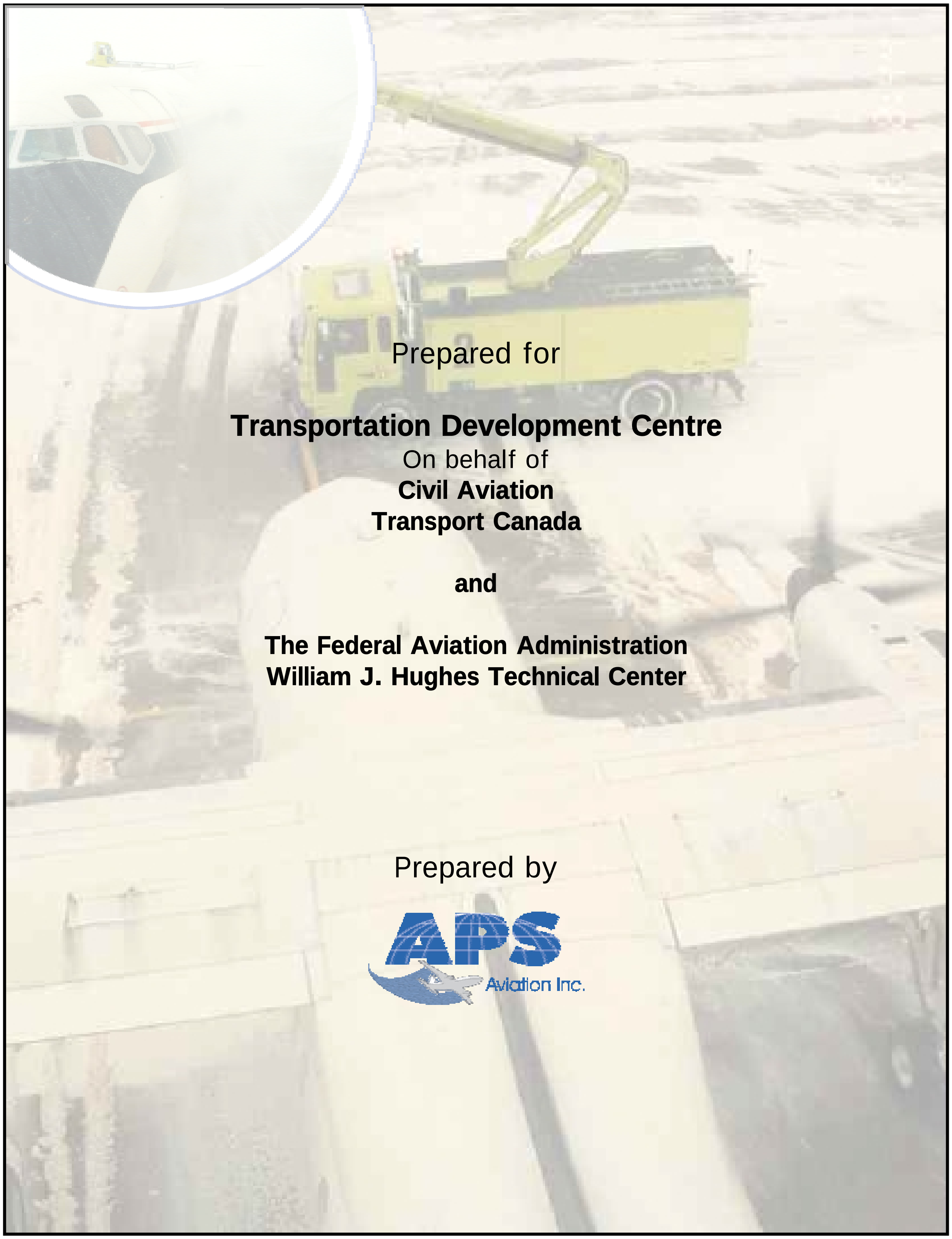
TP 14152E

A Potential Solution for De/Anti-Icing of Commuter Aircraft



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Transportation Development Centre
On behalf of
Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

November 2003
Final Version 1.0

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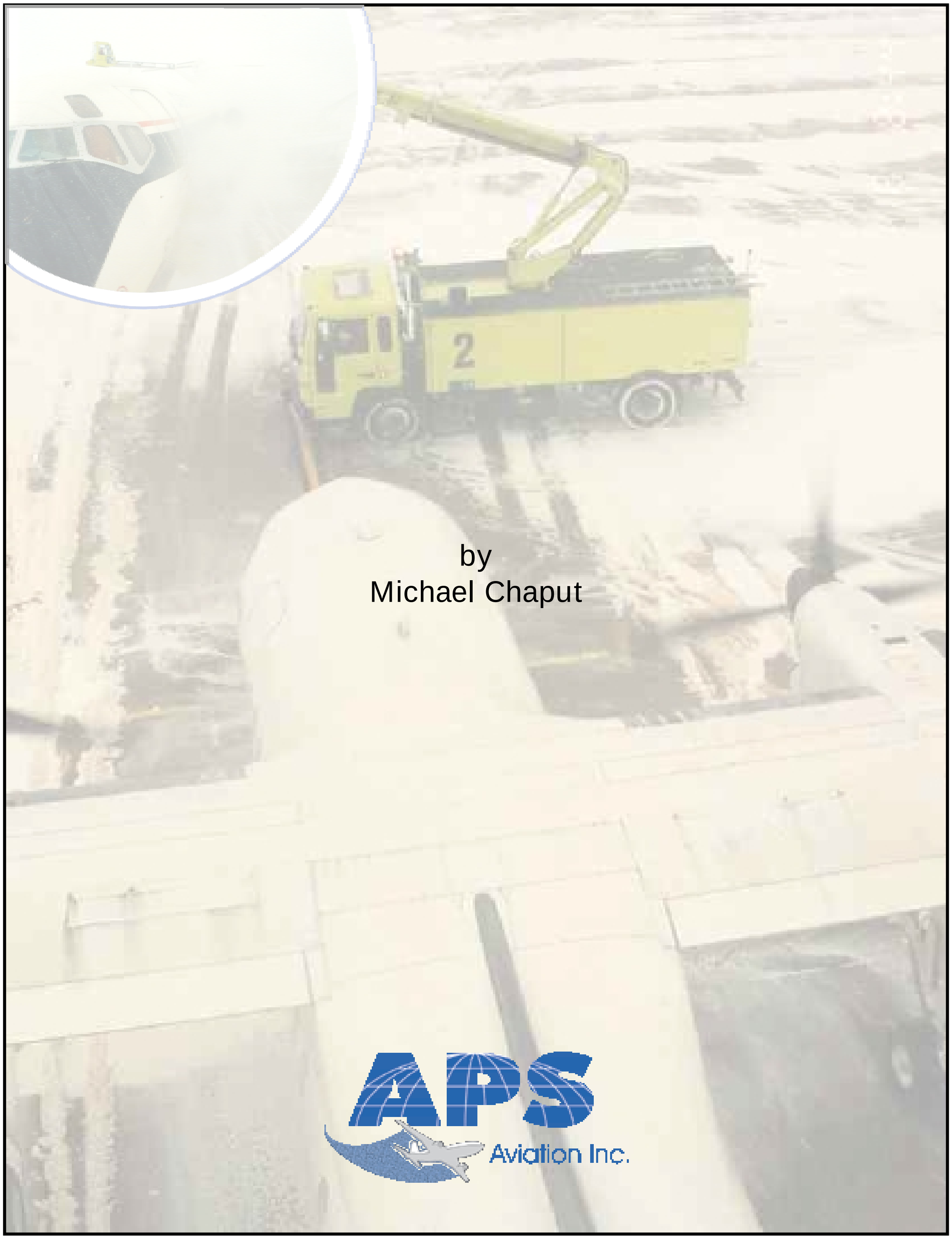

by
Michael Chaput

APS Aviation Inc.

November 2003
Final Version 1.0

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The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

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Un sommaire français se trouve avant la table des matières.

PREFACE

Under contract to the Transportation Development Centre of Transport Canada and in conjunction with the Federal Aviation Administration, APS Aviation Inc. (APS) has undertaken a research program to advance aircraft ground de/anti-icing technology. The specific objectives of the APS test program are the following:

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To evaluate the parameters specified in Proposed Aerospace Standard 5485 for frost endurance time tests in a laboratory;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To further evaluate the flow of contaminated fluid from the wing of an aircraft during simulated takeoff runs;
- To compare endurance times in natural snow with those in laboratory snow;
- To compare fluid endurance time, holdover time and protection time;
- To compare snowfall rates obtained using the National Center for Atmospheric Research hotplate with rates obtained using rate pans;
- To further analyse the relationship between snowfall rate and visibility;
- To stimulate the development of Type III fluids;
- To measure endurance times of fluids applied using forced air-assisted systems;
- To conduct exploratory research, including measuring temperatures of applied Type IV fluids, measuring the effect of lag time on holdover time, evaluating the effectiveness of fluid coverage, and assessing the impact of taxi time on deicing holdover time; and
- To provide support services to Transport Canada.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2002-03 are documented in thirteen reports. The titles of the reports are as follows:

- TP 14144E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2002-03 Winter;
- TP 14145E Laboratory Test Parameters for Frost Endurance Time Tests;
- TP 14146E Winter Weather Impact on Holdover Time Table Format (1995-2003);
- TP 14147E Aircraft Takeoff Test Program for Winter 2002-03: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid;
- TP 14148E Endurance Time Testing in Snow: Comparison of Indoor and Outdoor Data for 2002-03;

- TP 14149E Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces;
- TP 14150E Evaluation of a Real-Time Snow Precipitation Gauge for Aircraft Deicing Operations;
- TP 14151E Relationship Between Visibility and Snowfall Intensity;
- TP 14152E A Potential Solution for De/Anti-Icing of Commuter Aircraft;
- TP 14153E Endurance Times of Fluids Applied with Forced Air Systems;
- TP 14154E Aircraft Ground Icing Exploratory Research for the 2002-03 Winter;
- TP 14155E Aircraft Ground Icing Research Support Activities for the 2002-03 Winter; and
- TP 14156E Variance in Endurance Times of De/Anti-Icing Fluids.

This report, TP 14152E, has the following objective:

- To stimulate the development of fluids with better holdover time performance than Type I fluids and to investigate the possibility of using a severely sheared anti-icing fluid that could be certified to AMS 1428.

This objective was met by conducting endurance time tests with Type IV fluids sprayed through Type I delivery systems, and with simulated Type III fluids.

ACKNOWLEDGEMENTS

This research has been funded by Transport Canada with support from the U.S. Federal Aviation Administration, William J. Hughes Technical Center. This program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Civil Aviation Group and the Transportation Development Centre of Transport Canada, the U.S. Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers. Special thanks are extended to US Airways Inc., Federal Express, American Eagle Airlines Inc., the National Center for Atmospheric Research, AéroMag 2000, Aéroports de Montreal, Ottawa International Airport Authority, GlobeGround North America, and Dow Chemical Company for provision of personnel and facilities and for their co-operation with the test program. APS would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Alia Alwaid, Stephanie Bendickson, Nicolas Blais, Richard Campbell, Mike Chaput, Sami Chebil, John D'Avirro, Peter Dawson, Caroline Duclos, Miljana Horvat, Luis Lopez, Bob MacCallum, Mark Mayodon, Chris McCormack, Nicoara Moc, Marco Ruggi, Sherry Silliker, Ben Slater, and Kim Vepsa.

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Research reports produced on behalf of Transport Canada for testing during previous winters are available from the Transportation Development Centre (TDC). Thirteen reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface.

16. Abstract

In 2002-03, APS examined potential solutions to address the holdover time restrictions of Type I fluid. One potential solution examined was the spraying of heated Type IV fluids through Type I spray equipment to produce a lower viscosity fluid. The idea was based on the assumption that production samples of heated Type IV fluid would retain sufficient viscosity following a spray through a Type I delivery system to provide a minimum of 15 minutes of holdover time in snow.

Testing was conducted at three American Eagle Airlines stations in 2003: Dubuque, Quebec City, and Dallas/Fort Worth. Viscosity and endurance time tests were performed with the Type IV samples collected at the three sites. Even when the Type IV fluid was severely sheared by the Type I spray equipment, the endurance time results with these samples were very long. The positive test results led to the belief that a severely sheared anti-icing fluid could be certified to AMS 1428 as a Type III fluid.

Transport Canada produces a Type III generic holdover time table annually even though no Type III fluids currently exist. In 2002-03, APS produced three simulated Type III fluids by mechanically shearing certified Type II products to low viscosity levels. Tests were performed in natural snow and simulated precipitation using standard endurance time testing procedures. The endurance time tests produced very encouraging results. One product had endurance times that were all above the values in the current Transport Canada Type III holdover time guidelines.

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15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)

Les rapports de recherche produits au nom de Transports Canada sur les essais réalisés au cours des hivers antérieurs peuvent être obtenus auprès du Centre de développement des transports (CDT). Le programme de la saison hivernale a donné lieu à treize rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports.

16. Résumé

En 2002-2003, APS a examiné des solutions potentielles au problème des courtes durées d'efficacité des liquides de type I. Une des solutions examinées consistait à vaporiser des liquides de type IV chauffés, mais à utiliser pour ce faire un équipement de vaporisation prévu pour les liquides de type I, de façon à abaisser la viscosité du liquide. On posait l'hypothèse que des échantillons de production de liquide de type IV chauffé, vaporisés à l'aide d'un équipement de vaporisation pour liquides de type I, seraient suffisamment visqueux pour demeurer efficaces pendant au moins 15 minutes dans des conditions neigeuses.

Les essais ont eu lieu en 2003 à trois postes de dégivrage exploités par American Eagle Airlines situés à Dubuque, Québec et Dallas/Fort Worth. Des essais de viscosité et d'endurance ont été réalisés avec les échantillons de liquides de type IV recueillis aux trois sites. Malgré le fort cisaillement subi par les échantillons lorsque vaporisés à l'aide d'un équipement prévu pour des liquides de type I, ceux-ci ont affiché de très longs temps d'endurance. Les résultats positifs des essais ont mené à penser qu'un liquide antigivre soumis à un fort cisaillement pourrait être homologué en tant que liquide de type III, selon la norme AMS 1428.

Transports Canada publie chaque année un tableau générique des durées d'efficacité de liquides de type III, même s'il n'existe présentement aucun liquide dit de type III. En 2002-2003, APS a produit trois liquides de type III simulés en abaissant, par cisaillement mécanique, la viscosité de liquides de type II. Les essais ont été menés sous neige naturelle et sous précipitations simulées, en appliquant les procédures d'essai d'endurance standard. Les temps d'endurance obtenus se sont avérés très encourageants. Un des produits a même affiché des temps d'endurance qui étaient tous supérieurs aux valeurs des tableaux des durées d'efficacité des liquides de type III publiés par Transports Canada.

17. Mots clés Type III, type I, aéronef de transport régional, propylène glycol, viscosité, durée d'efficacité, antigivrage, dégivrage, temps d'endurance, essai		18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.		
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EXECUTIVE SUMMARY

Background

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC) and the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) undertook a research program to examine a potential solution for the de/anti-icing of commuter aircraft.

The commuter aviation industry has traditionally relied heavily on Type I fluid as an aircraft ground anti-icing agent.

Prior to 1992, the Type I fluid holdover time table, published by the Association of European Airlines (AEA) and the International Organization for Standardization (ISO), contained a single value in the snow column, regardless of the ambient temperature: this value was 15 minutes. Beginning in 1992-93, a holdover time range was introduced for Type I fluid in snow, and the values were reduced to 6 to 15 minutes. The SAE Type I table remained the same from 1992-93 until 2000-01. In the winter of 1999-2000, several new Type I products entered the marketplace, and a series of fluid endurance time tests was conducted on the new Type I fluids using test parameters developed to test Type II and Type IV fluids. The results of these tests were presented at the annual meeting of the SAE G-12 Holdover Time Subcommittee held in Toulouse, France, in May 2000. At this meeting, the Holdover Time Subcommittee adopted holdover time values for Type I fluid that were significantly shorter than those published in previous years.

Many new developments in the test protocol for Type I fluids have occurred since 1990, contributing to an increase in the Type I holdover times agreed upon in Toulouse. Although the snow values generated by the new test protocol were an improvement over the reduced holdover time values agreed upon in Toulouse, the values were, in many cases, below the historical 6 to 15 minute holdover time range for Type I fluid in snow. Commuter operators that had traditionally used Type I fluid as an anti-icing agent continued to express concern that the new snow values would adversely affect their operations.

As a result of these concerns, APS began to examine potential solutions to address the holdover time restrictions of anti-icing operations with Type I fluid.

Spray Tests with Heated Type IV Fluid

In the fall of 2002, American Eagle Airlines and APS discussed one potential solution to the limitations of Type I anti-icing. Initial discussions centred on the possibility of spraying heated Type IV fluids through existing American Eagle Type I spray equipment as a means of producing a lower viscosity fluid. The idea was based on the assumption that production samples of heated Type IV fluid would retain sufficient viscosity following a spray through a Type I delivery system to provide the desired 15-minute minimum holdover time.

Testing was conducted at three American Eagle stations in 2003: Dubuque, Quebec City, and Dallas/Fort Worth. Testing was performed to verify the viscosity of Kilfrost ABC-S and Clariant MP IV 2001 production samples when sheared through different Type I truck/pump/nozzle combinations. Heated Type IV fluids were sprayed at the three stations in a one-step de/anti-icing procedure. Fluids were collected off the surface of aircraft wings or from fluid collection containers and returned to APS for viscosity testing and endurance time testing.

In Dubuque, the viscosity of the fluid sprayed through the Type I vehicle and nozzle was above the degraded viscosity of Kilfrost ABC-S that was tested for endurance times by APS in 1999-2000. The degraded viscosity sample of ABC-S tested in 1999-2000 had endurance times in excess of the generic Type II values. The fluid endurance time tests conducted with the ABC-S samples collected in Dubuque had results that were above or within the Type II generic holdover time ranges.

In Quebec City, the Type IV fluid sprayed through the Type I vehicle was severely sheared. The viscosity of the fluid collected in Quebec City was not measurable using the manufacturer's suggested viscosity measurement method. Fluid samples were nonetheless collected and returned to Montreal for endurance time testing. The endurance time results of the severely sheared sample from Quebec City were below generic Type II values, but were surprisingly well above the generic Type I values.

The endurance time test results of the Quebec City test samples led to the subsequent testing of simulated Type III products.

Due to a defective fluid pump in the spray vehicle available for tests in Dallas/Fort Worth, the shear forces exerted on the Type IV fluids at Dallas/Fort Worth were inconsistent with those of a normal operation. Because the deicing vehicle did not adequately shear the fluids, the viscosity and endurance time results gathered on the Dallas/Fort Worth fluids were deemed to be insignificant.

Endurance Time Testing of Simulated Type III Products

TC produces a Type III generic holdover time table annually, despite the fact that no Type III fluids currently exist.

In 2002-03, APS produced three simulated Type III fluids by mechanically shearing certified Type II products to low viscosity levels. Tests were performed on the fluids in natural snow and simulated precipitation using standard endurance time testing procedures.

The endurance time tests performed with the simulated Type III products produced very encouraging results. One product had endurance times that were all above the values in the current TC Type III holdover time guidelines. Endurance time tests performed with a slightly higher viscosity sample of the same product produced endurance time results that were marginally longer than those of the lower viscosity product. Most endurance time tests conducted with a third simulated Type III product were slightly below the generic Type III holdover times.

Conclusions

a) Despite having a very low viscosity, the simulated Type III fluids provided vastly superior holdover time performance than Type I fluid.

b) The holdover times provided by the simulated Type III fluids could provide the industry with operationally useful holdover times.

c) Type III fluids could potentially be used in one-step de/anti-icing operations, as Type I fluids currently are.

d) Because a Type III fluid based on a low viscosity anti-icing fluid formulation is undiluted, it would provide fluid freezing point protection across the holdover time table.

e) Type III fluid could likely be applied with Type I fluid spray equipment.

f) Due to the lower viscosity, the fluid would likely provide improved aerodynamics for commuter aircraft and alleviate current penalties imposed on operators.

Recommendations

a) TC should encourage fluid manufacturers to formulate new Type III fluids.

b) Any new Type III fluid formulation should be evaluated for endurance times over the entire range of conditions covered by the Type III holdover time guidelines.

c) An operational assessment for using Type III fluid in a one-step operation to replace Type I anti-icing should be conducted with a commuter operator in 2003-04, should fluid samples be made available for testing in the upcoming winter test season.

a) An evaluation of the dry-out and re-hydration problems associated with the use of heated Type III fluid formulations should be performed.

SOMMAIRE

À l'automne 2002, American Eagle Airlines et APS ont entrepris de chercher ensemble une solution aux restrictions touchant l'utilisation d'un liquide de type I en tant qu'agent antigivre. Ils ont d'abord envisagé la possibilité de vaporiser des liquides de type IV à l'aide de l'équipement de vaporisation de liquide de type I d'American Eagle, afin d'abaisser la viscosité du liquide. L'hypothèse posée était que des échantillons de production de liquide de type IV chauffé, vaporisés à l'aide d'un équipement de vaporisation pour liquides de type I, seraient suffisamment visqueux, pour avoir la durée d'efficacité souhaitée d'au moins 15 minutes.

En 2003, des essais ont eu lieu à trois postes de dégivrage exploités par American Eagle Airlines, à Dubuque, Québec et Dallas/Fort Worth. Ces essais visaient à vérifier la viscosité d'échantillons de production des liquides Kilfrost ABC-S et Clariant MP IV 2001 soumis au cisaillement lorsque vaporisés par différentes combinaisons de camion, pompe et ajutage de vaporisation. Les liquides de type IV chauffés ont été vaporisés aux trois postes de dégivrage dans une procédure de dégivrage/antigivrage à une seule étape. Les liquides ont été recueillis à la surface des ailes ou récupérés dans des contenants spéciaux et acheminés à APS pour des essais de viscosité et d'endurance.

À Dubuque, la viscosité du liquide vaporisé par un camion et un ajutage conçus pour des liquides de type I dépassait la viscosité du liquide Kilfrost ABC-S dégradé, enregistrée lors d'essais d'endurance menés par APS en 1999-2000. Par ailleurs, l'échantillon de ABC-S dégradé étudié en 1999-2000 affichait des temps d'endurance supérieurs aux valeurs génériques des liquides de type II. Les essais d'endurance réalisés sur les échantillons de ABC-S recueillis à Dubuque ont donné des résultats supérieurs ou équivalents aux plages de durées d'efficacité génériques des liquides de type II.

À Québec, le liquide de type IV vaporisé par le véhicule normalement utilisé pour vaporiser un liquide de type I était soumis à un fort cisaillement. La viscosité du liquide recueilli à Québec n'a pu être mesurée à l'aide de la méthode de viscosimétrie suggérée par le fabricant. Des échantillons de liquide ont quand même été recueillis et acheminés à Montréal pour des essais d'endurance. Les temps d'endurance obtenus étaient inférieurs aux durées d'efficacité génériques des liquides de type II, mais, fait étonnant, ils dépassaient de beaucoup les valeurs génériques des liquides de type I.

Les résultats des essais d'endurance de Québec ont naturellement débouché sur des essais de liquides de type III simulés.

En raison d'une défectuosité de la pompe du véhicule de vaporisation utilisé à Dallas/Fort Worth, les forces de cisaillement exercées sur les liquides de type IV n'étaient pas représentatives du fonctionnement normal de l'équipement. Et, faute d'un cisaillement adéquat, la viscosité des liquides et leurs temps d'endurance ont été jugés non significatifs.

Essais d'endurance de liquides de type III simulés

TC publie chaque année un tableau générique des durées d'efficacité de liquides de type III, même s'il n'existe présentement aucun liquide de type III.

En 2002-2003, APS a produit trois liquides de type III simulés, en abaissant, par cisaillement mécanique, la viscosité de liquides homologués de type II. Ces liquides ont été mis à l'essai sous des précipitations de neige naturelle et des précipitations simulées. Les procédures d'essai d'endurance standard ont été utilisées.

Ces essais ont donné des résultats très encourageants. Un des produits a même affiché des temps d'endurance tous supérieurs aux durées d'efficacité des liquides de type III publiées par TC. Les essais d'endurance réalisés avec un échantillon du même produit, mais légèrement plus visqueux, ont donné des temps d'endurance légèrement plus longs que ceux associés au produit moins visqueux. La plupart des essais d'endurance menés sur un troisième liquide de type III simulé ont donné des durées d'efficacité légèrement inférieures à celles du tableau générique établi pour les liquides de type III.

Conclusions

a) Malgré leur très faible viscosité, les liquides de type III simulés ont donné des durées d'efficacité de beaucoup meilleures que celles obtenues avec les liquides de type I.

b) Les durées d'efficacité obtenues avec les liquides de type III simulés pourraient s'avérer utiles à l'industrie.

c) Les liquides de type III pourraient potentiellement être utilisés au cours d'opérations de dégivrage/antigivrage à une seule étape, comme le sont actuellement les liquides de type I.

d) Comme un liquide de type III préparé à partir d'un liquide antigivre à faible viscosité est non dilué, il offrirait une protection contre le gel dans toutes les cases du tableau des durées d'efficacité.

e) Un liquide de type III pourrait probablement être appliqué à l'aide de l'équipement de vaporisation prévu pour les liquides de type I.

f) En raison de sa faible viscosité, le liquide améliorerait vraisemblablement la performance aérodynamique des aéronefs de transport régional, ce qui serait à l'avantage des exploitants.

Recommandations

a) Que TC encourage les fabricants de liquides à formuler des liquides de type III.

b) Que les temps d'endurance de toute nouvelle formulation de liquide de type III soient évalués dans toute la gamme des conditions prévues par les tableaux des durées d'efficacité des liquides de type III.

c) Que l'on évalue en situation opérationnelle, au cours de l'hiver 2003-2004, avec le concours d'un exploitant d'aéronefs de transport régional, l'utilisation d'un liquide de type III dans une procédure à une seule étape, au lieu d'un liquide antigivre de type I, si les échantillons de liquides nécessaires aux essais sont obtenus à temps.

d) Qu'une étude soit entreprise pour examiner les problèmes d'assèchement et de réhydratation associés à l'utilisation de liquides de type III chauffés.

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GLOSSARY

AEA	Association of European Airlines
AMS	Aerospace Material Specifications
APS	APS Aviation Inc.
cP	Centipoises
DBQ	Dubuque Regional Airport
DFW	Dallas/Fort Worth International Airport
ET	Endurance Time
FAA	Federal Aviation Administration
HOT	Holdover Time
ISO	International Organization for Standardization
MSC	Meteorological Service of Canada
NRC	National Research Council Canada
OAT	Outside Air Temperature
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre
YQB	Quebec City – Jean Lesage International Airport

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1. INTRODUCTION

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC) and the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) examined a potential solution for de/anti-icing of commuter aircraft with fluids that have improved relative to Type I fluids.

1.1 Background

1.1.1 The Early Years (Prior to 1992)

The commuter aviation industry has traditionally relied heavily on Type I fluid as an aircraft ground anti-icing agent.

Prior to 1992, the Type I fluid holdover time table, published by the Association of European Airlines (AEA) and the International Organization for Standardization (ISO), contained a single value in the snow column, regardless of the ambient temperature: this value was 15 minutes. The values in the table were initially based on operational experience and assumptions of fluid properties, but were not substantiated by any form of laboratory or field testing. The AEA/ISO Type I holdover time table from 1990 is shown in Table 1.1.

Table 1.1: 1990 AEA/ISO Type I Holdover Time Table

OAT [°C]	WEATHER CONDITIONS				
	Frost	Freezing Fog	Steady Snow	Freezing Rain	Rain on Cold Soaked Wing
+ 0 and above	45 min.	30 min.	15 min.	5 min.	15 min.
− 0 to − 7	45 min.	15 min.	15 min.	3 min.	
− 8 and below	30 min.	15 min.	15 min.		

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1.1.2 1992-93 to 2000-01

The initial Type I holdover time research conducted by TC in the early 1990s led to major changes in the fluid holdover time table values. In the first rounds of tests that took several winters to complete, it became clear that the AEA holdover time values were optimistic. Armed with test data for the first time in 1992, the Society of Automotive Engineers (SAE) G-12 Holdover Time Subcommittee decided to set a range of times in place of the single value that existed in the holdover time tables up to that point; the AEA values would apply to "light" conditions and the substantially reduced times, provided by the data collected from fluid endurance time testing, would apply to "moderate" conditions. Beginning in 1992-93, the holdover time range for Type I fluid in snow was 6 to 15 minutes. The SAE Type I fluid holdover time table from 1992-93 is shown in Table 1.2.

Table 1.2: SAE Type I Holdover Time Table 1992-93

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

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1.1.3 New Type I Testing in 1999-2000

The SAE Type I table remained the same from 1992-93 until 2000-01. In the winter of 1999-2000, several new Type I products entered the marketplace, and a series of fluid endurance time tests was conducted with the new Type I fluids using test parameters developed to test Type II and IV fluids. The results of these tests were presented at the annual meeting of the SAE G-12 Holdover Time Subcommittee held in Toulouse, France, in May 2000. At this meeting, the Holdover Time Subcommittee adopted holdover time values for Type I fluid that were significantly shorter than those published in previous years (see TC report TP 13659E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 1999-2000 Winter* (1)). The SAE Type I holdover time table, agreed upon at the Holdover Time Subcommittee meeting in Toulouse, appears in Table 1.3.

Table 1.3: SAE Type I Holdover Time Table 2000-01

OAT		Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
°C	°F	*FROST	FREEZING FOG	SNOW ①	**FREEZING DRIZZLE	LIGHT FRZ RAIN	RAIN ON COLD-SOAKED WING	OTHER***
above 0°	above 32°	0:45	0:12-0:30	0:07-0:12	0:05-0:08	0:02-0:05	0:02-0:05	
0 to -10	32 to 14	0:45	0:06-0:11	0:03-0:06	0:05-0:08	0:02-0:05	**CAUTION No holdover time**	
below -10	below 14	0:45	0:06-0:09	0:02-0:04	**guidelines exist**			

The changes to the Type I holdover times in snow were significant. At a precipitation rate of 10 g/dm²/h in the 0°C to -10°C cell, the fluid holdover time was reduced from 15 minutes to 6 minutes; at a rate of 25 g/dm²/h in the 0°C to -10°C cell, the time was reduced from 6 minutes to 3 minutes.

The reduction in fluid holdover times in snow led to concerned discussion at industry meetings. Several airlines indicated that they had operated safely with the 6 to 15 minute holdover time range in snow for years without incident, and the newly imposed reductions in Type I holdover times would severely compromise their operations in certain conditions and temperatures.

The concern raised by certain groups in the industry led to the general realization that the test protocol for Type I fluids was faulty. The test protocol did not take into account the transfer of heat from the heated Type I fluid to the wing surface nor the thermal mass of the wing itself. As a result of this realization, TC and the FAA questioned the validity of the new Type I test data and continued to publish the old Type I holdover time values. The SAE and AEA adopted the new numbers presented at the Toulouse meeting for their Type I holdover time tables.

1.1.4 Development of a New Type I Test Protocol and Recent Tests

Consequently, APS was asked to develop a new Type I fluid test protocol on behalf of TC and the FAA. Specifically, the objective was to develop a test protocol to measure endurance times for SAE Type I fluids that would simulate real field operations.

Research conducted prior to the 2001-02 winter test season led to the establishment of a new test procedure for outdoor snow tests in natural precipitation.

The key modifications to the Type I fluid test procedures were as follows:

a) Test Surface: a new test surface, which would provide a thermal equivalent to wing leading edges, was developed for use. This test surface was intended to produce an accurate representation of the temperature decay rate demonstrated by wings following application of heated deicing fluid in natural outdoor conditions;

b) Fluid Temperature: the recommended test temperature for the Type I fluid was changed from 20°C to 60ºC;

c) Fluid Application Quantity: the recommended quantity of Type I fluid was reduced from 1 L to 0.5 L; and

d) Fluid Application Procedure: the fluid was applied with a fluid spreader positioned along the top edge of the test surface.

The complete procedure is included in TC report TP 13994E, *Generation of Holdover Times Using the New Type I Fluid Test Protocol* (2).

Type I fluid endurance time tests were conducted during the winter of 2001-02 in natural snow conditions using the new test protocol. These tests were conducted over a range of temperatures, and the resulting data enabled the development of new Type I holdover time guidelines that were published by TC and the FAA for use in 2002-03 winter operations. Several modifications were also made to the Type I holdover time guideline format, most notably the addition of a light snow column and changes to the various temperature breakdowns contained within the tables. These modifications were made to allow for increased usage of the table based on the data collected.

For the 2003-04 winter season, additional modifications were made to the TC Type I holdover time guidelines (see TC report TP 14144E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2002-03 Winter* (3)). The modifications included:

a) Addition of a very light snow column;
b) A re-definition of the light snow data collection rate range; and
c) Addition of a -3°C to -6°C temperature breakdown.

The TC Type I Holdover Time Guidelines for the 2003-04 winter are shown in Table 1.4.

Table 1.4: Transport Canada Type I Holdover Time Guidelines 2003-04

°C	°F	FROST	FREEZING FOG	VERY LIGHT SNOW	LIGHT SNOW	MODERATE SNOW	FREEZING DRIZZLE	LIGHT FRZ RAIN	ROCSW
-3 and above	27 and above	45	11 -17	> 18	11 - 18	6 - 11	9 - 13	4 - 6	2 - 5
below -3 to -6	below 27 to 21	45	8 - 13	> 14	8 - 14	5 - 8	5 - 9	4 - 6	
below -6 to -10	below 21 to 14	45	6 - 10	> 11	6 - 11	4 - 6	4 - 7	2 - 5	
below -10	below 14	45	5 - 9	> 7	4 - 7	2 -4			

Although the snow values generated by the new test protocol were an improvement over the reduced holdover time values agreed upon by the SAE Committee in Toulouse, the values were, in many cases, below the historical 6 to 15 minute holdover time range for Type I fluid in snow. Commuter operators that had traditionally used Type I fluid as an anti-icing agent continued to express concern that the new snow values would adversely affect their operations.

As a result of these concerns, APS began to examine potential solutions to address the holdover time restrictions of anti-icing operations with Type I fluid.

1.2 Project Objectives

The objectives of this research program were to:

a) Evaluate the use of heated Type IV fluid applied with a Type I spray delivery system through:

- Viscosity tests with the collected fluid samples to determine the effect of shearing on the Type IV fluid samples; and
- Endurance time tests with the collected samples for comparison with current Type I and Type II holdover times.

b) Evaluate the endurance time performance of simulated Type III fluids through:

   - Endurance time tests in natural snow and simulated precipitation conditions on potential Type III products.

1.3 Work Statement

The work statement for these tests is provided in Appendix A.

1.4 Special Credits and Acknowledgements

The author of this report would like to acknowledge the contributions of Captain Ron Whipple of American Eagle Airlines. Discussions with Captain Whipple in Fall 2002 led to the inception of this research project, and his commitment and vision provided the project with a guiding light in the months that ensued. Without Captain Whipple's input, feedback, cooperation and persistence, this research project would not have been accomplished.

The author would also like to acknowledge and thank the American Eagle station managers and employees who supported the tests in Dubuque, Dallas/Fort Worth and Quebec City, as well as American Eagle and American Airlines for the provision of non-revenue flight tickets for the transport of APS test personnel to Dubuque and Dallas/Fort Worth.

As a final acknowledgement, the author would like to thank the fluid manufacturers – Clariant, Cryotech, Kilfrost, and Octagon Process – for the contribution of test fluids for the various field and laboratory tests related to this project.

2. EVALUATION OF HEATED TYPE IV FLUID APPLIED WITH A TYPE I SPRAY DELIVERY SYSTEM

2.1 Introduction

The recent reductions in the Type I holdover times in snow have adversely affected the wintertime operations of several operators that relied heavily on Type I as an anti-icing agent. In discussions with American Eagle Airlines in November 2002, the airline expressed interest in uncovering a new methodology or fluid type for anti-icing its fleet of turboprop and regional jet aircraft. The desired new product or methodology would provide, as a minimum, the historical Type I holdover time values in snow.

Discussions between American Eagle and APS led to the determination of the desired technology to replace Type I as a de/anti-icing fluid. The ideal solution would:

a) Consist of a single product (deicing and anti-icing fluid);

b) Provide holdover times in excess of 15 minutes in snow;

c) Possess fluid freeze point protection from above 0°C to below -25°C, thus allowing for de-frosting operations at cold temperatures;

d) Be applied to aircraft surfaces heated at a high pressure;

e) Be applied using current Type I spray equipment; and

f) Not cause fluid dry-out problems.

Initial discussions with American Eagle centred around the possibility of spraying heated Type IV fluids through existing American Eagle Type I spray equipment as a means of producing a lower viscosity fluid. The idea was based on the assumption that production samples of heated Type IV fluid would retain sufficient viscosity following a spray through a Type I delivery system to provide the desired 15-minute minimum holdover time.

Of particular interest to this study were two Type IV fluids, Kilfrost ABC-S and Clariant Safewing MP IV 2001, which had been tested for endurance times in severely degraded viscosity form in 1999-2000 (see TC report TP 13659E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 1999-2000 Winter* (1)) and 2001-02 (see TC report *TP 13991E, Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Test Program for the 2001-02 Winter* (4)), respectively. The degraded viscosity samples of both fluids provided holdover times in all table cells that were superior to generic Type II values. The AEA had even permitted use of these two degraded viscosity Type IV fluids with the generic Type II table. A comparison of the lowest on-wing viscosity and degraded viscosity for Kilfrost ABC-S and Clariant Safewing MP IV 2001 appear in Table 2.1. The lowest on-wing viscosity refers to the viscosity of the fluid that was tested in endurance time tests and appears on the fluid-specific table for any given fluid. The degraded viscosity refers to the viscosity of the degraded product that provided Type II generic results in fluid endurance time tests.

Table 2.1: Viscosities of Kilfrost ABC-S and Clariant Safewing MP IV 2001 Fluid Samples

Fluid	Sample	Viscosity (cP)	Viscosity Measurement Method
Kilfrost ABC-S	Lowest On-Wing Viscosity	17,000	20°C, 0.3 rpm, Spindle LV2, 150 mL beaker, 150 mL fluid, 10 minutes
Kilfrost ABC-S	Degraded Viscosity	3,900	20°C, 0.3 rpm, Spindle LV2, 150 mL beaker, 150 mL fluid, 10 minutes
Clariant 2001	Lowest On-Wing Viscosity	18,000	20°C, 0.3 rpm, Spindle SC4-34/13R, 10 mL fluid, 15 minutes
Clariant 2001	Degraded Viscosity	12,200	20°C, 0.3 rpm, Spindle SC4-34/13R, 10 mL fluid, 15 minutes

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As a first step in the testing process, APS proposed that production samples of Kilfrost ABC-S and Clariant Safewing MP IV 2001 be heated and sprayed through American Eagle Type I spray delivery systems to determine whether the viscosity of the fluid sprayed through the Type I vehicles would be in excess of the degraded viscosity listed in Table 2.1. If the viscosities of the sprayed fluids were higher than the degraded viscosities tested for holdover times, the case could be made that the Type II generic holdover time table values would apply to these fluids. The holdover times provided by the Type II generic table would be sufficient for the commuter industry to accept as a replacement to Type I anti-icing. The generic Type II holdover time table for 2003-04 winter operations is shown in Table 2.2.

To determine the effect of different spray vehicles on the viscosity of the Type IV sprayed fluids, tests were performed with Kilfrost ABC-S and Clariant Safewing MP IV 2001 Type IV fluids at three American Eagle stations: Dubuque, Quebec City and Dallas/Fort Worth. Fluids were heated and sprayed through various Type I spray systems, and subsequently collected for viscosity testing. In addition, fluid samples were collected and returned to Montreal for fluid endurance time testing.

Table 2.2: Type II Generic Holdover Time Guidelines for 2003-04 Winter Operations

OAT °C	OAT °F	SAE Type II Fluid Concentration Neat-Fluid/Water (Vol%/Vol%)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
			*FROST	FREEZING FOG	SNOW ①	***FREEZING DRIZZLE	LIGHT FRZ RAIN	RAIN ON COLD SOAKED WING	OTHER****
above 0	above 32	100/0	12:00	0:35-1:30	0:20-0:55	0:30-0:55	0:15-0:30	0:05-0:40	
		75/25	6:00	0:25-1:00	0:15-0:40	0:20-0:45	0:10-0:25	0:05-0:25	
		50/50	4:00	0:15-0:30	0:05-0:15	0:05-0:15	0:05-0:10		
0 to -3	32 to 27	100/0	8:00	0:35-1:30	0:20-0:45	0:30-0:55	0:15-0:30	CAUTION No holdover time guidelines exist	
		75/25	5:00	0:25-1:00	0:15-0:30	0:20-0:45	0:10-0:25		
		50/50	3:00	0:15-0:30	0:05-0:15	0:05-0:15	0:05-0:10		
below -3 to -14	below 27 to 7	100/0	8:00	0:20-1:05	0:15-0:35	**0:15-0:45	**0:10-0:25		
		75/25	5:00	0:20-0:55	0:15-0:25	**0:15-0:30	**0:10-0:20		
below -14 to -25	below 7 to -13	100/0	8:00	0:15-0:20	0:15-0:30				
below -25	below -13	100/0	SAE TYPE II fluid may be used below -25ºC (-13ºF) provided the freezing point of the fluid is at least 7ºC (13ºF) below the OAT and the aerodynamic acceptance criteria are met. Consider use of SAE Type I when SAE Type II fluid cannot be used.						

2.2 Methodology

This methodology section contains information that pertains to three separate research activities:

a) Type IV fluid spray tests with American Eagle;
b) Type IV fluid viscosity tests; and
c) Type IV fluid endurance time tests.

2.2.1 Test Sites

2.2.1.1 Test sites – Type IV fluid spray tests with American Eagle

Tests to collect heated Type IV fluid samples sprayed through Type I delivery systems were performed at three airport sites in North America (see Figure 2.1):

a) Dubuque, Iowa (DBQ);
b) Quebec City, Quebec (YQB); and
c) Dallas/Fort Worth, Texas (DFW).

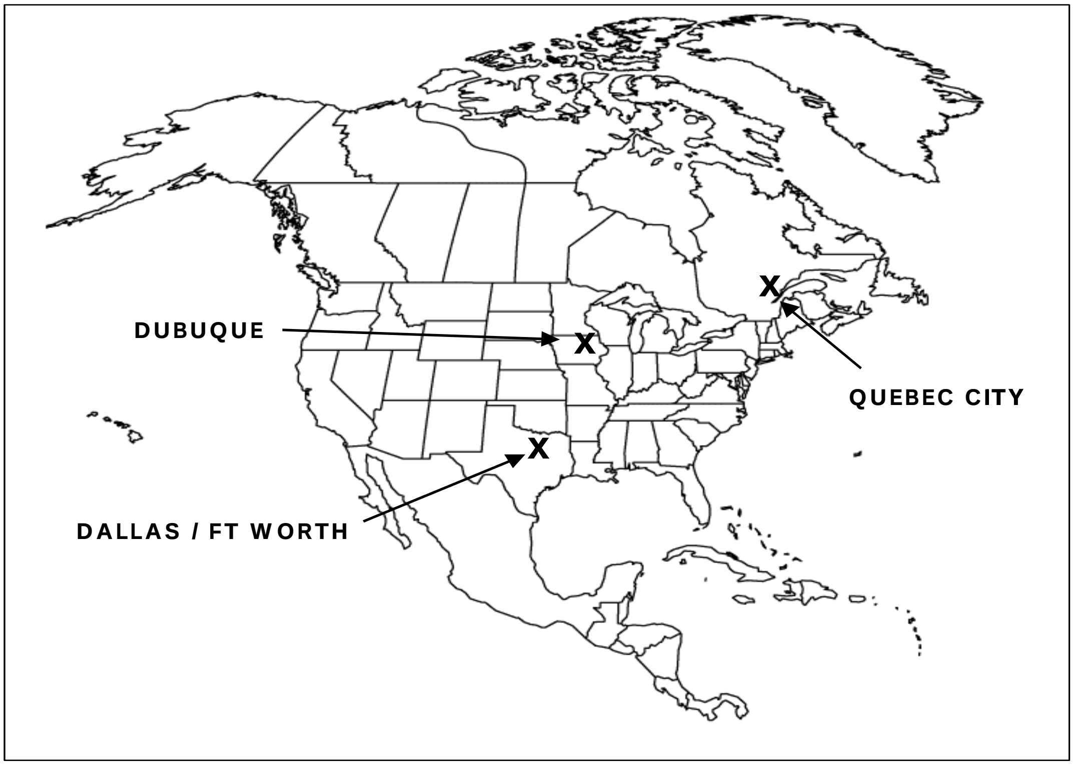

Figure 2.1: Test Sites for Type IV Spray Tests

Each of the selected test sites was an American Eagle station. Tests were originally planned for DBQ, YQB, and Baton Rouge, Louisiana. The tests in Baton Rouge were eventually moved to DFW to take advantage of the wealth of resources available at the DFW hub of American Eagle operations: deicing vehicles, mechanics, spray personnel, and different fluids.

These selected stations possessed different Type I de/anti-icing spray vehicles, and it was due to the uniqueness of each spray vehicle that each station was chosen. These will be further described in subsection 2.2.4.1.

2.2.1.2 Test sites – Type IV fluid viscosity tests

Viscosity measurements of the fluid samples retrieved from the tests in DBQ, YQB, and DFW were performed at the APS laboratory in Montreal.

2.2.1.3 Test sites – Type IV fluid endurance time tests

Natural snow endurance time testing of the Type IV fluid samples was performed at the APS Dorval Airport test site. The location of the site is shown on the plan view of the airport shown in Figure 2.2. Photo 2.1 was taken at the test site and shows the trailer and the associated equipment. The APS test site is located near the Meteorological Service of Canada (MSC) automated weather observation station (Photo 2.2).

Tests under conditions of freezing drizzle were conducted indoors at National Research Council Canada (NRC), where precipitation was artificially produced. Photo 2.3 provides a view of the building from the outside. Photo 2.4 provides an interior view of the test facility. The size of the chamber is 30 m by 5.4 m, with a height of 8 m. The lowest temperature achievable is -46ºC.

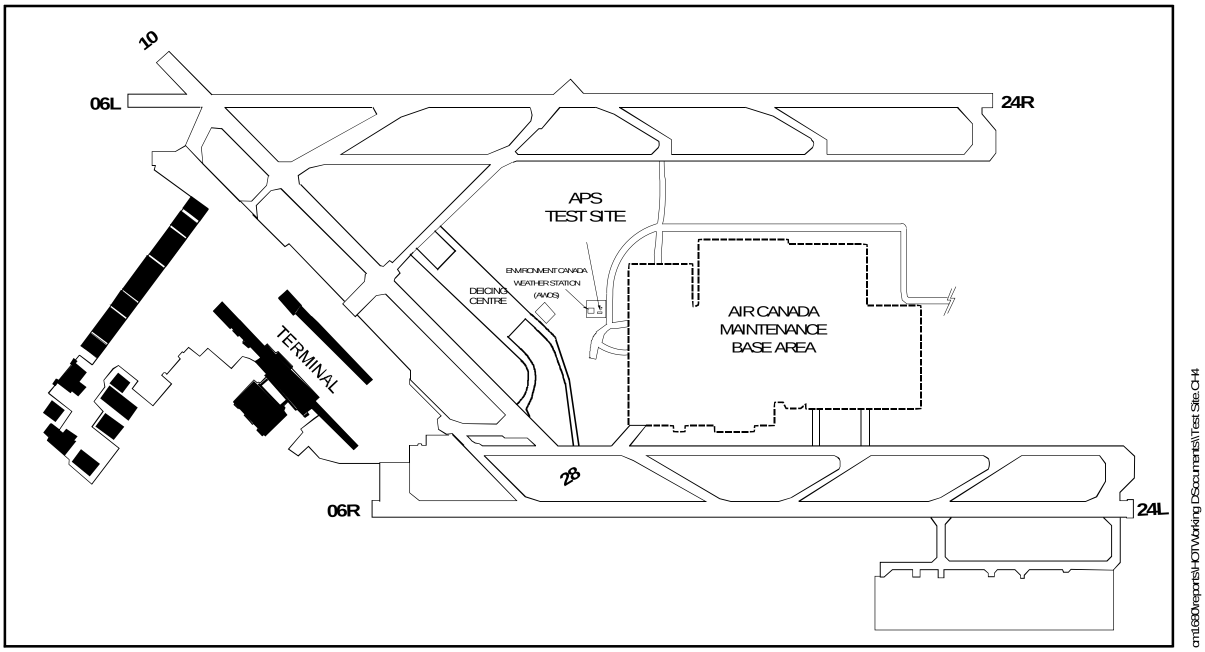

Figure 2.2: APS Test Site Location at Dorval Airport

2.2.2 Description of Test Procedures

2.2.2.1 Procedures – Type IV fluid spray tests with American Eagle

The procedure for heated Type IV spray tests through Type I spray equipment is included in Appendix B.

Prior to the start of testing, Kilfrost ABC-S Type IV fluid, manufactured by Cryotech, was delivered to each of the three selected test sites. Clariant Safewing MP IV 2001 fluid was also used in the tests conducted at DFW, as this fluid is used at DFW by American Airlines and American Eagle.

Prior to the arrival of APS and American Eagle test personnel at the airport test sites, American Eagle support crews loaded the fluids into the Type I spray vehicles and heated the fluids to 60°C (180°F).

Data such as the outside air temperature (OAT), fluid temperature, and information pertaining to the deicing vehicle used in testing were recorded on a prepared form by an APS observer. A sample of each virgin fluid from the truck was also obtained for viscosity tests prior to the spray process.

When the appropriate fluid temperature was attained, the fluid was sprayed and collected. At DBQ, the fluid was sprayed directly onto the wings of an over-nighting Embraer EMB-145 regional jet aircraft (see Photo 2.5). The fluid was removed from the wing using a squeegee and placed in one-litre sample containers. At YQB, the over-nighting aircraft was delayed from its airport of origin due to a snowstorm. Without an aircraft available for use, the fluid was sprayed onto a test stand used for fluid holdover time tests and was collected in a standard rate pan (see Photo 2.6). From the rate pan, the fluid was poured in one-litre sample containers (see Photo 2.7). At DFW, the airport insisted that spray tests be conducted in a designated area equipped with drains to collect the sprayed fluid. As such, no aircraft were used in DFW tests, and fluid was sprayed directly into plastic oil pans and 20-litre fluid containers (see Photo 2.8).

Samples collected for viscosity testing at each of the selected sites were placed in plastic one-litre containers. Fluids were also collected and returned to Montreal in 20-litre containers for fluid endurance time testing.

2.2.2.2 Procedures – Type IV fluid viscosity tests

Viscosity tests were run using the fluid manufacturer's recommended method of viscosity measurement for each fluid tested.

The method used to measure the viscosities of the Kilfrost ABC-S fluid samples was:

a) Spindle: LV2;
b) Temperature: 20°C;
c) Spindle rotation: 0.3 rpm;
d) Test duration: 10 minutes; and
e) Fluid quantity: fluid to the spindle notch in a 250 mL beaker.

The method used to measure the viscosities of the Clariant Safewing MP IV 2001 fluid samples was:

a) Spindle: SC4-34;
b) Temperature: 20°C;
c) Spindle rotation: 0.3 rpm;
d) Test duration: 15 minutes; and
e) Fluid quantity: 10 mL of fluid in the small sample adapter.

2.2.2.3 Procedures – Type IV fluid endurance time tests

The procedures employed for the endurance time testing of the Type IV fluid samples collected in DBQ, YQB, and DFW were identical to those used to develop fluid holdover times for new de/anti-icing fluid formulations. The complete procedures for these tests appear in an associated TC report, TP 14144E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2002-03 Winter* (3).

In general, fluid endurance time tests consisted of pouring the Type IV fluids onto clean aluminium plates inclined at 10° from the horizontal. The plates were mounted on a test stand and systematically exposed to a variety of natural or artificially produced icing conditions. For every plate, the elapsed time required to reach a predefined end condition was recorded. Test conditions, test parameters, and test bed specifications were determined based on SAE G-12 Holdover Time Subcommittee guidelines.

2.2.3 Data Forms

2.2.3.1 Data forms – Type IV fluid spray tests with American Eagle

One data form was used to record the specific information for each spray test at the various airport sites. This data form is shown in Figure 2.3.

2.2.3.2 Data forms – Type IV fluid viscosity tests

Viscosity data was recorded on an internal APS spreadsheet. A copy of this spreadsheet is shown in Table 2.3.

GENERAL FORM
TESTING OF HEATED TYPE IV FLUIDS SPRAYED THROUGH TYPE I SPRAY DELIVERY SYSTEMS

Airport: YQB DBQ BTR

Date: ________________________

Air Temperature (°C): ________________________

Fluid Type: ________________________

Fluid Temperature: ________________________

Deicing Vehicle: ________________________

Vehicle ID#: ________________________

Fluid Pump: ________________________

Nozzle Type: ________________________

Flow Rate and Spray Pattern: ________________________

Aircraft Type: ________________________

Additional Comments: ____
____

Observer: ________________________

Figure 2.3: General Form for Testing of Heated Type IV Fluids Sprayed Through Type I Spray Delivery Systems

Table 2.3: APS Viscosity Data Log

Test #	Bottle #	Date	Fluid Name	Batch #	Conc.	Temp [°C]	Time [mm:ss]	Spindle	Rpm	Torque	Viscosity Stated [cP]	Viscosity Measured [cP]	Signature	Comments

2.2.3.3 Data forms – Type IV fluid endurance time tests

Two data forms, one to record fluid failure times, the other to record precipitation rate data, were used during the 2002-03 winter natural snow endurance time tests. Both forms appear in Appendix C of TP 14144E (3).

Two similar data forms were used to manually record test data in the freezing drizzle tests conducted at NRC. These forms also appear in Appendix C of TP 14144E (3).

2.2.4 Equipment

APS measurement instruments and test equipment are calibrated and/or verified on an annual basis. This calibration is carried out according to a calibration plan developed by APS and based on approved ISO 9001 standards.

2.2.4.1 Equipment – Type IV fluid spray tests with American Eagle

The DBQ Type I spray vehicle was manufactured by Premier, model MT 35175 (see Photo 2.9), and equipped with a Task Force Tips Type I nozzle, Model BGH HT-150. The fluid pump on the Type I spray vehicle was manufactured by Goulds, Model 45HB17535. The fluid spray was performed by American Eagle personnel at the typical Type I fluid pressure of 150 psi.

The YQB spray vehicle was anticipated to represent a “worst-case” vehicle in the field. The truck consisted of an old Econoline van containing a small fluid pump and fluid tank (see Photo 2.10). Fluid was sprayed with a hose/nozzle combination that resembled a pressure-washing gun used in car washes. The fluid tank did not have a circulating pump, and the fluid temperature varied from 30°C to approximately 50°C depending on the quantity of fluid remaining and location of fluid in the tank. The truck was not equipped with instrumentation to determine the fluid pressure.

Tests at DFW were performed with an older model Premier MT 35175 (see Photo 2.11). The truck was equipped with a Goulds pump, Model JPM3616. Tests at DFW used both Type I and Type IV fluid spray nozzles manufactured by Task Force Tips. The Type I nozzle normally produced 150 psi of fluid pressure, the Type IV nozzle produced 50 psi.

It was determined during the tests at DFW that the fluid pump in the spray vehicle that was available for testing was defective, and therefore the shear forces exerted on the fluid in the DFW tests were inconsistent with those normally observed. Despite this realization, fluid samples were collected and returned to Montreal for viscosity and endurance time testing.

Fluid temperatures out of the nozzle of each spray vehicle were measured using a hand-held Wahl temperature probe.

Fluid samples for viscosity and endurance time testing were collected from the test sites and transported to Montreal in one-litre and 20-litre plastic containers, respectively.

2.2.4.2 Equipment – Type IV fluid viscosity tests

Viscosity measurements were carried out using a Model DV-1+ Brookfield viscometer (Photo 2.12) fitted with a Brookfield TC-500 constant temperature bath. The refrigerated TC-500 bath allows the viscosity tests to be conducted from -10°C to 130°C, with a stability of ± 0.03°C.

2.2.4.3 Equipment – Type IV fluid endurance time tests

The equipment used for fluid endurance time tests with the samples collected in DBQ, YQB, and DFW was identical to that used in fluid endurance time tests for the determination of holdover times. A comprehensive description of the equipment can be found in Appendices C and D of TP 14144E (3).

2.2.5 Fluids

Two fluids were used in heated Type IV fluid spray tests through Type I spray delivery systems:

a) Kilfrost ABC-S (manufactured by Cryotech); and
b) Clariant Safewing MP IV 2001.

The two fluids were selected because both had been tested in degraded viscosity form in previous years and displayed holdover time performance superior to the generic Type II holdover times in all cells of the table.

2.2.6 Personnel

2.2.6.1 Personnel – Type IV fluid spray tests with American Eagle

One APS employee was present at DBQ, YQB, and DFW to manage the fluid spray tests and collect the fluid samples.

American Eagle personnel tended to the deicing vehicles and sprayed the selected fluids.

2.2.6.2 Personnel – Type IV fluid viscosity tests

One APS technician was required to conduct the in-house viscosity measurements.

2.2.6.3 Personnel – Type IV fluid endurance time tests

The test site at Dorval Airport was staffed mainly by technicians and university students who were supervised by APS project staff. For natural snow endurance time tests on the samples collected in DBQ, YQB, and DFW, two APS personnel were required: one to determine plate failure times, the other to measure precipitation rates and record meteorological conditions during every test.

Personnel responsibilities for tests conducted in simulated precipitation conditions at the NRC chamber were similar to those of the natural snow tests.

2.3 Description and Processing of Data

2.3.1 Overview of Tests – Type IV Fluid Spray Tests with American Eagle

Tests conducted to collect heated Type IV samples when sprayed through Type I spray equipment were performed over four days in February and March 2003. Table 2.4 provides a summary of the tests conducted at the three airport sites.

The fluid pump in the spray vehicle used in the DFW tests was determined to be defective, and therefore the shear forces exerted on the various fluids used in the DFW tests were deemed to be significantly lower than expected.

2.3.2 Overview of Tests – Type IV Fluid Viscosity Tests

Prior to each spray test in DBQ, YQB and DFW, virgin samples of the Kilfrost ABC-S and Clariant Safewing MP IV 2001 fluids were gathered. After each fluid was heated and sprayed onto the various test surfaces, fluid samples were again collected and returned to Montreal for viscosity testing. A summary of the viscosity results for the sprayed Type IV tests appears in Table 2.5.

Table 2.4: Summary of the Tests Conducted to Collect Heated Type IV Fluid Samples Sprayed Through Type I Equipment

Date	Test	Test Location	Fluid Applied	Truck	Nozzle	OAT (°C)	Fluid Temp. (°C)
8-Feb-03	1	DBQ	Kilfrost ABC-S	Premier MT 35175	Type I	-16	64
22-Feb-03	2	YQB	Kilfrost ABC-S	Ford Econoline	Type I	-14	40
25-Mar-03	3	DFW	Clariant 2001	Premier MT 35175	Type I	21	71
25-Mar-03	4	DFW	Clariant 2001	Premier MT 35175	Type IV	21	71
26-Mar-03	5	DFW	Kilfrost ABC-S	Premier MT 35175	Type I	16	80
26-Mar-03	6	DFW	Kilfrost ABC-S	Premier MT 35175	Type IV	16	80

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Table 2.5: Summary of the Viscosity Results of the Heated Type IV Fluid Samples Sprayed Through Type I Equipment

Date	Test	Test Location	Fluid Applied	Truck	Nozzle	Avg. Virgin Viscosity (cP)	Avg. Sprayed Viscosity (cP)
8-Feb-03	1	DBQ	Kilfrost ABC-S	Premier MT 35175	Type I	16,500	6,800
22-Feb-03	2	YQB	Kilfrost ABC-S	Ford Econoline	Type I	23,600	Not measurable*
25-Mar-03	3	DFW	Clariant 2001	Premier MT 35175	Type I	18,750	15,100
25-Mar-03	4	DFW	Clariant 2001	Premier MT 35175	Type IV	18,750	16,000
26-Mar-03	5	DFW	Kilfrost ABC-S	Premier MT 35175	Type I	23,400	17,700
26-Mar-03	6	DFW	Kilfrost ABC-S	Premier MT 35175	Type IV	23,400	18,200

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* So low that is was not measurable with viscosity measurement method used.

2.3.3 Overview of Tests – Type IV Fluid Endurance Time Tests

Natural snow endurance time tests were conducted with the DBQ and YQB test samples. Because the DFW tests took place at the end of March, no natural snow tests were possible. Endurance time tests were performed with the DBQ and YQB fluid samples at NRC in Ottawa. Due to a limited quantity of available fluid, tests were conducted only in freezing drizzle.

The data log for the natural snow tests with the DBQ and YQB fluids appears in Table 2.6. The data log for the simulated precipitation tests at NRC with the DBQ and YQB fluids appears in Table 2.7.

The DFW fluid samples were tested for endurance times in simulated conditions, despite the fact the fluids were not properly sheared by the defective Type I vehicle. As the DFW results were deemed not to be relevant, the data log for the simulated precipitation tests at NRC with the DFW fluids appears in Appendix C.

2.4 Analysis and Observations

2.4.1 Dubuque Fluid Samples

2.4.1.1 Fluid viscosity

Two drums (400 L) of Kilfrost ABC-S were pumped into a Premier deicing truck equipped with a Type I pump and nozzle. The fluid was heated and sprayed onto the wings of an Embraer Regional Jet over-nighting at DBQ. The fluid was then squeegeed off the wing and collected in 1-litre sample containers for viscosity testing. Additional fluid was also collected in a 20-litre container for endurance time testing.

The fluid was heated adequately by the Type I deicing vehicle and the pressure at which the fluid was applied to the wing would have been sufficient to deice an aircraft in a normal wintertime operation.

The viscosities of the samples collected at DBQ were measured in Montreal. The average viscosity of the sprayed samples from the DBQ tests (6,800 cP) was well above the degraded viscosity for Kilfrost ABC-S (3,900 cP). As the average viscosity of the Type IV fluid samples collected at DBQ was above the degraded viscosity for Kilfrost ABC-S, it could be argued that the generic Type II fluid holdover times would apply to this fluid, based solely on viscosity being the only parameter used for determining the holdover time performance of the fluid.

Table 2.6: Summary of the Natural Snow Endurance Time Tests with Fluid Samples from DBQ and YQB

Test #	ET Test Date	Fluid Name	Fluid Origin	Fail Time (min)	Precip. Rate ($g/dm^2/h$)	Avg. Wind Speed (kph)	OAT (°C)
Q-1	2-Mar-03	Kilfrost ABC-S	YQB	13.1	25.6	19	0.2
Q-2	2-Mar-03	Kilfrost ABC-S	YQB	13	22.7	10	0.3
D-1	2-Mar-03	Kilfrost ABC-S	DBQ	20.3	25.6	18	0.2
D-2	2-Mar-03	Kilfrost ABC-S	DBQ	15.8	25.8	10	0.3
D-3	4-Mar-03	Kilfrost ABC-S	DBQ	50	6.8	3	-7.4
Q-3	4-Mar-03	Kilfrost ABC-S	YQB	32.4	5.2	2	-6.3
Q-4	5-Mar-03	Kilfrost ABC-S	YQB	40.2	6.2	14.6	-7.5
Q-5	5-Mar-03	Kilfrost ABC-S	YQB	29	6.4	14	-8.4
D-4	5-Mar-03	Kilfrost ABC-S	DBQ	58	4	5.2	-6.3
Q-6	8-Mar-03	Kilfrost ABC-S	YQB	23	9.9	12.7	-1.5
Q-7	8-Mar-03	Kilfrost ABC-S	YQB	13	34.7	11.5	-1.9
D-5	8-Mar-03	Kilfrost ABC-S	DBQ	24	19.3	15.2	-2.2
D-6	8-Mar-03	Kilfrost ABC-S	DBQ	18	32.7	15.6	-2
Q-8	9-Mar-03	Kilfrost ABC-S	YQB	15.6	22	19	-2.4
D-7	9-Mar-03	Kilfrost ABC-S	DBQ	18.3	28.4	18.5	-2.5

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Table 2.7: Summary of the Simulated Freezing Drizzle Endurance Time Tests with Fluid Samples from DBQ and YQB

Test #	ET Test Date	Fluid Name	Fluid Origin	Fail Time (min)	Precip. Rate ($g/dm^2/h$)	Precip. Type	OAT (°C)
D-8	8-Apr-03	Kilfrost ABC-S	DBQ	51.6	5.7	Zd	-10.3
Q-9	8-Apr-03	Kilfrost ABC-S	YQB	17.7	11.8	Zd	-10
Q-10	8-Apr-03	Kilfrost ABC-S	YQB	26.9	5.3	Zd	-10.4
D-9	8-Apr-03	Kilfrost ABC-S	DBQ	35.3	12	Zd	-10

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2.4.1.2 Fluid endurance time tests

Endurance time testing with the samples collected at DBQ was performed in natural snow and simulated freezing drizzle. The data logs for the natural snow and simulated freezing drizzle tests were previously shown in Tables 2.6 and 2.7, respectively.

Table 2.8 provides a comparison of the natural snow endurance times of the fluid samples collected in DBQ with the 2003-04 Type II and Type I generic holdover time guidelines. For example, test D-1 in Table 2.8 had an endurance time of 20.3 minutes. The rate of precipitation for the test, 25.6 g/dm^2/h, is considered to be at the lower end of the heavy snow rate category. As the heavy snow condition is not covered by the Type I and Type II fluid holdover time table guidelines, the applicable holdover time in heavy snow would be less than the lowest time in the moderate snow range. In this case, the Type II generic holdover time range in moderate snow is 20 to 45 minutes, and therefore, the applicable holdover time in heavy snow would be less than 20 minutes.

Table 2.8: Comparison of DQB Fluid Sample Endurance Times with Type II and Type I Generic Holdover Time Guidelines – Natural Snow Tests

Test #	Failure Time (min)	Temp (°C)	Rate (g/dm^2/h)	Snow Classification	Type II Generic HOT (min)	Type I Generic HOT (min)
D-1	20.3	0.2	25.6	Heavy	< 20	< 6
D-2	15.8	0.3	25.8	Heavy	< 20	< 6
D-3	50	-7.4	6.8	Light	> 35	6 to 11
D-4	58	-6.3	4	Light	> 35	6 to 11
D-5	24	-2.2	19.3	Moderate	20 to 45	6 to 11
D-6	18	-2	32.7	Heavy	< 20	< 6
D-7	18.3	-2.5	28.4	Heavy	< 20	< 6

In general, the natural snow endurance time results of the DBQ fluid samples were within or above the generic Type II holdover time ranges. The snow endurance time results of the DBQ fluid samples were also well above the generic Type I holdover time values.

Table 2.9 provides a comparison of the simulated freezing drizzle endurance times of the fluid samples collected in DBQ with the 2003-04 Type II and Type I generic holdover time guidelines.

Table 2.9: Comparison of DQB Fluid Sample Endurance Times with Type II and Type I Generic Holdover Time Guidelines – Freezing Drizzle Tests

Test #	Failure Time (min)	Temp (°C)	Rate (g/dm²/h)	Type II Generic HOT (min)	Type I Generic HOT (min)
D-8	51.6	-10.3	5.7	45	7
D-9	35.3	-10	12	15	4

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The freezing drizzle endurance time results of the DBQ fluid samples were above the generic Type II holdover times, and significantly above the generic Type I holdover times.

2.4.2 Quebec City Fluid Samples

2.4.2.1 Fluid viscosity

Two drums (400 L) of Kilfrost ABC-S were pumped into American Eagle's deicing vehicle at YQB. Fluid was sprayed with a hose/nozzle combination that resembled a pressure-washing gun used in car washes. The fluid tank did not have a circulating pump, which caused the fluid temperature to vary from 30°C to approximately 50°C depending on the quantity of fluid remaining and the location of the fluid in the tank. Due to the late arrival of the aircraft at YQB, fluid was sprayed into a rate pan located on a test stand and then transferred to 1-litre and 20-litre sample containers for viscosity and endurance time testing.

The sprayed fluid from the YQB tests appeared to be heavily sheared: it looked as if it were a green Type I fluid. Laboratory viscosity tests confirmed this visual observation. The viscosity of the sprayed fluid samples was immeasurable (below 100 cP) using the Kilfrost viscosity measuring method.

As the average viscosity of the Type IV fluid samples collected at YQB was below the degraded viscosity for Kilfrost ABC-S (3,900 cP), it was assumed that the generic Type II fluid holdover times would not apply to this fluid, based solely on viscosity being the only parameter used for determining the holdover time performance of the fluid.

2.4.2.2 Fluid endurance time tests

Despite the disappointing results from the spray tests in Quebec City, the sprayed fluid was collected and returned to Montreal for endurance time testing in natural and simulated conditions.

Table 2.10 provides a comparison of the natural snow endurance times of the fluid samples collected in YQB with the 2003-04 Type II and Type I generic holdover time guidelines.

Table 2.10: Comparison of YQB Fluid Sample Endurance Times with Type II and Type I Generic Holdover Time Guidelines – Natural Snow Tests

Test #	Failure Time (min)	Temp (°C)	Rate (g/dm²/h)	Snow Classification	Type II Generic Hot (min)	Type II Generic Hot (min)
Q-1	13.1	0.2	25.6	Heavy	< 20	< 6
Q-2	13	0.3	22.7	Moderate	20 to 55	6 to 11
Q-3	32.4	-6.3	5.2	Light	> 35	6 to 11
Q-4	40.2	-7.5	6.2	Light	> 35	6 to 11
Q-5	29	-8.4	6.4	Light	> 35	6 to 11
Q-6	23	-1.5	9.9	Light	45	11
Q-7	13	-1.9	34.7	Heavy	< 20	< 6
Q-8	15.6	-2.4	22	Moderate	20 to 45	6 to 11

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Natural snow results indicated that the sprayed samples had endurance times below the generic Type II values. It was surprising, however, that despite the extreme viscosity degradation caused by the YQB vehicle, the endurance times of the fluid ranged between 13 and 40 minutes in natural snow, depending on rate and temperature. Even at a rate of 34.7 g/dm²/hr, which coincides with a heavy snow event, the degraded YQB fluid provided 13 minutes of endurance time in snow. Most notably, the natural snow endurance times of the fluid collected in YQB were far superior to the generic Type I holdover times.

Table 2.11 provides a comparison of the simulated freezing drizzle endurance times of the fluid samples collected in YQB with the 2003-04 Type II and Type I generic holdover time guidelines.

Table 2.11: Comparison of YQB Fluid Sample Endurance Times with Type II and Type I Generic Holdover Time Guidelines – Freezing Drizzle Tests

Test #	Failure Time (min)	Temp (°C)	Rate (g/dm^2/h)	Type II Generic HOT (min)	Type I Generic HOT (min)
Q-9	17.7	-10	11.8	15	4
Q-10	26.9	-10.4	5.3	35	7

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As expected, the simulated freezing drizzle results for the samples collected in YQB were also below generic Type II values. It is noteworthy that the freezing drizzle results were approximately four times higher than the generic Type I values in the same condition and temperature.

2.4.3 Dallas/Fort Worth Tests

2.4.3.1 Fluid viscosity tests

Kilfrost ABC-S and Clariant Safewing MPIV 2001 fluids were pumped into an older model Premier deicing vehicle for tests at DFW. Both fluids were sprayed into collection buckets using both Type I and Type IV fluid nozzles.

It was determined during the tests at DFW that the fluid pump in the spray vehicle that was available for testing was defective, and therefore the shear forces exerted on the fluid in the DFW tests were inconsistent with those normally observed in a deicing operation. Nonethless, fluid samples were collected and returned to Montreal for viscosity and endurance time testing.

The viscosities of the samples collected at DFW were measured upon return to Montreal. The measurements for both fluids were well above the degraded viscosities tested for holdover times in previous years. In fact, only a modest viscosity reduction in the range of 10 to 20 percent was observed in the DFW tests. These results were expected due to the defective fluid pump on the spray vehicle.

2.4.3.2 Fluid endurance time tests

Endurance time tests were performed with the samples collected at DFW. The results were deemed insignificant due to the malfunctioning spray vehicle that did not adequately shear the Type IV fluids. All endurance time results with the partially sheared Type IV fluids were well above generic Type II holdover times and therefore are not even shown in this report.

2.5 Summary of Tests

The tests performed at DBQ with Kilfrost ABC-S demonstrated that it is possible to heat a Type IV production sample and spray it through a Type I vehicle to deice and anti-ice an aircraft. The viscosity of the fluid when sprayed through the Type I vehicle and nozzle was above the degraded viscosity of Kilfrost ABC-S that was tested for endurance times by APS in 1999-2000. The holdover times of this degraded Kilfrost ABC-S fluid were all above generic Type II values. Fluid endurance time tests conducted with the ABC-S samples collected in DBQ were also all above or within the Type II generic holdover time ranges.

The tests performed at YQB were initially believed to have failed. The Kilfrost ABC-S fluid was heated and sprayed through the Type I vehicle, severely shearing the Type IV fluid in the process. The viscosity of the fluid collected in YQB was not measurable using the manufacturer's suggested viscosity measurement method, and thus was well below the degraded viscosity of Kilfrost ABC-S that was tested for endurance times. Therefore, it was assumed that the YQB fluid would in no way match the endurance times provided by the Type II generic table. Fluid samples were nonetheless collected and sent to Montreal for endurance time testing.

Initial natural snow endurance time results with the YQB samples indicated that the fluid had endurance times below the generic Type II values. Despite the severe degradation in viscosity, the fluid still retained significant anti-icing performance, and the performance was far superior to the generic Type I holdover times.

Additional tests with the YQB samples in freezing drizzle confirmed the anti-icing performance observed in the snow tests. The freezing drizzle results were below the generic Type II values, but approximately four times higher than the generic Type I values in the same condition and temperature.

At this point, the focus of the research shifted from trying to spray an anti-icing fluid through a Type I vehicle (to provide a desired viscosity and holdover time) to the potential creation of a new fluid type based on a heavily sheared anti-icing fluid. The YQB endurance time test results were the basis for subsequent tests with simulated Type III products that will be discussed in greater detail in Section 3 of this report.

Many airframe manufacturers, in particular Bombardier and SAAB, have long argued that Type II and Type IV fluids may not be appropriate for use with certain commuter aircraft with slower rotation speeds, and have requested the introduction of anti-icing fluids with aerodynamic properties more suitable for these aircraft. Fluids designed for aircraft with slower rotation speed had previously been referred to as Type 1.5 or Type III products. Only two such products have ever been tested for holdover times, and these were tested prior to 1996-97. No commercial Type III products currently exist.

Photo 2.1: View of Dorval Test Site and Associated Equipment

Photo 2.2: MSC Observation Station at Dorval Airport

Photo 2.3: Outdoor View of NRC Facility

Photo 2.4: Inside View of Small End of NRC Facility

Photo 2.5: Heated Type IV Sprayed onto the Wings of an EMB-145 in DBQ

Photo 2.6: Heated Type IV Sprayed onto a Test Stand at YQB

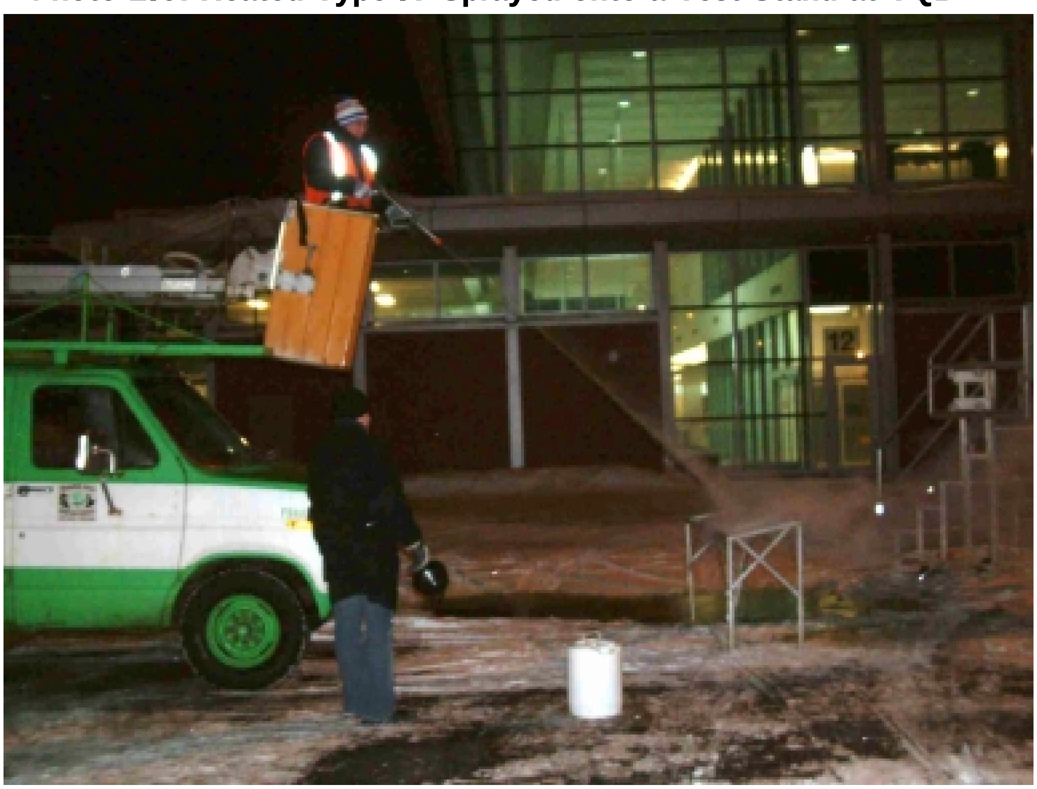

Photo 2.7: Transferring Type IV Fluid from Rate Pan to 1 Litre Sample Containers

Photo 2.8: Heated Type IV Spray into 20 Litre Containers at DFW

Photo 2.9: Type I Deicing Vehicle in Dubuque

Photo 2.10: Type I Deicing Vehicle in Quebec City

Photo 2.11: Type I Deicing Vehicle in Dallas/Fort Worth

Photo 2.12: Brookfield Digital Viscometer Model DV-1 + and Temperature Bath

3. EVALUATION OF THE ENDURANCE TIME PERFORMANCE OF SIMULATED TYPE III FLUIDS

3.1 Introduction

Due to the holdover time restrictions of Type I fluid, many operators of commuter aircraft have been forced to adopt Type IV anti-icing operations, despite the fact that these fluids are not recommended for use with many commuter aircraft with slow rotation speeds and short takeoff rolls. Many airlines have indicated that they may incur penalties in icing conditions as a result of the use of Type IV fluid. As no Type III fluids exist in the marketplace, manufacturers and operators of commuter aircraft have been forced to live with this reality.

The positive endurance time results obtained with the severely degraded viscosity Type IV fluid sample collected in spray tests at YQB led to the belief that a highly sheared Type II or Type IV anti-icing fluid – even one with a viscosity similar to a Type I fluid – would provide greatly improved holdover time values over a Type I fluid. Furthermore, it was conceivable that a highly sheared Type II or Type IV anti-icing fluid could be certified to Aerospace Material Specifications (AMS) 1428 as a Type III fluid.

Type III is a de/anti-icing fluid designed for aircraft with lower rotation speeds. Two Type III fluids, Union Carbide 250-3 and Ultra+ (66%), were previously tested for endurance times in 1991-92 and 1996-97, respectively. The results of these tests appear in TC reports TP 11454E, *Aircraft Ground De/Anti-Icing Holdover Time Field Testing Program for the 1991-92 Winter* (5) and TP 13131E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time Field Testing Program for the 1996-97 Winter* (6). Union Carbide 250-3 was produced commercially but later discontinued; Ultra+ (66%) was never produced commercially. Despite the fact that no Type III fluids exist in the marketplace, TC has continued to publish the Type III generic table annually. The table is based on the Ultra+ (66%) endurance time results from 1996-97 testing. Table 3.1 shows the current TC Type III holdover time guidelines.

Hoping to reproduce the endurance time results obtained with the severely sheared YQB fluid, which were far superior to the current Type I holdover times, APS mechanically sheared two certified Type II fluids down to a low viscosity level, and tested the fluids for endurance times in all conditions contained within the holdover time tables. After consultation with the fluid manufacturers to determine the appropriate viscosity level to test, samples of the two products were placed in a conventional kitchen blender and sheared to the desired viscosity. The mechanically sheared products produced by APS personnel are referred to as "simulated Type III products" in this report.

Endurance time tests with the simulated Type III products were performed in natural snow and simulated precipitation conditions. Due to a very limited quantity of available fluid, only one fluid, a certified Type II fluid sheared to a 500 cP viscosity, was tested in all conditions.

Table 3.1: Transport Canada Type III Generic Holdover Time Guidelines

OAT		Approximate Holdover Times Under Various Weather Conditions (minutes) (hours)					
°C	**°F**	**FROST**	**FREEZING FOG**	**SNOW**	**FREEZING DRIZZLE**	**LIGHT FRZ RAIN**	**RAIN ON COLD SOAKED WING**
above 0	**above 32**	*05:00*	*50-90*	*15-30*	*25-50*	*15-25*	*5-35*
0 to -3	**32 to 27**	*04:00*	*50-90*	*15-25*	*25-50*	*15-25*	
below -3 to -14	**below 27 to 7**	*04:00*	*30-60*	*10-20*	*15-30*	*10-20*	
below -14	**below 7**	SAE Type III Fluid may be used below -14ºC (7ºF) provided the freezing point of the fluid is at least 7ºC (13ºF) below the OAT and the aerodynamic acceptance criteria are met. Consider use of SAE Type I when SAE Type III fluid cannot be used.					

3.2 Methodology

3.2.1 Test Sites

Natural snow endurance time testing of one simulated Type III fluid was performed at the APS Dorval Airport test site.

Tests under conditions of freezing drizzle, light freezing rain, freezing fog, and rain on a cold-soaked wing were conducted indoors at NRC, where precipitation was artificially produced. The test plan for endurance time tests in simulated conditions with the simulated Type III fluids has been included in Appendix C of

TC report TP 14144E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2002-03 Winter* (3).

3.2.2 Description of Test Procedures

The procedures employed for the endurance time testing of the simulated Type III fluid samples were identical to those used to develop fluid holdover times for new de/anti-icing fluid formulations. The complete procedures for these tests appear in TP 14144E (3).

In general, fluid endurance time tests consisted of pouring 1 L of the simulated Type III fluid, at ambient temperature, onto clean aluminium plates inclined at 10° from the horizontal. The plates were mounted on a test stand and systematically exposed to a variety of natural or artificially produced icing conditions. For every plate, the elapsed time required to reach a predefined end condition was recorded. Test conditions, test parameters, and test bed specifications were determined based on SAE G-12 Holdover Time Subcommittee guidelines.

3.2.3 Data Forms

Two data forms, one to record fluid failure times, the other to record precipitation rate data, were used during the 2002-03 winter natural snow endurance time tests. Both forms appear in Appendix C of TP 14144E (3).

Two similar data forms were used to manually record test data in the freezing drizzle tests conducted at NRC. These forms appear in Appendix D of TP 14144E (3).

3.2.4 Equipment

The equipment used for fluid endurance time tests with the simulated Type III fluids was identical to that used in fluid endurance time tests for the determination of holdover times. A comprehensive description of the equipment can be found in Appendices C and D of TP 14144E (3).

An off-the-shelf kitchen blender was used to mechanically shear the Type II fluids to low viscosity levels. Fluid viscosities were measured using the viscometer and temperature bath described in 2.2.4.2.

3.2.5 Fluids

Several fluid manufacturers were contacted in an attempt to solicit fluids that were characteristic of Type III fluids.

Endurance time tests were ultimately performed with two certified Type II products that were mechanically sheared to varying degrees to simulate potential Type III fluids:

a) Clariant Safewing MP II 2025 Type II, mechanically sheared to a viscosity of 1,500 cP (referred to as Clariant 2025 D1500 in this report);

b) Clariant Safewing MP II 2025 Type II, mechanically sheared to a viscosity of 500 cP (referred to as Clariant 2025 D500 in this report); and

c) Octagon E-Max II Type II, mechanically sheared to a viscosity of 500 cP (referred to as Octagon E Max II D500 in this report).

Due to restrictions in the quantity of fluid available for these tests, only the Clariant 2025 D500 was tested in all simulated conditions. The other two products were tested in very limited fashion.

3.2.6 Personnel

The site at Dorval was staffed mainly by technicians and university students supervised by APS project staff.

Personnel responsibilities for tests conducted in simulated precipitation conditions at the NRC chamber were similar to those of the natural snow tests.

3.3 Description and Processing of Data

Endurance time tests were performed with the three simulated Type III products. Tests were performed in natural snow and simulated precipitation.

The data log for the natural snow tests with the simulated Type III fluids appears in Table 3.2. The data log for the simulated precipitation tests at NRC appears in Table 3.3.

Table 3.2: Summary of the Natural Snow Endurance Time Tests with Simulated Type III Fluid Samples

ET Test Date	Fluid Name	Fail Time (min)	Precip. Rate (g/dm²/h)	OAT (°C)
5-Apr-03	C2025 D500	38	15	-5
5-Apr-03	C2025 D500	27	20	-5
5-Apr-03	C2025 D500	22	19	-5
5-Apr-03	C2025 D500	39	14.0	-5
5-Apr-03	C2025 D500	39	8.0	-5
5-Apr-03	C2025 D500	26	15.0	-5
5-Apr-03	C2025 D500	28	16.0	-5
5-Apr-03	C2025 D500	26	17.0	-5

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Table 3.3: Summary of the Simulated Precipitation Endurance Time Tests with Simulated Type III Fluid Samples

ET Test Date	Fluid Name	Precip. Type	Fail Time (min)	Precip. Rate (g/dm²/h)	OAT (°C)
2-Apr-03	C2025 D1500	Zfog	64.8	4.6	-3.2
8-Apr-03	C2025 D1500	Zr-	18.2	26.9	-9.9
4-Apr-03	C2025 D1500	Zd	54.8	5	-3.2
9-Apr-03	C2025 D500	CSW	49.9	5.6	0.4
9-Apr-03	C2025 D500	Zd	31.4	12.1	-3.3
7-Apr-03	C2025 D500	Zfog	55.5	2.0	-25.2
7-Apr-03	C2025 D500	Zfog	23	5.0	-24.2
10-Apr-03	C2025 D500	Zfog	72.3	2.3	-14.2
10-Apr-03	C2025 D500	Zfog	36.5	5.7	-14.4
9-Apr-03	C2025 D500	CSW	11.1	76.0	1.1
3-Apr-03	C2025 D500	Zfog	86.6	2.3	-3.1
2-Apr-03	C2025 D500	Zfog	57.8	4.5	-3.2
2-Apr-03	C2025 D500	Zfog	58.5	4.4	-3.2
8-Apr-03	C2025 D500	Zr-	23.4	13.1	-9.8
8-Apr-03	C2025 D500	Zr-	15.8	26.8	-9.9
8-Apr-03	C2025 D500	Zr-	16	26.4	-9.9
8-Apr-03	C2025 D500	Zd	40.9	4.9	-10.4
9-Apr-03	C2025 D500	Zr-	226.1	13.0	-3.1
9-Apr-03	C2025 D500	Zr-	19.8	26.4	-3
9-Apr-03	C2025 D500	Zr-	19.9	25.0	-3.1
8-Apr-03	C2025 D500	Zd	23.3	11.6	-10.1
8-Apr-03	C2025 D500	Zd	23.2	11.5	-10.1
4-Apr-03	C2025 D500	Zd	50.1	5.1	-3.2
2-Apr-03	E Max D500	Zfog	37.3	4.6	-3.2
8-Apr-03	E Max D500	Zr-	11.5	26.5	-9.8
9-Apr-03	E Max D500	Zr-	11.8	25.7	-3
4-Apr-03	E Max D500	Zd	34.2	5.2	-3.2
9-Apr-03	E Max D500	Zd	18.7	12.1	-3.3

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3.4 Analysis and Observations

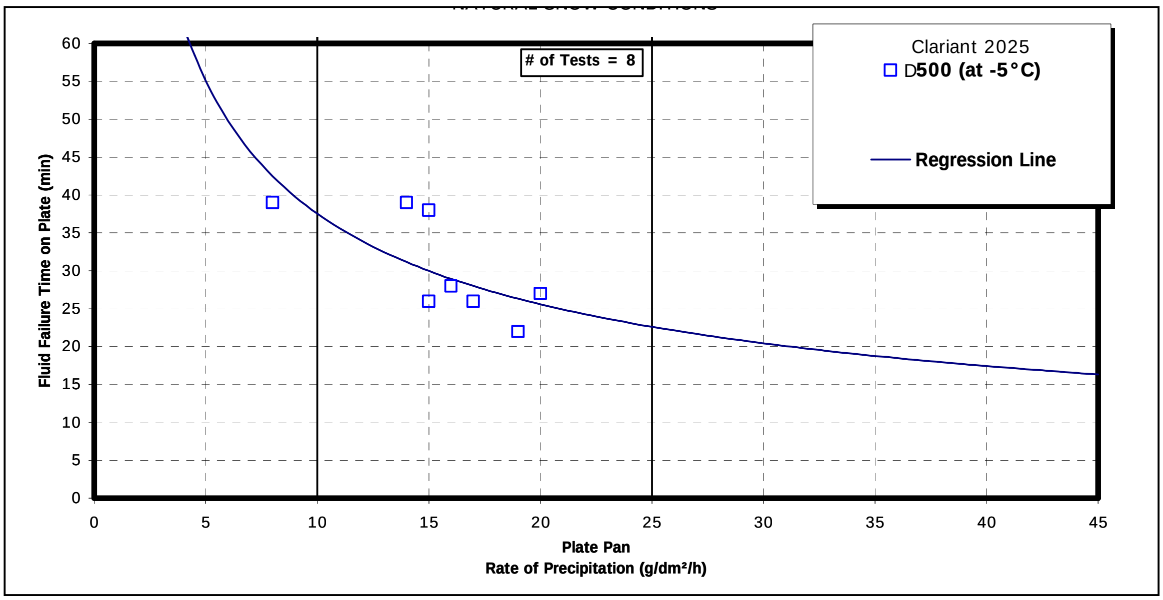
3.4.1 Endurance Time Results – Clariant 2025 D500

Endurance time tests with the simulated Type III Clariant 2025 D500 were performed in all conditions contained within the holdover tables, with the exception of frost: snow, freezing fog, freezing drizzle, light freezing rain, and rain on a cold-soaked wing were all tested.

3.4.1.1 Natural snow

The natural snow results with the Clariant 2025 D500 simulated Type III product are shown in Figure 3.1.

Figure 3.1: Effect of Rate of Precipitation on Endurance Time – Clariant 2025 D500 – Natural Snow



Tests in natural snow were conducted on only one occasion, at a temperature of -5°C. The results were very positive. After rounding was applied, the holdover time range of the D500 product, based on the eight data points collected, was 25 to 40 minutes. The holdover time range can be determined by where the regression curve in Figure 3.1 intercepts the moderate snow rate limits of 10 and 25 g/dm²/h. This holdover time range is higher than those contained within the snow column of the current TC Type III holdover time guidelines (shown in Table 3.1).

3.4.1.2 Freezing fog

The freezing fog endurance time results with the Clariant 2025 D500 simulated Type III product are shown in Figure 3.2.

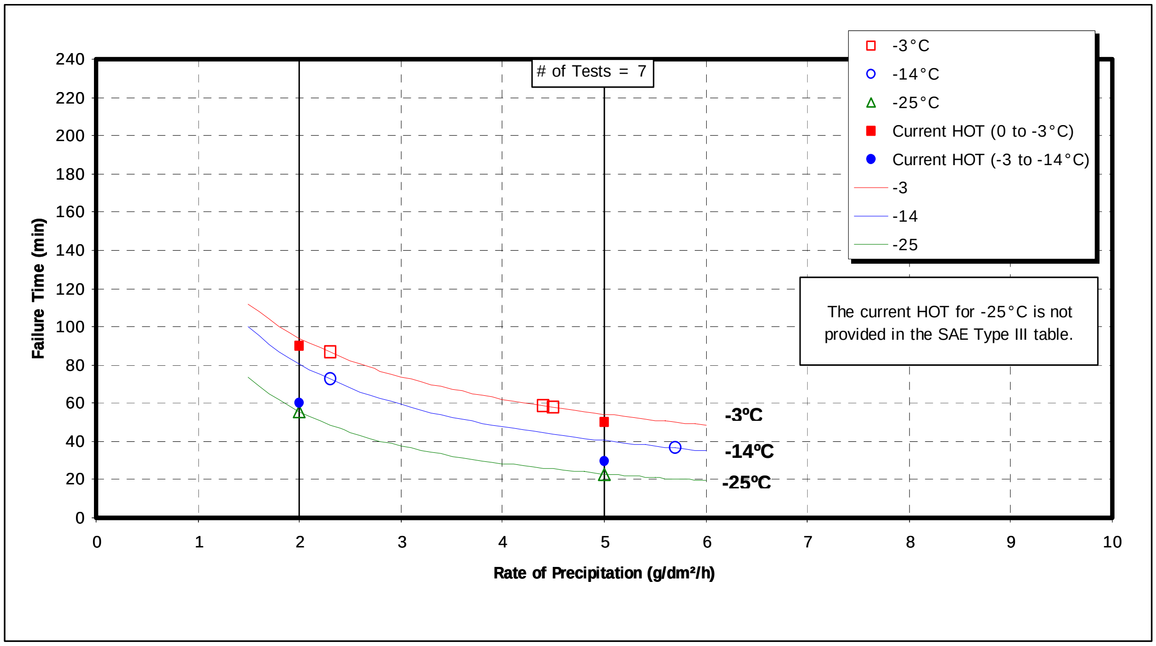


Figure 3.2: Effect of Rate of Precipitation on Endurance Time – Clariant 2025 D500 – Freezing Fog

Tests in simulated freezing fog were conducted at three temperatures: -3°C, -14°C and -25°C. The endurance time results of the Clariant 2025 D500 product were above the current Type III holdover time guidelines at -3°C and -14°C. The endurance time tests in freezing fog at -25°C were the first ever conducted with Type III. The two fluids that were tested in 1991-92 and 1996-97 were based on dilutions of a more concentrated product, and therefore both had freezing point limitations that prevented the products from being used below -14°C. Because the Clariant 2025 D500 was based on a mechanically sheared, undiluted Type II fluid, no freezing point penalty existed, and the fluid could be used as other neat anti-icing fluids.

3.4.1.3 Freezing drizzle

The freezing drizzle endurance time results with the Clariant 2025 D500 simulated Type III product are shown in Figure 3.3.

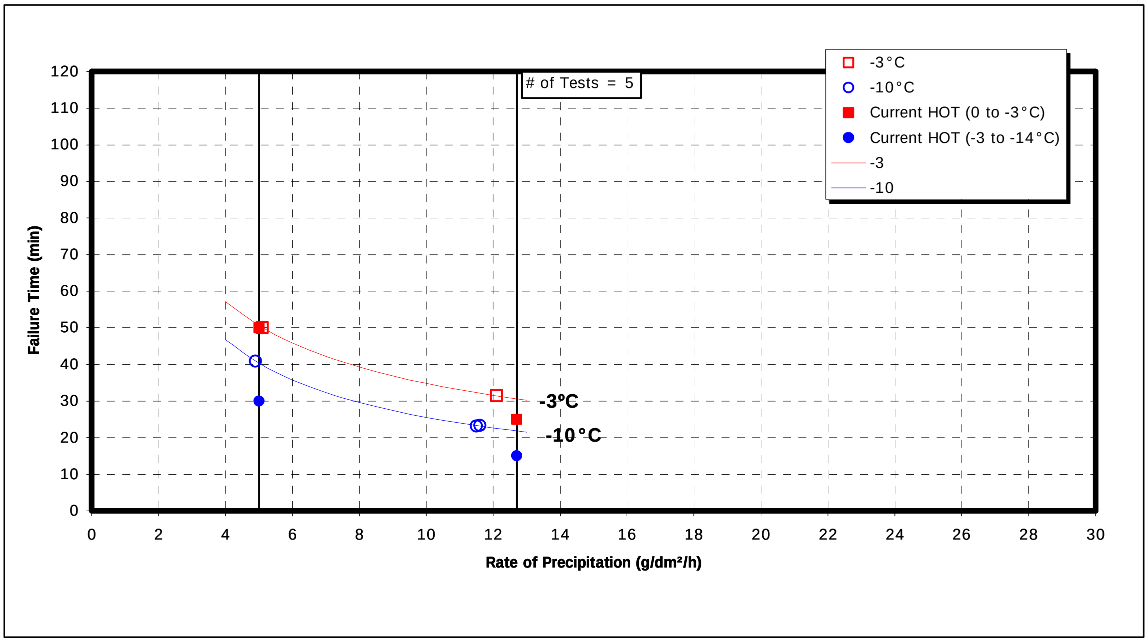


Figure 3.3: Effect of Rate of Precipitation on Endurance Time – Clariant 2025 D500 – Freezing Drizzle

Tests in simulated freezing drizzle were conducted at two temperatures: -3°C and -10°C. The endurance time results of the Clariant 2025 D500 product were above the current Type III holdover time guidelines at both temperatures.

3.4.1.4 Light freezing rain

The light freezing rain endurance time results with the Clariant 2025 D500 simulated Type III product are shown in Figure 3.4.

Tests in simulated light freezing rain were performed at two temperatures: -3°C and -10°C. Once again, the endurance time results of the Clariant 2025 D500 product were above the current Type III holdover time guidelines at both temperatures.

3.4.1.5 Rain on a cold-soaked wing

The rain on a cold-soaked wing endurance time results with the Clariant 2025 D500 simulated Type III product are shown in Figure 3.5.

Tests in simulated rain on a cold-soaked wing were performed at +1°C. Once again, the endurance time results of the Clariant 2025 D500 product were above the current Type III holdover time guidelines.

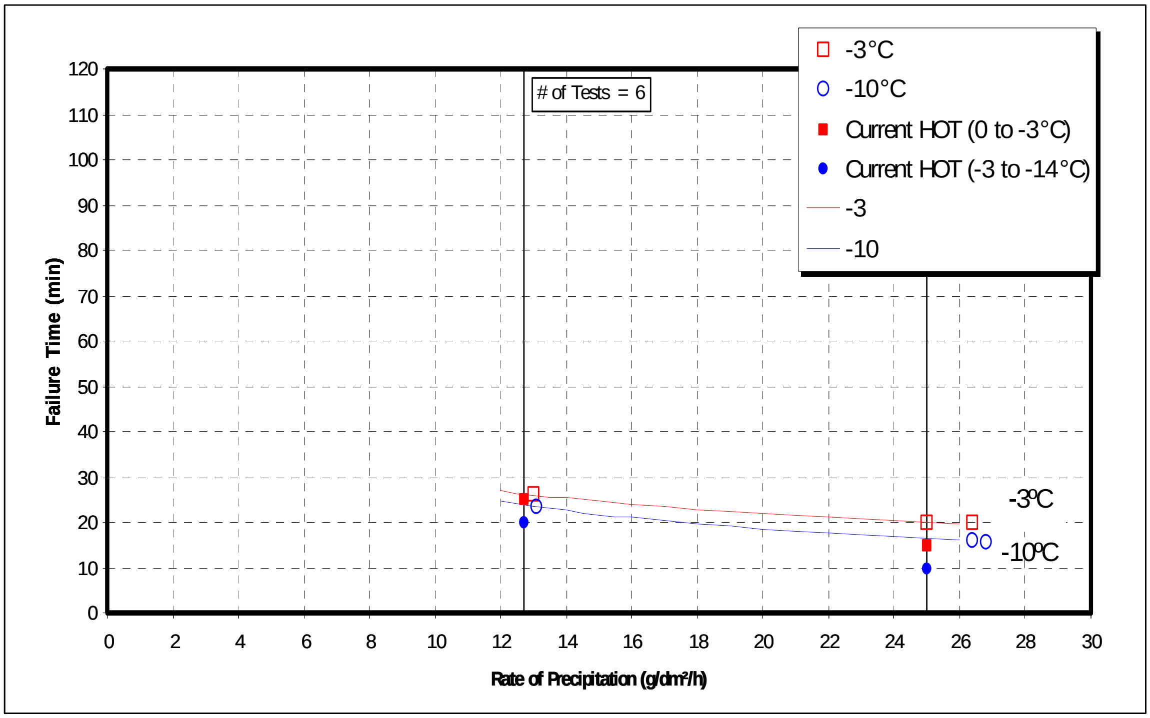


Figure 3.4: Effect of Rate of Precipitation on Endurance Time – Clariant 2025 D500 – Light Freezing Rain

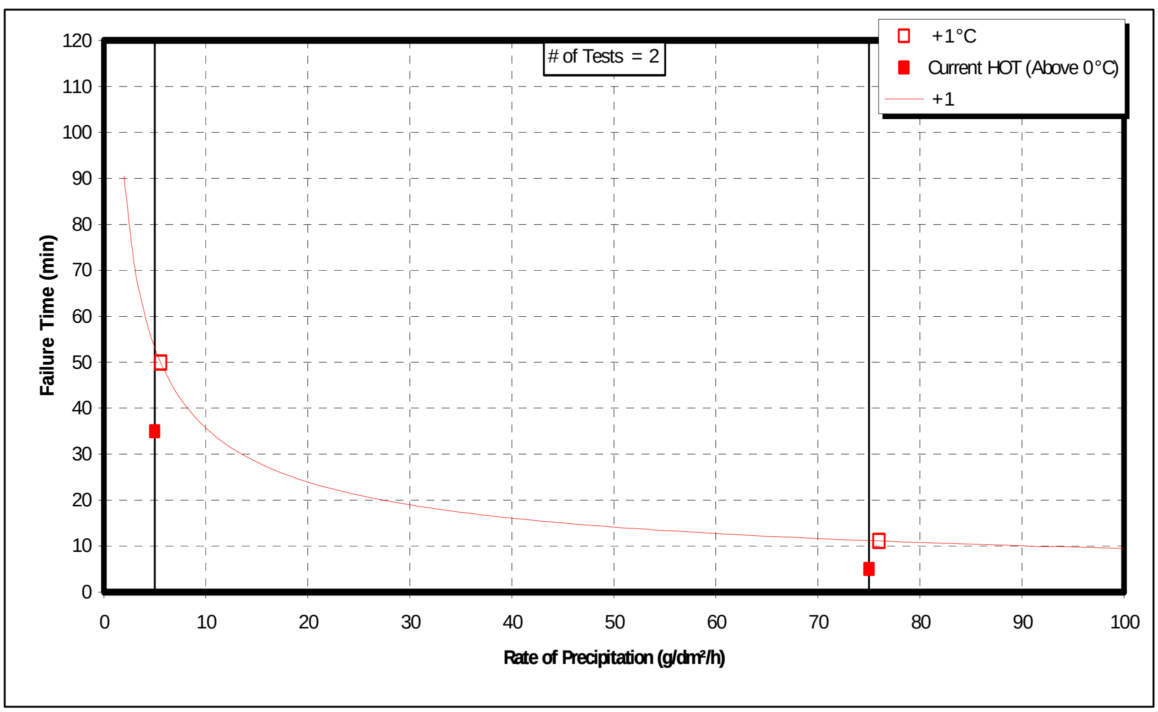


Figure 3.5: Effect of Rate of Precipitation on Endurance Time – Clariant 2025 D500 – Rain on a Cold-Soaked Wing

3.4.2 Endurance Time Results – Clariant 2025 D1500

Three endurance time tests were run with a higher viscosity sample (1500 cP) of the Clariant 2025 product, Clariant 2025 D1500. One test was run in each of the following simulated conditions:

a) Freezing fog, high rate, -3°C;
b) Light freezing rain, high rate, -10°C; and
c) Freezing drizzle, low rate, -3°C.

Table 3.4 provides a comparison of the endurance time obtained in each test with the holdover times in the current Type III table.

All three endurance time tests with the Clariant 2025 D1500 had values above the current Type III holdover time guidelines. The endurance times of the D1500 were only slightly longer than the D500 times.

Table 3.4: Comparison of Endurance Time Results with Clariant 2025 D1500 to Type III Generic Holdover Time Guidelines

ET Test Date	Fluid Name	Fail Time (min)	Precip. Rate (g/dm2/h)	Precip. Type	OAT (°C)	Current Type III HOT (min)
2-Apr-03	C2025 D1500	64.8	4.6	Zfog	-3.2	50
8-Apr-03	C2025 D1500	18.2	26.9	Zr-	-9.9	10
4-Apr-03	C2025 D1500	54.8	5	Zd	-3.2	50

M:\Groups\CM1747\Reports\Type IV thru Type I Equipment\working docs\Table 3.4.xls

3.4.3 Endurance Time Results – Octagon E-Max D500

Five endurance time tests were run with another simulated Type III product, Octagon E-Max D500. One test was run in each of the following simulated conditions:

a) Freezing fog, high rate, -3°C;
b) Light freezing rain, high rate, -10°C;
c) Light freezing rain, high rate, -3°C;
d) Freezing drizzle, low rate, -3°C; and
e) Freezing drizzle, high rate, -3°C.

Table 3.5 provides a comparison of the endurance time obtained in each test with the holdover times in the current Type III table.

Table 3.5: Comparison of Endurance Time Results with Octagon E-Max D500 to Type III Generic Holdover Time Guidelines

ET Test Date	Fluid Name	Fail Time (min)	Precip. Rate ($g/dm^2/h$)	Precip. Type	OAT (°C)	Current Type III HOT (min)
2-Apr-03	E-Max D500	37.3	4.6	Zfog	-3.2	50
8-Apr-03	E-Max D500	11.5	26.5	Zr-	-9.8	10
9-Apr-03	E-Max D500	11.8	25.7	Zr-	-3	15
4-Apr-03	E-Max D500	34.2	5.2	Zd	-3.2	50
9-Apr-03	E-Max D500	18.7	12.1	Zd	-3.3	25

M:\Groups\CM1747\Reports\Type IV thru Type I Equipment\working docs\Table 3.5.xls

Four of the five endurance time tests with the Octagon E-Max D500 had values below the current Type III holdover time guidelines.

3.5 Summary of Tests

3.5.1 Endurance Time Tests

The endurance time tests performed with the simulated Type III products in natural snow and simulated precipitation produced very encouraging results.

Tests were performed in all conditions and temperatures contained within the current Type III table with one simulated Type III product: Clariant 2025 D500. The holdover times of this fluid were all above the values in the current TC Type III holdover time guidelines. Table 3.6 shows the results of the endurance time tests with the Clariant 2025 D500 product superimposed on the TC Type III holdover time guidelines. The current values in the TC Type III holdover time guidelines are shown in italics. The endurance time values from 2002-03 testing with Clariant 2025 D500 are shown in bold type.

Because the simulated Type III fluid was based on an undiluted formulation, an additional temperature breakdown, below -14 to -25°C, has been added to the table. Endurance time tests were conducted with the Clariant 2025 D500 at -25°C, and the values have been added to the table. Natural snow tests with the Clariant 2025 D500 were not performed, due to a lack of snow events in this temperature range, and therefore a question mark fills the below -14 to -25°C cell in the snow column.

Table 3.6: Comparison of Endurance Time Results with Clariant 2025 D500 and the Generic Type III Holdover Time Guidelines

OAT		Approximate Holdover Times Under Various Weather Conditions (minutes)					
		(hours)					
°C	°F	FROST	FREEZING FOG	SNOW	FREEZING DRIZZLE	LIGHT FRZ RAIN	RAIN ON COLD SOAKED WING
above 0	above 32	_05:00_	_50-90_ **55-95**	_15-30_ **25-40**	_25-50_ **30-50**	_15-25_ **20-25**	_5-35_ **10-55**
0 to -3	32 to 27	_04:00_	_50-90_ **55-95**	_15-25_ **25-40**	_25-50_ **30-50**	_15-25_ **20-25**	
below -3 to -14	below 27 to 7	_04:00_	_30-60_ **40-80**	_10-20_ **25-40**	_*15-30_ **20-40**	_*10-20_ **15-25**	
below -14 to -25ºC	below 7 to -13		**25-55**	**?**			

Note: Italic values are the current Type III table values
Bold values are the endurance time results with C2025 D500
*To -10ºC

The endurance time results with the Clariant 2025 D500 product were significantly higher than the Type I holdover time table values.

Endurance time tests were also performed with a higher viscosity sample of Clariant 2025, referred to as Clariant 2025 D1500. The endurance time results with this fluid were marginally longer than those of the Clariant 2025 D500.

Endurance time tests were also performed with Octagon E-Max D500. Most of the endurance times with this product were below the current Type III holdover time guidelines.

Feasibility of Using a Type III Fluid as a Solution to Operational Limitations of Type I Anti-Icing

Prior to the start of testing, in the fall of 2002, discussions between American Eagle and APS led to the development of a list of items that needed to be considered for any new technology or fluid type designed as a potential replacement for Type I anti-icing.

The new technology or fluid type would:

a) Consist of a single product (deicing and anti-icing fluid);

b) Provide holdover times in excess of 15 minutes in snow;

c) Possess fluid freezing point protection from above 0°C to below -25°C, thus allowing for de-frosting operations at cold temperatures;

d) Be applied to aircraft surfaces heated at a high pressure;

e) Be applied using current Type I spray equipment; and

f) Not cause fluid dry-out problems.

The 2002-03 testing with simulated Type III fluids provided very promising results from a holdover time perspective. As holdover time is only one of the six considerations listed above, each bulleted item is examined in this section as it pertains to the potential use of Type III fluid, based on a low viscosity anti-icing fluid formulation as a replacement for Type I anti-icing.

3.5.1.1 Could Type III fluid be used in one-step de/anti-icing operations?

Heated Type II and Type IV fluids are currently being used in one-step and two-step operations in several countries. There is no reason to believe that a Type III fluid, based on a low viscosity formulation, could not be used in the same application.

3.5.1.2 Could Type III fluid provide more than 15 minutes of holdover time in snow?

The recent tests with the simulated Type III product have indicated that their holdover time performance is well above the historical 6 to 15 minute holdover time range for Type I fluids in snow. The Clariant 2025 D500 performed better than even the current Type III holdover time table values in snow.

3.5.1.3 Could Type III fluid provide fluid freezing point protection from above 0°C to -25°C?

A Type III fluid formulation, based on a highly sheared or very low viscosity formulation, would provide freezing point protection right across this temperature range, and therefore would even allow for de-frosting operations at colder temperatures. Previous Type III fluids, based on diluted fluid formulations, had freezing point limitations below -14°C.

3.5.1.4 Could Type III fluid be heated and applied at high pressure?

High viscosity Type IV fluids from the DBQ and YQB tests were heated and sprayed through Type I spray delivery systems. Both fluids were sprayed with adequate pressure to deice an aircraft in a winter precipitation event. There is no reason to believe that a lower viscosity fluid would not provide similar performance. Furthermore, heated Type II and Type IV fluids are in widespread use in several countries for deicing purposes.

3.5.1.5 Could Type III fluid be applied using current Type I deicing equipment?

For use of the fluid-specific holdover time values for any fluid, operators must ensure that the fluid sprayed through the de/anti-icing nozzle and onto the wing has a viscosity equal to or above the viscosity set by the manufacturer as the lowest on-wing viscosity for that product. The process would be no different for any Type III fluid based on a low viscosity fluid formulation. The operator would need to ensure that the viscosity of the Type III product on the wing meets the minimum viscosity set by the manufacturer, regardless of the method used to apply the fluid.

No tests have been conducted to verify the viscosities of low viscosity anti-icing formulations sprayed through Type I spray systems. These tests could be performed as part of an operational assessment of Type III fluid in an actual wintertime operation.

3.5.1.6 Will Type III fluid cause fluid dry-out problems?

The international aviation industry has grappled with anti-icing fluid dry-out and re-hydration problems for several years. The problems are much more pronounced in Europe, where Type II and Type IV anti-icing fluids are heated and used in one-step de/anti-icing operations. As the Type III fluid that has been discussed in this report would likely be used in a similar one-step fashion, the question has been raised whether Type III fluid would cause similar fluid dry-out and re-hydration issues.

In discussions with a fluid manufacturer, it was indicated that the Type III fluid, based on a low viscosity formulation, would contain fewer polymers in the formulation and therefore would likely have greatly reduced fluid dry-out and re-hydration possibilities. The manufacturer conducted preliminary tests to compare the dry-out and re-hydration properties of a low viscosity Type III formulation versus a high viscosity Type II formulation (based on an identical fluid formulation other than viscosity). The results indicated that the problem was less severe with the low viscosity product.

Additional tests, perhaps based on the Buehler Test contained within SAE AMS 1428, could be performed to verify these concerns.

3.6 Moving Forward

The results of endurance time testing with simulated Type III fluid were presented at the SAE G-12 Holdover Time and Future Technology Subcommittee meetings in Vancouver, British Columbia, in May 2003 and sparked a significant amount of industry interest. Several operators have expressed a desire to procure a fluid with similar performance for their operations, and several fluid manufacturers expressed interest in formulating a fluid to meet the requirements.

The research conducted by APS in 2002-03 was performed on mechanically sheared Type II products designed to simulate potential Type III properties. Because it would be arduous for a fluid manufacturer to provide users in the field with the massive quantities of pre-sheared products that would be required for their de/anti-icing operations, fluid manufacturers would likely need to formulate low viscosity anti-icing fluids, based perhaps on the viscosity and endurance time information presented in this report.

To verify whether a fluid could be formulated to match the mechanically sheared results presented in this report, APS performed simulated snow tests with two fluid samples received from a fluid manufacturer in the summer of 2003. The first fluid consisted of a formulated product mechanically sheared to a low viscosity. The second consisted of a fluid formulated by the manufacturer to the match the viscosity of the mechanically sheared fluid. Both fluids had similar holdover times in simulated snow.

Any new Type III fluid would also need to be tested and certified to AMS 1428. The aerodynamic acceptance of the Type III fluids would need to meet aircraft manufacturer approval.

Type III fluids could potentially be used in neat and diluted forms, to address environmental concerns or to reduce costs. Type III fluids could also be used in two-step de/anti-icing operations, which would consist of a first-step deicing operation with a diluted 50/50 or 75/25 Type III fluid, followed by an anti-icing operation with a neat Type III fluid. The fluid manufacturer would therefore need to determine the future application of the fluid, and determine which fluid samples would be sent to the test agency for endurance time testing.

4. CONCLUSIONS

4.1 Evaluation of Heated Type IV Fluid Applied with a Type I Spray Delivery System

4.1.1 Dubuque Tests

The tests performed in Dubuque with Kilfrost ABC-S demonstrated that it is possible to heat a Type IV production sample and spray it through a Type I vehicle to deice and anti-ice an aircraft. The viscosity of the fluid sprayed through the Type I vehicle and nozzle was above the degraded viscosity of Kilfrost ABC-S that was tested for endurance times by APS in 1999-2000. The fluid endurance time tests conducted with the ABC-S samples collected at DBQ had results that were above or within the Type II generic holdover time ranges. The endurance times of the DBQ samples were also well above generic Type I holdover time values.

4.1.2 Quebec City Tests

The Kilfrost ABC-S fluid was heated and sprayed through an inadequate Type I vehicle, severely shearing the Type IV fluid in the process. The viscosity of the fluid collected in YQB was not measurable using the manufacturer's suggested viscosity measurement method, and was thus well below the degraded viscosity of the Kilfrost ABC-S that was tested for endurance times. Fluid samples were nonetheless collected and sent to Montreal for endurance time testing.

Initial natural snow endurance time results with the YQB samples indicated that the fluid had endurance times below the generic Type II values. Despite the severe degradation in viscosity, however, the fluid still retained significant anti-icing performance, and the performance was far superior to the generic Type I holdover times.

Additional tests with the YQB samples in freezing drizzle confirmed the anti-icing performance observed in the snow tests. The freezing drizzle results were below the generic Type II values, but approximately four times higher than the generic Type I values in the same condition and temperature.

The endurance time test results of the YQB test samples led to the subsequent testing of simulated Type III products.

4.1.3 Dallas/Fort Worth Tests

Due to a defective fluid pump in the spray vehicle available for tests in DFW, the shear forces exerted on the Type IV fluids at DFW were inconsistent with those of a normal operation. Because the deicing vehicle did not adequately shear the fluids, the viscosity and endurance time results gathered on the DFW fluids were deemed to be insignificant.

4.2 Evaluation of the Endurance Time Performance of Simulated Type III Fluids

TC continues to produce generic Type III holdover time guidelines, despite there being no certified Type III fluids existing in the marketplace.

In 2002-03, APS produced three simulated Type III fluids by mechanically shearing certified Type II products to low viscosity levels. Tests were performed on the fluids in natural snow and simulated precipitation using standard endurance time testing procedures.

The endurance time tests performed with the simulated Type III products produced very encouraging results. One product, Clariant 2025 D500, had endurance times that were all above the values in the current TC Type III holdover time guidelines. Endurance time tests performed with a higher viscosity sample of Clariant 2025, referred to as Clariant 2025 D1500, produced endurance time results that were marginally longer than those of the Clariant 2025 D500.

Endurance time tests were also performed with Octagon E-Max D500. Four of the five endurance times with this product were slightly below the current Type III holdover time guidelines.

4.2.1 General Conclusions

a) Despite having a very low viscosity, the simulated Type III fluids provided vastly superior holdover time performance than Type I fluid.

b) The holdover times provided by the simulated Type III fluids could provide the industry with operationally useful holdover times.

c) Type III fluids could potentially be used in one-step de/anti-icing operations, as Type I fluids currently are.

d) Because a Type III fluid based on a low viscosity anti-icing fluid formulation is undiluted, it would provide fluid freezing point protection across the holdover time table.

e) Type III fluid could likely be applied with Type I fluid spray equipment.

f) Due to the lower viscosity, the fluid would likely provide improved aerodynamics for commuter aircraft and alleviate current penalties imposed on operators.

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5. RECOMMENDATIONS

a) TC should encourage fluid manufacturers to formulate new Type III fluids.

b) Any new Type III fluid formulation should be evaluated for endurance times over the entire range of conditions covered by the Type III holdover time guidelines.

c) An operational assessment for using Type III fluid in a one-step operation to replace Type I anti-icing should be conducted with a commuter operator in 2003-04, should fluid samples be made available for testing in the upcoming winter test season.

d) An evaluation of the dry-out and re-hydration problems associated with the use of heated Type III fluid formulations should be performed.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
2002-03

5.12 Endurance Time Testing With Type III Fluids

5.12.1 Prepare procedure for testing Type III fluids outdoors during snowfalls;

5.12.2 Conduct flat plate tests under natural snow conditions on fluids that have been conditioned to simulate Type III fluid properties (Fluids for Type III tests must be sheared);

5.12.3 Prepare a test procedure for the conduct of endurance time tests in simulated precipitation at NRC Climatic Environment Facility;

5.12.4 Conduct flat plate tests under freezing precipitation conditions on fluids that have been conditioned to simulate Type III fluid properties;

5.12.5 Analyze data collected, report the findings and prepare presentation material.

5.13 Use of Heated Type IV Fluid Applied with a Type I Nozzle

5.13.1 Examine the results of American Eagle's winter operations with Type I fluid documenting the duration of holdover times actually used in live operations and the incidence of returns for an additional deicing, to understand whether they support published holdover times;

5.13.2 Design a test and prepare a test procedure to evaluate the use of heated Type IV fluid applied with a Type I nozzle;

5.13.3 Manage and conduct the spray tests at selected sites;

5.13.4 Conduct viscosity tests with the collected samples;

5.13.5 Analyze results; and

5.13.6 Prepare a report and presentation material.

APPENDIX B

EXPERIMENTAL PROGRAM
TESTING OF HEATED TYPE IV FLUIDS SPRAYED THROUGH
TYPE I SPRAY DELIVERY SYSTEMS

CM1747.001

EXPERIMENTAL PROGRAM
TESTING OF HEATED TYPE IV FLUIDS SPRAYED THROUGH TYPE I SPRAY DELIVERY SYSTEMS

Winter 2002 - 2003

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Michael Chaput

Reviewed by: John D'Avirro

January 29, 2003
Version 1.0

Editorial Revision
September 24, 2004
Version 1.1

APS Aviation Inc.

EXPERIMENTAL PROGRAM
TESTING OF HEATED TYPE IV FLUIDS SPRAYED THROUGH
TYPE I SPRAY DELIVERY SYSTEMS

Winter 2002 - 2003

1. BACKGROUND

Recent holdover time reductions have strained the use of Type I fluids as anti-icing agents under certain winter precipitation conditions and temperatures. To protect certain markets, several commuter airlines are moving toward the widespread purchase of conventional Type IV spray vehicles to conduct de/anti-icing operations that have traditionally been satisfied with Type I fluids. For certain companies, the cost to equip all winter operating stations with Type IV capability will be astronomically high.

In light of these recent developments, companies are examining other de/anti-icing alternatives to remedy this problem. One potential solution is promising. This procedure would involve the use of a Type IV anti-icing fluid applied heated with a Type I fluid delivery vehicle. It is understood that spraying a Type IV fluid with a Type I truck and nozzle would potentially decrease the viscosity of the fluid beyond the minimum on-wing viscosity required for use of the fluid-specific holdover time guidelines for any Type IV fluid.

Two Type IV fluids, Kilfrost ABC-S and Clariant MP IV 2001, have been tested for holdover times in degraded viscosity form for all precipitation conditions and temperatures. The holdover times for both fluids were all in excess of the generic Type II values. Currently, the Association of European Airlines (AEA) allows the use of either fluid with the Type II generic holdover time table.

Kilfrost ABC-S, for example, has been tested for fluid endurance times in all conditions at a viscosity of 3,900 cP. This viscosity is well below the lowest on-wing viscosity of 17,000 cP that appears on the Kilfrost ABC-S fluid-specific holdover time guidelines published by Transport Canada. The holdover times for the 3,900 cP sample of ABC-S were all above the Type II generic values.

Because Kilfrost – or any other manufacturer – ships fluid at viscosity levels well above those listed on the fluid-specific tables, a substantial viscosity buffer exists. In the case of the Kilfrost fluid, this buffer would likely compensate for the additional shear exerted on the fluid when sprayed through a Type I spray vehicle, without degrading the fluid below the 3,900 cP level required for use with the generic Type II holdover times. The Type II generic values would provide sufficient holdover time protection for the commuter airlines in all conditions. Furthermore, since the fluid is undiluted, it could be used to de-frost at low temperatures, enabling commuters to carry only one fluid at all stations without the procurement of expensive Type IV delivery vehicles, saving a considerable amount of money.

Testing will be conducted to verify the viscosity of production samples of one Type IV fluid when sheared through different Type I truck/pump/nozzle combinations. Heated Type IV fluids will be sprayed onto an aircraft at two stations in a one-step de/anti-icing procedure, in conjunction with a commuter airline. American Eagle has offered use of its aircraft and deicing vehicles. Residual Type IV fluids will be collected off the upper aircraft surfaces and sent to APS for viscosity and endurance time testing.

If the sheared production samples collected on the wing provide viscosity values above the tested degraded viscosities, the generic Type II values could apply to these fluids. Any Type IV fluid could be used in this manner, provided the holdover time substantiation of the degraded viscosity sample was completed and produced values in excess of the generic Type II values in all cells. The degraded viscosity would thereby become the lowest acceptable viscosity for use with the generic Type II values. The responsibility would then lie with the operator to ensure the minimum viscosity requirements are met.

2. OBJECTIVE

The overall objective of this test project is to examine the use of heated Type IV fluid (with degraded viscosity as a result of shearing through a Type I spray delivery system) as a potential solution to the current holdover time limitations of Type I de/anti-icing fluid. To achieve this objective, APS will:

- Collect production samples of undiluted Type IV fluid when heated and sheared through a Type I delivery system;
- Verify the viscosity of these samples to ensure they are above the lowest on-wing viscosity for the degraded sample; and
- Conduct a selection of endurance time tests to ensure compliance of the fluid with the generic Type II holdover time guidelines.

3. TEST PROCEDURE

Type IV production samples will be delivered to three American Eagle (AEA) stations: Quebec City, Quebec; Dubuque, Iowa; and Baton Rouge, Louisiana. These three stations were selected because they possess widely varying deicing equipment. AEA deicing vehicles will be emptied of their Type I contents and loaded with the Type IV fluid provided. A sample of the virgin fluid will be collected from the transportation container for viscosity verification. The

Type IV fluid in the trucks will be heated to a minimum of 60°C prior to the application of the fluid to the wings of the aircraft. A hand-held temperature gauge will be used to verify the fluid temperature.

When the fluid has reached (or exceeded) the minimum temperature, it will be sprayed onto the wing using the Type I spray apparatus. Standard industry procedures for fluid application will apply.

The heated fluid will be sprayed onto the wings of an Embraer Regional Jet by AEA deicing crews in a one-step operation under the supervision of APS personnel. Fluid samples on the wing will be collected by APS and placed in 1-litre sample containers. The sample containers will be sent to Montreal for viscosity verification. In addition, APS will collect 20 litres of the sprayed fluid and have it transported to Montreal for endurance time testing in natural snow and simulated precipitation conditions.

The deicing truck will then be emptied of the remaining Type IV fluid and replenished with Type I. The aircraft will be cleaned with Type I fluid prior to its subsequent departure.

Viscosity tests of the samples collected in Quebec City, Dubuque, and Baton Rouge will be conducted in Montreal. Viscosities of the sheared samples will be measured and compared to those of the virgin production samples.

Endurance time tests will be conducted with the sheared samples at the Dorval Airport test site and at the NRC chamber in Ottawa. Standard fluid endurance time test procedures will apply. Fluid will be applied to the plates at ambient temperature. Tests will be conducted in the following conditions:

- Natural snow: 10-15 tests in various temperature and rate conditions;
- Freezing drizzle: -10°C, 5 and 12.7 g/dm^2/h (1 test in each condition); and
- Light freezing rain: -3°C, 12.7 and 25 g/dm^2/h (1 test in each condition).

One endurance time test will also be conducted in natural snow using fluid heated to 60°C.

All endurance time test results will be compared to the Kilfrost ABC-S degraded viscosity holdover times and the generic Type II holdover times.

4. EQUIPMENT AND FLUIDS

4.1 Equipment

The following equipment will be required for the collection of samples at the airport sites:

- Hand-held temperature gauge;
- 1-litre sample containers;
- Funnels;
- Spatulas to remove fluid samples from wing surfaces; and
- 20-litre fluid container for transport of endurance time samples to Montreal.

For endurance time tests with the samples collected at the selected airport sites, the same equipment outlined in an associated procedure, *Experimental Program for Natural Precipitation Flat Plate Testing,* will be used.

4.2 Fluids

To examine the feasibility of using Type IV fluids in this manner, only one fluid will be tested in 2002-03 winter tests: Kilfrost ABC-S Type IV, provided by Cryotech. Endurance time tests with a degraded viscosity sample of this fluid have already been conducted in all conditions. Additional testing could be conducted with any other Type IV fluid in the future, provided the results of this preliminary work prove promising.

Fluids will be applied heated (to a minimum of 60°C) to aircraft surfaces using standard application techniques.

5. PERSONNEL

One APS employee will be needed to manage the spray tests and collect samples off aircraft wings at the selected airport sites.

One technician will be required for in-house fluid viscosity tests when the samples are submitted from the airports. Additional personnel will also be required for endurance time testing of the collected samples. These tests will be conducted alongside endurance time tests of new fluids.

6. DATA FORMS

One data form (see Figure B-1) will be to record test information during the collection of fluid samples at the selected airport sites.

For endurance time testing of the samples collected at the selected airport sites, the same data forms presented in an associated procedure, *Experimental Program for Natural Precipitation Flat Plate Testing,* will be used.

Figure B-1: General Form
Testing of Heated Type IV Fluids Sprayed Through Type I Spray Delivery Systems

Airport: **YQB** **DBQ** **BTR**

Date: ______________________________

Air Temperature (°C): ______________________________

Fluid Type: ______________________________

Fluid Temperature: ______________________________

Deicing Vehicle: ______________________________

Vehicle ID#: ______________________________

Fluid Pump: ______________________________

Nozzle Type: ______________________________

Flow Rate and Spray Pattern: ______________________________

Aircraft Type: ______________________________

Additional Comments: ______________________________

____

Observer: ______________________________

APPENDIX C

LOG OF SIMULATED PRECIPITATION TESTS WITH FLUID SAMPLES COLLECTED AT DFW

Log of Simulated Precipitation Tests with Fluid Samples Collected at DFW

Test #	Date	Fluid Name	Fluid Qty	Fail Time (min)	Actual Rate of Precip ($g/dm^2/h$)	Actual Chamber Temp. (°C)	Precipitation (Type)	Comments
HT4-51	2-Apr-03	Kilfrost ABC-S	1L	64.0	4.7	-3.2	Freezing Fog	Type I Nozzle
HT4-50	2-Apr-03	Clariant Safewing MPIV 2001	1L	87.4	4.4	-3.2	Freezing Fog	Type I Nozzle
HT4-15	4-Apr-03	Kilfrost ABC-S	1L	85.8	5.0	-3.2	Freezing Drizzle	Type IV Nozzle
HT4-14	4-Apr-03	Clariant Safewing MPIV 2001	1L	85.7	4.8	-3.2	Freezing Drizzle	Type I Nozzle
HT4-13	4-Apr-03	Clariant Safewing MPIV 2001	1L	84.3	5.0	-3.2	Freezing Drizzle	Type IV Nozzle
HT4-100	7-Apr-03	Clariant Safewing MPIV 2001	1L	50.7	5.0	-24.2	Freezing Fog	Type I Nozzle (-25°C)
HT4-101	7-Apr-03	Clariant Safewing MPIV 2001	1L	48.2	4.8	-24.2	Freezing Fog	Type I Nozzle (60°C)
HT4-8	8-Apr-03	Clariant Safewing MPIV 2001	1L	40.1	12.2	-10	Freezing drizzle	Dallas / Type IV Nozzle
HT4-9	8-Apr-03	Clariant Safewing MPIV 2001	1L	41.5	12.6	-10.1	Freezing drizzle	Dallas / Type I Nozzle
HT4-10	8-Apr-03	Kilfrost ABC-S	1L	44.8	13.2	-10.1	Freezing drizzle	Dallas / Type IV Nozzle
HT4-11	8-Apr-03	Kilfrost ABC-S	1L	44.8	12.1	-10.1	Freezing drizzle	Dallas / Type I Nozzle
HT4-27	8-Apr-03	Kilfrost ABC-S	1L	17.4	25.1	-10.1	Light freezing rain	Dallas / Type IV Nozzle
HT4-28	8-Apr-03	Kilfrost ABC-S	1L	29.7	26.1	-10.4	Light freezing rain	Dallas / Type I Nozzle
HT4-25	8-Apr-03	Clariant Safewing MPIV 2001	1L	26.7	26.0	-10.2	Light freezing rain	Dallas / Type IV Nozzle
HT4-26	8-Apr-03	Clariant Safewing MPIV 2001	1L	28.1	26.0	-10.2	Light freezing rain	Dallas / Type I Nozzle
HT4-23	8-Apr-03	Kilfrost ABC-S	1L	33.0	13.1	-10.1	Light freezing rain	Dallas / Type IV Nozzle
HT4-24	8-Apr-03	Kilfrost ABC-S	1L	41.1	13.1	-10.1	Light freezing rain	Dallas / Type I Nozzle
HT4-21	8-Apr-03	Clariant Safewing MPIV 2001	1L	29.2	13.7	-10	Light freezing rain	Dallas / Type IV Nozzle
HT4-22	8-Apr-03	Clariant Safewing MPIV 2001	1L	37.3	13.6	-10	Light freezing rain	Dallas / Type I nozzle
HT4-2	8-Apr-03	Clariant Safewing MPIV 2001	1L	61.0	5.6	-10.3	Freezing drizzle	Dallas / Type IV Nozzle
HT4-3	8-Apr-03	Clariant Safewing MPIV 2001	1L	57.4	5.7	-10.3	Freezing drizzle	Dallas / Type I Nozzle
HT4-5	8-Apr-03	Kilfrost ABC-S	1L	85.3	4.9	-10.3	Freezing drizzle	Dallas / Type I Nozzle
HT4-32	9-Apr-03	Kilfrost ABC-S	1L	38.3	12.6	-3.1	Light freezing rain	Type I Nozzle
HT4-37	9-Apr-03	Clariant Safewing MPIV 2001	1L	21.8	25.8	-2.9	Light freezing rain	Type I Nozzle
HT4-39	9-Apr-03	Kilfrost ABC-S	1L	30.8	25.7	-2.9	Light freezing rain	Type I Nozzle
HT4-20	9-Apr-03	Kilfrost ABC-S	1L	42.2	12.8	-3.3	Freezing drizzle	Dallas/Type I Nozzle

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