyse statistique a permis d'obtenir des courbes de régression (r^2 = 0,93) mettant en rapport ces deux paramètres dans le cas d'un agent de type I ordinaire. Bien que certaines valeurs mesurées aient été inférieures aux valeurs minimales correspondantes indiquées dans les lignes directrices de la SAE, les taux de précipitation constatés correspondent à l'existence d'un brouillard très dense, qui aurait réduit la visibilité à un point tel qu'aucun aéronef n'aurait pu décoller dans des conditions aussi difficiles.

Un nombre restreint d'essais ont été menés aussi par temps exempt de précipitation. Les résultats montrent que les fluides de type I s'étalent sur une couche plus fine que celle laissée par les fluides de type II et III, et qu'ils se stabilisent de deux à trois fois plus vite.

Il est apparu lors des essais avec des détecteurs de verglas que ces dispositifs pourraient bien servir ultérieurement dans la détermination des durées d'efficacité des fluides de type II et III seulement. Sauf que, lors des essais sous neige naturelle, le critère à retenir devrait se définir non plus comme étant «la perte du pouvoir d'absorption», mais plutôt comme «l'apparition de neige fondante (bouillie de neige)».

Malgré la grande dispersion observée, les données obtenues avec des surfaces incurvées (profil d'aile du Beech King Air, empennage horizontal, maquette du bord d'attaque du F-28) montrent un rapport de 1 : 1 entre une surface portante d'aéronef et une plaque plane, ce qui cadre bien avec les résultats obtenus par United Airlines sur les gros appareils de transport civil.

Essais futurs

Les essais futurs devraient porter sur l'emploi de fluides de type II dilués (50/50 et 75/25) sous toutes sortes de précipitation, afin de vérifier les durées d'efficacité prescrites par la SAE à leur égard. Il faudra aussi les vérifier dans le cas de certains fluides de type I, II et III concentrés, notamment sous brouillard verglaçant, afin de pallier la pauvreté de l'information disponible à cet égard. Et, afin d'approfondir l'effet du vent sur les durées d'efficacité, il est proposé de mener des essais à l'abri du vent dans un montage construit exprès appelé écran Wyoming. Il faudra en outre entreprendre d'autres essais sous neige naturelle avec des surfaces portantes d'aéronef, afin de vérifier (atténuer la dispersion) le rapport de 1 : 1 résultant des essais menés par le contractant et par United Airlines. Il sera nécessaire d'approfondir le phénomène de surrefroidissement par des essais particuliers conçus et entrepris à la lumière des essais préliminaires de cette année.

Il est recommandé que les essais de fluides fassent l'objet d'un suivi mettant en oeuvre un ensemble de moyens visant à réduire la subjectivité quant à la détermination du moment où un fluide cesse d'opérer, tels que détecteurs de givre, caméras vidéo et capteur opto-électronique à distance. Il faudra aussi améliorer les instruments et les procédures d'observations météorologiques, afin de déterminer avec une précision accrue le taux d'absorption d'eau par les fluides. Le taux mesuré à l'aide du pluviomètre serait celui-là même qu'un pilote pourrait obtenir de l'aéroport, alors que le taux mesuré à partir du bac représente sans doute de très près ce qui tombe réellement sur les plaques. On pourrait par ailleurs installer un écran autour du pluviomètre pour le protéger contre l'effet du vent, utiliser un dispositif pour mesurer la concentration de neige dans l'air ou un POSS pour mesurer la vitesse finale de chute des précipitations, recueillir les précipitations dans des bacs et enfin observer et caractériser les chutes de neige en fonction de sa catégorie.

SECTION NUMBER			PAGE NUMBER
1.	INTRODUCTION		1
2.	METHODOLOGY		4
	2.1	Test Sites	4
	2.2	Test Procedures and Data Forms	6
		2.2.1 Determination of End Condition	12
	2.3	Equipment	13
		2.3.1 Dorval Equipment	13
		2.3.2 Sensors	14
		2.3.3 Freezing Fog Precipitation Rate Measurements	15
		2.3.4 Freezing Drizzle Precipitation Rate Measurements	15
	2.4	Fluids	16
	2.5	Personnel and Participants	16
	2.6	Analysis Methodology	18
3.	DESCRIPTION OF DATA		19
	3.1	Dorval Natural Snow Tests	19
		3.1.1 Usable and Unusable Data	19
		3.1.2 Distribution of Fluids Tested and Test Location	21
		3.1.3 Frequency of Average Precipitation Rates	21
		3.1.4 Frequency of Other Meteorological Conditions	23
		3.1.5 Distribution of Failure Times	28
	3.2	Freezing Drizzle	28
		3.2.1 Usable and Unusable Data	28
		3.2.2 Distribution of Fluids Tested and Test Location	31
		3.2.3 Frequency of Average Precipitation Rates	31
		3.2.4 Frequency of Other Meteorological Conditions	31
		3.2.5 Distribution of Failure Times	34
	3.3	Freezing Fog Tests	34
		3.3.1 Usable and Unusable Data	34
		3.3.2 Distribution of Fluids Tested and Test Location	36
		3.3.3 Frequency of Average Precipitation Rates	36
		3.3.4 Frequency of Other Meteorological Conditions	38
		3.3.5 Distribution of Failure Times	38

SECTION NUMBER		PAGE NUMBER

3.4 Artificial Snow Tests 38
3.5 Wing Surface Tests 40
3.6 Cold-soaking Tests 40
3.7 Sensor Tests 40

4. METEOROLOGICAL ANALYSIS 42

4.1 Summary of Test Success 42
4.2 Comparison of Meteorological Parameters 44
4.2.1 Comparison of Precipitation Collection Devices at Dorval 44
4.2.2 Visibility vs Rate of Precipitation 48
4.2.3 Type of Precipitation vs Precipitation Rate 50
4.2.4 Comparison of Meteorological Measurements 52

5. ANALYSIS 54

5.1 Flat Plate Tests 54
5.1.1 Natural Snow Conditions 56
5.1.1.1 Type I Fluids in Snow 57
5.1.1.2 Type II Fluids in Snow 63
5.1.1.3 Type III Fluids in Snow 66
5.1.2 Artificial Snow Conditions 69
5.1.3 Freezing Drizzle Conditions 74
5.1.3.1 Type I Fluids in Freezing Drizzle 76
5.1.3.2 Type II Fluids in Freezing Drizzle 76
5.1.3.3 Type III Fluids in Freezing Drizzle 80
5.1.4 Freezing Fog Conditions 83
5.1.4.1 Type I Fluids in Freezing Fog 83
5.1.4.2 Type II and Type III Fluids in Freezing Fog 85
5.1.5 No Precipitation Conditions 87
5.1.6 Rain on a Cold-soaked Surface 89
5.2 Ice Sensor Tests 91
5.2.1 Natural Snow Conditions 93
5.2.2 Artificial Snow Conditions 96
5.2.3 Freezing Drizzle Conditions 96
5.2.4 Freezing Fog Conditions 96
5.2.5 No Precipitation Conditions 96
5.3 Aircraft Surface Tests 101
5.4 Dimensional Analysis on a Type II Fluid 104

SECTION NUMBER			PAGE NUMBER

6.	CONCLUSIONS		111
	6.1	Test Procedures and Equipment	111
	6.2	Meteorological Analysis	112
	6.3	Flat Plate Tests	113
		6.3.1 Natural Snow	113
		6.3.2 Artificial Snow	114
		6.3.3 Freezing Drizzle	114
		6.3.4 Freezing Fog	115
		6.3.5 No Precipitation Condition	116
		6.3.6 Rain on a Cold-Soaked Surface	116
	6.4	Ice Sensor Tests	116
	6.5	Aircraft Surface Tests	117
7.	RECOMMENDATIONS ON FUTURE TESTING		118

APPENDICES

APPENDIX A - TEST PROCEDURES AND EQUIPMENT LIST

APPENDIX B - SAE/ISO HOLDOVER TIMES TABLES

APPENDIX C - INTERNATIONAL CLASSIFICATION FOR SOLID PRECIPITATION

APPENDIX D - FULL SCALE AIRCRAFT TESTING

APPENDIX E - DETERMINATION OF SENSOR FAILURE TIME

APPENDIX F - DE/ANTI-ICING FLUID HOLDOVER TIME MEASUREMENTS AIRCRAFT AND FROSTICATOR PANEL CORRELATION SNOW CONDITIONS AT DENVER UNITED AIRLINES

APPENDIX G - COMPARISON OF HOLDOVER TIME EFFECTIVENESS OF TYPE III FLUIDS SHIELDED VERSUS UNSHIELDED PRECIPITATION GAUGE 1991-1992 FIELD TESTING

TABLE NUMBER		PAGE NUMBER
3.1	NUMBER AND TYPES OF TESTS PERFORMED WITH CURVED SURFACES	41
3.2	NUMBER AND TYPES OF TESTS PERFORMED WITH SENSORS	41
5.1	MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR SNOW	58
5.2	MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR FREEZING DRIZZLE	75
5.3	MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR FREEZING FOG	84
5.4	INFLUENCE OF VARIOUS PARAMETERS ON A-199 TYPE II FLUID FAILURE	110

PHOTO NUMBER		PAGE NUMBER
2.1	HELICOPTER ICING FREEZING FOG SIMULATION	7
2.2	CLIMATIC ENGINEERING FACILITY FREEZING DRIZZLE SIMULATION	7
5.1	WAVE FORMATION ON FLAT PLATE	60

FIGURE NUMBER		PAGE NUMBER
2.1	TEST SITE AT DORVAL AIRPORT	5
2.2	F-28 WING LEADING EDGE SECTION	8
2.3	SCHEMATICS OF PLATE PAN AND SEALED BOX	9
2.4	TEST PLATFORM	11
2.5	SIMULATED FREEZING DRIZZLE	17

FIGURE NUMBER | **PAGE NUMBER**

FIGURE NUMBER		PAGE NUMBER
3.1	DISTRIBUTION OF TESTS FOR 1992-1993	20
3.2	NUMBER OF NATURAL SNOW PLATE TESTS	20
3.3	DISTRIBUTION OF PRECIPITATION RATES	22
3.4	DISTRIBUTION OF AIR TEMPERATURE	24
3.5	DISTRIBUTION OF RELATIVE HUMIDITY	25
3.6	DISTRIBUTION OF WIND SPEED	26
3.7	DISTRIBUTION OF WIND DIRECTION	27
3.8	DISTRIBUTION OF FAILURE TIME	29
3.9	NUMBER OF SIMULATED FREEZING DRIZZLE TESTS	30
3.10	DISTRIBUTION OF RATE OF PRECIPITATION	32
3.11	DISTRIBUTION OF AIR TEMPERATURE	33
3.12	DISTRIBUTION OF FAILURE TIME	35
3.13	NUMBER OF SIMULATED FREEZING FOG TESTS	37
3.14	DISTRIBUTION OF PRECIPITATION RATE	37
3.15	DISTRIBUTION OF AIR TEMPERATURE	39
3.16	DISTRIBUTION OF FAILURE TIME	39
4.1	SUCCESS OF TESTS	43
4.2	COMPARISON OF PRECIPITATION COLLECTION DEVICES EUROPEAN VS ENVIRONMENT CANADA	46
4.3	COMPARISON OF PRECIPITATION COLLECTION DEVICES PLATE PAN VS ENVIRONMENT CANADA	46
4.4	VISIBILITY VS PRECIPITATION	49
4.5	TYPE OF PRECIPITATION VS PRECIPITATION RATE	51

FIGURE NUMBER		PAGE NUMBER
4.6	WIND SPEED COMPARISON TEST SITE VS ENVIRONMENT CANADA	53
5.1	EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	58
5.2	EFFECT OF WIND AND RATE OF PRECIPITATION ON TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	60
5.3	EFFECT OF PRECIPITATION TYPE AND RATE OF PRECIPITATION ON TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	62
5.4	EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON TYPE II FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	64
5.5	EFFECT OF WIND AND RATE OF PRECIPITATION ON TYPE II FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	64
5.6	EFFECT OF PRECIPITATION AND RATE OF PRECIPITATION ON TYPE II FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	65
5.7	OBSERVED FLUID FAILURE TIME VS PREDICTED FLUID FAILURE TIME	67
5.8	EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON TYPE III FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	68
5.9	EFFECT OF WIND AND RATE OF PRECIPITATION ON TYPE III FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	68
5.10	EFFECT OF PRECIPITATION TYPE AND RATE OF PRECIPITATION ON TYPE III FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS	70
5.11	COMPARISON OF TYPE I FLUID FAILURE TIME IN ARTIFICIAL AND NATURAL SNOW CONDITIONS	72

FIGURE NUMBER		PAGE NUMBER
5.12	COMPARISON OF TYPE II FLUID FAILURE TIME IN ARTIFICIAL AND NATURAL SNOW CONDITIONS	73
5.13	COMPARISON OF TYPE III FLUID FAILURE TIME IN ARTIFICIAL AND NATURAL SNOW CONDITIONS	73
5.14	EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS	77
5.15	TYPE II FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS	77
5.16	COMPARISON OF TYPE II FLUID FAILURE TIME IN NATURAL AND SIMULATED FREEZING DRIZZLE CONDITIONS	79
5.17	COMPARISON OF FLUID A-199 FAILURE TIME IN NATURAL AND SIMULATED FREEZING DRIZZLE CONDITIONS	79
5.18	TYPE II 75/25 DILUTED FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS	81
5.19	TYPE II 50/50 DILUTED FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS	81
5.20	COMPARISON OF TYPE III FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS	82
5.21	TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS	84
5.22	TYPE I FLUID MULTI-VARIABLE REGRESSION CURVES IN FREEZING FOG	86
5.23	FLUID B-213 MULTI-VARIABLE REGRESSION CURVE IN FREEZING FOG	86
5.24	TYPE II AND TYPE III FLUID FAILURE TIME IN FREEZING FOG	88
5.25	TYPICAL THICKNESS DECAY AT 15 CM LINE FOR VARIOUS FLUIDS	88

FIGURE NUMBER		PAGE NUMBER
5.26	TYPICAL FLUID DISTRIBUTION FOR TYPE I FLUID	90
5.27	TYPICAL SENSOR RESPONSE TO VARIOUS FORMS OF PRECIPITATION ON A-199 TYPE II FLUID	92
5.28	TYPICAL SENSOR RESPONSE TO VARIOUS FORMS OF PRECIPITATION FOR FLUID B-204 (TYPE I)	94
5.29	TYPICAL SENSOR RESPONSE TO SNOWFALL ON A-205 TYPE II FLUID	94
5.30	SENSOR RESPONSE TO TYPE II FLUID FAILURE IN NATURAL SNOW CONDITIONS	95
5.31	SENSOR RESPONSE TO TYPE II FLUID SLUSH FAILURE IN NATURAL SNOW CONDITIONS	95
5.32	SENSOR RESPONSE TO FLUID FAILURE IN ARTIFICIAL SNOW CONDITIONS	97
5.33	SENSOR RESPONSE TO FLUID FAILURE IN FREEZING DRIZZLE CONDITIONS	97
5.34	SENSOR RESPONSE TO FLUID FAILURE IN FREEZING FOG CONDITIONS	98
5.35	TYPE I FLUID THICKNESS DECAY WITH NO PRECIPITATION MEASURED FLUID THICKNESS	99
5.36	SENSOR ADMITTANCE	99
5.37	TYPICAL SENSOR ADMITTANCE VS FILM THICKNESS CURVE FOR TYPE I FLUID	100
5.38	FLUID FAILURE ON FLAT PLATE VS CURVED SURFACE	102
5.39	A-199 TYPE II FLUID FAILURE TIME VS RATE OF PRECIPITATION IN SNOW CONDITIONS	105
5.40	NON-DIMENSIONAL TIME VS NON-DIMENSIONAL NUMBERS	107
5.41	EFFECT OF TEMPERATURE ON FLUID FAILURE TIME IN SNOW CONDITIONS	107

FIGURE NUMBER		PAGE NUMBER
5.42	EFFECT OF RELATIVE HUMIDITY ON FLUID FAILURE TIME IN SNOW CONDITIONS	108
5.43	EFFECT OF HEAD WIND SPEED ON FLUID FAILURE TIME IN SNOW CONDITIONS	108
7.1	DESCRIPTION OF WYOMING SHIELD	119

LIST OF ACRONYMS

A/D	Analog to Digital (converter)
AES	Atmospheric Environment Services (Canada)
APS	APS Aviation Inc.
CASP	Canadian Atlantic Storms Program
FAA	Federal Aviation Administration (USA)
NRC	National Research Council
RH	Relative Humidity
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre
UCAR	Union Carbide
UQAC	Université du Québec à Chicoutimi
POSS	Precipitation Occurrence Sensor System
MANOBS	Manual of Surface Weather Observations

1. INTRODUCTION

At the request of the Transportation Development Centre (TDC) of Transport Canada, APS Aviation Inc. (APS) undertook a study to manage, conduct and analyze holdover time tests used to assess the time effectiveness of the commercially produced de/anti-icing fluids.

In the last decade, a number of fatal aircraft accidents have occurred on take-off during periods of freezing precipitation or precipitation which could contaminate aerodynamic surfaces. In several of these accidents the effectiveness of ground de/anti-icing has been suspect. Until recently in Canada, aircraft were deiced using only Type I deicing fluids, in various forms of dilution. While excellent for removing ice and snow which has already accumulated on the wings of aircraft, Type I fluids do not offer any sort of extended duration protection against further ice build up. Lengthy queues for take-off at congested airports, with the accompanying longer anti-icing protection requirement led to examination of the use in North America of the European anti-icing fluids known as Type II fluids. While these fluids provide increased protection against freezing precipitation when compared to Type I fluids, their rheological properties are such that the fluids themselves cause aerodynamic penalties in aircraft with relatively low takeoff speeds. Most commuter and general aviation aircraft fit into this category. Type III (formerly known as Type 1.5) fluids were developed to provide commuter aircraft with increased protection from precipitation without the aerodynamic penalties associated with the more viscous Type II fluids.

The need for field testing of the fluids was identified over four years ago and has been addressed through various programs with varying levels of success. Following a series of meetings on holdover time, held in 1988-1989 under SAE auspices with many major airlines and de/anti-icing fluid manufacturers, Air Canada and the Transportation Development Centre took the initiative to develop a small field test program for the 1989-1990 winter season to determine fluid effectiveness under real precipitation conditions. The results were unsatisfactory for a number of reasons that were subsequently addressed at a TDC-sponsored meeting of the SAE Ad Hoc Committee Working Group (Aircraft Ground Deicing Tests), June 6th, 1990, in Montreal. Agreement was reached on standardized test equipment, procedures and the scope of the data to be collected during the 1990-1991 winter. The results of the 1990-1991 worldwide testing program, which concentrated on Type II fluids, were published by Aviation Planning Services Ltd. in the Transport Canada report TP 11206E, **Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1990-1991 Winter**.

Testing during the 1991-1992 winter was on a smaller scale and had a slightly redirected focus. Type III fluids were the only fluids tested, with particular attention to a locally manufactured fluid. The intention was not to carry out extensive tests of all Type III fluids, but rather to gain a better understanding of the variances between fluids and, most importantly, to improve test methods, gain better insight into the real-world modes of fluid failure and to gain some understanding of the precipitation conditions that rapidly compromise the fluids.

The test activities included collecting short time interval meteorological information via a computerized data acquisition system at Dorval Airport (Montreal, Quebec) and the field testing of Type III fluids at two Canadian Airport sites, Dorval and St. John's, Newfoundland. The testing at St. John's was performed in conjunction with CASP II, the Canadian Atlantic Storms Program, supervised by Atmospheric Environment Services, Canada. At Dorval, in addition to flat plate testing, curved plates and wing sections were included. Two series of artificial snow (snow gun) tests, the last of which included preliminary testing of an ice sensor, were carried out using the snow making equipment at Mont Rigaud, a local ski hill near Montreal.

The results of the 1991-1992 test program, which concentrated on Type III fluids, were published by Aviation Planning Services Ltd. in the Transport Canada report TP 11454E, **Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1991-1992 Winter**.

1. INTRODUCTION

Testing during the 1992-1993 winter included not only testing of snow at Dorval, but also testing of freezing drizzle at NRC's indoor Climatic Engineering Facility and testing of freezing fog at NRC's outdoor Helicopter Icing Facility. Three fluid types were tested, from various fluid manufacturers, with an emphasis on Type I. The test site was changed from Air Canada's Dorval hangar roof-top location to a site on airport grounds located adjacent to Atmospheric Environment Services (AES), Environment Canada's meteorological station.

Ice sensors from a Canadian manufacturer were installed on four of the flat plates in order to determine whether these instruments could be used for the objective determination of the end condition. In addition, a number of fluid thickness tests (with sensors) were carried out, particularly on Type I fluids in the absence of precipitation.

The success of the project depended heavily on the collaboration of TDC, de/anti-icing fluid suppliers, the NRC, AES, FAA, Transport Canada Aircraft Services and Air Canada. The influence and assistance of TDC was instrumental in achieving this cooperation.

Section 2 of the report outlines the testing procedures and equipment requirements with special emphasis on the problems experienced with both. Subsequent sections describe the deficiencies and subjectivities in the collected data obtained, and deal with the analysis of the data, through failure curves and statistical and theoretical analyses. The final section provides a discussion of future testing and conclusions, based on both the testing experience and the data analysis.

2. METHODOLOGY

The methodology description is sub-divided into six sections dealing with testing sites; test procedures and data forms, equipment, fluids, personnel and participants, and analysis methodology.

2.1 Test Sites

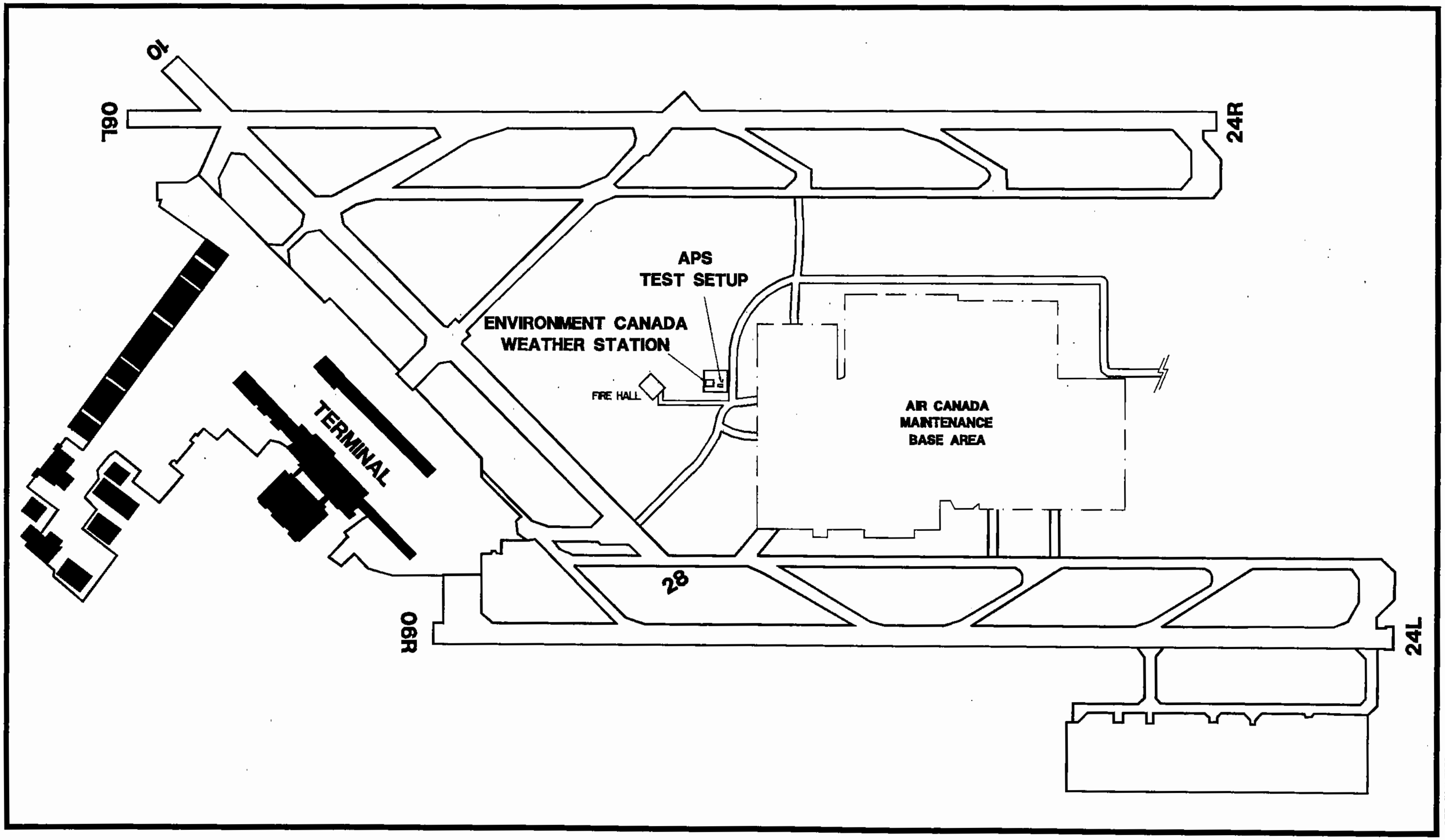
In-situ testing for the 1992-1993 winter was performed at Montreal's Dorval airport. The site was relocated from the roof-top of Air Canada's maintenance facility where it had been for previous years' testing, to the weather observation site at Dorval Airport. The location of the site at Dorval is shown on the plan view of the airport in Figure 2.1. Advantages of the relocation to the new site include:

- location at ground level to better reflect aircraft conditions.
- easy access to the site, both when testing during precipitation conditions and when equipment was needed to test at other locations such as Rigaud and Ottawa.
- security clearance was not required.
- meteorological data was available from Environment Canada, to back-up and complement the APS computerized meteorological data acquisition system.
- Air Canada personnel were not distracted from their normal duties.
- In order to increase the number of tests, two stands were used for the 1992-1993 test season.

In addition, in-situ testing was carried out by United Airlines at Denver's Stapleton Airport and by the NRC in Ottawa. These tests were not incorporated as part of this report.

FIGURE 2.1

TEST SITE AT DORVAL AIRPORT



Testing for simulated freezing fog and freezing drizzle was carried out at NRC's outdoor Helicopter Icing Facility and NRC's indoor Climatic Engineering Facility. These facilities are shown in Photos 2.1 and 2.2, while the characteristics of the facilities and the simulated precipitation are described below.

- NRC Helicopter Icing Facility (freezing fog) Characteristics:
  - Nozzle array: 23 m (75 ft) wide x 5 m (16 ft) high
  - Spray nozzles: 161 steam-atomized water nozzles
  - Natural wind speeds
  - Natural air temperatures

- Freezing Fog Characteristics:
  - Droplet median volume diameter: 30 µm
  - Liquid Water Content: 0.2 to 0.6 g m^{-3}

- NRC Climatic Engineering Facility (Freezing Drizzle) 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

- Freezing Drizzle Characteristics:
  - Droplet median volume diameter: near 100 µm
  - Precipitation Rate: 10 to 47 g/dm^2/hr

2.2 Test Procedures and Data Forms

Generally, the testing consisted of pouring de/anti-icing fluids onto clean test sections (which are exposed to various winter precipitation conditions) and recording the elapsed times before the test sections reached the end condition. Test sections included: flat aluminum plates, inclined at 10°; curved aluminum wing section approximating the leading edge of the F-28 (approximately mid-span); a horizontal stabilizer of a Super Beech King Air aircraft; an actual Super Beech King Air aircraft; and a sealed box/plate section used for simulation of cold-soaking. A typical flat plate can be seen in Figure 2 of Appendix A, while the schematic for the F-28 leading edge and the sealed box is shown in Figures 2.2 and 2.3. Also shown in Figure 2.3 is a collection (plate) pan which is of the

PHOTO 2.1

HELICOPTER ICING FREEZING FOG SIMULATION

PHOTO 2.2

CLIMATIC ENGINEERING FACILITY FREEZING DRIZZLE SIMULATION

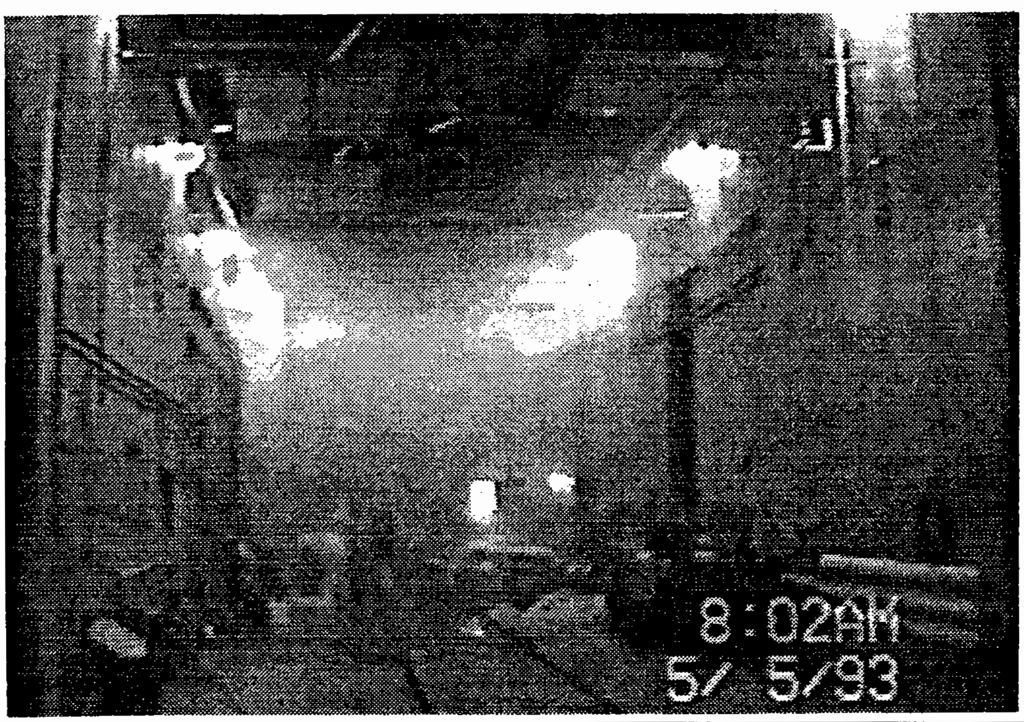


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FIGURE 2.2

F-28 WING LEADING EDGE SECTION

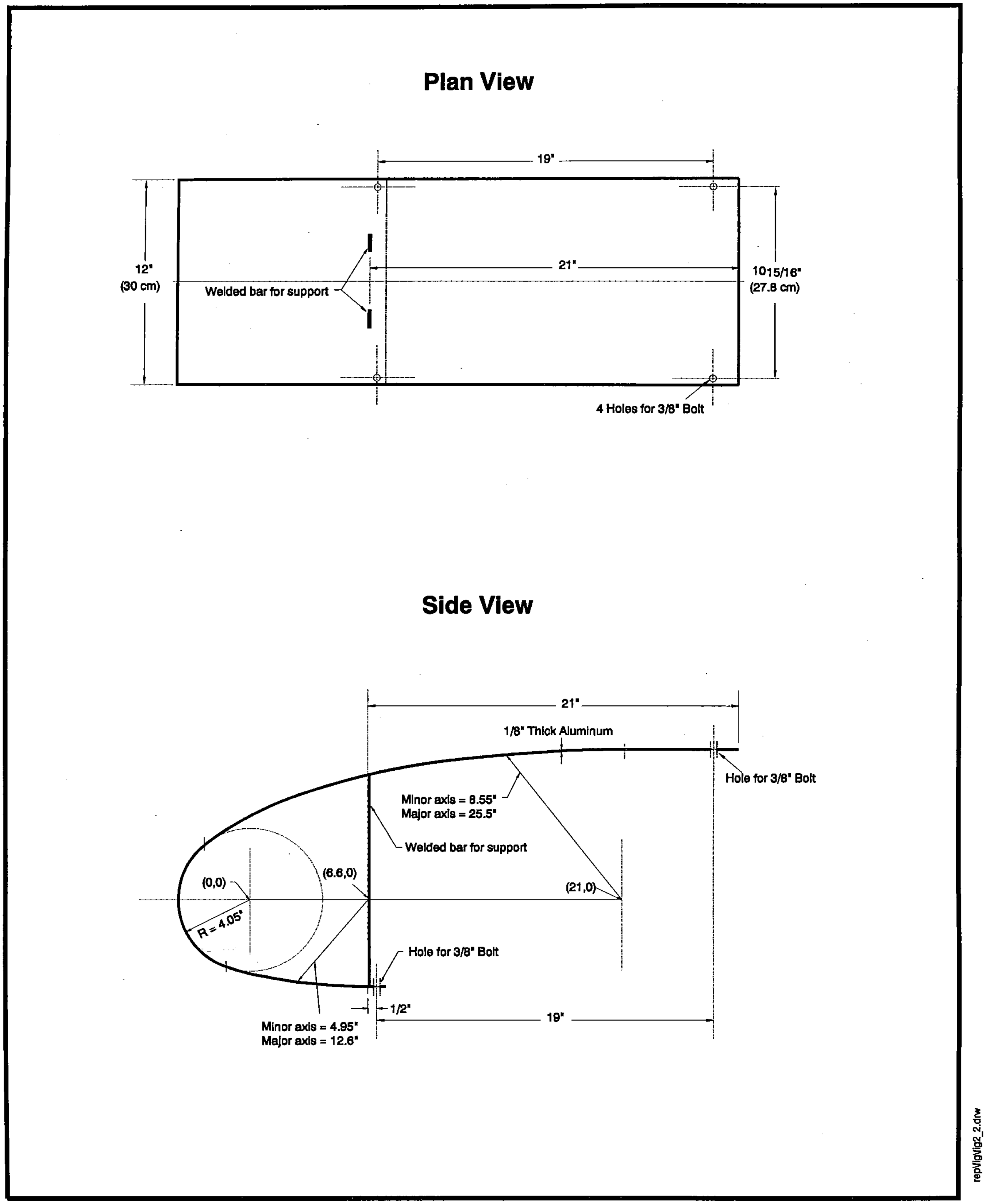
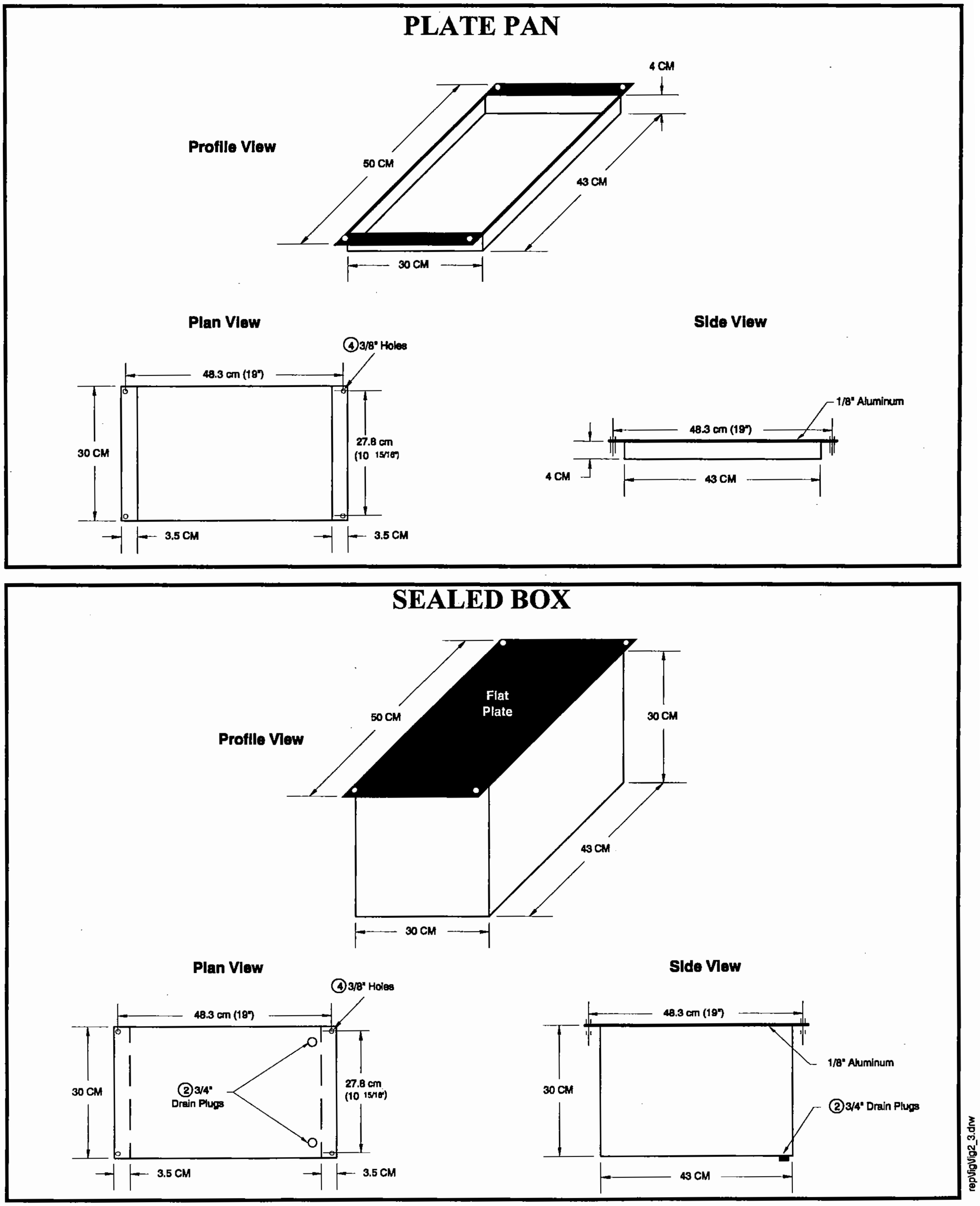


FIGURE 2.3

SCHEMATICS OF PLATE PAN AND SEALED BOX



same size as a standard plate and used for measuring precipitation. Many flat plate tests were performed incorporating IM 101 and FM 202 ice sensors, which measured electrical properties of whichever substance was present on the sensor head.

Complete details of the actual test procedures supplied to the program participants are provided in Appendix A, while a brief list of the required steps follows:

- orient test stand to face into wind;
- ensure test sections are clean and install on stand;
- pour fluids evenly over entire test section surface until saturated;
- monitor test sections until final end condition (see Section 2.2.1 below) is reached on all plates or 60 minutes has elapsed; and,
- clean plates with isopropyl alcohol and begin entire procedure again.

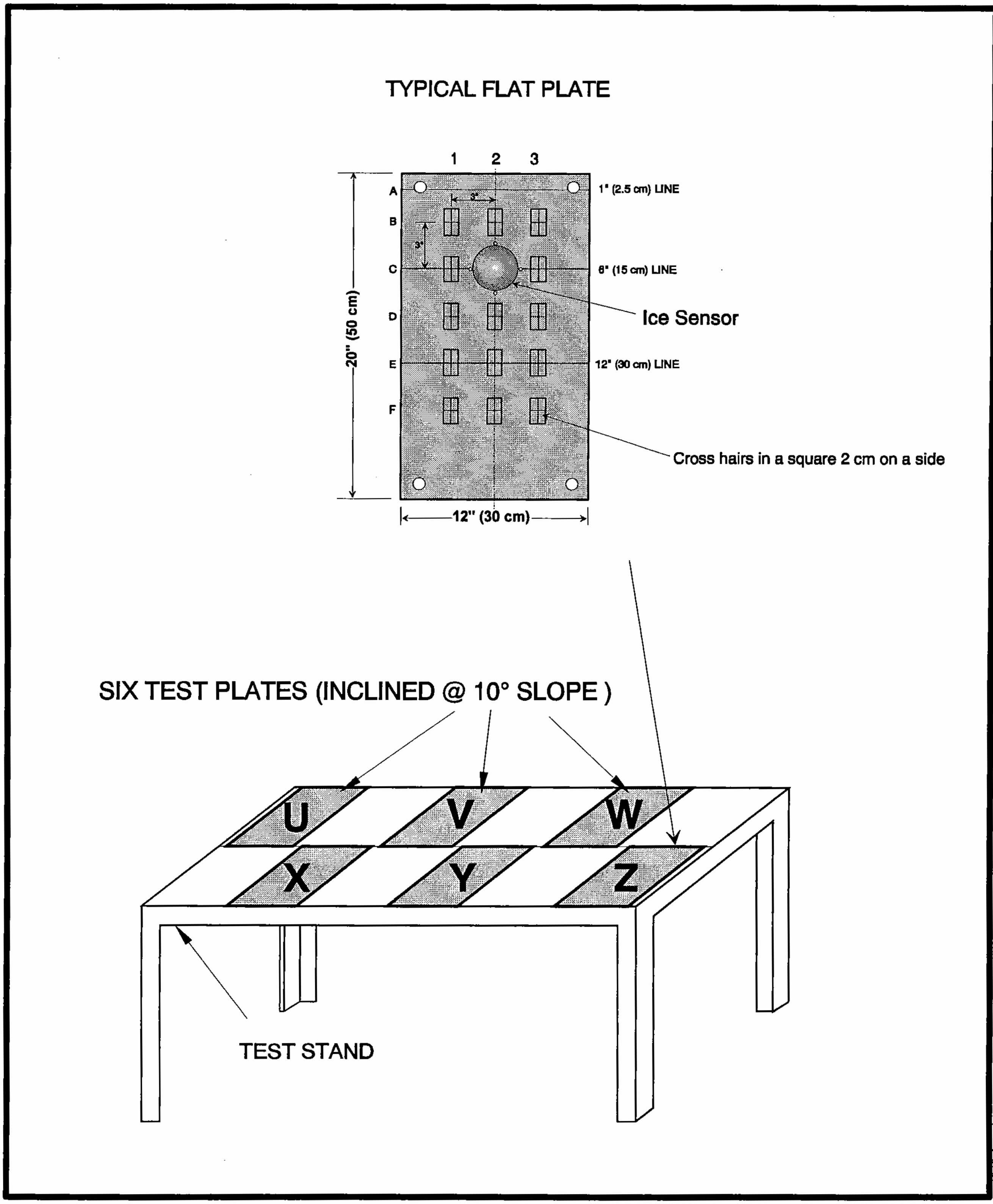
The plates were marked with three parallel lines, 2.5 cm, 15 cm and 30 cm from the top of the plate. The plates were also marked with 15 crosshairs. These crosshairs were used in determining whether end conditions were achieved. Figure 2.4 depicts the markings on a typical flat plate.

The following are some of the major changes to the test procedure from the 1991-1992 season to the 1992-1993 test season:

- measurement of wind direction and orientation of the test platform
- use of a plate pan on the test platform to measure water content and compare with the rain/snow gauge
- measurement of fluid thickness at the 15 cm line only between the three to five minutes interval following test commencement time
- the stand was not covered with a plastic tarp prior to the start of the test
- data forms were made of "Poly AR+2" water resistant synthetic paper

FIGURE 2.4

TEST PLATFORM



and pressurized space pens were used for recording results.

One major addition to the data form in 1992-1993 was to record the visual observation time at which slush started to form on the sensor head; when the sensor head was 1/4, 1/2, and 3/4 covered; and when it was completely covered. The objective of this was to try to correlate the observed times with the admittance readings from the sensor. An analysis of this can be found in Section 5.2.1.

All data acquired during testing was recorded on supplied data forms, which are also included in Appendix A. The Dorval meteorological data was automatically recorded and stored on a computer.

2.2.1 Determination of End Condition

As mentioned in Section 1, the procedure evolved from the experiences of various test programs for the three previous winter seasons. In the report of the 1990-1991 test program, the subjectivity of the test end conditions was mentioned as a key reason for the scattered nature of the resulting data. It was decided to eliminate two of the previous three end conditions: freezing at the 2.5 cm line, which was often found to be misinterpreted, and loss of gloss (a condition where the fluid was said to have failed when it lost its reflective properties) which was a rather nebulous condition and was often associated with high failure times. Nevertheless, the loss of gloss type of failure resurfaced in the 1992-1993 test season when conducting freezing fog, freezing drizzle and artificial snow testing. The failure time for this type of condition was therefore based on the criteria set forth for loss of gloss in the 1990-1991 test season.

The remaining end condition, obscuration of crosshairs by snow or ice, was more rigidly defined in the 1990-1991 testing season. This end condition was satisfied when five of the fifteen crosshairs on a plate were obscured from the tester's view. Testing experience showed that viewing the crosshairs depended on the time elapsed since the crosshairs had been marked, the manner in which the markings were applied, and from which angle the markings were viewed as well as the type and density of snow falling. The 1991-1992 and 1992-1993 end condition during snow was defined as the point when snow was no longer being absorbed or accommodated by the fluid. This was to be when snow was seen to be resting or bridging on top of the fluid, above a complete crosshair, when viewed from in front of the test stand (perpendicular to the plates). The failure time above each individual crosshair was recorded, resulting in up to 15 failure points for each test plate.

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. To remove all subjectivity the use of ice sensors to provide the trigger for determining end conditions was investigated and is discussed in detail in Section 5.2 of this report.

2.3 Equipment

The following subsections provide a description of some of the major equipment and where it was used.

2.3.1 Dorval Equipment

The equipment list and specifications are included in Appendix A. Equipment was required to record precipitation, temperature, wind speed and direction.

Testing in North America over previous years employed a heated rain/snow gauge tipping bucket to measure precipitation. The model registered a "tip" for every g/dm^2 of snow that fell (which equated to

0.1 mm of liquid precipitation). This proved to be too coarse for most of the precipitation conditions measured. A light to medium snow fall would register only four or five tips over a one hour period. A model used in Europe (an ombrometer) had a resolution twenty times finer than the North American model. The ombrometer counted "drops" as opposed to "tips" and registered a "drop" for every .05 g/dm^2 of precipitation. This unit was adopted for use in the 1991-1992 and 1992-1993 testing program. The high resolution of the ombrometer should not be confused with accuracy. Test results from the 1992-1993 season have shown that heavy winds resulted in the ombrometer and the test section receiving different amounts of precipitation. In addition, since the 1992-1993 Dorval test site was located beside the Environment Canada meteorological station, the meteorological data was compared. The results of this comparison are shown in Section 4.2.

The ombrometer was connected to a central computer via a serial cable. Similarly connected were an anemometer and wind vane to measure wind speed and direction, as well as temperature and humidity probes.

The ombrometer drop count, wind speed and direction, temperature and relative humidity were each sampled every ten seconds. This sampling also continued when no other testing occurred to provide a more complete meteorological picture.

2.3.2 Sensors

The ice sensors used in the 1992-1993 season included a modified IM 101 and three FM 202 sensors from Instrumar Ltd of St. John's, Newfoundland. Three other FM 202 sensors were provided for evaluation to UQAC, the NRC and United in Denver. The sensors record the admittance (inverse of electrical impedance) of the substance with which it is in contact (air, water, fluids, ice snow, slush, etc.). The admittance is converted to values between 0 to 255 by an A/D converter at a frequency of 1 Hz. Hence, one value was recorded every second.

The tests with precipitation are carried out in a similar manner to the regular tests described in Section 2.2, except that the sensor is mounted flush on the test plate at the centre of the 15 cm (6") line.

In the fluid thickness testing (without precipitation) the fluid was applied on the test plates and thicknesses at the 2.5 cm (1"), 15 cm (6"), and 30 cm (12") lines were measured at regular time intervals until the thickness reading stabilized. Environmental conditions, including temperature, relative humidity and wind speed were also recorded. Sensor responses under these conditions were also collected simultaneously.

2.3.3 Freezing Fog Precipitation Rate Measurements

The rate of precipitation for freezing fog, as simulated in the NRC test site, was measured using the plate pan and the European tipping bucket (ombrometer). The ombrometer did not record any precipitation since the fog precipitation rates were relatively low and it is believed that the heat generated by the ombrometer forced out any potential deposition of the fog. Therefore, the rates computed from the plate pan weight measurements were used for the analysis.

2.3.4 Freezing Drizzle Precipitation Rate Measurements

Initially, the rate of precipitation for freezing drizzle, as simulated in the NRC Climatic Engineering Facility, was measured using the ombrometer, which was located in the centre of the edge of the test stand. After a few tests, it was found by cake pan measurements that the rates of precipitation varied from one plate to another. This occurred particularly when comparing the front to the back of the stand, i.e. locations U, V, W vs X, Y, Z. The two test stands, located at opposite ends, also had substantial variations in the measured rates of precipitation.

It was also found that the rate varied from time to time at the same location. This variation can be seen from the plot (see Figure 2.5) of the rate of precipitation vs time of day for testing on May 4, 1993. In an eleven minute period (the average test duration), the average rate varied from a low of 34 $g/dm^2/hr$ to a maximum of 57 $g/dm^2/hr$, which is substantial. The variations were partially resolved by taking plate pan measurements at each plate location, before and after some of the tests, and using these measurements for this analysis.

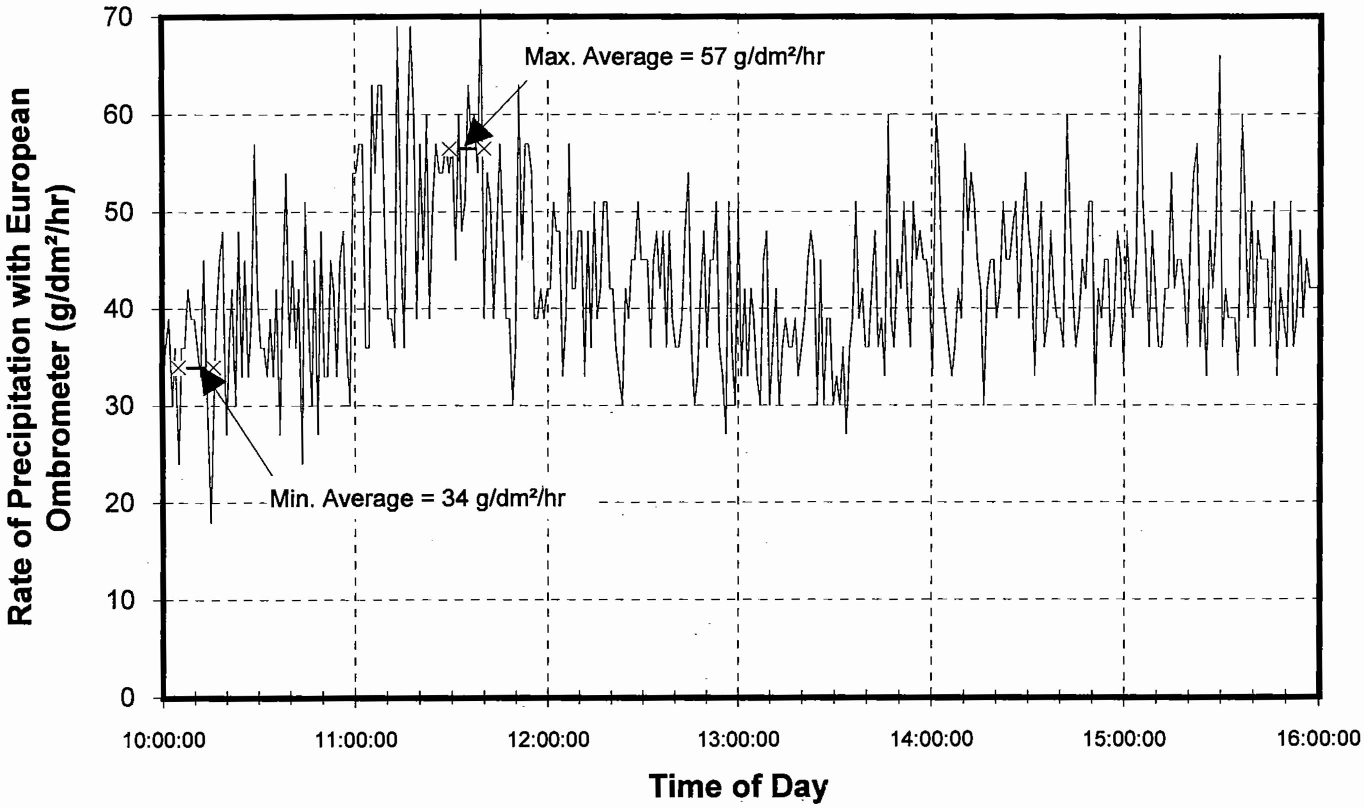
2.4 Fluids

As mentioned, Type I, II and III fluids were tested and these were provided by Union Carbide, Kilfrost, Octagon, Texaco and Hoechst. The Type II fluids obtained were based on neat concentrations (no dilution), while Type I fluids were requested at standard dilutions. A few freezing drizzle tests were conducted with Type II fluids at 75/25 and 50/50 concentrations. The fluids were ordered in November and received in December 1992.

2.5 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 analysts a thorough understanding of the intricacies and potential problems with the data collection process. The main difficulty with respect to staffing in previous years was the inability to cover a suitable number of snow periods, especially night-time snowfalls. This was solved by having a greater number of participants available for testing and by instituting a sliding pay scale which compensated testers more during the night-time than during the day.

FIGURE 2.5
SIMULATED FREEZING DRIZZLE
Rate of Precipitation - May 04/93



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2.6 Analysis Methodology

Before all the collected data was analyzed, the raw data underwent some manipulation and verification, specifically to correct or remove any obvious errors from the meteorological data. 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 different stages, which were driven by various deadlines. The initial focus was on the preparation of a verbal status report of the project to TDC in mid April 1993 and the requirement for a presentation of the results for the SAE Aircraft Ground Deicing Conference held from June 15 to 17, 1993 in Salt Lake City, Utah. Additional presentation work was required for a meeting with the Dryden Commission Implementation Program R&D group, which was held in early June 1993. General analyses consisting of the preparation of various failure time versus precipitation rate curves were performed for the SAE Ad Hoc Committee meeting of August 4th and 5th, 1993 in Montreal, Canada.

3. DESCRIPTION OF DATA

This section provides a description of the data collected. Breakdowns will be provided for the quantity of data received, by fluid type, distributions of the basic weather parameters such as temperature, precipitation, wind speed and direction, and humidity over the range of the tests collected. This will be presented for snow tests conducted at Dorval, freezing drizzle and fog tests conducted in Ottawa, and artificial snow tests of Rigaud. In addition, a brief description of the data collected during wing surface tests and tests with the cold-soaked box will be provided. Figure 3.1 provides a summary of the breakdowns of these tests, which were carried out in 1992-1993. Lastly, the type of data collected with the ice sensors will be described.

3.1 Dorval Natural Snow Tests

3.1.1 Usable and Unusable Data

During the 1992-1993 test season, APS collected test data from 76 forms for the two stands located at Dorval. Each form contained data for up to six test plates, or four to six flat plates with the F-28 wing section, plate pan, and/or control plate. As shown in Figure 3.2, these data forms contained a total of 441 test points of which 165 points were not used either because the tests were aborted due to problems experienced with the plates and/or meteorological equipment, or resulting from the non-occurrence of failures during the test run. In addition, twelve of the 165 unusable data points had excessive crosswinds and tailwinds, and these were removed from the analysis. While the test procedure calls for the stand to be facing into the wind, for these tests the wind changed direction during the test. Of the remaining 276 usable tests, a total of 151 tests were of Type I, 95 were of Type II and 30 were of Type III fluids. The number of usable tests performed during this test season from Dorval was equivalent to 1990-1991 but more than 1991-1992.

FIGURE 3.1

DISTRIBUTION OF TESTS FOR 1992 - 1993

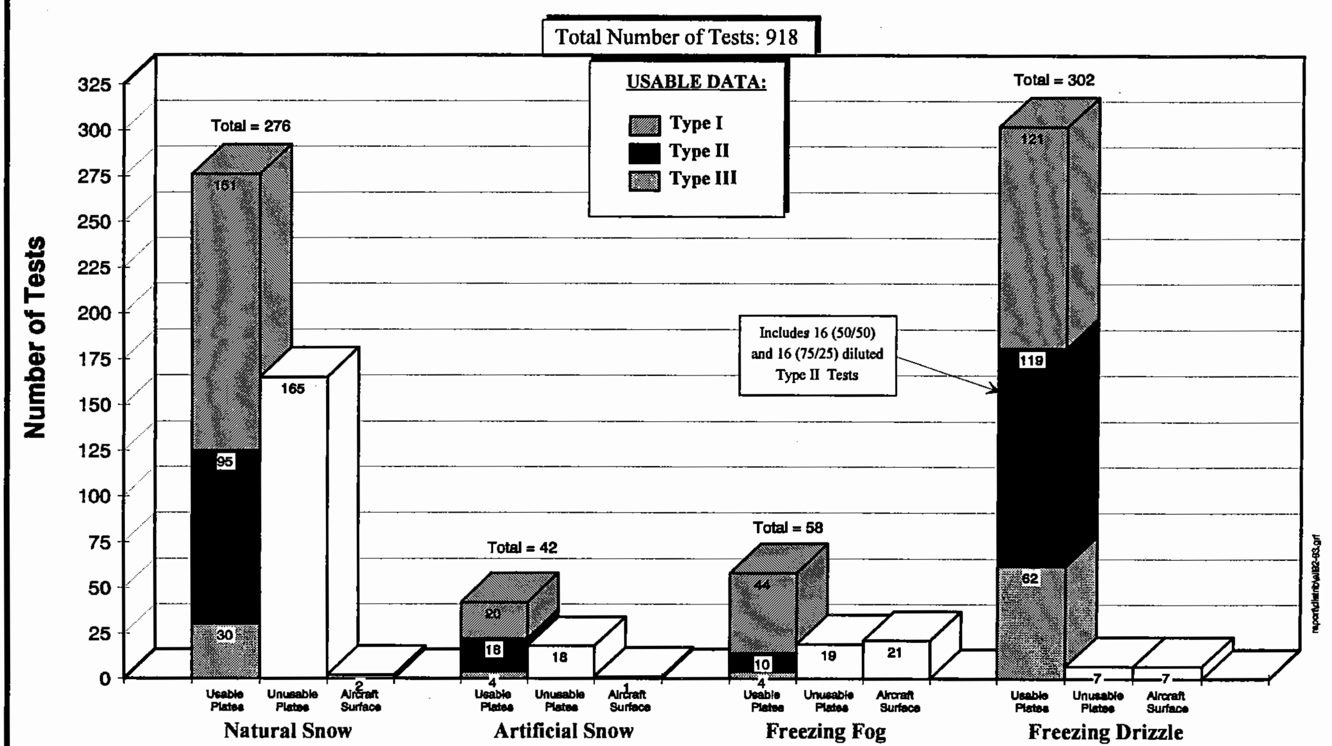
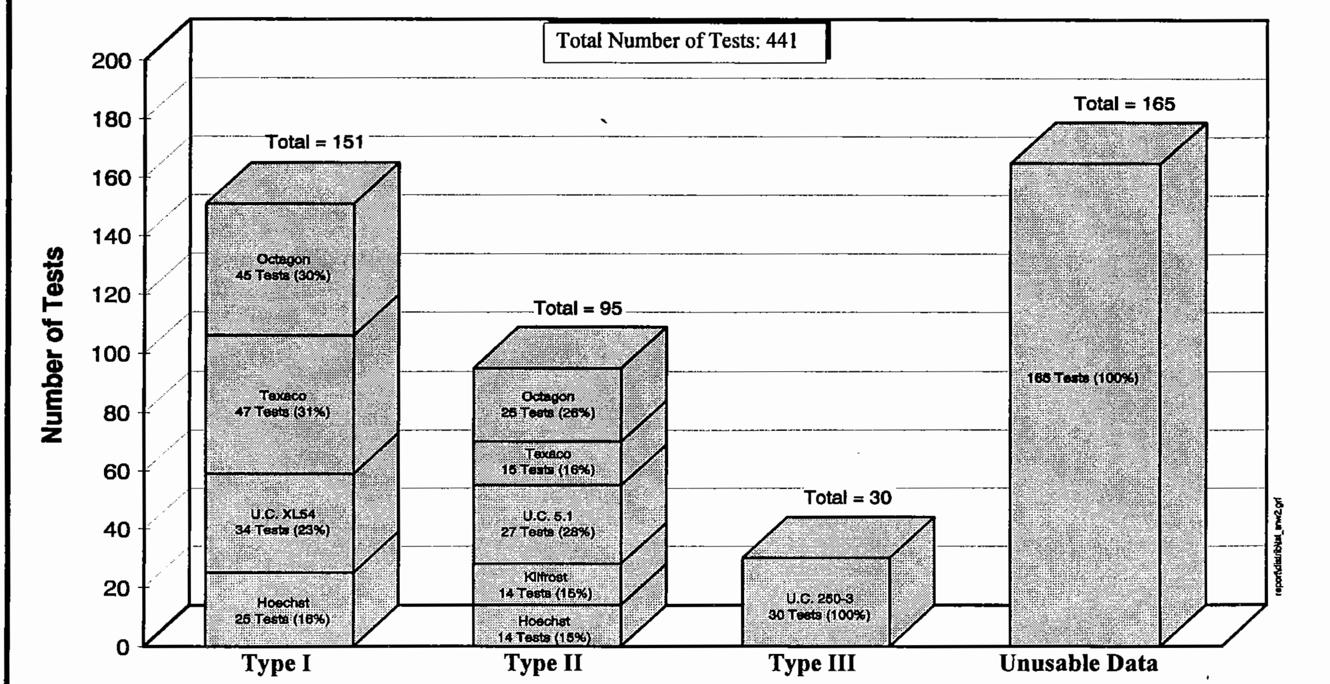


FIGURE 3.2

NUMBER OF NATURAL SNOW PLATE TESTS

DORVAL TESTING 1992-1993



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3.1.2 Distribution of Fluids Tested and Test Location

As mentioned earlier, all of the 276 usable tests were carried out at Dorval. Independent tests were conducted by United Airlines in Denver and by the NRC in Ottawa. The results of the United tests are provided in Appendix F, while those of the NRC were presented at a conference on ground deicing in June 1991 at Salt Lake City .

For the 151 Type I test points, over 60% were equally divided between Octagon and Texaco, while the balance of the tests were with Union Carbide's XL54 and Hoechst. For the 95 Type II test points, over 50% were equally divided between Octagon and Union Carbide's 5.1, while the balance was equally divided between Texaco, Kilfrost and Hoechst. For the 30 Type III test points, only Union Carbide 250-3 was used for all of the tests. These breakdowns are also shown in Figure 3.2.

3.1.3 Frequency of Average Precipitation Rates

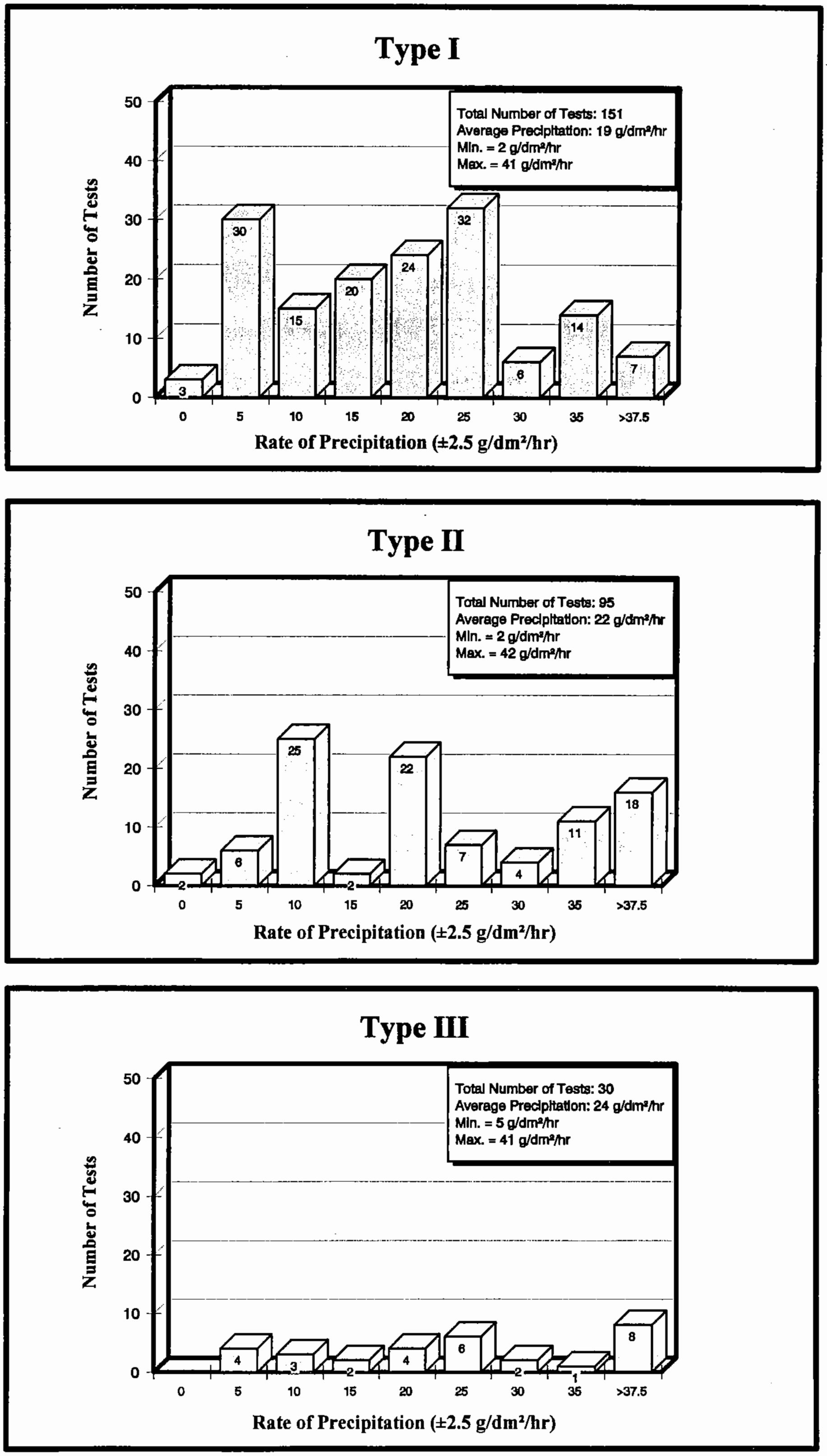
Figure 3.3 shows the distribution of average precipitation rates recorded at Dorval. The average rates were calculated by dividing, the total precipitation recorded from start of test to time of failure, by the failure time.

A key consideration when examining Figure 3.3 is that all fluid qualification tests are performed at a steady rate of 5 g/dm^2/hr. This figure shows that approximately 90% of the tests were performed at precipitation rates in excess of this value. When comparing the average rate of precipitation from Figure 3.3 with the rates from the previous two years, it was found that the rates from this test season were much higher. This may be partly explained by the equipment used to measure precipitation (see Section 4.2.1).

FIGURE 3.3

DISTRIBUTION OF PRECIPITATION RATE

Snow Tests 1992-1993



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3.1.4 Frequency of Other Meteorological Conditions

The distribution of meteorological factors such as temperature, relative humidity, wind speed and wind direction is presented in Figures 3.4, 3.5, 3.6, and 3.7, respectively. All values are averages based on the data collected at Dorval with the automated computer data acquisition system. The average air temperature was -5°C, while the coldest average during a test was -21°C and the warmest was 0.1°C. The distribution of average relative humidity is shown in Figure 3.5. The average relative humidity was 77% RH, while the maximum and minimum relative humidity values were 92% and 52%.

Figure 3.6 gives some insight into the influence of wind during precipitation conditions. The average wind speed was 18 kph, while the maximum and minimum average wind speeds were 39 kph and 4 kph. While these averages may not seem excessive, it should be noted that, like precipitation, wind is rarely constant and an average wind speed does not preclude the existence of gusts three or four times the average. The distribution of the difference in angle between the test platform and the average direction of the wind during a test is shown in Figure 3.7.

When comparing the 1992-1993 meteorological conditions during precipitation to that of the previous years, the following observations can be made regarding the 1992-1993 season:

- air temperatures were much colder
- relative humidity was lower
- wind speeds were comparable to 1990-1991, but much higher than 1991-1992.

Generally, many of the snow falls in 1992-1993 were categorized as blizzard conditions with high winds and blowing/drifting snow.

FIGURE 3.4

DISTRIBUTION OF AIR TEMPERATURE

Snow Tests 1992-1993

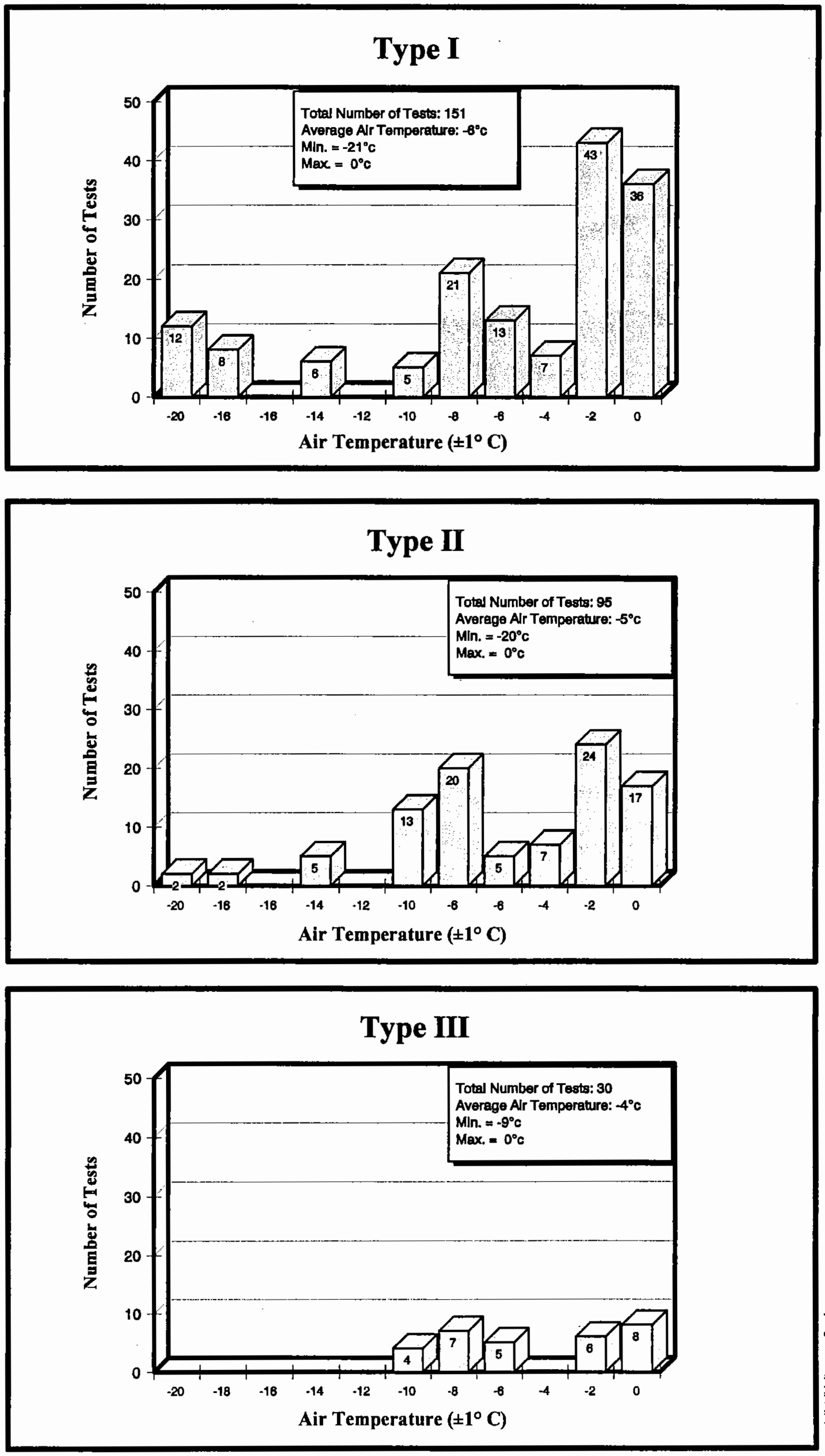

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FIGURE 3.5

DISTRIBUTION OF RELATIVE HUMIDITY

Snow Tests 1992-1993

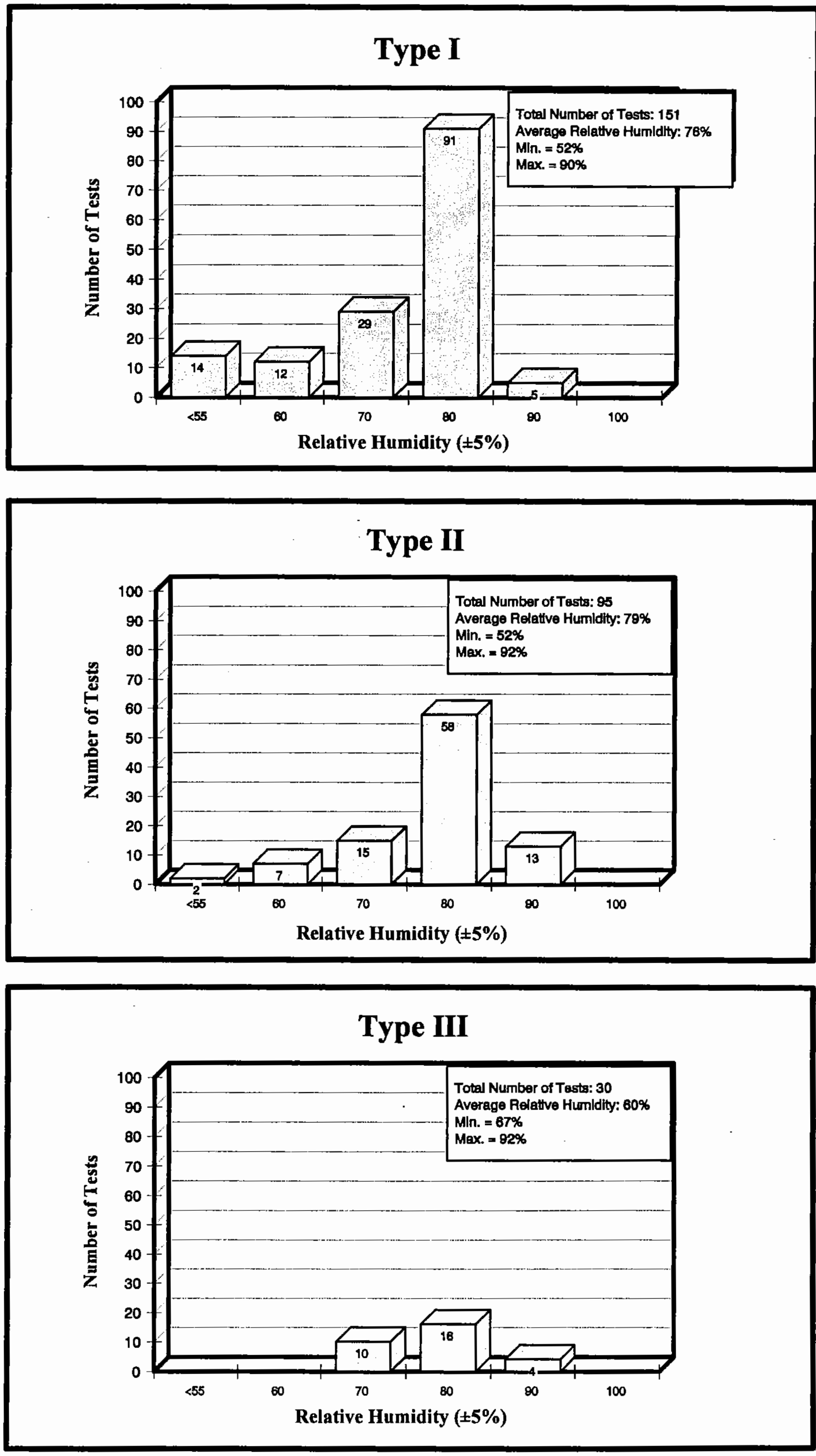

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FIGURE 3.6

DISTRIBUTION OF WIND SPEED

Snow Tests 1992-1993

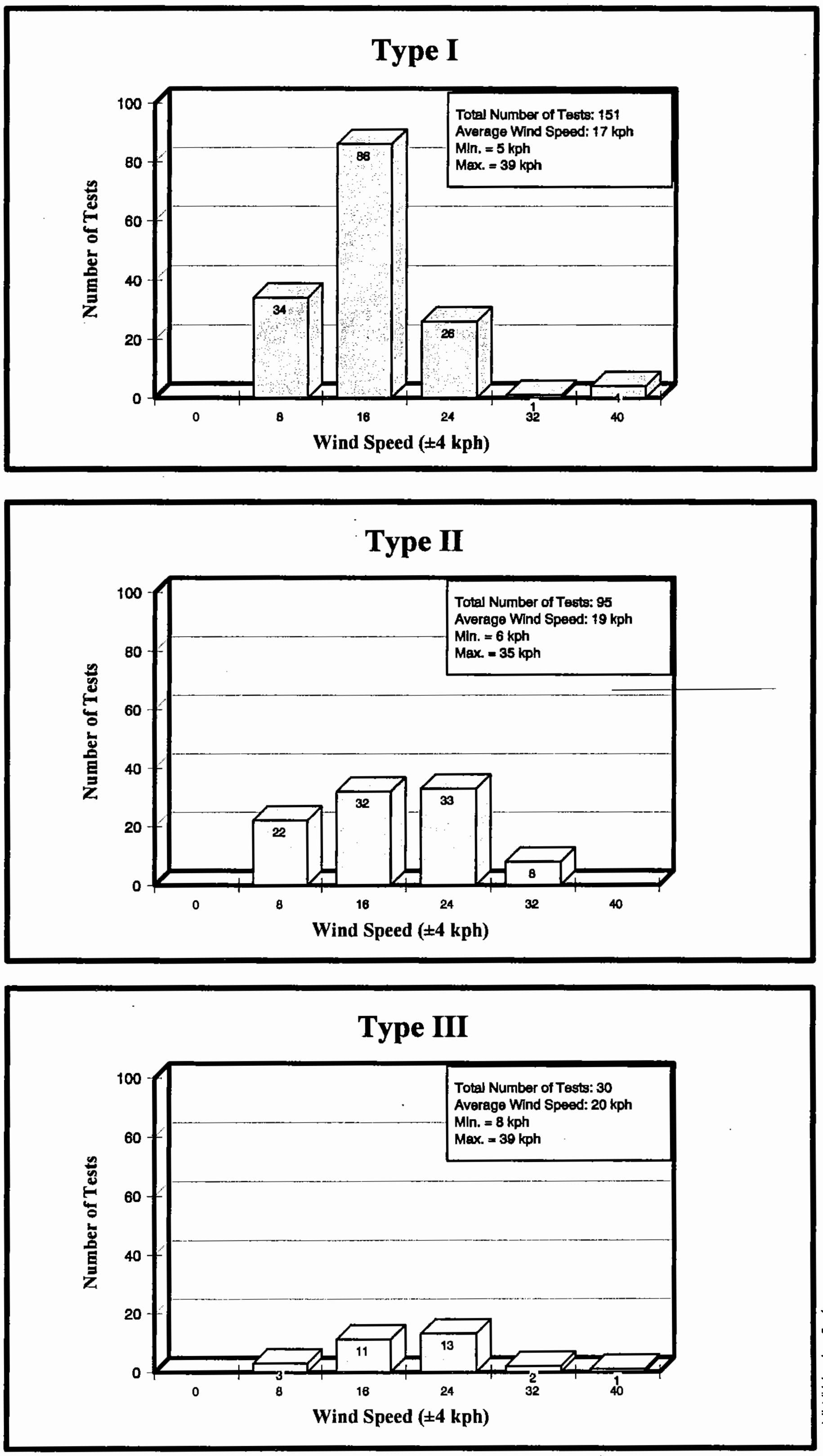

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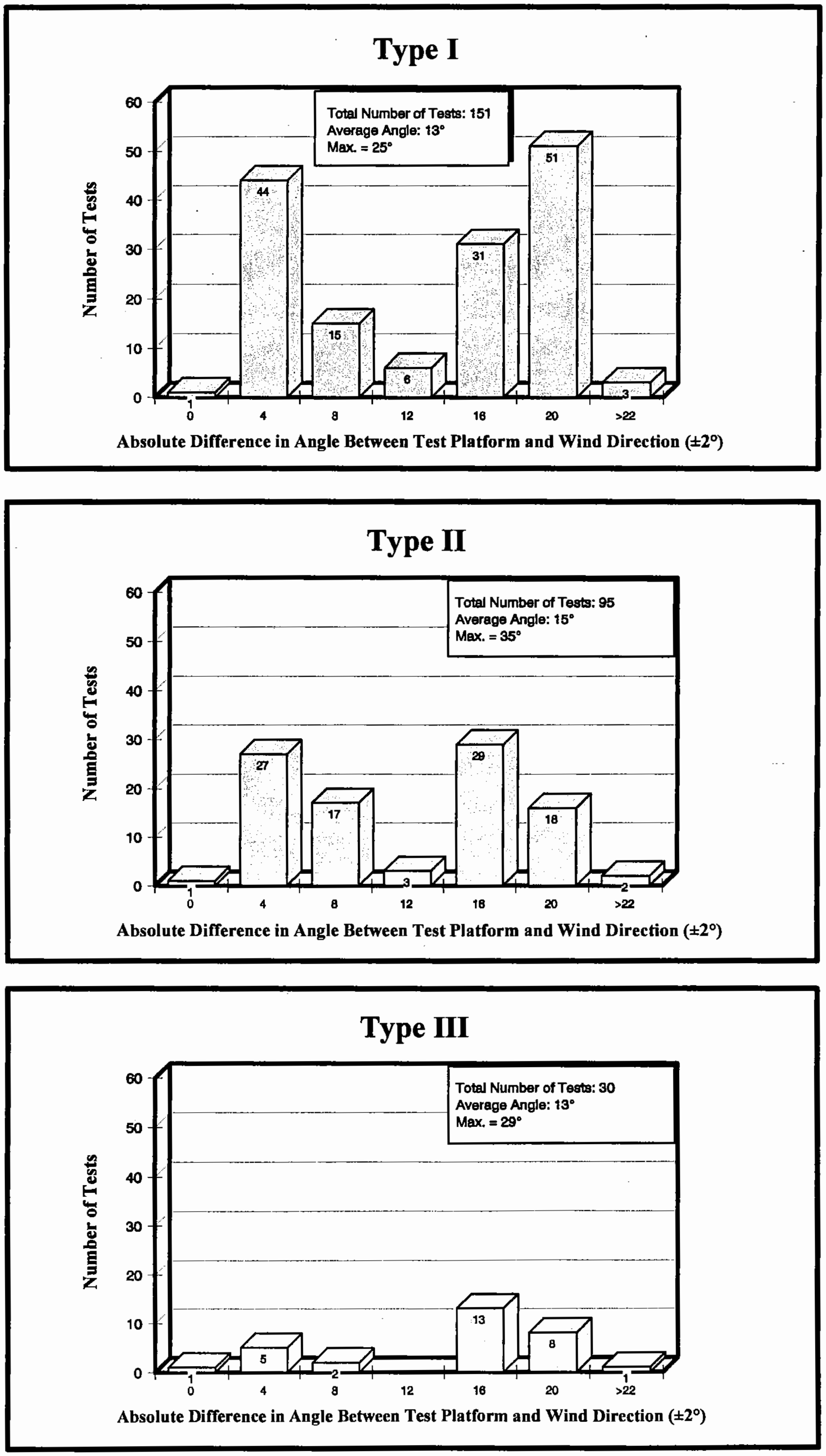
FIGURE 3.7

DISTRIBUTION OF WIND DIRECTION

Snow Tests 1992-1993



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3.1.5 Distribution of Failure Times

The distributions of fluid failure times on the plates is shown in Figure 3.8. This type of chart was produced for each fluid type. Each chart includes a number of statistical parameters such as average failure time, minimum and maximum times, the median, 5th percentile and 95th percentile failure times. The average plate failure times for each type of fluid is as follows: 22 minutes for Type I's; 32 minutes for Type III's, and 39 minutes for Type II's.

3.2 Freezing Drizzle

3.2.1 Usable and Unusable Data

During the period of May 3 to May 7, 1993, APS collected test data from 51 forms for the freezing drizzle tests in Ottawa. Almost every form contained data for six test plates. As shown in Figure 3.9, these data forms contained a total of 309 test points of which 302 points were usable. Of the usable tests, a total of 121 tests were of Type I, 87 were of Type II and 62 were of Type III fluids. In addition, 32 tests were conducted with 75/25 50/50 diluted Type II concentrations.

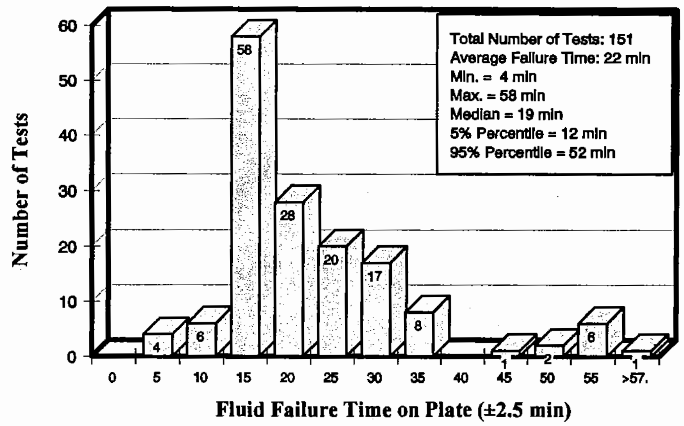
The non-usable tests resulted mostly from the first run. Prior to the start of the first run, thick ice on the plates was removed with hot water. The failure times for this first run were extremely high (28 minutes vs the average of four minutes for Type I's) and this was caused, in part, from the heating of the plates with the hot water. As this was the first run of the day, the rate of precipitation was also lower than the equilibrium level reached later in the day. It can be deduced that deicing with hot water may have an impact on the failure times of the de/anti-icing fluids.

FIGURE 3.8

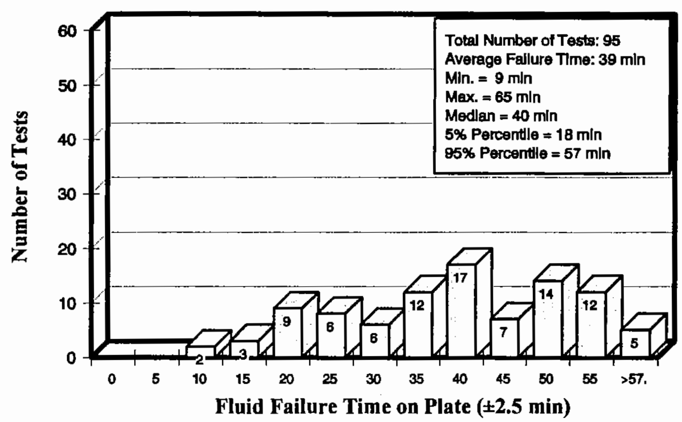
DISTRIBUTION OF FAILURE TIME

Snow Tests 1992-1993

Type I



Type II



Type III

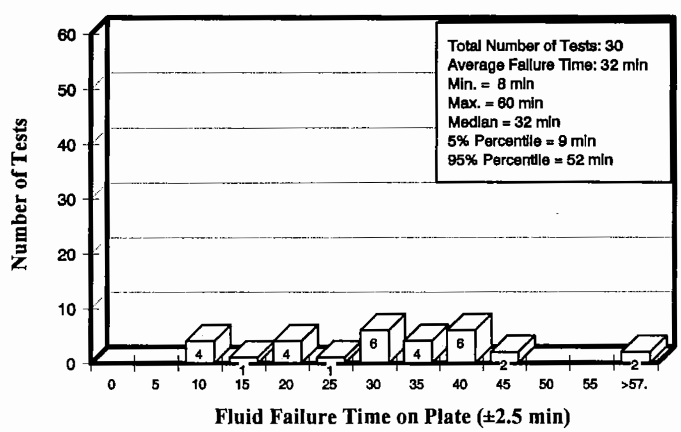


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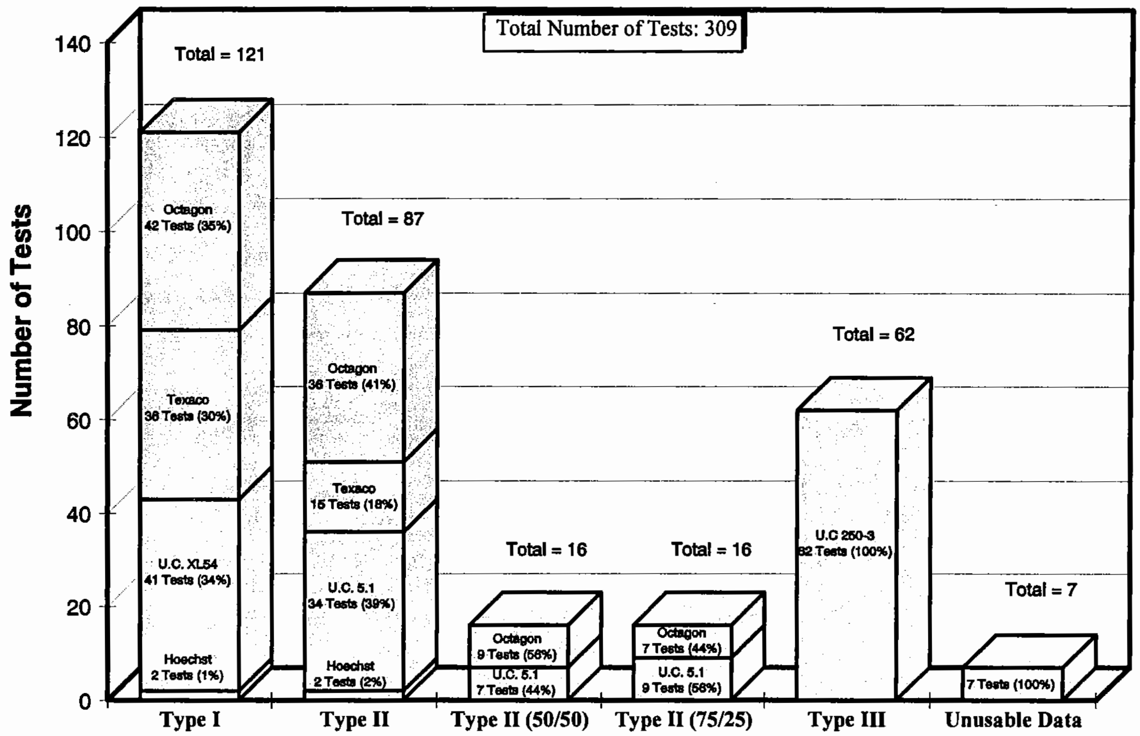
FIGURE 3.9

NUMBER OF SIMULATED FREEZING DRIZZLE TESTS

FREEZING DRIZZLE TESTING 1992-1993



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3.2.2 Distribution of Fluids Tested and Test Location

As mentioned earlier, all of the 302 usable tests were carried out at NRC's climatic engineering facility in Ottawa. The 121 Type I test points were equally divided between Octagon, Union Carbide and Texaco, with only a few tests with Hoechst. For the 87 Type II test points, 80% of the tests were equally divided between Octagon and Union Carbide, while the balance of the points were divided between Texaco and Hoechst. The diluted Type II tests were carried out equally with fluid from Octagon and Union Carbide. For the 62 Type III test points, only Union Carbide 250-3 was used for all the tests. These breakdowns are also shown in Figure 3.9.

3.2.3 Frequency of Average Precipitation Rates

Figure 3.10 shows the distribution of average precipitation rates recorded at the NRC facilities. As described in Section 2.3.4, the average precipitation rates for freezing drizzle were computed using weight measurements taken with the plate pans.

Figure 3.10 shows that the rate of precipitation varies from about 10 to 47 g/dm^2/hr. This is classified as a heavy drizzle according to the MANOBS and as a result, the failure time values obtained from the testing should be considered as conservative.

3.2.4 Frequency of Other Meteorological Conditions

The only meteorological factor which was varied during the freezing drizzle tests was temperature. The distribution of the temperatures is presented in Figure 3.11, which shows that the majority of the tests were conducted with temperatures from -5°C to -2°C. On one of the test days, the temperature was lowered to values ranging from -9°C to -7°C. It is interesting to note that the two temperature groups shown in Figure 3.11

FIGURE 3.10

DISTRIBUTION OF RATE OF PRECIPITATION

Freezing Drizzle Tests 1992-1993

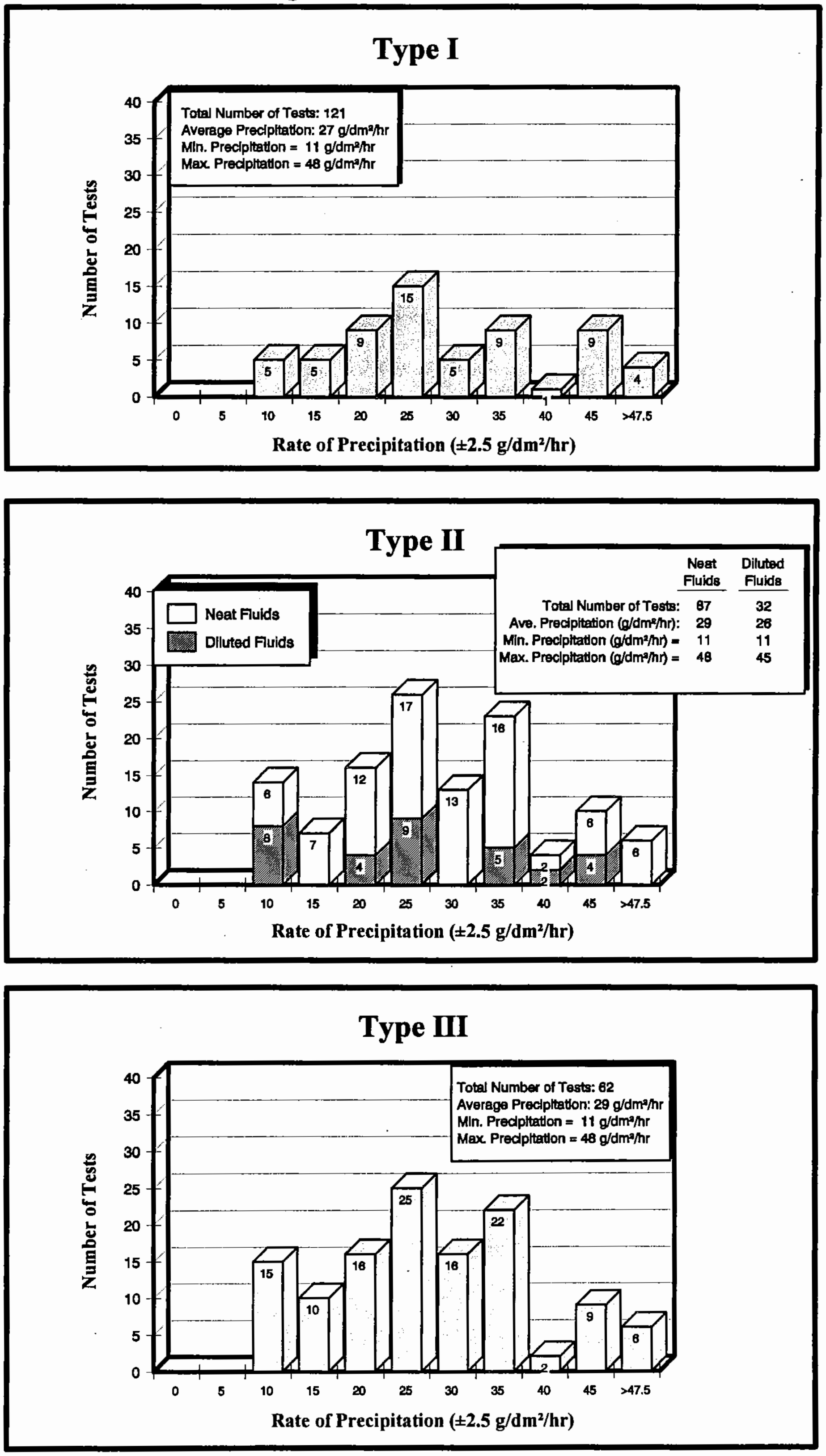

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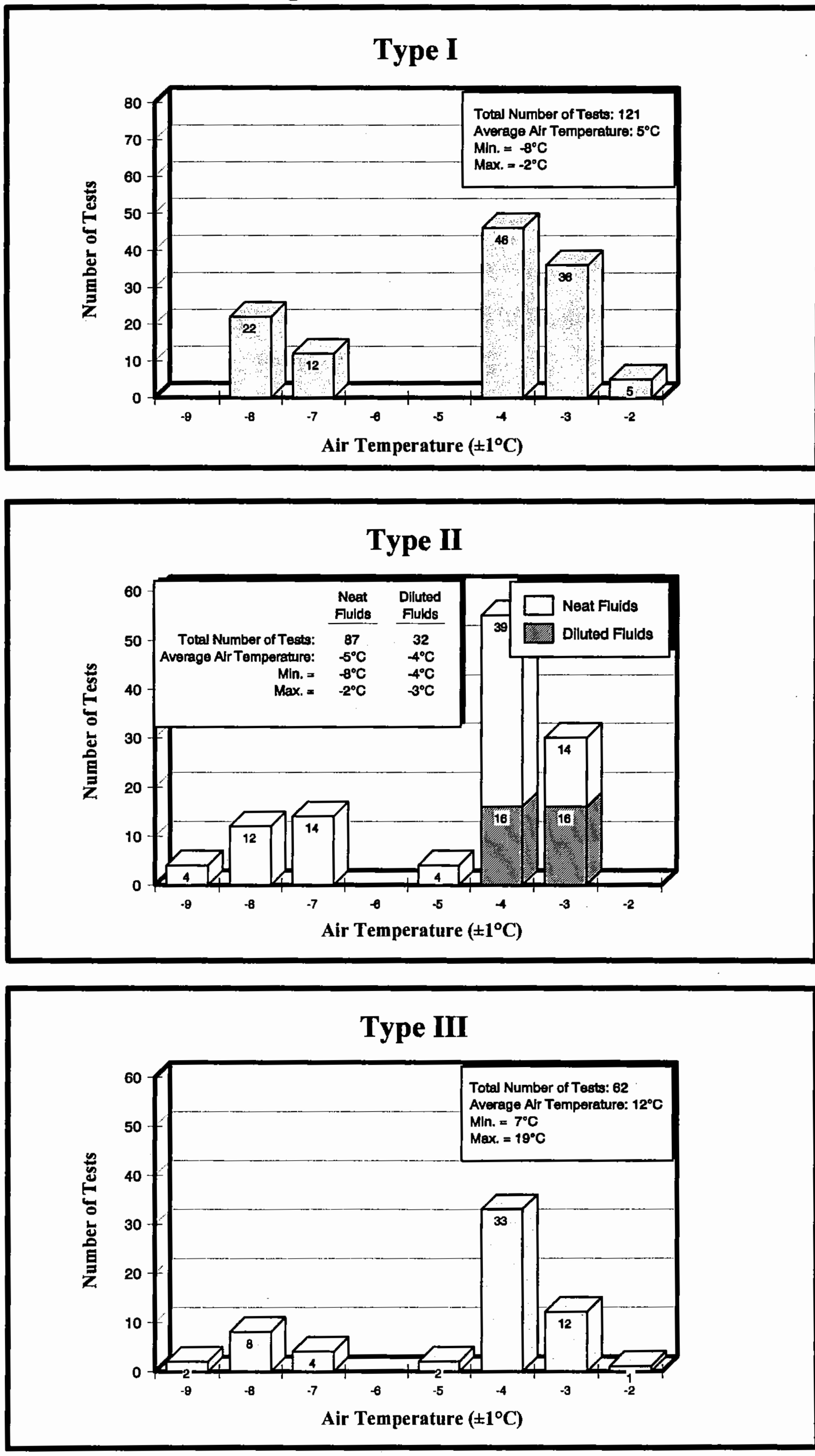
FIGURE 3.11

DISTRIBUTION OF AIR TEMPERATURE

Freezing Drizzle Tests 1992-1993



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had different failure modes, designated as "Rime-ice" type of failure and "glossy ice sheet" type of failure. With the "glossy ice sheet" failure mode, which occurred in the -5°C to -2°C temperature range, a glossy thin sheet of ice would form over the fluid at the top of the plate and gradually move down. In general, when the thin ice sheets were forming, fluid was still present underneath the ice enabling the sheet of ice to move if force was applied. During the "Rime ice" failure mode, which occurred in the -7°C to -9°C temperature range, opaque ice would form at the top of the plate and gradually move downward. The texture was of sandpaper roughness, and less fluid was present beneath the ice. It was interesting to note that, in general, the Type II fluids tested during the colder temperatures (i.e. rime ice failure modes) had higher failure times. This is discussed in more detail in Section 5.1.3.

3.2.5 Distribution of Failure Times

The distribution of fluid failure times on the plates is shown in Figure 3.12 for each fluid type. It can be noted that the average failure time of the 75/25 fluids is comparable to the Type III fluids.

3.3 Freezing Fog Tests

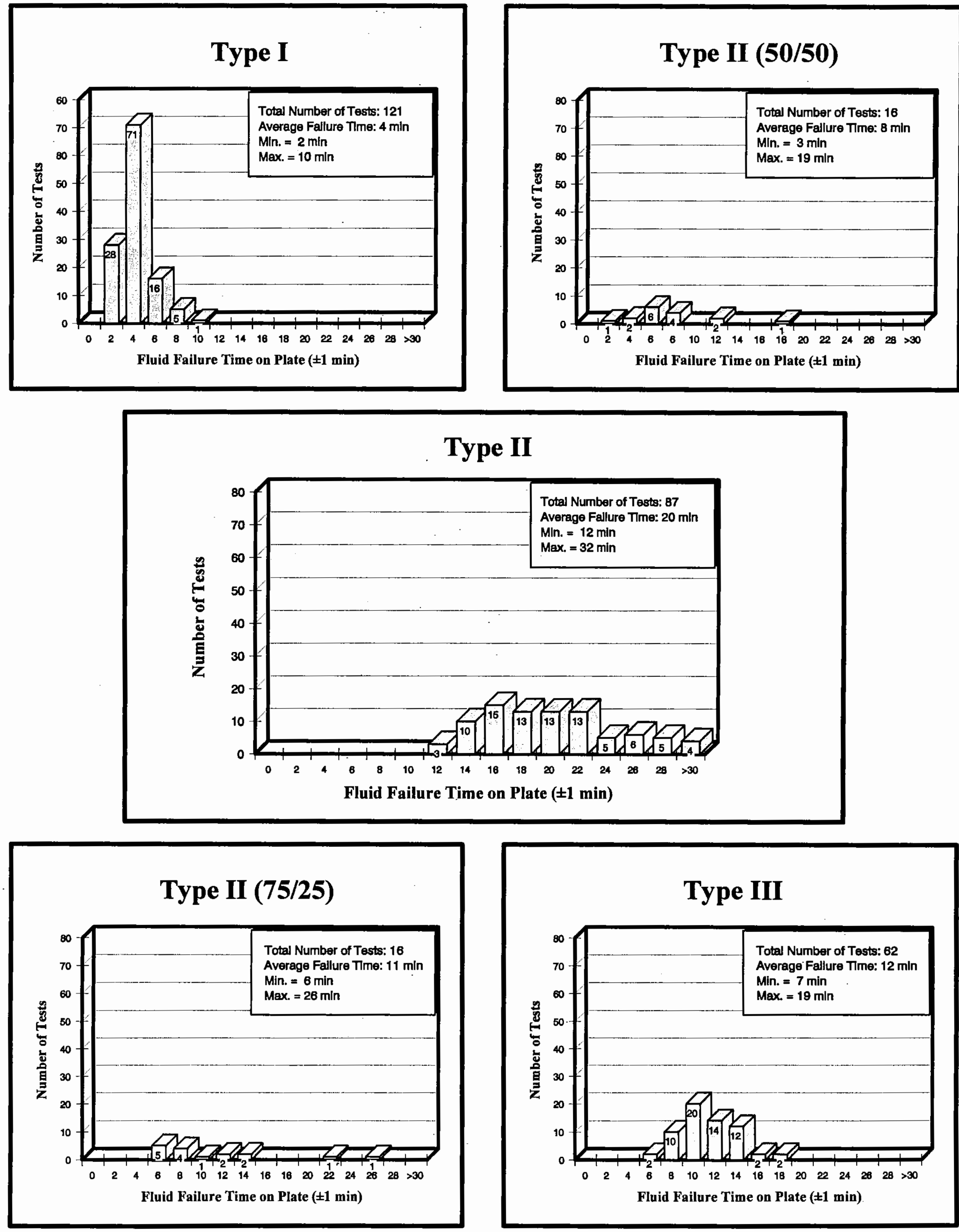
3.3.1 Usable and Unusable Data

APS collected test data on 17 forms from the outdoor freezing fog tests in Ottawa. These data forms contained a total of 77 test points of which 19 points were not used, because the tests were aborted either due to wind direction changes, or warmer temperatures. It should be noted that constant wind speed and direction are extremely crucial for this type of test in order to maintain the constant flux of simulated fog onto the test stand or aircraft. Of the usable tests, a total of 44 tests were of Type I, ten were of Type II and four were of Type III fluids.

FIGURE 3.12

DISTRIBUTION OF FAILURE TIME

Freezing Drizzle Tests 1992-1993



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This is shown in Figure 3.13.

Once again, the low number of Type II and Type III tests (these take considerably longer to fail) resulted from the lack of constant and low to moderate wind speeds, coupled with a lack of low wind direction variability. The testing was further complicated by the Beech King Air aircraft which often had to be towed to a different position (to be placed in the fog). Moving the aircraft took up a substantial amount of time and often when the weather was warmer (mid-day), the aircraft and the tow tractor would get stuck in the snow.

Tests were conducted on three days: February 24, March 18, and March 19, 1993. The shortage of testable days resulted from the lack of meteorological conditions suitable for testing and other logistical requirements such as the securement of the aircraft and compaction of the snow on the test site.

3.3.2 Distribution of Fluids Tested and Test Location

As mentioned earlier, all of the 58 usable tests were carried out at NRC's outdoor Helicopter icing facility in Ottawa. For the 44 Type I test points, about 90% of the tests were divided equally between Octagon, Texaco and Union Carbide, while the balance of the tests were with Hoechst. The ten Type II tests were divided amongst four fluid manufacturers, while the four Type III test points were with the Union Carbide fluid. These breakdowns are shown in Figure 3.13.

3.3.3 Frequency of Average Precipitation Rates

Figure 3.14 provides the distribution of average precipitation rates recorded at the icing facility. As previously mentioned, these rates were measured with the plate pan. It can be seen that the rates vary from about 2 to 10 $g/dm^2/hr$, which is on average nearly 1/4 the rates experienced during snow and freezing drizzle.

FIGURE 3.13

NUMBER OF SIMULTED FREEZING FOG TESTS

Freezing Fog Tests 1992-1993

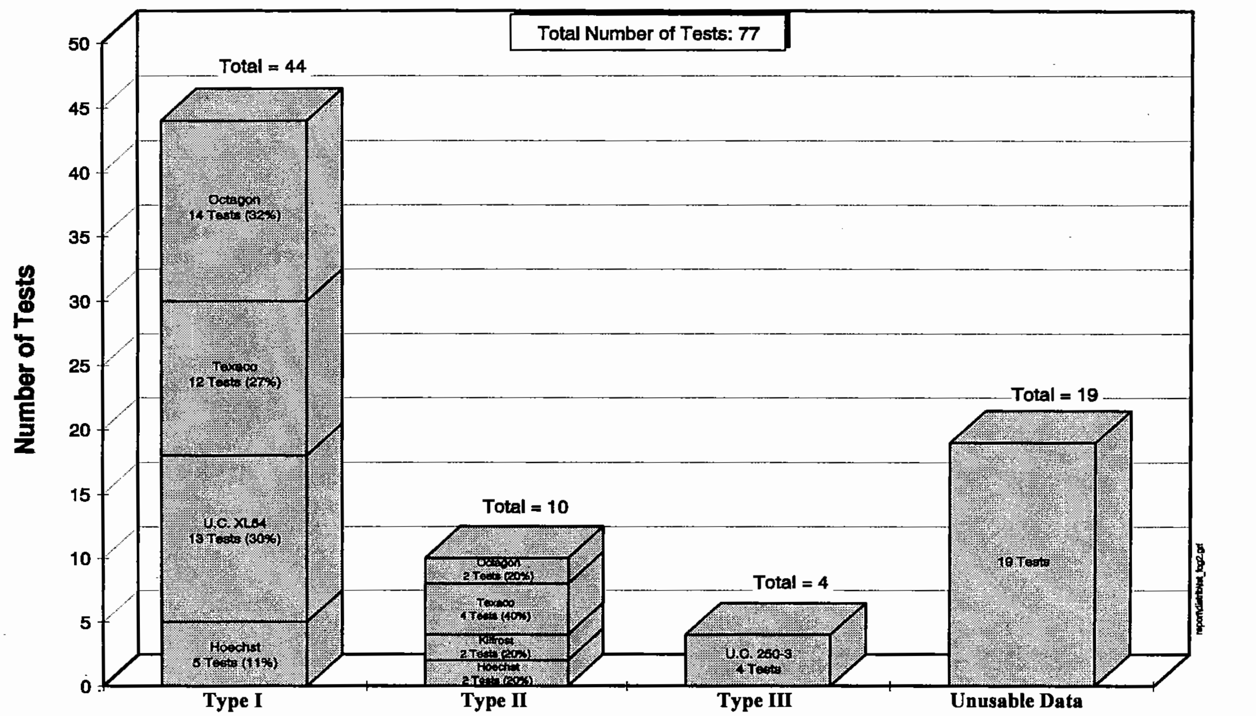
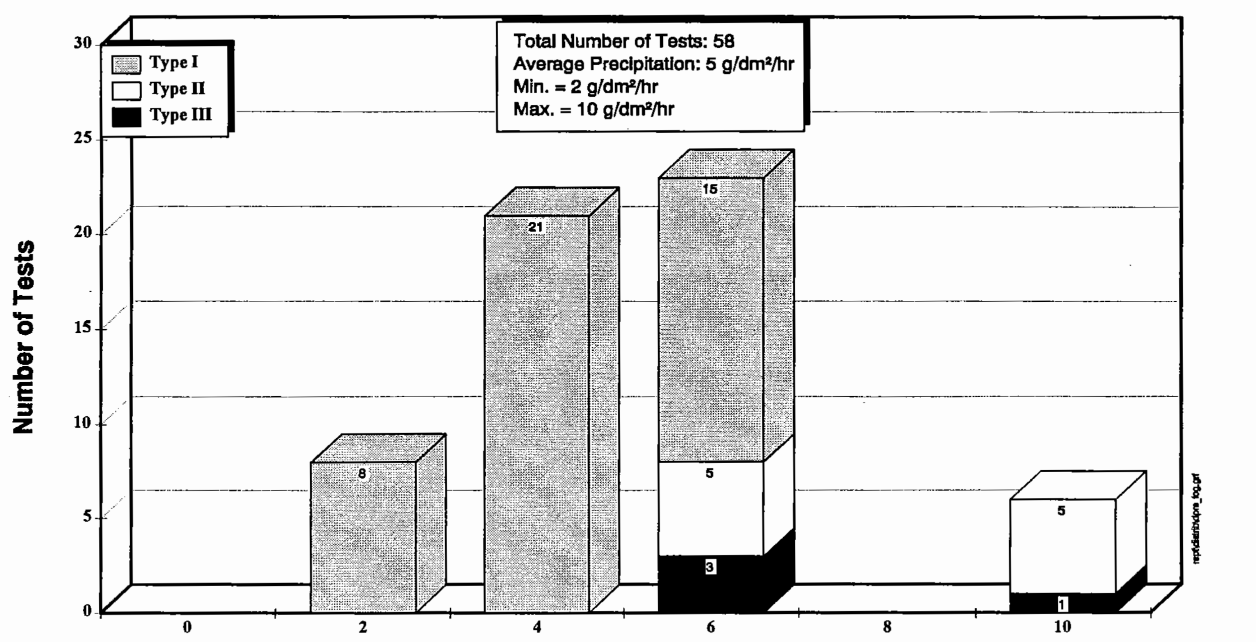


FIGURE 3.14

DISTRIBUTION OF PRECIPITATION RATE

Freezing Fog Tests 1992-1993



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3.3.4 Frequency of Other Meteorological Conditions

The only meteorological factor which varied substantially during the freezing fog tests is temperature. The distribution of temperatures is presented in Figure 3.15, which shows that the test temperatures varied from about -5°C to -14°C. Testing was postponed when temperatures were warmer than -5°C. The sun was too strong and caused any ice forming on the plates and fluids to melt when the fog was being temporarily shifted by the wind.

Wind conditions were not recorded during the tests, but those reported at Ottawa International airport varied from 0 to 13 kph with an average of about 7 kph. It is not believed that variability in the wind speed was a major factor in the reported failure times.

3.3.5 Distribution of Failure Times

The distribution of Type I fluid failure times on the plates, during the freezing fog tests is shown in Figure 3.16. As was previously mentioned, there was insufficient tests conducted with Type II and Type III fluids.

3.4 Artificial Snow Tests

APS collected test data from 10 forms for the artificial snow tests at Mont Rigaud. These tests were carried out on March 10, 1993 using the snow making equipment at Rigaud, a local ski hill near Montreal. As was shown in Figure 3.1, these data forms contained a total of 42 usable test points, the majority of which were with Type I and II fluids. Tests were conducted mostly with Octagon, Texaco and Union Carbide fluids. A number of unusable tests resulted mostly from the sun and warming temperatures in the middle of the day.

FIGURE 3.15
DISTRIBUTION OF AIR TEMPERATURE
Freezing Fog Tests 1992-1993

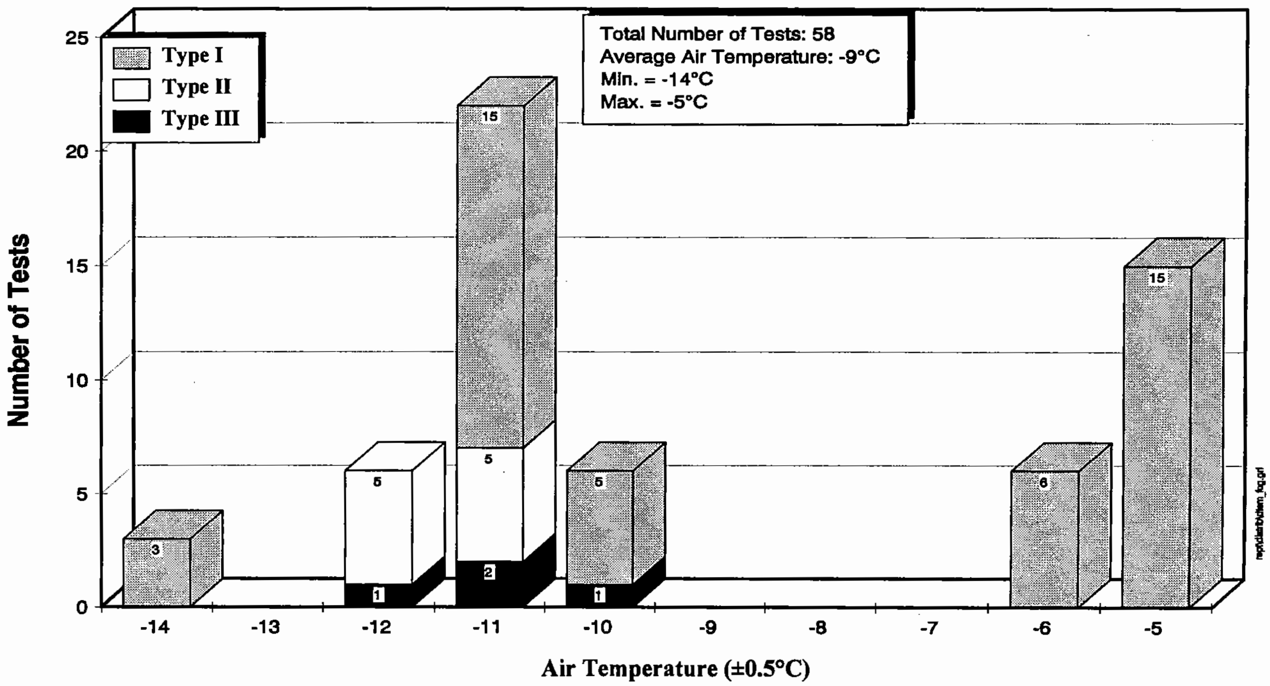
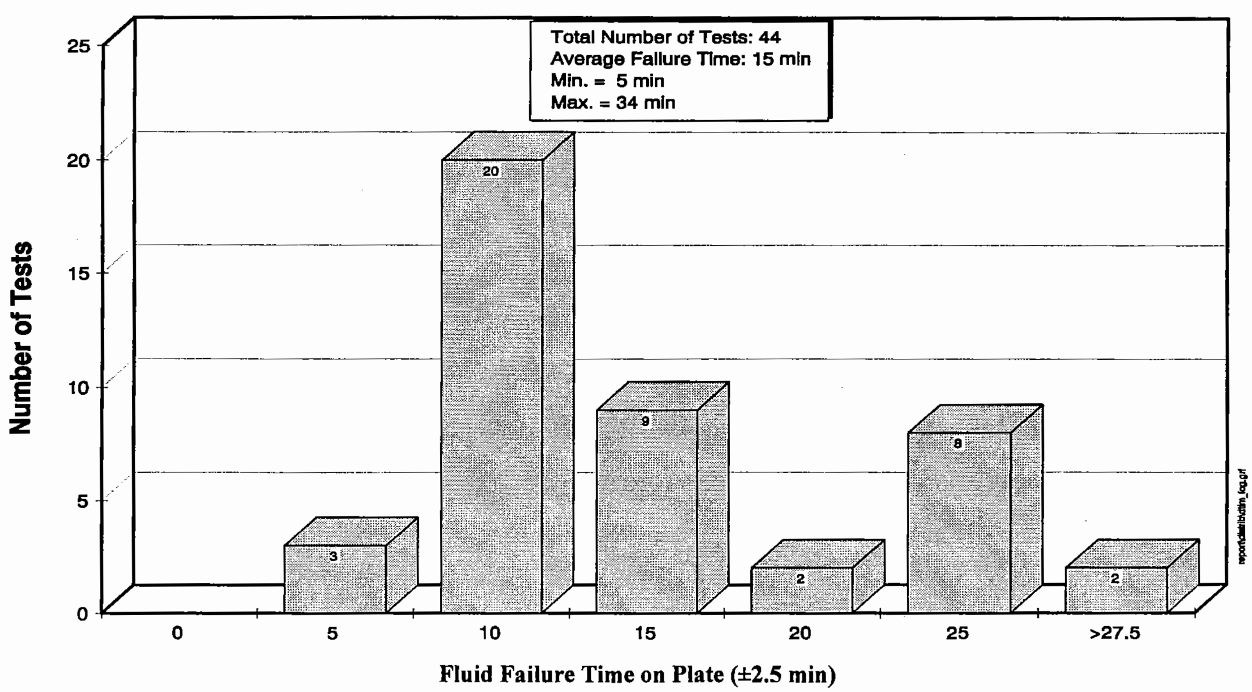


FIGURE 3.16
DISTRIBUTION OF FAILURE TIME
Type I Fluid Freezing Fog Tests 1992-1993



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The precipitation rates during the artificial snow tests varied from 43 to 138 g/dm^2/hr, which are much higher than the rates experienced during natural snow conditions. Temperatures and wind speeds for these tests were in the range of -3°C to 0°C and less than 15 kph, respectively. Further discussion of the results of the artificial snow tests is provided in Section 5.1.2.

3.5 Wing Surface Tests

As can be seen in Table 3.1, a total of 31 usable wing tests were conducted, two test points during natural snow, one with artificial snow, twenty-one test points during the simulated freezing fog, and seven during freezing drizzle. These tests were conducted with either the F-28 leading edge section, the horizontal stabilizer of the Beech King Air, or the actual Beech King Air. The tests were conducted simultaneously with flat plate tests in order to correlate the two results. A discussion of the results of these tests is presented in Section 5.3.

3.6 Cold-soaking Tests

Cold-soaking tests were conducted on April 22 and 23, 1993 during rain. These were preliminary tests conducted to observe the behaviour of fluids on the cold-soaked box section discussed in Section 2. A further description of the results is provided in Section 5.1.6.

3.7 Sensor Tests

A total of 165 tests (listed in Table 3.2) were performed using the ice sensors in natural snow at the Dorval site, artificial snow at the Rigaud site, and simulated freezing drizzle and fog at the National Research Council testing facilities in Ottawa. Some 40% of the testing was performed under natural snow conditions, followed by 35% under simulated freezing drizzle conditions, 12% in artificial snow, 12% in freezing fog and 5% without precipitation (thickness tests). The fluids consisted of three Types I's, three Type II's and one Type III. Two sensor tests were carried out with diluted Type II fluids under freezing drizzle simulated conditions.

TABLE 3.1
NUMBER AND TYPES OF TESTS PERFORMED WITH CURVED SURFACES

Fluid Type		Natural Snow	Artificial Snow	Freezing Fog	Freezing Drizzle	Total
Type I	B-204	2	-	9	-	11
	B-210	-	-	-	-	0
	B-212	-	-	8	2	10
	B-213	-	-	-	1	1
Type II	A-205	-	-	1	-	1
	A-209	-	-	-	-	0
	A-199	-	1	2	2	5
Type II (Diluted)	A-210	-	-	-	-	0
	A-211	-	-	-	-	0
Type III	A-200	-	-	1	2	3
Total		2	1	21	7	31

TABLE 3.2
NUMBER AND TYPES OF TESTS PERFORMED WITH SENSORS

Fluid Type		Natural Snow	Artificial Snow	Freezing Fog	Freezing Drizzle	Fluid Thickness (No Precipitation)	Total
Type I	B-204	17	-	9	6	4	36
	B-212	16	3	5	7	2	33
	B-213	7	-	3	9	-	19
Type II	A-205	10	-	1	8	-	19
	A-209	7	-	-	6	-	13
	A-199	11	6	1	6	2	26
Type II (Diluted)	A-210	-	-	-	1	-	1
	A-211	-	-	-	1	-	1
Type III	A-200	-	2	2	13	-	17
Total		68	11	21	57	8	165

4. METEOROLOGICAL ANALYSIS

This section examines meteorology with two different objectives. Section 4.1 presents an analysis comparable to those of the 1990-1991 and the 1991-1992 reports which describe the success achieved in performing tests. It identifies the number of days when testing could have occurred, and on how many of these days testing actually did occur. Section 4.2 presents an analysis which compares various meteorological devices and data.

4.1 Summary of Test Success

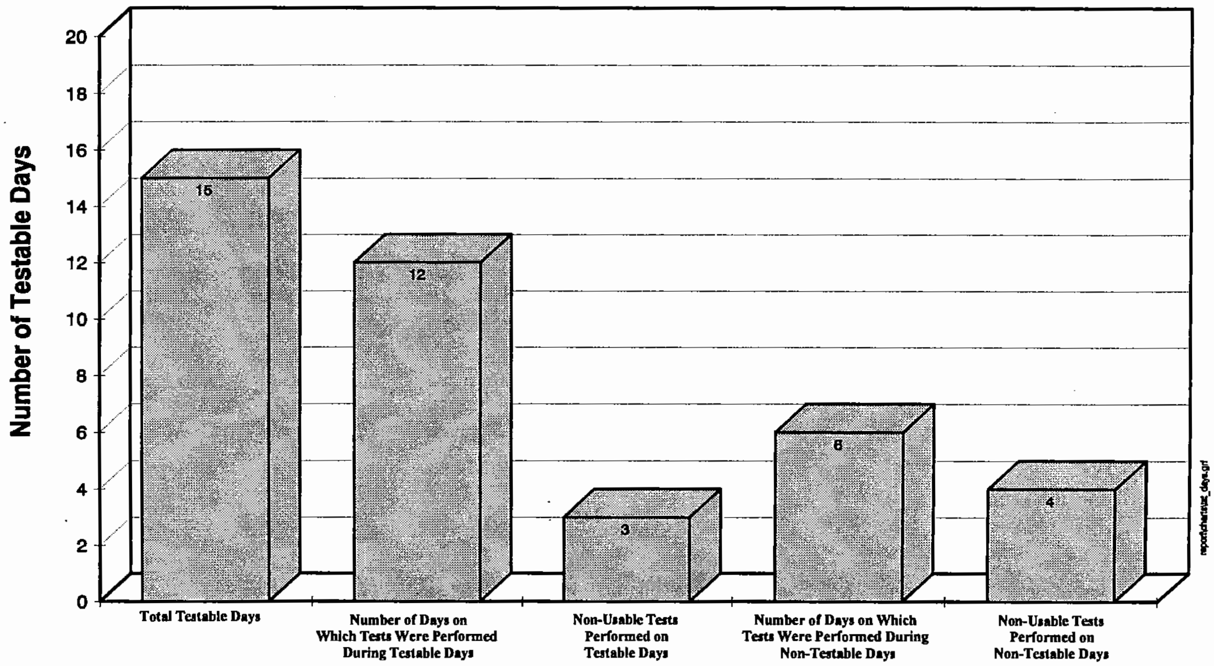
With the assistance of data from the AES, APS was able to obtain relatively detailed meteorological information for the Dorval test site. This AES data was used in order to maintain continuity with previous years' testing.

As in previous years, an average precipitation of 3 $g/dm^2/hr$ (or 0.3 mm/hr of water), during the precipitation period, was set as the minimum precipitation requirement for a day to be defined as "testable". This limit value, equates to about 0.3 cm of snow per hour and is expected to be insufficient to yield a successful test, even though normal fluctuations during an extended period of low average precipitation can provide a productive test period.

Dorval experienced a total of 15 testable days and tests were performed on twelve of those days. Two of the twelve testing days resulted in tests being non-usable due to high wind speeds and low rates of precipitation. The three testable days when tests were not carried out, all occurred on the second day of the following two-day periods: January 28/29, February 16/17 and March 13/14. Tests lasted for long periods during these days, and other personnel were not available. In addition, testing on March 14, 1993 became hazardous due to the heavy winds and snow. Testing was also performed on days which were classified as non-testable. These tests did not always provide usable results. Overall, tests were performed on 18 different days. The levels of success are presented in Figure 4.1.

FIGURE 4.1
SUCCESS OF TESTS

DORVAL TESTING 1992-1993



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The total snowfall recorded at Dorval for the 1990-1991, 1991-1992 and 1992-1993 winters was 197 cm, 206 cm, and 243 cm, respectively, while the average snowfall for a season is 214 cm. The 15 testable days in 1992-1993 were the highest in the last three years.

4.2 Comparison of Meteorological Parameters

The following subsections take an in depth look at precipitation collection devices, visibility in relation to specific precipitation rates, and type of precipitation versus precipitation rate. The last section compares the site wind speed measurements with those from AES.

4.2.1 Comparison of Precipitation Collection Devices at Dorval

For the snow tests at Dorval two methods were used to record precipitation rate: the European tipping bucket (ombrometer) which measures the rate of precipitation in increments of 0.05 g/dm^2, and the plate pan which was only used during the second half of the test season. The plate pan which is pre-wetted and pre-weighed, is used to record total precipitation from the beginning to the end of the test. The pan is installed on the stand, beside the flat plates, at a 10° incline. The plate pan measurement appears to be very representative of the actual snow affecting the plates but it does not reflect increases and decreases in the rate of precipitation over a test, nor does it provide total precipitation for each plate (unless they all have equal failure times).

Upon comparing results of the two methods, a one-to-one direct relationship of the rate of precipitation, plus or minus a small margin for error, was expected. As this was not the case, a re-evaluation of the precipitation data from both the ombrometer and the plate pan was necessary.

Precipitation data was also acquired from Meteoglobe Canada Inc. who are under contract to the City of Montreal to provide precipitation data. The precipitation was measured from a tipping bucket located adjacent to Environment Canada's equipment. Any future reference to this equipment in this report will be labelled as "Environment Canada tipping bucket". This data is considered representative of the weather conditions at the test site due to its proximity. The Environment Canada tipping bucket is not as sensitive (one tip for every 2 g/dm^2 of snow) as the ombrometer, however the data is considered more accurate due to the wind shield mounted on the gauge. The wind shield's basic function is to remove the effects of the wind.

As can be seen in Figure 4.2, a comparison of Environment Canada's precipitation measurements with the ombrometer does not indicate a direct relationship. The ombrometer results appear to have been greatly affected by the wind. Values that do approach the one-to-one relationship are the low wind speed cases. As the wind speed increases, the values tend to move farther away from the one-to-one line. This leads one to conclude that wind speed is an important factor in the measurement of precipitation rates.

Figure 4.3 better exemplifies a one-to-one relationship. The comparison of Environment Canada's precipitation data with the plate data shows an improved correlation between these two instruments. The best fit line matches with the one-to-one relationship almost exactly. The scatter in the data may be attributed primarily to two factors, wind speed and human error in the weighing of the plate pan. The following problems were experienced with the weigh scale:

- the balance needed a mechanical adjustment after receipt from the factory. This was detected and corrected after a few tests,
- snow, ice or water could easily fall into the pan from the person's clothes when weighing,

FIGURE 4.2
COMPARISON OF PRECIPITATION COLLECTION DEVICES
EUROPEAN OMBROMETER vs ENVIRONMENT CANADA

DORVAL TESTING 1992-1993

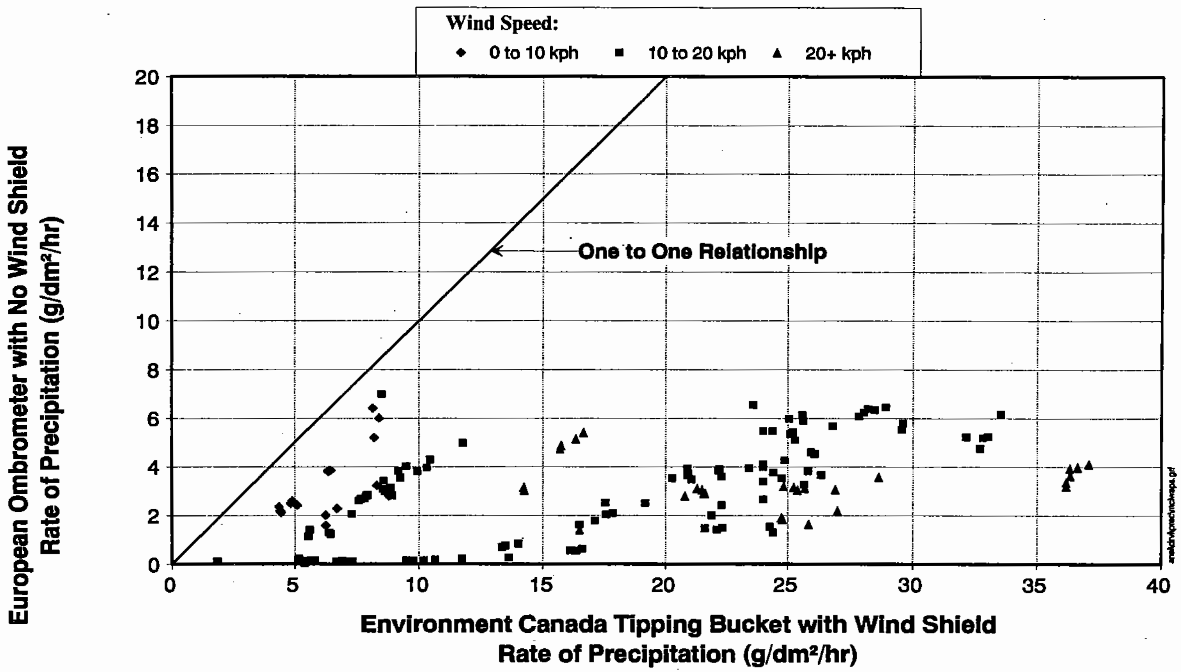
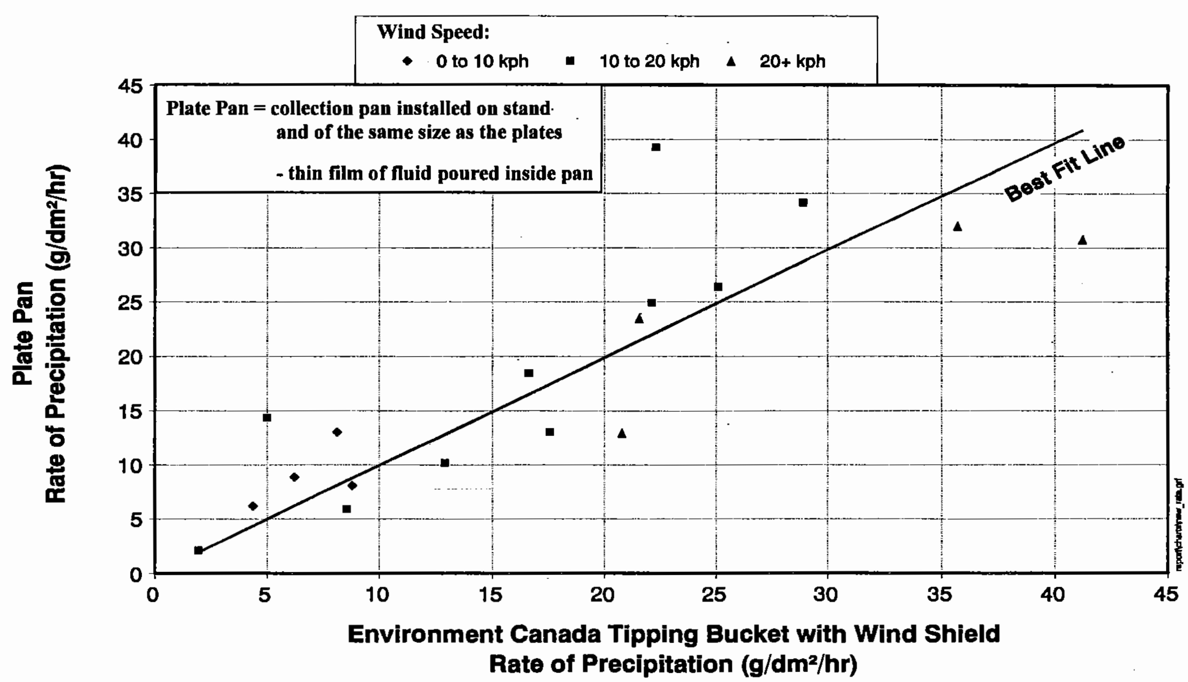


FIGURE 4.3
COMPARISON OF PRECIPITATION COLLECTION DEVICES
PLATE PAN vs ENVIRONMENT CANADA

DORVAL TESTING 1992-1993



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- the mechanical nature of the balance can cause substantial errors in the readings, and
- the pan is much larger than the balance, which cause the pan to occasionally tip.

As was noted in Figure 4.2 and as can be seen in Figure 4.3, the values with low wind speeds are closer to the one-to-one relationship line than the values with higher wind speeds.

Based on the above comparison, the snow test results for the 1992-1993 test season were analyzed using the Environment Canada tipping bucket. Precipitation rates from the ombrometer were considered to be too low, while data with the plate pan was only collected on a few of the tests at the end of the test season.

For 1993-1994 testing it is recommended to use two methods to measure precipitation: the ombrometer with a wind shield and at least two plate pans. **The rate measured with the ombrometer would be that which a pilot could obtain from the airport, and the rate measured from the plate pan is likely very representative of what is actually falling onto the plates.** In order to correlate these two methods of measurement, the terminal velocity of the falling precipitation is required. This can either be calculated from a snow mass concentration device or directly obtained by using a doppler radar precipitation occurrence sensor system (POSS). A snow mass concentration device would likely be available from the NRC for 1993-1994 testing.

4.2.2 Visibility vs Rate of Precipitation

Figure 4.4 illustrates relationships between visibility in miles for various rates of precipitation. The visibility data was obtained from observations by Environment Canada at Dorval airport. The data points represent the precipitation rates, using Environment Canada's tipping bucket with a wind shield, for all 1992-1993 snow tests versus the predominant visibility during the time of testing.

Superimposed over the data is a curve developed at the NRC. The NRC performed a series of experiments which lead to the development of a best-fit curve which estimates precipitation rate (R) from visibility (V). This relationship has a coefficient of correlation of 91%.

Based on Environment Canada's (MANOBS) visibility criteria for light, moderate and heavy snow and the NRC curve, it can be seen from Figure 4.4 that the rates associated with the various visibilities are as follows:

- light — 0 to 10 $g/dm^2/hr$
- moderate — 10 to 25 $g/dm^2/hr$
- heavy — > 25 $g/dm^2/hr$

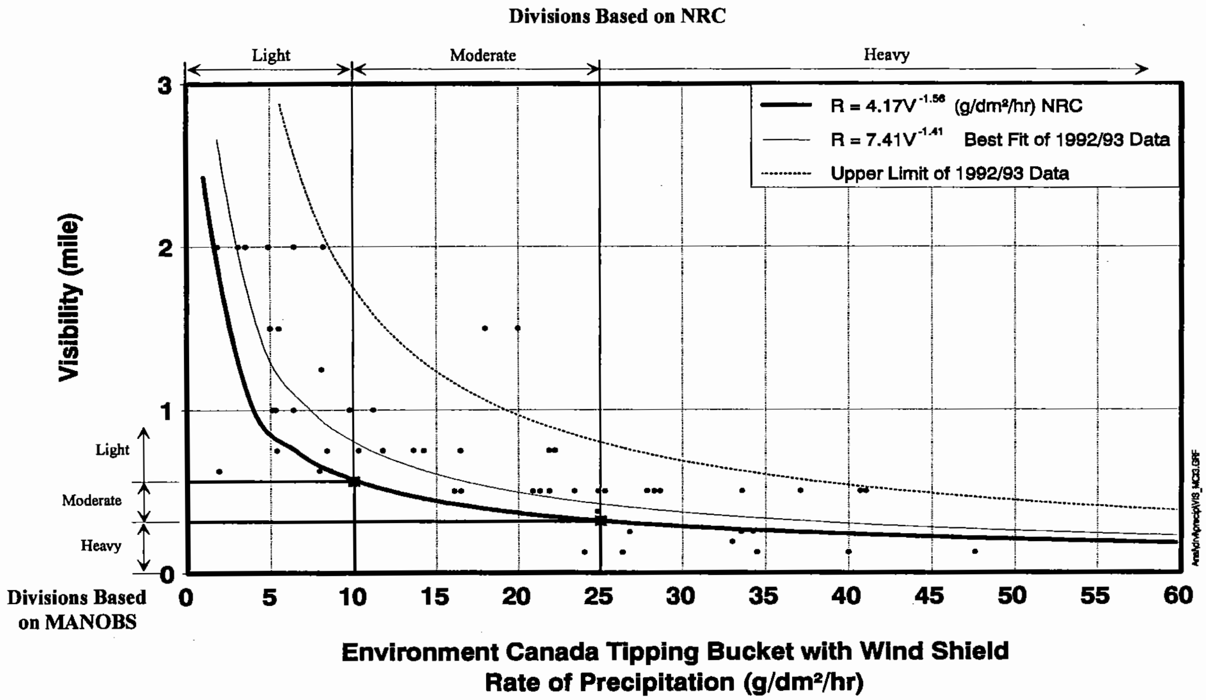
Superimposed over the data is the best-fit curve for the 1992-1993 data. Although this curve is slightly higher than the NRC curve, it still tends to follow the same trend.

Also shown on the chart is an upper bound curve, which ignores the two upper points. Based on the 1992-1993 data at Dorval and the NRC divisions, one can hypothesize that visibility in excess of 1¾ miles is necessary to guarantee that the snow is "light", and visibility in excess of ¾ mile is necessary to guarantee that the snow is "not heavy". Another perspective on the categorization of type of precipitation is provided in the next section.

FIGURE 4.4

VISIBILITY vs PRECIPITATION

DORVAL TESTING 1992-1993



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4.2.3 Type of Precipitation vs Precipitation Rate

Figure 4.5 associates snow types with specific precipitation rates, from the 1992-1993 snow tests at Dorval. The precipitation rates were computed using the Environment Canada tipping bucket from the tests in the 1992-1993 data sample. The snow types were observed by Environment Canada at Dorval and represent the conditions that are predominant during a particular test. Therefore, for each test, there was a specific precipitation rate and a specific snow type associated with it.

Snow type is broken down into three basic categories, light, moderate and heavy snow. Added to these categories are secondary factors, blowing snow and light snow grain. The secondary factors tend to move a particular value from one basic category to the next highest category. For example, the moderate snow/blowing snow precipitation rates are equivalent to the precipitation rates resulting from heavy snow.

In addition, the Environment Canada data indicates the times when there is drifting snow. It is interesting to note that all the points above 10 g/dm^2/hr in the light snow category were reported as having drifting snow. Furthermore, the points above 25 g/dm^2/hr in the moderate snow category also reported drifting snow.

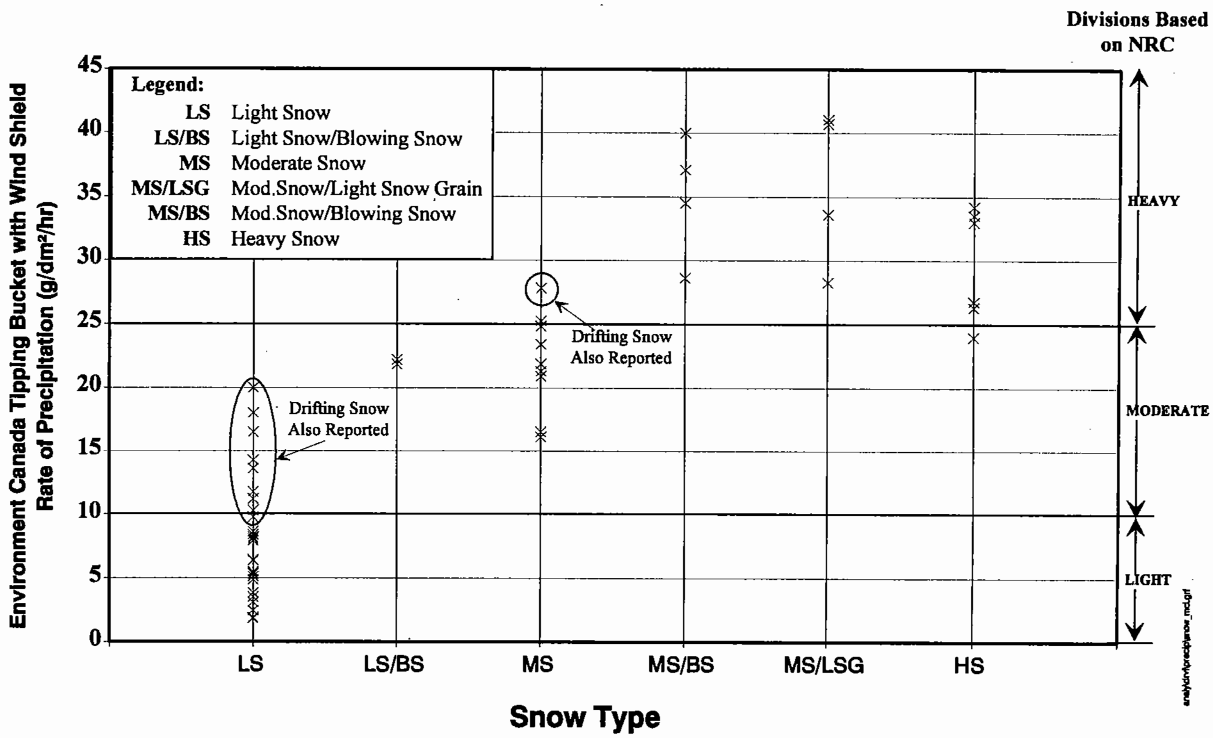
Based on the above discussion of the data points shown in Figure 4.5, the following basic categories can be defined:

- **light group**
  - light snow (ls)
- **moderate group**
  - light snow/blowing snow (ls/bs)
  - light snow/drifting snow (ls/ds)
  - moderate snow (ms)
- **heavy group**
  - moderate snow/blowing snow (ms/bs)
  - moderate snow/drifting snow (ms/ds)
  - moderate snow/light snow grain (ms/lsg)
  - heavy snow (hs)

FIGURE 4.5

TYPE OF PRECIPITATION vs PRECIPITATION RATE

DORVAL TESTING 1992-1993



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Based on the research conducted to date, the above categorization could be used for the short term. For the long term, it is obvious that more research and improved snow sensoring equipment is required.

4.2.4 Comparison of Meteorological Measurements

Figure 4.6 represents test site wind speed measurements versus Environment Canada's wind speed measurements. In both cases wind speed is computed to be the average wind speed over the duration of the test. The coefficient of correlation between the two sets of data is approximately 95%. The test site measurements are consistently in the range of approximately 70% of those from Environment Canada.

The difference in the two data sets can be attributed to the variation in height of the two instruments. Environment Canada's anemometer is at a height of ten meters, while the test site instrument is at a height of three meters. The test site data is considered representative of the true test conditions, and as a result, this data was used for the analysis.

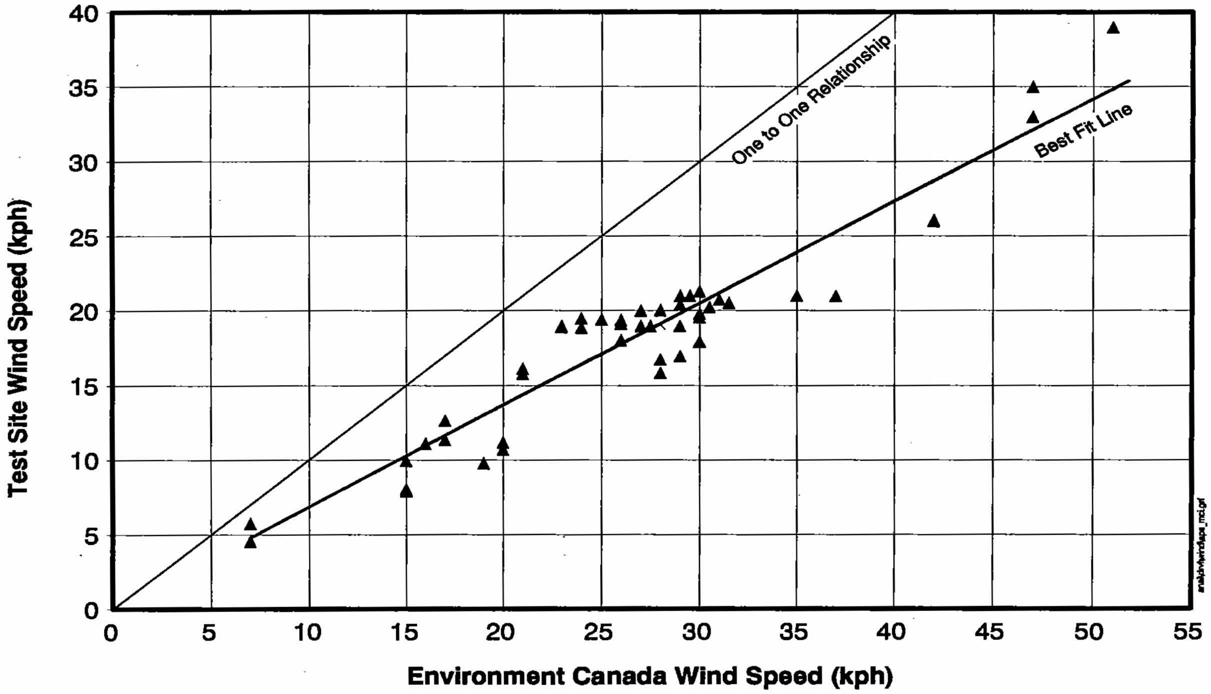
When comparing the temperature, humidity and wind direction, it was found that the two data sets have little or no discrepancies.

FIGURE 4.6

WIND SPEED COMPARISON

TEST SITE vs ENVIRONMENT CANADA

DORVAL TESTING 1992-1993



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5. ANALYSIS

The results are sub-divided into three main sections, namely flat plate tests, ice sensor tests and aircraft surface tests, which are discussed separately in their respective sections.

5.1 Flat Plate Tests

The objectives of the flat plate tests were:

a) to verify the currently used SAE holdover times reported in the table of Appendix B.

b) to identify the important (environmental) parameters which influence the fluid failure time and develop correlation equations where possible.

c) to develop recommendations and changes to test procedures for future testing.

The flat plate tests were conducted under six general categories of conditions, which are natural snow, artificial snow, freezing drizzle, freezing fog, no precipitation and rain on a cold-soaked surface. Each of these data sets were further sub-divided into the fluid Types (I, II, and III) and are discussed separately in the following sections. Throughout the discussions, it is presumed that a 1:1 relationship exists between fluid failure times on the flat plate and on an aircraft surface. Further discussion on this matter can be found in Section 5.3 of this report.

Two basic methods of analysis were performed on the data: a statistical analysis and a dimensional analysis. The statistical analysis primarily involved the multi-variable regression to determine the existence (if any) of a relationship between the fluid failure time with various parameters such as the rate of precipitation, temperature and relative humidity.

The general methodology of the regression process of the statistical analysis was to regress failure time against all the other variables in a stepwise manner. The process continued until only significant variables remained in the predictor equation. Key elements in determining the quality of a regression fit are the R^2 value and the shape of the standardized residual distribution. R^2 is expressed as a percentage and is known as the multiple coefficient of determination. An R^2 of 80%, for instance, essentially indicates that the regression equation could account for 80% of the variation in the data. The standard residual is the difference between the predicted value for a given set of conditions and the observed value divided by the standard deviation. It is important that the distribution of the set of standardized residuals is normal, or bell shaped. 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.

For each individual analysis, different relationships among the variables were examined. Four general relationships were applied to all regressions. A simple linear relationship, two semi-log relationships, the first having failure time represented as in the logarithmic scale, and the second having precipitation represented in the logarithmic scale. The fourth relationship is a log/log relation with both fail time and precipitation rate transformed to a logarithmic scale.

The multi-variable regression yielded some useful relationships and information for all tests and provided useful insight into the relevant parameters to be used for the dimensional analysis in the snow tests. The dimensional analysis was also performed to establish a relationship based on known physical phenomena associated with the process of fluid failure due to contamination (dilution) resulting from the precipitation. A useful equation was obtained for A-199 (Type II) fluid in snow conditions and is presented in Section 5.4.

5.1.1 Natural Snow Conditions

In general for a given fluid, the failure time under snow conditions is governed by the following measured parameters: rate of precipitation, wind speed, air temperature and relative humidity. Although the latter was not expected to have an influence on the failure time, considering that the tests are carried out close to adiabatic (no heat transfer) conditions, it is a good indicator of the snow type, which in turn is believed to have a strong influence on the fluid failure time.

Limited data on the snow classifications developed in 1951 by the International Commission on Snow and Ice was collected during the test season. This data was not used for the analysis because the classifications shown in Appendix C were only obtained late in the test season, and for many of the tests the type of snow was mostly spatial dendrite or irregular crystal.

The parameters used in the regression analysis are fluid type, rate of precipitation, reported snow type by AES, wind speed and direction, temperature, and relative humidity. The snow type variable was discarded after preliminary analysis, since it showed that it is highly correlated with the rate of precipitation (see Figure 4.5). The fluid type and wind are represented by discrete variables assigned 0 or 1, as will be shown in subsequent sections.

The results of the regression analysis for the set of snow data is summarized in Table 5.1. Type II and III fluid data yielded higher R^2 values (0.81 to 0.96) than the Type I fluid data (0.48 to 0.81). This is believed to be caused primarily by the shorter failure time of Type I fluids, which results in a higher percentage observation error.

According to the equations in Table 5.1 :

a) The fluid failure time generally decreases with an increasing rate of precipitation in a logarithmic manner;

b) colder temperatures (where it appears as a parameter) result in lower failure times;

c) high and low winds cause lower failure times than moderate winds;

d) high relative humidity causes lower failure time;

e) cross-winds are not a factor except for the A-209 (Type II) fluid data set, where higher crosswinds result in faster failure times.

The multi-variable regression also served to determine the parameters to be used in the dimensional analysis, which was performed using the Type II fluid data. A useful equation was developed for A-199 (Type II) fluid and is further discussed in Section 5.1.1.2. The resulting relationship must be validated for all types of fluids under all forms of precipitation.

5.1.1.1 *Type I Fluids in Snow*

Figure 5.1 shows a plot of the fluid failure time versus the rate of precipitation for all the tests performed with Type I fluids. Despite the large scatter, due to a number of factors including instrument inaccuracies, human observation error, varying environmental conditions, and difference in fluids, the fluid failure time generally decreases with an increasing rate of precipitation, as one would expect. The current SAE holdover time range of 6 to 15 minutes (see Appendix B) for Type I fluids at any outside air temperature is also shown in Figure 5.1. The three failure times below the lower limit of 6 minutes were points obtained not only at the upper end of the rate of precipitation (above 35 g/dm^2/hr), but also at the lower end of the

TABLE 5.1

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR SNOW

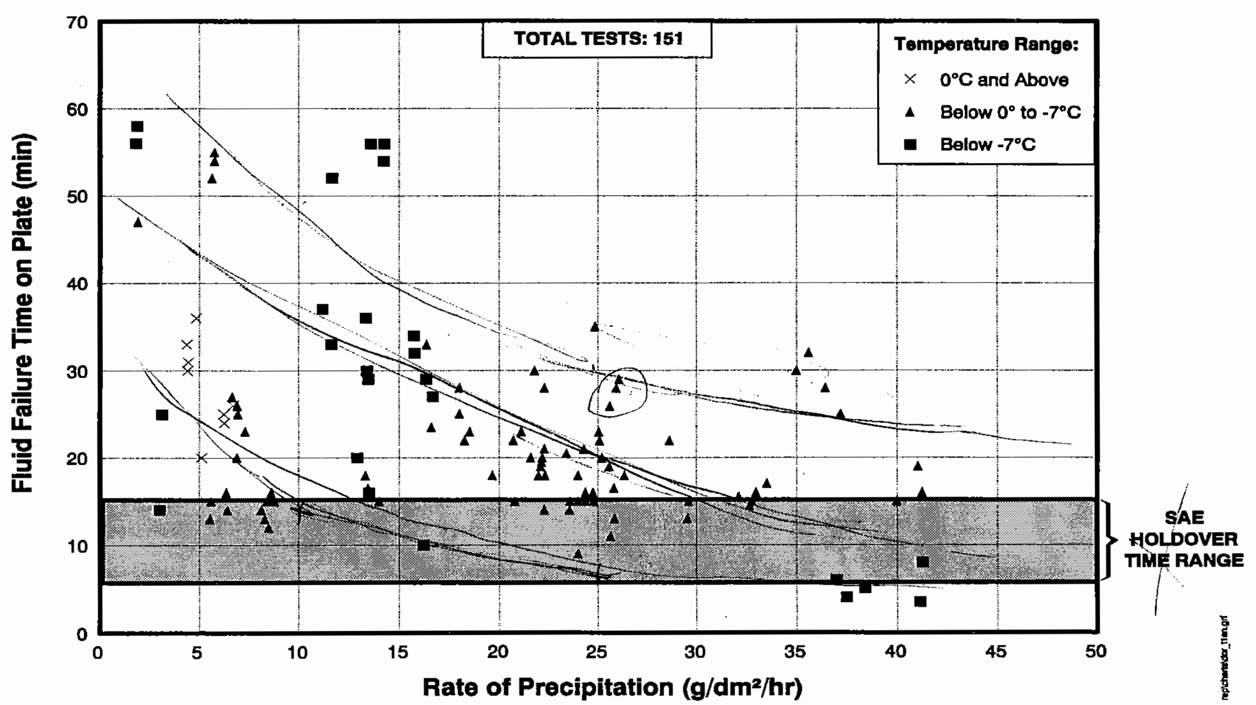
Fluid Type	No. of Tests	Equation	R^2	Std. Err.
All Type I	151	log fail = 1.29 + .0811 (B-204) + .0959 (B-213) + .219 low + .512 mod - .400 log rate	58%	0.135
Type I B-210	25	log fail = 1.5 + .335 mod - .456 log rate	49%	0.177
Type I B-204	45	log fail = 1.63 + .310 mod - .447 log rate	73%	0.102
Type I B-212	47	log fail = 2.92 + .0237 temp - .0177 rh + .251 mod - .310 log rate	48%	0.137
Type I B-213	34	log fail = 1.97 - .0141 rh + .344 low + .460 mod	81%	0.097
All Type II	95	log fail = 2.60 + .0536 (A-201) + .109 (A-209) + .0219 temp - .00655 rh + .125 mod - .408 log rate	85%	0.072
Type II A-199	27	log fail = 2.73 + .0232 temp - .00851 rh + .184 mod - .419 log rate	88%	0.078
Type II A-209	15	log fail = 5.02 + .0679 temp - .0383 rh - .0195 x_wind	82%	0.039
Type II A-205	25	log fail = 2.10 + .0125 temp + .117 mod - .440 log rate	81%	0.062
Type II A-201	14	log fail = 3.09 + .0232 temp - .00979 rh - .155 low - .445 log rate	96%	0.040
Type II A-208	14	log fail = 2.27 + .0212 temp + .194 mod - .583 log rate	84%	0.097
All Type III	30	log fail = 2.82 + .0274 temp - .0108 rh + .186 mod - .416 log rate	86%	0.093

fail = Failure Time (min)
rate = Rate of Precipitation (g/dm²/hr)
low = Low Wind Speed (0 to 15 kph) = 1, otherwise = 0
mod = Moderate Wind Speed (15 to 25 kph) = 1, otherwise = 0
temp = Air Temperature (°C)
rh = Relative Humidty (%)
x_wind Cross Wind (kph)

note: high wind speeds (above 25 kph) are represented by setting the values of "low" and "mod" to 0.

FIGURE 5.1

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



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temperature range (below -7°C). 102 out of the 151 failure times (68%) lie above the SAE upper limit of 15 minutes.

The same points are plotted in Figure 5.2 with a break-down in the direct wind speeds. It is interesting to note that the previously mentioned three points below the SAE range were also a result of high head winds, and can be considered to represent a worst case scenario. Although these tests were carried out under the heavy snow storm of March 13, 1993, they cannot be discarded, as Montreal International Airport in Dorval (where the testing was conducted) remained operational. In fact, some flights destined for U.S. cities on the east coast were redirected to Montreal. To further investigate the effect of the head wind on the fluid failure time, the best-fit curve is drawn for the moderate wind group. The low and high wind points fall below this line, which leads to the following hypothesis: After fluid application on the plate, which is at a 10° decline, gravity will cause the fluid to flow from the top to bottom, where some run-off occurs. In the absence of direct wind, the run-off rate due to gravity causes the film thickness at the 15 cm line (where failure is called) to be reduced, hence reducing the fluid failure time. As the wind speed increases, the rate of fluid loss decreases, helping the fluid maintain its thickness over the plate. Depending on the fluid properties, there is an "optimum" wind speed (perhaps corresponding to the "moderate" group) at which the shear forces induced on the fluid by the air velocity counterbalance the gravitational (potential) energy, resulting in minimum fluid loss. The losses from the sides due to the cross wind components are negligible. This is confirmed by the statistical analysis. During high winds, the fluid is at times pushed off the top of the plate resulting in thinning of the fluid and lower failure times. The failure mode under these conditions is unusual in that the fluid/precipitation mixture forms waves on the plate as shown in Photo 5.1.

FIGURE 5.2
EFFECT OF WIND AND RATE OF PRECIPITATION ON TYPE I FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

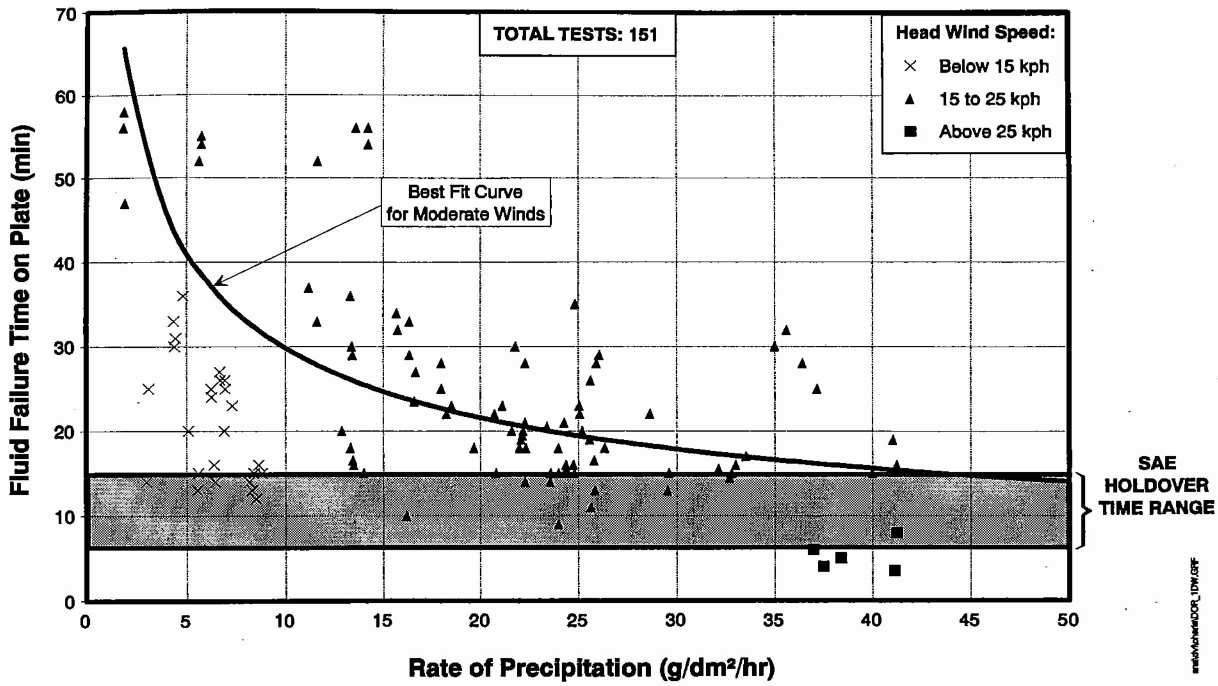

PHOTO 5.1
WAVE FORMATION ON FLAT PLATE

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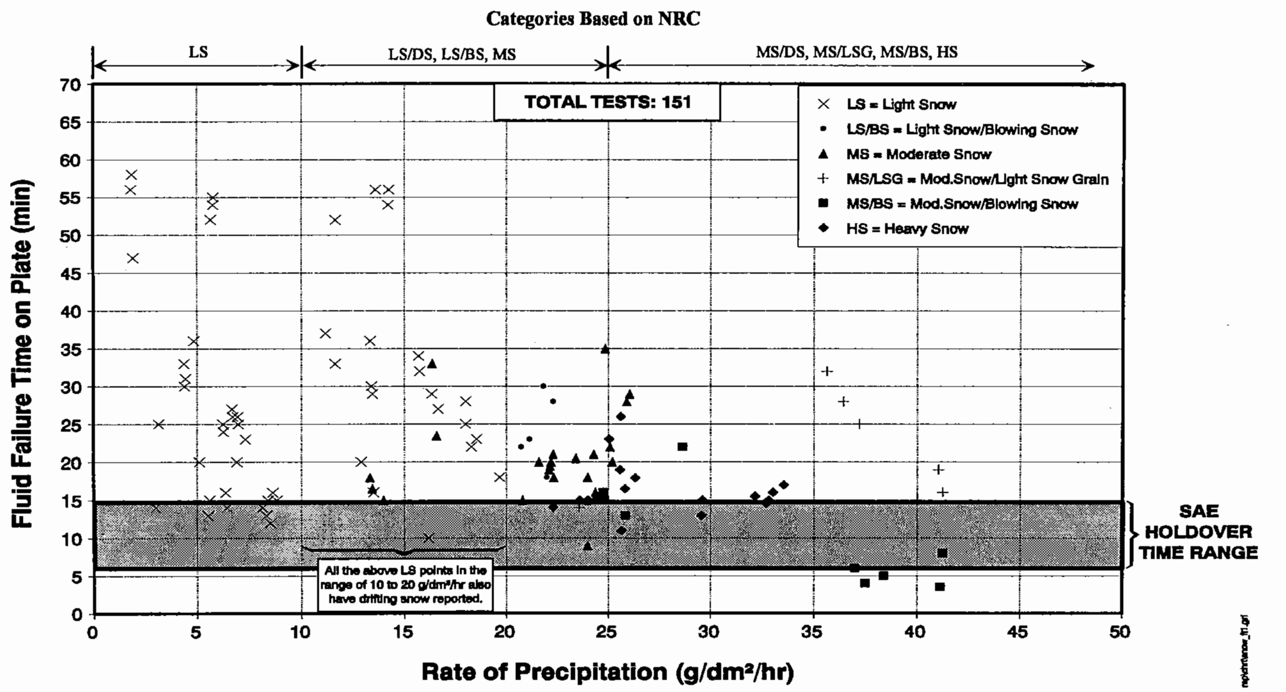
Figure 5.3 is a plot of fluid failure time versus the rate of precipitation with the points identified according to the meteorological reports at the time of the test according to Environment Canada. The correlation between the descriptive meteorological report and the rate of precipitation, introduced in Section 4.2.3, is marked on top of the graph of Figure 5.3. It is generally observed that points which lie outside their range have drifting snow associated with them. The current SAE limit for Type I fluids in snow (see Appendix B), which is marked on the graph, is reported as a range of 6 to 15 minutes (at any outside air temperature). Since this may lead to some uncertainty as to which value may be used by the pilot, it is proposed that a holdover time be reported for each of the three general snow groups defined in Section 4.2.3 (i.e. light, moderate and heavy). Using the substantial test data (151) obtained at Dorval during the 1992-1993 season, the Type I fluid holdover times under the light, moderate and heavy snow groups could be 12 minutes, 8 minutes and 3 minutes, respectively. Further research pertaining to the above discussion should be carried out. The multi-variable regression analysis (see Table 5.1) yielded interesting results despite the low R^2s. The general equation for Type I fluids not only model the effects of wind and rate of precipitation correctly but also distinguishes between the various fluids, except for Type I fluids B-210 and B-212, which are considered to behave in the same manner.

FIGURE 5.3

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



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5.1.1.2 *Type II Fluids in Snow*

The plot of fluid failure time versus rate of precipitation for Type II fluids (Figure 5.4) shows a more pronounced effect of rate of precipitation on failure time. The SAE holdover time, which is between 20 and 45 minutes (see Appendix B) for an outside air temperature below 0°C, is also shown on the graph. The SAE limit for temperatures of 0°C and above ranges from 25 to 90 minutes. Only three data points were obtained, under this condition, and the failure times range between 52 and 56 minutes, as shown in Figure 5.4. For temperatures below 0°C, 36 points out of 92 (39%) fall above the SAE upper limit of 45 minutes.

The eight failure times (8%) below the SAE lower limit of 20 minutes occurred during the heavy snow storm of March 13, 1993 when the air temperature was below -7°C and the rate of precipitation was above 34 g/dm^2/hr. Figure 5.5 identifies these points to be in the high wind category as well; hence they can be considered to represent a worst-case scenario. A best-fit for the moderate wind group is drawn in order to verify the hypothesis presented in Section 5.1.1.1 to account for the effect of head wind. While the low and moderate wind points generally lie along the same curve, the high wind group of points are all below it. The low wind phenomena described in Section 5.1.1.1 for Type I fluids is not predominant for Type II, probably because the latter has a higher viscosity and "adheres" better to the plate. Nevertheless, the same fluid/precipitation separation (see Photo 5.1) is observed in the Type II tests during windy conditions.

Figure 5.6 shows a plot of fluid failure time versus the rate of precipitation with the three general snow intensity groups introduced in Section 4.2.3 marked on the top of the graph. It is generally observed that points which lie outside their range have drifting snow associated with them. As in the case of Type I

FIGURE 5.4

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

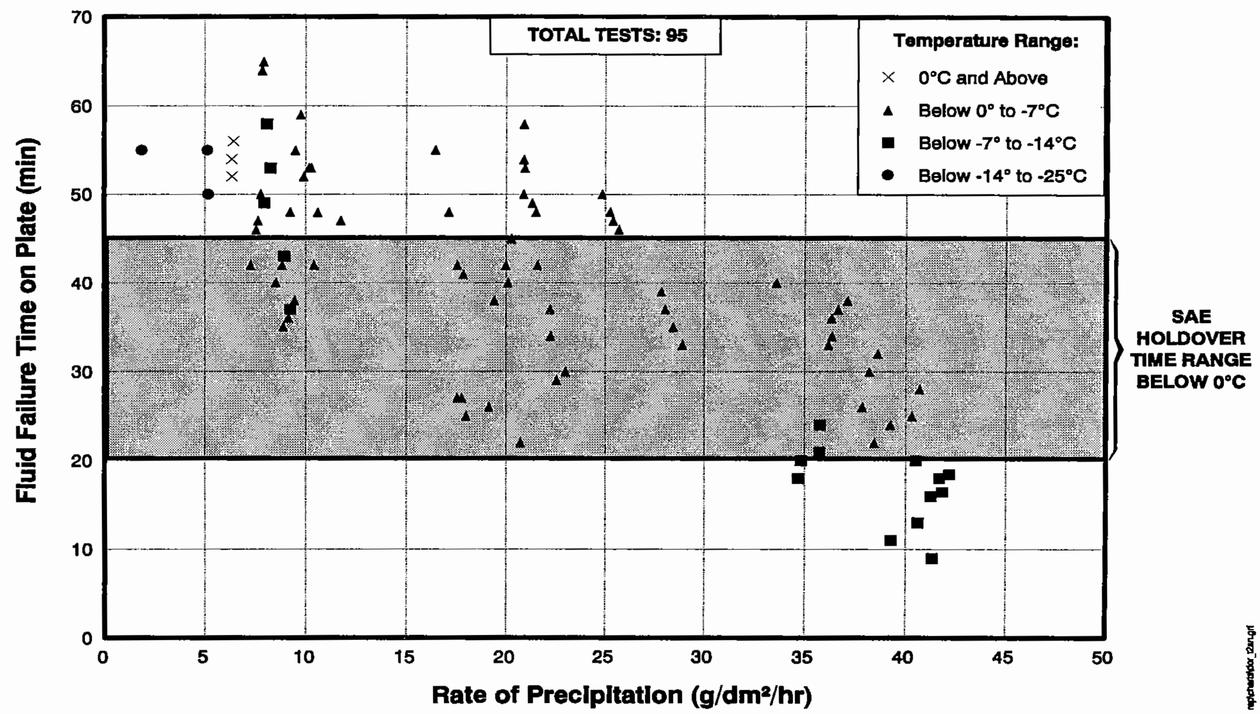


FIGURE 5.5

EFFECT OF WIND AND RATE OF PRECIPITATION ON TYPE II FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS

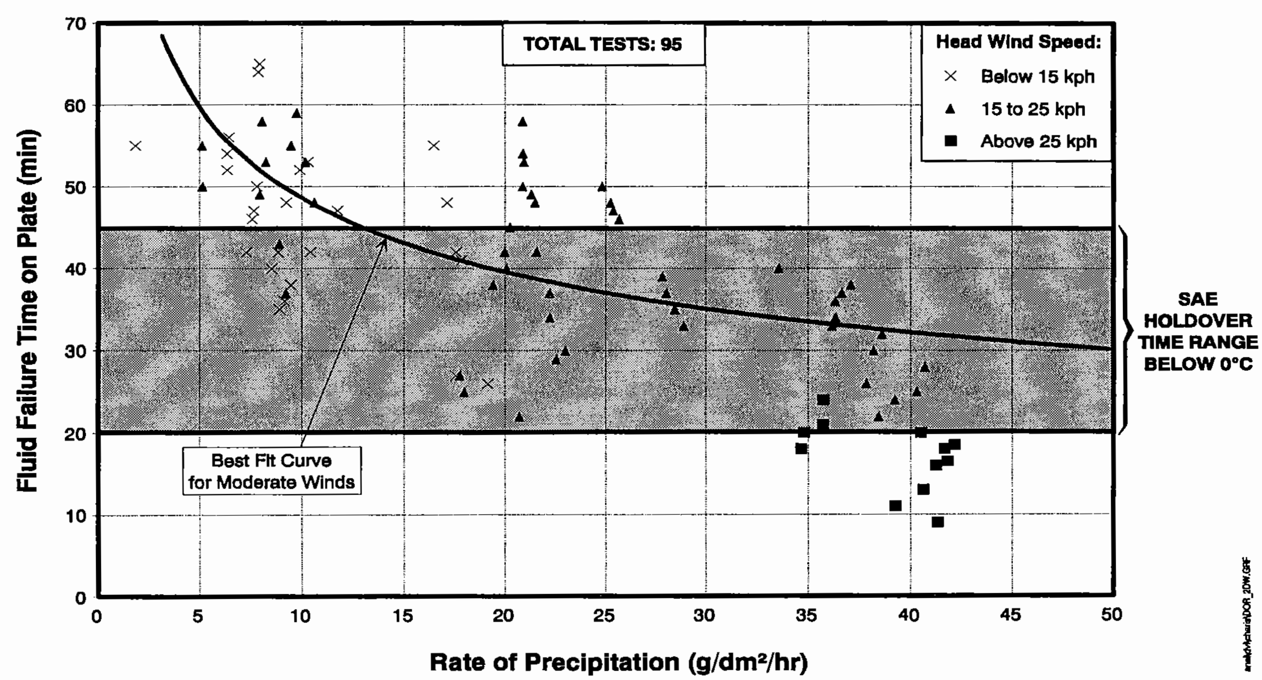
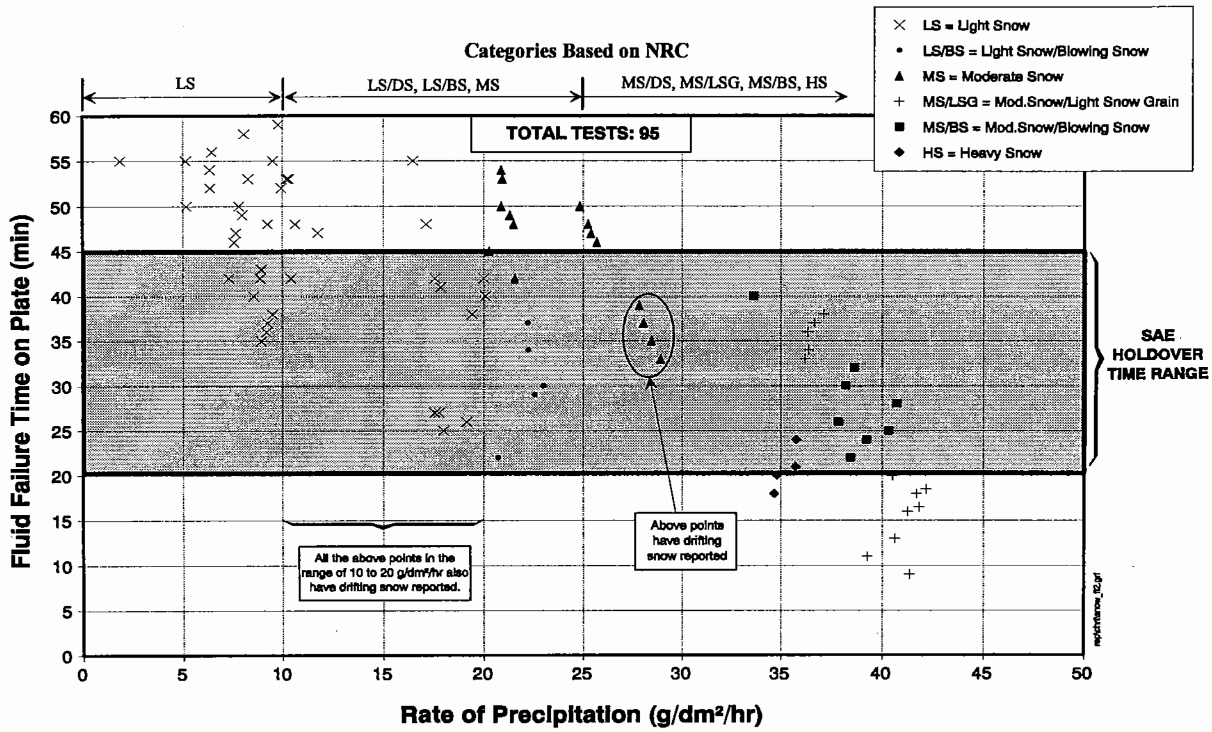


FIGURE 5.6

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



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fluid, one can report a single holdover time per group to allow the pilot to determine a holdover time with more confidence. From the data set obtained from 95 tests at Dorval, the holdover times which may be employed as guidelines are: 35 minutes for light snow group, 20 minutes for moderate snow group and 9 minutes for heavy snow group.

The multi-variable regression on the Type II data (see Table 5.1) resulted in higher R^2 values (0.85 for the general equation) than those for the Type I data. Figure 5.7 shows a plot of observed fluid failure time versus the time predicted by this equation using the actual data set. Although the Type II A-201 equation resulted in a high R^2 of 0.96, the data set contained only 14 test points.

A dimensional analysis based on known physical phenomena was performed for Fluid A-199 (Type II) during snow conditions and is presented in Section 5.4.

5.1.1.3 *Type III Fluids in Snow*

The plot of failure time versus rate of precipitation for the Type III fluids (Figures 5.8 and 5.9) shows tendencies consistent with the Type I and II results. That is, high rate of precipitation and low temperatures tend to lower the failure time; and the wind effect described in Section 5.1.1.1 also applies to the Type III fluid tests. Figure 5.9 also shows that the low wind data is generally in agreement with the calm wind curve established in Report TP 11454E, prepared for the 1991-1992 test season. No SAE holdover time range is available for Type III fluids at the time of publication of this report. The limits shown in Figures 5.8 and 5.9 are those for the current Type I and II fluids and are

FIGURE 5.7

OBSERVED FLUID FAILURE TIME vs PREDICTED FLUID FAILURE TIME

TYPE II FLUID IN SNOW CONDITIONS

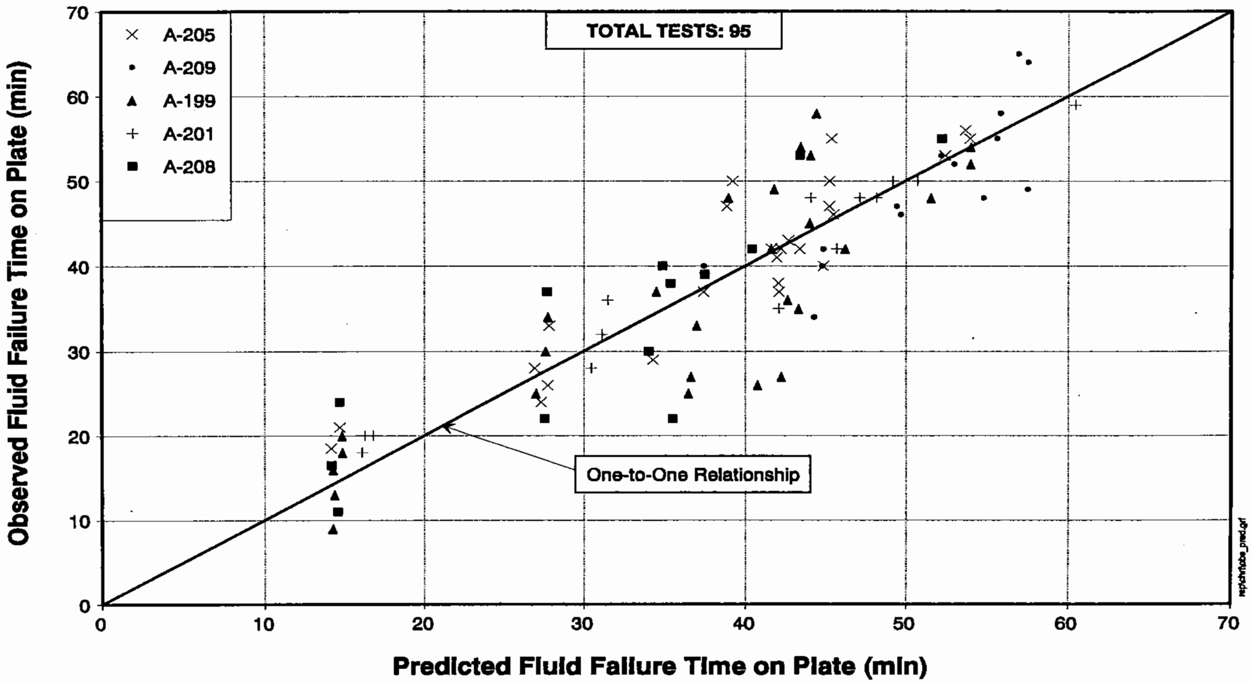


FIGURE 5.8

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

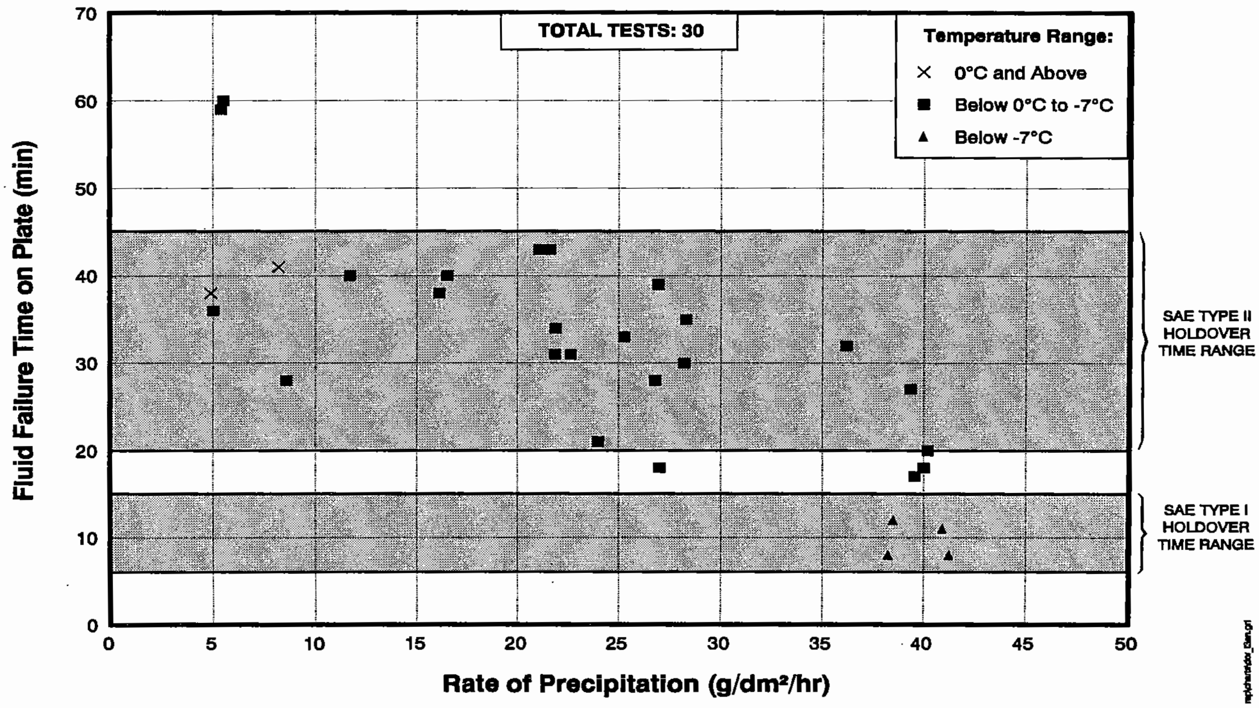
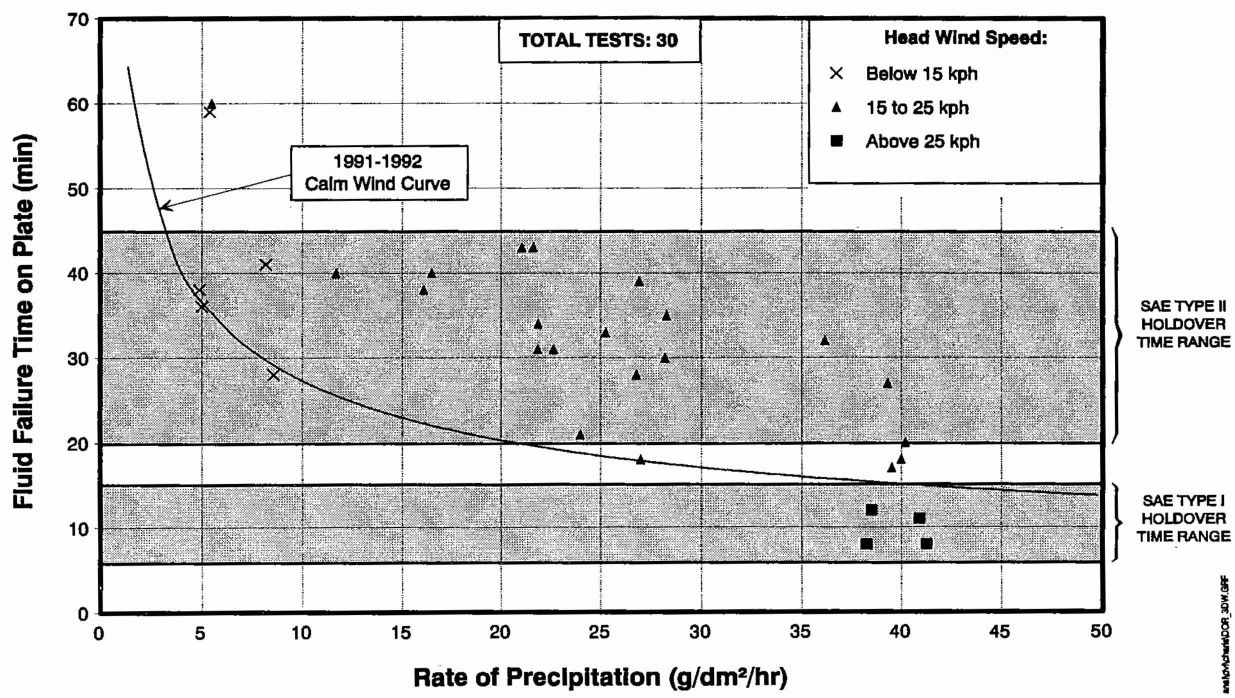


FIGURE 5.9

EFFECT OF WIND AND RATE OF PRECIPITATION ON TYPE III FLUID FAILURE TIME IN NATURAL SNOW CONDITIONS



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for reference purposes only. The data and results from the 1991-1992 test season (Type III tests) should be reviewed and combined with this year's testing, if holdover time tables are to be derived.

Figure 5.10 is a plot of fluid failure time versus rate of precipitation with the test points identified according to the meteorological report obtained at the time of the test. The three general categories discussed in Section 4.2.3 are marked on top of the graph. It is generally observed that the points which lie outside their range have drifting snow associated with them.

The statistical analysis of the Type III data set (see Table 5.1) yielded an equation (of 0.86 R^2) with temperature, relative humidity, wind speed and rate of precipitation represented correctly with respect to the expected tendencies discussed for the Type I and II fluids.

A more detailed report entitled "Comparison of Holdover Time Effectiveness of Type III Fluids - Shielded vs Unshielded Precipitation Gauge" is contained in Appendix G. This study contains the revised analysis of Type III tests contained in a previous report TP 11454E.

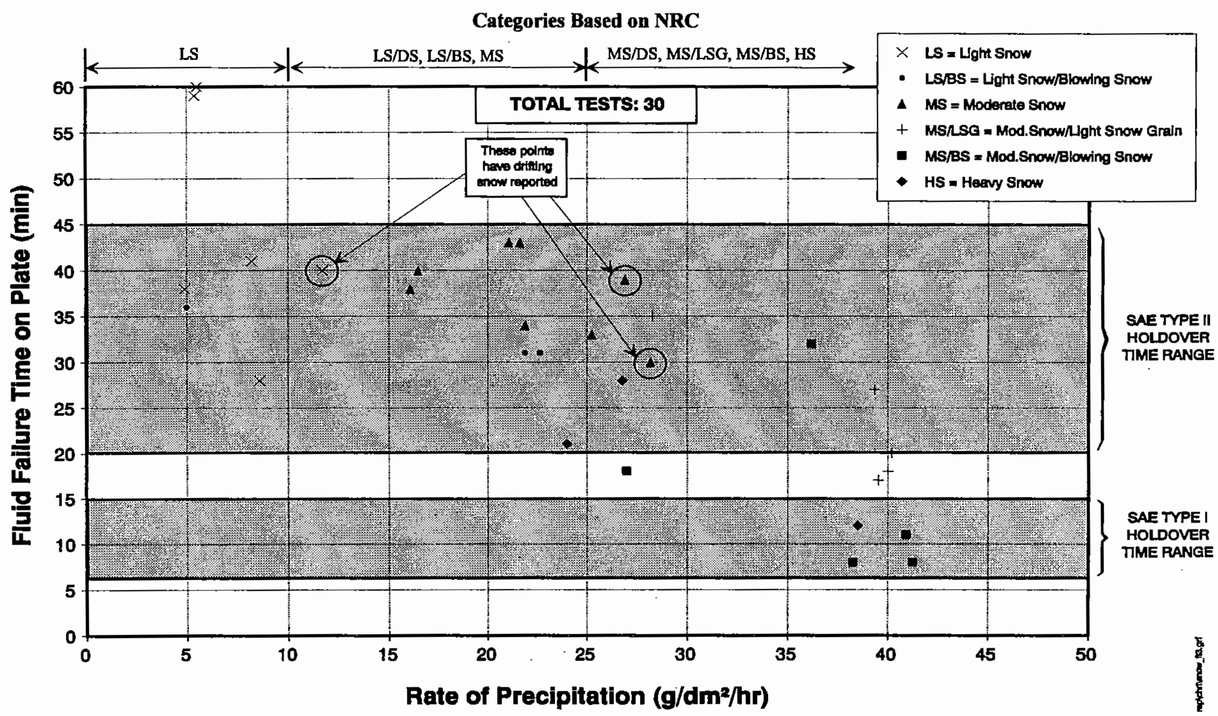
5.1.2 Artificial Snow Conditions

The primary objective of these tests was to determine whether artificial snow could be used to simulate natural snowfall for the purpose of fluid testing. The advantages of artificial snow testing are:

a) Artificial snow is readily producible. This is especially desirable during mild weather when natural snowfall occurrence may be lacking;

FIGURE 5.10

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



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b) The rate of precipitation can be controlled by varying the direction of the snow guns;
c) Testing can be planned in advance.

The disadvantages of artificial snow testing are:

a) The set-up time is long since the test is a temporary one;
b) Windy conditions cannot be simulated;
c) It is difficult to obtain low enough rates of precipitation to simulate natural conditions;
d) The snow type produced may not represent that found in natural conditions.

Despite the disadvantages listed above, the artificial snow tests yielded some interesting results. Figure 5.11 shows a plot of fluid failure time versus rate of precipitation for Type I fluids in artificial snow. The natural snow test points, which were previously discussed, are shown on the same graph. Two general conclusions can be drawn from this graph. The first is that the rates of precipitation resulting from the artificial snow tests are much higher (up to 3.5 times) than those recorded under natural precipitation. The second observation is that the fluid failure time of combined (artificial/natural snow) data generally follows a logarithmic trend with the rate of precipitation. Similar graphs are plotted for Type II and III in Figures 5.12 and 5.13 respectively, and the same conclusion can be drawn.

In light of these results, despite the difference between natural and artificial snow crystals, the precipitation onto the fluid covered test plates seems to result in the same effect on the fluid failure time. Future testing is necessary to verify this general observation, in particular at the lower rates of precipitation, if these conditions can be obtained with different nozzles.

FIGURE 5.11

COMPARISON OF TYPE I FLUID FAILURE TIME IN ARTIFICIAL AND NATURAL SNOW CONDITIONS

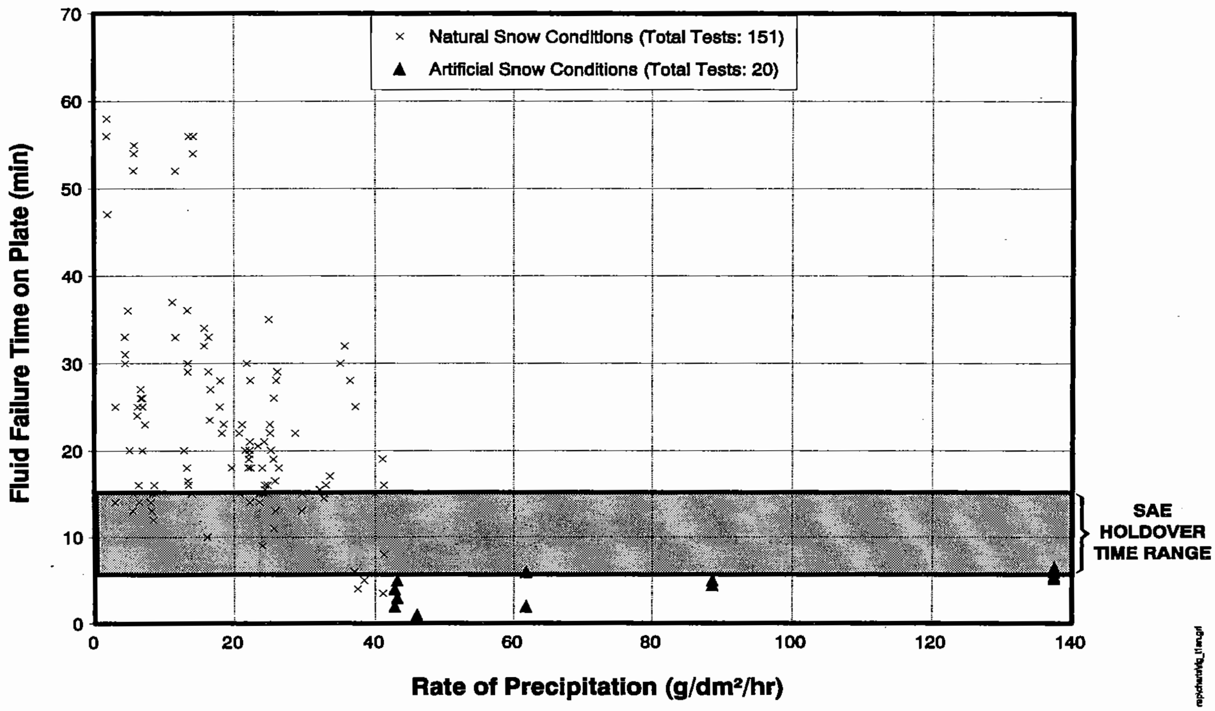

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FIGURE 5.12

COMPARISON OF TYPE II FLUID FAILURE TIME IN ARTIFICIAL AND NATURAL SNOW CONDITIONS

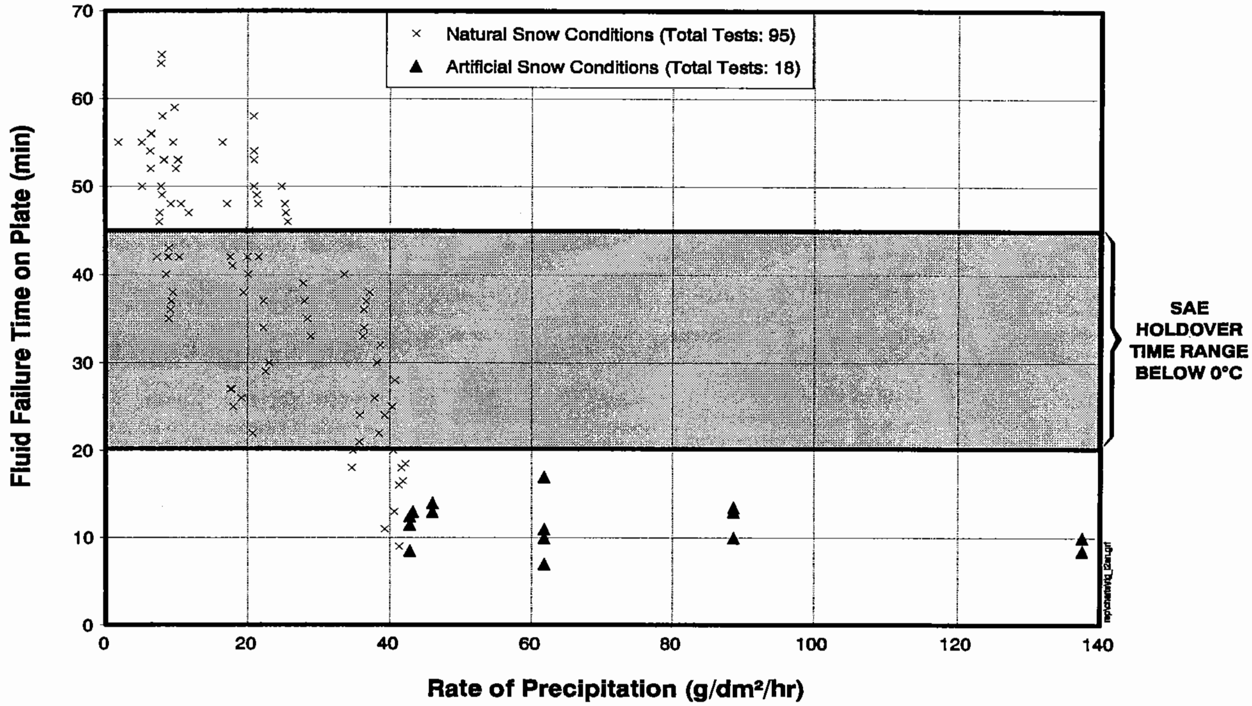
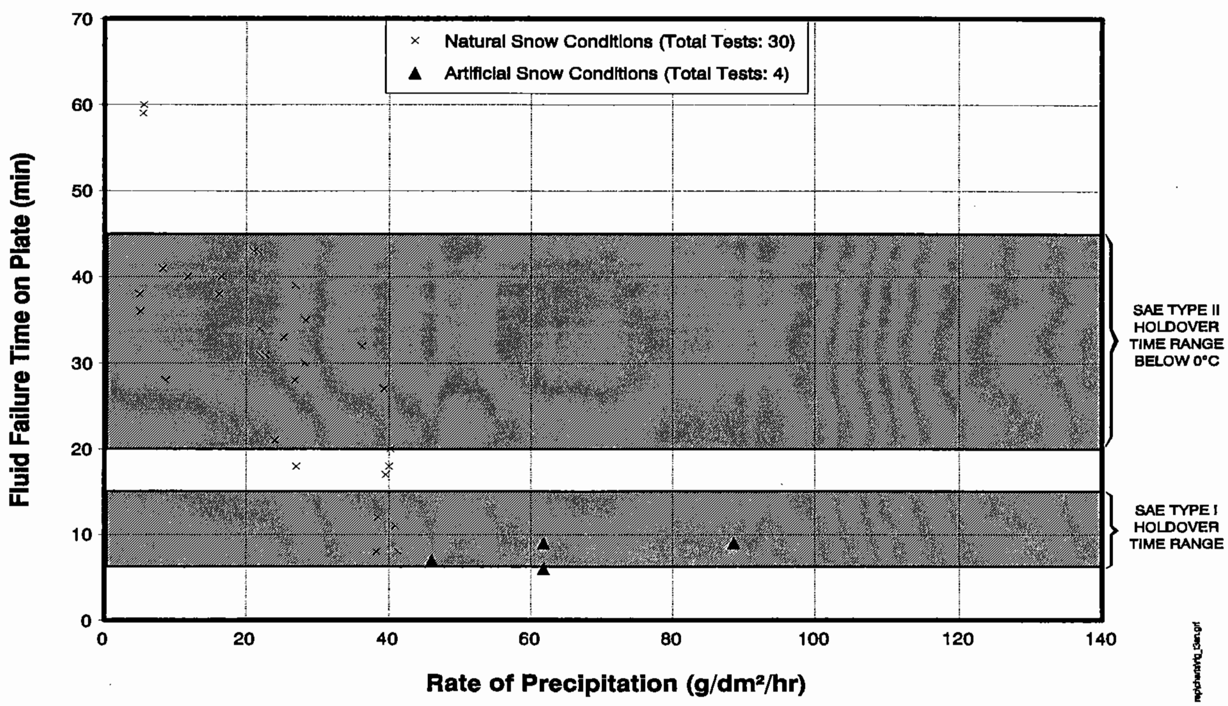


FIGURE 5.13

COMPARISON OF TYPE III FLUID FAILURE TIME IN ARTIFICIAL AND NATURAL SNOW CONDITIONS



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5.1.3 Freezing Drizzle Conditions

In general, for a given fluid, failure times under the simulated freezing drizzle conditions are governed by the rate of precipitation and air temperature. The effects of wind and relative humidity are not considered because their range was not significant enough to perform any form of analysis. In any case, during natural conditions, these two parameters are not expected to have a great effect on the fluid failure time. The rate of precipitation set in the cold chamber, described in Section 3.2, ranged from 10 to 47 $g/dm^2/hr$ and is classified as a heavy drizzle according to the MANOBS document; hence the data is conservative when determining the fluid protection time. Some drizzle data obtained under natural conditions will confirm that typical rates of precipitation in natural conditions are at the lower end of the test range, or lower in most instances.

A summary of the results of the statistical analysis on the freezing drizzle data is listed in Table 5.2. The equation reported for each data set indicates that fluid failure time generally varies with the rate of precipitation in a log-log relationship, which is in agreement with relationships developed for laboratory experiments carried at UQAC. The low R^2 (0.456 to 0.670) indicates that only weak relationships exist between the failure time and the most relevant parameters over the test ranges.

It is believed that the low R^2 can be attributed to the fact that the test range of the rate of precipitation lay in a domain where its influence on the fluid failure time is minimal. Nevertheless, the correlation equations are presented in order to demonstrate the relevant parameters and their influence on the fluid failure time. The statistical analysis shows that the relevant parameters are the rate of precipitation, the temperature and the failure mode. The latter is a qualitative parameter (see Section 3.2.4)

TABLE 5.2

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR FREEZING DRIZZLE

Fluid Type	No. of Tests	Equation	R^2	Std. Err.
All Type I	121	log fail = 1.58 - 0.183 fail_md + 0.0819 temp - 0.325 log rate	51%	0.099
Type I B-212	36	log fail = 1.35 + 0.0446 temp - 0.397 log rate	58%	0.103
Type I B-204	42	log fail = 1.51 - 0.224 fail_md + 0.0891 temp - 0.223 log rate	44%	0.097
Type I B-213	41	log fail = 1.77 - 0.233 fail_md + 0.0912 temp - 0.401 log rate	55%	0.100
All Type II	87	log fail = 1.76 + 0.0449 (A-209) - 0.130 (A-199) - 0.0566 fail_ md - 0.266 log rate	67%	0.060
Type II A-199	34	log fail = 1.58 - 0.0507 fail_md - 0.236 log rate	46%	0.056
Type II A-205	36	log fail = 1.78 - 0.0688 fail_md - 0.279 log rate	55%	0.059
Type II A-209	15	log fail = 3.14 - 0.501 fail_md + 0.158 temp - 0.463 log rate	57%	0.063
All Type III	62	log fail = 1.55 - 0.0428 fail_md - 0.325 log rate	46%	0.069

fail_md Fail Mode is 0 when (0° to -5°C), or 1 when (< -5°C)
fail = Failure Time (min)
rate = Rate of Precipitation ($g/dm^2/hr$)
low = Low Wind Speed (0 to 15 kph) = 1, otherwise = 0
mod = Moderate Wind Speed (15 to 25 kph) = 1, otherwise = 0
temp = Air Temperature (°C)
rh = Relative Humidty (%)

note: high wind speeds (above 25 kph) are represented by setting the values of "low" and "mod" to 0.

based on observations that at temperatures in the -5°C to -2°C temperature range, the failure is defined as "glossy ice sheet", and at temperatures ranging from -7°C to -9°C, "rime-ice" formed at failure. The "fail_md" variable is assigned 0 for "glossy ice sheet" and 1 for "rime-ice".

5.1.3.1 *Type I Fluids in Freezing Drizzle*

The plot of failure time versus rate of precipitation in Figure 5.14 shows that the rate of precipitation has a slight effect on the failure time over the test range of 10 to 47 g/dm^2/hr. A similar plot as a function of fluid type (not shown here) did not disclose significant variations between each of the fluids, and this conclusion is supported by the statistical analysis. Figure 5.14 shows that not only do all points lie above the SAE lower limit of 1 minute at an outside air temperature of below 0°C according to Appendix B, but that 90% of the points lie either on or above the SAE upper limit of three minutes. All of the data points below 30 g/dm^2/hr are on or above the three minute SAE limit. The SAE limits for temperatures of 0°C and above, of two to five minutes, cannot be confirmed since no tests were conducted under this condition. It is generally believed that this occurrence is not only rare, but also difficult to simulate. Another observation is that the temperature tends to lower the failure time as one would expect. This observation is supported by the statistical analysis shown in Table 5.2 for Type I fluids, and similar patterns exist for the individual fluids.

5.1.3.2 *Type II Fluids in Freezing Drizzle*

Figure 5.15 shows that the rate of precipitation has only a slight effect on the Type II fluid failure times over the test range of 10 to 47 g/dm^2/hr. While fluids A-208 and A-205 have similar failure times on average, fluid A-199 is consistently below the

FIGURE 5.14

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

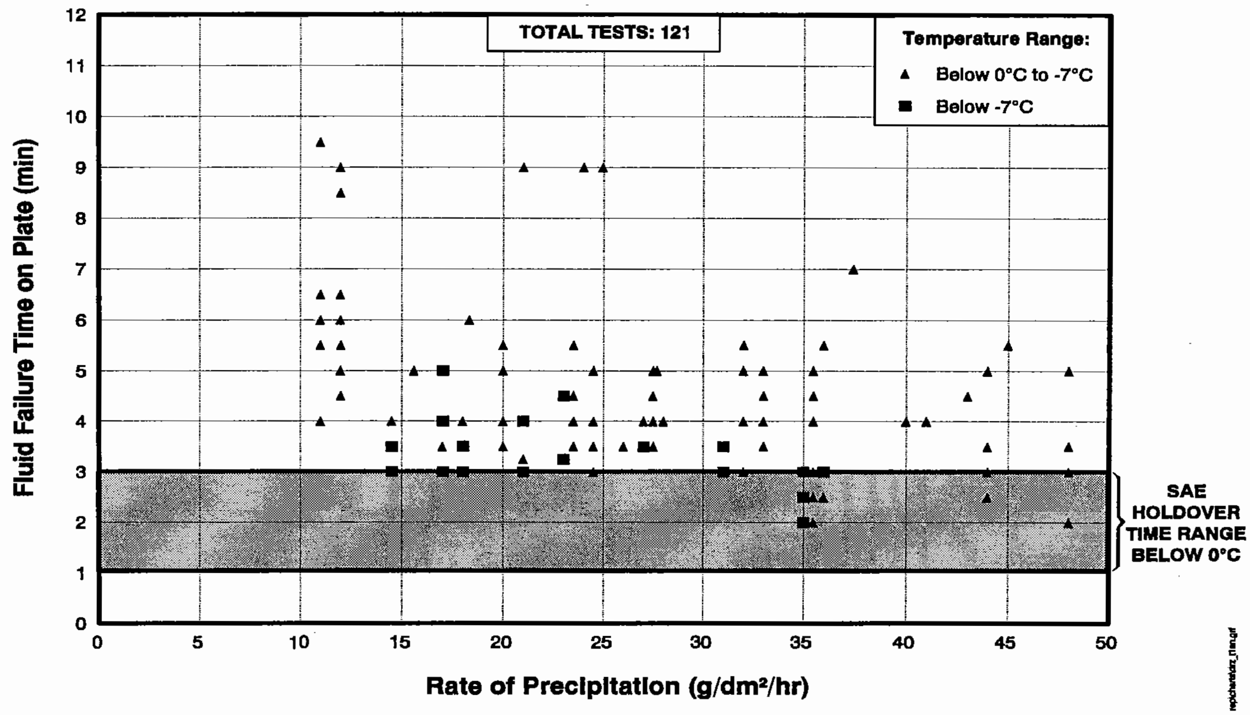
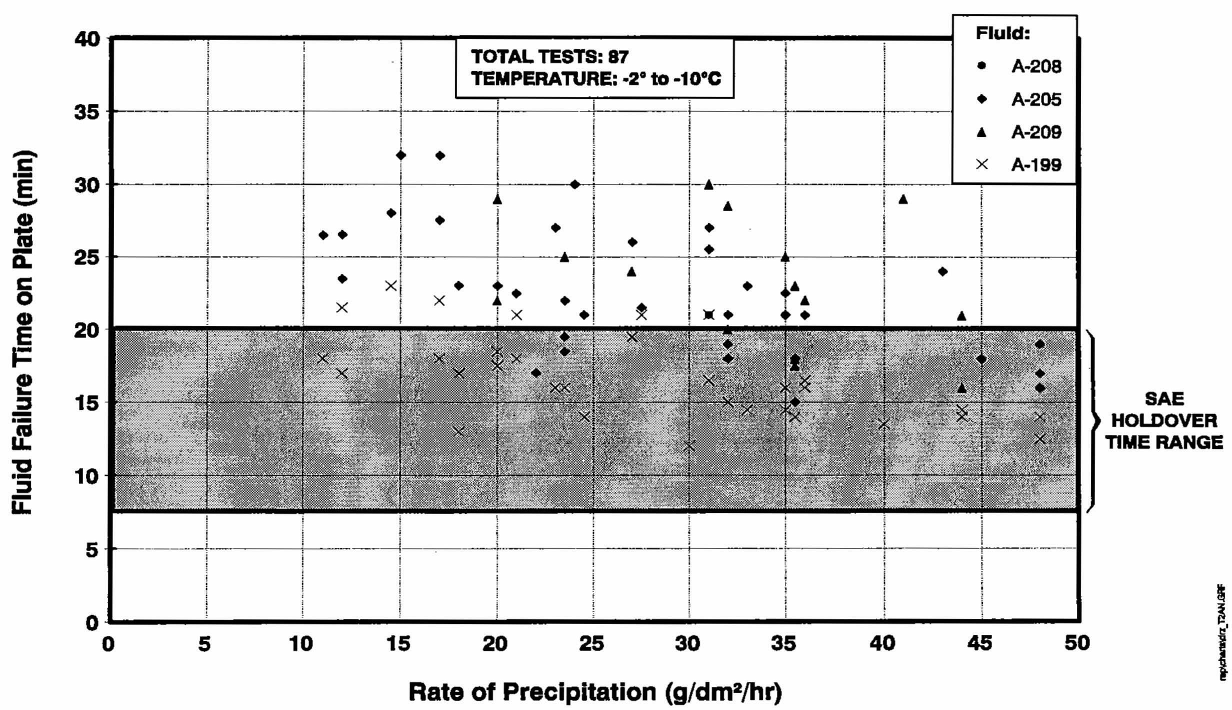


FIGURE 5.15

TYPE II FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS



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other fluids. Over the test range, fluid A-209 appears to have higher failure times than the other fluids, and this is confirmed by the statistical analysis. Nevertheless, all points fall above the SAE lower limit marked on the chart; however, only 50% of the points fall above the upper limit of 20 minutes. Natural drizzle test points obtained in the 1990-1991 winter season are superimposed on this year's (1992-1993) results in Figure 5.16 to allow comparison of the two results. It can be seen that the rate of precipitation and the temperature in the simulated conditions are more severe than the natural ones; hence, this year's data is conservative for holdover times.

The statistical analysis presented in Table 5.2 shows that all the Type II relationships are best represented by a log-log relationship between failure time and rate of precipitation. Failure mode (i.e. temperature) was also present in all equations; however, its effect (high failure times at colder temperatures) is not as expected. It appeared that at warmer temperatures, the mixing of the precipitation into the fluid was slower, which lead to a layer of thin ice on top of the fluid.

The statistical analysis also showed that when the natural drizzle points from 1990-1991 were added to this year's data, the coefficient of determination improved from 0.67 to 0.79 for fluid A-199. Shown in Figure 5.17 is a plot of the combined natural/simulated fluid A-199 test points with its corresponding best fit curve. Although studies at UQAC suggest that the laboratory water spray endurance conditions are representative of natural freezing conditions, Figure 5.17 shows that the water spray endurance curve is below that of the combined simulated/natural freezing drizzle best-fit line over most of the test range. Over this year's test range of 10 to 47 g/dm^2/hr, the difference is in the order of seven minutes. One possible explanation for this time lag is that the failure times in laboratory

FIGURE 5.16

COMPARISON OF TYPE II FLUID FAILURE TIME IN NATURAL AND SIMULATED FREEZING DRIZZLE CONDITIONS

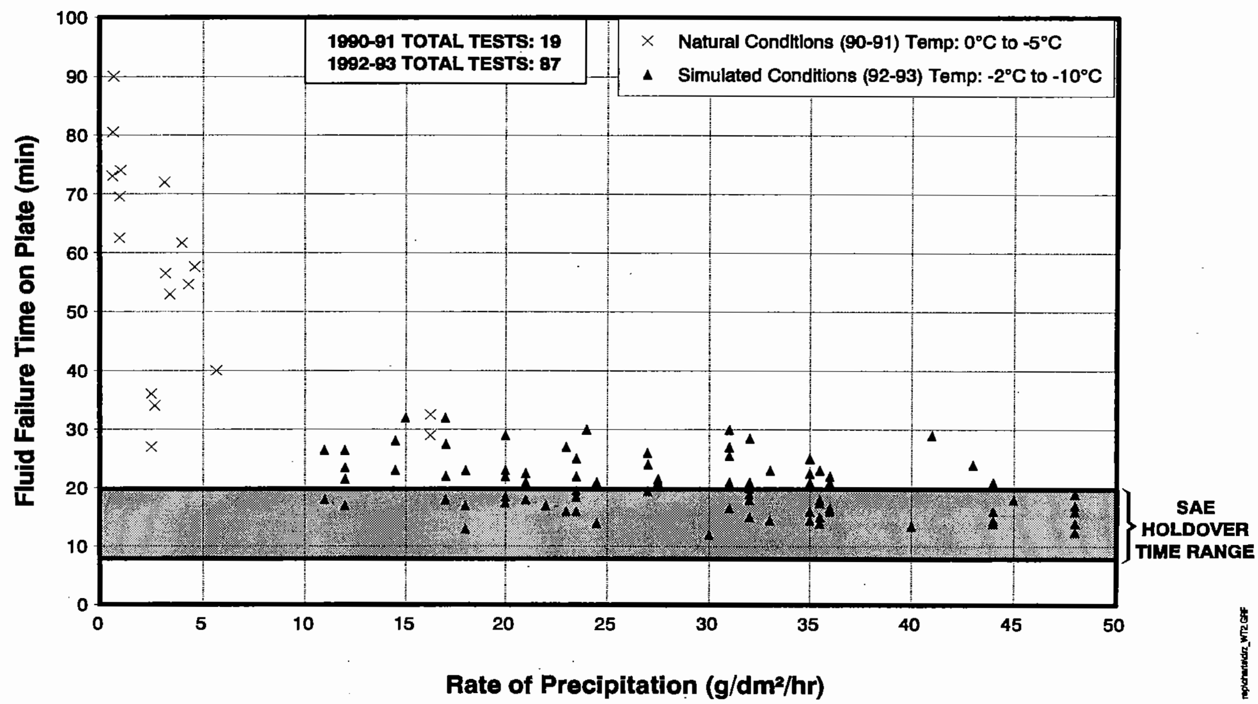
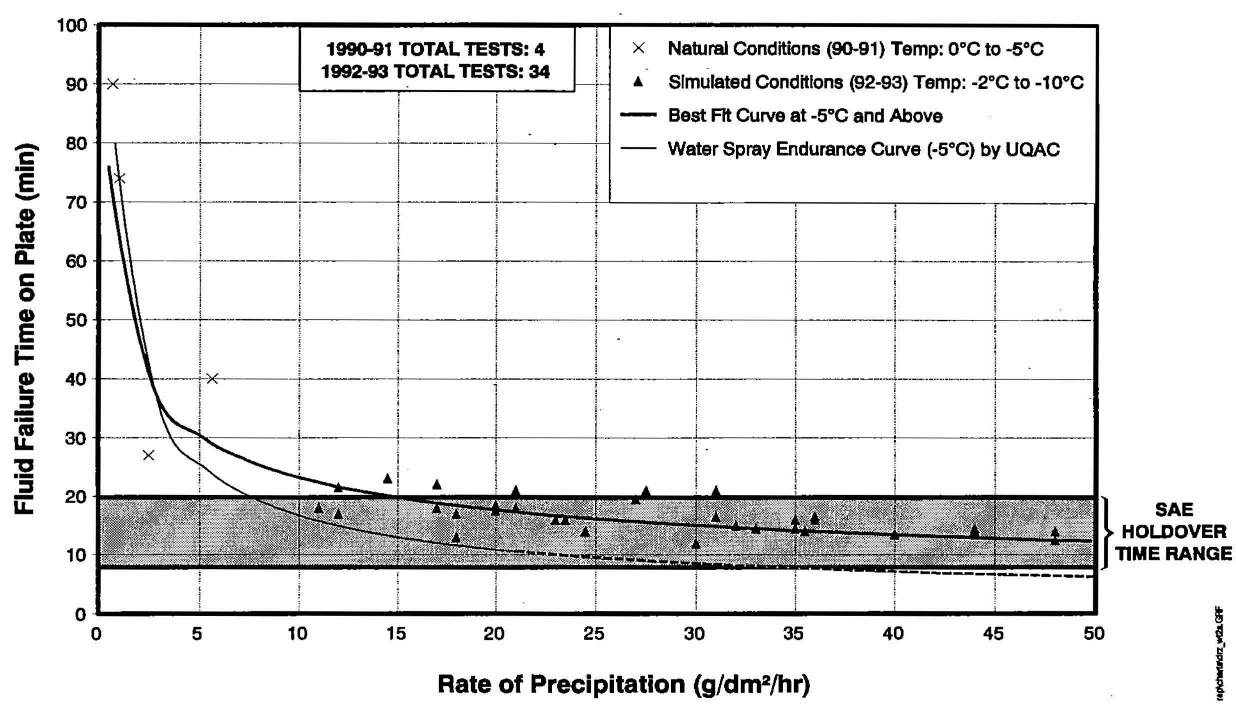


FIGURE 5.17

COMPARISON OF FLUID A-199 FAILURE TIME IN NATURAL AND SIMULATED FREEZING DRIZZLE CONDITIONS



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tests are reported at 2.5 cm (1") from the top of the plate and in simulated/natural tests they are reported at 15 cm (6"). Furthermore, the test plate size is slightly different. The diluted Type II fluid results are presented with some reservations as the mixing procedure was not closely controlled due to the lack of appropriate test equipment and appropriate water. Diluted fluids were only tested at the end of the test period and as a result only 16 data points for each dilution were obtained. Diluted Type II (75/25) fluid test results are shown in Figure 5.18. Failure times varied from 6 to 26 minutes whilst the SAE limit, according to Appendix B, ranges from four to ten minutes. Therefore, all test points fall above the lower limit and seven of the sixteen (44%) fall above the upper limit. The diluted Type II (50/50) fluid test failure times shown in Figure 5.19 ranged from 2.5 to 17 minutes. The SAE limit for this type of fluid and temperatures below 0°C varies from one to three minutes. The SAE limit of two to five minutes for temperatures of 0°C and above was not verified by the simulated freezing drizzle tests. All of the test points fall above the SAE lower limit, and 15 of the 16 points (94%) fall above the upper limit. More tests must be conducted to verify the results of both the diluted Type II 50/50 and 72/25 fluid concentrations.

5.1.3.3 *Type III Fluids in Freezing Drizzle*

In Figure 5.20, the Type III fluid (A-200) failure times are plotted against the rate of precipitation. Also shown on the chart are the SAE limits for Type I and Type II fluids. It is interesting to note that all the test points lie above the Type I upper limit of three minutes and only one point falls below the Type II lower limit. The two points obtained under natural outdoor tests performed in the 1990-1991 season are shown on the same chart. The statistical analysis showed that the natural outdoor tests increase

FIGURE 5.18

TYPE II 75/25 DILUTED FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS

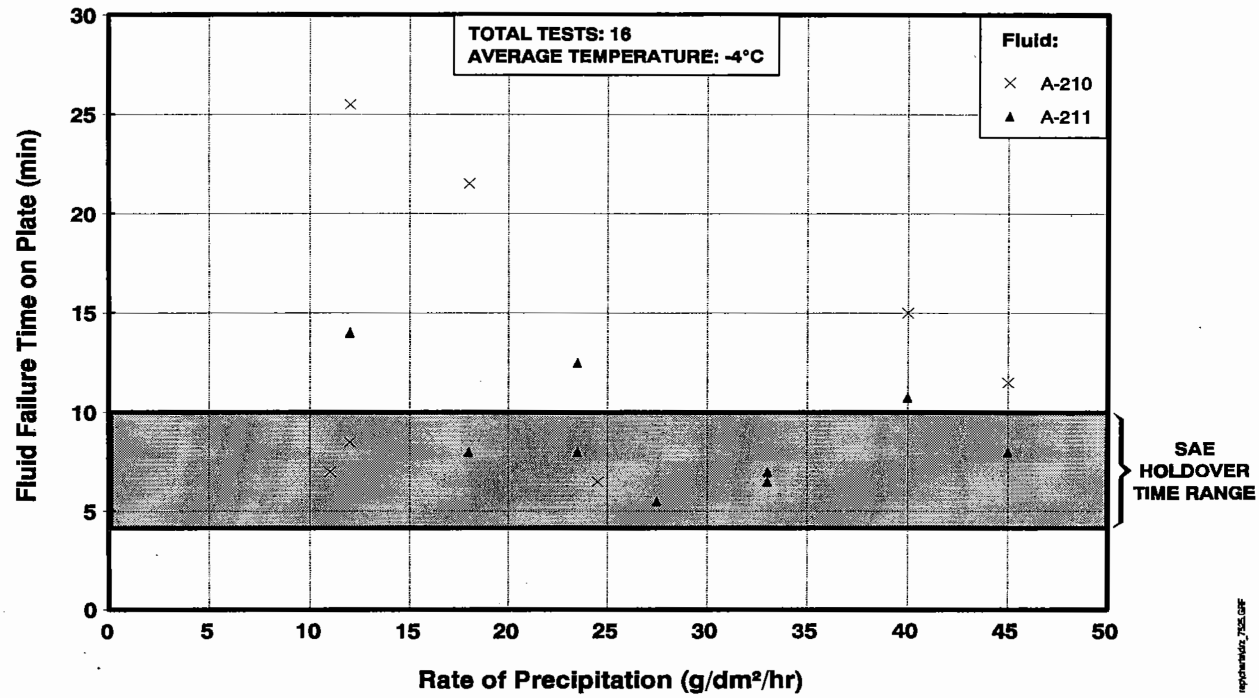

FIGURE 5.19

TYPE II 50/50 DILUTED FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS

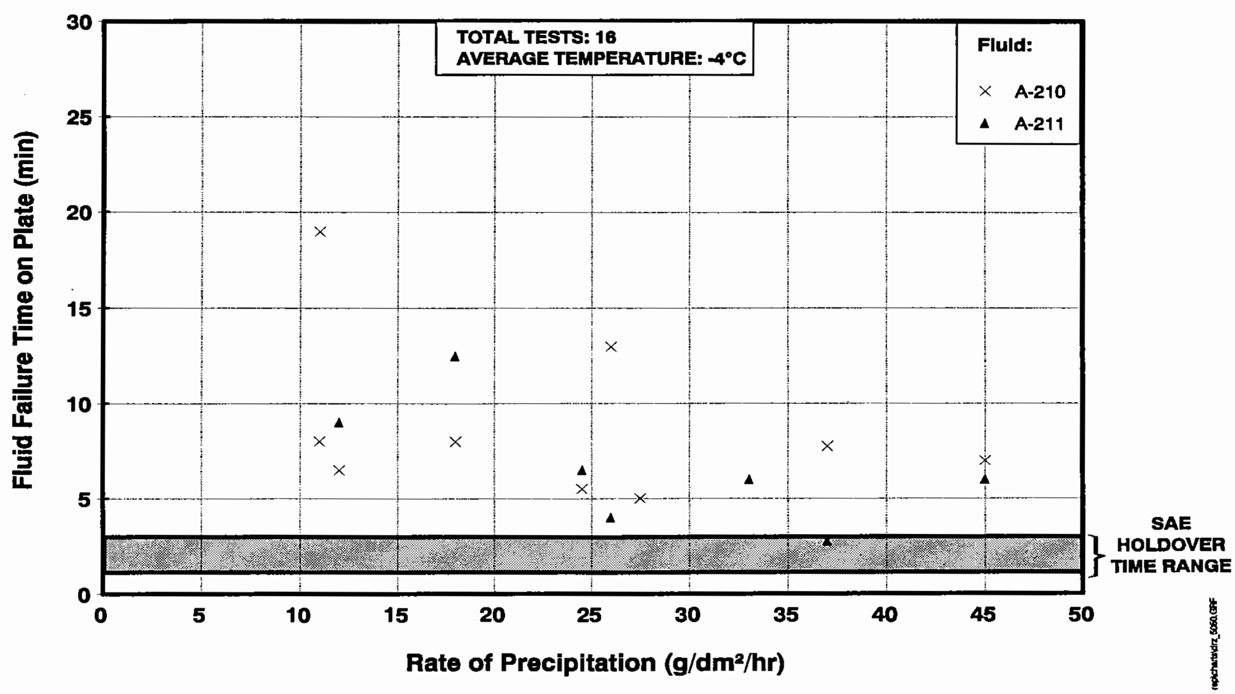

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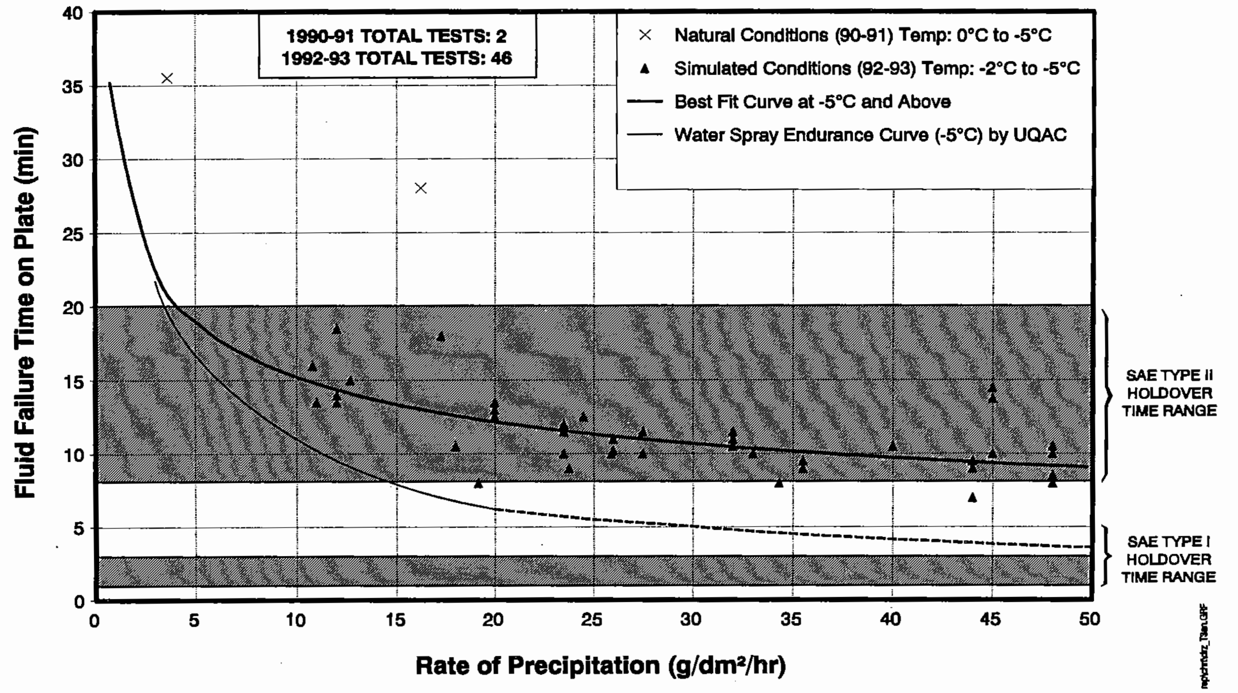
FIGURE 5.20

COMPARISON OF TYPE III FLUID FAILURE TIME IN SIMULATED FREEZING DRIZZLE CONDITIONS



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the coefficient of determination (R^2) from 0.46 to 0.54. As in the case of Type II fluids, the laboratory water spray endurance curve for Type III fluid is lower (by approximately six minutes) than the best-fit curve for the combined simulated/natural freezing drizzle tests. This is also most likely attributed to the difference in plate size and the location of the reported fluid failure as mentioned in Section 5.1.3.2.

5.1.4 Freezing Fog Conditions

Given a fluid type, the main parameter affecting the failure time in freezing fog tests at the NRC, is the rate of precipitation. Although the fog generated at the test site ranges from 1.8 to 9.9 g/dm²/hr, freezing fog in natural conditions typically results in precipitation in the lower end of this range. Tests were performed over a wide temperature range (-5°C to -14°C), but the multi-variable regression analysis (see results in Table 5.3) shows that temperature has an insignificant effect on the fluid failure time in the freezing fog conditions. Because the range of the wind speed and the relative humidity during the tests was small (which is the case in natural freezing fog conditions), these two parameters do not appear in the final equation. A useful correlation was obtained for a Type I fluid, but there was insufficient data for the Type II and III fluids to develop any relationship.

5.1.4.1 *Type I Fluids in Freezing Fog*

Figure 5.21 shows that the fluid failure time generally decreases with increasing precipitation rate. The scatter is mainly due to the different fluids tested rather than to the temperature, and it is seen that the Type I fluid B-210 generally has the lowest failure time. Only one point fell below the SAE lower limit of six minutes for temperatures below 0°C. Fifteen of the 44 points (34%) are above the upper limit of 15 minutes. Although laboratory results from UQAC suggest that a log-log relation

TABLE 5.3

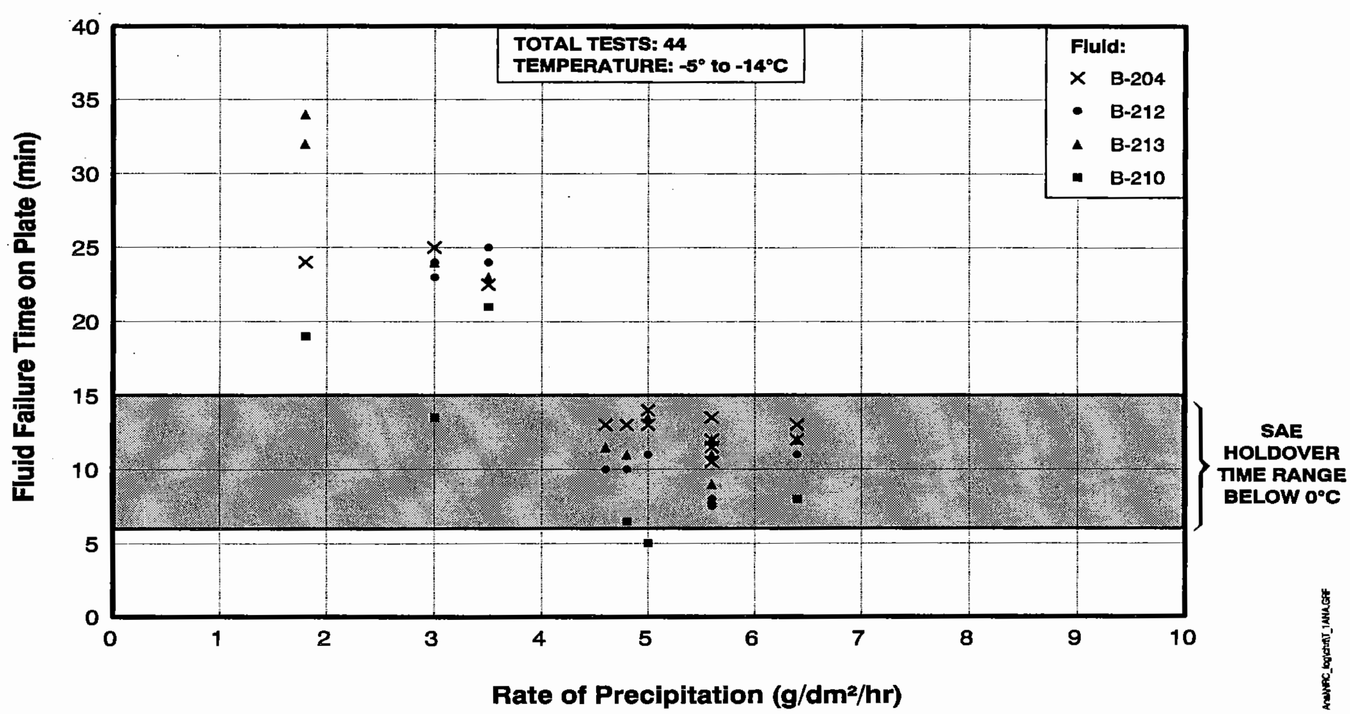
MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR FREEZING FOG

Equation #	Fluid Type	No. of Tests	Equation	R^2	Std. Err.
5.2	All Type I	44	fail = 37.5 + 5.16 (B-204) + 3.78 (B-212) + 4.57 (B-213) - 41.7 log rate	80%	3.293
5.2a	All Type I's Except B-210	38	fail = 42.3 - 42.0 log rate	81%	3.055
5.3	Type I B-212	12	fail = 52.4 - 58.9 log rate	81%	3.279
5.4	Type I B-204	14	fail = 34.3 - 29.1 log rate	78%	2.367
5.5	Type I B-213	13	fail = 44.9 - 46.2 log rate	93%	2.436

fail = Failure Time (min)
rate = Rate of Precipitation ($g/dm^2/hr$)

FIGURE 5.21

TYPE I FLUID FAILURE TIME IN SIMULATED FREEZING FOG CONDITIONS



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between rate and failure time should exist, a semi-logarithmic relationship proved to be stronger. One explanation for this may be that the range of rate of precipitation for the simulated freezing fog tests are at the lower end of the test range of the laboratory tests at UQAC. Table 5.3 provides the results of the statistical analysis for the Type I fluids, which shows relatively high R^2s ranging from 0.78 to 0.93. The statistical curves for all Type I fluids (Equation 5.2) from Table 5.4 are depicted graphically in Figure 5.22. It can be seen that the B-204, B-212 and B-213 fluid curves are very close to one another, and can be grouped together as one equation. Also shown on this chart is Equation 5.2a which resulted from the removal of the B-210 fluid data points, and is a more simplified equation with a higher R^2 of 0.81.

The following equation was obtained for fluid B-213, with a high R^2 of 0.93.

$$\text{fail} = 44.9 - 46.2 \log \text{rate} \qquad (5.5)$$

where fail ≡ failure time [minutes]
rate ≡ rate of precipitation [$g/dm^2/hr$]

Figure 5.23 shows this equation together with the test data points from fluid B-213, and it is observed that the points lie close to the curve described by Equation 5.5.

A stepwise regression was performed for the complete Type I data set, and five observations were identified as outliers. This analysis resulted in a much improved R^2 of 0.90 (from 0.80).

5.1.4.2 *Type II and Type III Fluids in Freezing Fog*

It can be seen that Type II fluids generally provide longer protection times than the Type III fluids at a given rate of

FIGURE 5.22
TYPE I FLUID MULTI-VARIABLE REGRESSION CURVES IN FREEZING FOG

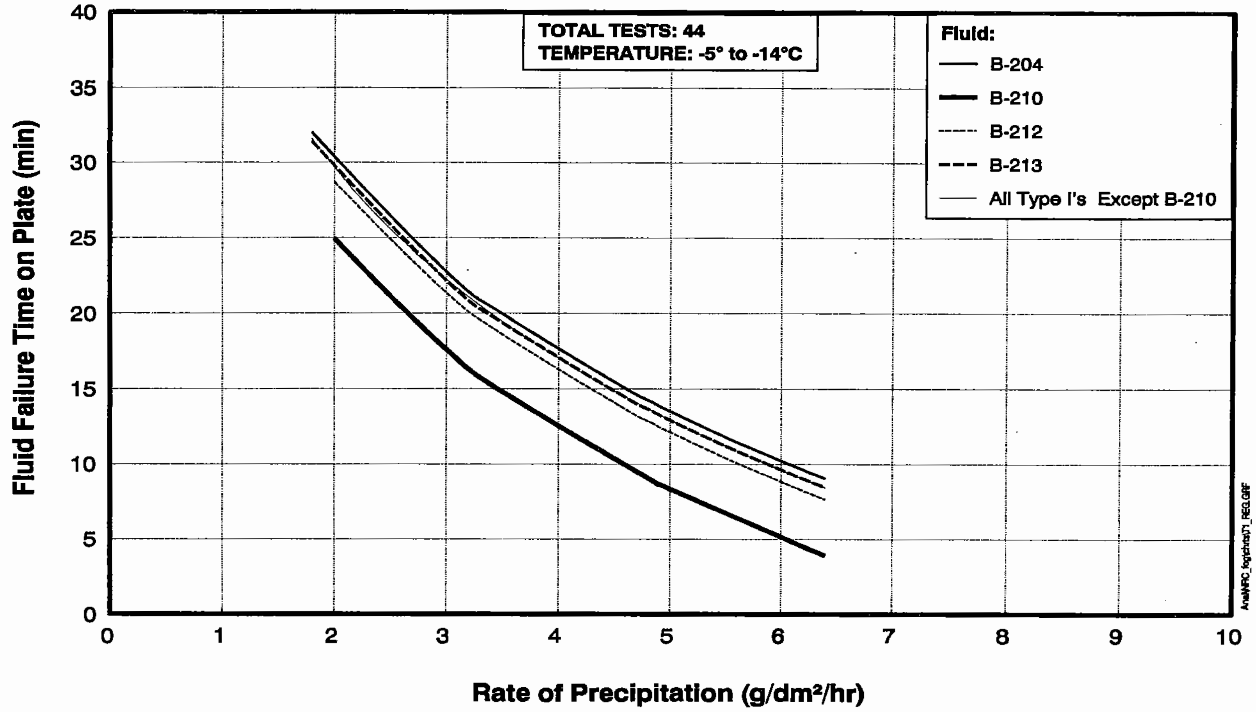
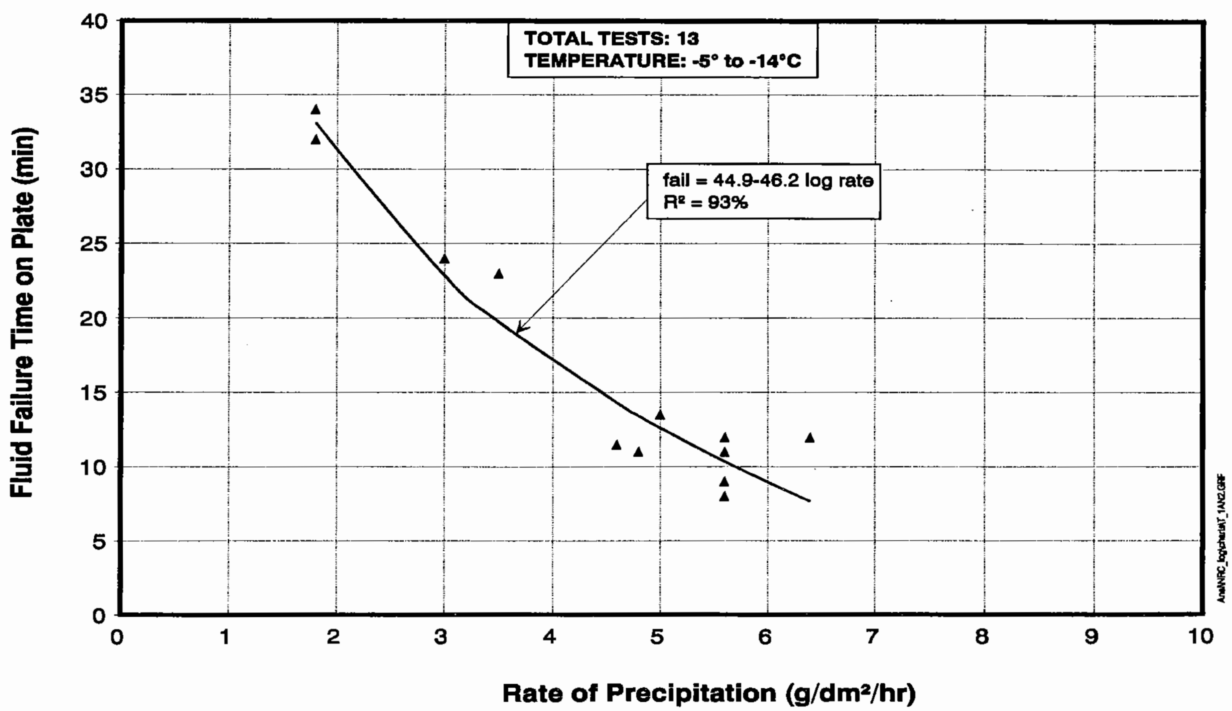


FIGURE 5.23
FLUID B-213 MUTI-VARIATE REGRESSION CURVE IN FREEZING FOG



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precipitation. Nine out of ten Type II data points fell above the SAE lower limit of 35 minutes for temperatures below 0°C. The results of the tests are shown in Figure 5.24. The SAE holdover time range of 75 to 180 minutes for temperatures of 0°C and above cannot be verified at the present time as this condition was not simulated in any of the tests.

Figure 5.24 also shows that Type III fluid failure times ranged from 27 to 35 minutes. No SAE holdover time is available for this type of fluid at the time of publication of this document. Despite the difficulty in obtaining usable results, as described in Section 3.3 for Type II and III fluids in freezing fog, more tests need to be carried out.

5.1.5 No Precipitation Conditions

A number of flat plate tests were conducted in the absence of any precipitation to study the thickness distribution over the plate as a function of time. Although previous tests have already been done for the Type II and III fluids, (1990-1991 and 1991-1992 reports) no thickness tests had been carried out for Type I fluid. Hence, the objective of these tests was to study the thickness distribution primarily for Type I fluids. In addition, these thickness distributions were used to assist in the calibration of the sensors. The results are presented in Section 5.2.5.

Figure 5.25 shows typical thickness decays of Type I, II and III fluids at the 15 cm line. The Type III data shown is from the 1991-1992 season. As expected, the stabilized film thickness is greatest (approximately 22 mils or 0.56 mm) for the viscous Type II fluid and smallest (approximately 4 mils or 0.10 mm) for the less viscous Type I fluid. The Type III fluid stabilized thickness lies between that of the Type I and II (approximately 12 mils or 0.30 mm). While the Type II and III fluid stabilization periods are similar (from 10 to 15 minutes), the Type I fluid thickness stabilizes within five minutes, most probably because

FIGURE 5.24

TYPE II AND TYPE III FLUID FAILURE TIME IN FREEZING FOG

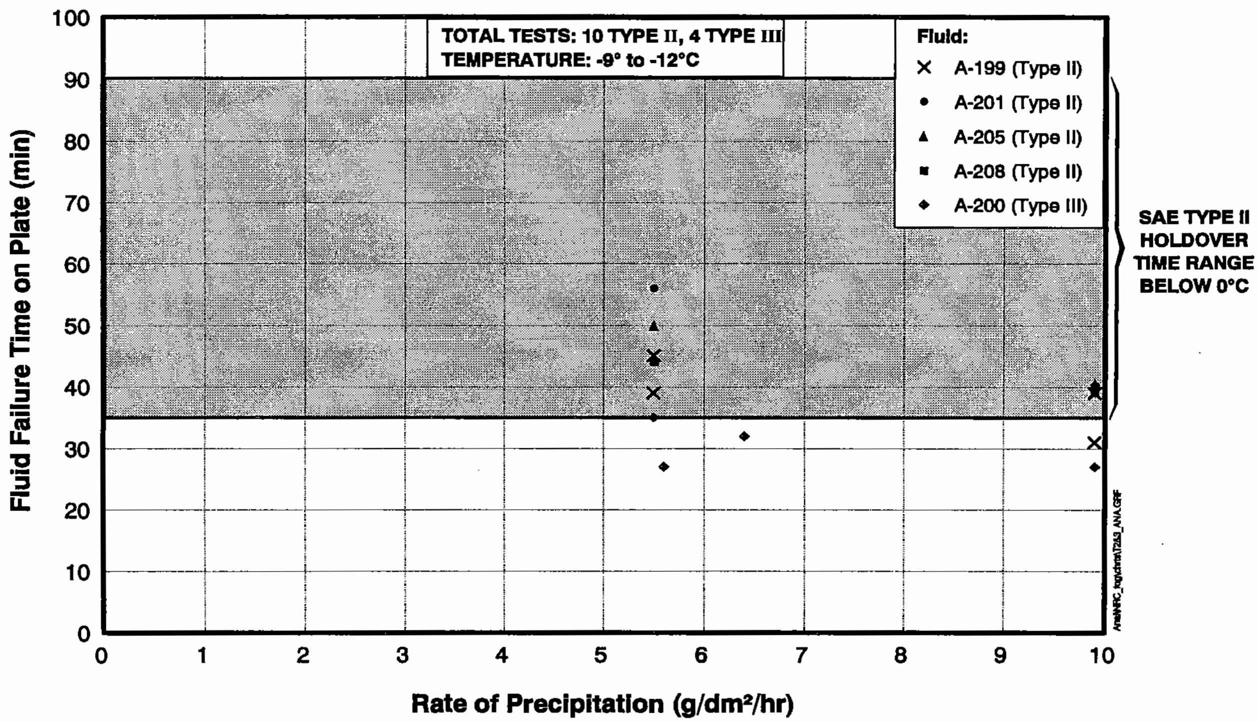
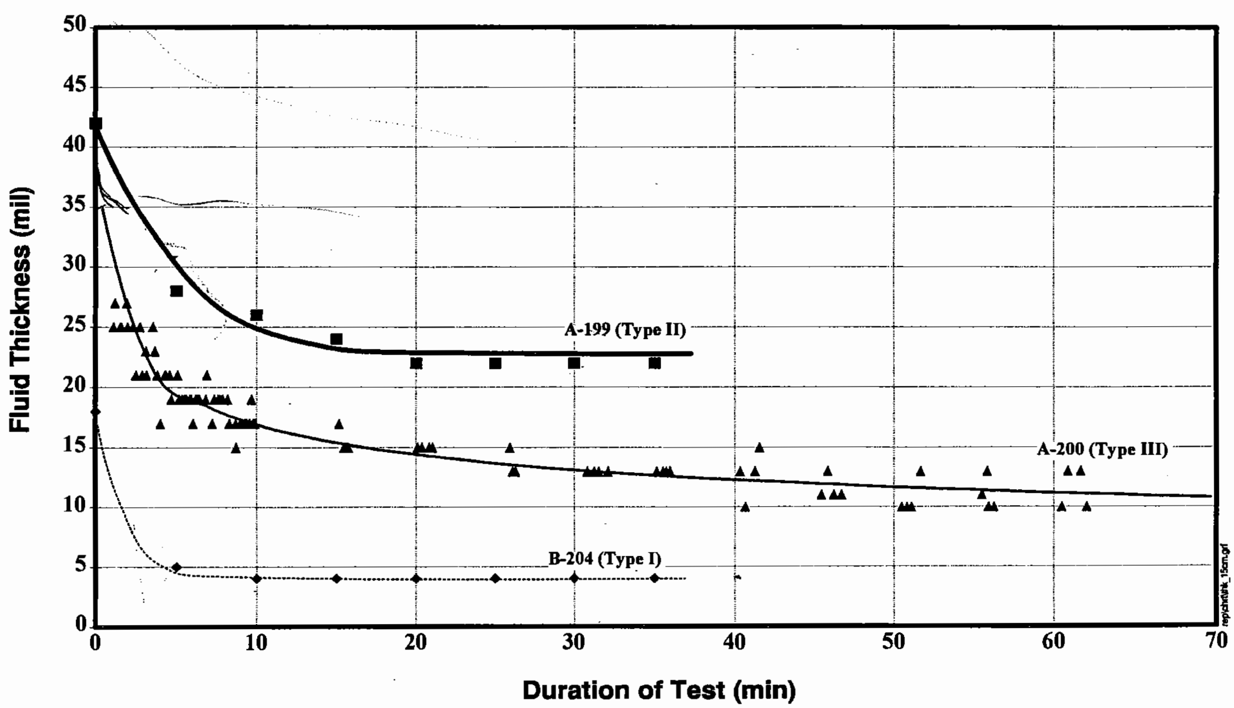


FIGURE 5.25

TYPICAL THICKNESS DECAY AT 15 CM LINE FOR VARIOUS FLUIDS



of its low viscosity. Figure 5.26 shows Type I fluid thickness distribution over the plate as a function of time in the (transient) first five minute period. The fluid is thinnest at the 2.5 cm line (top of the plate) and thickest towards the bottom of the plate due to the 10° decline. This is confirmed by a general observation of fluid failure progression from the top of the plate, where the protection film is thinnest, to the bottom of the plate, where the fluid has a maximum thickness.

5.1.6 Rain on a Cold-soaked Surface

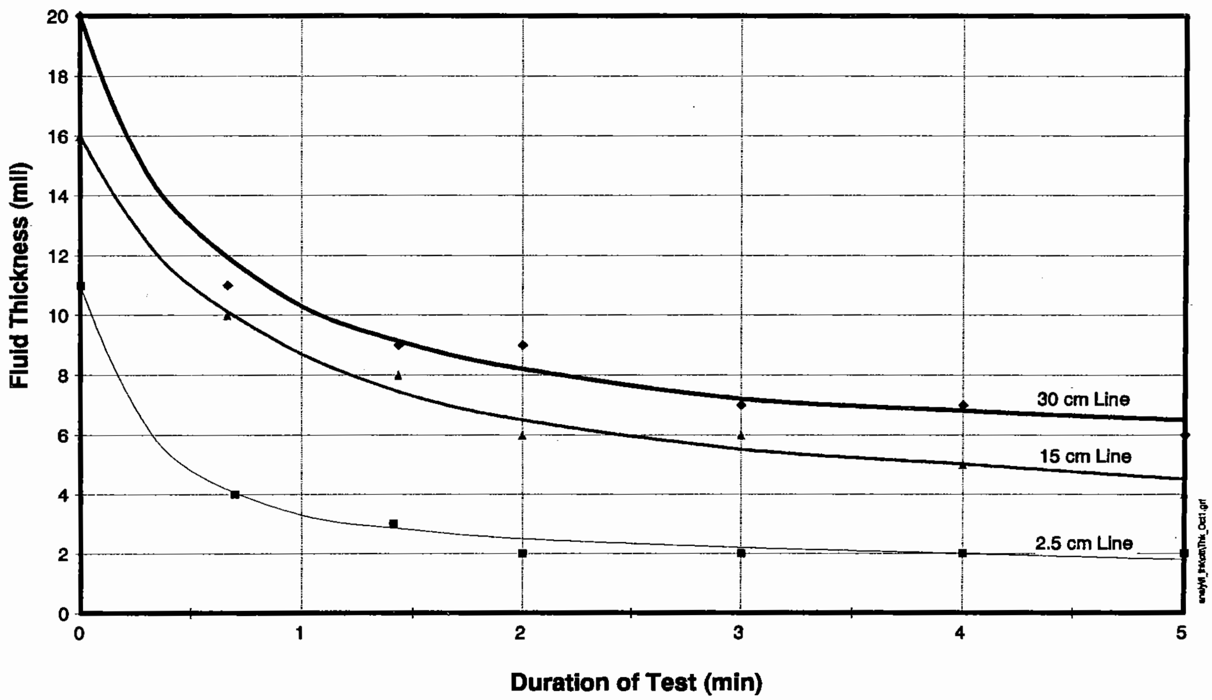
The objective of the cold-soaked flat plate tests was to investigate the effect of rain on a cold-soaked surface such as the wing skin of an aircraft with cold fuel. These preliminary experiments, which were filmed (on video), were conducted under rain at ambient air temperatures above 0°C. The test consisted of pouring a Type I fluid on the top face of the aluminum box (see Figure 2.3), which was partially filled with a Type II fluid and cooled in a freezer. A simultaneous test was performed on a flat plate with the same Type I fluid. And a control plate with no fluid was also observed.

One such test, conducted on April 22, 1993, resulted in the formation of slush within ten minutes into the test and the first contamination was observed fifteen minutes from pouring time. Loss of gloss on the entire panel was observed 34 minutes into the test. It is interesting to note that the SAE guidelines of six to fifteen minutes for Type I fluids specified in Appendix B are in the same order of magnitude. Throughout the test, both the control plate (with no fluid) and the fluid covered flat plate remained uncontaminated.

This preliminary study indicated that the cold-soaked phenomenon observed on aircraft can be simulated in tests and should be pursued in future testing programs. Recommendations on future cold-soaking testing methods and equipment are presented in Section 7 of the report.

FIGURE 5.26

TYPICAL FLUID DISTRIBUTION FOR TYPE I FLUID (FLUID B-204)



5.2 Ice Sensor Tests

The objectives of the ice sensor tests were:

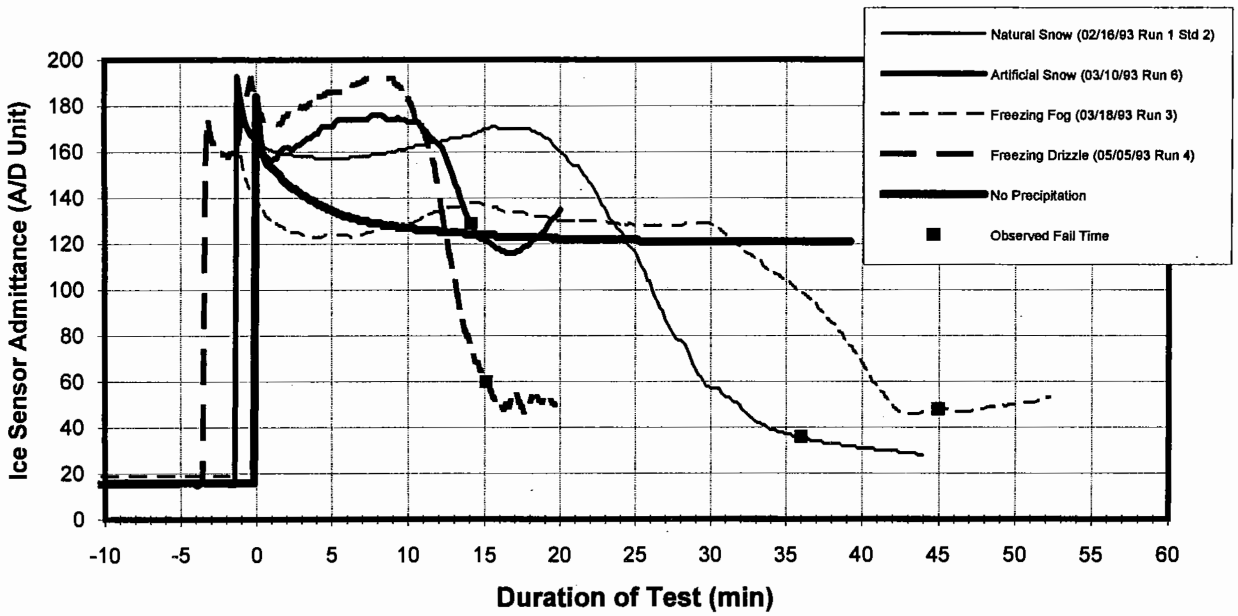
a) to evaluate their usefulness in future de/anti-icing tests, particularly in the determination of the fluid failure time under all forms of precipitation;

b) to calibrate the instruments with different types of de/anti-icing fluids in the absence of precipitation.

The ice sensor tests are essentially flat plate tests with Instrumar's IM 101 and FM 202 sensors (see Sections 2.3.2 and 3.7 for description), mounted at the centre of the 15 cm line (where failure is reported). Sensor admittance traces for a typical Type II fluid under the various forms of precipitation are plotted in Figure 5.27. Type III curves (not shown) display similar characteristics. The clear distinction between the 'no precipitation' trace and the traces under precipitation suggests that the sensor may be useful in some form for failure time detection and/or warning in future testing. It is observed that the curves associated with the various forms of precipitation exhibit similar characteristics. Before fluid application, the sensor admittance remains constant. The reading increases sharply when the fluid is poured and it starts to drop to a minimum value within a few minutes.

The initial drop in admittance reflects the thinning action of the fluid as is discussed in Section 5.2.5. This thinning process, however, is counteracted by the absorption of precipitation by the fluid causing the admittance to gradually increase again. As the absorption reaches a saturation point, the admittance attains a maximum value and drops off to a lower level with a pronounced gradient for all the precipitation types. As could be expected, it was observed that the period before which the curve drops off is longest for fog where the (measured) rate of precipitation is the lowest, and shortest for the freezing drizzle and artificial snow where the rates are highest.

FIGURE 5.27
TYPICAL SENSOR RESPONSE TO VARIOUS FORMS OF PRECIPITATION ON A-199 TYPE II FLUID



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The observed fluid failure time as well as the sensor failure time were marked on each curve in order to illustrate the relationship between the sensor curves and the observed failure times. The definition and a description of the determination of the sensor failure time is provided in Appendix E.

Figure 5.28 shows typical traces of sensor response to various precipitation compared to a typical test without precipitation for Type I fluids. Although much less pronounced, the sensor responses are consistent with those of Type II and III fluids. Most probably the traces are less pronounced because the tests are usually shorter for Type I fluids, and thus the fluid thinning has more of an effect on the sensor admittance reading than does the rate of water addition. This explains why the natural snow and freezing fog (both relatively low rates) curves are closer to the zero precipitation curve than is the freezing drizzle (high rate) curve. If the test procedure were to allow the fluid to settle to its equilibrium thickness before being exposed to precipitation, then one would expect the sensor to be more responsive to Type I fluid failure.

5.2.1 Natural Snow Conditions

For Type II fluids, it was generally observed that the admittance traces for the snow conditions are sensitive to the ambient temperature. Figure 5.29 shows that while the sensor failure time can easily be located at -2°C, it is not so at -7°C and -20°C because the "drop" in the curve tends to be less pronounced at lower ambient temperatures (below -7°C). It is also observed that lower rates of precipitation generally result in less pronounced drops in the curve. Figure 5.30 shows a plot of the sensor failure time against the observed failure time for all Type II fluids tested. The plot shows that the visual detection of failure times varies significantly from the instrument determinations. However, when the same sensor failure time is plotted against the slush failure times (see Section 2.2 for definition) in Figure 5.31, a better correlation is obtained. It can be concluded that both a sensor and visual detection of slush formation for Type II fluids agree to a great degree, while the detection

FIGURE 5.28
TYPICAL SENSOR RESPONSE TO VARIOUS FORMS OF PRECIPITATION FOR FLUID B-204 (Type I)

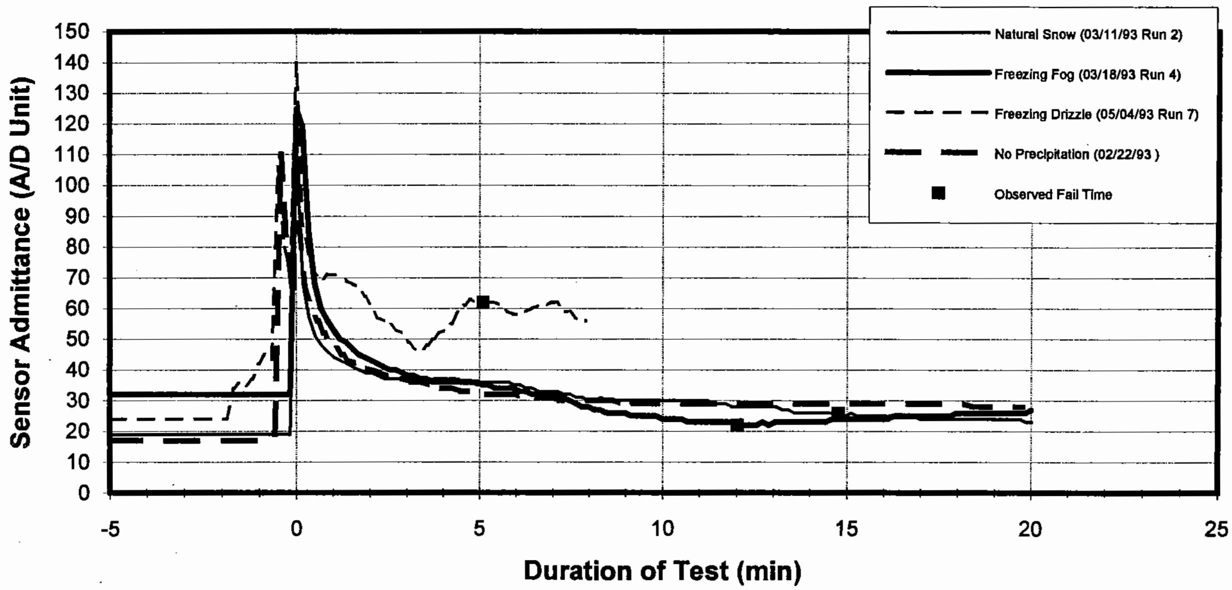

FIGURE 5.29
TYPICAL SENSOR RESPONSE TO SNOWFALL ON A-205 TYPE II FLUID

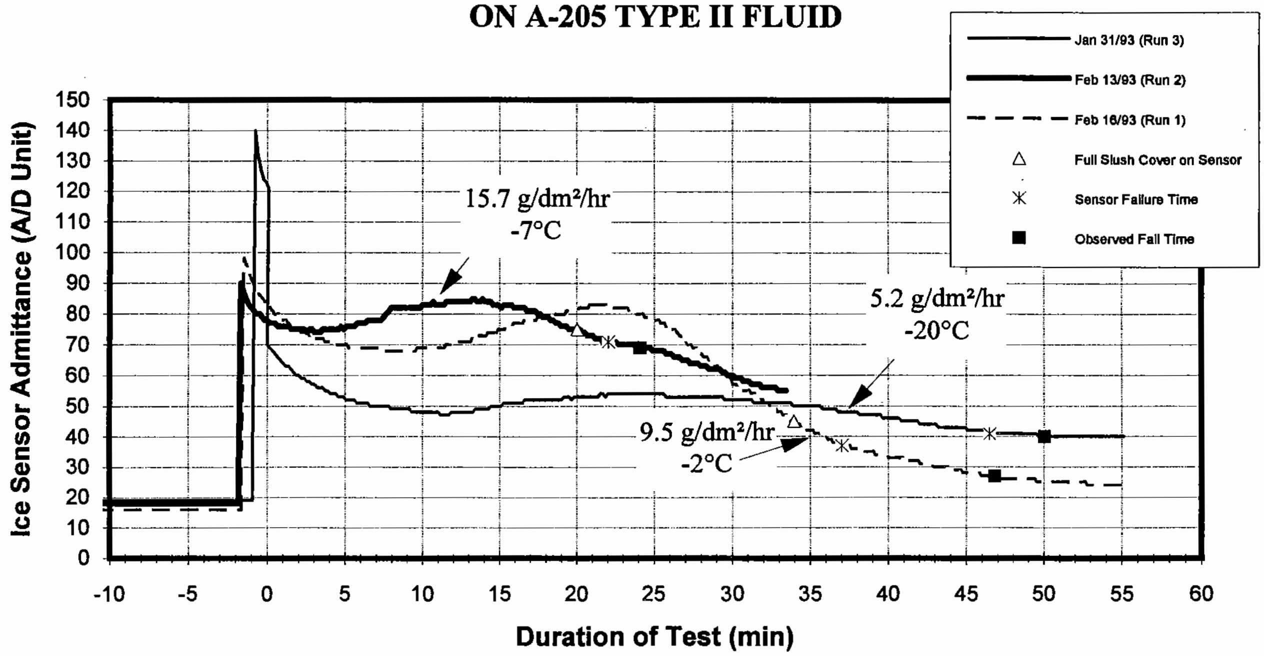

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FIGURE 5.30

SENSOR RESPONSE TO TYPE II FLUID FAILURE IN NATURAL SNOW CONDITIONS

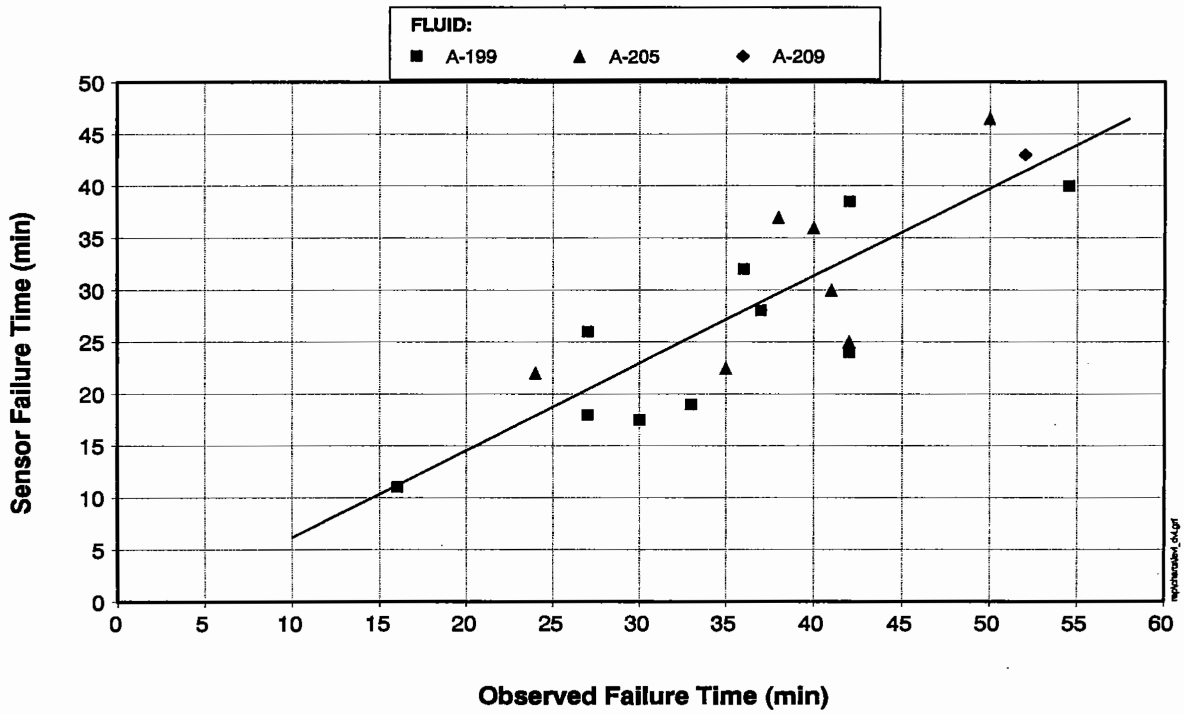
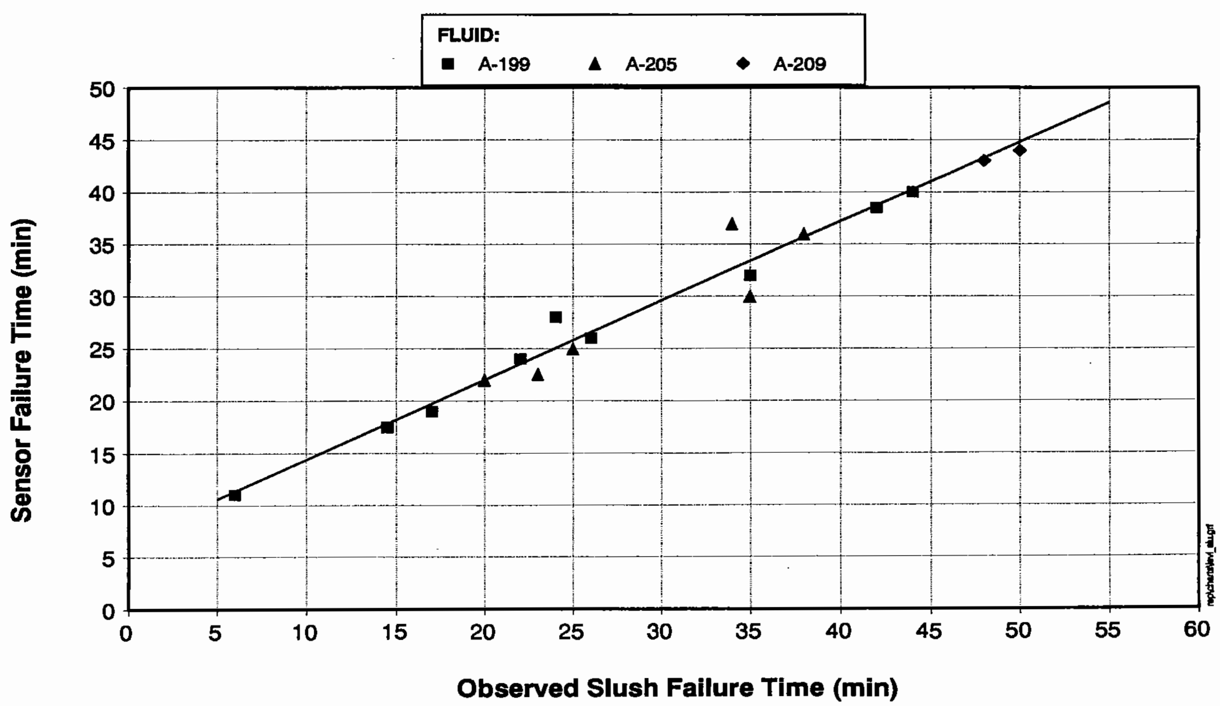


FIGURE 5.31

SENSOR RESPONSE TO TYPE II FLUID SLUSH FAILURE IN NATURAL SNOW CONDITIONS



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of fluid failures as defined in the procedures (i.e. lack of absorption of snow) plotted against the senor failure time shows a larger scatter.

5.2.2 Artificial Snow Conditions

Although the number of tests in artificial snow is limited, Figure 5.32 shows the potential of a correlation between sensor reading with observed failure time, (loss of gloss) for both Type II and III fluids.

5.2.3 Freezing Drizzle Conditions

A good correlation between sensor failure time and observed failure time (loss of gloss) was obtained for Type II and Type III fluids as shown in Figure 5.33. The degree of scatter is within the expected experimental error.

5.2.4 Freezing Fog Conditions

Although only four data points (see Figure 5.34) were obtained for Type II and Type III tests, they show the potential existence of a correlation between sensor failure time versus observed failure time (loss of gloss).

5.2.5 No Precipitation Conditions

Figure 5.35 shows a typical thickness decay as a function of time at the 15 cm line for Type I fluid. Figure 5.36 shows the corresponding sensor admittance trace. A plot of admittance versus the fluid film thickness (Figure 5.37) shows that the sensor admittance is a function of the fluid thickness. This indicates that the absolute admittance value should not be used to determine the sensor failure time and that a first derivative (gradient) analysis or other optimum interpretation algorithm as discussed in Appendix E is preferable to eliminate the effect of the thickness decay.

FIGURE 5.32
SENSOR RESPONSE TO FLUID FAILURE IN ARTIFICIAL SNOW CONDITIONS

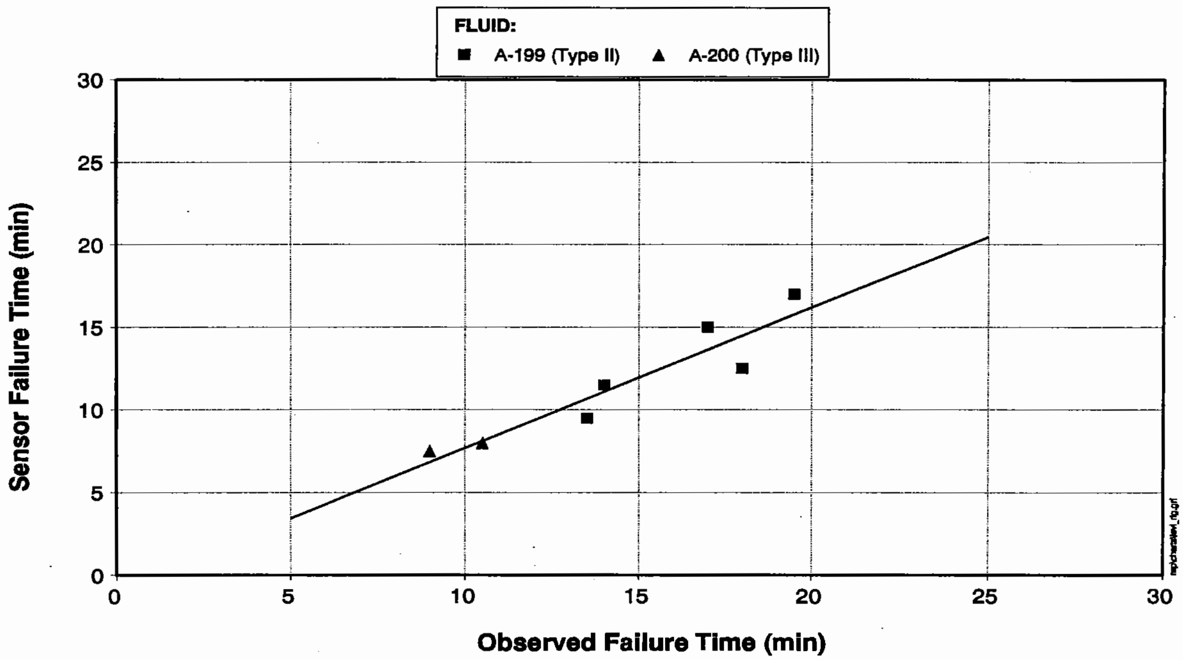

FIGURE 5.33
SENSOR RESPONSE TO FLUID FAILURE IN FREEZING DRIZZLE CONDITIONS

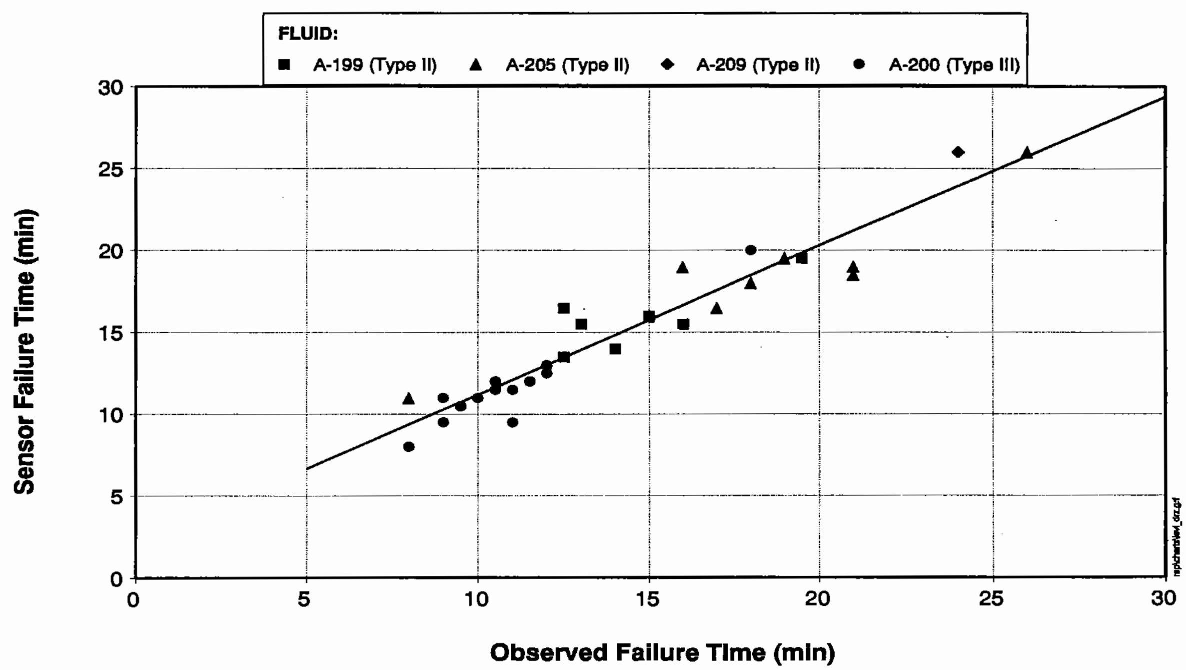

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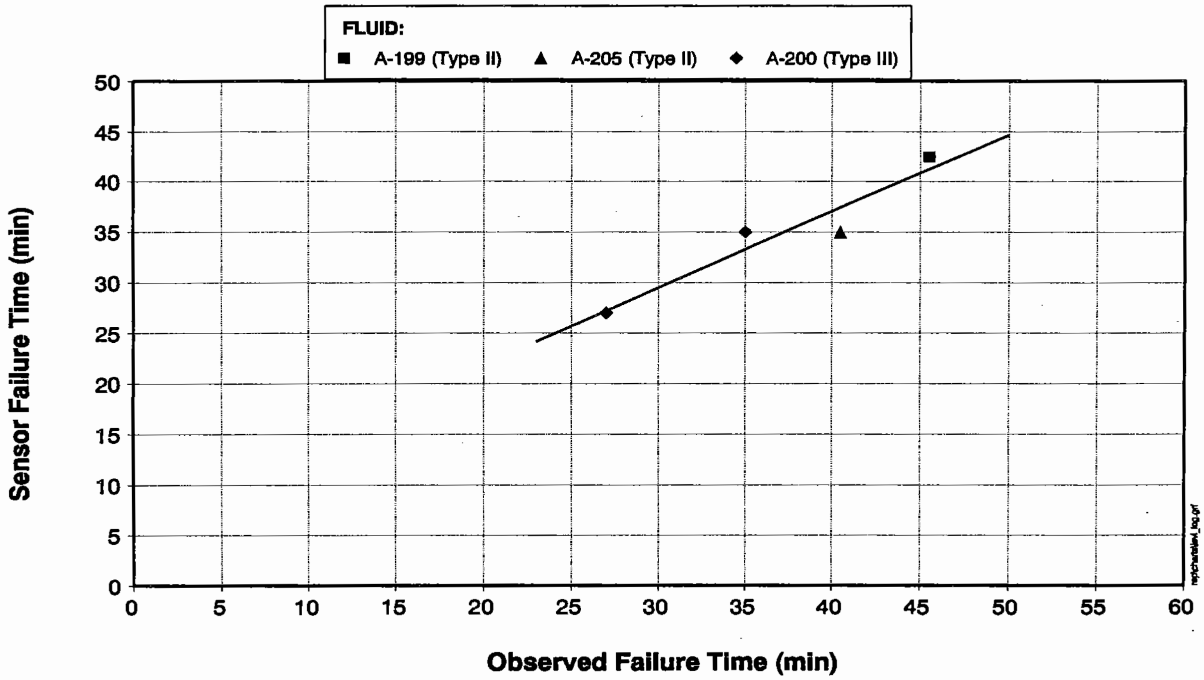
FIGURE 5.34
SENSOR RESPONSE TO FLUID FAILURE IN FREEZING FOG CONDITIONS



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TYPE I FLUID THICKNESS DECAY WITH NO PRECIPITATION (Fluid B-204)

FIGURE 5.35

MEASURED FLUID THICKNESS

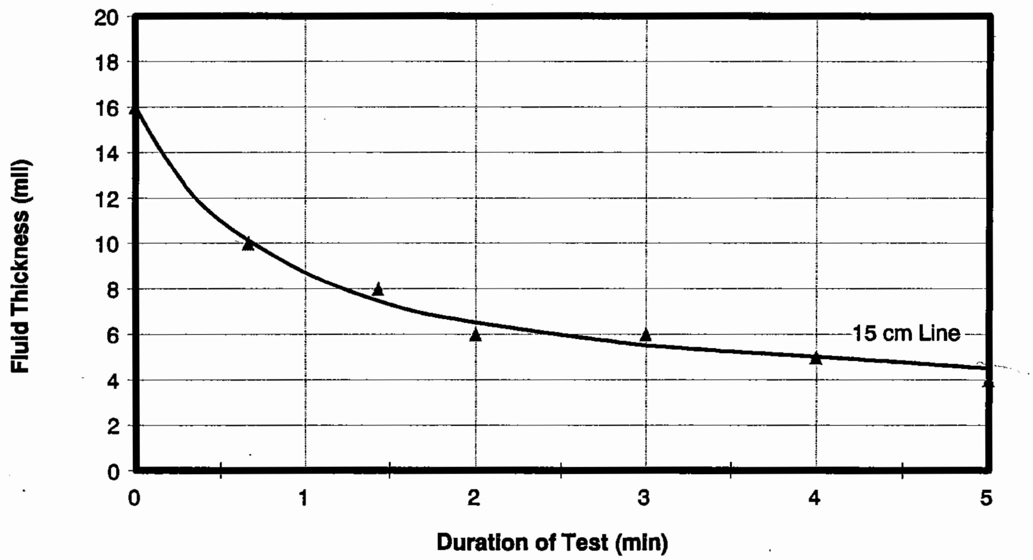

FIGURE 5.36

SENSOR ADMITTANCE

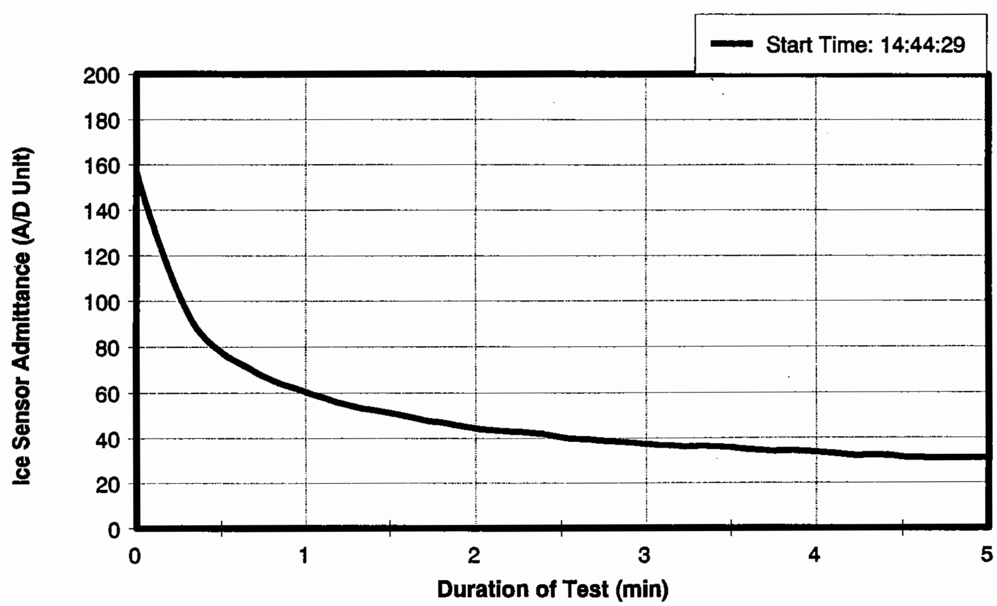

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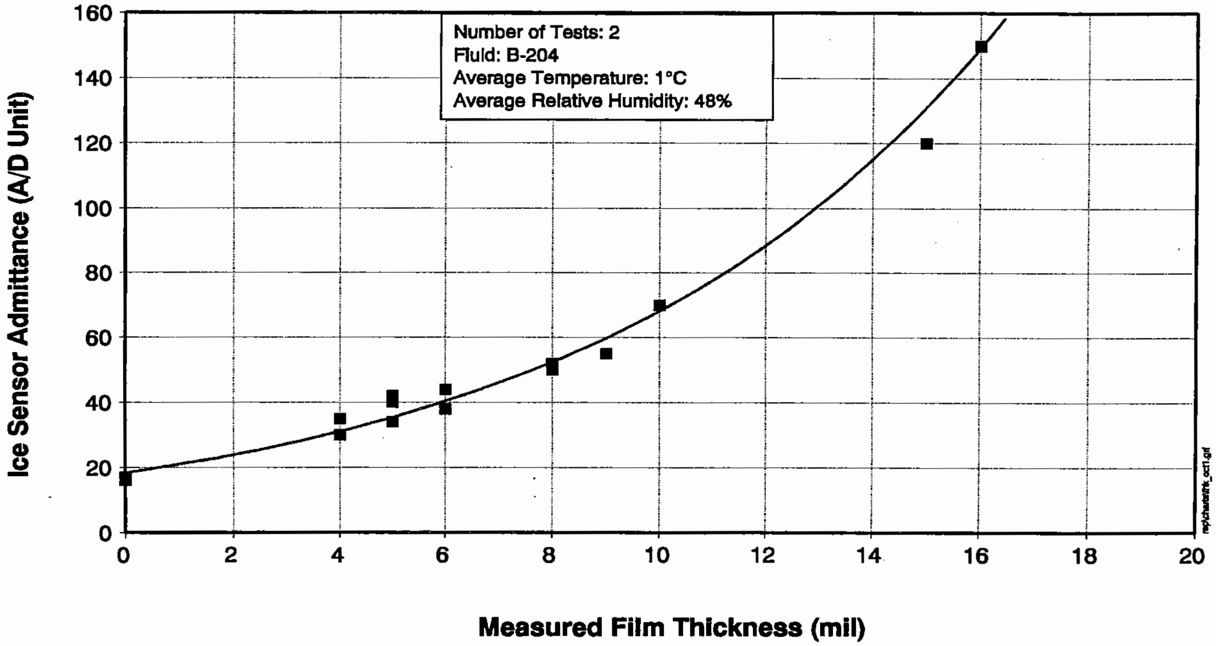
FIGURE 5.37
TYPICAL SENSOR ADMITTANCE
vs
FILM THICKNESS CURVE FOR TYPE I FLUID



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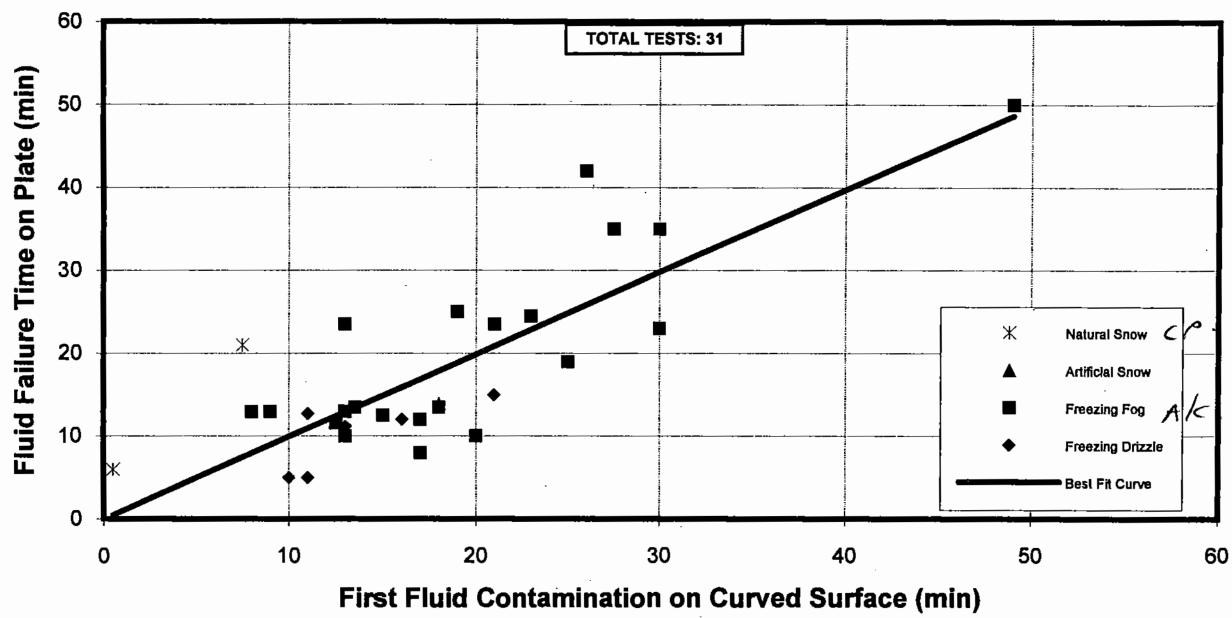
5.3 Aircraft Surface Tests

Some of the plate tests (discussed in Section 5.1) were carried out simultaneously with the same fluid on one or more of the following: the F-28 curved plate, the horizontal stabilizer, and the Super Beech King Air aircraft wing described in Section 2. The objective was to correlate the fluid failure times on flat plates with those on aircraft surfaces, which have curvatures, protrusions (rivets and lugs) and discontinuities. Tests performed by United Airlines (see Appendix F) at Denver Airport suggest a 1:1 relationship between fluid failure on a flat plate and a large jet aircraft. Similar experiments conducted by NRC showed that fluid failure on a model wing occurred consistently later than on a flat plate (up to four times later in one test). The preliminary results of the NRC tests were presented at the conference in Salt Lake City .

Figure 5.38 is a plot of the first fluid contamination on the curved surfaces against the fluid failure time on the flat plates. The figure shows the results obtained for tests involving all three types of fluids on the three curved surfaces in various environmental conditions. The chart shows that 31 data points were collected, with the majority of these during the simulated freezing fog tests. It can be seen that the best fit line has a 1:1 relationship between the flat plate and the curved surface, as is assumed in the discussions pertaining to the SAE/ISO holdover time table in Appendix B. While there is scatter in the data points, these results match closely with those suggested by the United Airlines tests in Denver.

The first fluid contamination time rather than the failure time was used on the curved surface, because it violates the "clean wing" requirement. A breakdown of the points based on the three different curved surfaces on which the fluids were tested showed no reduction in the scatter of points in cases where a sufficient number of tests were performed.

FIGURE 5.38
FLUID FAILURE ON FLAT PLATE vs CURVED SURFACE



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A large part of the scatter can be attributed to the subjectivity of the (human) observation of the first contamination time, especially when no documented procedure was set at the time of the tests. Other factors contributing to the scatter are:

i) On the F-28 wing section plate, the first contamination generally occurred on the edges (discontinuities). This may not be representative of a larger aircraft wing surface.

ii) The aircraft wing contamination generally initiates at corners, around riveted areas and/or around protrusions (such as probes). Hence, the correlation between aircraft and flat plate may be aircraft specific.

iii) Although it was ensured that both flat plate and curved surface were saturated with fluid, the fluid flow (thickness distribution as a function of time) and dilution rate over the different surface geometries are influenced by environmental factors such as wind, temperature, and rate of precipitation, which can partly contribute to the scatter.

While these results match closely with those of United Airlines, the difference when comparing with the results from the NRC is attributed primarily to subjectivity in the determination of the end condition. The points shown in Figure 5.38 are based on first fluid contamination time, whereas the end condition from the NRC refers to "holdover time". This partly explains the fact that failures on NRC's model wing occurred later than on the flat plate.

More aircraft surface tests need to be carried out, with a documented procedure provided to the program participants. When first contamination starts at corners, edges or protrusions on the surface, these observations need to be documented and charted, together with their associated times.

5.4 Dimensional Analysis of a Type II Fluid

In light of the scatter in the natural snow tests, even within the fluid type as shown by Figure 5.39, a dimensional analysis was performed on the A-199 (Type II) fluid data. A simple linear regression of rate versus time yields a coefficient (R^2) of only 0.54 for this data set. The dimensional analysis yielded the following equation relating the fluid failure time with the various relevant parameters for the A-199 (Type II) fluid with a coefficient of determination (R^2) of 0.95:

$$T = 151.43 + 5.32\,[Re_f^{-1}\, Re_a^{-0.5}\, (c/c_o)^{-1.5}(RH)^{0.5}] \qquad (5.1)$$

where, the non-dimensional time is expressed as:
$T \equiv t/(\eta_f \,/\, g h_o \rho_f)$
$t \equiv$ fluid failure time [s]
$g \equiv$ gravity [m/s^2]
$h_o \equiv$ initial fluid thickness [m]
$\rho_f \equiv$ density of fluid [kg/m^3]
$\eta_f \equiv$ non-newtonian absolute viscosity of fluid [N.s/m^2]

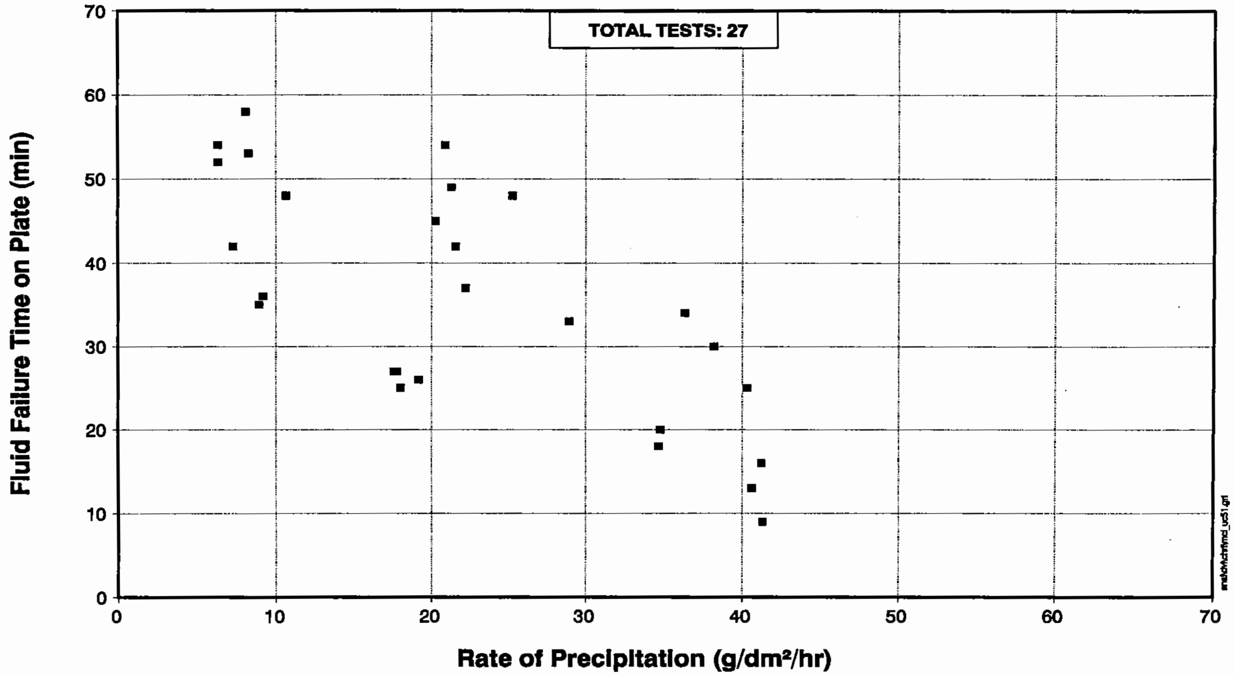
the Reynolds number for fluid flow:
$Re_f = \rho_f\, v_f h_f \,/\, \eta_f$
$v_f \equiv$ velocity of fluid [m/s]
$h_f \equiv$ fluid thickness [m]

the Reynolds number for air flow:
$Re_a = \rho_a\, v_a\, l \,/\, \mu_a$
$\rho_a \equiv$ density of air [kg/m^3]
$v_a \equiv$ velocity of air [m/s]
$l \equiv$ plate length [m]
$\mu_a \equiv$ absolute viscosity of air [N.s/m^2]

the non-dimensional concentration:
$c/c_o = h_o/(h_o + h_p)$
$h_p \equiv$ total precipitation on plate [m]

FIGURE 5.39

A-199 TYPE II FLUID FAILURE TIME vs RATE OF PRECIPITATION IN SNOW CONDITIONS



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the non-dimensional humidity:
RH

Equation 5.1, represented graphically in Figure 5.40, was developed with the following assumptions, which must be considered whenever the formula is used:

(a) The Reynolds number for air flow Re_a is in the laminar region,
(b) The Reynolds number for fluid flow assumes a creeping flow of the protective fluid mixture,
(c) The tests are carried out under adiabatic (no heat transfer) conditions,
(d) Although the ambient relative humidity (RH) should not be a relevant parameter in an adiabatic process, it is used in Equation 5.1 to include its influence on the water content and type of snow, and
(e) There is no substantial viscosity change due to dilution of the fluid.

Equation 5.1 was used to generate the plots in Figures 5.41, 5.42, and 5.43 in order to demonstrate the effect of precipitation rate, temperature, wind speed and relative humidity on the fluid failure time for a Type II fluid in snow tests. It can be seen from these figures that with a temperature of - 5°C, relative humidity of 80% RH and wind speed of 20 kph (average conditions for the data set), the rate of precipitation reduces the fluid failure time by approximately 2 minutes per $g/dm^2/hr$. Under average precipitation and average conditions of the data set, the temperature effect on the fluid failure time is in the order of 6 minutes per °C (see Figure 5.41), the relative humidity effect is approximately -1 minute per % RH (see Figure 5.42), and the wind effect is in the order of 5 minutes per kph (see Figure 5.43).

FIGURE 5.40
NON-DIMENSIONAL TIME vs NON-DIMENSIONAL NUMBERS

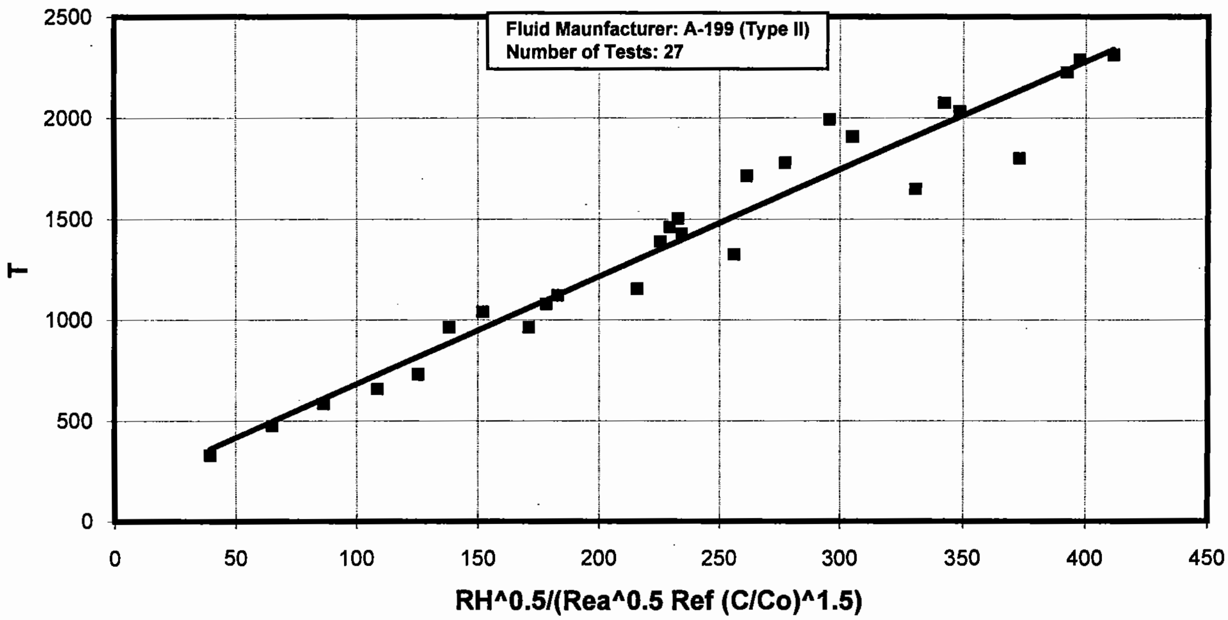

FIGURE 5.41
EFFECT OF TEMPERATURE ON FLUID FAILURE TIME IN SNOW CONDITIONS

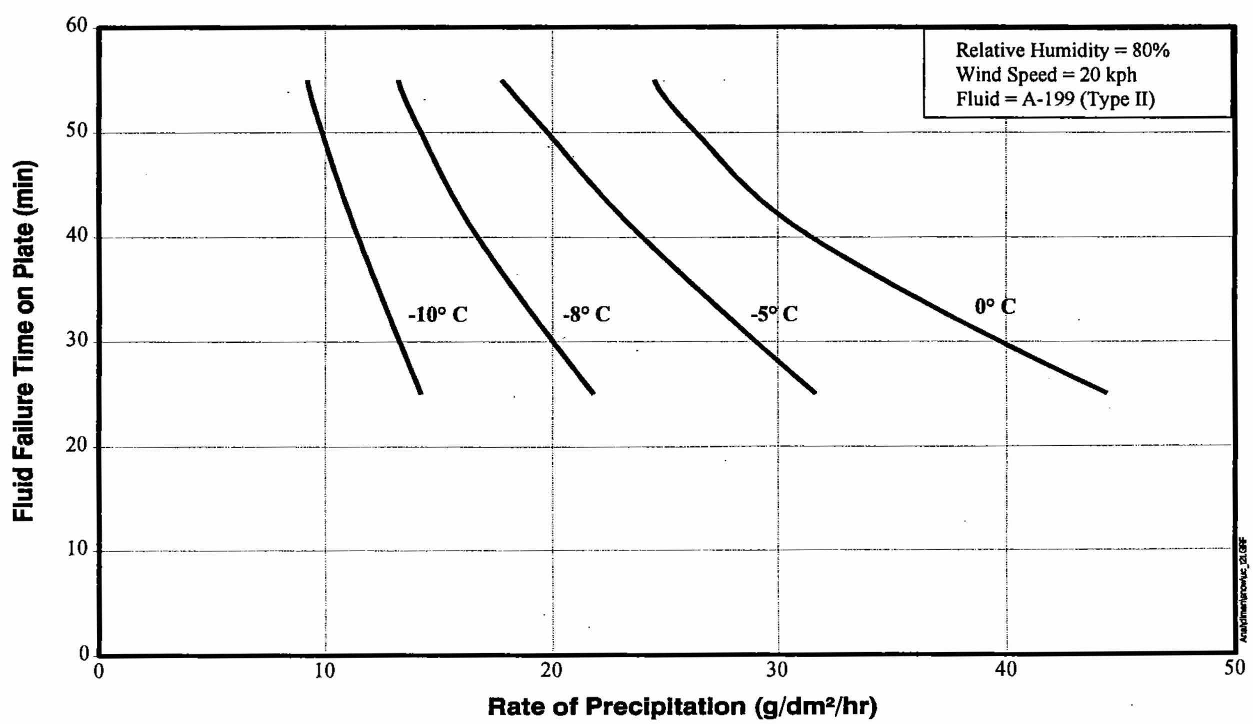

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FIGURE 5.42

EFFECT OF RELATIVE HUMIDITY ON FLUID FAILURE TIME IN SNOW CONDITIONS

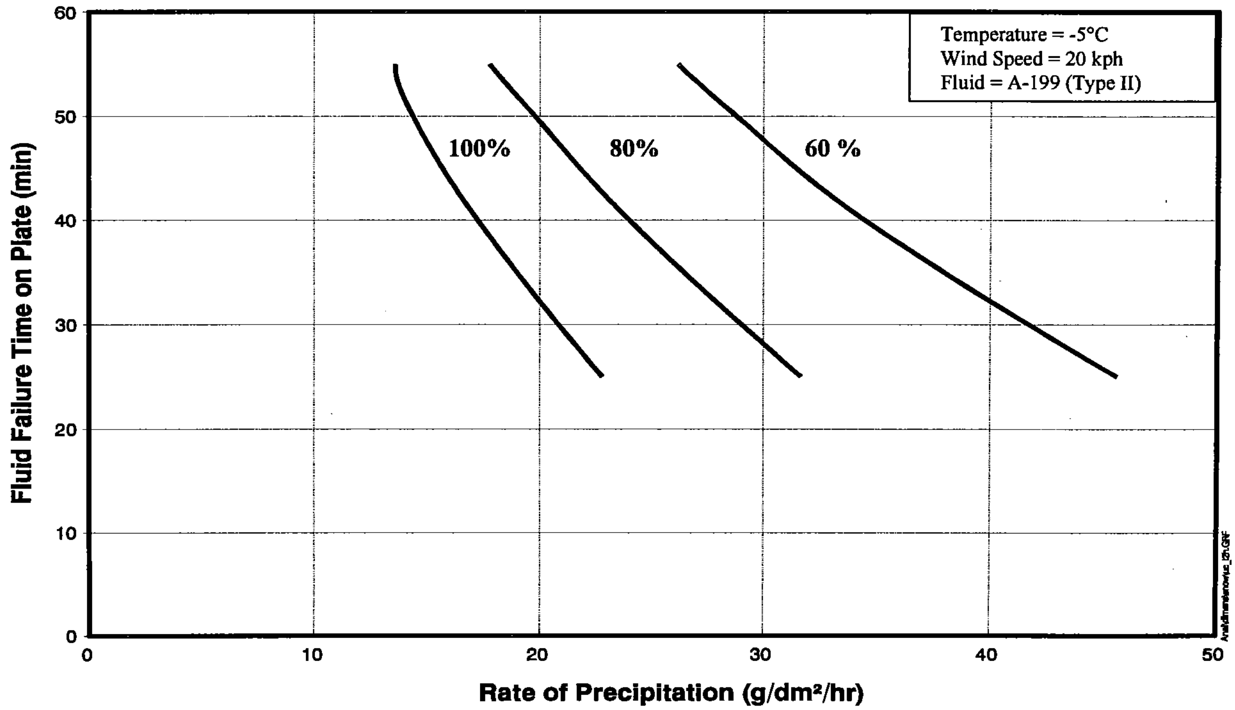
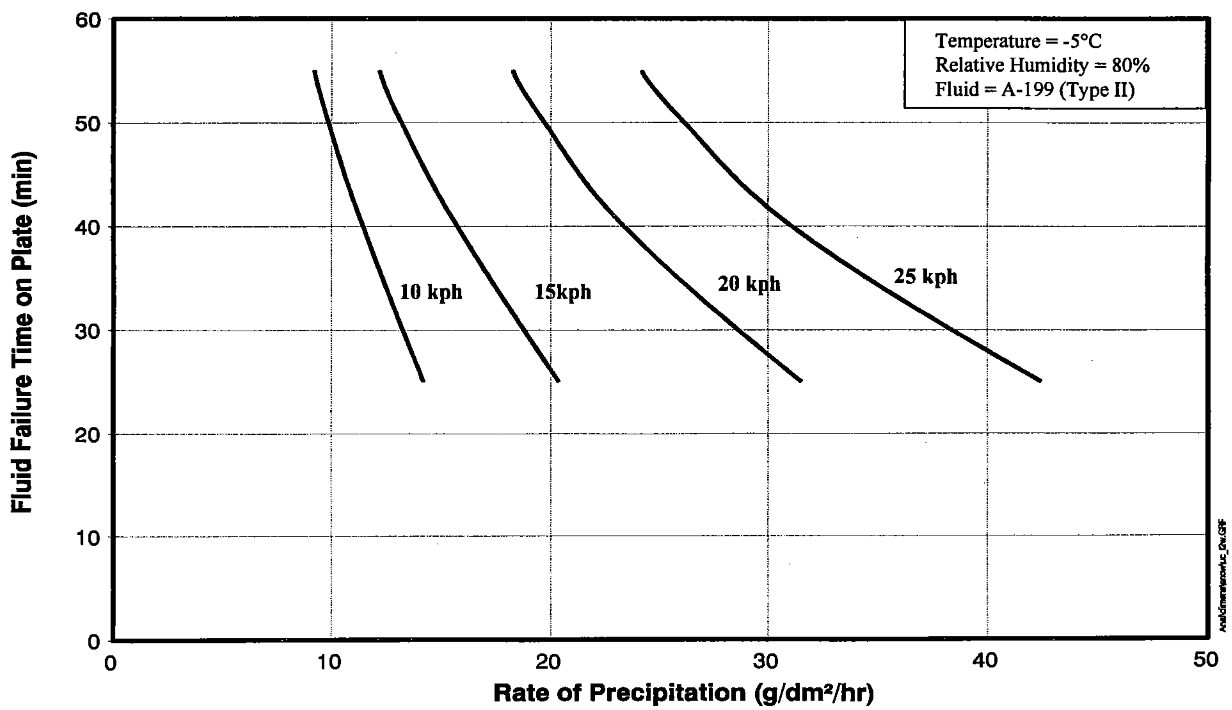


FIGURE 5.43

EFFECT OF HEAD WIND SPEED ON FLUID FAILURE TIME IN SNOW CONDITIONS



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In order to determine the relative influence of the rate of precipitation, temperature, wind and relative humidity on the fluid failure time, one must assign an equivalent increment based on the expected range of test values of each of these parameters (see Table 5.4). For this analysis, the range about the mean encompassing 2/3 of the test points was used. Table 5.4 shows that, according to the dimensional analysis based on fluid A-199 (Type II) data, the wind has the strongest effect on failure time, followed by the rate of precipitation and temperature, which have almost equal influences on the failure time. As expected, the relative humidity has a relatively weak effect on the failure time.

TABLE 5.4

INFLUENCE OF VARIOUS PARAMETERS ON A-199 TYPE II FLUID FAILURE

	Test Data Range Using One Standard Deviation	1°C Increment [1] Equivalence	Increase in Failure Time per Parameter Unit [2]	Increase in Failure Time per Equivalent Parameter Computed by Multiplication of Two Adjacent Columns
Direct Wind Speed	13 to 27 kph	1.75 kph	5.0 min	8.8 min
Temperature	-9° to -1°C	1.0°C	6.0 min	6.0 min
Rate of Precipitation	10 to 35 g/dm²/hr	3.1 g/dm²/hr	-2.0 min	6.2 min
Relative Humidity	73 to 87 %	1.8%	-1.0 min	-1.8 min

1 Obtained from the difference of the data range divided by the range for temperature (8°C)

2 Extracted from Figures 5.41 to 5.43

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6. CONCLUSIONS

As is apparent when comparing the analysis contained in this report with that included in the 1990-1991 and 1991-1992 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. While the improvement in meteorological data collection contributed greatly to this result, a factor not to be overlooked is that the scope of the tests was larger than in the previous years. Not only were freezing fog and drizzle tests conducted, Type I, II and III fluids were tested using fluids from five different manufacturers. Many of the recommendations for future testing from the 1991-1992 report were implemented in the 1992-1993 testing. Similarly, changes suggested in Section 7 may also play a pivotal role in improving the quality of the recorded data in future testing.

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; ice sensor tests; and aircraft surface tests.

6.1 Test Procedures and Equipment

- Relocation of the natural snow test site from Air Canada's maintenance facility roof-top to AES's weather observation site was advantageous primarily due to the ease of access and the availability of meteorological data from Environment Canada as back-up.

- Major changes to the test procedure such as measurement of wind direction and use of a plate pan provided useful insights into the explanation of the variance in the test data.

- In future testing, the Instrumar ice sensors could be successfully used to determine the end condition, which will remove any tester subjectivity, a major source of the scatter in the data.

6.2 Meteorological Analysis

- A comparison of Environment Canada precipitation measurements with the ombrometer did not lead to a one-to-one relationship, since the ombrometer is greatly affected by the wind.

- Comparison of Environment Canada data with the plate pan data provided an improved correlation between the two instruments.

- Any future measurements with the plate pan should be done in duplicate to minimize human error. The plate pan contents should be weighed using an electronic balance, once again to decrease the error.

- In order to correlate the measurements of precipitation from the ombrometer and the plate pan, the terminal velocity of the falling precipitation is required. This can be computed using a snow mass concentration device (from the NRC), or directly from a POSS.

- A preliminary relationship of visibility and precipitation rate was developed by the NRC. This relationship, when applied to the snow types measured by Environment Canada as a function of precipitation rate, resulted in a categorization of snow types into three groups (light, moderate and heavy), which may be used in the short term. For the longer term, more research and improved snow sensoring equipment are required.

- When comparing the other meteorological data from the test site with that of Environment Canada, the only major differences occurred in the wind speed. The test site wind speeds were about 70% lower because of the difference in height of the anemometers.

6.3 Flat Plate Tests

Tests were undertaken in natural snow, artificial snow, freezing drizzle, freezing fog, no precipitation and rain on a cold-soaked surface.

6.3.1 Natural Snow

- The multi-variable linear and non-linear regression generally resulted in higher R^2 values than those of previous years. The R^2 for the Type II and Type III regressions ranged from 81% to 96%.

- A dimensional analysis of the fluid A-199 (Type II) data set resulted in a useful correlation between fluid failure time, direct wind speed, temperature, rate of precipitation and relative humidity with an R^2 of 95%. The relationship shows wind having the strongest influence followed by the rate of precipitation and temperature (almost equal influence), with the relative humidity having a weak effect.

- The wind has significant effect on the failure time of Type I, II and III fluids. In general, low and high winds tend to lower the failure times at a given rate of precipitation. It is suspected that this is due to the combined effect of gravity and wind forces on the plate.

- The fluid failure time generally decreases with an increasing rate of precipitation in a logarithmic manner.

- Cold temperatures generally result in lower failure times.

- Because the tests are performed under adiabatic (no heat transfer) conditions, the relative humidity should not be a factor. However, the analysis shows that it has a weak influence on the fluid failure time, probably because it is correlated with the snow type.

- Amongst the Type I and II fluids, a slight difference due to the different fluid brands was observed. Only one Type III fluid was tested.

- The Type I and II fluid tests which resulted in failure times below the corresponding SAE guidelines were all performed under the snow storm of March 13, 1993 when the rate of precipitation was above 34 $g/dm^2/hr$, the average winds were in excess of 25 kph and the temperatures were below -7°C. Montreal International Airport remained operational on that day.

- In the Type I fluid tests, only 3 out of the 151 tests resulted in failure time inferior to the SAE lower limit and 68% of the times were higher than the upper limit.

- In the Type II fluid tests, 8% of the times fell below the lower limit but only 39% fell above the upper limit.

6.3.2 Artificial Snow

- The log-log relationship between the fluid failure time and the rate of precipitation in the natural snow results seems to also hold for the high precipitation rates in the artificial snow tests.

- The precipitation of artificial snow onto the fluid covered plates seems to be quite representative of the natural condition despite the different snow crystals produced.

6.3.3 Freezing Drizzle

- The statistical analysis of the test results provided an insight into the factors affecting the failure times.

- Simulated freezing drizzle tests provided a good correlation with natural conditions.

- Both simulated and natural freezing drizzle results correlate quite well with the laboratory water spray endurance curve reported by UQAC for a typical Type II and Type III fluid.

- Fluid failure time in freezing drizzle is generally governed by the fluid type, the rate of precipitation and the temperature.

- For Type I fluids, all test points lie above the SAE lower limits and 90% lie on or above the upper limit.

- For Type II fluids, all test points lie above the SAE lower limit but only 50% lie above the upper limit.

- The limited 75/25 diluted Type II data shows failure times above the lower limit with 44% of the times greater than the upper limit.

- The limited 50/50 diluted Type II tests resulted in failure times above the SAE lower limit with 94% of the times above the upper limit.

6.3.4 Freezing Fog

- The two main parameters affecting fluid failure in freezing fog are fluid type and rate of precipitation.

- The rate of precipitation occurring in nature is believed to be in the lower end of the test range under the simulated conditions.

- A useful relationship relating fluid failure time and rate of precipitation was established for a typical Type I fluid with an R^2 of 93%.

- In Type I fluid tests, only one out of 44 tests resulted in times below the SAE lower limit; 34% of the points lie above the upper limit.

- Among the limited Type II fluid tests, 9 out of 10 points are above the lower limit, but none lasted beyond the upper bound.

6.3.5 No Precipitation Condition

- The Type I fluid thickness stabilizes within 5 minutes, which is 2 to 3 times faster than those of Type II and III fluids.

- The stabilized thickness is greatest for Type II fluids followed by Type III and then Type I.

- The Type I fluid thickness distribution is such that it is thinnest near the top of the test plate and thickest near the bottom, which is consistent with the Type II and Type III results.

6.3.6 Rain on a Cold-Soaked Surface

- This preliminary study indicated that the cold-soaking phenomena observed on aircraft can be simulated and should be pursued on future testing programs.

6.4 Ice Sensor Tests

- The current IM 101 and FM 202 sensors cannot detect Type I fluid failure for any of the precipitation (natural and artificial snow, freezing drizzle and fog) and should not be used to determine failure on future Type I fluid tests. However, it would still be useful if the test procedures are changed to eliminate the transient fluid thinning period.

- In artificial snow tests, the limited data obtained showed the possibility of a good correlation between sensor reading and observed failures for Type II and III fluids.

- In freezing drizzle tests, a good correlation between sensor reading and observed failure was obtained for Type II and III fluids.

- In freezing fog tests, the limited data obtained showed the possibility of a good correlation between sensor reading and observed failures for Type II and III fluids.

- Sensor admittance versus fluid calibration curves have been obtained and should be verified in future thickness tests (without precipitation).

- The thickness decay curve for Type I is similar to those for Type II and III but stabilizes more rapidly (within five minutes).

6.5 Aircraft Surface Tests

- The test data on the curved surfaces (wing, horizontal stabilizer and the leading edge plate) showed a 1:1 relationship with the flat plate, which is consistent with the results obtained by United Airlines on a large commercial jet aircraft.

7. RECOMMENDATIONS ON FUTURE TESTING

This section outlines the direction and scope for future testing. The positive results obtained due to improvements in the meteorological data collection can not be overlooked. Future testing should, therefore, be undertaken on the basis that a plan is in place to refine the data even further.

- Focus the 1993-1994 test program on diluted (75/25 and 50/50) Type II fluids, in order to verify the SAE limits specified for these fluid mixes under the various environmental conditions. Some secondary Type I, II and III (neat) tests should be performed simultaneously.

- Record the fluid failure event via a combination of ice sensors, video camera and an electro-optical external sensor. This will minimize the error resulting from the subjective nature of visual observations of the end condition.

- For the natural snow tests at Dorval:

  a) Call the fluid failure criteria at "slush contamination" as well as at the usual "non-absorption capability", to study the difference;

  b) Perform flat plate tests simultaneously inside and outside a "Wyoming" wind shield (see Figure 7.1), to study the effect of winds;

  c) Shield the ombrometer from wind in order to obtain more meaningful readings of rate of precipitation;

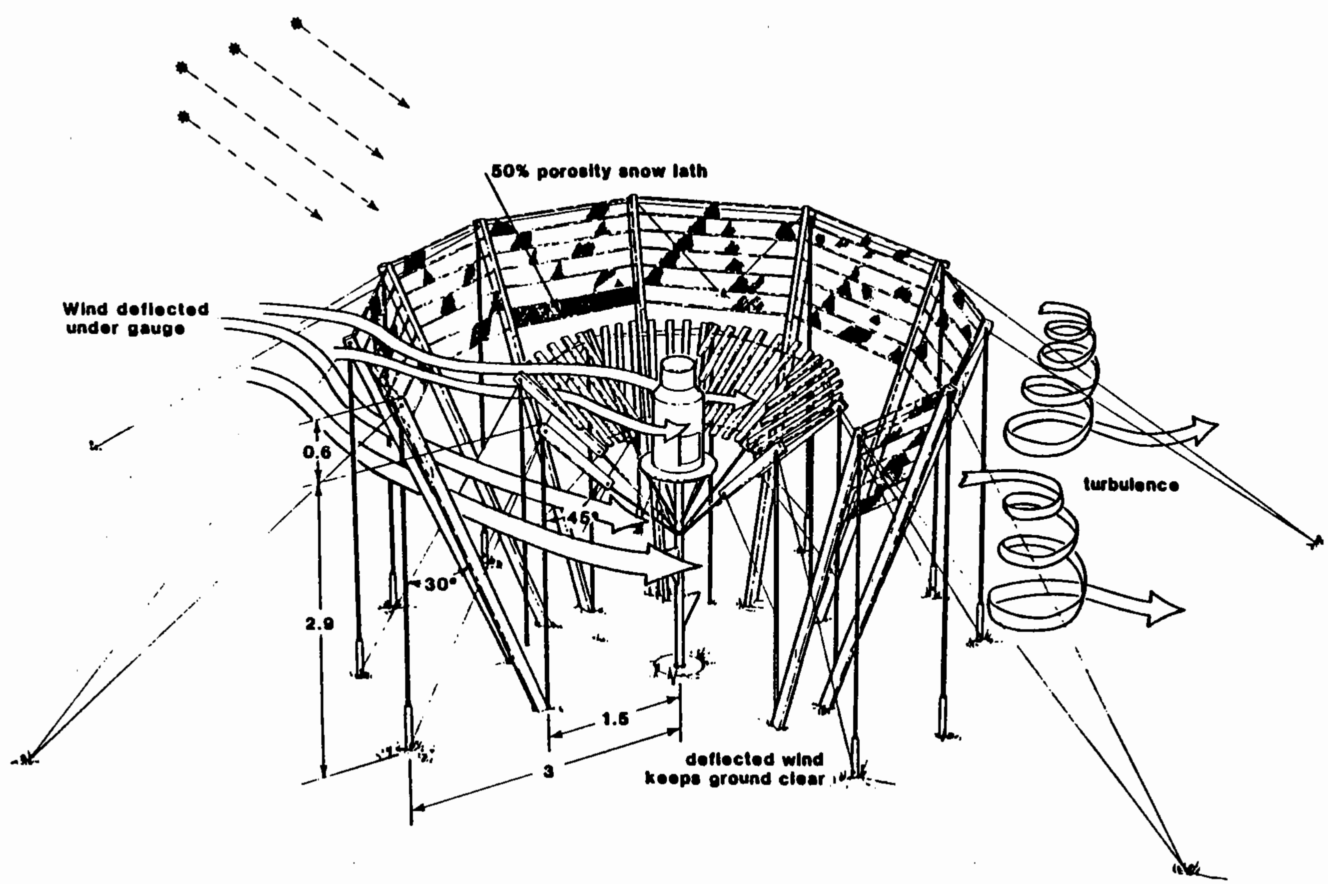
  d) Use a snow mass concentration measuring device OR a terminal velocity measuring instrument such as the POSS to more accurately determine the quantity of water landing on the test plates;

  e) Locate one plate pan in the wind shield and at least one outside in order to study the effect of wind on the rate of precipitation;

FIGURE 7.1

DESCRIPTION OF WYOMING SHIELD

A cross-section of the Wyoming Shield reveals its simple but effective design



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f) Identify the snow type according to a simple classification and record for each test;

g) Combine this year's (1992-1993) Type III fluid test results with the 1991-1992 data to aid in the establishment of the holdover time guidelines.

- In artificial snow tests, consider lowering the rate of precipitation (perhaps with different nozzles) to a level that is more representative of natural conditions.

- In freezing drizzle tests, lower the rate of precipitation in order to represent more closely the natural conditions, particularly for the diluted Type II fluids.

- In freezing fog tests, concentrate on Type II and III as well as the diluted Type II (75/25 and 50/50) fluids.

- For the cold-soaked surface testing:

  a) The box should be shallower but filled up (with fluid) to retain the cold temperature on the top panel;

  b) Tests on two boxes should be carried out simultaneously, one with fluid applied externally and one without;

  c) A suitable temperature probe should be used to monitor the skin temperature of the top panel;

  d) A removable insulating jacket should be used to minimize heat transfer in the side and bottom panels.

- For the ice sensor tests:

  a) During natural snow, the current sensors may be employed for Type II fluids but will not agree with visual failure determination unless the failure criterion is changed from "loss of absorption capability" to "appearance of slush".

  b) More artificial snow tests should be performed to investigate the existence of the good correlation between the sensor and observed failure times.

  c) Future freezing drizzle tests could be performed using sensors to reduce experimental errors.

  d) Further freezing fog tests should be performed to investigate the existence of the good correlation.

- Some hot water testing should be performed on flat plates.

- A more definitive aircraft surface fluid failure criteria must be established. Also, more aircraft testing under snow must be carried out. Various options are presented in Appendix D.

- More effective snow clearing around the test stand is required to avoid accumulated snow being blown onto the test plates. A snowblower will be required for this purpose, provided it does not interfere with AES equipment.

- Anchor attachments for the (proposed) wind shield and the (existing) weather recording instrument platform are required.

- Hardware/software must be designed to collect and process the data from the various items of equipment (sensors, ombrometer, thermometer, anemometer and the relative humidity meter). The system should not only be capable of displaying any of these parameters but should also be able to predict failure times using a database/theoretical analysis of previous data.

- Since the bulk of testing will be conducted on diluted fluids, a refractometer should be purchased to ensure the proper dilution of the fluids.

- Fluid thickness tests should be carried out for diluted 50/50 and 75/25 Type II fluids. Sensor admittance versus fluid calibration curves should be verified in future thickness tests (without precipitation).

- For the recording of test results, use "Poly Ar+2" water resistant synthetic paper and pressurized space pens.

APPENDIX A

TEST PROCEDURES AND EQUIPMENT LIST

FIELD TESTING OF DE/ANTI-ICING FLUID FOR THE PURPOSE OF SUBSTANTIATING HOLDOVER TIME TABLES

Version 3.0
1992-1993

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 - Weathertronics Model 1600
range 0-1000 counts
linearity 0.05%
(B) Power Supply & Enclosure - Weathertronics Model 1020

(C) LCD Digital Display - Weathertronics Model 1991

2.1.1.4 PC Interface Option

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

2.1.2 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

A large low cakepan (6"x6"x2" minimum) may be used to collect and weigh snow.

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 the 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).

2.2.1 Cole Parmer P/N N-08110-25, probe P/N N-08500-55 available from Cole Parmer Instrument Company, Chicago Illinois.

2.2.2 Omega 450AKT Thermocouple thermometer available from Omega Engineering Stamford Connecticut.

2.2.3 or thermocouple thermometer equivalent to 2.2.1 or 2.2.2.

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 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 cm from each side; this marks off a working area of 2 26 x 50 cm on each panel. All marks shall be made using a 1/8" thick black marker, 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. Supports may be needed under the panels to avoid sagging under heavy loads.

2.5 Fluid Application

The fluid should be poured onto the plates from a beaker or a bottle.

Alternatively, the fluid may be sprayed on with a low pressure garden sprayer equipped with a ¼ P3510 Flatjet Nozzle (35 degree angle). The Flatjet Nozzle is available from Spraying Systems Company USA.

2.6 Film Thickness Gauge

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 Videorecorder

Where feasible a videocamera 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 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.

2.10 Additional Equipment

- Squeegee
- Extension power cords
- Stopwatch

3. DE/ANTI-ICING FLUIDS (INCLUDES INSTRUCTIONS FOR FLUID SUPPLIERS)

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 will 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.

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 the new wind direction.

4.1.2 Rain Gauge

Place the Rain/Gauge on one side of the test fixture at a distance between 1 and 2 meters from the 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 if maybe necessary to raise the snow gauge above the drift level but no higher than the test panel.
It may be preferable to use a rain gauge snow fence such as the Weathertronics wind screen Model 6410.

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 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 milligram. Weigh again after test completion to determine the true water content reading of the snow.

Use of more than one cake pan is recommended to provide multiple readings through the course of the test period; mounting one pan on the test stand along side the plates at the same orientation and one horizontally off the stand is recommended.

4.2 Test Panel Preparation

4.2.1 Before the start of each day's testing, wash the panels with a solvent such as isopropyl alcohol followed by a wash with an alkali detergent. Rinse thoroughly with water and dry.

Between tests wash the panels with pure glycol (NOT type I fluid) and wipe dry.

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

Store fluids in containers at room temperature between 20-24 C.
Except for type 1 fluids, all fluids should be 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 sane fluid, load the second test fluid on panel V followed by panel Y; use location W as the bare test panel and location Z for a precipitation measuring device such as a cake pan. Allow the fluid to settle for five (5) minutes.

4.3.4 Thickness Measurement

Between the 3-5 minutes interval following test commencement time measure the fluid thickness at the centre of the 15 cm line (C in figure 2).

4.4 Holdover Time Testing

4.4.1 Set the timer on as the first fluid application starts. Note the time when fluid application is completed.

4.4.2 Commence recording the test with a video recorder or take pictures at time 0 and then at one (1) and five (5) minute intervals for freezing rain and snow respectively until the test reaches the END CONDITIONS.

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, e.g. white snow) on the fluid at the crosshair when viewed from the front (i.e. perpendicular to the plate). The crosshair does **NOT** need to be obscured (as was the case in the 1990-1991 test season), you are looking for an indication that the fluid can no longer accommodate the precipitation at this point.

or

- Ice (or crusty snow) has formed on the crosshair (look for ice crystals). This condition is only applicable during freezing rain/drizzle or during a mixture of snow and freezing rain/drizzle.

As these determinations are subjective in nature, the following is **very important**:

- 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 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

At the end of the test as the plate is being cleaned record for each plate any of the following occurrences:

1) There are some frozen patches on the plate itself;
2) A sheet of ice (not necessarily covering a large area) has formed on the fluid itself but has not reached the plate;
3) Any case where the fluid is difficult to remove not covered by cases 1 or 2, e.g. the fluid/snow mixture has a paste-like consistency.

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.

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 1
TEST STAND

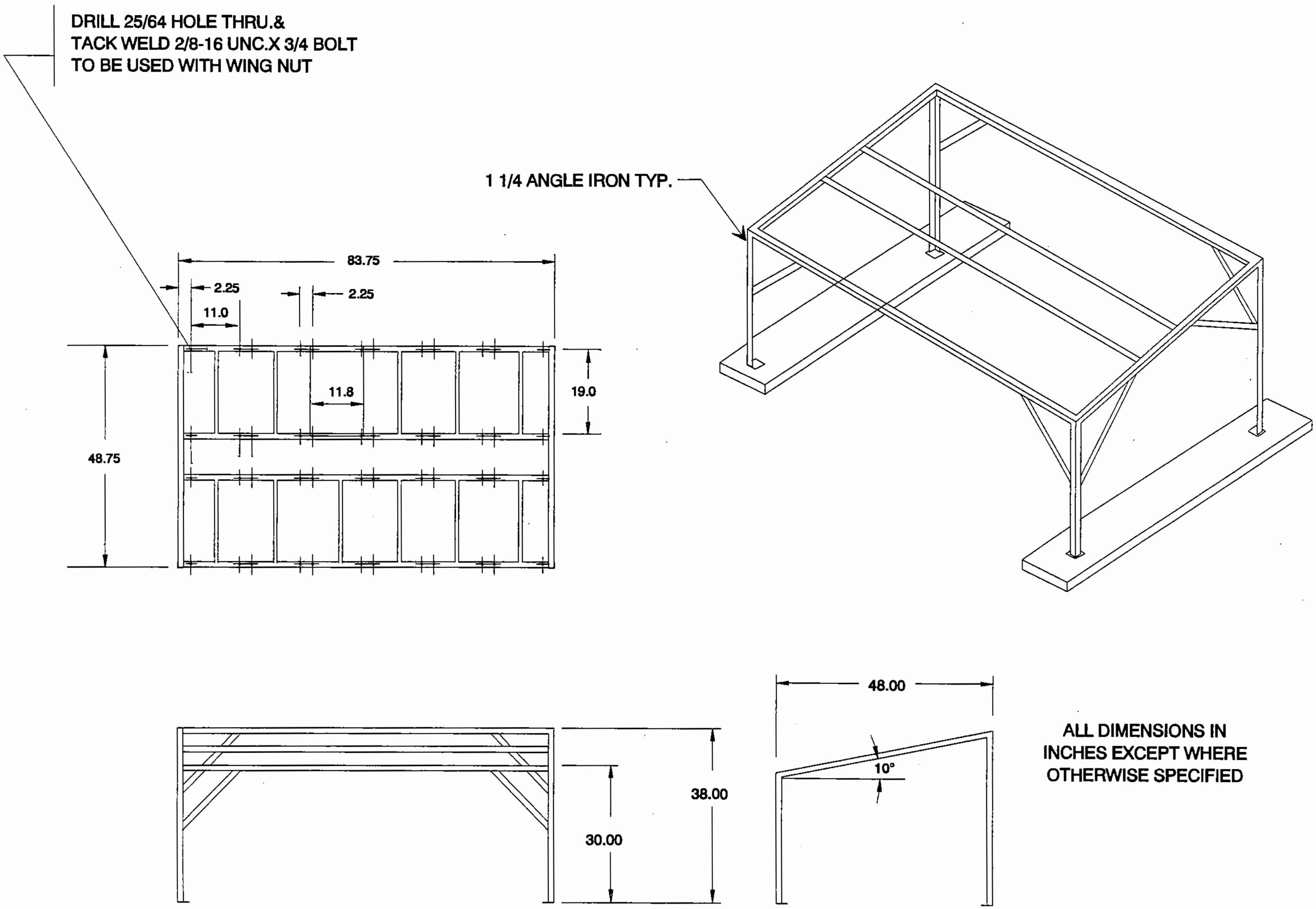

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FIGURE 2
FLAT PLATE MARKINGS

TYPICAL PLATE

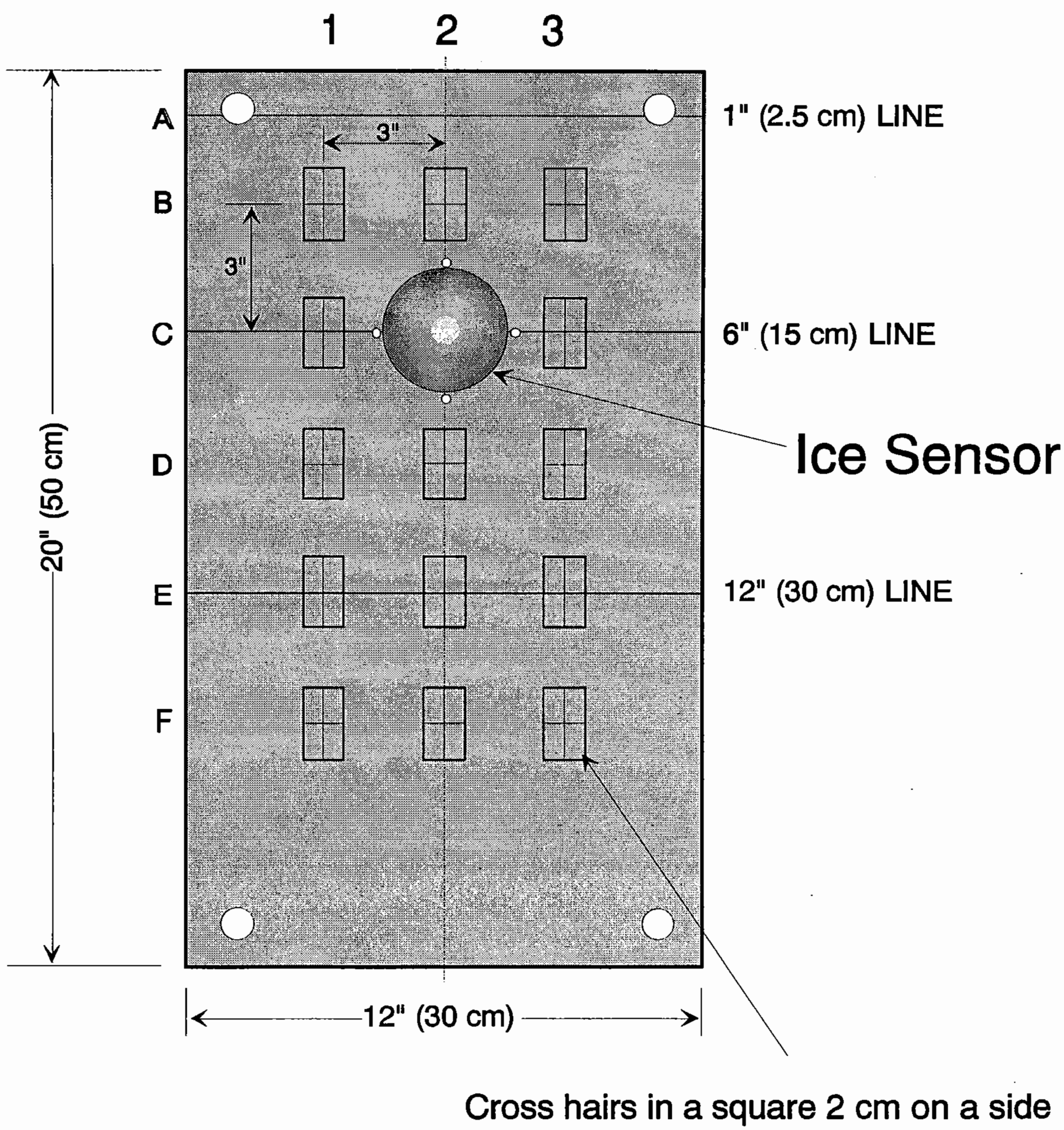


TABLE 1
DE/ANTI-ICING DATA FORM

REMEMBER TO SYNCHRONIZE TIME

28-Sep-93

LOCATION:	DATE:	RUN NUMBER:	CIRCLE SENSOR PLATE: u v w x y z
	Time Before Fluid Application:	Time After Fluid Application:	STAND # :

FLUID FILM THICKNESS MEASUREMENTS

		PLATE U	PLATE V	PLATE W
TIME FROM START		: min:sec	: min:sec	: min:sec
THICKNESS	15 cm LINE	mils	mils	mils
		PLATE X	PLATE Y	PLATE Z
TIME FROM START		: min:sec	: min:sec	: min:sec
THICKNESS	15 cm LINE	mils	mils	mils

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

DIRECTION OF STAND:

CONTROL PLATE COMMENTS:

SNOW/RAIN CATEGORIES:

OTHER COMMENTS:

PERFORMED BY: ASSISTED BY:

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (MINUTES)

	Plate U			Plate V			Plate W		
FLUID NAME / SENSOR NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE CONTAMINATION									

TIME OF SLUSH FORMATION ON SENSOR HEAD	1st	¼	½	¾	Full	1st	¼	½	¾	Full

DIFFICULTIES IN REMOVING FLUID (ICE, etc.)			

	Plate X			Plate Y			Plate Z		
FLUID NAME / SENSOR NAME									
B1 B2 B3									
C1 C2 C3									
D1 D2 D3									
E1 E2 E3									
F1 F2 F3									
TIME TO FIRST PLATE CONTAMINATION									

TIME OF SLUSH FORMATION ON SENSOR HEAD	1st	¼	½	¾	Full	1st	¼	½	¾	Full

DIFFICULTIES IN REMOVING FLUID (ICE, etc.)			

APPENDIX B
SAE/ISO HOLDOVER TIME TABLES

APPENDIX B

SAE/ISO HOLDOVER TIME TABLES

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 °C	OAT °F	Type II Fluid Concentration Neat-Fluid/Water [% by Volume]	Approximate Holdover Times Anticipated Under Various Weather Conditions (hours: minutes) 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 °C	OAT °F	Approximate Holdover Times Anticipated Under Various Weather Conditions (hours:minutes) 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		

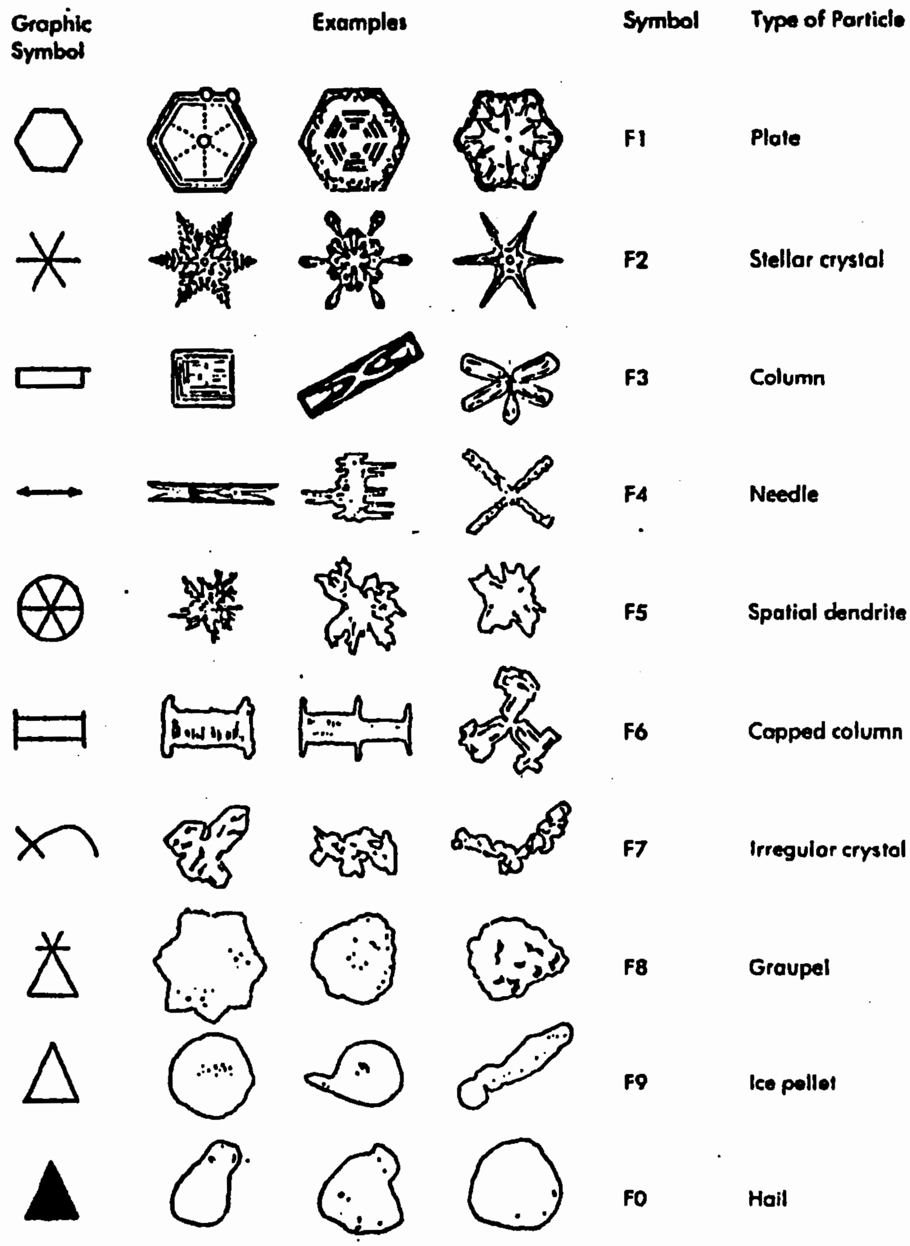
THIS TABLE DOES NOT APPLY TO OTHER THAN SAE OR ISO TYPE I FPD FLUIDS.

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

APPENDIX C
INTERNATIONAL CLASSIFICATION FOR SOLID PRECIPITATION

APPENDIX C

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 D
FULL SCALE AIRCRAFT TESTING

FLUID FAILURE TESTING ON FULL SCALE AIRCRAFT

Introduction

Field tests conducted by United Airlines at Denver Airport during several past winter season have shown that a one to one relationship exists between de/anti-icing fluid failure time on a flat plate and that on a large commercial jet aircraft. This result was somewhat substantiated by preliminary tests conducted by APS Aviation on a variety of small aircraft surfaces. However, these tests were primarily conducted under simulated freezing fog and freezing drizzle and artificial snow conditions with only a limited number carried out under natural winter conditions. Furthermore, the criterion for the aircraft surface fluid failure was subjective and could vary depending on the observer.

Hence, the scope of the 1993-1994 test program should include flat plate versus full scale aircraft comparison tests under natural winter conditions using a small size aircraft with a well defined failure criterion. Three recommended options are outlined with a discussion on the advantages and disadvantages of each, the required equipment and some sources from where this equipment may be obtained. A brief description of the discarded options are also presented for completeness. A series of tests on the existing Beech King Air horizontal stabilizer and the F-28 leading edge model can also be performed in conjunction with the selected option.

Option A: Full-Scale Aircraft at Gatineau Airport

In this option, an aircraft will be leased for the period of testing and tested outside a hangar of Gatineau Airport. Preliminary discussions with the airport administration indicates that the airport towing and de/anti-icing services will be available for use. Pemair is the principal operator from this airport with its fleet of Beech King Air's.

Advantages:

- The actual de/anti-icing fluid application procedures can be replicated during the tests;
- Airport is close to ADGA's corporate headquarters in Hull;
- Access to towing and de/anti-icing services is convenient as the airport operation is small;
- Security clearance is easy to obtain;
- The airport administrator has indicated that he has no objections to use other fluids (other than the Type I being used) on the de/anti-icing truck.

Disadvantages:

- Because this site will be temporary, some set-up time will be required before each testing period;
- Displacement of personnel and equipment will be required as the proposed site is approximately 200 km away from the regular testing facilities at Dorval.

Contacts:

Airport Director of Operations: (819) 663-0737

Pemair: (819) 663-9903

Option B: Full-Scale Aircraft Testing at Montreal International Airport

In this option, an aircraft will be leased and testing will be carried out in the general aviation grounds of the airport. The de/anti-icing will be performed by a de/anti-icing agent servicing aircraft at this location. One general aviation operator who is willing to lease an aircraft for the testing is Somiper Aviation. A Beech King Air, a Metro liner or a Cessna Citation can be leased at a rate of under $200 per day. This operator also owns a de-icing vehicle filled with a Type I fluid but he has no objections to using any other approved fluids. Hudson General could also provide the de-icing.

Advantages:

- Actual de/anti-icing fluid application procedures can be replicated during the tests;
- The proposed site is very close to the current permanent test grounds and hence set-up time is shorter than Option A;
- Test personnel can be available at relatively short notice;
- There should be little or no security clearance required to gain access to the grounds.

Disadvantages:

- The choice of fluid(s) is restricted to what is currently used unless supplied.
- An aircraft can be made available only if it is not used or leased out.

Contacts:

Somiper Aviation: 631-3000

Hudson General: 748-2277

Option C: Wing Testing at Existing Test Site

In this option, an entire wing of a commuter or general aviation category aircraft will be secured on stands at the existing test site beside the flat plate test stands. A manual de/anti-icing fluid application will be devised for the tests. The wing can either be obtained from various sources. One source currently under investigation is Canadair, where a Challenger or RJ wing may be available after fatigue testing. Other sources could be a scrap dealer such as White Industries in Kansas City, who can supply a wing from a variety of aircraft including the Learjet 23, the Jet Commander (Israeli version of Learjet), the Hawker Siddeley and the Fairchild Metro II. The cost of a wing ranges from $3000 to $20000 (excluding transport and taxes) depending on the model.

Advantages:

- This option will require less set-up time as the installation will be a permanent one;
- More test data will be obtained under this option.

Disadvantages:

- The initial set-up requires time to design, construction and installation of the wing test rig which includes support legs, cables and brackets;
- The manual fluid application may not represent fully the application by an aircraft de/anti-icing vehicle. However, this drawback may be compensated by performing thickness tests in the absence of precipitation and correlating the results with similar tests performed on the same wing with an actual de/anti-icing vehicle.

Contacts:

Canadair: 744-1511

White Industries: 1-800-821-7733

Discarded Options

The following additional alternatives were also investigated but discarded for various reasons described below:

(i) The DC-8 parked in the general aviation area where Somiper Aviation operates could have been used except that, due to the height of the wings off the ground, a de-icing vehicle with a boom would have been required and visual inspection of the fluid failure would have been difficult;

(ii) An alternative to Option C, whereby a de/anti-icing vehicle (from Hudson General for instance) is used to apply the fluid was also considered. This was discarded because the vehicle would have a problem in getting close enough to the wing at the existing test site and the spray may contaminate the nearby Environment Canada's meteorological instrumentation during windy conditions;

(iii) Another alternative to Option C could be to conduct the wing tests in the general aviation area so that the de/anti-icing vehicle could be used. The drawback of this option is the displacement of the wing and a testing space is required.

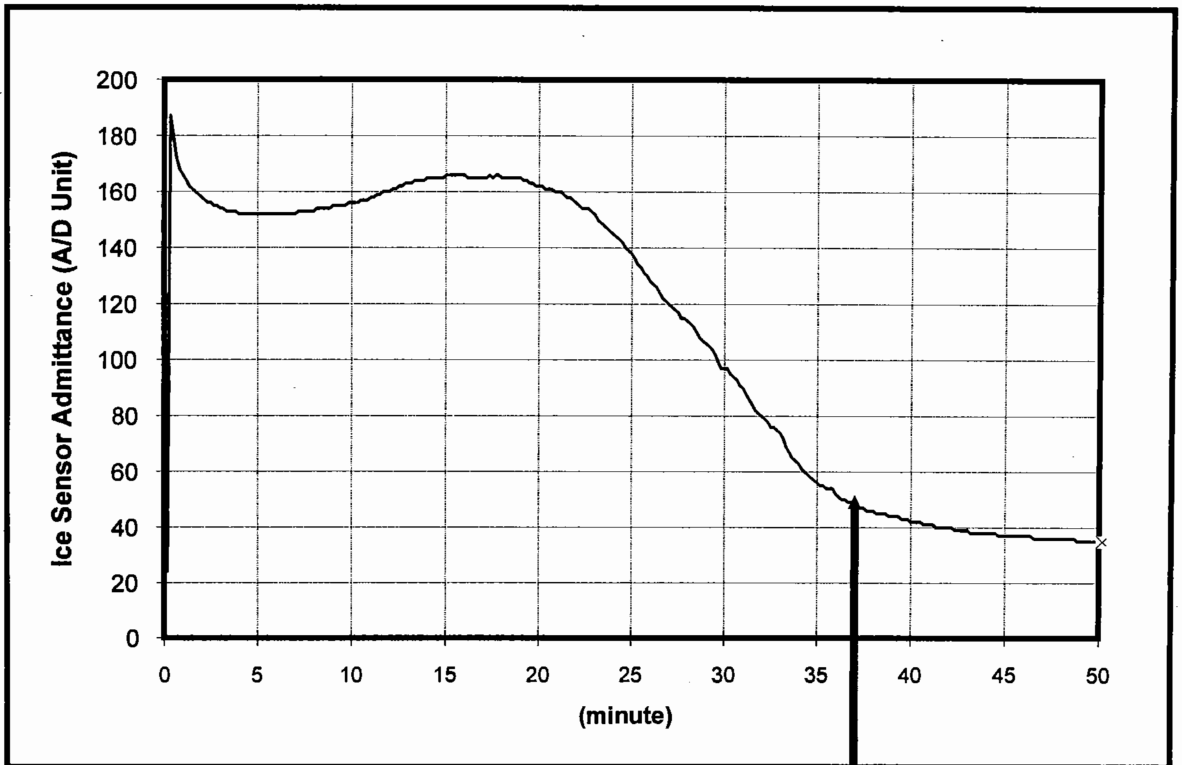
APPENDIX E

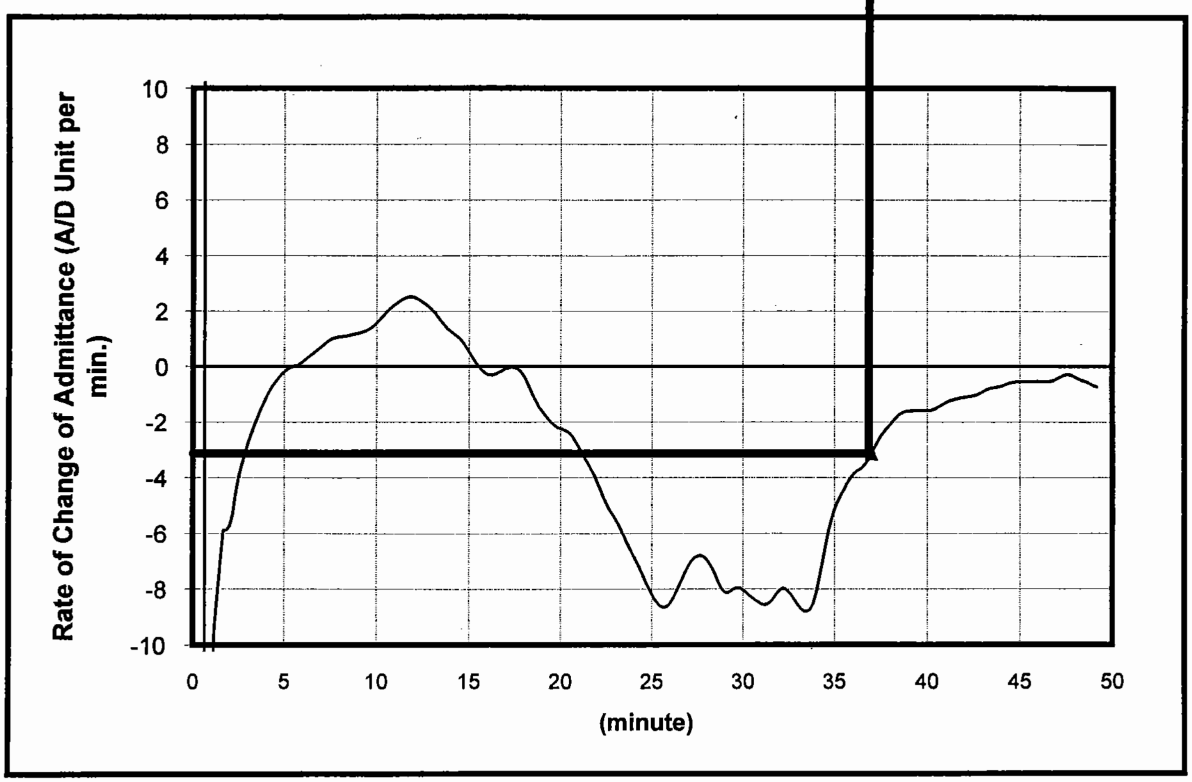
DETERMINATION OF SENSOR FAILURE TIME

DETERMINATION OF SENSOR FAILURE TIME

The sensor failure time is defined as the time at which the admittance begins to level off (approaches zero slope). Although this time can be easily determined visually from the sensor admittance traces for the artificial snow, freezing fog and freezing drizzle tests, this is not the case for the natural snow tests. In future tests, a first derivative (gradient) trace or a more optimum interpretation may be used to remove all subjectivity from the determination of this time. Figure E.1 is an example of such a method of sensor failure time determination created by plotting the first derivative of the admittance versus time curve. Ideally, failure could be signalled when the trace of this curve reaches the zero value. However, under natural snow conditions it has been observed that the slope may not reach zero for some time after a visual failure has been called. Using a zero slope as a trigger could therefore over estimate failure times significantly. To counteract this, an arbitrary tolerance of -3.0 A/D units per minute has been included. A failure call would then be triggered when the rate of change of admittance reached -3.0 A/D units per minute. This value is clearly shown in Figure E.1. Future testing may provide sufficient information to alter the value of the tolerance used. Alternatively an interpretation algorithm, perhaps with consideration to time history, needs to be developed.

FIGURE E.1
SENSOR FAILURE TIME DETERMINATION





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APPENDIX F
DE/ANTI-ICING FLUID HOLDOVER TIME MEASUREMENTS
AIRCRAFT AND FROSTICATOR PANEL CORRELATION
SNOW CONDITIONS AT DENVER
UNITED AIRLINES

Deicing/Anti-Icing Fluid Holdover Time Measurements Aircraft and Frosticator Panel Correlation - Snow Conditions

Murray H. Kuperman
United Airlines
Engineering
Maintenance Operations Center
San Francisco, California

R. K. Moore
United Airlines
Ramp Services Training
Stapleton Airport
Denver, Colorado

Deicing/Anti-Icing Fluid Holdover Time Measurements Aircraft and Frosticator Panel Correlation - Snow Conditions

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ABSTRACT

Deicing fluid (Type I), used to remove frost, ice and snow from aircraft surfaces and Anti-Icing fluid (Type II), used as a surface covering to protect against further freezing precipitation, have finite protection times. Protection or holdover times are a function of many variables; among them type of fluid and viscosity, storm water content, temperature, wind speed and direction.

FAA regulations require that an aircraft be "clean" for takeoff which means no adhering frost, ice, snow or slush on aircraft aerodynamic surfaces. The end of holdover time, in theory, marks the transition from a clean to a contaminated surface. Holdover time should be used as a departure planning tool by the pilot in command in conjunction with a pretakeoff check.

This paper describes four years of effort measuring fluid holdover times at Denver Stapleton and Chicago O'Hare airports in freezing precipitation conditions. The majority of tests were conducted in snowstorms. Test results substantiate the present SAE Holdover range of time guidelines for snow.

The 1992/1993 winter holdover time testing procedure included comparing protection times of fluids sprayed on a 727 aircraft wing versus test panels. The difficulties in conducting winter tests in general are discussed. To encourage further comment and test effort, we prepared a videotape of our test procedure and results. This videotape was shown at the June 1993 SAE Ground Deicing Conference.

INTRODUCTION

Late in 1987, improved aerodynamic performance anti-icing fluids were introduced to the airlines as a method of obtaining longer "clean wing" freezing precipitation protection. A United team investigated both laboratory climatic chamber testing and operational use of anti-icing fluids by visiting Lufthansa, British Airways, SAS, Air Canada and several fluid suppliers. We then flight tested three materials on a 727 aircraft at Denver Colorado.

Upon completion of testing, we worked with equipment suppliers and participated on an SAE Ad Hoc committee to develop deicing truck modifications for spraying Type I and II fluids from the same basket. Facilities for storing and pumping Type II were then developed and installed in Chicago and Denver for an operational evaluation. After testing at ORD and DEN, Type II was implemented at 32 additional airports. During this operational development period, we worked with the SAE and ISO to develop Type I and II material and application standards. These standards have been incorporated into our Winter Operations plan in conformance with 14 CFR 121.629.

HOLDOVER TIME

During our laboratory climatic chamber studies of Type II fluid protection time, it became apparent that precipitation water content was a major variable. Given variations in storm water content, we then questioned whether a holdover time guideline which specifies one time under a particular weather classification, e.g. STEADY SNOW, would be appropriate for all storms in all regions of the country. We decided that testing in "real" weather was necessary and proceeded to develop a method based on a fluid supplier's laboratory procedure and test panel configuration. In winter 1989/1990, a one inch ice front was considered to be the end of protection time for the fluid measured. Weather parameters such as temperature, relative humidity, wind direction and speed were recorded during the test. The fluid was allowed to settle for three minutes prior to test start. Measured holdover times were inconsistent reflecting the large number of weather related and procedural variables.

Before the 1990/1991 winter, we participated in a SAE Working group formed to develop an improved method for measuring holdover time. The group is chaired by the FAA and Transport Canada. 1989/1990 test procedures were deemed inadequate because the test panels were small, had flanges at the edges and scribed distance lines. We also found that an ice front did not form on all test panels. Some panels had random snow accumulation and some had slush buildup. We decided to use larger aluminum panels (30 X 50 cm), sloped at 10 degrees and offset mounted in a steel frame. All distance lines would be inked or painted and there would be no flanges to deflect airflow over the

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panels. End of protection time had three criteria, any one of the three sufficient to end the test. The criteria were a one inch ice front or random snow accumulation - 5 of 15 grids obscured or fluid loss of gloss with 5 of 15 grids obscured. All test sites used the same Type I and II fluids which were supplied in a sheared condition by the material manufacturer.

During the 1991/1992 winter, we compared panel holdover time tests with the holdover time of fluid applied to a 737 aircraft wing positioned into the wind. Coverage of one third of the wing leading edge area was selected as the end of protection time. Attempts to video the tests met with varying degrees of success so we decided to improve the procedure for the 1992/1993 season.

1992/1993 HOLDOVER TIME TESTS - Working with the SAE and the National Center for Atmospheric Research (NCAR), we developed a test program with the following goals:

1. Test during winter storms to obtain Type I and II fluid freezing precipitation protection time (holdover) information to validate SAE/ISO guidelines on an aircraft wing, on Frosticator test panels and compare test results obtained on the two surfaces.
2. Video aircraft continuously during the storm at the following locations: cabin interior best vantage point to wing exterior, leading and trailing edges of the wing in close-up and wide angle.
3. Video the 30 X 50 cm Frosticator panel continuously for comparison with 727 aircraft wing condition.
4. Validate "Nowcasting" radar measurement of snowfall water content and rate (NCAR activity) using electronic snow gauges, manual snow gauge and cakepan catch. Weather parameters (wind direction/speed, temperature, humidity) are measured by NCAR PAM station.
5. Provide ground ice detector computer information to Transport Canada to assist in correlating "end of protection times" between test sites.
6. Provide a video summary of test results comparing aircraft surfaces and the Frosticator panel for industry discussion and correlation purposes.

1992/1993 HOLDOVER TIME TEST PROCEDURE

Equipment needed - As follows:

727 aircraft
Type I/II deicing/anti-icing truck
Work stands
High intensity lighting
Several extension cords
Six VHS video cameras with tripods
Frosticator test stand with test panel
Digital thermocouple thermometer and probe
Digital humidity indicator
Digital electronic balance
Stop watch
Two 6 X 6 inch snow collection pans
Eight inch diameter snow gage
Belfort and ETI snow gages
Wyoming Shields
PAM Weather station
(Portable/Automated/Mesoscale)
Computer modem, computers etc.

Personnel needed - minimum of four: deicing/anti-icing truck operator, two video camera persons and a Frosticator test stand operator. For consistency purposes, the same people should call the end of protection time for each test.

Environment needed - Freezing precipitation with minimum duration of two hours - more intense storm than snow flurries.

Materials needed - As follows:

- o Heated 50/50 Type I fluid mix in the truck.
- o Similar Type I fluid in one quart nalgene bottles - room temperature.
- o Concentrated Type II fluid in the truck.
- o Similar Type II fluid in one quart nalgene bottles - room temperature. Retain sample from truck for viscosity measurement.
- o Isopropyl alcohol for test panel cleaning.

Preliminary Action required - after obtaining the equipment and materials mentioned above.

1. Install fresh batteries in all battery-powered equipment.
2. In case of PAM station problem, arrange for computer tabulation of tower windspeed and direction versus time. Ensure NCAR PAM station and snow gauges operational.
3. Make sure Frosticator panel grids are visible and repaint if necessary.
4. Locate aircraft with wing trailing edges into the wind, deicing truck at the ready, work stands with video cameras operating and Frosticator test stand slightly outboard of the wing tip positioned with wind blowing up the panel from bottom to top. Locate high intensity lighting to assure good visibility of upper wing and Frosticator surfaces. Be careful not to locate any of the lights too close to test surfaces where they can shield the wing or panel.
5. Heat Type I deicing truck fluid to 180 degF. Type II fluid to be applied cold. Frosticator test panel fluid to be applied at room temperature (inside trailer).
6. If windy, wipe a thin layer of glycol around inside surfaces of collection pans and snow gage to aid in snow retention. Weigh snow collection pans to nearest 0.1 gram; cover and locate one pan adjacent to aircraft and the other in the Frosticator stand. Cover snow gage and locate between aircraft and test stand.
7. Clean Frosticator panel of dirt, snow, ice etc. and keep clean prior to fluid application. Wipe panel with Type I prior to test fluid application.
8. Obtain blank holdover time data recording sheet and indicate test location, date and test start time. Record test fluid type, manufacturer and concentration.

Ready to Test - Proceed as follows:

1. If PAM station is not operating, measure and record air temperature and relative humidity.

Otherwise, record start time of day to correlate with PAM weather parameters and snow gage measurements for Nowcasting. Make sure wind speed and direction readings are being provided. Record the type of precipitation.

2. If Type I deicing fluid test, clean all freezing precipitation from the aircraft using high pressure heated glycol. Test time starts at beginning of final glycol pass. Uncover the snow gage and collection pans. At the same time the aircraft wing is sprayed, apply Type I fluid to the Frosticator test panel. Begin videos of wing leading edge and other locations.
3. If Type II fluid test, clean freezing precipitation from the aircraft using step 2 procedure, cleaning the Frosticator test panel with Type I fluid. Within three minutes, apply Type II cold concentrate to the aircraft wing and test panel. Test time starts immediately. Measure and record Type II fluid thickness on the test panel 6 inch line # 1 grid location five minutes into the test. Uncover collection pans and snow gauge and begin the videos.

Test end condition - defined as when accumulating precipitation fails to be absorbed over about one third of the panel or aircraft surface tested.

Record the contamination locations and holdover time. Cover the snow collection pans and record height of snow in the gauge. Weigh the snow collection pans and determine the storm water content in grams per square decimeter per hour. If PAM station is not operating, remeasure and record air temperature and relative humidity plus final wind speed and direction. Otherwise, correlate NCAR weather measurements with test time. Begin the next test when ready.

DIFFICULTIES ENCOUNTERED IN TESTING - A good amount of perseverance is required on the part of the test team since many things can happen to ruin a holdover time test. For example:

- o The test aircraft is late in arriving
- o The aircraft needs maintenance and can't be used
- o The predicted storm is late in arriving
- o The storm never happens
- o The storm misses your location by a few miles
- o The storm is early and you can't land
- o The storm stops halfway through the test
- o The deicing truck breaks down
- o The deicing truck runs out of fluid
- o The truck heaters won't recycle
- o You can't replenish the trucks from the airport supply
- o The video cameras freeze
- o A connector cable breaks
- o The high intensity lights go out
- o Digital measurement devices freeze or indicate error
- o Can it snow with a digital humidity gage at 20% R.H.?
- o You dump a snow collection pan on the way to weigh
- o Horizontal snow is difficult to collect

HOLDOVER TIME TEST RESULTS

Tables One thru Four detail holdover time test results of 50/50 Type I and 100/0 Type II fluids. Storm water content and weather parameters are given for each test and the results of testing are summarized on Graphs One and Two. Since the test procedure changed each year, observations of end of protection time on panels give a most conservative guideline which is several minutes shorter then on-aircraft test results. The on-aircraft times validate the SAE/ISO guidelines for snow conditions of 6 to 15 minutes for Type I and 20 to 45 minutes for Type II. The shorter times reflect fluid protection during a heavy or wet snow and the longer times light or low water content snow. Some data was collected in very wet heavy snow conditions which required the airport to close - especially on March 8-9, 1992. Results are also available from tests accomplished during the four year program using other then 50/50 and 100/0 fluid concentrations.

Some of the test equipment and two typical "end of protection time" snow contamination comparisons between the aircraft wing and Frosticator panel are shown in Figures One thru Twelve. A summary videotape of testing and wing/panel correlations for the 1992/1993 winter has been completed and will be shown during the June 15-17 SAE conference.

Wind speed and direction related to the orientation of the aircraft were critical during testing. During freezing precipitation, these factors determined where and how fast wing contamination occurred. During 1991/1992 tests, the 737 aircraft oriented with the wind up and over leading edges had leading edge contamination. Trailing edge contamination was the rule in 1992/1993 since the 727 aircraft was located with the wind up and over trailing edges. In the real world of aircraft dispatch, the aircraft may change heading several times and the storm heading may change so the importance of a pretakeoff check of wing condition can not be overstated.

CONCLUSIONS

1. End of protection or holdover times on Frosticator panels are similar to those observed on an aircraft wing. Some part of the wing was always contaminated with freezing precipitation when one third of the panel area was covered with snow. Test results confirm present SAE/ISO Snow holdover time guidelines.
2. Observation of Type II fluid condition at the holdover time endpoint revealed precipitation collected on top of the film. This contamination could be easily removed. We therefore conclude that Type II protects against precipitation adhesion for longer then presently assigned guidelines.
3. Holdover time endpoints are much easier to "read" on Frosticator panels.
4. Aircraft holdover time endpoints will vary due to the many weather and operational factors affecting fluid performance and human perception of what constitutes too much contamination.

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5. Visual endpoint standards (pictures of sample wing contamination) would help but not eliminate variation in observer-perception of what constitutes a "clean" wing for takeoff.
6. Quantification of storm water content and weather parameters real time (Nowcasting) would help to reduce holdover time assignment variability. Receipt of PAM weather data provided more accurate test information this year compared with past measurement methods.

ACKNOWLEDGMENT

The authors wish to acknowledge the assistance of numerous United Airlines employees, the Federal Aviation Administration Technical Center, Stapleton International Airport Field Maintenance, Transport Canada, the National Center for Atmospheric Research and the SAE Holdover Time Working Group of Committee G-12 in accomplishing our fluid protection time measurement program.

APPENDIX

Table One	Results of Winter 1992/1993 Holdover Time Tests
Table Two	Results of Winter 1991/1992 Holdover Time Tests
Table Three	Results of Winter 1990/1991 Holdover Time Tests
Table Four	Results of Winter 1989/1990 Holdover Time Tests
Graph One	50/50 Type I Holdover Time versus Water Content
Graph Two	100/0 Type II Holdover Time versus Water Content
Figure One	NCAR Weather Measurement Equipment Site
Figure Two	Video Camera Enclosure-Leading Edge Position
Figure Three	Video Camera Enclosure-Trailing Edge Position
Figure Four	Frosticator Test Stand in Position
Figure Five	NCAR Weather/Transport Canada Ice Gage Computer
Figure Six	NCAR Weather Radar & PAM Station Display
Figure Seven	Type II Fluid Application to the Aircraft
Figure Eight	Type II Fluid Application to Frosticator Panel
Figure Nine	End of Protection Time - Aircraft Type II Fluid
Figure Ten	End of Protection Time - Panel Type II Fluid
Figure Eleven	End Protection Time - Aircraft Type II Fluid
Figure Twelve	End Protection Time - Panel Type II Fluid

Table One

Results of United Airlines Winter 1992/1993
Holdover Time Tests - Denver/Stapleton Airport - 727 Aircraft

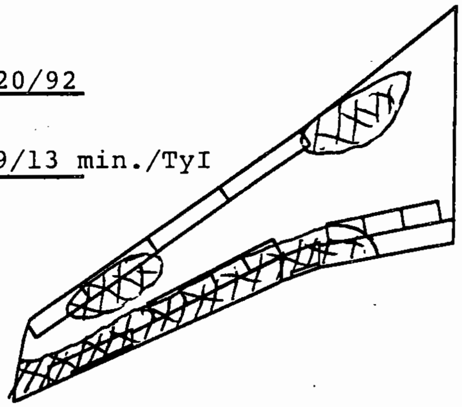
START TIME	FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	PPTN RATE
November 20, 1992: Ty I=Tex WD30 50/50, Ty II=Kil ABC3 100/0								
1609	I	33.8	13	Snow	33.0	11	82	0.9
1702	II	14.8	28	Snow	32.2	13	82	0.5
1852	II	11.0	31	Snow	31.8	14	84	0.2
December 12-13, 1992: Ty I=UCAR ADF-2D 50/50								
1746	I	4.5	15	Snow	24.6	12	88	1.6
1835	I	3.2	22	Snow	25.0	10	88	Nm
0747	I	7.5	12	Snow	21.0	8	92	3.1
0830	I	3.5	15	Snow	22.0	9	92	1.6
January 19, 1993: Ty I=UCAR ADF-2D 50/50								
0639	I	4.9	14	Snow	17.5	6	70	0.5
February 10, 1993: Ty I=Oct ADF+ 50/50								
0937	I	1.0	>66	Snow	27.2	4	85	Neg
1106	I	0.2	>79	Snow	25.6	10	82	Neg
1825	I	0.3	>66	Snow	20.9	2	54	Neg
February 24, 1993: Ty I=Oct ADF+ 50/50								
1808	I	10.8	11	Snow	27.7	5	87	1.4
1832	I	19.2	7	Snow	27.5	5	87	2.1
1847	I	8.1	11	Snow	27.5	5	87	1.4
March 11-12, 1993: Ty I=Oct ADF+ 50/50, Ty II=Kil ABC3 100/0								
1624	II	5.0	60	Snow	28.6	6	82	0.4
1746	II	1.8	75	Snow	24.4	12	88	0.3
1907	I	5.2	14	Snow	22.1	16	88	1.6
1933	II	12.2	20	Snow	20.6	14	92	1.5
2006	II	5.8	36	Snow	19.6	10	86	0.6
2100	I	11.8	7	Snow	19.6	8	88	3.2
2143	II	8.9	32	Snow	19.0	7	85	0.7
2241	II	13.7	25	Snow	18.6	6	85	0.9
2327	I	17.1	8	Snow	18.2	8	85	2.8
0000	II	12.5	30	Snow	18.0	10	85	0.8

Fluid holdover time (HOLD TIME) specified in minutes and precipitation rate (PPTN RATE) specified in inches per hour. PPTN RATE on 3/11-12 may be off due horizontal snow. Some aircraft wing contamination always visible at end of test.

WING CONTAMINATION TEST RESULTS

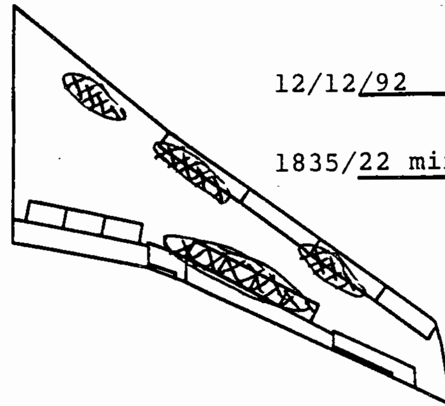
11/20/92

1609/13 min./TyI



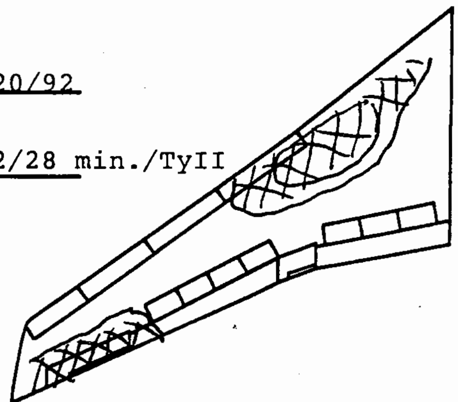
12/12/92

1835/22 min./TyI



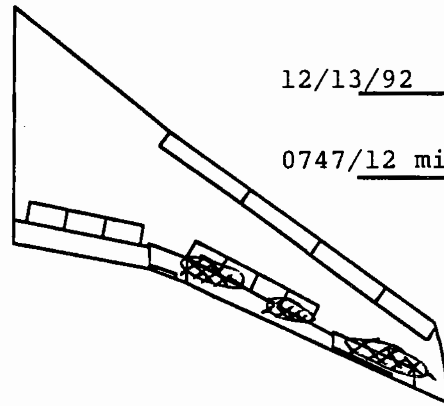
11/20/92

1702/28 min./TyII



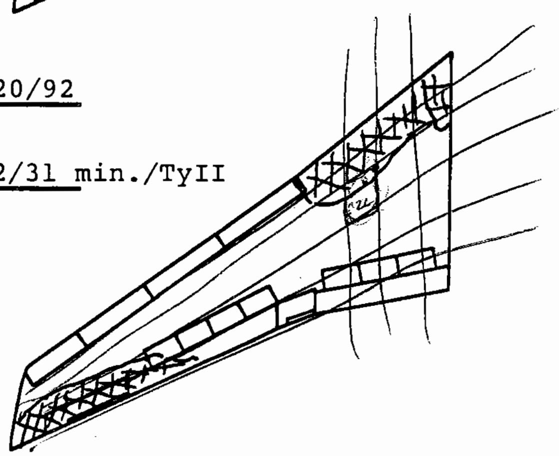
12/13/92

0747/12 min./TyI



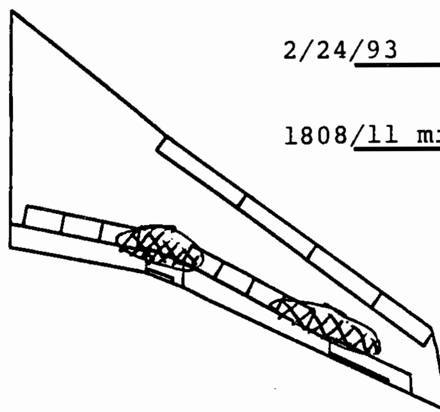
11/20/92

1852/31 min./TyII



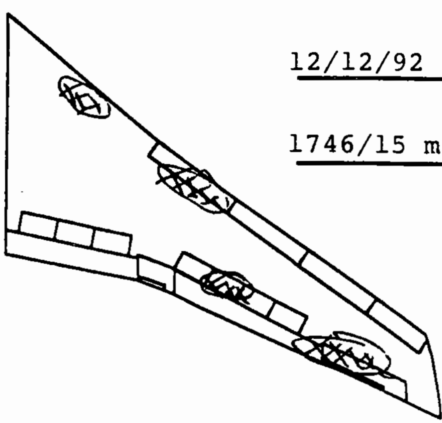
2/24/93

1808/11 min./TyI



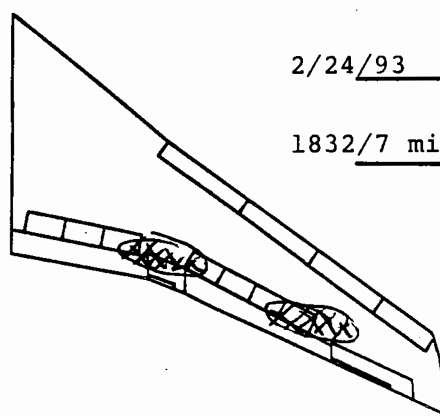
12/12/92

1746/15 min./TyI

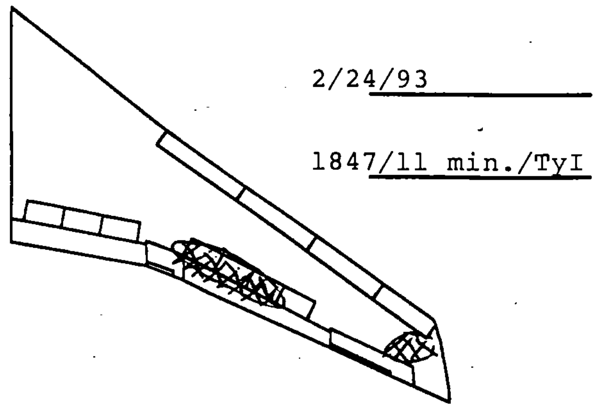


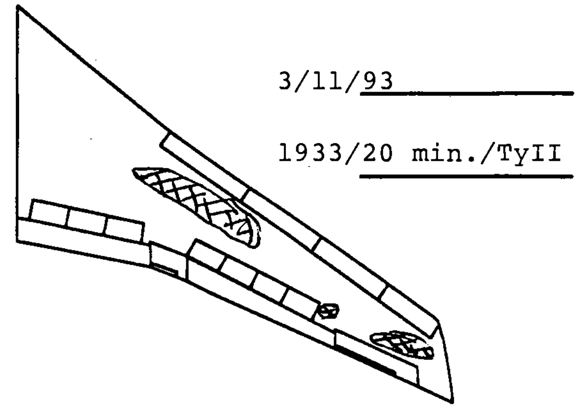
2/24/93

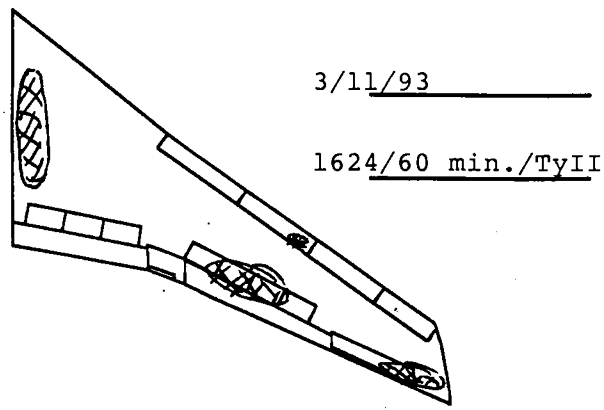
1832/7 min./TyI

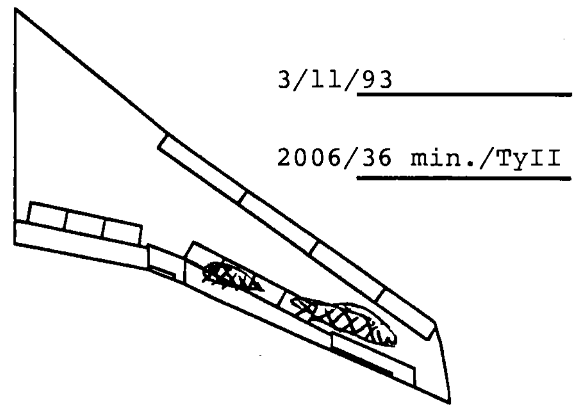


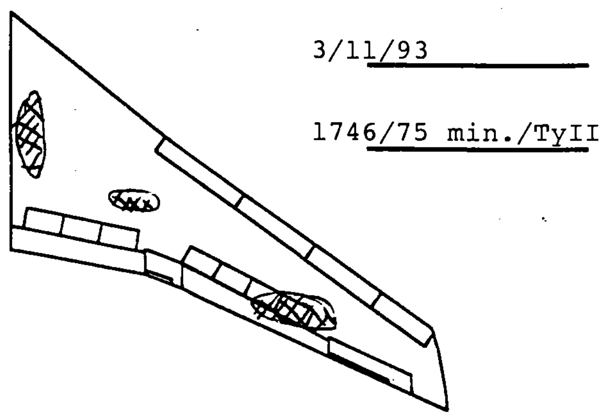
WING CONTAMINATION TEST RESULTS

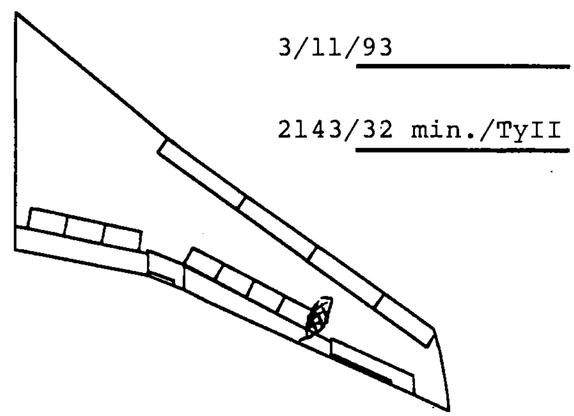


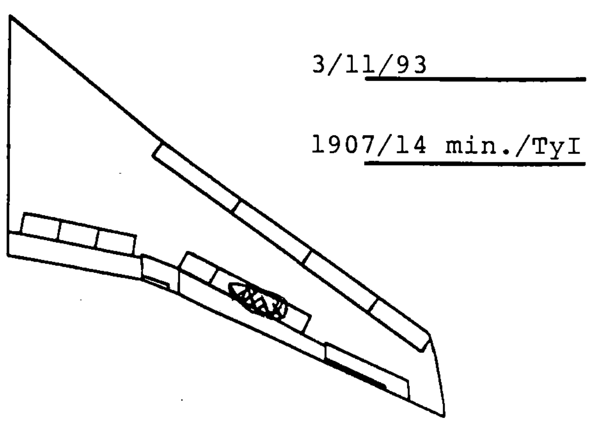












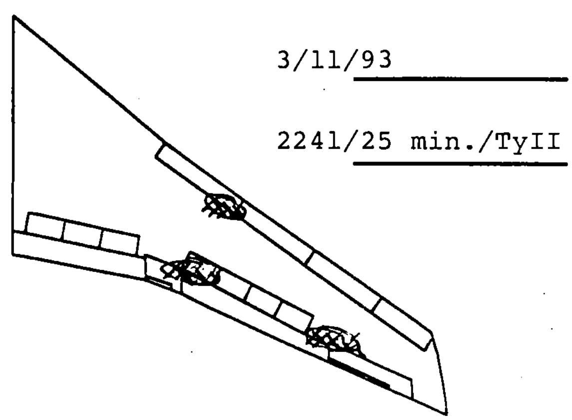


Table Two

Results of United Airlines Winter 1991/1992
Holdover Time Tests - Denver/Stapleton Airport - 737 Aircraft

START TIME	FLUID TYPE	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	PPTN RATE
January 14, 1992: Ty I=Tex WD30 50/50								
2245	I	9.0	19	Snow	18.5	16	65	0.4
2320	I	12.2	16	Snow	18.0	10	66	0.4
2355	I	2.5	>45	Snow	17.5	10	66	0.2
March 8-9, 1992: Ty I=Tex WD30 40/60, Ty II=Kil ABC3 100/0								
1844	I	85.1	5	Snow	32.0	23	78	6.0
1902	II	118.6	7	Snow	32.2	29	83	4.3
1922	II	99.4	12	Snow	32.0	29	84	2.5
1952	I	189.1	4	Snow	32.0	34	87	1.9
2014	II	65.8	13	Snow	31.7	34	88	1.2
2219	I	89.2	6	Snow	29.0	34	63	1.2
2242	II	33.8	18	Snow	30.5	34	80	1.2
2310	I	24.8	8	Snow	30.6	29	89	0.9
2331	II	21.0	24	Snow	30.1	29	91	0.6
0011	I	37.5	6	Snow	29.9	29	92	1.2
0027	II	41.1	15	Snow	29.9	29	93	3.0
0053	I	32.4	7	Snow	29.9	32	93	1.1
0112	II	13.6	33	Snow	29.4	32	93	1.4
0350	I	8.9	16	Snow	27.0	20	60	0.2
March 21, 1992: Ty I=Tex WD30 50/50, Ty II=Kil ABC3 100/0								
1614	I	5.7	33	Snow	31.6	10	62	Nm
1732	I	9.2	19	Snow	31.6	3	77	Nm
1810	I	3.2	35	Snow	30.6	4	78	Nm
1856	I	18.0	10	Snow	30.4	5	80	Nm
1922	II	2.6	91	Snow	29.8	3	80	Nm

Fluid holdover time (HOLD TIME) specified in minutes and precipitation rate (PPTN RATE) specified in inches per hour. Some aircraft wing contamination always visible at end of test. End of holdover time either random snow accumulation (1/3 of panel or wing leading edge area) or ice front formation. Wind direction up/over aircraft wing leading edge as opposed to 92/93 tests where aircraft oriented with wind up/over wing trailing edge.

Table Three

Results of UA Winter 1990/1991 Holdover Time Tests - Denver Stapleton and Chicago O'Hare - 30X50 cm Frosticator Panels

START TIME	FLUID TYPE	STN	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	PPTN RATE
(See fluid test code below. All Type I 50/50, Type II 100/0)									
January 15-16, 1991									
2247	I-U	DEN	7.0	30	Snow	32.7	6	36	0.9
	II-D	DEN	7.0	64	Snow	32.7	6	36	0.9
	II-K	DEN	7.0	63	Snow	32.7	6	36	0.9
0023	I-O	DEN	16.5	26	Snow	31	6	44	0.8
	II-O	DEN	16.5	36	Snow	31	6	44	0.8
	II-K	DEN	16.5	37	Snow	31	6	44	0.8
0731	I-O	DEN	8.2	9	Snow	31.4	9	22	0.8
January 19, 1991									
1000	I-O	DEN	3.3	6	Snow	20	22	21	0.2
	II-K	DEN	3.3	40	Snow	20	22	21	0.2
	II-O	DEN	3.3	55	Snow	20	22	21	0.2
1600	I-U	DEN	8.6	24	Snow	32	9	19	0.2
	II-D	DEN	8.6	52	Snow	32	9	19	0.2
	II-K	DEN	8.6	53	Snow	32	9	19	0.2
1724	I-O	DEN	16.6	8	Snow	29.5	20	21	0.9
	II-O	DEN	16.6	22	Snow	29.5	20	21	0.9
	II-D	DEN	16.6	26	Snow	29.5	20	21	0.9
1823	I-O	DEN	9.8	3	Snow	27	18	21	0.5
	II-K	DEN	9.8	24	Snow	27	18	21	0.5
	II-O	DEN	9.8	25	Snow	27	18	21	0.5
1935	I-U	DEN	13.0	8	Snow	23	22	22	0.7
	II-K	DEN	13.0	31	Snow	23	22	22	0.7
	II-D	DEN	13.0	32	Snow	23	22	22	0.7
2045	I-U	DEN	11.0	6	Snow	24	28	20	0.5
	II-D	DEN	11.0	17	Snow	24	28	20	0.5
	II-O	DEN	11.0	19	Snow	24	28	20	0.5
January 28, 1991									
1855	I-U	DEN	5.9	27	Snow	22	14	26	0.2
	II-D	DEN	5.9	41	Snow	22	14	26	0.2
	II-K	DEN	5.9	43	Snow	22	14	26	0.2
2025	I-O	DEN	6.9	12	Snow	18	15	18	0.3
	II-K	DEN	6.9	30	Snow	18	15	18	0.3
	II-O	DEN	6.9	34	Snow	18	15	18	0.3
2155	I-U	DEN	8.0	5	Snow	14	16	13	0.2
	II-O	DEN	8.0	13	Snow	14	16	13	0.2
	II-D	DEN	8.0	19	Snow	14	16	13	0.2
January 29, 1991									
0620	II-K	ORD	7.2	53	Snow	32.7	6	74	0.9
	II-D	ORD	7.2	57	Snow	32.7	6	74	0.9

Table Three Continued

Results of UA Winter 1990/1991 Holdover Time Tests - Denver Stapleton and Chicago O'Hare - 30X50 cm Frosticator Panels

START TIME	FLUID TYPE	STN	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	PPTN RATE
February 13, 1991									
1930	I-O	ORD	41.0	3	Snow	23.5	10	92	Nm
	II-D	ORD	41.0	18	Snow	23.5	10	92	Nm
2005	I-O	ORD	11.3	4	Snow	16.5	12	91	Nm
	II-D	ORD	11.3	36	Snow	16.5	12	91	Nm
	II-K	ORD	11.3	36	Snow	16.5	12	91	Nm
February 14, 1991									
0810	II-D	ORD	7.6	21	FrzRn	31.5	5	96	Nm
	II-K	ORD	7.6	21	FrzRn	31.5	5	96	Nm
February 16, 1991									
0635	I-D	ORD	18.7	2	Snow	34	3	61	Nm
	II-D	ORD	18.7	32	Snow	34	3	61	Nm
February 18, 1991									
0842	II-K	ORD	1.7	65	Snow	32	8	86	Nm
	II-D	ORD	1.7	68	Snow	32	8	86	Nm
	II-O	ORD	1.7	68	Snow	32	8	86	Nm
February 27, 1991									
2130	II-D	ORD	6.3	37	Snow	28.5	2	54	Nm
February 28, 1991									
0508	II-D	ORD	51.7	11	Hail	17	30	68	Nm
March 3, 1991									
1904	I-O	ORD	10.6	4	Snow	33.5	7	83	Nm
	II-K	ORD	10.6	63	Snow	33.5	7	83	Nm
	II-O	ORD	10.6	68	Snow	33.5	7	83	Nm
March 12, 1991									
0100	I-U	DEN	17.4	6	Snow	31	0	32	0.6
	II-D	DEN	17.4	18	Snow	31	0	32	0.6
	II-O	DEN	17.4	26	Snow	31	0	32	0.6
2105	II-K	ORD	21.2	26	Snow	31	28	93	1.4
	II-D	ORD	21.2	31	Snow	31	28	93	1.4
2202	II-O	ORD	12.7	43	Snow	31	24	93	1.0
	II-D	ORD	12.7	43	Snow	31	24	93	1.0
	II-K	ORD	12.7	43	Snow	31	24	93	1.0
2315	II-O	ORD	5.1	65	Snow	29.5	34	98	0.7
	II-D	ORD	5.1	65	Snow	29.5	34	98	0.7

Table Three Continued

Results of UA Winter 1990/1991 Holdover Time Tests - Denver Stapleton and Chicago O'Hare - 30X50 cm Frosticator Panels

START TIME	FLUID TYPE	STN	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	PPTN RATE
April 12, 1991									
0200	I-O	DEN	21.4	4	Snow	30.5	0	22	0.8
	II-K	DEN	21.4	16	Snow	30.5	0	22	0.8
	II-D	DEN	21.4	17	Snow	30.5	0	22	0.8
0255	I-U	DEN	19.0	5	Snow	30	0	23	0.8
	II-O	DEN	19.0	24	Snow	30	0	23	0.8
	II-K	DEN	19.0	25	Snow	30	0	23	0.8
0355	I-U	DEN	21.6	5	Snow	30	0	22	0.7
	II-D	DEN	21.6	16	Snow	30	0	22	0.7
	II-K	DEN	21.6	16	Snow	30	0	22	0.7
0500	I-O	DEN	21.4	5	Snow	28	0	21	0.9
	II-O	DEN	21.4	18	Snow	28	0	21	0.9
	II-K	DEN	21.4	21	Snow	28	0	21	0.9

Fluid holdover time (HOLD TIME) specified in minutes and precipitation rate (PPTN RATE) specified in inches per hour. End of holdover time either progressive surface freezing - time for one inch ice front to form, random snow accumulation to obscure five crosshairs or 1/3 of panel or fluid loss of gloss and slush to obscure five crosshairs or 1/3 of panel. Wind direction up/over panel.

Type I Code:
- D = Dow 146AR
- O = Octagon ADF+
- U = Union Carbide ADF 2D

Type II Code:
- D = Dow Flightgard 2000
- K = Kilfrost ABC3
- O = Octagon Forty Below

Table Four

Results of UA Winter 1989/1990 Holdover Time Tests - Denver Stapleton and Chicago O'Hare - 10X30 cm Flanged Panels

FLUID TYPE	STN	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	PPTN RATE
(See fluid test code below. All Type I 50/50, Type II 100/0)								
December 10, 1989								
I-T	DEN	1.1	9	Snow	24	9	32	Nr
December 12, 1989								
II-K	DEN	5.9	52	Snow	27	9	29	Nr
II-K	DEN	5.9	37	Snow	27	9	29	Nr
December 13, 1989								
II-D	ORD	2.2	29	Snow	36	6	72	Nr
December 19, 1989								
II-K	DEN	8.4	46	Snow	30	12	45	Nr
II-D	DEN	8.4	43	Snow	30	12	45	Nr
II-S	DEN	7.7	36	Snow	28	12	45	Nr
I-T	DEN	9.5	6	Snow	26	12	45	Nr
II-D	ORD	26.6	29	Snow	9	11	92	Nr
December 31, 1989								
I-D	ORD	0.6	17	Snow	30	9	73	Nr
January 11, 1990								
II-D	ORD	1.8	66	Snow	27	20	52	Nr
January 25, 1990								
II-D	ORD	27.0	28	Snow/Fr	34	12	92	Nr
I-T	ORD	27.0	3	Snow/Fr	34	12	92	Nr
II-D	ORD	27.0	22	Snow/Fr	34	12	92	Nr
II-D	ORD	11.0	18	Snow	32	7	82	Nr
I-D	ORD	19.8	1	Snow	33	20	96	Nr
II-D	ORD	19.8	>30	Snow	33	20	96	Nr
February 13, 1990								
II-S	DEN	1.3	87	Snow	20	14	56	Nr
II-D	DEN	1.3	85	Snow	20	14	56	Nr
II-K	DEN	1.3	87	Snow	20	14	56	Nr
I-O	DEN	0.9	17	Snow	20	6	55	Nr
I-T	DEN	0.9	16	Snow	20	6	55	Nr
I-D	DEN	0.9	6	Snow	20	6	55	Nr
February 14, 1990								
II-S	DEN	3.0	34	Snow	10	13	60	Nr
II-D	DEN	3.0	36	Snow	10	13	60	Nr
II-K	DEN	3.0	31	Snow	10	13	60	Nr

Table Four Continued

Results of UA Winter 1989/1990 Holdover Time Tests - Denver Stapleton and Chicago O'Hare - 10X30 cm Flanged Panels

FLUID TYPE	STN	H2O CONT (G/D2/HR)	HOLD TIME	COND	TEMP (degF)	WIND (mph)	R.H. (%)	PPTN RATE
February 14, 1990 cont'd								
I-O	DEN	1.4	4	Snow	7	14	60	Nr
I-T	DEN	1.4	7	Snow	7	14	60	Nr
February 22, 1990								
II-D	ORD	24.8	36	Snow	42	24	99	Nr
II-D	ORD	25.6	17	Snow	37	24	99	Nr
March 5, 1990								
II-D	ORD	10.3	68	Snow	31	30	84	Nr
II-K	ORD	10.3	75	Snow	31	30	84	Nr
March 18, 1990								
II-D	ORD	2.6	65	Snow	34	16	73	Nr

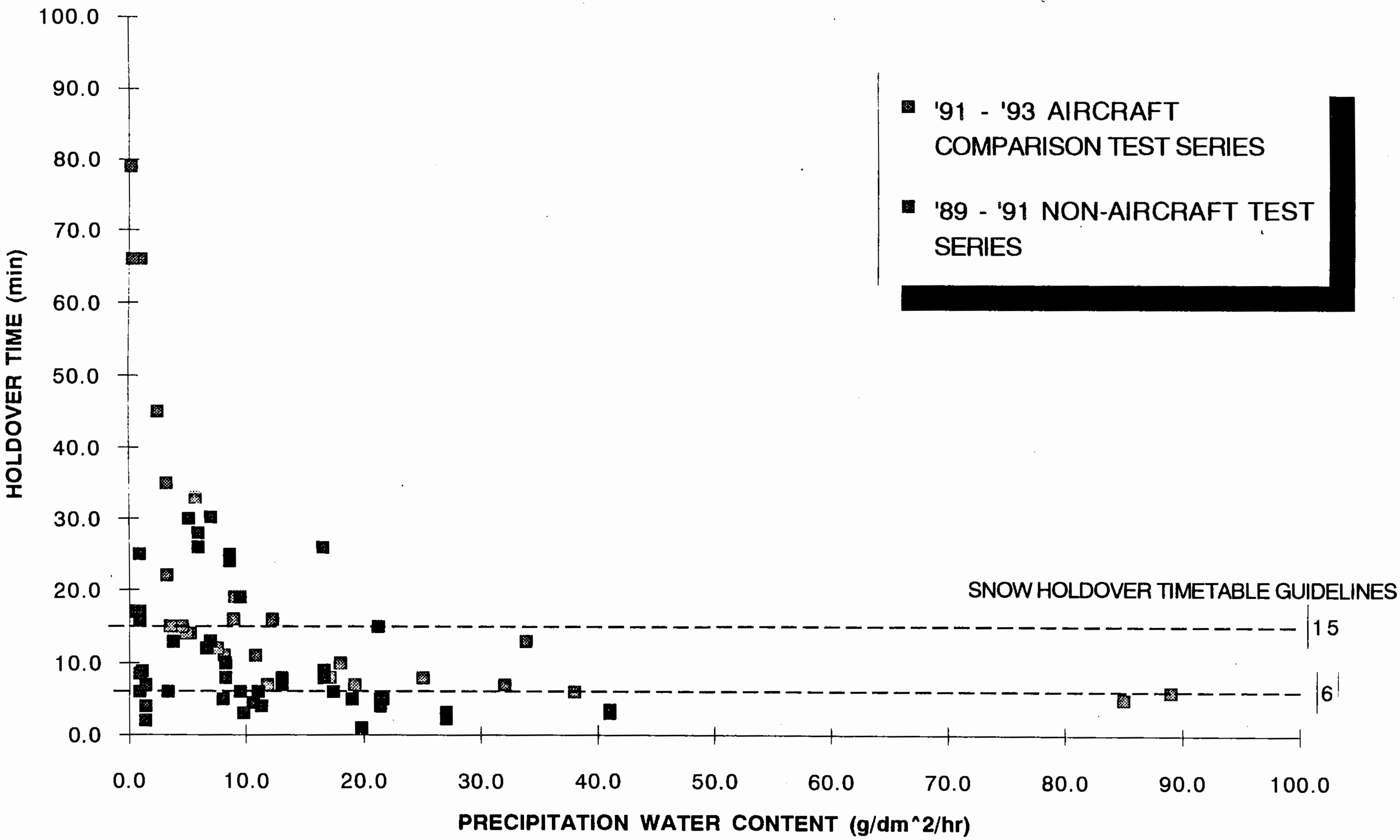
Fluid holdover time (HOLD TIME) specified in minutes. End of holdover time defined when a one inch ice front forms down the top edge of the panel. Wind direction up/over panel.

Type I Code:
- D = Dow 146AR
- O = Octagon ADF+
- T = Texaco WD20

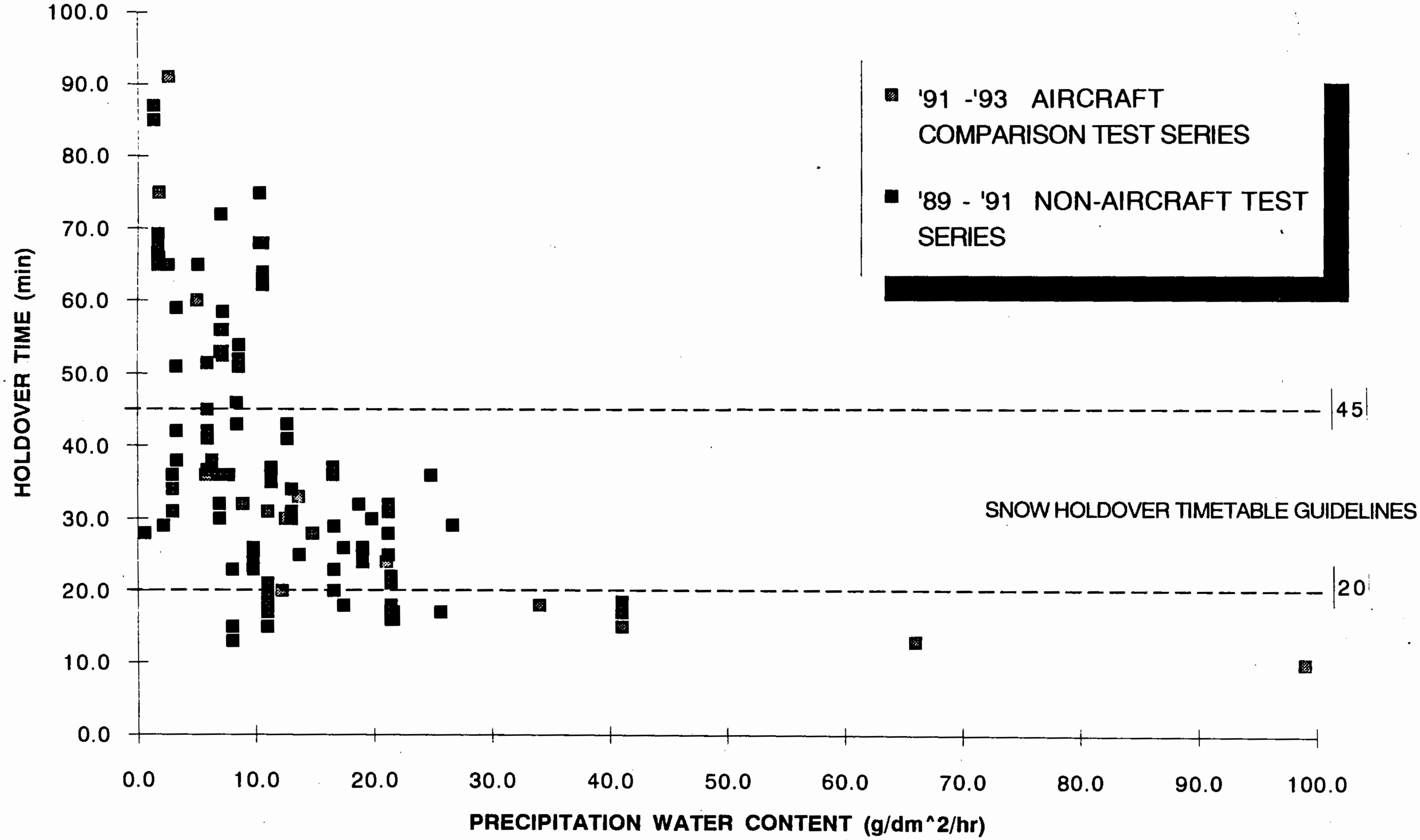
Type II Code:
- D = Dow Flightgard 2000
- K = Kilfrost ABC3
- S = SPCA AD104

Graph One. **RESULTS OF UNITED AIRLINES HOLDOVER TIME TESTS**

TYPE I FLUIDS (50/50)



Graph Two. **RESULTS OF UNITED AIRLINES HOLDOVER TIME TESTS TYPE II FLUIDS**



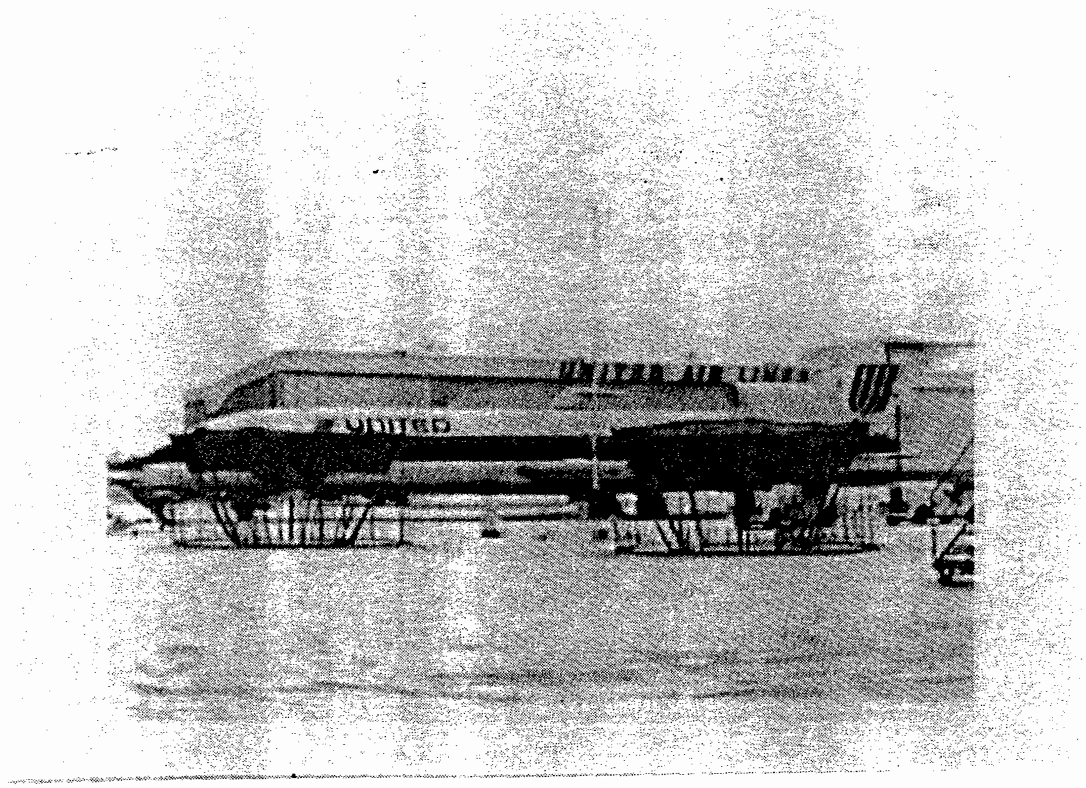


Figure One. NCAR Weather Measurement Equipment Site

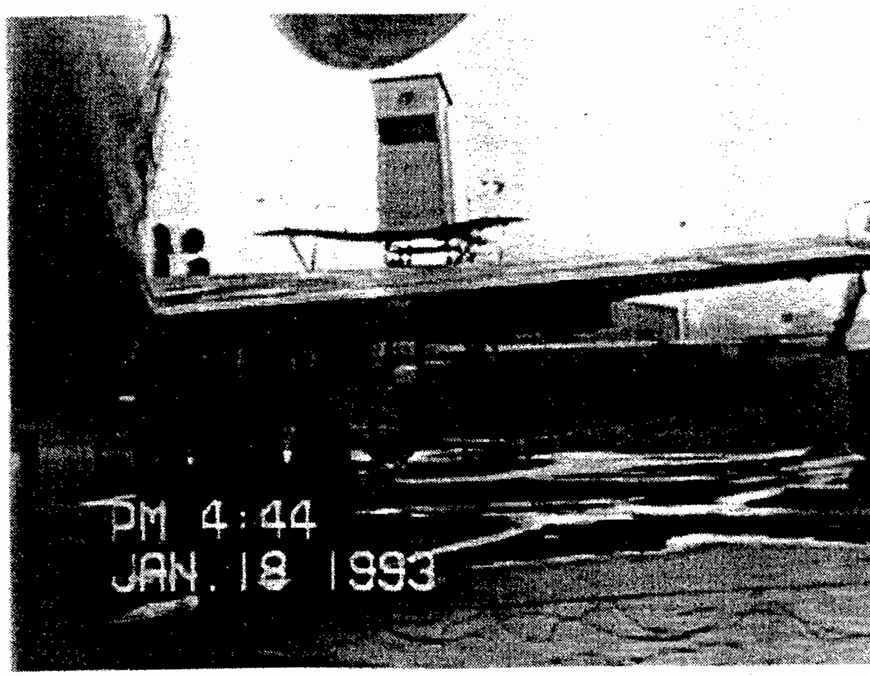


Figure Two. Video Camera Enclosure - Leading Edge Position

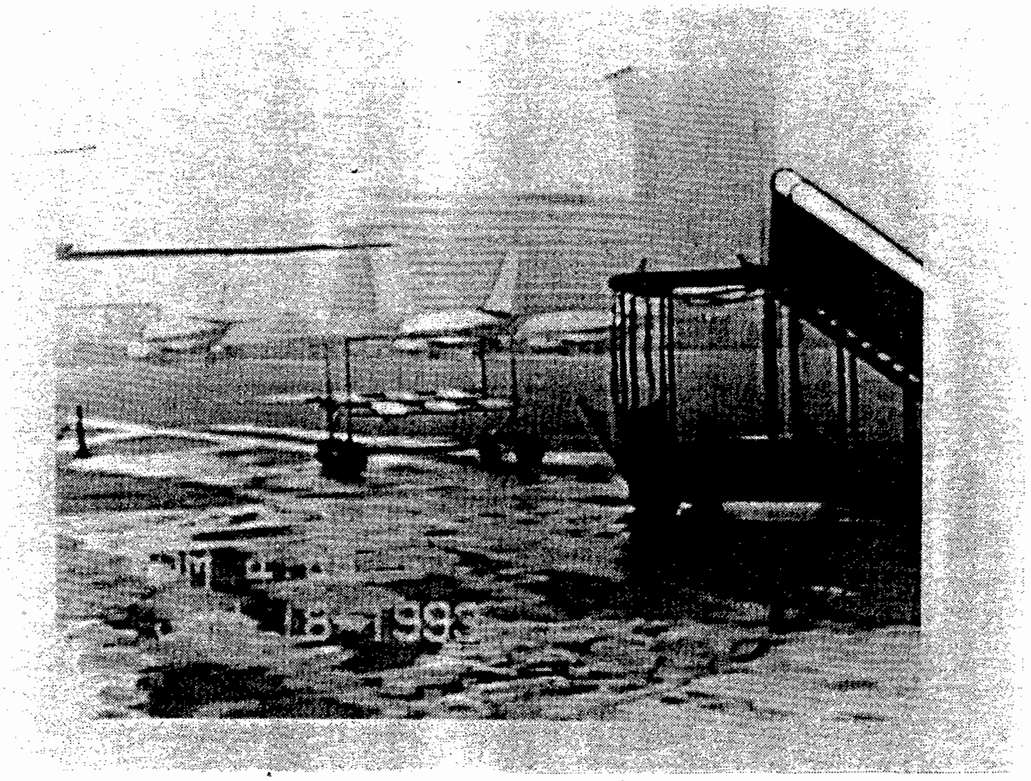


Figure Three. Video Camera Enclosure - Trailing Edge Position

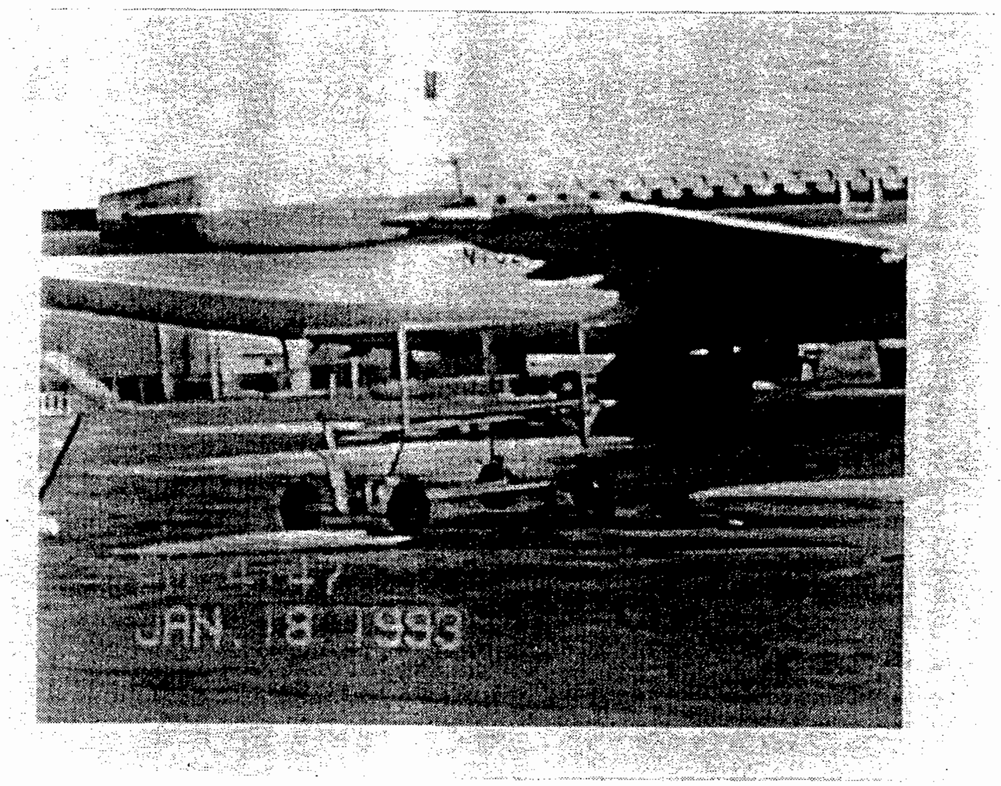


Figure Four. Frosticator Test Stand in Position

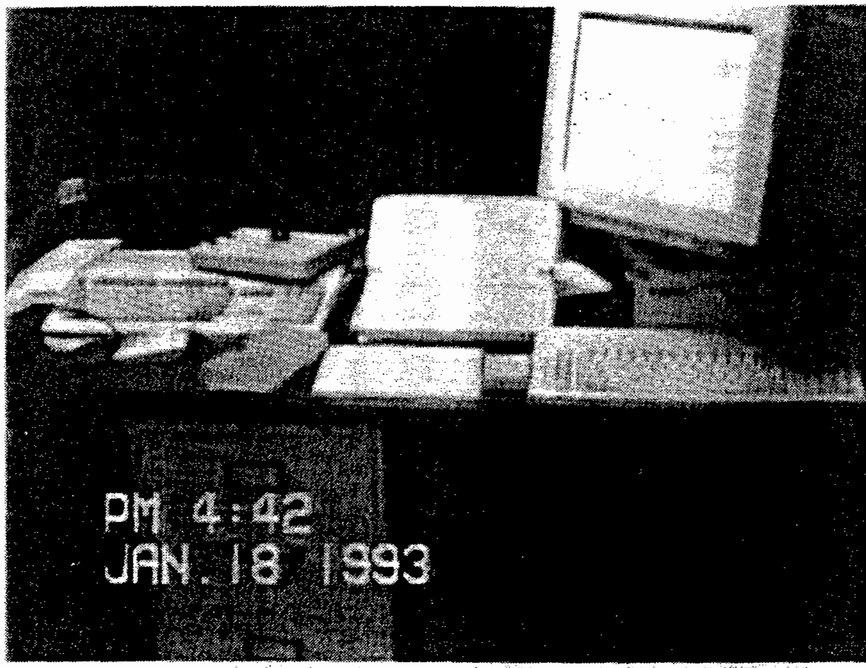


Figure Five. NCAR Weather/Transport Canada Ice Gage Computers

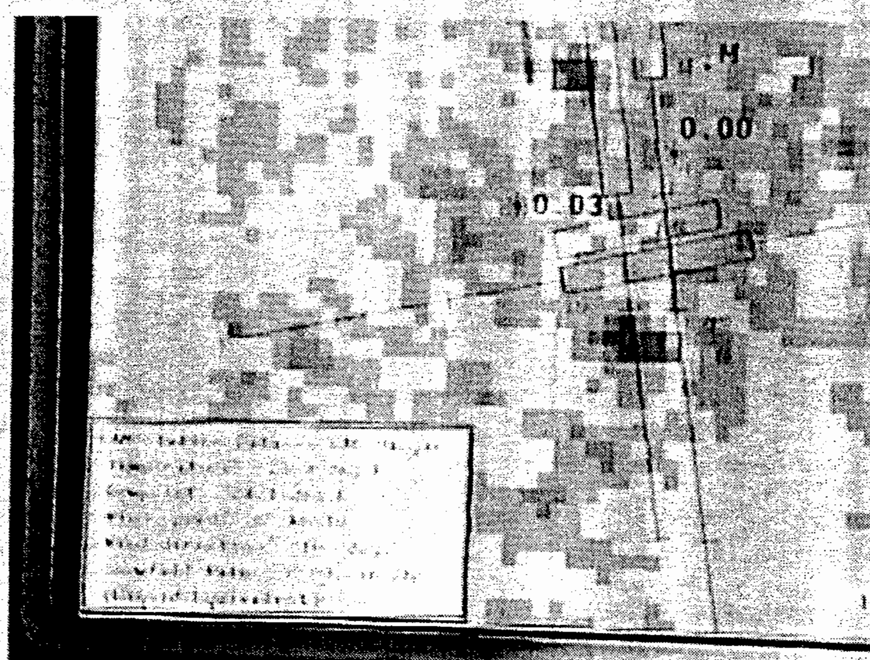


Figure Six. NCAR Weather Radar & PAM Station Display

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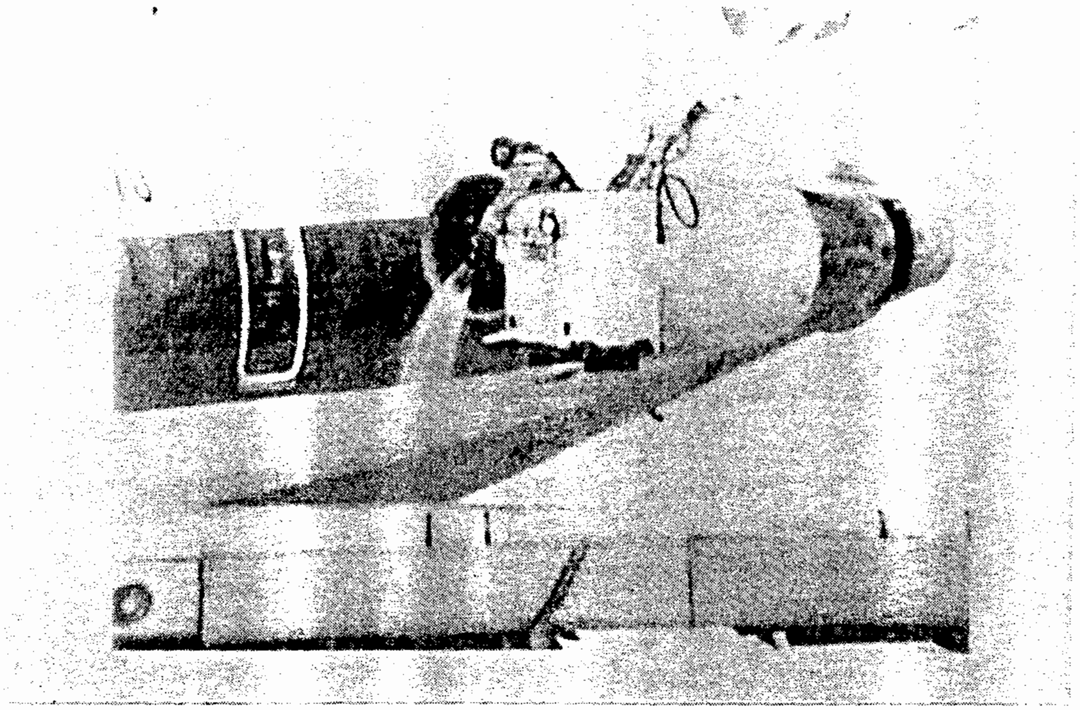

Figure Seven. Type II Fluid Application to the Aircraft

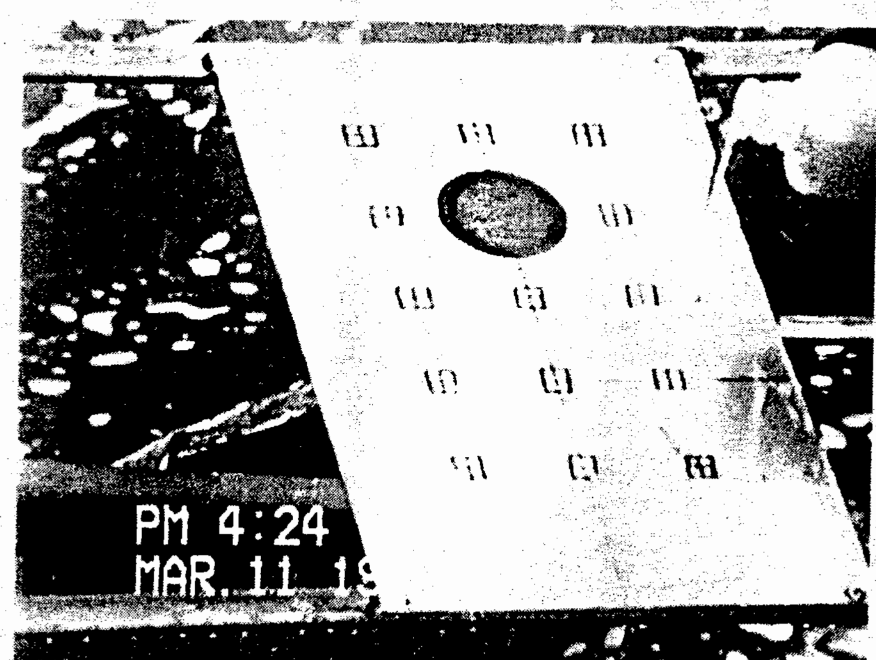

Figure Eight. Type II Fluid Application to Frosticator Panel

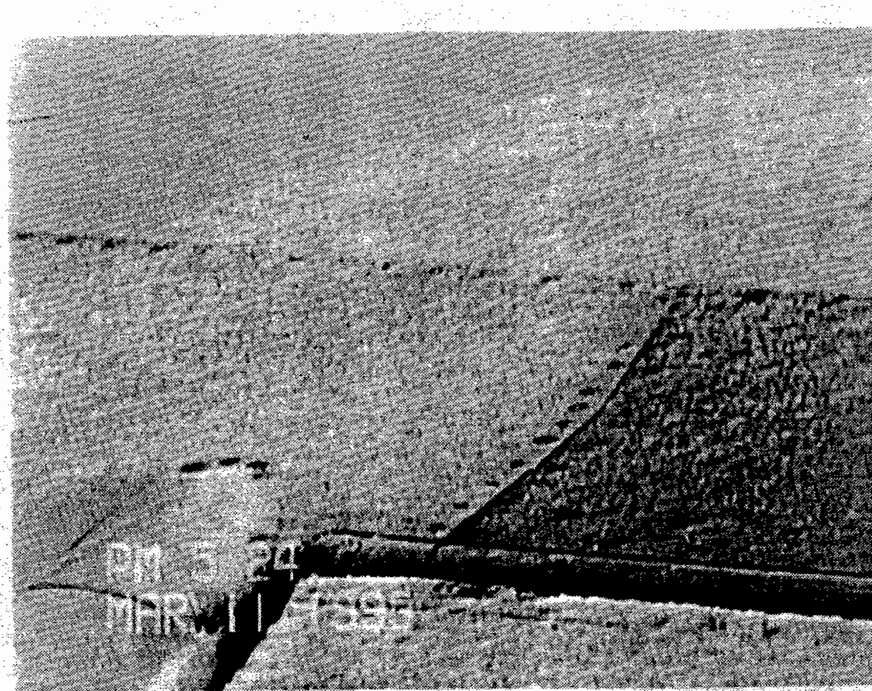

Figure Nine. End of Protection Time - Aircraft Type II Fluid

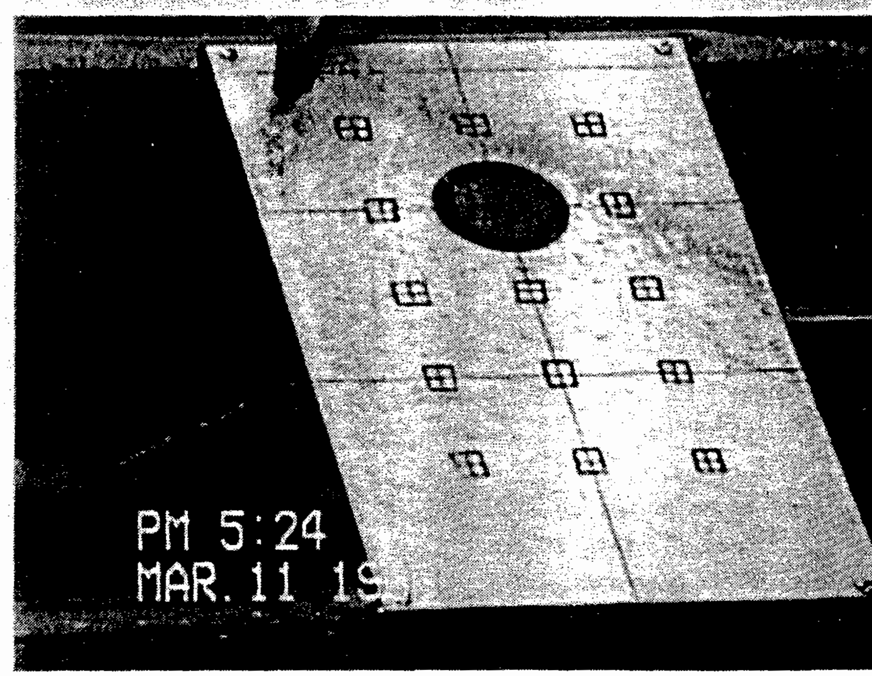

Figure Ten. End of Protection Time - Panel Type II Fluid

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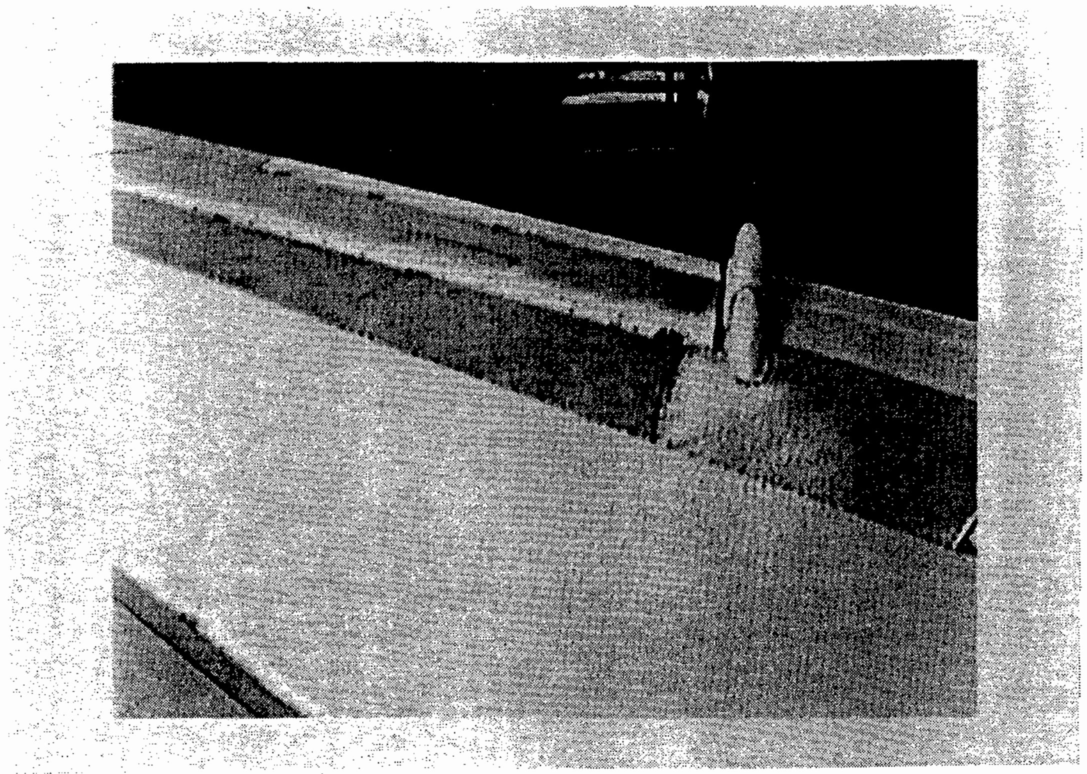

Figure Eleven. End of Protection Time-Aircraft Type II Fluid

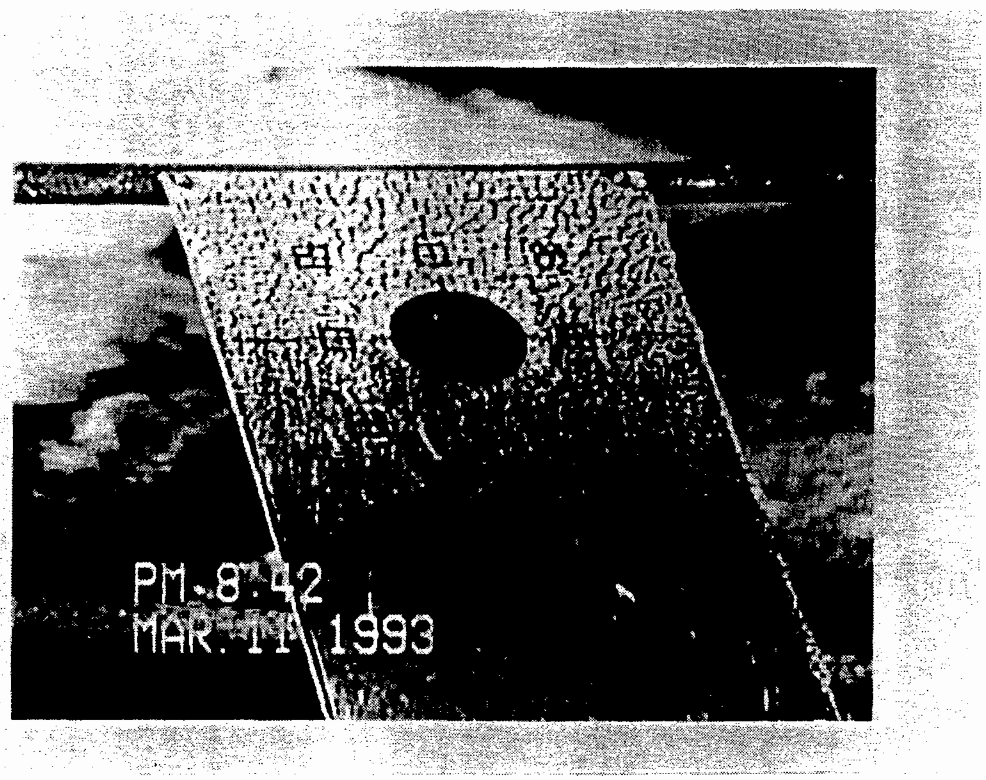

Figure Twelve. End of Protection Time-Panel Type II Fluid

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APPENDIX G

COMPARISON OF HOLDOVER TIME EFFECTIVENESS OF TYPE III FLUIDS

SHIELDED VERSUS UNSHIELDED PRECIPITATION GAUGE 1991-1992 FIELD TESTING

Addendum to TP 11454E
APS Project No.: 492-1100/C1127

Comparison of Holdover Time Effectiveness of Type III Fluids

Shielded Versus Unshielded Precipitation Gauge

1991-1992 Field Testing

Prepared for

**Transportation Development Centre
And
Dryden Commission Implementation Program
Transport Canada**

by

APS Aviation Inc.

February 1993

TABLE OF CONTENTS

PAGE

1. INTRODUCTION 1

2. DESCRIPTION OF DATA 1

3. METEOROLOGICAL ANALYSIS 2

4. ANALYSIS 4

   4.1 1991/92 Natural Precipitation Tests 4

      4.1.1 Comparison of Precipitation Gauges 4

      4.1.2 Secondary Analysis of Results 6

         4.1.2.1 Type of Precipitation Effect 6
         4.1.2.2 Effect of Wind 10
         4.1.2.3 Effect of Temperature 11
         4.1.2.4 Other Outliers 11

   4.2 Inclusion of Natural Precipitation Tests from 1992/93 11

5. CONCLUSION 13

1. INTRODUCTION

Based on discussions with Dryden Commission Implementation Project (DCIP) Office, APS Aviation Inc. (APS) undertook a brief study to analyze holdover time tests used to assess the time effectiveness of Type III fluids. A study on Type III fluids was produced in October 1992 for the 1991/92 winter. The analysis in that report (TP 11454E) was based on natural precipitation rates which were obtained using the European Ombrometer. A more recent study for the 1992/93 winter TP 11836E (contained in the main body of this document) showed that this precipitation gauge, particularly without a wind protection element, was not adequate to predict rates of natural snow precipitation.

Therefore, the objective of this analysis is to compare the time effectiveness of Type III fluids using the data from the ombrometer to the newly acquired data from a different, but shielded precipitation device located at the Atmospheric Environment Services (AES) site at Dorval.

2. DESCRIPTION OF DATA

During the 1991/92 test season 260 natural snow test points were collected, and from this set 99 points were not used in the 1991/92 analysis. A number of the non-useable points resulted from faulty precipitation equipment (eg. ombrometer) or losses in data due to power failures. Union Carbide (UCAR) Type II fluid 250-3 was used for 138 of the useable 161 test points (more than 85%).

As was mentioned, a number of points were considered non-useable. Some of these points were reinstated for this analysis since the alternate precipitation data was available. As a result, 172 UCAR test points, during natural precipitation conditions at Dorval, were used for this analysis.

3. METEOROLOGICAL ANALYSIS

For the natural precipitation tests at Dorval, the European tipping bucket (ombrometer) was used to measure the rate of precipitation. This instrument, which did not contain a wind protection shield, was used for analysing the data contained in report TP 11454E. An alternate source of precipitation data was acquired recently from Meteoglobe Canada Inc., who were under contract to the City of Montreal to collect precipitation data at Dorval. The precipitation was measured from a tipping bucket located adjacent to Environment Canada's equipment. Any future reference to this equipment in this report will be labelled as "Environment Canada tipping bucket". The Environment Canada tipping bucket is not as sensitive (one tip for every 2 g/dm^2 of snow) as the ombrometer, however the data is considered more accurate due to the wind shield mounted on the gauge.

As can be seen in Figure 3.1, a comparison of Environment Canada's precipitation measurements with the ombrometer does not indicate a direct relationship. The ombrometer results appear to have been greatly affected by other factors such as wind. Values that do approach the one-to-one relationship are the low wind speed cases. This leads to the conclusion that wind speed is an important factor in the measurement of precipitation rates.

A comparison (1992/93 data) of Environment Canada's precipitation data with plate pan data (wetted collection pan installed on stand and of the same size and inclination of the plates) showed a one-to-one relationship between these two devices (see main body of this document). As a result of this comparison, it was felt that precipitation rates from the un-shielded ombrometer were too low. An analysis of the plate failure times using Environment Canada's shielded precipitation gauge is provided in the next section.

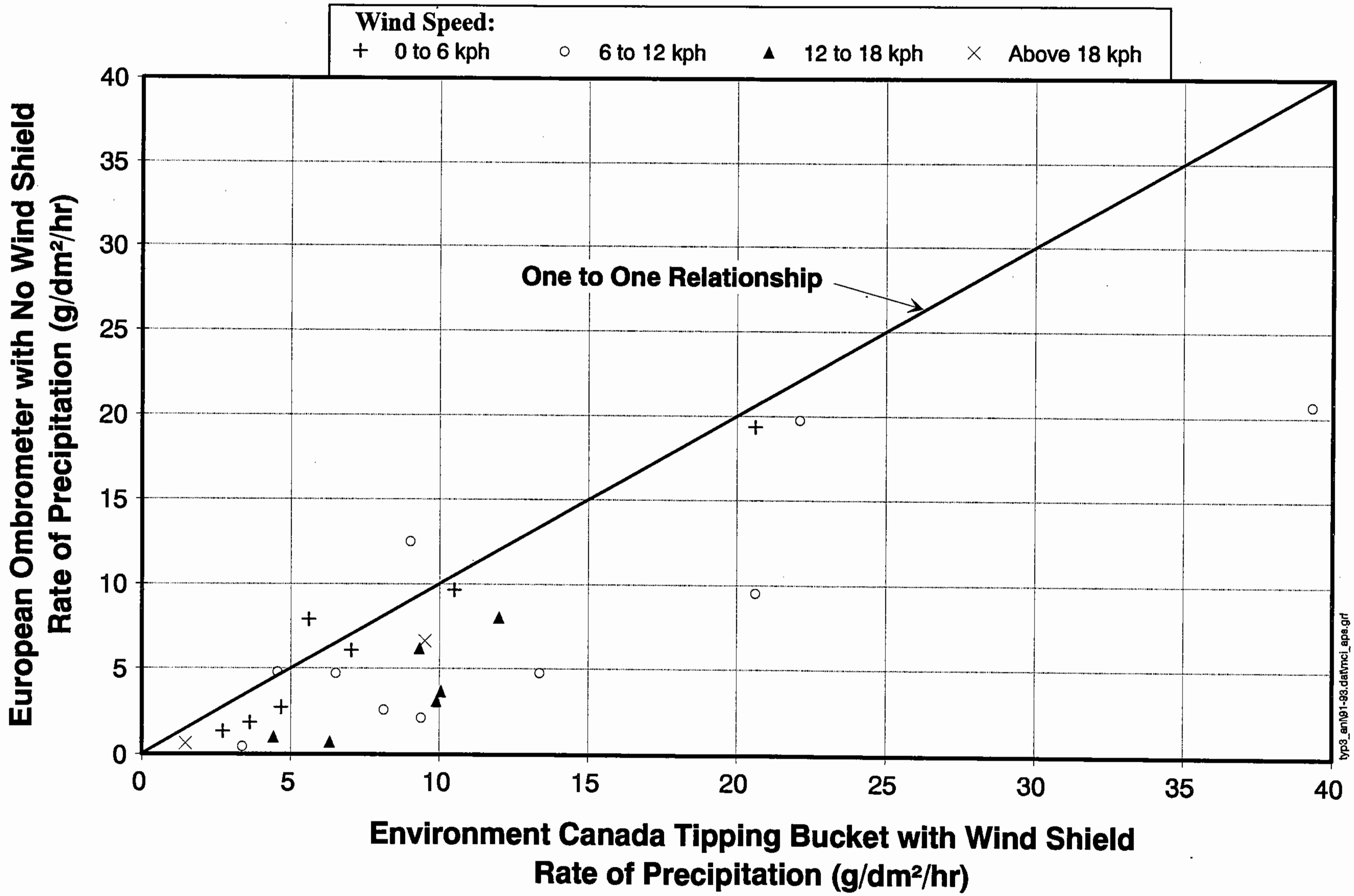
Average temperature, humidity and wind speed were also compared for the 1991/92 test season. While both temperature and wind speed data between APS' equipment and that of Environment Canada compared as expected, the relative humidity did not. Therefore, relative humidity from Environment Canada was used for this analysis.

FIGURE 3.1

COMPARISON OF PRECIPITATION COLLECTION DEVICES

EUROPEAN OMBROMETER vs ENVIRONMENT CANADA

DORVAL TESTING 1991-1992



4. ANALYSIS

The results of the analysis are sub-divided in two main sections, namely, analysis of 1991/92 data with Environment Canada's precipitation gauge, and inclusion of the Type III data set from tests conducted in the 1992/93 winter season (see main body of this document).

4.1 1991/92 Natural Precipitation Tests

A number of analyses were performed on the data described in Section 2. This section is divided in two sub-sections as follows: firstly, the previous results are summarized and compared to the new results; the second section provides a graphical and statistical presentation of the results to help determine the existence of a relationship.

4.1.1 Comparison of Precipitation Gauges

Figure 4.1 shows the plot of the fluid failure time versus the rate of precipitation (using the European Ombrometer) for tests performed with Type III UCAR 250-3 fluid. Figure 4.2 shows a similar plot, but this time the abscissa is plotted using Environment Canada's precipitation gauge measurements. When comparing the two charts it is rather obvious that the rates of precipitation are higher with the shielded gauge, and most importantly the scatter is much less with the data from Environment Canada, assuming a logarithmic trend between failure time and rate of precipitation. Figure 4.2 shows tendencies which are consistent with previous in-situ and laboratory testing - high rates of precipitation tend to lower the failure time.

FIGURE 4.1
FLUID FAILURE TIME vs RATE OF PRECIPITATION
(EUROPEAN OMBROMETER)
1991 - 1992

Type III UCAR 250-3

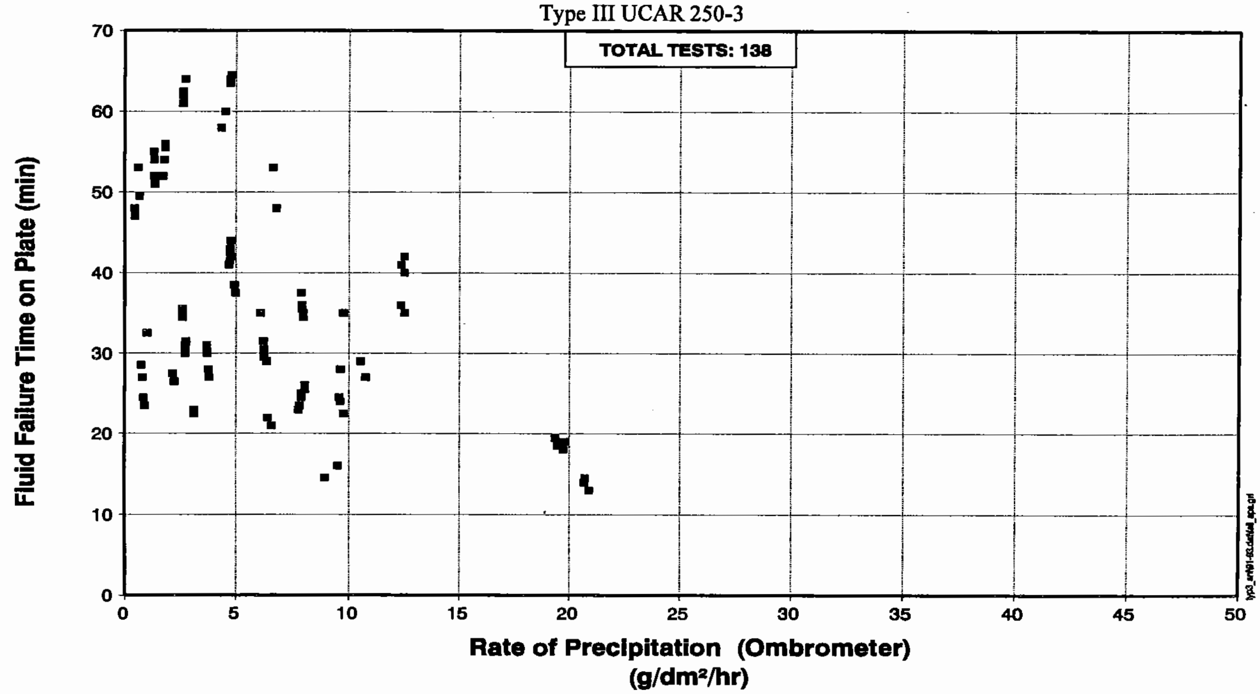
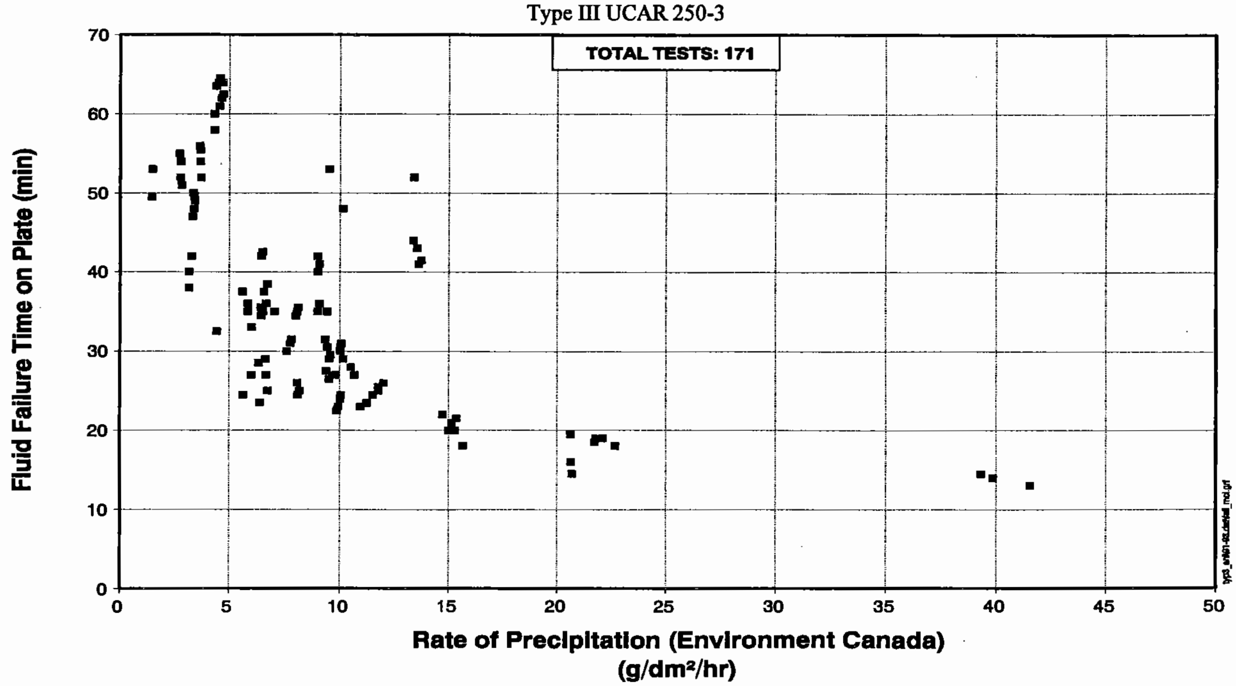


FIGURE 4.2
FLUID FAILURE TIME vs RATE OF PRECIPITATION
(ENVIRONMENT CANADA)
1991 - 1992

Type III UCAR 250-3



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4.1.2 Secondary Analysis of Results

Figure 4.3 shows a plot of plate failure time versus rate of precipitation from Environment Canada as a function of type of precipitation. Figures 4.4 and 4.5 show the plot of fluid failure time versus the rate of precipitation from Environment Canada as a function of wind speed and temperature.

In the analysis of the results in the 1991/92 Type III report, the multi-variate regressions yielded R^2 values which were unacceptably low. However, when test points with winds exceeding 5 kph were removed, a promising logarithmic relationship emerged with an R^2 value of 91%. Table 4.1 provides the regression results for the data based on precipitation rates from Environment Canada, while the following sub-sections focus in on the secondary analysis.

4.1.2.1 Type of Precipitation Effect

After careful examination of Figures 4.3 through 4.5, test points considered as outliers were reviewed. The breakdown by type of precipitation in Figure 4.3 clearly shows this effect. Natural snow and freezing precipitation have different characteristics and should be analysed separately. The fact that a few of the freezing precipitation points have longer failure times than the natural snow points probably resulted since the failure mechanism in freezing precipitation is not only unusual, but different.

FIGURE 4.3

EFFECT OF TYPE OF PRECIPITATION AND RATE OF PRECIPITATION ON TYPE III UCAR 250-3 FLUID FAILURE TIME

1991 - 1992

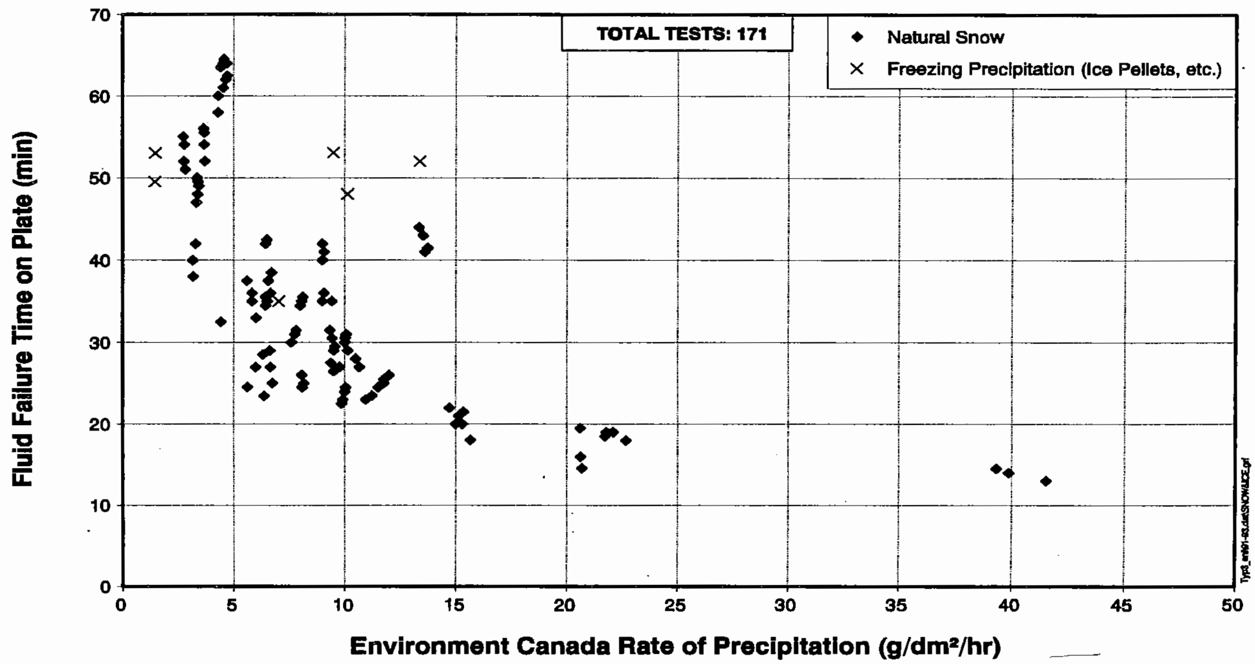

FIGURE 4.4

EFFECT OF WIND SPEED AND RATE OF PRECIPITATION ON TYPE III UCAR 250-3 FLUID FAILURE TIME

1991 - 1992

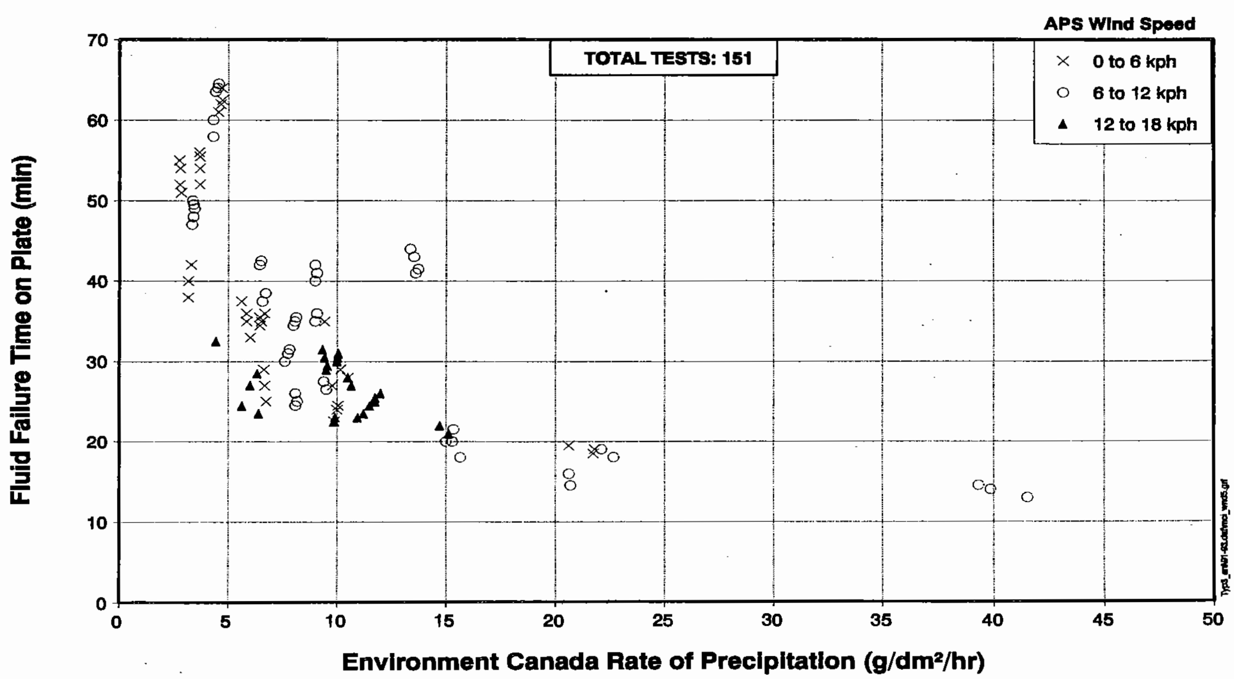

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FIGURE 4.5

EFFECT OF TEMPERATURE AND RATE OF PRECIPITATION ON TYPE III UCAR 250-3 FLUID FAILURE TIME

1991 - 1992

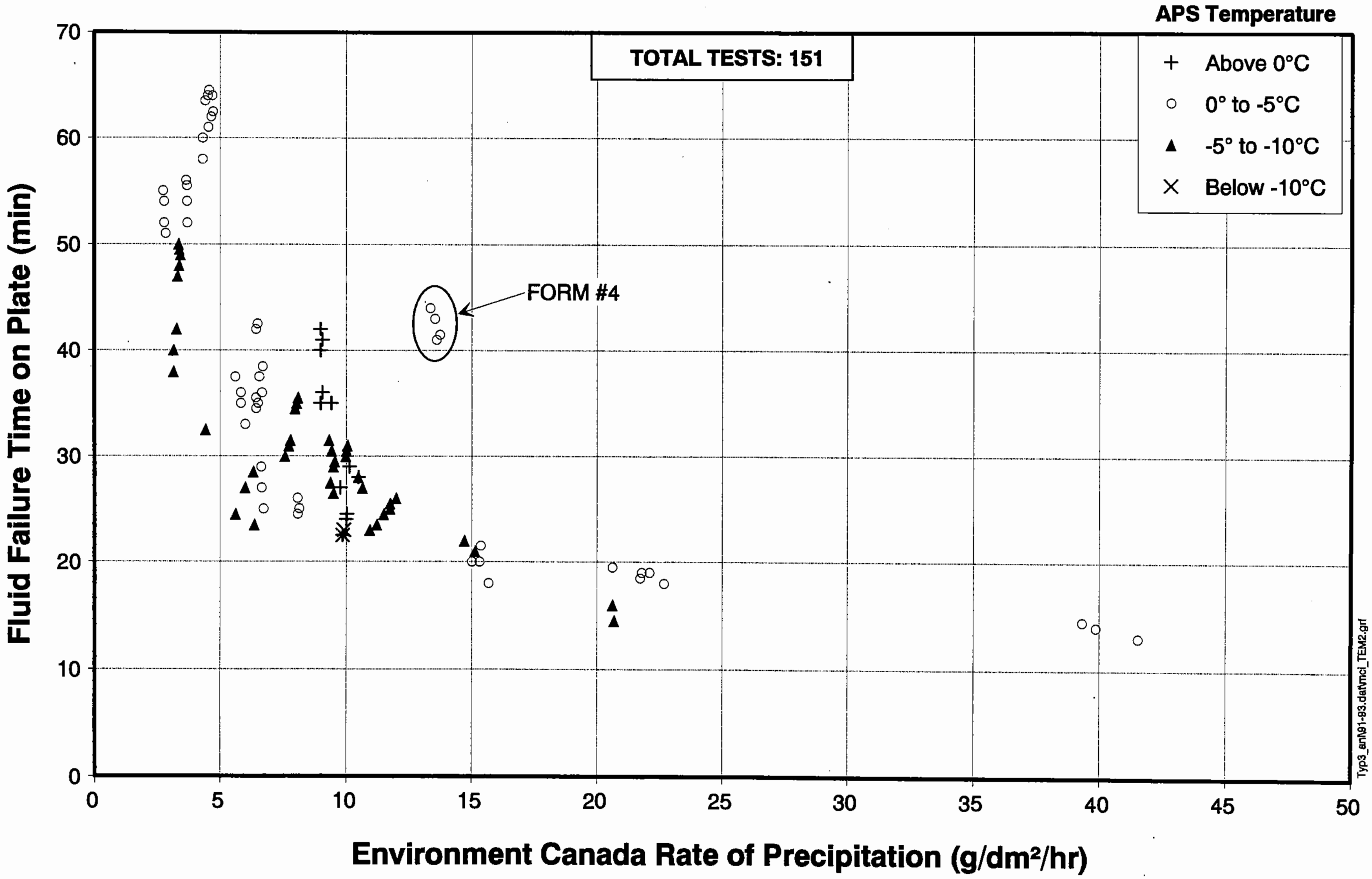


TABLE 4.1

MULTI-VARIABLE REGRESSION ANALYSIS RESULTS FOR TYPE III UCAR 250-3 FLUID IN SNOW CONDITIONS

Equation #	No. of Tests	Equation	R^2	Notes
4.1	151	log fail = 2.95 - 0.632 log rate + 0.0303 temp - 0.00825 rh - 0.142 low	83%	Basic Analysis
4.2	53	log fail = 3.22 - 0.799 log rate + 0.0475 temp - 0.0112 rh	93%	Same as Equation 4.1, but with "low" wind speed points only
4.3	145	log fail = 2.98 - 0.644 log rate + 0.0288 temp - 0.00871 rh - 0.124 low	90%	Same as Equation 4.1, but with Form #4 removed
4.4	181	log fail = 2.06 - 0.559 log rate + 0.0191 temp + 0.0955 MD + 0.285 HGH	82%	Same as Equation 4.1, but regression includes 1992/93 data

fail = Failure Time (min)
rate = Rate of Precipitation ($g/dm^2/hr$)
temp = Air Temperature (°C)
rh = Relative Humidty (%)

For Equations 4.1, 4.2 and 4.3

low = Low Wind Speed (0 to 6 kph) = 1, otherwise = 0
mod = Moderate Wind Speed (6 to 12 kph) = 1, otherwise = 0
hi = High Wind Speed (12 to 18 kph) = 1, otherwise = 0

For Equation 4.4

LW = Low Wind Speed (0 to 6 kph) = 1, otherwise = 0
MD = Moderate Wind Speed (6 to 18 kph) = 1, otherwise = 0
HGH = High Wind Speed (18 to 24 kph) = 1, otherwise = 0
VHI = Very High Wind Speed (above 24 kph) = 1, otherwise = 0

typ3_anl\TBL4_1.XLS

During simulated freezing drizzle and fog tests in the 1992/93 test season, the "loss of gloss" failure mode was used to determine the end condition. The testers, unfamiliar with this type of precipitation, may have been "waiting" for the "loss of absorption capability" type of failure as opposed to the "loss of gloss" failure mode. As a result, only tests under natural "snow" conditions were retained for further analysis.

4.1.2.2 Effect of Wind

Figure 4.4 shows the remaining test points (151) as a function of wind speed. A statistical analysis of these points results in a regression curve whose descriptive function, shown in Table 4.1 as Equation 4.1, has an R^2 of 83%. The regression curve indicates that failure time decreases as the precipitation rate increases and temperature decreases.

It was shown in the 1992/93 report (main document) that moderate winds have an effect of prolonging the failure time, since the wind forces counterbalance the gravitational energy of the fluid. Equation 4.1 in Table 4.1 confirms this hypothesis -low wind (0 to 6 kph) test points generally failed quicker then moderate wind test points. It should be noted that wind speeds in the 1991/92 season were much lower than in 1992/93 (8 kph vs 20 kph). Since the winds in the 1991/92 data set were generally either low or moderate, temperature had a more predominant effect. Equation 4.2 in Table 4.1 was derived by selecting and analysing the points with low wind speeds (0 to 6 kph). As was observed in the 1991/92 report, the R^2s are very high, suggesting a good correlation amongst the data points. Equation 4.2 shows that the R^2

for the "low wind" points is 93%.

4.1.2.3 Effect of Temperature

Figure 4.5 clearly shows that temperature is a meaningful parameter in the determination of failure time. This was confirmed by Equation 4.1 in the statistical analysis, which implies that as temperatures decrease, Type III plate failure times also decrease.

4.1.2.4 Other Outliers

There is one test (six points) which is circled in Figure 4.5 as Form #4. This is considered to be an outlier by the statistical software used for the analysis. While there is no valid reason to believe that this test should be removed, if it was, the R^2 would jump from 83% to 90% (see Equation 4.3 of Table 4.1).

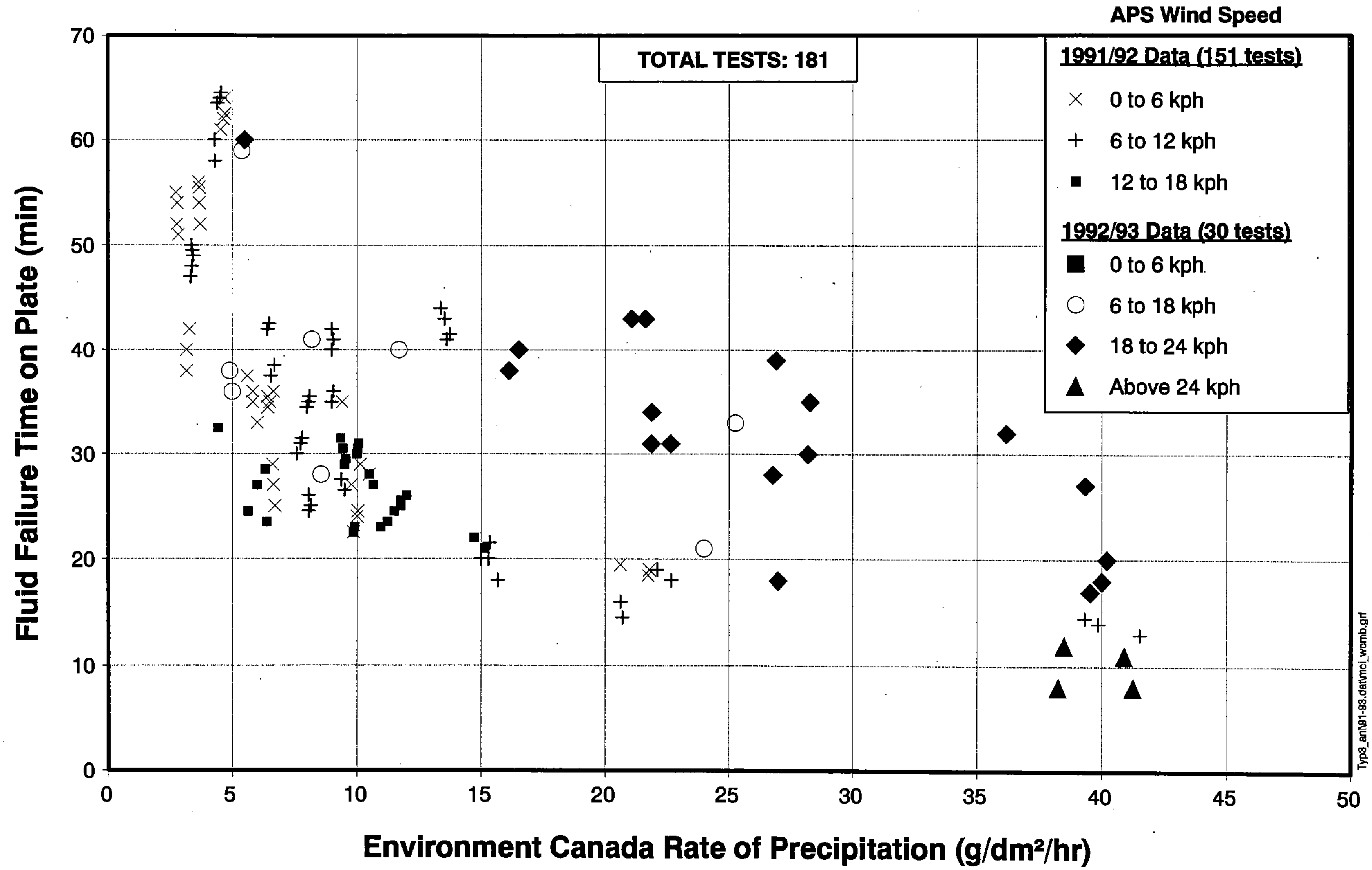
4.2 Inclusion of Natural Precipitation Tests from 1992/93

Figure 4.6 shows the 30 test points from 1992/93 (main document) superimposed over the 1991/92 data. It is interesting to note the difference in wind speeds from one year to the next. In 1992/93, there were no test points with winds less than 6 kph. The 6 to 18 kph points from 1992/93 are generally in agreement with the points from 1991/92. The 18 to 24 kph points from 1992/93 are above the 1991/92 points. This once again confirms that moderate winds generally have the tendency of keeping the fluid on the plate longer. The few points from 1992/93 with winds above 25 kph generally follow a similar pattern as the low wind points.

FIGURE 4.6

EFFECT OF WIND SPEED AND RATE OF PRECIPITATION ON TYPE III UCAR 250-3 FLUID FAILURE TIME

1991 - 1993



While the points from 1991/92 were combined on Figure 4.6 with those of 1992/93, some procedural differences in conducting the tests should be noted. During 1991/92 test panels were covered for 10 minutes prior to being exposed to the precipitation, and the test location in 1991/92 was on the roof of Air Canada's maintenance facility rather than the open field adjacent to the AES building. To compensate for the plates not being covered for 10 minutes in 1992/93, two minutes was added to the failure times in 1991/92, in order to carry out the regression. The two minutes is based on fluid settling time variation experiments under standard water spray endurance test conditions at UQAC. The regression equation resulting from combining the two data sets (with the two minute adjustment) is presented as Equation 4.4 of Table 4.1.

5. CONCLUSION

The results of the analysis showed that relationships between failure times of the fluids versus other variables are far more evident in this report than was the case in the 1991/92 report. The improvement in precipitation measurements using Environment Canada's precipitation gauge with a wind shield contributed greatly to this result. The analysis shows that the rates of precipitation when measured with a wind protection element have a strong influence on failure times. Fluid failure time generally decreases with an increasing rate of precipitation in a logarithmic manner, and cold temperatures generally result in lower failure times. Furthermore, it was shown that wind has a significant effect on failure time. In general, moderate winds tend to increase the failure times at a given rate of precipitation.