TP 14445E

Evaluation of Type IV Fluids Applied Using Forced Air Assist Equipment

Prepared for

Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

November 2005
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By:

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APS Aviation Inc.

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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

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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PREFACE

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

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To conduct endurance time tests in frost on various test surfaces;
- To assist with the operational evaluation of Type III fluids;
- To finalize the laboratory snow test protocol with Type II, III and IV fluids;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To assist the SAE G-12 Ground Equipment Subcommittee in evaluating forced air-assist systems;
- To evaluate the possibility of using a fluid failure sensor in holdover time testing;
- To conduct endurance time tests on non-aluminum plates;
- To examine the effect of heat on Type II, III and IV fluid endurance times;
- To provide support for human factor tactile tests; and
- To conduct general and exploratory de/anti-icing research.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2004-05 are documented in nine reports. The titles of the reports are as follows:

- TP 14443E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2004-05 Winter;
- TP 14444E Winter Weather Impact on Holdover Time Table Format (1995-2005);
- TP 14445E Evaluation of Type IV Fluids Applied Using Forced Air Assist Equipment;
- TP 14446E A Sensor for Detecting Anti-Icing Fluid Failure: Phase II;
- TP 14447E Effect of Heat on Endurance Times of Anti-Icing Fluids;
- TP 14448E Aircraft Ground Deicing Fluid Endurance Times on Composite Surfaces;
- TP 14449E Development of Ice Samples for Visual and Tactile Ice Detection Capability Tests;
- TP 14450E Development of Ice Samples for Comparison Study of Human and Sensor Capability to Detect Ice on Aircraft; and
- TP 14451E Aircraft Ground Icing General Research Activities During the 2004-05 Winter.

In addition, the following interim report is being prepared:

- *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions.*

This report, TP 14445E, has the following objective:

- To evaluate Type IV fluids applied using forced air assist.

To satisfy this objective, APS Aviation Inc. personnel travelled to the FedEx facility in Pittsburgh, Pennsylvania to participate in forced air systems testing.

PROGRAM ACKNOWLEDGEMENTS

This multi-year research program has been funded by the Civil Aviation Group, Transport Canada with support from the Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ. This program could not have been accomplished without the participation of many organizations. APS Aviation Inc. would therefore like to thank the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers.

APS Aviation Inc. 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: Stephanie Bendickson, Nicolas Blais, Michael Chaput, Sami Chebil, John D'Avirro, Peter Dawson, Stéphane Gosselin, Mark Mayodon, Chris McCormack, Nicoara Moc, Filomeno Pepe, Marco Ruggi, Joey Tiano, Kim Vepsa, and David Youssef.

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APS Aviation Inc. would like to thank the staff at the FedEx facility in Pittsburgh for accommodating the mobile laboratory and assisting the lab team as required.

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Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada. These are available from the Transportation Development Centre. Nine reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface. This project was co-sponsored by the Federal Aviation Administration.

16. Abstract

Forced air systems have been in development for more than five years. One major concern is that current holdover time values may not be valid when Type II or Type IV fluids are applied with forced air systems. Testing by FedEx in 2003-04 compared the viscosity of fluids applied with forced air to the viscosity of fluids applied with a conventional system. The tests showed that fluid viscosity decreased more with a forced air application than with a conventional application.

Two changes were made to the Type II/IV procedure following the unsuccessful 2003-04 test session. First, the approval criterion was changed: the viscosity of fluid applied with the forced air system would be compared to the lowest on wing viscosity instead of to the conventional application viscosity. Second, a requirement was added that pre-tests be conducted to fix the equipment setup prior to evaluation of the equipment with specific fluids.

Using the new test procedure, FedEx conducted tests in January 2005 with four Type IV fluids and two forced air deicing trucks. One of the four tested fluids could be approved for use without restrictions on viscosity. Two fluids could be approved for use with forced air with limitations on delivered viscosities. One fluid could not be approved as the sample sent for testing did not conform to the test requirements.

Following the test session, it was concluded that the new procedure was an improvement over the previous version of the procedure, and that the changes should remain in the procedure for future testing.

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Plusieurs rapports de recherche sur des essais de technologies de dégivrage et d'antigivrage ont été produits au cours des hivers précédents pour le compte de Transports Canada. Ils sont disponibles au Centre de développement des transports. Neuf rapports (dont celui-ci) ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos. Ce projet était coparrainé par la Federal Aviation Administration.

16. Résumé

Des systèmes à air forcé sont mis au point depuis plus de cinq ans. L'une des principales préoccupations soulevées est la possibilité que les valeurs actuelles des durées d'efficacité ne soient pas valides lorsque des liquides de types II ou IV sont appliqués à l'aide de systèmes à air forcé. Des tests ont été effectués par FedEx en 2003-2004 afin de comparer la viscosité des liquides appliqués à l'aide de systèmes à air forcé à la viscosité des liquides appliqués de façon traditionnelle. Les résultats obtenus ont démontré que l'application de liquides à l'aide de systèmes à air forcé entraîne une diminution de leur viscosité supérieure à celle observée lors d'une application traditionnelle.

Deux changements ont été apportés à la procédure relative aux liquides de types II/IV à la suite de la séance d'essai infructueuse de 2003-2004. Premièrement, le critère d'approbation a été modifié : la viscosité des liquides appliqués à l'aide de systèmes à air forcé est désormais comparée à leur plus basse viscosité sur l'aile plutôt qu'à leur viscosité lors d'une application traditionnelle. Deuxièmement, une condition stipulant que des tests préliminaires établissant la configuration de l'équipement doivent être menés avant son évaluation avec des liquides précis a été ajoutée.

À l'aide de cette nouvelle procédure, FedEx a mené des tests en janvier 2005 avec quatre liquides de type IV et deux camions de dégivrage à air forcé. L'un des quatre liquides évalués a pu être approuvé pour utilisation, et ce, sans restrictions de viscosité. Deux liquides ont pu être approuvés pour utilisation à l'aide de systèmes à air forcé, mais avec des restrictions sur les viscosités livrables. Un liquide n'a pas pu être approuvé, l'échantillon envoyé pour essai n'étant pas conforme aux critères d'évaluation.

À la suite de la séance d'essai, il a été conclu que la nouvelle procédure constituait une amélioration par rapport à sa version précédente, et que ces changements devraient continuer d'y figurer dans le cadre des tests à venir.

17. Mots clés Viscosité, air forcé, assisté par air, durées d'efficacité, liquides, plus basse viscosité sur l'aile	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), with support from the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) has undertaken a research program to further advance aircraft ground de/anti-icing technology. In recent years one of the research activities has been the advancement of forced air deicing systems.

Background

Forced air systems have been in development for more than five years. In 1999-2000, APS wrote TC report, TP 13664E, *Safety Issues and Concerns of Forced Air Systems* (1), which first documented possible safety issues that could arise from their use in field operations. One concern was that current holdover time values would not be valid when Type II or Type IV fluids were applied with forced air systems.

Fluid viscosity was agreed to be an appropriate method of evaluating holdover times. Testing by FedEx in 2003-04 compared the viscosity of fluid applied with forced air to the viscosity of fluid applied with a conventional system. The tests showed that fluid viscosity decreased more with a forced air application than with a conventional application.

Two changes were made to the Type II/IV procedure following the unsuccessful 2003-04 test session. First, the approval criterion was changed: the viscosity of fluid applied with the forced air system would be compared to the lowest on-wing viscosity (LOWV) instead of to the conventional application viscosity. Second, a requirement was added to the procedure in which the equipment settings had to be fixed prior to the evaluation of the equipment with specific fluids.

FedEx conducted a one-week test session in early January 2005 to establish the fixed setup it would test. Two weeks later, a second test session evaluated four FedEx forced air systems (two deicing trucks, each evaluated with and without an air sleeve) and four anti-icing fluids.

Data/Analysis

Tests took place in clear conditions with fluid cooled to -5°C. Fluid was applied to a JetStar wing using the forced air systems. Samples were immediately collected off the wing and brought to the lab for viscosity measurement. Samples of the fluid tote viscosity were also measured.

The viscosity of the tested fluids was compared to the LOWV. Using a formula given in the test protocol, the lowest acceptable delivered viscosity (LADV) was determined. The LADV is the lowest viscosity a fluid can have that ensures the viscosity will not go below the LOWV when applied with forced air.

One of the four tested fluids had an LADV below the low end of the standard delivered viscosity range and therefore could be approved for use without restrictions on viscosity. Two fluids had LADVs above the low end of the standard delivered viscosity range, but below the high end, and therefore could be approved for use with forced air with limitations on delivered viscosities. One fluid could not be approved as the sample sent for testing did not conform to the test requirements.

Conclusions

Two major changes were made to the Type II/IV forced air test procedure in 2004-05. The first change was the addition of a requirement to conduct pre-tests to fix the equipment setup. This proved to be a necessary and valuable addition as it ensures test results are applicable to actual operations and assists operators in determining appropriate setups prior to the actual test session. The second change was to the acceptance criterion: the viscosities of fluids applied with forced air are now compared to the LOWV, rather than to viscosities achieved with fluids applied with conventional systems. This method seems to be a reasonable approach for evaluating forced air systems.

Kilfrost ABC-S can be accepted for use with both the FMC Tempest II (TII) deicing truck and the FMC LMD 2000 (LMD) deicing truck, both with or without the air sleeve, with no restrictions on delivered viscosity. Octagon Max-Flight 04 and Clariant Safewing 2001 can be accepted for use with both the TII and LMD deicing trucks, with or without the air sleeve. However, the minimum acceptable viscosity of delivered fluid for these two fluids is higher than that of a fluid accepted for use with conventional systems. Dow UCAR Ultra+ cannot be accepted for use with forced air systems since the manufacturer provided fluid that did not conform to the test protocol requirements.

The presence of an air sleeve does not have a significant impact on the change in viscosity caused by forced air application. Neither deicing truck used in the tests was found to consistently cause more degradation to fluid viscosity than the other.

Recommendations

It is recommended that regulatory bodies continue to be involved in forced air evaluations and be present at test sessions. A laboratory such as APS should continue to act as an independent lab.

SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports (CDT) de Transports Canada (TC) et avec l'appui de la Federal Aviation Administration (FAA), APS Aviation Inc. (APS) a entrepris un programme de recherche visant à faire progresser les technologies associées au dégivrage et à l'antigivrage d'aéronefs au sol. Au cours des dernières années, l'une des activités de recherche s'est concentrée sur le développement de systèmes de dégivrage à air forcé.

Contexte

Des systèmes à air forcé sont mis au point depuis plus de cinq ans. En 1999-2000, APS a rédigé pour TC le rapport TP 13664E, *Safety Issues and Concerns of Forced Air Systems* (1), le premier à rendre compte des problèmes de sécurité pouvant découler de l'utilisation des systèmes à air forcé lors d'opérations sur le terrain. L'une des préoccupations soulevées était que les valeurs des durées d'efficacité du moment ne seraient pas valides lors de l'application des liquides de types II ou IV à l'aide de systèmes à air forcé.

Il a été convenu que la viscosité des liquides s'avérait une méthode d'évaluation des durées d'efficacité appropriée. Des tests ont été effectués par FedEx en 2003-2004 afin de comparer la viscosité des liquides appliqués à l'aide de systèmes à air forcé à la viscosité des liquides appliqués de façon traditionnelle. Les résultats obtenus ont démontré que l'application de liquides à l'aide de systèmes à air forcé entraîne une diminution de leur viscosité supérieure à celle observée lors d'une application traditionnelle.

Deux changements ont été apportés à la procédure relative aux liquides de types II/IV à la suite de la séance d'essai infructueuse de 2003-2004. Premièrement, le critère d'approbation a été modifié : la viscosité des liquides appliqués à l'aide de systèmes à air forcé est désormais comparée à leur plus basse viscosité sur l'aile plutôt qu'à leur viscosité lors d'une application traditionnelle. Deuxièmement, une condition stipulant que les paramètres de l'équipement doivent être établis avant son évaluation avec des liquides précis a été ajoutée à la procédure.

FedEX a organisé une séance d'essai d'une semaine au début de janvier 2005 dans le but de déterminer la configuration définitive qui serait évaluée. Une seconde séance a été tenue deux semaines plus tard, cette fois afin d'évaluer quatre systèmes à air forcé de FedEx (deux camions de dégivrage, chacun analysé avec et sans manchon pneumatique) et quatre liquides d'antigivrage.

Données/analyse

Les essais ont été menés dans des conditions claires, avec des liquides refroidis à -5°C. Ces liquides ont été appliqués sur une aile Jetstar à l'aide de systèmes à air forcé. Des échantillons ont immédiatement été recueillis sur l'aile et apportés au laboratoire pour en mesurer la viscosité. Des échantillons de la viscosité des liquides dans les récipients ont également été mesurés.

La viscosité des liquides testés a été comparée à la plus basse viscosité sur l'aile (LOWV). À l'aide d'une formule présentée dans le protocole d'essai, la plus basse viscosité livrable (LADV) a été établie. La plus basse viscosité livrable constitue la plus basse viscosité que peut avoir un liquide sans descendre sous la plus basse viscosité sur l'aile lors d'une application à l'aide de systèmes à air forcé.

L'un des quatre liquides évalués présentait une plus basse viscosité livrable se situant au-dessous de la valeur inférieure de la fourchette de viscosité livrable standard, et a donc pu être approuvé pour utilisation sans restrictions de viscosité. Deux liquides présentaient une plus basse viscosité livrable se situant au-dessus de la valeur inférieure de la fourchette de viscosité livrable standard, mais au-dessous de sa valeur supérieure, et ont donc pu être approuvés pour utilisation à l'aide de systèmes à air forcé, mais avec des restrictions sur les viscosités livrables. Un liquide n'a pas pu être approuvé, l'échantillon envoyé pour essai n'étant pas conforme aux critères d'évaluation.

Conclusions

Deux changements majeurs ont été apportés à la procédure d'essai relative aux liquides de types II/IV appliqués à l'aide de systèmes à air forcé en 2004-2005. Le premier changement a été l'ajout d'une condition stipulant que des tests préliminaires établissant la configuration de l'équipement doivent être menés. Cet ajout s'est avéré nécessaire et utile, puisqu'il permet d'assurer que les résultats des tests s'appliquent aux opérations réelles et qu'il aide les exploitants aériens à déterminer les paramètres appropriés avant que ne soit menée la séance proprement dite. Le second changement concerne le critère d'approbation : la viscosité des liquides appliqués à l'aide de systèmes à air forcé est désormais comparée à leur plus basse viscosité sur l'aile plutôt qu'à leur viscosité lors d'une application traditionnelle. Cette méthode apparaît comme une approche raisonnable pour l'évaluation des systèmes à air forcé.

Le liquide Kilfrost ABC-S peut être accepté pour utilisation avec les camions de dégivrage FMC Tempest II (TII) et FMC LMD 2000 (LMD), avec ou sans manchon pneumatique, et ce, sans restrictions sur les viscosités livrables. Les liquides Octagon Max-Flight 04 et Clariant Safewing 2001 peuvent être acceptés pour utilisation avec les camions de dégivrage TII et LMD, avec ou sans manchon pneumatique. La viscosité livrable minimale pour ces deux liquides s'avère cependant plus élevée que celle d'un liquide accepté pour utilisation avec des systèmes traditionnels. Le liquide Dow UCAR Ultra+ ne peut pas être accepté pour utilisation avec des systèmes à air forcé, son fabricant ayant fourni un liquide non conforme aux critères du protocole d'essai.

La présence d'un manchon pneumatique n'exerce pas une influence significative sur le changement de viscosité causé par une application à l'aide de systèmes à air forcé. Aucun des deux camions de dégivrage utilisés dans le cadre des tests n'a été systématiquement associé à une dégradation de la viscosité des liquides supérieure à l'autre.

Recommandations

Il est recommandé que les organismes de réglementation continuent de participer aux évaluations des systèmes à air forcé et de prendre part aux séances d'essai. Un laboratoire comme APS devrait continuer d'agir à titre de laboratoire indépendant.

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GLOSSARY

APS	APS Aviation Inc.
FAA	Federal Aviation Administration
LADV	Lowest Acceptable Delivered Viscosity
LMD	LMD 2000
LOWV	Lowest On-Wing Viscosity
OAT	Outside Air Temperature
SAE	Society of Automotive Engineers
TII	Tempest II
TC	Transport Canada
TDC	Transportation Development Centre

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1. INTRODUCTION

Under winter precipitation conditions, aircraft are cleaned with a freezing point depressant fluid and protected against further accumulation by an additional application of such a fluid, possibly thickened to extend the protection time. Aircraft ground deicing had, until recently, never been researched and there is still an incomplete understanding of the hazard and of what can be done to reduce the risks posed by the operation of aircraft in winter precipitation conditions. This "winter operations contaminated aircraft – ground" program of research is aimed at overcoming this lack of knowledge.

Since the early 1990s, the Transportation Development Centre (TDC) of Transport Canada (TC) has managed and conducted de/anti-icing related tests at various sites in Canada; it has also coordinated worldwide testing and evaluation of evolving technologies related to de/anti-icing operations with the co-operation of the United States Federal Aviation Administration (FAA), the National Research Council Canada (NRC), Atmospheric Environment Services, several major airlines, and deicing fluid manufacturers. The TDC is continuing its research, development, testing and evaluation program.

Under contract to the TDC, with support from the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) has undertaken research program to further advance aircraft ground de/anti-icing technology. In recent years, one of these research activities has been the advancement of forced air systems.

1.1 Background

Forced air systems have been in development for more than five years. In 1999-2000, APS produced the TC report, TP 13664E, *Safety Issues and Concerns of Forced Air Systems* (1), which first documented possible safety issues that could arise from their use in field operations. The Society of Automotive Engineers (SAE) G-12 Aircraft Ground Deicing Equipment Subcommittee subsequently proposed a Forced Air Working Group to focus on the project.

Over the next several winters, the work group developed test procedures for use with forced air systems. A Type I fluid procedure was published in November 2001. This procedure provides guidance to operators wanting to use forced air with Type I fluid as the first step in a two-step de/anti-icing operation. Holdover times are not affected by forced air system use in this situation, as the Type I forced air application is followed by a conventional application of Type II or Type IV fluid.

However, concern arose that the current holdover time values would not be valid when Type II or Type IV fluids were applied with forced air systems. The purpose of the Type II/IV procedure was therefore to evaluate the effect of forced air applications on holdover times of Type II/IV fluids. The Type II/IV procedure went through several revisions, as the best way to evaluate the outcome was debated. A detailed account of this history is given in the TC report, TP 14380E, *A Protocol for Testing Fluids Applied with Forced Air Systems* (2).

Measuring fluid viscosity was eventually accepted as an appropriate method of evaluating holdover times. The viscosity of fluids applied with forced air deicing systems would be compared to the viscosity of fluids applied with conventional deicing systems. Each forced air system/fluid combination would be approved by the regulators individually if the viscosities were similar. APS assisted in tests conducted by FedEx in the winter of 2003-04 using this procedure. However, unlike preliminary tests which showed similar fluid viscosities between the conventional and forced air system applications, the tests showed fluid viscosity decreased more with a forced air application than with a conventional application. These tests are documented in TP 14380E (2).

1.2 Developments in 2004-05

Two changes were made to the Type II/IV procedure following the 2003-04 test session. First, it was recognized that the standard for accepting forced air equipment may have been too rigid. Several fluids that did not meet the standard in 2003-04 testing had viscosities above the lowest on-wing viscosity (LOWV), which is the standard required of fluids applied with conventional systems. The approval criterion was changed: the viscosity of the fluid applied with the forced air system would be compared to the LOWV instead of to the conventional application viscosity.

Second, it was theorized that settings on the forced air equipment could have led to the varying results seen in 2003-04, and that changing the settings could eliminate the variability *and* minimize the effect the application had on fluid viscosity. To account for this, a requirement was added to the procedure in which the settings had to be "fixed" prior to evaluation of the equipment with specific fluids. Once tested, and if the fluid met the approval criterion, only the setup tested would be accepted by the regulatory authorities.

In early January 2005, FedEx conducted a one-week test session at their facility in Pittsburgh, Pennsylvania to find the "optimal" equipment setup to use with their forced air systems. The optimal setup would cause the least amount of shearing to the anti-icing fluid without causing a hindrance to the deicing operation. APS was present at this test session to measure fluid viscosities.

Two weeks later, a second test session was held in order to evaluate two FedEx deicing trucks and four anti-icing fluids with the fixed setup selected at the previous test session. This report details this second test session.

1.3 Objective

APS' objective in forced air research is to assist the SAE ground equipment committee in evaluating forced air systems. This includes updating test procedures as necessary, and participating in operator field tests of de/anti-icing fluids.

At the FedEx field tests, APS' primary objective was to measure in-situ viscosities of the tested fluids and compare them to the standards given by the regulatory authorities.

The scope of work for this project is outlined in an excerpt from the TDC work statement provided in Appendix A.

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2. METHODOLOGY

2.1 Procedure

In November 2004, a meeting was held to discuss changes to the Type II/IV forced air test procedure published in December 2003. The meeting was attended by APS, FedEx, the FAA and FMC. Following the meeting, APS incorporated several changes into the procedure.

1) Ambient Temperature: A requirement was added stipulating that testing take place at an ambient temperature of less than 0°C.

2) Approval Criterion: The approval criterion was changed so the viscosity of the tested fluids was compared to the fluid's LOWV.

3) Fixed Setup: A requirement was added that the variable settings on the forced air system be "fixed" and that all tests be conducted with the fixed setup.

Key components of the final version of the procedure include:

- Tests take place in clear (no precipitation) conditions, or in a place sheltered from all precipitation;
- Tests take place below 0°C;
- An aircraft wing is used as a test bed; alternate surfaces are not acceptable;
- Initial viscosity of test fluid is in the middle of the viscosity delivery range;
- Viscosity measurements are made immediately after application;
- The angle of fluid spray and the distance between nozzle and wing are fixed;
- The test surface is cleaned between applications of test fluids; and
- The deicing truck tank is cleaned between test fluids.

At the FedEx test session, the activities below were carried out to meet the procedural requirements.

- To avoid contamination from natural precipitation, most fluids were applied to the wing inside the FedEx hangar.

- The position of the truck relative to the test surface was measured prior to each fluid application. The setup is shown in Photo 2.1. It should be noted that the horizontal distance was 2.9 m (9.5 ft.) for several tests.

- Immediately following fluid application, fluid samples were collected from the wing (see Photo 2.2). Care was taken not to shear the samples as they were collected.

- APS' mobile viscosity laboratory (see Photo 2.3) was brought in from Montreal to enable immediate testing of fluid viscosity.

- After each fluid application, the wing was cleaned with Type I fluid. After the wing was deiced, the Type I fluid was blown off the wing using forced air. This procedure prevented the test fluid from being contaminated by either the previous test fluid or Type I fluid. The Type IV test fluid was then applied and squeegeed off; this ensured that the only residue on the wing was from the test fluid. Following this process, the test fluid was reapplied using forced air assist.

The final version of the Type II/IV procedure, Version 4.0, is included in Appendix B. In addition, a test matrix was developed specifically for the FedEx tests. The test matrix was published in a separate procedure, which is also included in Appendix B.

2.2 Test Site

Tests were conducted at the FedEx hangar at the Pittsburgh International Airport in Pittsburgh, Pennsylvania. The majority of tests were conducted inside the hangar. Several tests were conducted outside the hangar in clear conditions.

2.3 Equipment

2.3.1 Test Surface

A Lockheed JetStar wing owned by TC was transported from Montreal to Pittsburgh and used as a test bed. The same wing was used in the 2003-04 FedEx forced air tests in Rochester, New York. The shipment was arranged by APS and funded by FedEx. The wing is shown in Photo 2.4.

2.3.2 Forced Air Systems

Two FMC deicing trucks were tested: the FMC Tempest II (TII) and the FMC LMD 2000 (LMD). These trucks are shown in Photos 2.5 and 2.6, respectively.

Prior to the test session, preliminary tests were carried out by FedEx to determine the optimal equipment setup. Several variables were examined. These included fluid flow rate, airflow pressure, nozzle position, and presence of an air sleeve.

The preliminary tests were conducted with Kilfrost ABC-S because it experienced the most viscosity degradation when applied with forced air in the 2003-04 tests. It was therefore assumed that results of testing with this fluid would give the worst-case results.

The optimal setup was found to be:

- Fluid flow rate: 94.6 lpm (litres/minute) or 25 gpm (grams/minute);
- Airflow pressure: 41.4 kPa (6 psi); and
- Nozzle position: 17.8 cm (7”) between centre points of air and fluid nozzles, achieved by inserting a 7.6 cm (3”) separator.

Because testing with the air sleeve sometimes gave higher viscosities and sometimes gave lower viscosities, it was decided tests would be conducted both with and without the air sleeve so that both setups could potentially be certified. The air sleeve is shown in Photo 2.7.

2.4 Refrigerated Truck

There was concern that during the test session in Pittsburgh the outside air temperature (OAT) would not be lower than 0°C as required in the procedure. FedEx obtained approval from the FAA to store the fluids at -5°C and to test the cooled fluids even if the temperature went slightly above 0°C. This was also seen as a way to equalize the test conditions for all of the fluids. To cool the fluids, FedEx brought in a refrigerated truck which was kept at -5°C. Fluids were placed in the refrigerated truck several days before the test session, and remained there until they were moved to the deicing trucks for testing. A picture of the fluids stored in the refrigerated truck is shown in Photo 2.8.

2.5 Fluids

Four Type IV fluids were tested: Kilfrost ABC-S, Dow UCAR Ultra+, Octagon Max-Flight 04, and Clariant Safewing MP IV 2001. All of these fluids are propylene glycol based, with the exception of Dow UCAR Ultra+, which is ethylene glycol based.

Fluid manufacturers were asked to send fluids with viscosities in the middle of their respective production ranges. The Clariant fluid did not meet this requirement; however, a different batch of fluid on-hand at FedEx's facility in Pittsburgh was closer to the required viscosity, and was substituted for the test fluid. The Dow UCAR Ultra+ sample was significantly higher than its usual production range. The sample was used, as no other samples were available. Fluid acceptance is discussed in more detail in Subsection 3.2.

The fluid manufacturer fluid certificates of analysis are included in Appendix C.

2.5.1 Viscosity Measurement Equipment

Two Brookfield LV DV-I+ digital viscometers were used to measure fluid viscosity (see Photo 2.9). Each viscometer was equipped with a small sample adaptor and attached to a temperature-circulating bath. Prior to testing, viscometer accuracy was checked using the manufacturer's stated procedure for small sample adaptor calibration (given in Brookfield operating manual no. M/92-021-J1297, page 30).

Whenever possible, fluid manufacturer viscosity measurement methods were used. Due to time constraints it was not feasible to use methods requiring large samples. In these cases fluid manufacturers recommended alternate small sample methods and provided a conversion formula or factor between the two methods.

The following viscosity measurement methods were used:

- Kilfrost ABC-S: Spindle 31, 10 mL, 20°C, 0.3 rpm, 10 minutes;
- Dow UCAR Ultra+: Spindle 31, 10 mL, 0°C, 0.3 rpm, 10 minutes;
- Octagon Max-Flight: Spindle 34, 10 mL, 20°C, 0.3 rpm, 10 minutes; and
- Clariant Safewing 2001: Spindle 34, 10 mL, 20°C, 0.3 rpm, 15 minutes.

All samples were centrifuged before viscosity tests were conducted. As per standard viscosity measurement procedure, two measurements were taken per sample. To eliminate any discrepancy between the two viscometers, one measurement was done on each viscometer. The viscosity reported is an average of the two measurements.

2.6 Samples Collected

For each fluid and truck combination, four viscosity samples were collected: fluid tote, truck tank, on-wing (sprayed with air sleeve), and on-wing (sprayed without air sleeve). In most cases, fluid from the same tote was loaded into both (TII and LMD) deicing trucks. In these cases only one fluid tote sample was taken.

Viscosity of the fluid tote samples was measured at the beginning of the test session. Viscosity of the on-wing samples was measured immediately following application. Truck tank samples were collected in case on wing viscosities were not as expected, and some type of contamination in the truck was suspected. This did not occur so the samples were never tested.

2.7 Personnel

The Pittsburgh test session was organized by FedEx, who invited representatives from TC, the FAA, SAE, truck manufacturers and various fluid manufacturers to observe the tests. APS was invited to act as an independent laboratory for the tests. A list of attendees is included in Appendix D.

Two APS technicians were required to run the mobile viscosity laboratory. In addition, a project manager was present to offer guidance and support to all parties during the test session.

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Photo 2.1: Position of Nozzle Relative to Test Surface

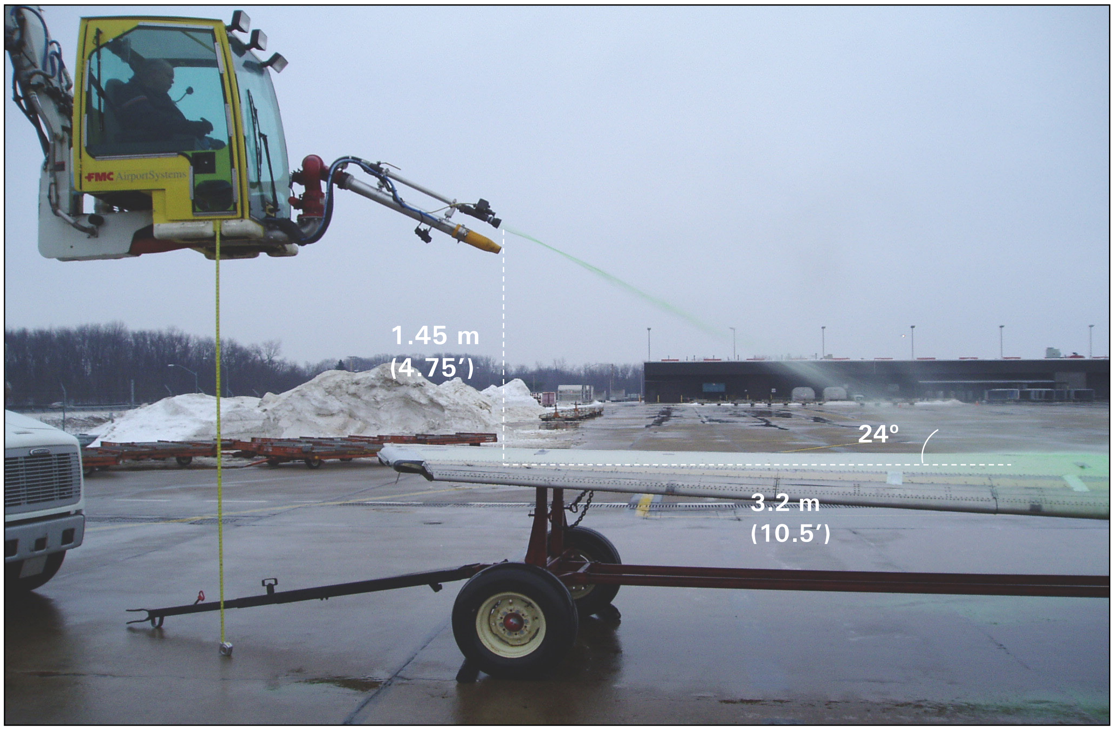

Photo 2.2: Sample Collection

Photo 2.3: APS Mobile Viscosity Laboratory

Photo 2.4: Transport Canada JetStar Wing

Photo 2.5: FMC Tempest II Deicing Truck

Photo 2.6: FMC LMD 2000 Deicing Truck

Photo 2.7: Air Sleeve

Photo 2.8: Fluid Storage in Refrigerated Truck

Photo 2.9: Brookfield LV DV-I+ Digital Viscometer

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3. DATA

3.1 Summary of Daily Testing

Tests were conducted over three days from January 24th to 26th. Following is a summary of each day of testing.

3.1.1 January 24th, 2005

The average OAT was -11°C and the sky was overcast with some flurries in the afternoon. The morning and early afternoon were spent setting up the APS mobile lab and preparing the deicing trucks for testing. The APS mobile lab was set up in an electrical room on the second floor of the office in the FedEx hangar. The viscosities of the fluid tote samples were measured. In the afternoon Kilfrost ABC-S was tested in the TII deicing truck inside the hangar.

3.1.2 January 25th, 2005

The average OAT was -2°C and the sky was partially overcast with no precipitation. Tests with Kilfrost ABC-S in the LMD deicing truck were conducted in the morning. All Dow UCAR Ultra+ and Octagon Max-Flight 04 tests were conducted in the afternoon. The tests took place inside the hangar. Additional fluid tote samples of Clariant Safewing 2001 were collected and measured (see Subsection 3.2).

3.1.3 January 26th, 2005

The average OAT was 0°C and the sky was partially overcast with no precipitation. In the morning, Clariant Safewing 2001 was tested. The fluids were sprayed outdoors. Clean up and pack up took up the remainder of the day.

3.2 Acceptance of Fluid Samples

The viscosities of the samples sent for testing were measured on the first day. The procedure required that the samples have viscosities approximately in the middle of their respective production range (specified by the fluid manufacturer). The fluid tote viscosities are given in Table 3.1.

Table 3.1: Tote Viscosities

Fluid (Production Range[1])	Sample No.	Sample Description	Viscosity (mPa.s)	Sample Acceptance
Kilfrost ABC-S (20,000 to 30,000 mPa.s)	1A	Original Sample, Tote 1	25,276	Yes
	1B	Original Sample, Tote 2	27,164	Yes
Dow UCAR Ultra+ (40,000 to 53,000 mPa.s)	8	Original Sample	63,950	No
Octagon Max-Flight 04 (7,000 to 12,000 mPa.s)	15	Original Sample	10,100	Yes
Clariant Safewing 2001 (20,000 to 30,000 mPa.s)	22A	Original Sample, Tote 1	31,100	No
	22B	Original Sample, Tote 2	30,900	No
	22C	FedEx Sample 1	27,500	Yes
	22D	FedEx Sample 2	31,000	No

[1] Provided by the fluid manufacturer. Winter 2004-05 values given

The Kilfrost ABC-S and Octagon Max-Flight 04 samples were immediately accepted for testing. The Dow UCAR Ultra+ sample was not accepted for testing; however, it was decided testing would still be carried out for the purpose of gathering information.

Clariant sent two fluid totes for testing. Both totes had viscosities higher than the upper limit of the production range and therefore could not be accepted. At the time of testing, FedEx was using Clariant Safewing 2001 in its Pittsburgh facility, and had several unused totes on hand. Two of these totes were tested. One had a viscosity of 27,500 mPa.s and was accepted for testing.

3.3 Fluid Viscosity

The log of tests is presented in Table 3.2. The viscosity data is presented by fluid in Figures 3.1 to 3.4. Results from the LMD deicing truck are shown on the left side of the charts; the results from the TII deicing truck are shown on the right side of the charts. The LOWV is shown on the graphs with a horizontal line.

Where necessary, the viscosity values have been converted to reflect measurement values consistent with the fluid manufacturers' viscosity measurement methods (see Subsection 2.5.1).

Table 3.2: Log of Tests

Test No.	Fluid	Truck	Sample	Viscosity (mPa.s)	Degradation from Tote
1B	Kilfrost ABC-S	TII	Fluid Tote	27,164[1]	n/a
3B	Kilfrost ABC-S	TII	On-Wing	21,943[1]	-19%
4A	Kilfrost ABC-S	TII	On-Wing (A/S[2])	22,109[1]	-19%
1A	Kilfrost ABC-S	LMD	Fluid Tote	25,276[1]	n/a
6	Kilfrost ABC-S	LMD	On-Wing	19,665[1]	-22%
7	Kilfrost ABC-S	LMD	On-Wing (A/S)	21,165[1]	-16%
8	Dow UCAR Ultra+	Both	Fluid Tote	63,950	n/a
10	Dow UCAR Ultra+	LMD	On-Wing	60,750	-5%
11	Dow UCAR Ultra+	LMD	On-Wing (A/S)	61,300	-4%
13	Dow UCAR Ultra+	TII	On-Wing	69,150	8%
14	Dow UCAR Ultra+	TII	On-Wing (A/S)	66,400	4%
15	Octagon Max-Flight 04	Both	Fluid Tote	10,100[1]	n/a
17	Octagon Max-Flight 04	LMD	On-Wing	7,700[1]	-24%
18	Octagon Max-Flight 04	LMD	On-Wing (A/S)	7,600[1]	-25%
20	Octagon Max-Flight 04	TII	On-Wing	6,800[1]	-33%
21	Octagon Max-Flight 04	TII	On-Wing (A/S)	6,600[1]	-35%
22C	Clariant Safewing 2001	Both	Fluid Tote	27,500	n/a
24	Clariant Safewing 2001	LMD	On-Wing	21,600	-21%
25	Clariant Safewing 2001	LMD	On-Wing (A/S)	23,600	-14%
27	Clariant Safewing 2001	TII	On-Wing	22,000	-20%
28	Clariant Safewing 2001	TII	On-Wing (A/S)	22,600	-18%

[1] These numbers have been converted to reflect measurement values consistent with the fluid manufacturer's standard method. A conversion formula or factor was provided by the fluid manufacturer

[2] A/S indicates tests were conducted with the air sleeve inserted

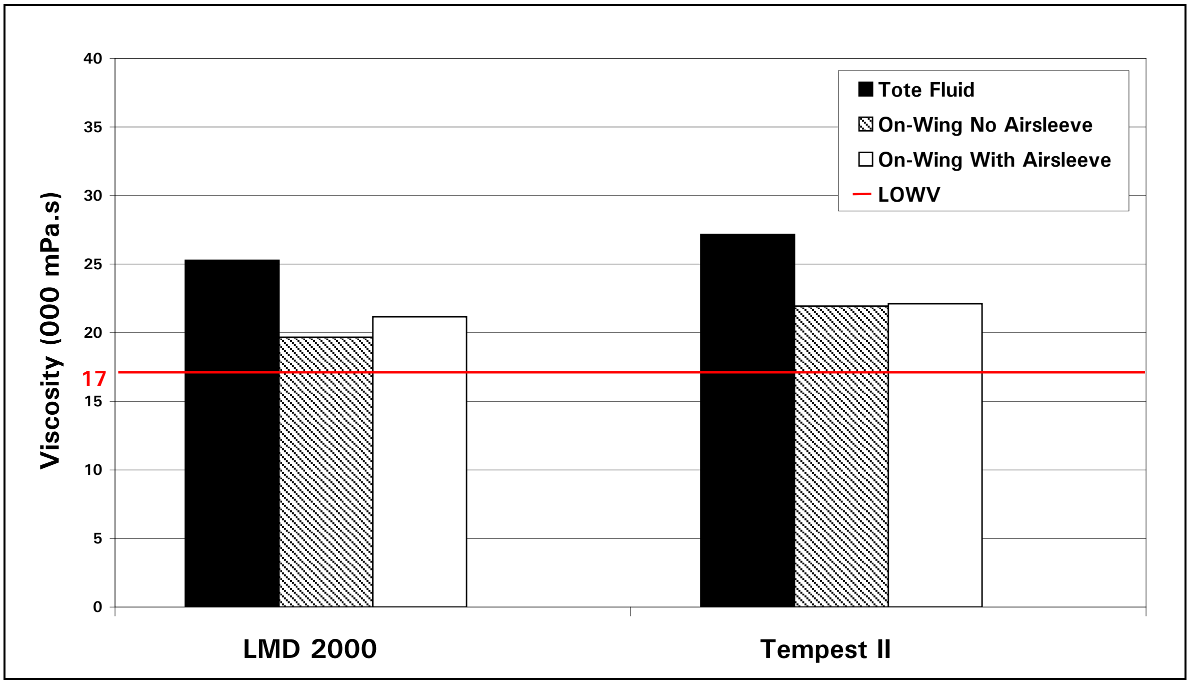

Figure 3.1: Viscosity of Kilfrost ABC-S Samples

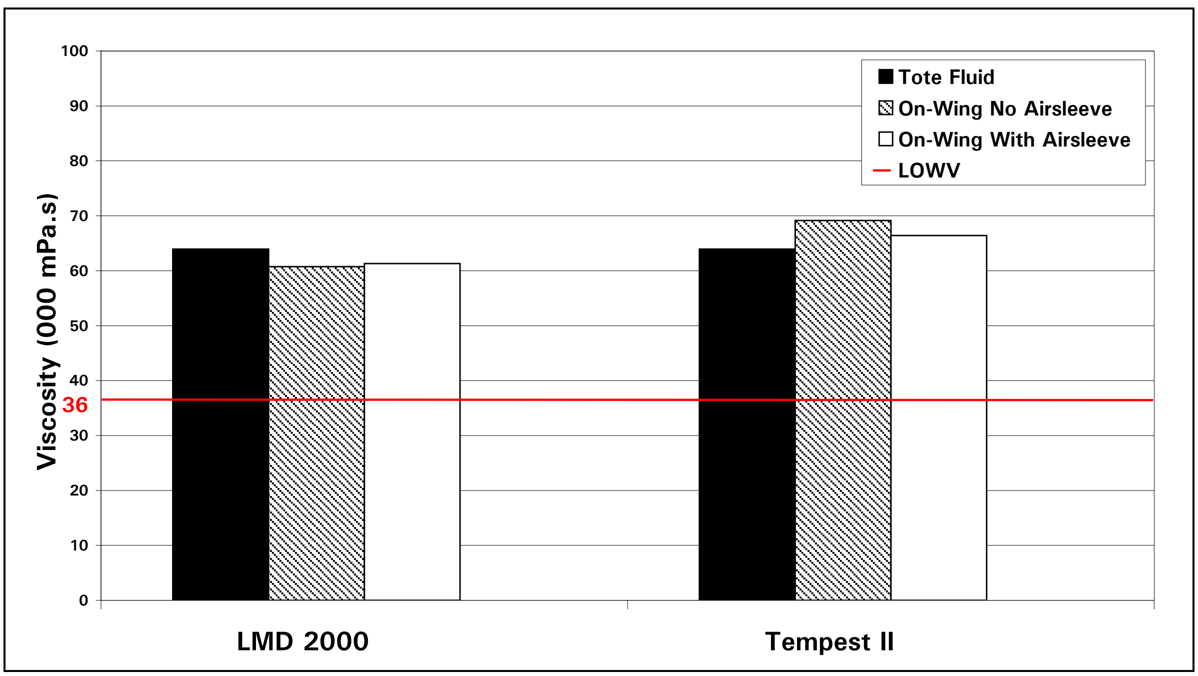

Figure 3.2: Viscosity of Dow UCAR Ultra+ Samples

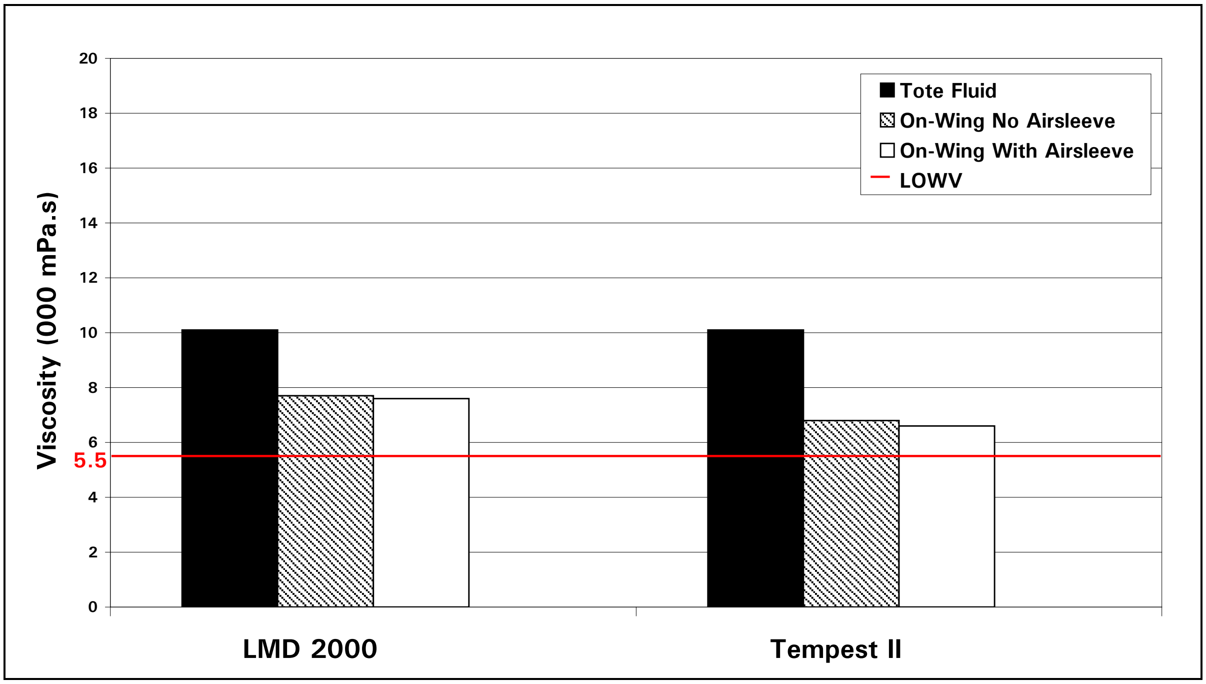

Figure 3.3: Viscosity of Octagon Max-Flight 04 Samples

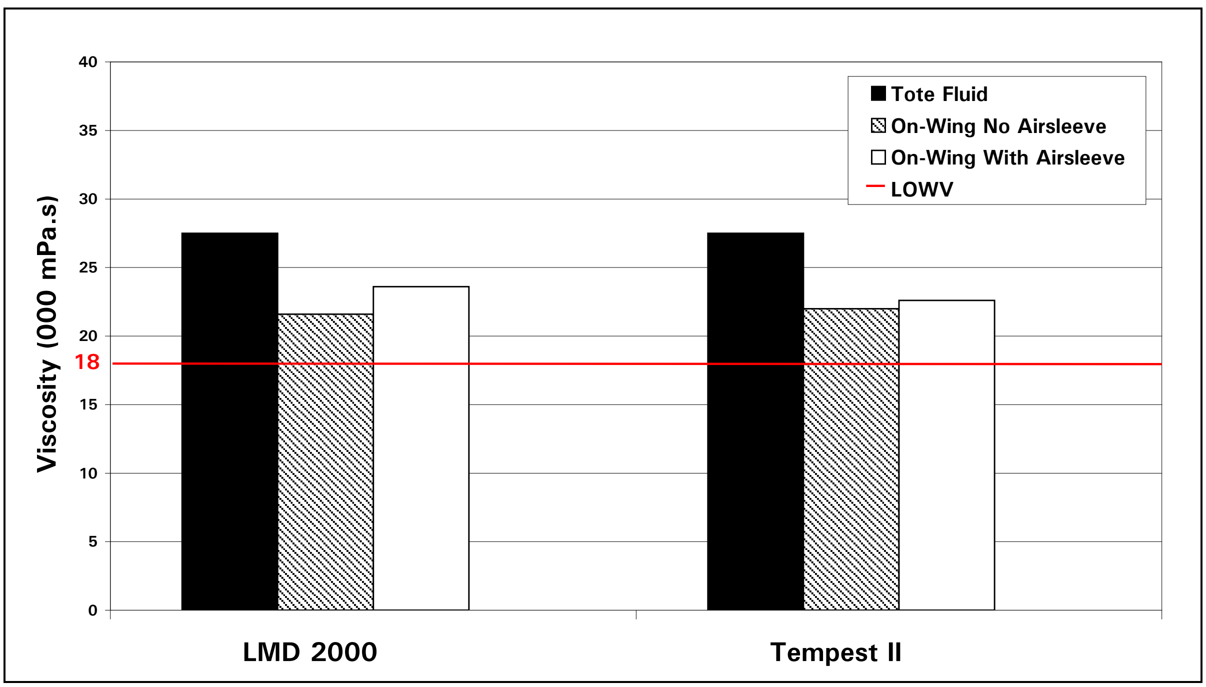

Figure 3.4: Viscosity of Clariant Safewing 2001 Samples

3.4 Fluid Density

Fluid densities of the samples were measured after the samples were collected (see Photo 3.1). The following procedure was used to measure density:

1. A 250 mL volumetric flask was weighed;
2. The flask was filled with test fluid; and
3. The filled flask was weighed.

Density was calculated by subtracting the flask weight from the filled flask weight and dividing by the flask volume.

Results are shown in Table 3.3. The third column gives the density of the fluid before it was applied to the wing. This was taken from the fluid tote sample. The fourth column gives the density of the fluid after application. The last column shows the change in density that occurred from the fluid application.

Table 3.3: Fluid Densities

Fluid	Forced Air System[1]	Initial Density (g/mL)	Applied Density (g/mL)	Density Change
Kilfrost ABC-S	Tempest II (A/S)	1.00	1.00	0%
Kilfrost ABC-S	Tempest II	1.00	0.99	-1%
Kilfrost ABC-S	LMD 2000 (A/S)	1.02	0.97	-5%
Kilfrost ABC-S	LMD 2000	1.02	0.98	-4%
Dow/UCAR Ultra+	Tempest II (A/S)	0.99	0.98	-1%
Dow/UCAR Ultra+	Tempest II	0.99	0.98	-1%
Dow/UCAR Ultra+	LMD 2000 (A/S)	0.99	0.96	-3%
Dow/UCAR Ultra+	LMD 2000	0.99	0.97	-2%
Octagon Max-Flight 04	Tempest II (A/S)	1.04	1.01	-3%
Octagon Max-Flight 04	Tempest II	1.04	1.00	-3%
Octagon Max-Flight 04	LMD 2000 (A/S)	1.04	1.00	-3%
Octagon Max-Flight 04	LMD 2000	1.04	1.01	-3%
Clariant Safewing 2001	Tempest II (A/S)	1.02	0.97	-5%
Clariant Safewing 2001	Tempest II	1.02	0.98	-4%
Clariant Safewing 2001	LMD 2000 (A/S)	1.02	0.97	-5%
Clariant Safewing 2001	LMD 2000	1.02	0.95	-6%

[1] A/S indicates tests were conducted with the air sleeve inserted

3.5 Fluid Thickness

Following fluid application, fluid thickness measurements were taken on the wing (see Photo 3.2). Results are shown in Table 3.4. The measured values have been corrected as per the thickness gauge instructions.

Table 3.4: Fluid Thickness after Application

Fluid	Forced Air System[1]	Thickness (mils)	Thickness (mm)
Kilfrost ABC-S	Tempest II (A/S)	88	2.2
Kilfrost ABC-S	Tempest II	88	2.2
Kilfrost ABC-S	LMD 2000 (A/S)	73	1.8
Kilfrost ABC-S	LMD 2000	73	1.8
Dow/UCAR Ultra+	Tempest II (A/S)	138	3.5
Dow/UCAR Ultra+	Tempest II	116	2.9
Dow/UCAR Ultra+	LMD 2000 (A/S)	123	3.1
Dow/UCAR Ultra+	LMD 2000	131	3.3
Octagon Max-Flight 04	Tempest II (A/S)	88	2.2
Octagon Max-Flight 04	Tempest II	88	2.2
Octagon Max-Flight 04	LMD 2000 (A/S)	100	2.5
Octagon Max-Flight 04	LMD 2000	73	1.8
Clariant Safewing 2001	Tempest II (A/S)	73	1.8
Clariant Safewing 2001	Tempest II	73	1.8
Clariant Safewing 2001	LMD 2000 (A/S)	73	1.8
Clariant Safewing 2001	LMD 2000	68	1.7

[1] A/S indicates tests were conducted with the air sleeve inserted

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Photo 3.1: Measuring Fluid Density

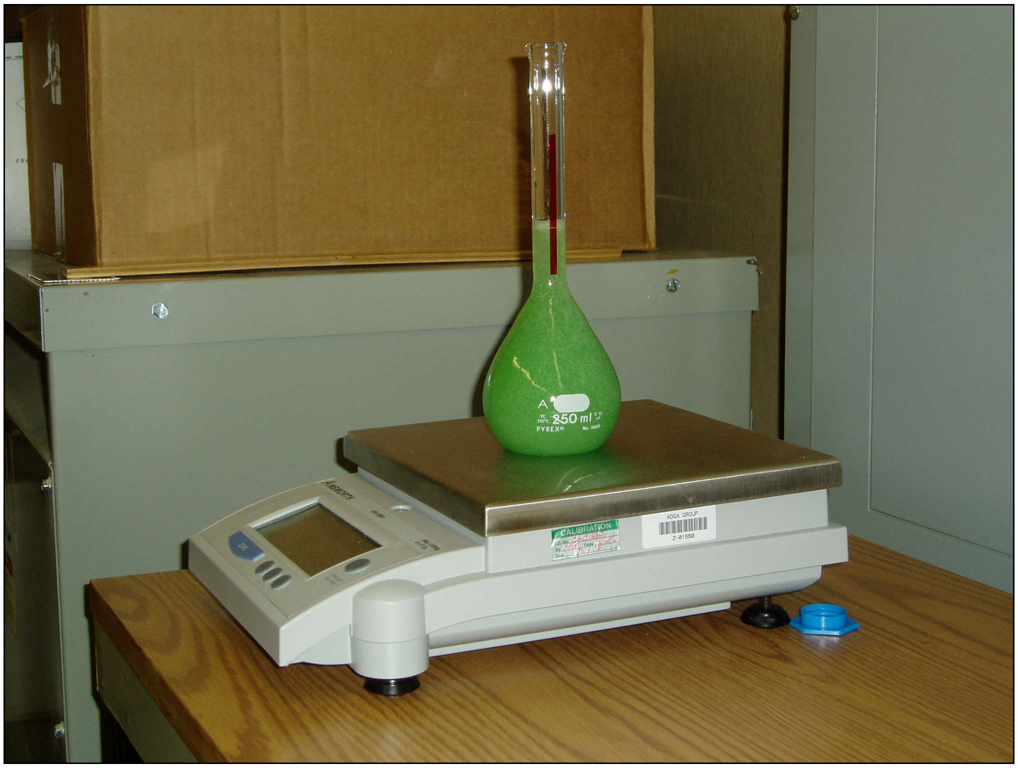

Photo 3.2: Measuring Fluid Thickness

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4. ANALYSIS

4.1 Acceptance of Fluids with Specific Forced Air Systems

4.1.1 Lowest Acceptable Delivered Viscosity

As described in the test procedure (see Appendix B), a formula must be applied to determine if a forced air system will be accepted for use with a specific fluid. This formula calculates the lowest acceptable delivered viscosity (LADV) of the fluid. A fluid must have a viscosity at or above the LADV when it is delivered to ensure its viscosity will not go below the LOWV when it is applied with the forced air system. Holdover times may be shorter than indicated in the holdover time tables if fluids have a viscosity below the LOWV.

The LADV formula is based on the ratio of fluid viscosity reduction applied to the LOWV. The LADV is calculated as follows:

a) $$\text{LADV} = \text{LOWV} \times \frac{\text{Fluid Viscosity in Tote}}{\text{Tested On-Wing Viscosity}}$$

b) The calculated value is rounded up to the nearest even 500 mPa.s.

The acceptable range of delivered fluid viscosity for use of holdover time guidelines with forced air will be from the lowest viscosity derived from the formula in a) and b) to the high end of the manufacturer’s delivery range.

4.1.2 Example of LADV Calculation

To illustrate the calculation of LADV, the following example is given. The pertinent test parameters are:

- Fluid: Clariant Safewing 2001
- Truck: Tempest II
- Air Sleeve: With Air Sleeve

The pertinent test variable values are:

- LOWV = 18,000 mPa.s
- Tote Fluid Viscosity = 27,500 mPa.s
- On-wing Test Viscosity = 22,600 mPa.s

To calculate the LADV:

- LADV = LOWV x $\frac{\text{Fluid Viscosity in Tote}}{\text{Tested On-Wing Viscosity}}$

  = 18,000 x 27,500 / 22,600

  = 21,900 mPa.s

- Value is rounded up to nearest 500 mPa.s

  ⇒ 21,900 mPa.s becomes 22,000 mPa.s

4.1.3 LADV of Tested Fluids

Table 4.1 shows the LADV for each of the tested fluids and forced air deicing trucks. The 2005-06 viscosity delivery range is also given for each fluid.

Table 4.1: Lowest Acceptable Delivered Fluid Viscosities

Fluid	Forced Air System[1]	LADV (mPa.s)	Fluid Viscosity Delivery Range[2] (mPa.s)
Kilfrost ABC-S	Tempest II (A/S)	21,000	25,000 to 30,000
Kilfrost ABC-S	Tempest II	21,500	
Kilfrost ABC-S	LMD 2000 (A/S)	20,500	
Kilfrost ABC-S	LMD 2000	22,000	
Dow/UCAR Ultra+	Tempest II (A/S)	-[3]	40,000 to 53,000
Dow/UCAR Ultra+	Tempest II	-[3]	
Dow/UCAR Ultra+	LMD 2000 (A/S)	-[3]	
Dow/UCAR Ultra+	LMD 2000	-[3]	
Octagon Max-Flight 04	Tempest II (A/S)	8,500	7,000 to 12,000
Octagon Max-Flight 04	Tempest II	8,500	
Octagon Max-Flight 04	LMD 2000 (A/S)	7,500	
Octagon Max-Flight 04	LMD 2000	7,500	
Clariant Safewing 2001	Tempest II (A/S)	22,000	20,000 to 30,000
Clariant Safewing 2001	Tempest II	22,500	
Clariant Safewing 2001	LMD 2000 (A/S)	21,000	
Clariant Safewing 2001	LMD 2000	23,000	

[1] A/S indicates air sleeve inserted
[2] Range provided by the fluid manufacturer. Winter 2005-06 values given
[3] Numbers are not provided for Dow UCAR Ultra+ because the fluid delivered was not in the requested viscosity range

It should be noted that the bottom of the Kilfrost ABC-S delivery range changed from 20,000 mPa.s to 25,000 mPa.s for the winter of 2005-06. The implications of this change are discussed in Subsection 4.1.5.

4.1.4 Acceptable Delivery Viscosity Ranges

The lower limit of the acceptable delivered viscosity range for each fluid and forced air system combination is the LADV or, if the LADV is below the lower limit of the standard delivery range, it is that value. The upper limit is the top of the standard delivery range. The acceptable delivery viscosity ranges for the tested fluids and forced air systems are given in Table 4.2.

Table 4.2: Acceptable Delivery Viscosity Ranges for use with Forced Air Systems

Fluid	**Forced Air System**[1]	**Standard Delivery Range** (mPa.s)	**Forced Air Delivery Range** (mPa.s)
Kilfrost ABC-S	Tempest II (A/S)	25,000 to 30,000	25,000 to 30,000
Kilfrost ABC-S	Tempest II		25,000 to 30,000
Kilfrost ABC-S	LMD 2000 (A/S)		25,000 to 30,000
Kilfrost ABC-S	LMD 2000		25,000 to 30,000
Dow/UCAR Ultra+	Tempest II (A/S)	40,000 to 53,000	-[2]
Dow/UCAR Ultra+	Tempest II		-[2]
Dow/UCAR Ultra+	LMD 2000 (A/S)		-[2]
Dow/UCAR Ultra+	LMD 2000		-[2]
Octagon Max-Flight 04	Tempest II (A/S)	7,000 to 12,000	8,500 to 12,000
Octagon Max-Flight 04	Tempest II		8,500 to 12,000
Octagon Max-Flight 04	LMD 2000 (A/S)		7,500 to 12,000
Octagon Max-Flight 04	LMD 2000		7,500 to 12,000
Clariant Safewing 2001	Tempest II (A/S)	20,000 to 30,000	22,000 to 30,000
Clariant Safewing 2001	Tempest II		22,500 to 30,000
Clariant Safewing 2001	LMD 2000 (A/S)		21,000 to 30,000
Clariant Safewing 2001	LMD 2000		23,000 to 30,000

[1] A/S indicates air sleeve inserted

[2] Numbers are not provided for Dow UCAR Ultra+ because the fluid delivered was not in the requested viscosity range

In summary, if Octagon Max-Flight 04 and Clariant Safewing 2001 are used with the tested forced air systems, delivered fluids cannot be accepted if they are at the bottom of their standard delivery ranges. There are no limitations when accepting Kilfrost ABC-S for use with the tested forced air systems.

The LADV analysis was not completed for Dow UCAR Ultra+, as the test sample did not meet the criteria set out in the test protocol (see Subsection 3.2). However, it should be noted that when this fluid was applied using the TII deicing truck, the fluid viscosity increased. This was the only fluid/truck combination to achieve this result. When Dow UCAR Ultra+ was applied using the LMD deicing truck, it experienced the smallest percentage decrease (~5 percent) of any of the other fluids in either of the deicing trucks. These results are likely a result of the fluid chemistry: Ultra+ was the only ethylene glycol fluid tested.

4.1.5 Implication of Kilfrost ABC-S Viscosity Delivery Range Change

Following the FedEx forced air test session in January 2005, Kilfrost announced the lower limit of the viscosity delivery range for ABC-S would change from 20,000 mPa.s to 25,000 mPa.s for the winter 2005-06 season. This had positive implications for forced air usage because the LADV for ABC-S was below 25,000 mPa.s for all of the forced air systems tested and therefore FedEx would have no viscosity restrictions when using Kilfrost ABC-S with forced air deicing systems.

However, the validity of the ABC-S test results came into question as a result of the change made to the viscosity delivery range. The test protocol stipulates that forced air testing must be conducted with fluid samples with an initial viscosity in the middle of the viscosity delivery range. Since the ABC-S viscosity delivery range changed, it was possible the fluid samples that were tested were not in the middle of the new viscosity delivery range and therefore no longer met this requirement. Upon closer examination, however, it was found not to be an issue in this case.

One of the ABC-S samples submitted for testing in 2004-05 had a viscosity of approximately 27,000 mPa.s. This sample was accepted as being in the middle of the old viscosity delivery range (20,000 to 30,000 mPa.s) even though it was several thousand mPa.s above the midpoint. Some leniency was given with the viscosity requirement because it is difficult to produce a fluid with an exact viscosity value, and because viscosity often changes somewhat during shipment from the production facility to the customer. A similar sample was accepted for Clariant Safewing 2001.

Coincidently, the 27,000 mPa.s sample falls in the middle of the new ABC-S viscosity delivery range (25,000 to 30,000 mPa.s) and therefore would easily have been accepted for testing if the new viscosity delivery range was considered during the sample acceptance phase.

The second ABC-S sample had a viscosity of approximately 25,000 mPa.s, which is in the middle of the old ABC-S delivery range, but at the lower end of the new delivery range. The concern with testing a sample at the lower end of the viscosity range is that if a sample with a higher viscosity is actually used, a larger percentage decrease in viscosity may occur with an application (previous research has shown that higher viscosity fluids are more susceptible to shearing during application) bringing the viscosity below the LOWV.

Of the two forced air tests conducted with this sample, the largest viscosity decrease was 22 percent. Hypothetically, if a fluid with a viscosity of 27,750 mPa.s were tested and its viscosity decreased by 30 percent (an unlikely result considering the 27,000 mPa.s sample decreased by only 19 percent) the on-wing sample would have a viscosity of 19,250 mPa.s. This is still above the LOWV value (17,000 mPa.s) and would result in a LADV (24,500 mPa.s) still low enough to accept the fluid for use with forced air with no restrictions on delivered viscosity.

Retesting Kilfrost ABC-S is therefore not required nor recommended.

4.2 Comparison of Tempest II and LMD 2000 Deicing Trucks

There were differences in viscosities of fluids applied with the TII and the LMD deicing trucks. However, one was not consistently lower than the other. The relative results are shown in Table 4.3.

Table 4.3: Decrease in Viscosity of Fluids Applied with Tempest II and LMD 2000 Deicing Trucks

Fluid (With or Without Air Sleeve)	Tempest II	LMD 2000	Difference
Kilfrost ABC-S (Without)	-19%	-22%	-3%
Octagon Max-Flight 04 (Without)	-33%	-24%	9%
Clariant Safewing 2001 (Without)	-20%	-21%	-1%
Kilfrost ABC-S (With)	-19%	-16%	2%
Octagon Max-Flight 04 (With)	-35%	-25%	10%
Clariant Safewing 2001 (With)	-18%	-14%	4%

4.3 Effect of Air Sleeve

The addition of an air sleeve does not appear to have a significant influence on fluid viscosity (see Table 4.4 below).

Table 4.4: Decrease in Viscosity of Fluids Applied with and without Air Sleeve

Fluid (Deicing Truck)	With A/S	Without A/S	Difference
Kilfrost ABC-S (TII)	-19%	-19%	1%
Octagon Max-Flight 04 (TII)	-35%	-33%	-2%
Clariant Safewing 2001 (TII)	-18%	-20%	2%
Kilfrost ABC-S (LMD)	-16%	-22%	6%
Octagon Max-Flight 04 (LMD)	-25%	-24%	-1%
Clariant Safewing 2001 (LMD)	-14%	-21%	7%

5. CONCLUSIONS

5.1 Procedure

A new procedure was developed for testing forced air systems with Type II/IV fluids in 2004-05. The two major changes made to the procedure used in 2003-04 were: the requirement to conduct pre-tests to fix the equipment setup, and changing the acceptance criteria (from the comparison of forced air viscosities to conventional viscosities, to calculating the LADV).

The pre-tests to fix the equipment setup proved to be a necessary and valuable step in the procedure. In addition to ensuring that the results achieved during the test session are applicable to actual operations, the pre-tests also help the operator determine an appropriate setup prior to the actual test session.

Comparing the viscosity of fluids applied with forced air to the LOWV seems to be a reasonable approach for evaluating forced air systems. The LADV can be calculated by applying the formula that was developed, and gives operators an easy way of determining whether a batch of fluid can be used with their forced air systems.

5.2 Fluid Acceptance

The acceptance of the tested fluids for use with forced air systems is fluid dependent.

a) Kilfrost ABC-S can be accepted for use with both the TII and LMD deicing trucks, with or without the air sleeve. The acceptable viscosity of fluid delivered for forced air systems is the same as that of conventional systems.

b) Octagon Max-Flight 04 can be accepted for use with both the TII and LMD deicing trucks, with or without the air sleeve. However, the minimum acceptable viscosity of delivered fluids is higher than that of fluids accepted for use with conventional systems. The LADV of Octagon Max-Flight 04 is deicing truck dependent.

- TII: 8,500 mPa.s
- LMD: 7,500 mPa.s

c) Clariant Safewing 2001 can be accepted for use with both the TII and LMD deicing trucks, with or without the air sleeve. However, the minimum acceptable viscosity of delivered fluids is higher than that of fluids accepted for use with conventional systems. The LADV of Clariant Safewing 2001 is forced air system dependent.

- TII with air sleeve: 22,000 mPa.s
- TII without air sleeve: 22,500 mPa.s
- LMD with air sleeve: 21,000 mPa.s
- LMD without air sleeve: 23,000 mPa.s

d) Dow UCAR Ultra+ cannot be accepted for use with forced air systems since the manufacturer provided fluid that did not conform to the test protocol requirements.

5.3 Other Observations

In addition, it was observed that:

a) The presence of an air sleeve does not have a significant impact on the change in viscosity caused by forced air application; and

b) Although there are minor differences in the impact that the TII and LMD deicing trucks have on fluid viscosity, neither truck consistently causes more degradation to fluid viscosity than the other.

6. RECOMMENDATIONS

It is recommended that regulatory bodies continue to be involved in forced air evaluations and be present at test sessions. A laboratory such as APS should continue to act as an independent lab.

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REFERENCES

1. Dawson, P., *Safety Issues and Concerns of Forced Air Deicing Systems*, APS Aviation Inc., Transportation Development Centre, Montreal, November 2000, TP 13664E, 100.

2. Bendickson, S., *A Protocol for Testing Fluids Applied with Forced Air Systems,* APS Aviation Inc., Transportation Development Centre, Montreal, October 2004, TP 14380E, XX (to be published).

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2003-05

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2003-05

6.8 Forced Air System Evaluation

a) Continue to assist the SAE ground equipment committee in its evaluation of forced air-assisted systems;

b) Subject to approval by TC on a case-by-case basis:

- Monitor and participate in some operator field tests of air-assisted Type II/IV fluids, and report on observations; and
- Monitor and participate in some operator field tests of air-assisted Type I fluid as a first-step procedure.

c) Support the SAE ground equipment committee development of an SAE ARP for forced air deicing systems.

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APPENDIX B

TEST PROCEDURES

- Procedure: Test Program – Forced Air Systems Type II/III/IV Fluid Applied Over the Forced Air Stream
- Procedure: Test Program – Viscosity Tests of Fluids Applied with FedEX Forced Air Systems

PROCEDURE:
TEST PROGRAM – FORCED AIR SYSTEMS TYPE II/III/IV FLUID APPLIED OVER THE FORCED AIR STREAM

CM1892.001 (04-05)

TEST PROGRAM – FORCED AIR SYSTEMS

TYPE II/III/IV FLUID *APPLIED OVER* THE FORCED AIR STREAM

Prepared for:

Federal Aviation Administration
Flight Safety Branch

Transport Canada
Transportation Development Centre

SAE G-12 Equipment Subcommittee
Forced Air Working Group

Prepared by: for Peter Dawson

Reviewed by: John D'Avirro

APS Aviation Inc.

January 20, 2005
Version 4.0

TEST PROGRAM – FORCED AIR SYSTEMS TYPE II/III/IV FLUID APPLIED OVER THE FORCED AIR STREAM

1. OBJECTIVE

These tests are designed to examine whether published holdover time guidelines (HOT) can be approved for use when Type II/III/IV fluid is applied to aircraft surfaces with the assistance of forced air systems.

In the forced air systems currently in operation, the nature of the assistance typically can take either of two modes:

- The fluid nozzle can be positioned above the forced air nozzle, with the goal of carrying the fluid stream on top of the air stream. This method is normally referred to as the air-assist mode.
- The fluid nozzle can be positioned to inject fluid within the air stream, where the fluid is mixed with, and carried as part of the air stream. This method is normally referred to as the fluid injection mode.

Tests to date have indicated that the fluid injection mode seriously degrades fluid viscosity and does not produce results that support use of HOT guidelines, thus this test procedure applies only to the fluid-over-air mode of application.

In this test, the viscosity of the air-assisted fluid application is to be measured and submitted to the regulatory authorities for a decision on whether published holdover time guidelines can be used for the air-assisted fluid application. The decision is based on a comparison of the viscosity of the air-assisted fluid with the fluid manufacturer's value for lowest-on-wing-viscosity (LOWV). Conventional spray applications are not examined in this procedure, since in prior investigation, it has been shown that conventional application of anti-icing fluids using proper equipments and techniques provide fluids on the aircrafts surfaces whose viscosities exceed the LOWVs.

This test may follow joint research efforts by the equipment operator and the equipment manufacturer to determine the specific equipment configuration that produces the best air-assisted fluid application. The resulting configuration will be documented and the fluid viscosity test will be conducted with equipment configured to that specification.

This test procedure supersedes previous versions of the test procedures provided to the SAE G-12 Ground Equipment subcommittee. The principal changes are:

- The decision criteria are now based on comparison of the air-assisted fluid viscosity to the test fluid's lowest on-wing viscosity, rather than to results from conventional application. Conventional applications are not measured in this test. A formula is used to derive the lowest delivered fluid viscosity acceptable for use with HOT guidelines from the test data.
- The previous version of the test procedure included an activity wherein the quality of fluid distribution over the sprayed wing was examined. Because that activity was voluntary on the part of the operator and not included in the approval process, it has been removed. The fluid film thickness when applied to the wing will be measured.

2. GENERAL

Each combination of forced air deicing truck configuration and SAE Type II/III/IV fluid requires individual approval for use of HOT guidelines. The following steps are involved in the approval process:

1. The operator coordinates a test session, inviting representatives from the FAA Technical Center, Transport Canada (TDC), forced air equipment manufacturer and APS Aviation.
2. Fluid manufacturers may be invited to observe with the stipulation that their access to test results will be limited to their own fluid.
3. Test data will be restricted until the FAA Technical Center and Transport Canada (TDC) conduct a peer review to ensure its validity.
4. APS Aviation will conduct the fluid viscosity measurement at the test site, in accordance with established test procedures. Viscosity test of fluids will include: viscosity of the fluid as delivered in the tote and/or the truck tank, and viscosity of the fluid recovered from the aircraft wing, following centrifuging. Advice on the number of fluids and forced air trucks to be tested will be needed in order to estimate the overall duration of testing.
5. APS Aviation will be responsible for assembling and reporting on the data, and presenting results at subsequent SAE G-12 meetings.
6. The manufacturer or operator's maintenance staff will verify that the forced air systems planned for use in testing are operating within manufacturer specifications.
7. The ambient temperature for the test must be below freezing. Dry conditions are needed.

8. Tests are to be conducted on aircraft wing surfaces, not substitute surfaces.
9. The test involves applying fluid onto the wing, lifting a fluid sample, and measuring its aeration and viscosity.
10. Viscosities of fluid samples from the truck tank and storage tank or tote are measured.
11. APS Aviation will assemble and submit the results to the following FAA/TC addressees to be considered for approval to use Type II/III/IV published HOT guidelines, for that specific truck/fluid combination.

Warren M. Underwood Aerospace Engineer, Flight Safety Research FAA Technical Center Building 210 AAR 470 Atlantic City International Airport Atlantic City, NJ 08405 USA Warren.Underwood@faa.gov	Barry Myers Senior Development Officer Transport Canada Transportation Development Centre 800 René-Lévesque Blvd. West, 6th Floor Montréal, Québec H3B 1X9 Canada myersbb@tc.gc.ca

3. TEST CONDITIONS

3.1 Weather Conditions

These tests are performed in dry conditions preferably at below freezing temperatures.

3.2 Test Surface

Tests are to be conducted on a dry wing surface.

3.3 Test Fluid

Fluid for testing is to be delivered with a viscosity at the mid-point of the manufacturer's standard production range, ± 10%. The equipment operator will request fluid for test from the fluid manufacturer, specifying absolute values for the highest and lowest viscosity acceptable for the test.

The viscosities of the fluids delivered for testing will be measured at the beginning of the test session. If a fluid has a viscosity beyond the range requested, the regulatory authorities will be advised so they can rule on its acceptability for test, with consideration of potential inter-laboratory measurement errors. Because sprayed fluid viscosity degradation has been seen to be reduced at lower initial viscosities, variations in delivered fluid viscosity in that direction are more serious as they may produce optimistic results.

The viscosity of the fluid, when it passes through the nozzle and is sheared, can be influenced by the fluid temperature. The fluid shall be maintained at a temperature of -5°C, in advance of the testing.

Care must be taken to ensure that there is no residue of Type I fluid on the test wing, as this will result in mixing of Type I within the Type II/III/IV fluid, producing inaccurate viscosity measurements.

The following procedure will avoid this risk:

1. Flush the tested Type II/III/IV fluid from the wing surface with a spray of Type I fluid. Forced air can be used to assist in this process.
2. Apply a coating of the next fluid scheduled for test.
3. Remove that fluid with squeegees.
4. Conduct the air-assist test with the next fluid.

If an out-of-service aircraft is used for testing, the final cleaning of test fluid from the wing following the last test is to be performed with heated Type I fluid, prior to returning the aircraft to service.

Similarly, care must be taken to avoid contamination in the truck tank when changing over from one test fluid to another. The following procedure has been used successfully to avoid this risk:

1. Empty the tank entirely.
2. Partially fill the tank with water. Drive the truck in a pattern that will cause the water to splash about within the tank. Drain the water.
3. Partially fill the tank with the new test fluid. Drain the fluid.
4. Fill the tank with the quantity needed of the new test fluid, and conduct the test.

3.4 Configuration of Forced Air System

The configuration of the forced air systems used for testing must be in accordance with manufacturer's specifications and pre-programmed for the requisite airflow velocity and pressure. If the airflow can be manually controlled by the operator, the test is to be conducted at maximum airflow.

The operating performance of forced air systems planned for use in these tests is to be checked prior to tests. This may be done by the manufacturer or by the operator's technical staff in accordance with manufacturer's guidelines. Certification that systems are operating within manufacturers specifications is required for each truck used in testing. A Declaration of Equipment Conformity (Attachment 1) is to be submitted for each combination of forced air deicing vehicle and fluid tested.

An operator signature verifies that deicing trucks used for tests have been checked to confirm that they operate in accordance with manufacturer's specifications. The specifications for the forced air system may be provided by completing the form, or by attaching a copy of the manufacturer's equipment description.

3.5 Test Matrix

A test matrix with estimated time lines will be developed by APS Aviation based on the number of fluids and trucks planned for test.

3.6 Test Equipment

A list of equipment needed to conduct the tests is provided in Attachment 2.

3.7 Data Form

One data form (Attachment 3 – Fluid Viscosity Data Form) is used for these tests.

4. TEST PROCEDURE

4.1 Fluid Temperature in Truck

The temperature of the fluid in the tank of the truck and out from the nozzle shall be measured.

4.2 Fluid Application

Fluid is to be applied with the nozzle positioned a nominal 3.0 m (10 ft) distant from the wing test area where the fluid sample is to be taken. The air-stream is to be at a 30° angle to the wing test surface. The wing surface will be marked to indicate where fluid is to be collected for test. As well, a line 2.7 m (8.7 ft) distant from the collection area will be marked directly underneath where the nozzle should be positioned, so only the nozzle height over wing (1.5 m or 5.0 ft) will need to be checked to ensure the correct geometry (see Figure 1). Fluid is to be applied with four sweeps (in one direction, then the other) across the test surface area. Do not sweep up and down to avoid increasing the angle of incidence above the specified 30°. At the end of the fourth sweep, direct the air/fluid stream off the edge of the wing away from the test area while shutting down.

4.3 Measuring Fluid Thickness

The fluid should be allowed to settle for at least 3 minutes, and the fluid thickness should be measured on the wing at the area where it is to be collected. Record the thickness on the fluid viscosity data form (Attachment 3).

Refer to Attachment 4 for equipment and procedures.

4.4 Collecting Fluid Samples

In preparation for collecting samples, the sample bottles will be labelled. Initial samples are required from the fluid tote and truck tanks, to serve as a reference base. The truck samples may be taken directly from the tank by dipping from the top, or from the bottom drain valve. If taken from the drain valve, fluid should be allowed to drain to completely flush the line before taking the sample.

To gather samples from the wing surface, fluid will be pulled together on the wing surface using flexible plastic sheets as scrapers. The accumulated fluid will be gathered onto one plastic sheet, and, by bending the plastic sheet, the lifted fluid will be poured into the sample bottle. Plastic dustpans are also suitable for fluid collection. Two people are needed for this activity. Alternatively, if the wing structure allows it, the fluid can be directed to the edge of the wing using the plastic dustpans, and then captured as it falls off.

4.4.1 Measuring Aeration

The volume of a container will be measured prior to testing. This container will become the designated aeration measurement container. To measure fluid aeration, the empty capped container will be weighed with a scale of suitable accuracy. The container will then be filled to overflowing with the sample fluid and capped. The weight of the container will be measured and recorded and the fluid density calculated based on the recorded weight of the capped empty bottle and its volume capacity.

4.4.2 Measuring Viscosity

All viscosity tests will be conducted using the small sample adapter. In cases where this differs from the fluid manufacturer method reported in HOT guidelines, the fluid manufacturer will be contacted to provide an alternative method using the small sample adapter.

Before measuring viscosity, fluid samples will be centrifuged until they are substantially free of trapped air bubbles. Centrifugation of 5 to 10 minutes at 3400 rpm is usually sufficient for this purpose. Consult the APS Aviation procedure *Instructions for Measuring Anti-Icing Fluid Viscosity Using the Brookfield DV-1 Viscometer* for detailed directions on viscometer usage.

5. APPROVAL CRITERIA

The decision on approving the truck/air Type II/III/IV fluid application for use of HOT Guidelines will be based on a comparison of the measured viscosity of the applied fluid with the LOWV for that fluid.

A formula will be applied to calculate the lowest delivered-fluid-viscosity acceptable for use with HOT guidelines. This formula will be based on the ratio of fluid viscosity reduction, applied to the LOWV.

a. **Lowest acceptable shipment viscosity for use of HOT = LOWV X $\frac{\text{Fluid viscosity in tote}}{\text{Air-assist test result}}$**

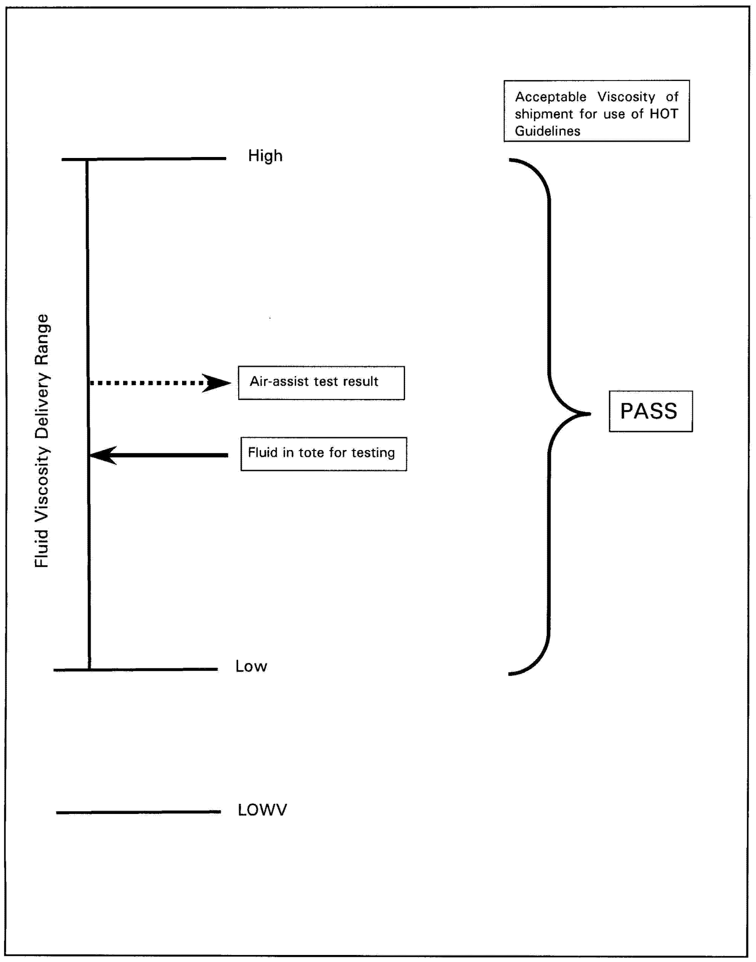
b. **The calculated value in a will be rounded up to the nearest even 500 cP.**

c. **The acceptable range of delivered fluid viscosity for use of HOT guidelines with air-assist will be from the high end of the manufacturers delivery range to the lowest viscosity derived from the formula in a and b.**

In general, three types of cases will occur, described as follows.

Case 1: ***Viscosity of tested fluid is greater than that delivered***. In this case, all fluid within the manufacturer's fluid delivery range will be deemed acceptable for air-assist application with the tested truck. This is shown graphically in the following schematic.

SCHEMATIC OF VISCOSITY FOR CASE 1



Case 2: Viscosity of tested fluid is less than that delivered, but greater than LOWV. In this case, fluids delivered with a viscosity above the test fluid's delivered viscosity will be deemed acceptable for air-assist application with the tested truck. The formula will be applied to calculate the lowest delivered-fluid-viscosity acceptable. An example follows.

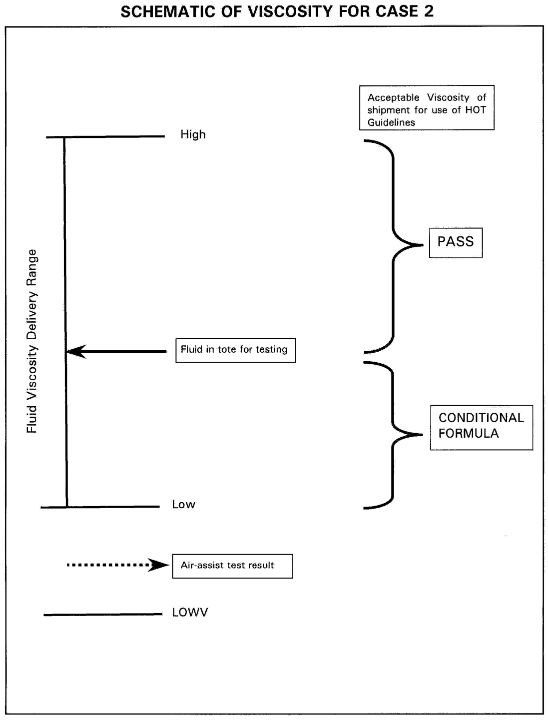
Manufacturer range	Hi end	20 000 cP
	Lo end	10 000 cP
Fluid in tote		15 000 cP
Test result		9 000 cP
Fluid LOWV		7 600 cP

Lowest delivered fluid viscosity acceptable for use of HOT:

= LOWV X (Fluid in tote/air-assist test result)
= 7 600 X (15 000/9 000)
= 12 667 cP

Rounding up to the next 500 cP increment gives 13 000 cP. The acceptable fluid viscosity range for use of HOT Guidelines is from 20 000 to 13 000 cP.

SCHEMATIC OF VISCOSITY FOR CASE 2



Case 3: Viscosity of tested fluid is less than LOWV. In this case, the formula will be applied to calculate the lowest delivered-fluid-viscosity acceptable. An example follows.

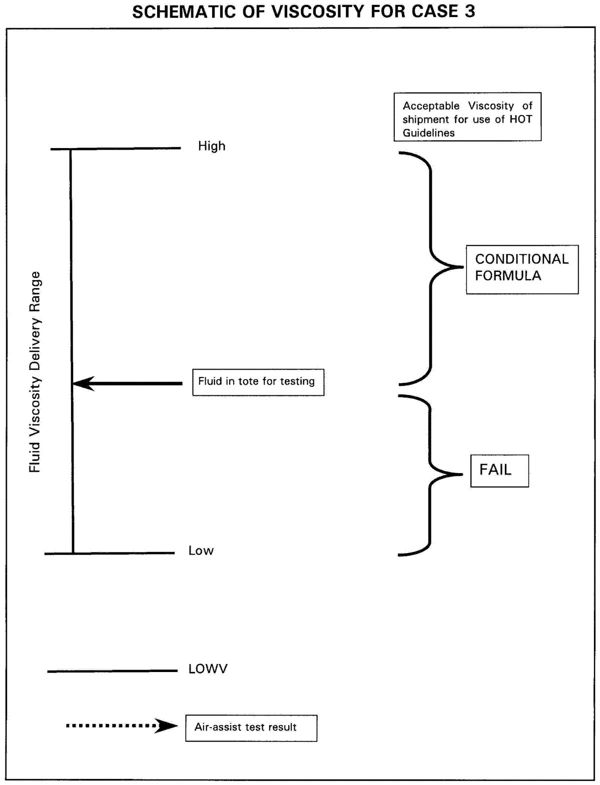
Manufacturer range	Hi end	20 000 cP
	Lo end	10 000 cP
Fluid in tote		15 000 cP
Test result		6 500 cP
Fluid LOWV		7 600 cP

Lowest delivered fluid viscosity acceptable for use of HOT:

= LOWV X (Fluid in tote/air-assist test result)
= 7 600 X (15 000 / 6 500)
= 17 538 cP

Rounding up to the next 500 cP increment gives 18 000 cP. The acceptable fluid viscosity range for use of HOT Guidelines is from 20 000 to 18 000 cP.

SCHEMATIC OF VISCOSITY FOR CASE 3



ATTACHMENT 1: SAE G-12 EQUIPMENT SUBCOMMITTEE TYPE II/III/IV FLUID WITH AIR ASSIST DECLARATION OF EQUIPMENT CONFORMITY

(Complete One Per Test Session For Each Truck/Fluid Combination)

OPERATOR ________________ LOCATION ____________________ DATE ___________________

FLUID MANUFACTURER AND TYPE ____

TRUCK MANUFACTURER AND TYPE ____

TRUCK SERIAL NUMBER (S) ____

VERTICAL DISTANCE BETWEEN FLUID AND AIR NOZZLES ______________________________

FLUID NOZZLE TYPE ________________________

FLUID PRESSURE __________________________ AIR PRESSURE __________________________

FLUID FLOW RATE _________________________ AIR FLOW RATE __________________________

(Operator verifies that deicing trucks used for these tests have been checked to confirm operation in accordance with manufacturer's specifications. System specifications can be provided by completion of the following or by submission of the manufacturer's system description.)

OPERATOR REPRESENTATIVE NAME (BLOCK LETTERS), SIGNATURE AND TELEPHONE

______________________________ ___________________________ ___________________________

ATTACHMENT 2: TEST EQUIPMENT CHECKLIST

Test Equipment	**Status**
Test procedures	
Data Forms	
Clipboards	
Pencils	
Wiper rags	
Fluid sample containers with labels	
Plastic or apparatus to lift fluid samples from wing	
Viscometer equipment, including centrifuge and syringe	
Weigh Scale	
Temperature probe	
Duct Tape	
Funnels	
Marker for wing surface	
Thickness gauges	
Test Site Requirements	
Level Table(s) (minimum 1.8 by 0.75 m (6 feet by 2.5 feet))	
Chair	
Electricity	
Hot Water	
Heated Room (20°C), if possible	
Nighttime Facility Access	

ATTACHMENT 3: SAE G-12 EQUIPMENT SUBCOMMITTEE FLUID VISCOSITY – DATA FORM

TEST DETAILS:

Sample # ______

Operator: ______ Location: ______

Truck Type: ______ Truck Serial #: ______

Fluid Brand: ______ Fluid Name: ______

Fluid Type: I II III IV Fluid Dilution: 100% 75% 50%

Sample: ❒ Tote ❒ Truck ❒ On-Wing Time of Application: ______

AIR ASSIST SETUP:

Fluid Flow (gpm) ______ Air Flow (psi) ______ Nozzle Position ______

Other (airsleeve, etc): ______

FLUID CHARACTERISTICS:

Temp. (in Truck): ______ Temp. (Nozzle): ______

Thickness: ______ Density: ______

VISCOSITY MEASUREMENT:

Time of Measurement: ______ Viscosity: ______

Measurement Method: ______

COMMENTS:

______

Technician: ______ OAT: ______ Date: ______

M:\Groups\CM1892 (TC-Deicing 04-05)\Procedures\Forced Air Assist\SAE Procedure\Working Documents\Data Form

ATTACHMENT 4: MEASURING FLUID FILM THICKNESS

Fluid thickness can be measured with use of a wet film thickness gauge. Two types are recommended as follows.

The Octagon wet film thickness gage ranges from 0.4 to 400 mils. It is available with a micron scale on the reverse side. This gauge is suitable for normal on-wing thickness for Type II / Type IV fluid. Part number WF-OCT.

The second gauge is a standard stock gage ranging from 1 to 80 mil. This gauge gives better accuracy for thinner films, such as seen with Type I fluid on wings, or thinner applications of Type II / Type IV fluid. Part number WF-CCA.

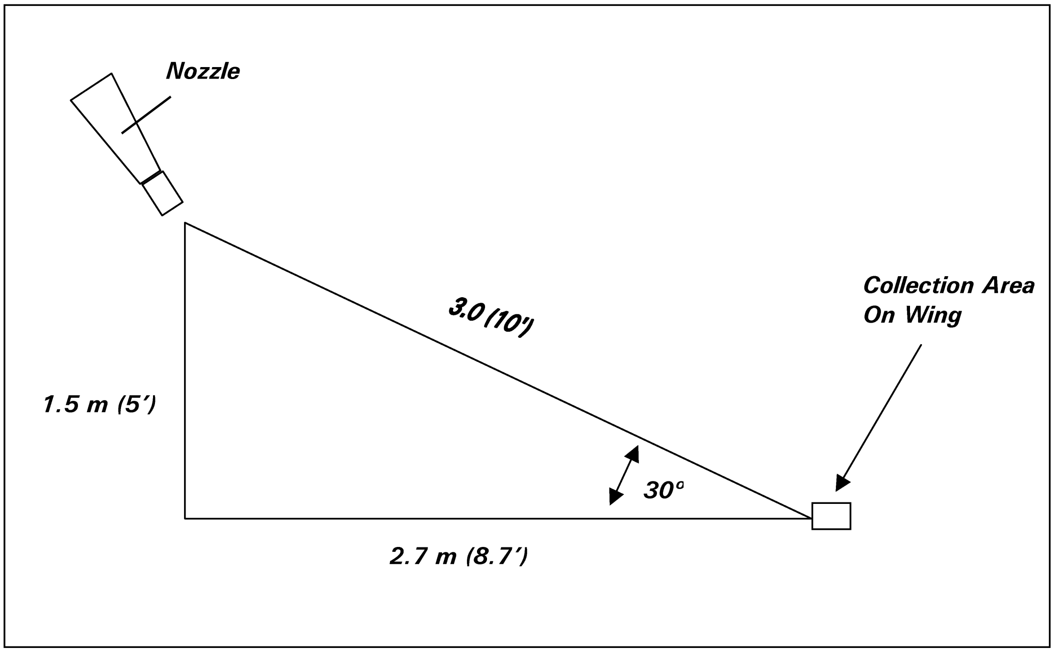
Both gauges are available from:

Paul N. Gardner Company, Inc.
316 NE 1st St. POMPANO BEACH, Fl 33060
1-800-762-2478 (954) 946-9454 FAX (954) 946-9309

Instructions for Use

1. Place the gauge in the fluid at 90º to the underlying surface, selecting the gauge side that allows a tooth to touch the fluid surface.
2. Note the last tooth that is wetted. This can be done by withdrawing the gauge and observing which is the last tooth wetted, or by peering under the gauge while inserted in the fluid, noting which is the last tooth touching the fluid surface. With clear fluid, the latter method usually works better.
3. Record the value of the last tooth wetted.
4. Dry the gauge before next use.
5. If repeat measurements are taken, ensure that the gauge is slightly offset from the previously measured location as the fluid surface may still be indented from the earlier measure.

FIGURE 1: POSITIONING OF NOZZLE AND WING



PROCEDURE:
TEST PROGRAM – VISCOSITY TESTS OF FLUIDS APPLIED WITH FEDEX FORCED AIR SYSTEMS

CM1892.001 (04-05)

TEST PROGRAM – VISCOSITY TESTS OF FLUIDS APPLIED WITH FEDEX FORCED AIR SYSTEMS

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Stephanie Bendickson

Reviewed by: John D'Avirro

APS Aviation Inc.

Version 1.0
January 20, 2005

TEST PROGRAM: VISCOSITY OF FLUIDS APPLIED WITH FEDEX FORCED AIR SYSTEMS

Winter 2004-05

1. OBJECTIVE

These tests are being conducted to assess whether published holdover time guidelines (HOT) can be approved for use when Type IV fluid is applied to aircraft surfaces with the assistance of FedEx forced air systems.

The tests will examine the extent to which fluid viscosity is affected by air-assisted fluid application. Fluid viscosity data generated by these tests will form the basis of the request for approval to use holdover times for air-assisted Type IV Fluid applications. The approval criteria and the detailed test procedure are given in the SAE document entitled "Test Program – Forced Air Systems, Type II/III/IV Fluid Applied over the Forced Air Stream".

2. PROCEDURE

The procedure for the conduct of these tests is described in the SAE document mentioned above. The SAE document gives a generic procedure that must be used by any operator wanting air assist equipment approved for use with Type II,III or IV fluids. As per Section 3.5 of the SAE document, APS Aviation has prepared this document to provide the test matrix and test session specific details for the FedEx test session in January 2005.

2.1 Location

Tests will be conducted at the FedEx facilities at the Pittsburgh International Airport in Pittsburgh, Pennsylvania. In case of precipitation during the test session, fluid application will take place inside the FedEx hangar.

An equipment room within the hangar will be used as a laboratory for the viscosity tests. Access to the lab, and to test results, will be limited as required in the SAE procedure.

2.2 Deicing Trucks

Two deicing trucks will be tested: the FMC Tempest II and the FMC LMD 2000.

2.3 Fluids

Four fluids will be tested: Clariant Safewing MP IV 2001, Octagon Max-Flight, Kilfrost ABC-S and UCAR Ultra+.

2.4 Test Matrix

The test matrix is shown in Attachment I. The truck tank samples will be considered lower priority than the other samples and will be tested when time permits.

2.5 Viscosity Measurement Methods

As per the SAE procedure, only small sample adaptor viscosity measurement methods will be used. Kilfrost and Octagon fluids will therefore be measured the following alternate methods (given to APS by the manufacturers), as their standard methods do not use the small sample adaptor:

- Octagon: Spindle SC4-34/13R, small sample adapter, 10 mL, 20°C, 0.3 rpm, 10 minutes.
- Kilfrost: Spindle SC4-31/13R, small sample adapter, 10 mL, 20°C, 0.3 rpm, 10 minutes.

2.6 Personnel

Three personnel are required. The Project Leader (JD) will coordinate tests and collect samples and Tester 1 (SB) and Tester 2 (SC) will run the viscometers and help with sample collection if required.

3. DATA FORMS

The required data forms are given in the SAE procedure.

ATTACHMENT 1: TEST PLAN

Test	Date	Fluid	Truck	Sample	Viscosity (mPa.s)
1	01/24	Kilfrost ABC-S	N/A	Tote	
2	01/24	Kilfrost ABC-S	FMC LMD 2000	Truck Tank	
3	01/24	Kilfrost ABC-S	FMC LMD 2000	Air	
4	01/24	Kilfrost ABC-S	FMC LMD 2000	Air (Sleeve)	
5	01/24	Kilfrost ABC-S	FMC Tempest II	Truck Tank	
6	01/24	Kilfrost ABC-S	FMC Tempest II	Air	
7	01/24	Kilfrost ABC-S	FMC Tempest II	Air (Sleeve)	

Test	Date	Fluid	Truck	Sample	Viscosity (mPa.s)
8	01/25	UCAR Ultra+	N/A	Tote	
9	01/25	UCAR Ultra+	FMC LMD 2000	Truck Tank	
10	01/25	UCAR Ultra+	FMC LMD 2000	Air	
11	01/25	UCAR Ultra+	FMC LMD 2000	Air (Sleeve)	
12	01/25	UCAR Ultra+	FMC Tempest II	Truck Tank	
13	01/25	UCAR Ultra+	FMC Tempest II	Air	
14	01/25	UCAR Ultra+	FMC Tempest II	Air (Sleeve)	

Test	Date	Fluid	Truck	Sample	Viscosity (mPa.s)
15	01/25	Octagon Max-Flight	N/A	Tote	
16	01/25	Octagon Max-Flight	FMC LMD 2000	Truck Tank	
17	01/25	Octagon Max-Flight	FMC LMD 2000	Air	
18	01/25	Octagon Max-Flight	FMC LMD 2000	Air (Sleeve)	
19	01/25	Octagon Max-Flight	FMC Tempest II	Truck Tank	
20	01/25	Octagon Max-Flight	FMC Tempest II	Air	
21	01/25	Octagon Max-Flight	FMC Tempest II	Air (Sleeve)	

ATTACHMENT 1: TEST PLAN (cont'd)

Test	Date	Fluid	Truck	Sample	Viscosity (mPa.s)
22	01/26	Clariant Safewing 2001	N/A	Tote	
23	01/26	Clariant Safewing 2001	FMC LMD 2000	Truck Tank	
24	01/26	Clariant Safewing 2001	FMC LMD 2000	Air	
25	01/26	Clariant Safewing 2001	FMC LMD 2000	Air (Sleeve)	
26	01/26	Clariant Safewing 2001	FMC Tempest II	Truck Tank	
27	01/26	Clariant Safewing 2001	FMC Tempest II	Air	
28	01/26	Clariant Safewing 2001	FMC Tempest II	Air (Sleeve)	

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APPENDIX C

FLUID MANUFACTURER FLUID CERTIFICATES OF ANALYSIS

CERTIFICATE OF ANALYSIS: KILFROST ABC-S

CRYOTECH Deicing Technology

CERTIFICATE OF ANALYSIS

PRODUCT DESCRIPTION: Kilfrost ABC-S, Type IV Fluid

SPECIFICATION NO. Current Revision of AMS 1428, Type IV Fluid

LOT REFERENCE 13564

TANK REFERENCE V 200

CRYOTECH B/L NO. X

RAILCAR NO. X

ACTUAL GAL. SHIPPED X

CUSTOMER B/L NO. 23509

CUSTOMER P.O. NO. Forced Air Test

ACTUAL GAL. SHIPPED 1590 gal

TEST		INSPECTION REQUIREMENTS	RESULT
Appearance		Clear, green fluid	Clear, green fluid
pH value		6.50 – 7.50	7.1
Refractive Index (20°C)		1.3900 – 1.3930	1.3918
Viscosity, mPa.s (20°C)			
0.3 rpm	(a)	20,000 – 30,000	26750
6 rpm	(b)	2,300 – 3,300	2790
30 rpm	(b)	850 – 1,300	1087

(a) Brookfield LVT using Spindle No. 2.
(b) Informational

The results of this inspection schedule show that the material is satisfactory and meets current SAE specifications. Also attached is a Material Safety Data Sheet for your files.

Signed Melissa Hottkamp

Position Chemist

For and on behalf of Cryotech Deicing Technology

Date December 29, 2004

6103 ORTHOWAY, FORT MADISON, IA 52627-9415 PHONE: (319) 372-6012 (800) 346-7237 FAX: (319) 372-2662
SHIPPING ADDRESS: 6103 ORTHOWAY, FORT MADISON, IA 52627-9415
E-MAIL: deicers@cryotech.com http://www.cryotech.com

CERTIFICATE OF ANALYSIS: DOW UCAR ULTRA+

Certificate 2335660 The Dow Chemical Company Page 1

Date: 01/19/2005 Certificate of Analysis Shipped: 01/12/2005

FILE COPY
FEDEX Fax: COA ARCHIVE
CARGO BLDG 2
PITTSBURGH INTL AIRPORT PA 15231-0000 UNITED STATES

Cust P.O.: FEDEX/FRANKS S/412-472-8190 Dlvy Note: 60167254 10
Cust Ref: Order No.: 08545690

Material: UCAR(TM) Aircraft Deicing/Anti-Icing
Fluid ULTRA+ SAE/ISO Type IV Fluid Spec: 00129420-S
Cust Mtl:

Batch: TA1001GK01
Orig. Batch:

Dlvy Qty:TE 2
Vehicle: JEVIC 9456
Ship from: THE DOW CHEMICAL COMPANY CHICAGO IL UNITED STATES

This material meets the requirements of the specification.

Feature	Units	Results TA1001GK01	Limits Minimum	Limits Maximum	Method
Sp. Grav. @ 20/20C	-	1.086	1.075	1.095	1B-11A-0.47
Viscosity	cPs	41,591	----	----	1B-11A-0.49
Appearance		Passes			1B-11A-0.35
pH at 25degC	-	8.8	8.5	9.5	1B-11A-0.21
Refractive Index	Pbrix	39.3	38.0	41.0	1B-11A-0.48
Refractive Index	-	1.3983	1.3958	1.4016	1B-70U12.19-1.1

Quality Coordinator
Biocides

For inquiries please contact Customer Service or local sales.
English: 800-232-2436 French: 800-565-1255

CERTIFICATE OF ANALYSIS: OCTAGON MAX FLIGHT 04

OCTAGON

OCTAGON PROCESS, INC.
596 River Road
Edgewater, NJ 07020
Phone: (201) 945-9400
Fax: (201) 945-1203

CERTIFICATE OF ANALYSIS

Product Name: **MAX FLIGHT 04**

Specification: **SAE / AMS 1428 TYPE IV ANTI-ICING FLUID - PROPYLENE GLYCOL BASED**

Lot #: F-21571-U   Quantity: 18,000 gallons   Location: Eddie Tank   Origin: OPI

Test Description		Production Range	Test Result	Test Method
APPEARANCE:		Clear to Hazy Green Liquid. Free of Undissolved Matter.	Pass	VISUAL
REFRACTIVE INDEX @ 20° C:		1.3900 – 1.3935	1.3919	ASTM D-1747
pH @ 25° C:		7.00 – 7.50	7.16	ASTM E-70
VISCOSITY @ 20° C: Sp#1	0.3 rpm	7,000 – 12,000 mPa·s	11,800 mPa·s	ASTM D-2196
Spindle # 2	6 rpm	Report	1,725 mPa·s	ASTM D-2196
	30 rpm	Report	740 mPa·s	ASTM D-2196

CERTIFIED BY: [signature]

TITLE: Q.C. Chemist   DATE: 1/6/05

NOTE : FOR FLUID ACCEPTANCE AT RECEIVING STATIONS WHERE A HAND HELD REFRACTOMETER IS USED, ACCEPT FLUID IF IN FOLLOWING RANGES:

(a) MISCO 10431 (Soft vinyl case)	34.50 to 37.00 (BRIX)
(b) MISCO 10431VP (Hard plastic case)	34.50 to 37.50 (BRIX)
(c) MISCO 7084 (Red)	-38°F to -42°F (PG scale)
(d) MISCO 7084VP (Orange)	-28°F to -32°F (PG scale)
(e) MISCO 7064VP (Orange)	-32°C to -36°C (PG scale)

Ship to: ____________________   Ship Date: ____________

____________________   Bill of Lading #: ____________

____________________   Customer P.O. #: ____________

Ship Quantity : ____________________   Order #: ____________

11/2004

CERTIFICATE OF ANALYSIS: CLARIANT SAFEWING MP IV 2001

-----Original Message-----
From: Bryan.McCreary@clariant.com [mailto:Bryan.McCreary@clariant.com]
Sent: Friday, January 28, 2005 4:20 PM
To: D'Avirro, John
Subject: Re: Request for Fluid Information_Forced Air tests in Pittsburgh

John,

The viscosity for FEDEX Tote#1 run at Mount Holly was: 27,380 cps with Brookfield at 0.3 rpm, 20C. with an RI Value of 1.3905. Of course the name is "Safewing MP IV 2001". I do not have a Certificate on analysis
or batch # at this time, since the material which we tested came from FedEx
out of teheir spray trucks.

Let me know if you need anything else.

Bryan