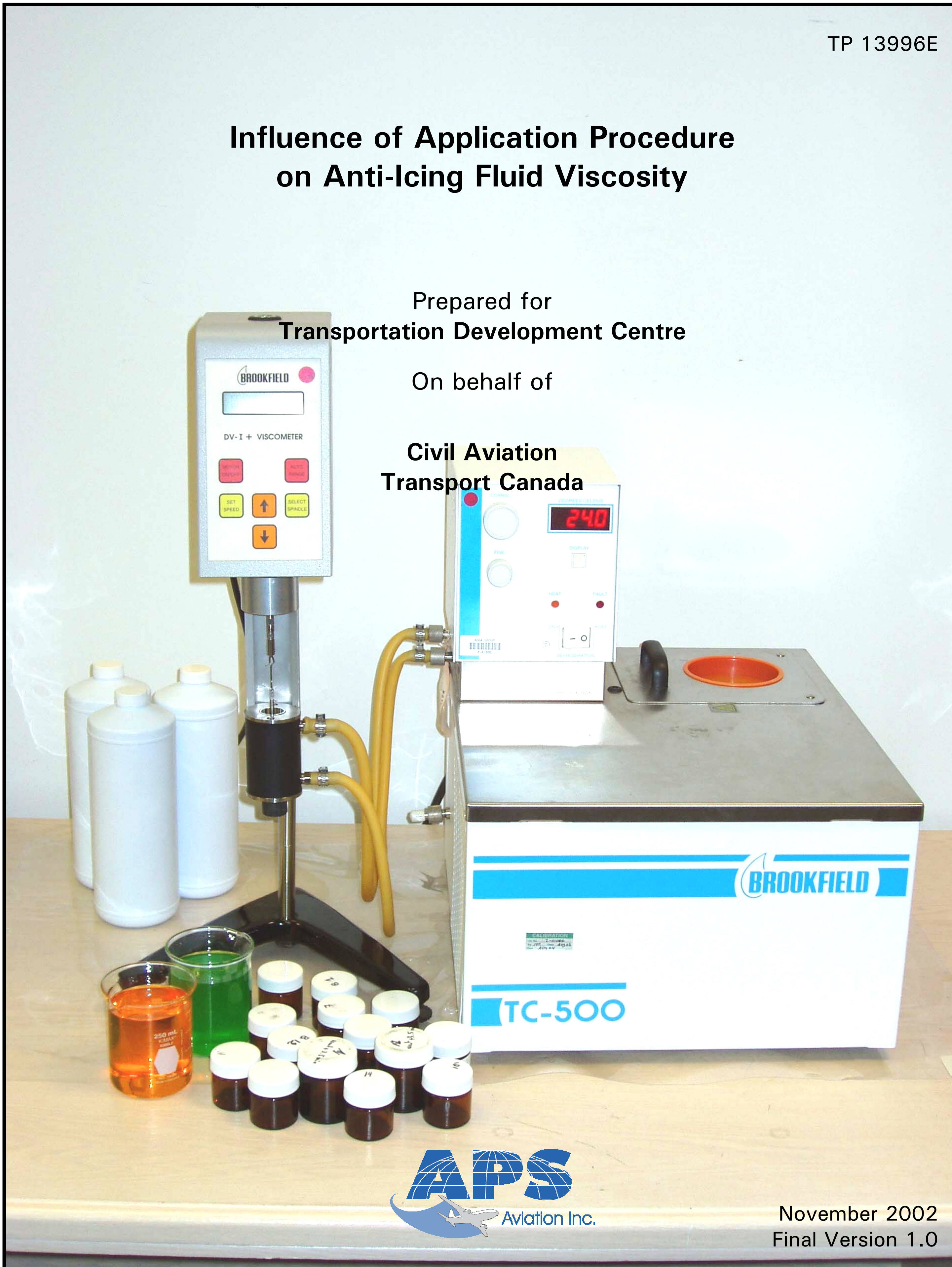
TP 13996E

Influence of Application Procedure on Anti-Icing Fluid Viscosity



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Transport Canada

APS Aviation Inc.

November 2002
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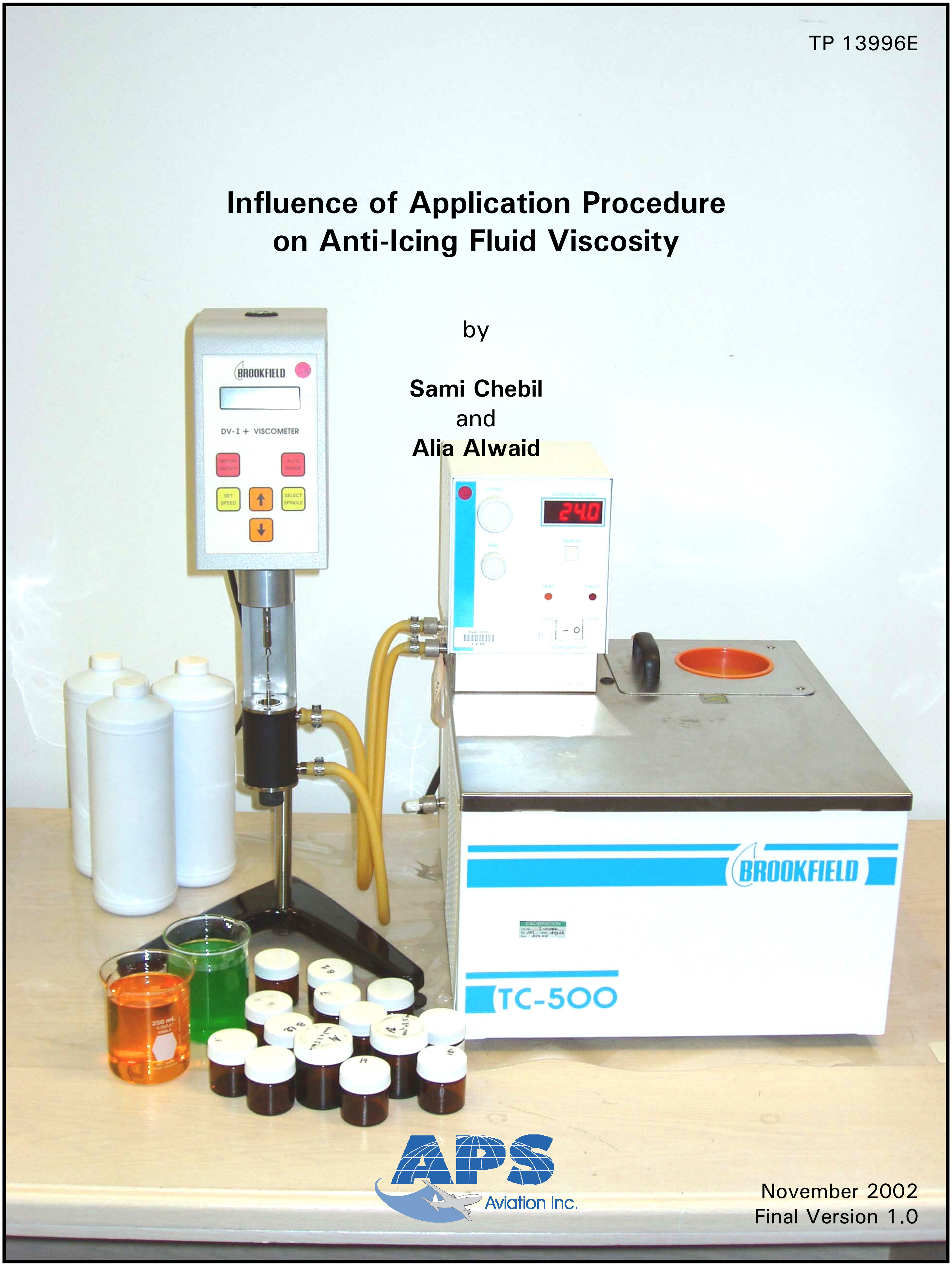

by

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November 2002
Final Version 1.0

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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, 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 AS 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 develop holdover times in snow using a more realistic protocol for Type I fluid endurance time testing;
- To further evaluate the flow of contaminated fluid from the wing of an aircraft during simulated takeoff runs;
- To examine the change in viscosity during the application process of Type IV fluids;
- To further evaluate hot water deicing;
- To compare endurance times in natural snow with those in artificial snow;
- To provide support for tactile tests at the Toronto Airport Central Deicing Facility;
- To utilize ice sensors for a pre-takeoff contamination check;
- To prepare the JetStar and Canadair RJ wings for thermodynamic tests; and
- To provide support services to Transport Canada.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2001-02 are documented in nine reports. The titles of the reports are as follows:

- TP 13991E Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter;
- TP 13992E Evaluation of Laboratory Test Parameters for Frost Endurance Time Tests;
- TP 13993E Impact of Winter Weather on Holdover Time Table Format;
- TP 13994E Generation of Holdover Times Using the New Type I Fluid Test Protocol;

- TP 13995E Aircraft Takeoff Test Program for Winter 2001-02: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid;
- TP 13996E Influence of Application Procedure on Anti-icing Fluid Viscosity;
- TP 13997E Endurance Time Tests in Snow: Reconciliation of Indoor and Outdoor Data 2000-02;
- TP 13998E Exploratory Aircraft Ground Icing Research for the 2001-02 Winter; and
- TP 13999E Support Activities to Aircraft Ground Icing Research for the 2001-02 Winter.

This report, TP 13996E, has the following objective:

- To examine the change in viscosity during the application process of Type IV fluids;

This objective was met by conducting a series of spray tests on wing surfaces. In addition, to determine the spraying and shearing effect on the endurance times of Type IV fluids, tests were conducted on flat plates under simulated precipitation. The effect on endurance time was evaluated.

ACKNOWLEDGEMENTS

This research has been funded by Transport Canada, with support from the 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 Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada (formerly known as Atmospheric Environment Services Canada), and several fluid manufacturers. Special thanks are extended to US Airways Inc., Air Canada, American Eagle Airlines Inc., the National Center for Atmospheric Research, AéroMag 2000, Aéroports de Montreal, Ottawa International Airport Authority, ATCO Airports, Aviation Boréale, 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: Nicolas Blais, Yagusha Bodnar, Alison Cairns, Robert Paris, Parimal Patel, Harvinder Rajwans, Ruth Tikkanen, Bob MacCallum, Trevor Leslie, Chris McCormack, and David Belisle.

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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). Nine reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface.

16. Abstract

A research program was undertaken to examine the change in viscosity of anti-icing fluids during the application process. This report is divided into three main sub-projects:

1 Preliminary Spray Tests: An airfoil was sprayed with Type IV fluid using a Task Force Tips nozzle. The procedure involved pouring heated Type I fluid on the airfoil, after which Type IV was sprayed. Samples were immediately tested for viscosity. Three Type IV fluids were tested. The results indicate that there is a decrease in viscosity due to both shearing of the Type IV fluid and the inclusion of Type I fluid.

2 Full-Scale Standard Spray Tests: Trained deicing operators, using a one-step application method, sprayed Type IV fluid onto aircraft wings. Fluid samples were collected and the viscosity was subsequently measured. Seven Type IV fluids were tested. Reductions of up to 38% in viscosity were found.

3 Endurance Time Tests: These tests reproduced the full-scale tests in a laboratory setting and demonstrated the effects of spraying versus pouring test samples as well as the pre-application of Type I fluid. There were viscosity reductions of up to 46% and endurance time reductions ranging from 2 to 43% (average of 29%), which were highly dependent on the fluid brand.

Samples from the preliminary spray tests were also stored for 16 months and the viscosities were monitored; reductions of up to 67% were observed.

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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 neuf rapports (dont celui-ci). On trouvera dans la préface l'objet de ces rapports.

16. Résumé

Une recherche a été entreprise pour examiner la variation de la viscosité des liquides antigivre pendant qu'ils sont appliqués. Ce rapport est subdivisé en trois grands sous-projets :

1. Essais de vaporisation avec application préalable de liquide de type I : une surface portante a été vaporisée de liquide de type IV à l'aide d'une buse *Task Force Tips*. La procédure consistait à verser d'abord un liquide de type I chauffé sur la surface portante, puis à vaporiser le liquide de type IV. Des échantillons étaient immédiatement recueillis et soumis à des essais de viscosité. Trois liquides de type IV ont été testés. Les résultats révèlent une diminution de la viscosité, attribuable à la fois au cisaillement du liquide de type IV et à l'application préalable de liquide de type I.
2. Essais standard de vaporisation en vraie grandeur : des préposés au dégivrage exercés vaporisaient du liquide de type IV sur les ailes d'un avion, selon une méthode d'application à une étape. Des échantillons du liquide étaient recueillis et leur viscosité était mesurée. Sept liquides de type IV ont été testés. Des diminutions de la viscosité allant jusqu'à 38 p. 100 ont été enregistrées.
3. Essais d'endurance : ces essais, identiques aux essais en vraie grandeur, mais en laboratoire, visaient à démontrer les effets de diverses méthodes d'application du liquide (liquide vaporisé, liquide versé, application préalable d'un liquide de type I). Des diminutions de la viscosité allant jusqu'à 46 p. 100 et des réductions de l'endurance variant de 2 p. 100 à 43 p. 100 (moyenne de 29 p. 100) ont été notées, lesquelles étaient fortement tributaires de la marque du liquide.

De plus, des échantillons recueillis lors des essais de vaporisation avec application préalable de liquide de type I ont été emmagasinés et soumis périodiquement à des essais de viscosité pendant 16 mois; des réductions allant jusqu'à 67 p. 100 de la viscosité ont été observées.

17. Mots clés Viscosité des liquides de type IV sur l'aile, effet de l'air entraîné/du cisaillement sur les mesures de viscosité, endurance	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Introduction

During the 1998-99 winter season, tests were conducted to examine the elimination of contaminated and failed anti-icing fluid mixtures from aircraft wings during takeoff. Viscosity measurements, carried out on samples of uncontaminated Type IV fluids taken from the wing, showed a significant decrease, dropping to almost 50 percent of the corresponding values of fluids taken from the drum that contained the fluid delivered by the manufacturer. For this reason, APS Aviation Inc. (APS) undertook a research program to measure the viscosity of Type IV fluids collected from the aircraft wing. The main objective was to study the spraying and shearing effect on Type IV fluid viscosities over time.

This report is divided into three main sub-projects:

- Preliminary spray tests;
- Full-scale standard spray tests; and
- Endurance time testing.

The Preliminary Spray Tests were conducted in the winter of 2000-01. An airfoil was sprayed with Type IV fluid using a Task Force Tips nozzle. In general, the procedure involved pouring heated Type I fluid on the airfoil followed by a spray application of Type IV. Eight runs using three fluids were carried out at the Dorval test site on a clear sunny day. The viscosity of the collected samples was immediately measured. In addition, the viscosity of stored samples was monitored over 16 months to investigate the degradation of fluid over time.

The full-scale standard spray tests and endurance time tests were conducted during the winter of 2001-02.

In the Full-Scale Standard Spray Tests, trained deicing operators used a one-step application method to spray Type IV fluid onto aircraft wings. Five full-scale runs were conducted at various deicing locations in North America on days with no precipitation. Four fluid brands were used for the tests and were sprayed from six deicing trucks. Fluid samples were collected and the viscosity was measured.

For the Endurance Time Testing, the standard endurance time test procedure was modified to investigate the impact of spraying anti-icing fluids on the performance of these fluids and results were compared to the endurance times observed using the standard test procedure. For some tests, Type I fluid was poured before the anti-icing fluids were sprayed. Thirty tests using four fluid brands were conducted under eight precipitation conditions at the National

Research Council Canada (NRC) environmental chamber. Samples were collected and viscosity was measured.

Conclusions

The main conclusions of the sub-projects included the following:

a) For the *Preliminary Spray Tests*, the shearing effect due to spraying could not be evaluated since the amount of Type I fluid in relation to Type IV fluid was an uncontrollable variable. However, the results indicate that there was a significant decrease in viscosity due to both shearing of the Type IV fluid and the inclusion of Type I fluid. Their separate effects on Type IV fluids were considered in subsequent tests.

b) Viscosity analysis over 16 months concluded that anti-icing fluid performance degrades over time by an average of 42 percent. The range varies between 16 and 67 percent, depending on the fluid brand. In addition, based on recent discussions with deicing operators, Type IV fluids may potentially degrade due to repetitive cooling and heating (by exchanging heat with Type I fluid) inside the truck tank, and due to layering effect caused by long periods of storage in large tanks.

c) For the *Full-Scale Standard Spray tests*, analysis of the viscosity samples collected from the wing during five full-scale standard spray tests led to the conclusion that the viscosity of sprayed Type IV fluids collected is lower by 19 percent than that of undisturbed fluids. Ranges vary between 6 and 38 percent depending on the fluid brand.

d) For the *Endurance Time Tests*, results from all tests conducted during this sub-project show that the viscosity of sprayed Type IV fluid collected from test plates is lower by 15 percent than that of undisturbed fluid; the range varies between 1 and 46 percent. It was concluded that the application procedure and the Type I fluid not only influence the viscosity but also the endurance time of anti-icing fluid by 29 percent. This variation (ranging between 2 and 43 percent) was found to be highly dependent on the fluid brand.

e) Results from all three sub-projects have concluded that spraying Type IV fluid could result in a notable change in the performance of fluids with respect to viscosity and endurance time, and the level of degradation is dependent on the fluid brand.

Recommendations

It is recommended that, from an operational perspective, operators be advised to strictly adhere to quality control checks and operational procedures because these affect fluid viscosity and endurance time. In addition, exploratory tests should be conducted to investigate whether fluid performance is significantly affected by fluid degradation due to repetitive cooling and heating, or by fluid degradation due to layering.

The adequacy of the current Endurance Time (ET) test procedures to replicate actual operations has long been scrutinized because the ET test does not use the sprayer application method. The test results clearly showed that there is a notable difference between spraying the fluid when conducting ET tests as opposed to pouring it. ET values in the sprayed tests were slightly lower than ET values in the standard pour test. In one instance, there was a significant difference. Although changing the Holdover Time (HOT) procedure to incorporate the shearing effect of fluid may be recommended, such an approach is unpractical, very expensive and may not be warranted. However, to ensure the fluid performs effectively, operators must be vigilant with respect to quality control checks and operational procedures regarding fluid viscosity.

Other parameters that should be investigated include the application temperature of the fluid and the effect that Type I has on the performance of the anti-icing fluid. Comparison of propylene-based Type IV fluid failure patterns on aircraft wings and on test plates is also recommended.

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SOMMAIRE

Introduction

Pendant l'hiver 1998-1999, des essais ont été effectués pour examiner l'élimination de mélanges de liquides antigivre contaminés et devenus inefficaces des ailes d'un avion pendant le décollage. Des mesures de viscosité, effectuées sur des échantillons de liquides de type IV non contaminés prélevés sur l'aile, ont révélé une forte diminution de la viscosité, celle-ci ne représentant que 50 p. 100 environ de la viscosité du liquide au sortir du contenant dans lequel il avait été livré par le fabricant. Pour cette raison, APS Aviation Inc. (APS) a entrepris un programme de recherche pour mesurer la viscosité des liquides de type IV recueillis sur l'aile de l'avion. Son principal objectif était d'étudier l'effet de la vaporisation et du cisaillement sur les valeurs de viscosité des liquides de type IV, avec le temps.

Ce rapport est subdivisé en trois grands sous-projets :

- Essais de vaporisation avec application préalable de liquide de type I
- Essais standard de vaporisation en vraie grandeur
- Essais d'endurance

Les *Essais de vaporisation avec application préalable de liquide de type I* ont eu lieu au cours de l'hiver 2000-2001. Une surface portante était vaporisée de liquide de type IV à l'aide d'une buse *Task Force Tips*. En général, la procédure consistait à verser d'abord un liquide de type I chauffé sur la surface portante, puis à vaporiser le liquide de type IV. Huit essais ont eu lieu au site d'essai de Dorval, par temps ensoleillé. Trois liquides ont été testés. La viscosité des échantillons recueillis était immédiatement mesurée. De plus, des échantillons ont été emmagasinés et soumis périodiquement à des essais de viscosité pendant 16 mois, afin d'examiner la dégradation du liquide avec le temps.

Les essais standard de vaporisation en vraie grandeur et les essais d'endurance ont été menés au cours de l'hiver 2001-2002.

Pour les *Essais standard de vaporisation en vraie grandeur*, des préposés au dégivrage exercés vaporisaient du liquide de type IV sur les ailes d'un avion, selon une méthode d'application à une étape. Cinq essais en vraie grandeur ont été menés à divers postes de dégivrage en Amérique du Nord, au cours de journées sans précipitation. Quatre marques de liquides ont été utilisées et vaporisées à partir de six camions de dégivrage. Des échantillons des liquides étaient recueillis et leur viscosité était mesurée.

Pour les *Essais d'endurance*, la procédure normale a été modifiée, pour permettre l'étude de l'effet de la vaporisation de liquides antigivre sur la performance de ces liquides. Les résultats de ces essais ont été comparés à ceux obtenus avec la méthode standard d'essai d'endurance (qui consiste à verser le liquide). Dans certains cas, un liquide de type I était versé avant que soient vaporisés les liquides antigivre. Trente essais utilisant quatre marques de liquides ont été réalisés sous huit conditions de précipitations dans la chambre environnementale du Conseil national de recherches du Canada CNRC). Des échantillons étaient recueillis et leur viscosité était mesurée.

Conclusions

Voici les principales conclusions qui se dégagent de chacun des sous-projets :

a) Pour les *Essais de vaporisation avec application préalable de liquide de type I*, l'effet de cisaillement dû à la vaporisation n'a pas pu être évalué, car il n'était pas possible de contrôler la variable des quantités relatives de liquide de type I et de type IV. Les résultats révèlent toutefois une diminution importante de la viscosité, attribuable à la fois au cisaillement du liquide de type IV et à l'application préalable de liquide de type I. L'effet de chacun de ces facteurs a été étudié lors d'essais subséquents.

b) Des résultats d'analyse de la viscosité sur 16 mois, il est ressorti que la performance des liquides antigivre se dégrade de 42 p. 100, en moyenne, avec le temps. Le pourcentage de dégradation variait de 16 p. 100 à 67 p. 100, selon la marque du liquide. De plus, des discussions récentes avec des préposés au dégivrage laissent penser que les liquides de type IV pourraient se dégrader en raison des cycles de refroidissement et de réchauffement auxquels ils sont soumis (par l'échange de chaleur avec le liquide de type I) à l'intérieur de la citerne du camion, et en raison de l'effet de stratification causé par de longs séjours dans des citernes de grand volume.

c) Pour les *Essais standard de vaporisation en vraie grandeur*, l'analyse de la viscosité des échantillons prélevés sur l'aile au cours de cinq essais a mené à la conclusion que la viscosité des liquides de type IV vaporisés puis prélevés est 19 p. 100 inférieure à celle des liquides «intacts». Le pourcentage de dégradation varie de 6 p. 100 à 38 p. 100 selon la marque du liquide.

d) Pour ce qui est des *Essais d'endurance*, les résultats des essais menés au cours de ce sous-projet révèlent que la viscosité d'un liquide de type IV prélevé sur les plaques d'essai est 15 p. 100 inférieure à celle d'un liquide intact, ce pourcentage variant de 1 p. 100 à 46 p. 100. Il a été conclu que la méthode d'application et le liquide de type I influent non seulement sur la viscosité, mais aussi sur l'endurance du liquide antigivre, dans une proportion de 29 p. 100. Cette diminution (qui varie de 2 p. 100 à 43 p. 100) s'est révélée fortement tributaire de la marque du liquide.

e) Les résultats des trois sous-projets ont mené à la conclusion que la vaporisation d'un liquide de type IV peut fortement influer sur la viscosité et l'endurance des liquides, et que le niveau de dégradation est tributaire de la marque du liquide.

Recommandations

Sur le plan pratique, il est recommandé de conseiller aux exploitants d'être très rigoureux dans l'application des contrôles de qualité et de respecter scrupuleusement les procédures opérationnelles, car celles-ci influent sur la viscosité et l'endurance. De plus, il y aurait lieu de mener des essais préliminaires pour examiner dans quelle mesure la performance du liquide est influencée par sa dégradation due aux cycles répétitifs de refroidissement et de réchauffement, ou à l'effet de stratification dans la citerne.

L'adéquation entre la méthode actuelle d'essai d'endurance et les opérations réelles a longtemps été examinée, car les essais d'endurance se font sans vaporisation. Les résultats des présents essais indiquent clairement que, lors des essais d'endurance, il existe une différence marquée entre la méthode de vaporisation et celle qui consiste à verser le liquide. Les valeurs d'endurance issues des essais par vaporisation étaient légèrement inférieures à celles obtenues lors des essais standard (liquide versé). Dans un des cas, la différence était significative. Certes, on pourrait recommander de modifier la méthode utilisée pour établir les durées d'efficacité de façon à tenir compte de l'effet de cisaillement du liquide, mais une telle approche est peu pratique et très coûteuse, et elle n'est pas nécessairement justifiée. Toutefois, pour s'assurer que le liquide est efficace, les exploitants doivent être vigilants en ce qui a trait aux contrôles de qualité et aux procédures opérationnelles, qui peuvent influer sur la viscosité du liquide.

D'autres paramètres méritent d'être examinés, dont la température d'application du liquide et l'effet de l'application préalable d'un liquide de type I sur la performance du liquide antigivre. Il est aussi recommandé de comparer la perte d'efficacité de liquides de type IV à base de propylène sur des ailes d'avion et sur des plaques d'essai.

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GLOSSARY

AEA	Association of European Airlines
APS	APS Aviation Inc.
CDF	Central Deicing Facility
CEF	Climatic Engineering Facility
DVT	Deicing Vehicle Type
ET	Endurance Tests
HOT	Holdover Time
LE	Leading Edge
MSC	Meteorological Service of Canada as of 2000, formerly known as Atmospheric Environmental Services (AES).
MVD	Mean Volume Diameter
NCAR	National Centre for Atmospheric Research
NRC	National Research Council Canada
OAT	Outside Air Temperature
SAE	Society of Automotive Engineers, Inc.
TC	Transport Canada
TDC	Transportation Development Centre
TE	Trailing Edge

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1. INTRODUCTION

During the winter of 1998-99, tests were conducted to examine the elimination of contaminated and failed anti-icing fluid mixtures from aircraft wings during takeoff. The purpose of these tests was to establish the conditions in which anti-icing fluid, contaminated by an accumulation of freezing precipitation, fails and is shed from the wing of a jet transport aircraft. Viscosity samples of uncontaminated Type IV fluids collected from aircraft wings exhibited a remarkable decrease of almost 50 percent of the corresponding values of fluids taken from the drum that contained the fluid delivered by the manufacturer. This observation gave rise to the need to conduct further tests.

1.1 Objectives

Over the past two winters, 2000-01 and 2001-02, APS Aviation Inc. (APS) has undertaken a research program to measure and evaluate the viscosity of anti-icing fluids after application on aircraft wings. The main objective of this research program was to compare the viscosity of the sprayed fluids versus that of the undisturbed fluids. This comparison led to an evaluation of the spraying and shearing effects on Type IV fluid endurance times. In order to satisfy this main objective, three sub-projects were carried out over the two winter seasons:

a) Preliminary Spray Tests (conducted in winter 2000-01);
b) Full-Scale Standard Spray Tests (conducted in winter 2001-02); and
c) Endurance Time Testing (also conducted in winter 2001-02).

A brief overview of the three sub-projects of the research program is depicted graphically in Figure 1.1.

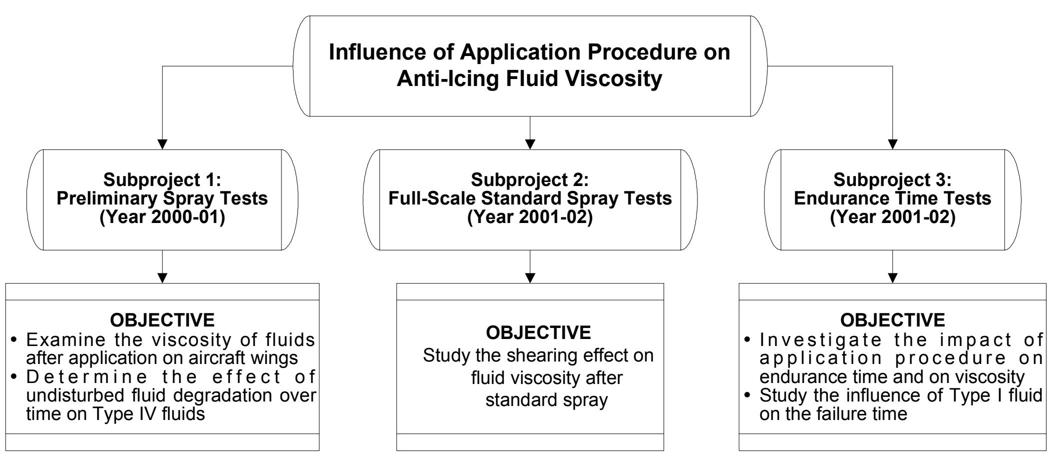

Figure 1.1: Description of the Three Sub-projects

The specific objectives of these sub-projects are described in more detail in Appendices A and B.

1.2 Preliminary Spray Tests (Winter 2000-01)

Tests were conducted in 2000-01 to examine the viscosity of fluids after application on aircraft wings, and to determine the range of values that are actually experienced during the holdover time (HOT) period. A 30 minute test period was chosen to characterize the holdover time (see Appendix A).

1.2.1 Methodology

An airfoil was sprayed with Type IV fluid using a pump equipped with a Task Force Tips nozzle that is normally used on deicing vehicles. Several fluids were tested. In general, the procedure involved first pouring heated Type I fluid on the airfoil and then spraying Type IV fluid on it. Fluid samples were collected and viscosity was measured immediately. Additional samples were collected and stored with the intention of analysing the effect of fluid storage over time. In addition, a sample of each (undisturbed) fluid was taken from the drum to provide a base value for comparison. Because these were preliminary tests, the spray pattern, distance from the wing, and fluid flow rate were kept constant.

1.2.2 Analysis and Recommendations

The data collection and analysis were presented in an interim report. Sections from that interim report have been reproduced here.

Analysis of the viscosity measurements, taken immediately (in situ) and after a period of time, proved to be ineffectual since the fluid samples collected were mixed with an undetermined amount of Type I fluid. In addition, the in situ viscosity was very difficult to measure due to the unstable sample temperature during the first minutes and also due to the entrained air (bubbles) created during the spraying. Stability of such a multiphase system (anti-icing fluid with bubbles) is particularly critical when measuring fluid viscosity. This led to the conclusion that the best way to study the immediate influence of application procedure would be to compare endurance times of poured versus sprayed Type IV fluids.

Recommendations derived from this preliminary investigation are given in Sections 1.2.2.1 and 1.2.2.3.

1.2.2.1 Full-scale spray tests

In order to have reproducible and comparable results, it was recommended that the use of Type I fluid should be avoided in future tests. In addition to controlling the test variables, it was also proposed that Type IV fluids be sprayed under the same conditions (same quantity, nozzle opening, temperature and angle of spray).

1.2.2.2 Endurance time tests

It was decided that the most conclusive way to study the influence of application procedure would be to conduct a series of tests with Type IV fluids and to compare the endurance times. It was suggested that Type IV fluids be sprayed on some plates and poured on others. It was proposed that the influence of Type I fluid could also be studied during these tests.

1.2.2.3 Degradation

As a result of the tests conducted in the winter of 2000-01, it was recommended that the degradation over time of the undisturbed fluids used during these tests be studied and reported in future work.

1.3 Research Carried Out in 2001-02

Tests were conducted in winter 2001-02 to address the recommendations outlined above. The objectives of these tests are stated in an excerpt from the Transport Canada Work Statement, which is provided in Appendix B. The aim of the work conducted in 2001-02 was to study the influence of the standard application procedure on deicing fluids from two perspectives:

a) Is the viscosity ‘‘degradation buffer’’, used during holdover time tests, representative of the fluids once they are sprayed in real operations? And how does it compare to the stated HOT table viscosity? (That is, should the viscosity of the fluids used for HOT tests be reduced further?); and,

b) Are the endurance time test results (obtained by using degraded fluids that are poured in the current HOT test procedure) representative of the endurance times in real operations? In other words, is the degradation buffer enough? Or should the procedure for conducting HOT tests be changed to include spraying the fluid as opposed to pouring it?

To address these separate (yet related) lines of questioning, the work was divided into two main sub-projects:

a) Full-Scale Standard Spray Tests; and
b) Endurance Time Testing.

In addition, viscosity measurements of undisturbed samples collected during the preliminary investigation in the winter of 2000-01 were taken over 16 months. The purpose of this exercise was to examine the degradation of the stored fluid over prolonged periods of time. A brief introduction to the two main sub-projects is given in subsections 1.3.1 and 1.3.2.

1.3.1 Full-Scale Standard Spray Tests

Aircraft wings were sprayed by trained deicing operators, using a one-step application method. Fluid samples were collected and the viscosity was measured.

The sole purpose of these tests was to collect samples and analyse the shearing effect, if any, by measuring fluid viscosity after the fluid was sprayed. No specific test program was developed; rather, APS personnel collected samples of sprayed fluids during tests carried out for other projects. This significantly reduced the cost of this sub-project. Samples were collected on five occasions. This report documents the results of the viscosity data collected.

Due to the nature of the tests involved and to the intended use of the samples collected for research purposes, the location of the tests conducted, the deicing operators, and the names of the fluids used were coded.

1.3.2 Endurance Time Testing

Endurance time tests were conducted to investigate the impact that spraying fluids has on endurance time.

The objective was to compare endurance times in the following scenarios:

a) *Standard endurance time test method:* The method that is currently used where normal production batch Type IV fluid is poured on plates;

b) *Real-time operation in a one-step anti-icing method:* The normal production batch Type IV fluid is sprayed onto plates; and

c) *Real-time operation in two-step anti-icing method:* Type I fluid is poured onto plates, followed by a spray application of normal production batch Type IV fluid.

These tests were conducted in April 2002 at National Research Council Canada (NRC) in Ottawa. The tests were scheduled to run simultaneously with the endurance time test program. A few positions on the endurance time test stand were used for the proposed sub-project. The tests were conducted under most of the precipitation conditions that were scheduled for the endurance time tests.

The impact on viscosity of a spray application of Type IV fluid (described above in scenarios b and c) was analysed by collecting samples and measuring their viscosity. The results were also compared to the viscosities of undisturbed fluids sampled from the drum.

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2. METHODOLOGY

The experimental methodology for the 2000-01 and 2001-02 winter sub-projects related to the viscosity changes of Type IV fluids due to the spraying process is presented in this section. A description is provided for the test sites, conditions, procedures, data forms, equipment, fluids, and personnel required to conduct the various tests.

As mentioned previously, this report is divided into three main sub-projects. Subsection 2.1 describes the methodology used in the preliminary spray tests (on-wing viscosity sub-project) conducted during the winter of 2000-01.

The methodology used for the full-scale standard spray tests and endurance time tests conducted during the winter of 2001-02 is described in Subsections 2.2 and 2.3.

Table 2.1 lists the three sub-projects, the dates they were conducted, and the various fluids used. As mentioned earlier, the sole purpose of these tests was to collect fluid samples and analyse the shearing effect, if any, on fluid viscosity and endurance time after the fluid was sprayed. Fluids used in these projects are therefore coded in this report to protect the identity of the fluid manufacturers. In some instances, a different batch of the same fluid was used during the different tests. This is indicated by a unique number for each batch/shipment used. For example, Fluid C5 indicates that five batches/shipments of Fluid C were used during the various test occasions; C1 was the first batch/shipment, C2 was the second, and so on.

Table 2.1: Overview of the Sub-projects

Sub-project	Test Date	Number of Type IV Fluids Tested	Coded Fluid	Ethylene- or Propylene-based
Preliminary Spray Tests	January 2001	3	Fluid A Fluid B1 Fluid C1	Propylene Propylene Ethylene
Full-Scale Standard Spray Tests	June 2001	2	Fluid C2 Fluid D1	Ethylene Propylene
	October 2001	2	Fluid B2 Fluid E1	Propylene Propylene
	November 2001	1	Fluid B3	Propylene
	February 2002	1	Fluid C3	Ethylene
	March 2002	1	Fluid C4	Ethylene
Endurance Time Tests	April 2002	4	Fluid C5 Fluid D2 Fluid F Fluid G	Ethylene Propylene Propylene Ethylene

2.1 Preliminary Spray Tests

Preliminary Type IV fluid spray tests were conducted during the winter of 2000-01 using an airfoil. Fluid samples were collected and tested for viscosity immediately after spray application. Viscosity values for each test were collected every minute for a duration of at least 30 minutes. Additional viscosity measurements of the sprayed fluid were taken over a period of 16 weeks. In addition, and as a secondary objective for these preliminary spray tests, viscosity runs were conducted over 16 months on undisturbed samples (from the truck) to examine the degradation of the stored fluid over prolonged periods of time.

Following is a description of the test methodology for these preliminary tests.

2.1.1 Icing Definitions

The issue of clarity when discussing fluid failure is significant. In order for all parties to arrive at a common point this section has been included. These definitions are taken directly from the Transport Canada report entitled, *Aircraft Anti-Icing Fluid Endurance, Holdover, and Failure Times Under Winter Precipitation Conditions: A Glossary of Terms,* TP 13832 (1).

Fluid failure
Two major forms of failure are currently in use: visual failure and adhesion failure.

Visual failure
A layer of ice crystals is plainly visible at the surface and the layer is building up thickness as precipitation continues. Generally, in the case of Type II, III, and IV fluids, uncontaminated fluid is in contact with the supporting surface at this time and therefore the ice crystal layer is not in contact with that surface and is not adhering to it. The growth of crystals in the fluid is compounded by incoming precipitation, resulting in an increased accumulation of crystals on the surface and thus in a visibly contaminated surface. When this area is large enough to be seen by an observer, a visual failure is adjudged. Obviously, the distance of the observer from the surface will influence what can be seen. For a test technician observing a plate from inches away, visual failure is characterized as a loss of gloss or obscuration of the surface by ice or slush affecting one third of a standard test plate surface. For an aircrew member viewing a wing through a window at night at a distance of several feet, only slush or bridging snow covering about one third of a critical area such as an aileron or a leading edge will be visible. Visual failure on test plates is the mode used to establish endurance times and thus holdover times.

Adhesion/Adherence failure
The failure of the fluid to perform as an anti-icing fluid. A layer of ice crystals builds up, the crystals come in contact with the surface below, and they are bonded to it.

Endurance time
The time from initial application of anti-icing fluid to a standard test plate to the moment of the standard plate failure for a specific test condition simulating a weather condition.

Holdover time
The time from initial application of anti-icing fluid onto an aircraft to the moment the fluid can no longer be guaranteed to provide protection at the anticipated takeoff time. These times must be at least five minutes less than the protection time, and may be substantially less.

2.1.2 Test Site

The preliminary spray tests during the winter of 2000-01 were performed at the APS Dorval Airport test site. The Dorval test site is shown in Photo 2.1.

2.1.3 Test Conditions

Tests were conducted in dry weather, under light sun radiation, with subfreezing outside air temperatures varying between -16°C and -9°C.

2.1.4 Description of Test Procedure

The test procedure established by APS for the preliminary spray tests is included in Appendix C. The use of four Type IV fluids was planned for this series of tests; however, due to time constraints, only three fluids were tested.

The major steps in the preliminary spray tests procedure were as follows:

a) Type I fluid was poured, followed by a spray of Type IV fluid;

b) Immediately after spraying, the mixed fluid sample was carefully collected (Photo 2.2) and the temperature was measured (Photo 2.3);

c) Viscosity, measured using the manufacturer's suggested method, was obtained at that temperature within seconds of the fluid collection. The readings from the viscometer were noted every minute over a one-hour period (Photos 2.4 and 2.5);

d) Two runs were conducted to check the reproducibility;

e) The viscosity versus time profiles of the collected fluid were compared to the undisturbed fluid over time; and

f) The viscosity of the same collected fluid was re-measured (in the following weeks and months) to see whether a significant change in fluid properties occurred after a prolonged period of time.

2.1.5 Data Form

The data form employed during the field viscosity measurement is shown in Figure C-2 (in Appendix C). A similar data form was used for laboratory viscosity tests (Figure C-3), although certain sections concerning spray details (pump used, spray technician, time of spray, etc.) were not applicable and therefore left blank.

2.1.6 Equipment

The list of test equipment used for the on-wing viscosity sub-project is included in Appendix C. The main technical characteristics of the major equipment employed – the portable Type IV fluid sprayer and the viscometer – are also outlined. APS measurement instruments and test equipment are calibrated/verified on an annual basis. This calibration is carried out according to a calibration plan based on approved ISO 9001 standards, and developed internally by APS.

2.1.6.1 Airfoil

Tests for the preliminary sub-project were performed on a 0.9 m wide x 1.8 m long (leading to trailing edge) airfoil section, with most of the contours and compound angles of a simple Fokker 28 aircraft wing (Photo 2.6).

2.1.6.2 Portable Type IV fluid sprayer

A portable Type IV fluid sprayer, developed by APS for testing in previous winters, was used for the application of the ethylene and propylene glycol-based Type IV fluids.

The Type IV fluid spray unit is shown in Photo 2.7. The portable sprayer was designed to enable outdoor and indoor testing in all conditions using various Type IV fluids, as required. There are three interrelated components: a fluid reservoir, a fluid pump, and a fluid application nozzle. The components of the portable sprayer are as follows:

a) A non-shearing fluid pump, identical to those installed in deicing vehicles, forces fluid from the reservoir. The fluid reservoir is a 200 L drum, adapted with the appropriate fittings and hoses to supply the pump and receive fluid when the application nozzle is closed;

b) A pressure gauge is used to monitor the pump system fluid pressure. An adjustable relief valve controls the system pressure. A check valve mounted at the root of the fluid supply hose prevents any fluid from draining back to the reservoir when the pump is turned off;

c) The pump is driven by an electric motor, which requires a generator capable of producing a minimum of 550 V, 30 kW, and three-phase current; and

d) A Task Force Tips nozzle, shown in Photo 2.8, is connected to the pump with a pressure-resistant rubber hose fitted with locking couplings.

The total weight of the sprayer system is approximately 315 kg (not including the generator) and can be transported easily with a pickup truck, although a winch is required for loading. The generator used was a large portable unit mounted on its own trailer, as shown in Photo 2.9.

2.1.6.3 Viscometer

Viscosity measurements were carried out using a Model DV-I+ Brookfield viscometer (Photo 2.10) fitted with a constant temperature bath (Brookfield TC-500). The refrigerated TC-500 bath provides fine control of temperature in a large variable range (from -10°C to 130°C) with a stability of ± 0.03°C.

The final viscosity value of fluids is taken after a specified time, when the readings have stabilized. During the first few minutes, fluids behave in various ways. The viscosity increases before stabilizing for some fluids while it decreases for others.

When they are pumped, the Type IV fluids are mixed with air, which becomes entrapped in the fluid. Stability of a dispersed phase is particularly critical when measuring the viscosity of this multiphase system. If the dispersed phase has a tendency to settle, a non-homogeneous fluid is produced and the fluid characteristics will change over time.

2.1.7 Fluids

The Type IV fluids included during the preliminary sub-project are listed below and the HOT table viscosities are given according to the manufacturer's method. All fluids used were undiluted (neat).

a) Fluid A: Certified propylene Type IV fluid. The viscosity was measured at the temperature of the in situ collected sample and based on the following method: 0.3 r/min, Spindle SC4-34/13R, 10 mL fluid; the measured Brix was 36;

b) Fluid B1: Certified propylene Type IV fluid. The viscosity was measured at the temperature of the in situ collected sample and based on the following method: 0.3 r/min, Spindle SC4-34/13R, 10 mL fluid; the measured Brix was 35.25; and

c) Fluid C1: Certified ethylene Type IV fluid. The viscosity was measured at the temperature of the in situ collected sample and based on the following method: 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid; the measured Brix was 39.

Prior to each Type IV fluid application, heated propylene Type I fluid was poured on the airfoil.

2.1.8 Personnel

Three APS research assistants participated in these preliminary spray tests. One research assistant monitored time and conducted spraying operations. The second collected and labelled fluid samples. The third monitored temperature of the fluid samples and conducted the viscosity measurements.

2.2 Full-Scale Standard Spray Tests

Aircraft wings were sprayed by trained deicing operators using a one-step application method. Fluid samples were collected, and the viscosity was measured.

The sole purpose of these tests was to collect samples and analyse the shearing effect, if any, by measuring fluid viscosity after the fluid was sprayed. No specific test program was developed; rather, APS personnel collected samples of sprayed fluids during tests carried out for other projects. This significantly reduced the cost of this sub-project. Samples were collected on five occasions.
This report documents the results of the viscosity data collected.

2.2.1 Test Sites

The first full-scale standard spray test was conducted at the Climatic Engineering Facility (CEF) of National Research Council Canada (NRC) in Ottawa. The CEF is partitioned into two sections separated by an insulated dividing door. Conditions in each section can be controlled independently, permitting several tests to be conducted simultaneously. Photo 2.11 gives a view of the building from outside. Interior views of the small and the large ends of the facility are provided in Photos 2.12 and 2.13, respectively. The size of the chamber is 30 m by 5.4 m and its total height is 8 m.

Four other full-scale standard spray tests were carried out at three different airports in Canada and the United States.

2.2.2 Test Conditions

The test conditions at the time of testing for each of the five full-scale test events are outlined below and described in more detail in Subsection 2.2.3.

1. Full-scale standard spray test #1:
   - Runs were carried out on a JetStar wing (Photo 2.14);
   - The testing chamber temperature was -25°C; and
   - The Type IV fluid was sprayed in conditions of no precipitation.

2. Full-scale standard spray test #2:
   - The outdoor air and wing temperatures were just over 15ºC; and
   - There was a high wind of 32 to 48 km/h throughout the test session.

3. Full-scale standard spray test #3:
   - The outside air temperature (OAT) hovered around 14.5°C to 15.5°C;
   - There was a cloudy sky and a low wind; and
   - Tests were conducted with both nose and tail into the wind.

4. Full-scale standard spray test #4:
   - The OAT was -13°C (warming to -9°C);
   - The wind velocity was approximately 10 km/h; and
   - The sky was mostly overcast.

5. Full-scale standard spray test #5:
   - Tests were conducted over two days (in March 2002);
   - The sky was mostly overcast;
   - The OAT varied between -11°C and -3°C; and
   - Before spraying, the wing surface temperature varied between -10°C and -2°C.

2.2.3 Description of Test Procedures

The test procedures to examine the influence of application procedure on anti-icing fluid viscosity involved three main steps:

a) Wings were sprayed using standard application;

b) Type IV fluid samples were collected in small bottles for viscosity measurements; and

c) Viscosity of the sprayed fluid was compared to the viscosity of an undisturbed sample taken from the truck.

Measurements were carried out using the Brookfield viscometer described in Subsection 2.1.5.3.

Table 2.2 outlines the five different full-scale standard spray tests and specifies for each the number of runs, the Deicing Vehicle Type (DVT) used, and the tested fluid.

Table 2.2: Brief Description of the Full-Scale Standard Spray Tests

Full Scale Test #	Run #	Deicing Vehicle Type (DVT #)	Sprayer Position	Tested Fluid
1	1	DVT0	Fixed	C2
	2	DVT0	Fixed	D1
2	1	DVT1	Fixed	E1
	2	DVT1	Moved by Operator	E1
	3	DVT2	Fixed	E1
	4	DVT1	Fixed	B2
	5	DVT1	Moved by Operator	B2
3	1	DVT3	Ahead of wing; downwind	B3
	2	DVT3	NR	B3
	3	DVT3	NR	B3
	4	DVT3	Ahead of wing; upwind	B3
4	1	DVT4	Fixed	C3
5	1 to 10	DVT5	NR	C4

NR: Not Reported

2.2.3.1 Full-scale standard spray test #1

A JetStar test wing at the CEF was used as the test surface. The standard application procedure was used in the spraying of the Type IV fluid by moving the bucket over the bare wing under conditions of no precipitation. The wing temperature was varied between -25ºC and -10ºC. Fluid samples were collected from the wing surface at both minimum (wing tip) and maximum (wing root) application distances. For all samples, viscosity measurements were obtained on-site according to the manufacturer method and re-checked a few days later in the APS laboratory. Runs were duplicated to check for reproducibility.

2.2.3.2 Full-scale standard spray test #2

Type IV spraying was conducted under no precipitation. Two DVTs were used (DVT1 and DVT2). Two Type IV fluids (Fluid B2 and Fluid E1) were tested (see Table 3.6). Both fixed and moving (manipulated by an operator) sprayers were tried. Two aircraft were used for testing. One was parked nose-into-the-wind and used for the first series of tests (DVT1 truck with Fluid E1). That aircraft was then recalled for maintenance, and a second aircraft was parked tail-into-the-wind and used for the rest of the testing.

Fluid samples were collected from the leading edge and the front of the wing surface. Fluid viscosity was measured in the APS laboratory a few days later according to the manufacturer method. Runs were duplicated to check for reproducibility.

2.2.3.3 Full-scale standard spray test #3

Only Fluid E2 was tested in full-scale spray test #3. A DVT3 truck with a fixed-design spray nozzle was used. This type of nozzle does not give the operator control over the shape of the spray fan. The shape of the fluid stream was very concentrated and hit the wing with some force. The spraying effect was tested on port and starboard wings.

Various distances separating the nozzle from the wing were tried before the test session to establish a consistent thickness of fluid. For an acceptable fluid coverage, the truck and cab were positioned with the nozzle 5 m from the wing surface. The effect of wind direction when spraying (downwind versus upwind) was tested as well. For each test, samples were collected at both minimum and maximum distances from the wing. Viscosity measurements were carried out in the fluid supplier laboratory and double-checked in the APS laboratory.

2.2.3.4 Full-scale standard spray test #4

In this test, the standard nozzle application was conducted only once on fluid C3. The fluid was applied downwind from a fixed position of the bucket.

A sample was collected and, after almost seven days, the viscosity was measured in the APS laboratory according to the manufacturer's method.

2.2.3.5 Full-scale standard spray test #5

Only one fluid was tested. Samples were collected from the wing surface and taken to the APS laboratory for viscosity measurements.

2.2.4 Fluids

All fluids used during these tests were neat. No Type I fluid was applied.

a) Full-scale standard spray test #1

- Fluid C2: certified ethylene Type IV neat. The viscosity was measured following the manufacturer's method: 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 0ºC. The viscosity of the normal production fluid taken from the truck was 35 800 mPa.s (millipascals x seconds). The measured Brix was 39; and

- Fluid D1: certified propylene Type IV neat. The method used to measure the viscosity was the following: 0.3 r/min, Spindle LV1, 500 mL fluid, 600 mL beaker, 33 min 20 s, Guard leg, 20ºC. The average viscosity of the normal production fluid taken from the truck was 7 100 mPa.s. The Brix measured at the APS laboratory was 36.

b) Full-scale standard spray test #2

- Fluid B2: certified propylene Type IV neat. The viscosity was measured according to the manufacturer's method: 0.3 r/min, Spindle SC4-34/13R, 10 mL fluid, 20ºC. The viscosity of the normal production fluid taken from the truck was 26 394 mPa.s. The Brix measured at the APS laboratory was 35; and

- Fluid E1: certified propylene Type IV neat. The manufacturer's suggested method to measure the viscosity was: 0.3 r/min, Spindle LV2, 250 mL fluid, 250 mL beaker, 10 min, Guard leg, 20ºC. The viscosity of the normal production fluid taken from the truck was 16 600 mPa.s. The Brix measured at the APS laboratory was 36.

c) Full-scale standard spray test #3

- Fluid B3: certified propylene Type IV neat. The viscosity was measured according to the following method: 0.3 r/min, Spindle SC4-34/13R, 10 mL fluid, 20ºC. The viscosity of the normal production fluid taken from the truck was 26 400 mPa.s. The Brix measured at the APS laboratory was 36.

d) Full-scale standard spray test #4

- Fluid C3: certified ethylene Type IV neat. The manufacturer's suggested method to measure the viscosity was: 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 0ºC. The viscosity of the normal production fluid taken from the truck was 44 200 mPa.s. The Brix measured at the APS laboratory was 39.25.

e) Full-scale standard spray test #5

- Fluid C4: certified ethylene Type IV neat. The manufacturer's method used to measure the viscosity was the following: 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 0ºC. The average viscosity of the normal production fluid taken from the truck was 42 637 mPa.s. The Brix measured at the APS laboratory was 39.

2.2.5 Personnel

The only activity carried out during these tests was to collect fluid samples and to measure their viscosity. As mentioned in Section 2.2, sampling and measurements were obtained in conjunction with other tests being conducted. Therefore, one assistant collected fluid samples from the wing surface and ran viscosity measurements at the test location immediately after collection, and/or later at the APS laboratory.

2.3 Endurance Time Tests

To save on costs, the tests were scheduled during the Endurance Time (ET) tests that were planned to develop the HOT tables. A few positions on the ET test stand were allotted for this purpose. Since some of the plates for the viscosity endurance time tests were sprayed, those tests were run before the HOT tests to avoid contaminating neighbouring plates. The tests were conducted under all precipitation conditions that were scheduled for the endurance tests.

2.3.1 Test Sites

ET tests were conducted indoors at NRC's CEF under conditions of freezing drizzle and light freezing rain.

2.3.2 Test Conditions

ET tests were conducted in conditions of freezing drizzle and light freezing rain. The Transport Canada report, *Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter*, TP 13826E (2) provides detailed descriptions of the methods used to produce and calibrate the fine water droplets in these precipitation tests.

2.3.3 Test Plan

Tests were carried out with four fluids under the different types of precipitation conditions, precipitation rates, and temperatures as summarized in Table 2.3.

A detailed summary of the tests conducted is provided in Section 3.3.

Table 2.3: Set-up of the Planned Tests for Endurance Time Tests

Set-Up	Fluid	Condition/Precipitation Rate (g/dm²/h)/Temperature (°C)
1	Fluid F	Freezing Drizzle/13/-10
	Fluid C5	Freezing Drizzle/13/-10
	Fluid G	Freezing Drizzle/13/-10
2	Fluid G	Freezing Drizzle/5/-10
3	Fluid C5	Freezing Drizzle/5/-3
4	Fluid D2	Freezing Drizzle/13/-3
5	Fluid D2	Light Freezing Rain/25/-10
6	Fluid D2	Light Freezing Rain/13/-10
7	Fluid C	Light Freezing Rain/25/-3
8	Fluid C	Light Freezing Rain/13/-3

2.3.4 Test Procedure

A copy of the corresponding test procedure is included in Appendix D. Tests were scheduled over six days at NRC. Five Type IV fluids were planned. Due to a problem of consistency, one fluid was disregarded. Precipitation conditions of light freezing rain (ZR) and freezing drizzle (ZD) were applied at both high and low rates, and at two different air temperatures. Three plates were used for each test. The major steps in this procedure were as follows:

a) On the first plate, Type IV fluid was applied using a two-step fluid application. One litre of Type I fluid was poured at 60°C rather than at room temperature, which had been planned in the procedure. Type IV fluid was sprayed on the plate after 3 minutes rather than immediately as was planned. These changes to the procedure were intended to replicate the real de/anti-icing sequencing used on an aircraft wing;

b) On the second plate, Type IV fluid was sprayed on bare aluminium without any deicing fluid (Photo 2.15);

c) Before each Type IV fluid spray application, a skirt was supposed to be placed around the plate to simulate the splashing effect of the fluid on aircraft wing. This skirt was discarded after the first tests since its effect seemed insignificant;

d) On the third plate, Type IV fluid was poured as per the standard endurance time test procedure (Photo 2.16 and Photo 2.17);

e) The fluid sampling was not as it had been planned in the test procedure. A small technical change was proposed to avoid fluid contamination with precipitation while taking a sample. Steps “a” and “b” were reproduced on a different stand, which was placed under no precipitation. The fluids were drained with a spatula in clean bottles. The collected samples were as follows:

   - From Step a: in situ Type I fluid mixed to sheared Type IV fluid;
   - From Step b: in situ sheared Type IV fluid; and
   - Sample collected from the drum, corresponding to the Type IV fluid poured on the third plate (step d).

f) In situ viscosity was measured following the manufacturer’s method. For the 10 mL samples (Fluid C5 and Fluid G described in Subsection 2.3.7), fluids were centrifuged for 3 minutes before each viscosity run to avoid entrained air effects; and

g) The HOT tests were conducted on the three plates according to the standard test procedure described in the Transport Canada report, *Aircraft Ground De/Anti-icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter*, TP 13826E (2) (Photo 2.18).

2.3.5 Data Forms

The data form used for the in situ viscosity measurements during the Endurance Time tests is shown in Table 2.4.

Table 2.4: Viscosity Measurement Data Form for the Endurance Time Testing

Run #:		**Manufacturer visc. method:**	
Location:	NRC	**Precipitation Type:**	
Date:		**Precipitation Rate (g/dm²/h):**	
Type I Fluid Name if Applied:		**Chamber Temperature (°C):**	
Type IV Fluid Name:			
Type IV Fluid Temperature before spray (°C):			
Brix Before Spray:			

	Prior to Testing	**Test Plate Sets ***		
		1	2	3
Sample Label				
Type I Applied	No	No	No	Yes
Type IV Application Procedure	N/A	Poured	Sprayed	Sprayed
Spray Time (Sec)	N/A	N/A		
Sample Temperature When Collected (°C)	N/A	N/A		
Brix				
Viscosity Measured (mPa.s)**		***		

* 2 plates per set if time will allow it.

** Using manufacturer's method.

*** Will be the same measured at APS laboratory (prior to testing).

2.3.6 Equipment

The list of the test equipment used is included in Appendix D; it is identical to the list used for standard endurance tests. The following additional materials were needed for the spray process, the fluid sampling and the viscosity analysis:

a) Task Force Tips nozzle and sprayer (refer to Section 2.1.6.2);

b) One-litre opaque plastic sample bottles;

c) Plastic funnels and scrapers to collect fluids;

d) Viscometer (refer to Section 2.1.6.3); and

e) Skirted plate: when Type IV fluid was sprayed, an extension (skirt) was added around the standard plate. A gap of about 1 cm would allow excess fluid to flow off the plate. The skirt was to provide a better simulation of fluid application on the wing, i.e., a proper simulation of fluid splashing effects (refer to Appendix D, Attachment II). As mentioned in Section 2.3.4, this skirt was discarded after the first tests since its effect seemed insignificant.

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

2.3.7 Fluids

For this sub-project, the following Type IV fluids were tested:

a) Fluid C5: certified ethylene Type IV neat. The viscosity method used was the following: 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 0ºC. The viscosity of the normal production fluid taken from the drum was 48 700 mPa.s; the measured Brix was 40;

b) Fluid D2: certified propylene Type IV neat. The viscosity method used was the following: 0.3 r/min, Spindle LV1, 500 mL fluid, 600 mL beaker, 33 min 20 s, Guard leg, 20ºC. The viscosity of the sample taken from the drum was 8 260 mPa.s; the measured Brix was 37;

c) Fluid F: discontinued propylene Type IV neat. The viscosity measured at 20ºC in APS laboratory was 6 780 mPa.s. (Method: 0.3 r/min, Spindle LV1, 500 mL fluid, 600 mL beaker, 33 min 20 s, Guard leg, 20ºC). The measured Brix was 36; and

d) Fluid G: not-certified ethylene Type IV fluid, with a viscosity of 26 700 mPa.s, measured at 20ºC in APS laboratory using the following method: 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 0ºC. The measured Brix was 32.5.

2.3.8 Personnel

For the ET tests, in addition to the personnel employed for the HOT tests, two extra persons were required. One sprayed the Type IV fluids, and the other sequenced the tests, collected the fluid samples, and conducted in situ viscosity measurements.

Photo 2.1: View of Dorval Test Site and Associated Equipment

Photo 2.2: Fluid Sampling

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Photo 2.3: Temperature Measurement Before Conducting Viscosity Test

Photo 2.4: Viscosity Test Preparation

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Photo 2.5: Viscosity Test Monitoring

Photo 2.6: Airfoil Section

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Photo 2.7: Mobile Type IV Fluid Sprayer Unit

Photo 2.8: Task Force Tips Nozzle

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Photo 2.9: Type IV Mobile Sprayer Set-up

Photo 2.10: Brookfield Digital Viscometer Model DV-I+ and Temperature Bath

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Photo 2.11: Outdoor View of National Research Council Canada Climatic Engineering Facility

Photo 2.12: Indoor View of Small End of Climatic Engineering Facility

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Photo 2.13: Indoor View of Large End of Climatic Engineering Facility

Photo 2.14: JetStar Wing Mounted on Boat Trailer

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Photo 2.15: Spraying Type IV Fluid

Photo 2.16: Pouring of Type IV Fluid

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Photo 2.17: Pouring of Type IV Fluid While Plate is Covered to Protect from Precipitation

Photo 2.18: Endurance Time Tests Conducted on the Three Plates

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3. DESCRIPTION AND PROCESSING OF DATA

This section provides an account of the data collected during the various tests under the three main sub-projects:

a) Preliminary Spray Tests;
b) Full-Scale Standard Spray Tests; and
c) Endurance Time Tests.

Figure 3.1 outlines the three main sub-projects and specifies the different fluids and tests conducted for each.

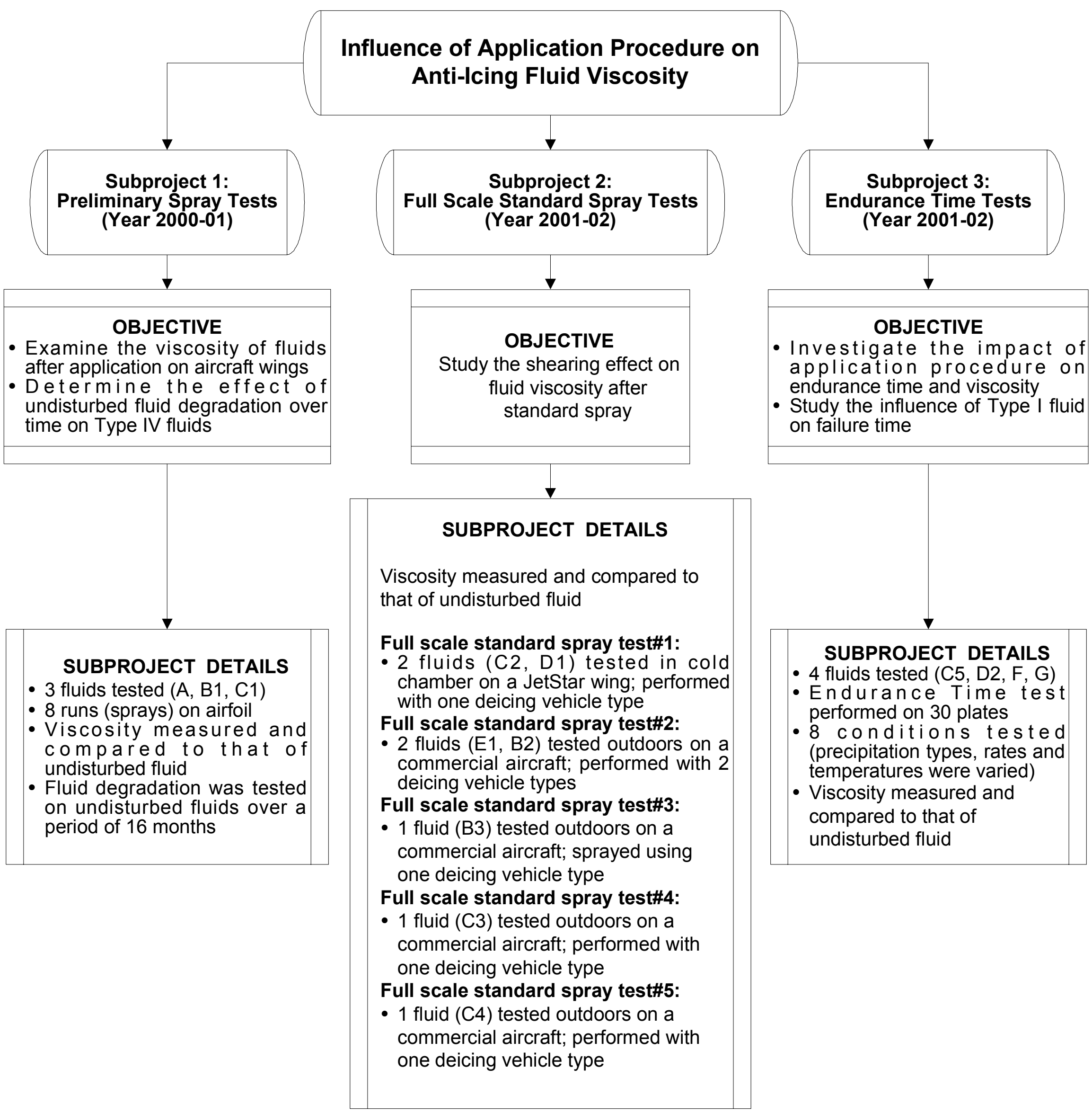

Figure 3.1: Detailed Description of the Three Sub-projects

3.1 Preliminary Spray Tests

Three spray applications were conducted using three different fluids. Samples were collected and viscosity was measured and compared to the undisturbed fluid.

The degradation of the undisturbed tested fluids over time was also monitored by conducting viscosity tests at several time intervals over 16 months.

The remainder of this subsection provides an account of the general conditions under which the spray tests took place, data collected for each of the three fluids, and viscosity data for undisturbed fluids intended to monitor the degradation of fluids over time.

3.1.1 General Conditions

Tests were carried out at the APS Dorval Airport test site on January 10, 2001, mostly during the day. The weather was predominantly sunny. The Outside Air Temperature (OAT) varied between -16°C and -9°C.

Type I fluid was initially heated to 60°C and then poured onto the airfoil surface. Type IV was then sprayed with a fluid pump fitted with a Task Force Tips nozzle. The interval between pouring the Type I and spraying the Type IV was less than one minute.

The propylene-based Type IV fluids (A and B1) were stored in a shed at a temperature of -9°C. Prior to spray application, the temperature of the ethylene-based Type IV Fluid C1 was +9°C. Fluid C1 was taken earlier in the day from an AéroMag truck that had been parked indoors. In transferring the fluids into drums for test purposes, fluid C1 was "pumped" from the truck into a drum, whereas fluids A and B1 were poured.

The thickness of the poured Type I fluid (before spraying of Type IV) ranged between 0.3 mm and 0.4 mm. The thickness of the fluid mix (Type I and Type IV) varied between 0.9 mm and 1.8 mm.

Before each spray application, the airfoil temperature was measured; it ranged between -13°C and -8°C.

Immediately after spraying, one sample of the "Type I and Type IV" mix was collected. Viscosity was measured as a function of time. The total time to spray the Type IV fluid, collect the mix, and start to measure the viscosity ranged between 2 and 4 minutes.

Approximately 30 minutes after spraying, the remaining fluid on the wing was collected and brought back to the laboratory. The viscosity of this sample was measured in the following weeks.

Temperature of the mixed fluid collected immediately after spray application of the Type IV fluid ranged between -1°C and +1°C. The viscosity of the collected fluid was measured at that temperature.

Viscosity readings of this sample were taken every minute for up to 60 minutes. When the viscosity stabilized, the test was stopped after a minimum of 30 minutes.

Table 3.1 provides an example of these readings taken on-site for the first run (Run #1) carried out on Fluid A. The associated test conditions are stated on the form.

The data shown in Table E-3 of Appendix E were obtained in the APS laboratory for the same Fluid A after two weeks. Data from these tables are plotted in Figure 3.2 . The code "R #1 (in situ)" indicates the viscosity readings obtained on-site immediately after the spray application of Type IV fluid; "R #1 (+2 weeks)" denotes the viscosity readings of the sample collected from the wing 30 minutes after the application and measured later at the APS laboratory.

For all tested fluids, the manufacturer's suggested method was followed. For Fluids A and B1, the spindle referenced SC4-34 was used with 10 mL fluid in the chamber 13R. The spindle speed was set at 0.3 r/min. For Fluid C1, the method suggested was 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid.

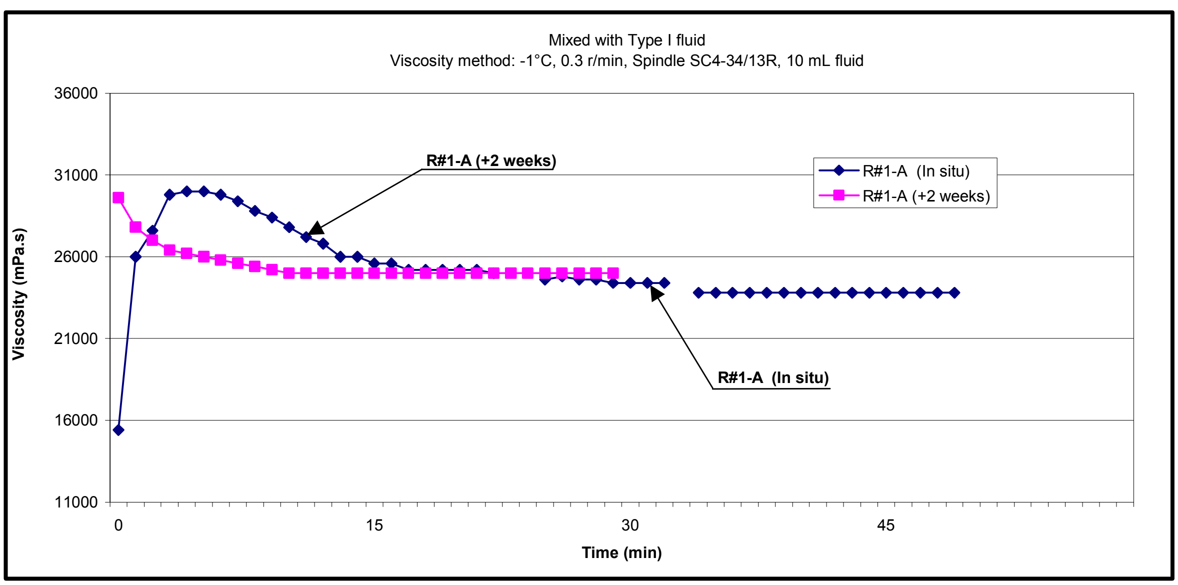

Figure 3.2: Viscosity versus Time for Fluid A Measured In Situ and in the Laboratory (after 2 weeks)

Table 3.1: Preliminary Spray Tests Field Measurement Data for Fluid A (Run #1)

Session:	1	Fluid Name:	Fluid A
Run Number:	1	Temp. of Fluid Prior to Spray:	-8.6°C
Location:	APS Site	Time of Spray:	49 s
Date:	1/10/01	Temp. of Fluid After Spray:	-1°C
OAT (°C):	-13.4°C	Time of Viscosity Measurement:	18:30:00
Pump Used:	APS Aviation pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #1-A

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	15400	**29:00**	24400
58:00	26000	**28:00**	24400
57:00	27600	**27:00**	24400
56:00	29800	**26:00**	24000
55:00	30000	**25:00**	23800
54:00	30000	**24:00**	23800
53:00	29800	**23:00**	23800
52:00	29400	**22:00**	23800
51:00	28800	**21:00**	23800
50:00	28400	**20:00**	23800
49:00	27800	**19:00**	23800
48:00	27200	**18:00**	23800
47:00	26800	**17:00**	23800
46:00	26000	**16:00**	23800
45:00	26000	**15:00**	23800
44:00	25600	**14:00**	23800
43:00	25600	**13:00**	23800
42:00	25200	**12:00**	23800
41:00	25200	**11:00**	23800
40:00	25200	**10:00**	23800
39:00	25200	**09:00**	
38:00	25200	**08:00**	
37:00	25000	**07:00**	
36:00	25000	**06:00**	
35:00	25000	**05:00**	
34:00	24600	**04:00**	
33:00	24800	**03:00**	
32:00	24600	**02:00**	
31:00	24600	**01:00**	
30:00	24400	**00:00**	

Table 3.2 provides a log of all tests with associated test conditions. Most of the tests were run more than once to ensure reproducibility.

Three fluids were tested: Fluids A, B1 and C1. Two spray applications were conducted using both fluids A and B1. Fluid C1 was sprayed four times.

Eight samples were collected from the wing for in situ viscosity measurements. Viscosity measurements were conducted at the APS laboratory on these eight collected samples, and on undisturbed fluids (taken from the drum).

3.1.2 Fluid A

Two runs were conducted using Fluid A. All data from these tests are included in Appendix E. The conditions, details, and viscosity (versus time) data are provided for both runs in Tables E-1 and E-2. The viscosity readings were also taken in the laboratory for the same sample (collected after 30 minutes on the wing) in the following 2 weeks, and are given in Tables E-3 and E-4. Viscosity measurements taken 12 weeks later are given in Tables E-5 and E-6. Table E-7 shows the data of the viscosity test carried out on the undisturbed sample at a specific temperature (-1°C).

3.1.3 Fluid B1

The same method was used for Fluid B1 and the data is provided in Appendix E. The viscosity (versus time) data obtained immediately after spraying is given in Tables E-8 and E-9. The laboratory measurements of the collected fluid were obtained after 3 weeks (Tables E-10 and E-11) and after 16 weeks (Tables E-12 and E-13). Data for undisturbed Fluid B1 are provided in Table E-14.

3.1.4 Fluid C1

Four runs were performed using Fluid C1. The on-wing viscosity field readings are given in Tables E-15, E-16, E-17 and E-18 of Appendix E. The third run was performed without Type I fluid. Viscosity measurements of samples collected during Runs #1 to #4 and obtained after 2 to 4 weeks are in Tables E-19, E-20, E-21, and E-22, respectively. Only Run #1 and Run #2 samples were tested after 16 weeks (Tables E-23 and E-24 in Appendix E). As shown in Tables E-25, E-26, and E-27 (Appendix E), viscosity measurements were obtained on the undisturbed sample at the specific field temperatures (+1ºC, -1ºC and -10ºC).

Table 3.2: Log of All Preliminary Spray Tests Conducted and Associated Condition

Ref.	Type IV Fluid	Run#	Temp. of the Sample (°C)	Mixing with Type I	Viscosity Method	Test Location	Date of the Viscosity Test (Month/Day/Year)	Label ****
1	A	Virgin Fluid	-1	No	0.3 r/min, Spindle SC4-34/13R, 10 mL fluid	APS Lab	1/24/2001	Rb-A
2		1		Yes (propylene type)		APS Dorval Test Site	1/10/2001 *	R#1-A (in-situ)
3				Yes (propylene type)		APS Lab	1/24/2001 **	R#1-A (+ 2 weeks)
4				Yes (propylene type)		APS Lab	4/5/2001 ***	R#1-A (+ 12 weeks)
5	A	2	-1	Yes (propylene type)	0.3 r/min, Spindle SC4-34/13R, 10 mL fluid	APS Dorval Test Site	1/10/2001 *	R#2-A (in-situ)
6				Yes (propylene type)		APS Lab	1/24/2001 **	R#2-A (+ 2 weeks)
7				Yes (propylene type)		APS Lab	4/5/2001 ***	R#2-A (+ 12 weeks)
8	B1	Virgin Fluid	-1	No	0.3 r/min, Spindle SC4-34/13R, 10 mL fluid	APS Lab	2/1/2001	Rb-B1
9		1		Yes (propylene type)		APS Dorval Test Site	1/10/2001 *	R#1-B1 (in-situ)
10				Yes (propylene type)		APS Lab	2/2/2001 **	R#1-B1 (+ 3 weeks)
11				Yes (propylene type)		APS Lab	4/30/2001 ***	R#1-B1 (+ 16 weeks)
12	B1	2	-1	Yes (propylene type)	0.3 RPM, Spindle SC4-34/13R, 10 mL fluid	APS Dorval Test Site	1/10/2001 *	R#2-B1 (in-situ)
13				Yes (propylene type)		APS Lab	2/2/2001 **	R#2-B1 (+ 3 weeks)
14				Yes (propylene type)		APS Lab	4/30/2001 ***	R#2-B1 (+ 16 weeks)
15	C1	Virgin Fluid	1	No	0.3 r/min, Spindle SC4-34/13R, 10 mL fluid	APS Lab	1/23/2001	Rb-C1
16		1		Yes (ethylene type)		APS Dorval Test Site	1/10/2001 *	R#1-C1 (in-situ)
17				Yes (ethylene type)		APS Lab	1/22/2001 **	R#1-C1 (+ 2 weeks)
18				Yes (ethylene type)		APS Lab	4/30/2001 ***	R#1-C1 (+ 16 weeks)
19	C1	Virgin Fluid	-1	No	0.3 r/min, Spindle SC4-34/13R, 10 mL fluid	APS Lab	1/23/2001	Rb-C1
20		2		Yes (ethylene type)		APS Dorval Test Site	1/10/2001 *	R#2-C1 (in-situ)
21				Yes (ethylene type)		APS Lab	1/22/2001 **	R#2-C1 (+ 2 weeks)
22				Yes (ethylene type)		APS Lab	4/30/2001 ***	R#2-C1 (+ 16 weeks)
23	C1	Virgin Fluid	-10	No	0.3 r/min, Spindle SC4-34/13R, 10 mL fluid	APS Lab	2/8/2001	Rb-C1
24		3		No		APS Dorval Test Site	1/10/2001 *	R#3-C1 (in-situ)
25				No		APS Lab	2/6/2001 **	R#3-C1 (+ 3 weeks)
26	C1	4	-1	Yes (ethylene type)		APS Dorval Test Site	1/10/2001 *	R#4-C1 (in-situ)
27				Yes (ethylene type)		APS Lab	1/23/2001 **	R#4-C1 (+ 2 weeks)

* First Viscosity Test (in-situ)
** Second Viscosity Test
*** Third Viscosity Test
**** R#X-Y (in-situ) is the label used for Fluid Y during Run#X and where the viscosity readings are measured in-situ.
R#X-Y (+Z weeks) is the label used for Fluid Y during Run#X and where the viscosity readings are measured after Z weeks.

3.1.5 Degradation of Undisturbed Fluid

To investigate anti-icing fluid degradation over time, viscosity measurements were obtained from all three fluids (A, B1, and C1) taken from the drum. These undisturbed fluid samples were stored in containers that were sealed carefully to avoid any evaporation and covered to protect the fluid from light radiation. To avoid fluid layering, containers were shaken softly (manually, to avoid creating air entrainment) prior to each run. Viscosity measurements of undisturbed fluids were obtained at constant temperatures (-1°C for Fluids A and B1, and 0°C for Fluid C1) over a period of 16 months (Table 3.3). Only readings after 30 minutes (average time for viscosity to stabilize) are reported.

Table 3.3: Time Effect on Viscosity for Fluids A, B1, and C1 (undisturbed)

Period of Time	Undisturbed Fluid Viscosity (mPa.s)*		
	A**	B1**	C1***
After 2 weeks	28 800	43 800	44 250
After 6 months	13 800	38 800	40 300
After 11 months	13 800	27 600	37 533
After 16 months	9 400	25 000	36 950
HOT Viscosity	12 500	25 000	36 000

* Readings are reported after 30 min, average of two runs
** Viscosity method: -1°C, 10 mL, Spindle #34 @ 0.3r/min
*** Viscosity method: 0°C, 10 mL, Spindle #31 @ 0.3r/min

The HOT table viscosities are also stated, although the values given for Fluids A and B1 are estimates. For Fluids A and B1, the viscosities reported in the HOT tables are given at 20°C, whereas test data was obtained at -1°C for these fluids. A method was needed to compare fluid viscosities at the same temperature. Because viscosity is a form of temperature, we estimated HOT viscosities at -1°C knowing the HOT table values at 20°C. Measurements were obtained for Fluids A and B1 at -1°C and at 20°C, and are reported in Table 3.4. The viscosity measured at -1°C was compared to viscosity measured at 20°C to obtain a ratio. This ratio was applied to the HOT table viscosity value at 20°C to calculate the viscosity estimate of the undisturbed fluids at -1°C.

Table 3.4: Estimation of the Holdover Time Viscosity of Fluids A and B1 at -1°C

Fluid	Measured Viscosity at 20°C	Measured Viscosity at -1°C	Ratio	HOT Viscosity at 20°C (From the manufacturer)	Estimated Viscosity at -1°C
A	4 100	8 050	1.96	6 400	12 568
B1	16 200	22 400	1.38	18 000	24 890

Measured viscosities are based on two runs and expressed in mPa.s.

3.2 Full-Scale Standard Spray Tests

APS personnel collected samples of sprayed fluids during tests carried out for other projects. Samples were collected on five occasions. Aircraft wings were sprayed by trained deicing operators, using a one-step application method. Fluid samples were collected and viscosity was measured. This section documents the results from the viscosity data collected during each of these five full-scale standard spray tests.

3.2.1 Full-Scale Standard Spray Test #1

Type IV fluid was applied from a deicing vehicle using a standard nozzle (Deicing Vehicle Type: DVT0). The JetStar bare wing was sprayed under conditions of no precipitation. The wing temperature ranged from -25ºC to -10ºC. Type IV fluid was sprayed as per normal operation, moving the bucket over the wing. Two runs were conducted with Fluid C2; only one run was carried out with Fluid D1. Type IV samples were lifted from the wing surface at both minimum (wing tip) and maximum (wing root) application distances.

Viscosity measurements were obtained immediately to analyse the condition of the fluid during the normal HOT period. For all samples, viscosity measurements were carried out on-site according to the manufacturer's method. A few days later, viscosity of the sample was measured again in the APS laboratory to check for reproducibility. In some cases (when a large quantity of fluid was recovered from the wing), viscosity measurements were performed on centrifuged samples in order to study the effect of air bubbles trapped in the fluid. Results for both fluids C2 and D1 are summarized in Table 3.5. Undisturbed samples were also extracted from truck tanks and tested.

3.2.1.1 Fluid C2

For the first run (Run #1_C2), approximately 40 L of Fluid C2 was sprayed with the standard nozzle. For the second run (Run #2_C2), the truck was moved 1.5 m. ahead for easier access to the wing root. This operation replicated the normal field procedure; a bucket was moved over the wing for better reach. The quantity of fluid sprayed in Run #2 was approximately 70 L.

3.2.1.2 Fluid D1

At first, the fluid was cold and very hard to pump. After a while, it flowed better; warmer fluid from the tank flushed out the cold fluid in the hose. The approximate quantity of fluid sprayed was 20 L.

Table 3.5: Full-Scale Standard Spray Test #1: Viscosity Measurements for Fluids C2 and D1

Run	Sample Label	Quantity of fluid sprayed (L)	Spray Time	Date of Sample Collection	Viscosity Test			Location of Sample	Centrifuged	Viscosity (mPa.s)
					Date	Time	Location			
Tank	Tank - Fluid C2	-	-	26-Jun-01	26-Jun-01	11:05	NRC	-	No	35800*
R#1_C2	R_2C - C2_Std. Nzle. Min	40	13:05	26-Jun-01	26-Jun-01	13:08	NRC	Minimum Effective Distance	No	33100*
						18:15			Yes	28200*
					13-Jul-01	11:25	APS Lab		No	32300*
	R2C - C2_ Std. Nzle. Max				13-Jul-01	12:45	APS Lab	Maximum Effective Distance	No	21300*
R#2_C2	R_2D - C2_ Std. Nzle. Min	70	13:30	26-Jun-01	26-Jun-01	13:33	NRC	Minimum Effective Distance	No	33200*
						16:00			Yes	34200*
					13-Jul-01	13:50	APS Lab		No	35100*
Tank	Tank - Fluid D1	-	-	29-Jun-01	29-Jun-01	10:10	NRC	-	No	7000 **
					13-Jul-01	11:05	APS Lab		No	7200**
R#1_D1	R#1_D1 Wing Root	20	11:18	29-Jun-01	29-Jun-01	11:32	NRC	Max (Wing Root)	No	4300**
	R#1_D1 Wing Tip					11:55		Min (Wing Tip)		4500**
					13-Jul-01	15:40	APS Lab		No	4500**

* Viscosity method: (OºC, 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 10 min)

** Viscosity method: (2OºC, 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 33 min 20 s); this was used as an alternative for the manufacturer's viscosity method (2OºC, 0.3 RPM, Spindle LV1, 500 mL fluid, 600 mL beaker, 33 min 20 s, Grd leg). Calibration tests show a 1.0:1.3 ratio for the 10 mL:500 mL procedures.

Note: HOT table viscosity for Fluid C2: 36000 mPa
HOT table viscosity for Fluid D1: 5540 mPa
Adjusted (for small sample adaptor) HOT table viscosity for Fluid D1: 4260 mPa

The viscosity manufacturer's method for Fluid D1 is 0.3 r/min, 20ºC, Spindle LV1, 500 mL fluid, 600 mL beaker, 33 min 20 s, guard leg. Due to small amounts of fluid recoverable from the wing, and in order to avoid removing large quantities of fluid, the method for viscosity measurement actually used was 20ºC, 0.3 r/min, Spindle SC4-31/13R, 10 mL fluid, 33 min 20 s. Calibration of undisturbed fluid was conducted prior to the test to provide a comparison between viscosity readings using the manufacturer's specification of 500 mL of fluid and readings of 10 mL samples.

Tests showed a 1.0:1.3 ratio for the 10 mL: 500 mL procedures. The HOT table viscosity for Fluid D1 was 5 540 mPa.s. Using the 10 mL suggested method, the adjusted HOT table viscosity for Fluid D1 was 4 260 mPa.s.

3.2.2 Full-Scale Standard Spray Test #2

Fluids B2 and E1 were used during these tests. The standard spraying effect was tested with two Deicing Vehicle Types (DVT1 and DVT2). With Fluid B2, only the DVT1 truck (using the conventional Type IV spray nozzle) was used. Both fixed and moving sprayers were tested. Moving sprayers were manipulated by an operator.

For each run, fluid samples were lifted from different parts of the wing: the leading edge (LE) and front; and the trailing edge (TE) and rear. The samples were brought to the APS laboratory and viscosity measurements were taken. The samples were also used to estimate change in fluid density attributable to aeration. Viscosity measurements taken seven days after spraying are summarized in Table 3.6.

For Fluid E1, the viscosity method usually used is LV2, 250 mL beaker, 250 mL fluid, 0.3 r/min, 20ºC, 10 min, guard leg. The manufacturer provided an equivalent viscosity method involving small fluid quantity. The adjusted method was SC4-31, 10 mL fluid, 0.3 r/min, 20ºC, 10 min.

When lifted fluid from the wing was sufficient, viscosity was tested on centrifuged and non-centrifuged samples. A manual centrifuge was used for this purpose.

3.2.3 Full-Scale Standard Spray Test #3

Only one fluid (Fluid B3) was tested using a DVT3. Four runs were performed using the conventional spray nozzle. Three runs were conducted with aircraft nose into the wind, one with aircraft tail into the wind. Various distances separating the nozzle from the wing were tried.

The fluid supplier representatives took samples from each run for viscosity measurement. Small samples were also taken back to the APS laboratory to check viscosity and to estimate the effect of any aeration on the specific gravity of the fluid. The viscosity runs were conducted approximately seven days after spraying. The results are provided in Table 3.7.

Table 3.6: Standard Application Effect on Type IV Fluid Viscosity: Summary for Full-Scale Standard Spray Test #2

Run #	Fluid Type	Truck Type	Sprayer Position	Comments	Specific Gravity	Viscosity (APS) (mPa.s) *	
						Centrifuged	Non Centrifuged
Truck tank	E1	DVT1	--	--	0.968	16 600	--
Run #1_E1	E1	DVT1	Fixed	--	1.005	10 800	12 100
Run #2_E1	E1	DVT1	Moved by Operator	--	1.012	14 400	--
Run #3_E1	E1	DVT2	Fixed	Down Wind From TE	0.988	13 400	15 000
Truck tank	B2	DVT1	--	--	--	26 394	--
Run #1_B2	B2	DVT1	Fixed	Down Wind From TE	1.022	21 200	22 000
Run #2_B2	B2	DVT1	Moved by Operator	Down Wind From TE	1.009	--	23 800

* Viscosity method used: for Fluid B2: SC4-34, 10 mL fluid, 0.3 r/min, 20°C, 15 min; for Fluid E1: SC4-31, 10 mL fluid, 0.3 r/min, 20°C, 10 min.

Notes:

1. When fluid samples are sufficient, viscosity measurements are double-checked and the average value is reported.
2. The specific gravity is measured at ambient temperature.
3. Fluid B2: the HOT table viscosity stated according to the manufacturer's method is 18 000 mPa.s (using the manufacturer's viscosity method).
4. Fluid E1: the adjusted HOT table viscosity is 14 500 mPa.s (using the adjusted manufacturer's viscosity method that involves a small fluid quantity).

Table 3.7: Standard Application Effect on Type IV Fluid Viscosity: Summary for Full-Scale Standard Spray Test #3

Run #	Sprayer Position	Distance from the Wing (m)	Location on Wing	Comments	Density (kg/L)	Viscosity (mPa.s)*
Truck tank	NA	--	--	--	1.05	26 400
Run #1_B3	Ahead of wing; downwind	3	Port	--	1.03	24 195
		6			1.01	24 995
Run #2_B3	NR	3	Starboard	Light fluid application; some LE missed	1.04	22 395
		9			1.01	23 595
Run #3_B3	NR	5	Port	Operator moved farther back to get fluid on LE	1.00	26 594
		9			1.00	24 595
Run #4_B3	Ahead of wing; upwind	3	Starboard	Aircraft turned so tail into wind	0.98	24 795
		9			NR	26 194

NR: Not Reported

* Centrifuged; viscosity method used: SC4-34, 10 mL fluid, 0.3 r/min, 20°C, 15 min.
Note: The specific gravity is measured at room temperature.

3.2.4 Full-Scale Standard Spray Test #4

Only one fluid (Fluid C3) was tested using the DVT4. A standard application test was conducted downwind from a fixed nozzle position. Fluid samples were collected from the Leading Edge (LE) of the wing and from the truck. Viscosity measurements were obtained (after approximately six days) in the fluid manufacturer's laboratory. Samples were also taken to the APS laboratory to measure viscosity and to take specific gravity measurements. A summary of the results is displayed in Table 3.8.

Table 3.8: Standard Application Effect on Type IV Fluid Viscosity: Summary for Full-Scale Standard Spray Test #4

Run #	Viscosity (mPa.s) *
Truck tank	44 200
Run #1_C3	43 200

* Centrifuged; viscosity method used: SC4-31, 10 mL fluid, 0.3 r/min, 0°C, 10 min.
Notes:
1. Approximate distance of the nozzle from the wing: 6 m.
2. Sample collected from the LE.
3. Sprayer orientation: from wing tip downwind.

3.2.5 Full-Scale Standard Spray Test #5

Aircraft wings were sprayed with Fluid C4. Tests were conducted over three days, March 6, 11 and 12, 2002. A sample was collected from each of the aircraft wings before the application of the simulated freezing rain (ZR) precipitation. For the purpose of this report, a total of ten samples were collected and compared to undisturbed fluids extracted from the trucks.

Table 3.9 gives a summary of the viscosity values of these ten samples. Values are compared to the average of four truck sample viscosities. Measurements were obtained approximately 15 days after spraying. The reported viscosities are based on the average of at least two measurements. The method used to conduct the tests was consistent with the manufacturer's stated method (SC4-31, 10 mL fluid, 0.3 r/min, 0°C, 10 min, centrifuged).

3.3 Endurance Time Tests

Endurance time testing was carried out at the NRC CEF from April 16 to 23, 2002. The use of five Type IV fluids was scheduled; however, only four were tested (Fluid C5, Fluid D2, Fluid F, and Fluid G). Tests were conducted in eight simulated weather conditions (precipitation type/rate and chamber temperature were varied). Table 3.10 provides a log of the tests conducted and includes the set conditions, the application procedure, the viscosity measurements, and the HOT results. Collected data and data processing are described in Subsections 3.3.1 to 3.3.3 for all the days of testing.

3.3.1 Day 1 (April 16)

On April 16, the first day of testing, one litre of Type I fluid at ambient temperature was poured on one of the two skirted plates (denoted as skirt + plate). Fluid G was then sprayed on both (with and without Type I) skirted plates. Skirts surrounding the plates were removed and drained for fluid sampling. Because these samples were collected under precipitation, the possibility of contamination with precipitation existed. Type IV fluid was then poured on a third plate. The HOT procedure was followed for each of the three test plates to determine the respective endurance times. Viscosity measurements of the sprayed fluid were obtained later the same day. The sample was centrifuged for 5 minutes (3 600 r/min).

Table 3.9: Standard Application Effect on Type IV Fluid Viscosity: Summary for Full-Scale Standard Spray Test #5 (Ottawa – March 11-12, 2002)

Truck Sample	Bottle #	Date	Run #	Viscosity (mPa.s)*
Sample from Truck #1	24	Mar-06-02	NR	43 300
Sample from Truck #2	25	Mar-12-02	1+2	42 450
Sample from Truck #3	26	Mar-12-02	1+2	41 300
Sample from Truck #4	27	Mar-12-02	1+2	43 500
Average of the Truck Samples				**42 637**

After Fluid Spray (Before ZR Precip.)	Bottle #	Date	Run #	Viscosity (mPa.s)*	Deviation from the Average Truck Sample Viscosity
After Fluid Spray	4	Mar-6-02	4	38 450	-11%
After Fluid Spray	5	Mar-6-02	5	42 450	-0.4%
Port Before Rotation	6	Mar-11-02	1	45 550	+7%
Starboard Before Rotation	8	Mar-11-02	1	42 950	+1%
Port Before Rotation	10	Mar-11-02	2	44 450	+4%
Starboard Before Rotation	12	Mar-11-02	2	43 650	+2%
Port Before Rotation	14	Mar-12-02	1	31 350	-26%
Starboard Before Rotation	17	Mar-12-02	1	32 000	-25%
Port Before Rotation/ Before Contamination	20	Mar-12-02	2	43 050	+1%
Starboard Before Rotation/ Before Contamination	22	Mar-12-02	2	42 300	-1%

*Viscosity method: 0.3 rpm, 0^{o}C, Spindle SC4-31, 10 mL, 10 min, centrifuged.
NR: Not Reported.

Table 3.10: Summary of the Endurance Time Tests (NRC, April 2002)

Test #	Date (Sequence)	Precipitation Type	Temperature (°C)	Actual Precipitation Rate (g/dm²/h)	Type IV Fluid	Application Procedure	Comments	Viscosity * (mPa.s)	HOT (min)
1	April 17 [2]	Freezing Drizzle	-10	12.9	Fluid F	Poured	Type I poured at 60°C; waited 3 min before spraying; no contamination; samples collected away from precipitation	6780	27
2	April 17 [2]	Freezing Drizzle	-10	12.7	Fluid F	Sprayed		6680	26
3	April 17 [2]	Freezing Drizzle	-10	13.4	Fluid F	Sprayed + Type I		6600	27
4	April 17 [3]	Freezing Drizzle	-10	13.5	Fluid C5	Poured	Type I poured at 60°C; waited 3 min before spraying; no contamination; samples collected away from precipitation	48700 **	56
5	April 17 [3]	Freezing Drizzle	-10	12.9	Fluid C5	Sprayed		43950 **	48
6	April 17 [3]	Freezing Drizzle	-10	13.2	Fluid C5	Sprayed + Type I		42400 **	29
7	April 17 [1]	Freezing Drizzle	-10	12.4	Fluid G	Poured	Type I poured at 60°C; waited 3 min before spraying; risk of contamination while pouring Type I	26700 **	56
8	April 17 [1]	Freezing Drizzle	-10	12.6	Fluid G	Sprayed		25100 **	55
9	April 17 [1]	Freezing Drizzle	-10	13.4	Fluid G	Sprayed + Type I		23500 **	52
10	April 16	Freezing Drizzle	-10	5.2	Fluid G	Poured	Type I at ambiant temp.; fluids collected under precip.; risk of contamination	26700 **	108
11	April 16	Freezing Drizzle	-10	5.2	Fluid G	Sprayed		24900 **	121
12	April 16	Freezing Drizzle	-10	5.2	Fluid G	Sprayed + Type I		10700 **	31
13	April 22	Freezing Drizzle	-3	5.3	Fluid C5	Poured	Skirt was eliminated; Type I poured at 60°C; waited 3 min before spraying; no contamination; samples collected away from precipitation; viscosity run was conducted in situ only on the sprayed Type IV fluids	48700 **	113
14	April 22	Freezing Drizzle	-3	5.2	Fluid C5	Sprayed		47400 **	106
15	April 22	Freezing Drizzle	-3	5	Fluid C5	Sprayed + Type I		44300 **	100
16	April 19	Freezing Drizzle	-3	12.7	Fluid D2	Poured		8260	114
17	April 19	Freezing Drizzle	-3	12.8	Fluid D2	Sprayed		3610	99
18	April 19	Freezing Drizzle	-3	13.2	Fluid D2	Sprayed + Type I		4520	64
19	April 18 [2]	Light Freezing Rain	-10	25.1	Fluid D2	Poured		8260	24
20	April 18 [2]	Light Freezing Rain	-10	24.9	Fluid D2	Sprayed		5270	19
21	April 18 [2]	Light Freezing Rain	-10	24.7	Fluid D2	Sprayed + Type I		4520	11
22	April 18 [1]	Light Freezing Rain	-10	13.2	Fluid D2	Poured		8260	46
23	April 18 [1]	Light Freezing Rain	-10	12.9	Fluid D2	Sprayed		5160	32
24	April 18 [1]	Light Freezing Rain	-10	12.5	Fluid D2	Sprayed + Type I		4520	31
25	April 23 [1]	Light Freezing Rain	-3	24.2	Fluid C5	Poured		48700 **	49
26	April 23 [1]	Light Freezing Rain	-3	24.7	Fluid C5	Sprayed		47400 **	41
27 ***	April 23 [1]	Light Freezing Rain	-3	24.9	Fluid C5	Sprayed + Type I		44300 **	31
28	April 23 [2]	Light Freezing Rain	-3	12.9	Fluid C5	Poured		48700 **	62
29	April 23 [2]	Light Freezing Rain	-3	13.2	Fluid C5	Sprayed		47400 **	54
30 ***	April 23 [2]	Light Freezing Rain	-3	12.9	Fluid C5	Sprayed + Type I		44300 **	47

* Measured according to standard methods (reported in subsection 2.3.6).
** Centrifuged for 5 min at 3600 rpm.
***Plates 27 and 30 were re-tested. Type IV was sprayed right after pouring Type I fluid (without waiting for 3 minutes).
The holdover times are almost unchangeable: 31 min for Plate 27-A and 46 min for Plate 30-A.

3.3.2 Day 2 (April 17)

A small change was proposed for tests using Fluid G (April 17, [1][1]). To reproduce the real-life deicing and anti-icing procedures, Type I fluid was poured at 60°C. Fluid G was sprayed three minutes after the Type I fluid was poured. During these three minutes, the plate covered with Type I was exposed to precipitation, causing a risk of contamination for that plate.

A metal rate pan was used to collect the sprayed Type IV fluid. Immediately after spraying, that rate pan and the skirt containing mixed Type I and Type IV fluids were taken away to avoid contamination from precipitation. The fluids were drained into bottles. Type IV fluid was then poured onto a third plate.

The endurance times were determined for the three test plates. Viscosity measurements of the sprayed Type IV fluid were carried out later the same day (Test #8). The sample was centrifuged for 5 min at 3 600 r/min before measurement.

In tests using Fluid F (April 17, [2]), plates were cleaned according to the standard procedure. To avoid contamination, an assistant provided cover while the plates were cleaned and the fluids were poured. The rest of the procedure was the same as that used for Fluid G.

To collect fluid samples (sprayed Type IV and "Type I + sprayed Type IV") for viscosity runs, a separate spraying sequence was conducted at the other end of the chamber, under no precipitation. Three clean plates and two metal rate pans were used for this purpose. Two litres of Type I fluid were poured on the three plates. After three minutes, Fluid F was sprayed at the same time on all five positions (3 plates and 2 rate pans). Samples were collected and labelled. A viscosity run was carried out in situ on the sprayed Type IV only. For Fluid F, the sample was not centrifuged because the viscosity measurement method involves a big sample (500 mL).

Tests with Fluid C5 (April 17, [3]) were conducted using the same procedure for Fluid F. Samples were taken under no precipitation. Only the viscosity of the sprayed Type IV was measured that day. The sample was centrifuged for five minutes before measurement.

[1] The bracketed numbers designate the sequence of the tests conducted that particular day.

3.3.3 Day 3 (April 18), Day 4 (April 19), Day 5 (April 22) and Day 6 (April 23)

In subsequent testing days, there were no major changes to the procedure. Pertinent details and comments for each set-up/fluid are provided in Table 3.10. The skirt was eliminated since it did not have an effect on the behaviour of the sprayed fluid.

3.3.4 General Comments

Plates 27 and 30 were re-tested. Type IV fluid was sprayed immediately after warm Type I fluid was poured (without a 3 minute delay). Holdover times were almost unchanged: 31 minutes for Plate 27-A (versus 31 minutes for Plate 27) and 46 minutes for Plate 30-A (versus 47 minutes for Plate 30). Tests were not duplicated because of time constraints and control costs. Brix and fluid thickness were not measured as planned in the procedure.

Over the next 15 days, viscosity measurements were obtained in the APS laboratory using standard manufacturer's viscosity methods (reported in Subsection 2.3.7) on all samples that were not measured in situ. The endurance time for each test plate was compiled. The results are provided in Table 3.10.

3.3.5 Summary of Changes to the Procedure

The following four modifications were made to the procedure:

a) Type I fluid was warmed to 60°C before pouring it;

b) With respect to the maximum allowable time lag of 3 minutes that exists between Type I and Type II/IV in a two-step operation, two sets of spray endurance tests had to be conducted. One test reflected the maximum recommended exposure to precipitation that is allowed between the Type I spray and the spray application of Type II/IV. This was replicated by pouring Type I on the plates and exposing the plates to 3 minutes of precipitation; after that, Type II/IV was sprayed. The second test reflected a situation of almost no time lag between Type I fluid and Type II/IV fluid sprays. To replicate this operation, Type I was poured and Type II/IV was sprayed immediately afterward;

c) Sampling of sprayed fluids was conducted away from precipitation. This required an additional set of plates for spray tests sprays under no precipitation; and

d) The use of the skirt was eliminated from the procedure because it had no tangible effect on sprayed fluid behaviour.

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4. ANALYSIS AND OBSERVATIONS

This chapter presents the test results and analysis for the different sub-projects. Discussions and observations are included.

4.1 Preliminary Spray Tests

This subsection documents the relevant analysis of data collected from the preliminary spray tests and the observations derived from these tests. Variables affecting the fluid viscosities are discussed and the degradation of undisturbed fluids over time is analysed. A complete documentation of sprays that included Type I fluid with Type IV fluid is available in Appendix F.

The procedure followed for most tests was to pour Type I fluid on the airfoil, followed by a spray of Type IV fluid. A sample was then lifted from the wing and viscosity measurements were obtained. There was a significant degradation in the viscosity of the composite fluid that was collected. The uncontrolled amount of Type I mixed in with Type IV led to the observation that the data collection was not repeatable.

4.1.1 Variables Affecting the Preliminary Spray Tests

The main purpose of these tests was to evaluate on-wing viscosity in the first minutes after spraying. Several variables probably affect on-wing fluid viscosity and are important to note in the analysis of results. These variables are based mainly on test observations; they include fluid temperature, fluid shearing, and Type I and Type IV fluid mixing.

4.1.1.1 Fluid temperature

One of the most obvious factors that can affect the behaviour of fluid viscosity is temperature. Some materials are quite sensitive to temperature; a relatively small variation can lead to a significant change in viscosity. Others are relatively insensitive. It is essential to consider the effect of temperature on viscosity when evaluating deicing and anti-icing fluids, which are subjected to temperature variations during processing. In normal field operations, anti-icing fluid temperature depends on the outdoor conditions (OAT, wind speed, etc.), and the average reservoir temperature (parked inside or outside; filled with hot Type I fluid or not). In future work, an average temperature should be estimated to reflect real-life application. To be representative of most of the field conditions, anti-icing fluids should be applied during the HOT tests at that average temperature.

4.1.1.2 Fluid shearing

What has happened to a sample before viscosity measurement can significantly affect the result, especially with fluids sensitive to heat or aging. Storage conditions, handling, pumping, and sample preparation techniques could affect subsequent viscosity tests. When a material is subjected to a variety of shear rates in processing or use (such as pumping), it is essential to know its viscosity at the projected shear rates.

4.1.1.3 Type I and Type IV mixing

There were two major steps in the on-wing viscosity test procedure: pouring the Type I fluid and spraying the Type IV fluid. The viscosity of the collected sample (mix of both fluids) is definitely affected by the Type I fluid (less viscous) remaining on the wing.

4.1.2 Summary of the Results for Preliminary Spray Tests to Measure Immediate Effect on Fluid Viscosity

All tests show that after 30 minutes, the viscosity of undisturbed Type IV fluids is higher than that of sprayed fluids collected from the wing. The decrease in viscosity is related to the shearing effect and also to the addition of Type I fluid.

According to the conducted tests, air trapped in the fluid seems to increase the viscosity of some fluids (A and B1) and decreases it for others (Fluid C1).

Viscosity took an average of 10 minutes to stabilize in situ. Analysing the viscosity behaviour of sprayed fluids within the first few minutes is not easy: samples need several minutes to reach a stable temperature. For that reason, it was decided that the most conclusive way to study the influence of the application procedure would be to conduct a series of tests with Type IV fluids comparing endurance times. This was done in the endurance time tests (sub-project 3); the results are discussed in Subsection 4.3.

4.1.3 Fluid Degradation Due to Storage

To study fluid degradation over time (in the case of prolonged storage), viscosity measurements were conducted over 16 months on undisturbed fluids A, B1, and C1. Readings taken after 30 minutes were compared to the initial measurements taken in situ. The results are summarized in Figures 4.1, 4.2 and 4.3.

The data demonstrates that the effect of degradation on undisturbed fluid viscosity could be an issue. The extent of changes in viscosity depends on the fluid product. Over the period of sixteen months, viscosity dropped by 67 percent for Fluid A, by 43 percent for Fluid B1, and by 16 percent for Fluid C1 (Table 4.1). The viscosity values for all fluids tested closely approached the corresponding HOT table viscosities (Figures 4.1 to 4.3). Storage of some Type IV fluids for a year could change their performance.

Table 4.1: Viscosity Decrease over Time for Fluids A, B1, and C1

Period of Time	Viscosity Decrease Relative to the Initial Measurement (%)		
	A	B1	C1
After 6 months	52%	11%	9%
After 11 months	52%	37%	15%
After 16 months	67%	43%	16%

In addition, based on recent discussions with deicing operators, two other forms of Type IV fluid degradation could be possible:

a) Repetitive cooling and heating:
During de/anti-icing operations, heat exchange may occur inside the truck between the heated Type I fluid (at a temperature varying between 20ºC and 60ºC) and the Type IV fluid. The effect of repetitive cooling and heating of a Type IV fluid could involve changes to its performance; and

b) Layering of fluid:
After being stored for long periods of time, Type IV fluids have been found to layer in large tanks, leading to changes in their characteristics. Mixing may be required in advance of anti-icing operations.

Because these two issues were exposed recently, exploratory tests have not been carried out but have been recommended.

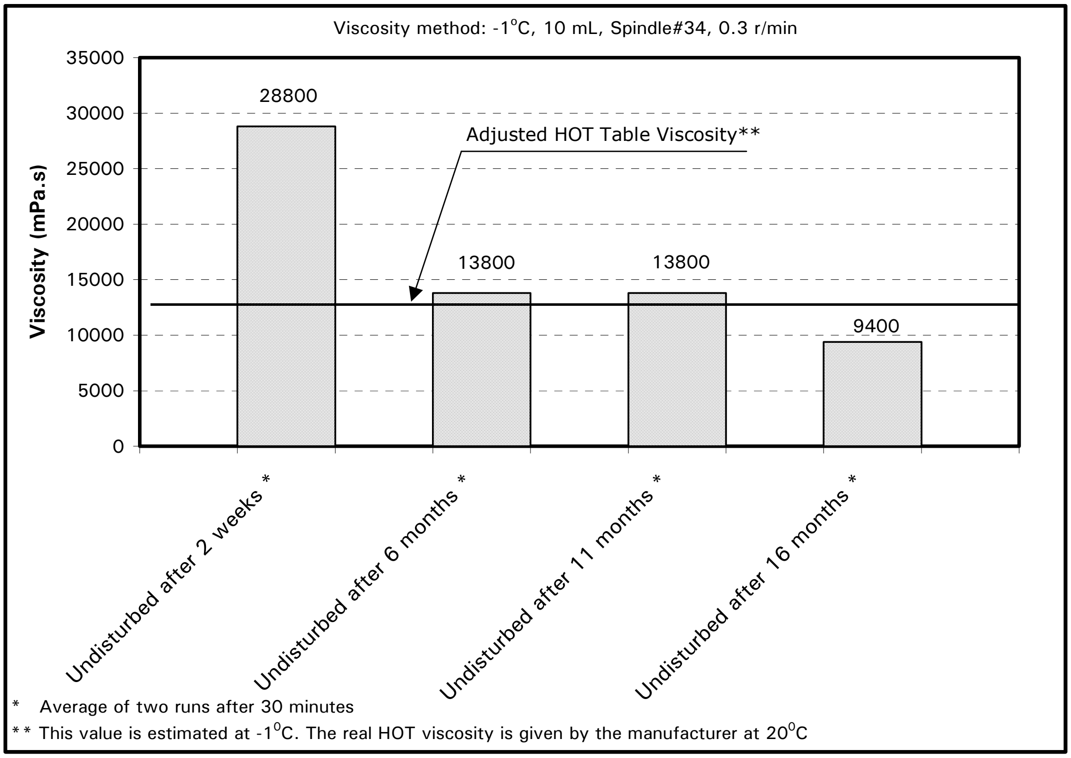

Figure 4.1: Time Effect on Viscosity for Fluid A After 16 Months

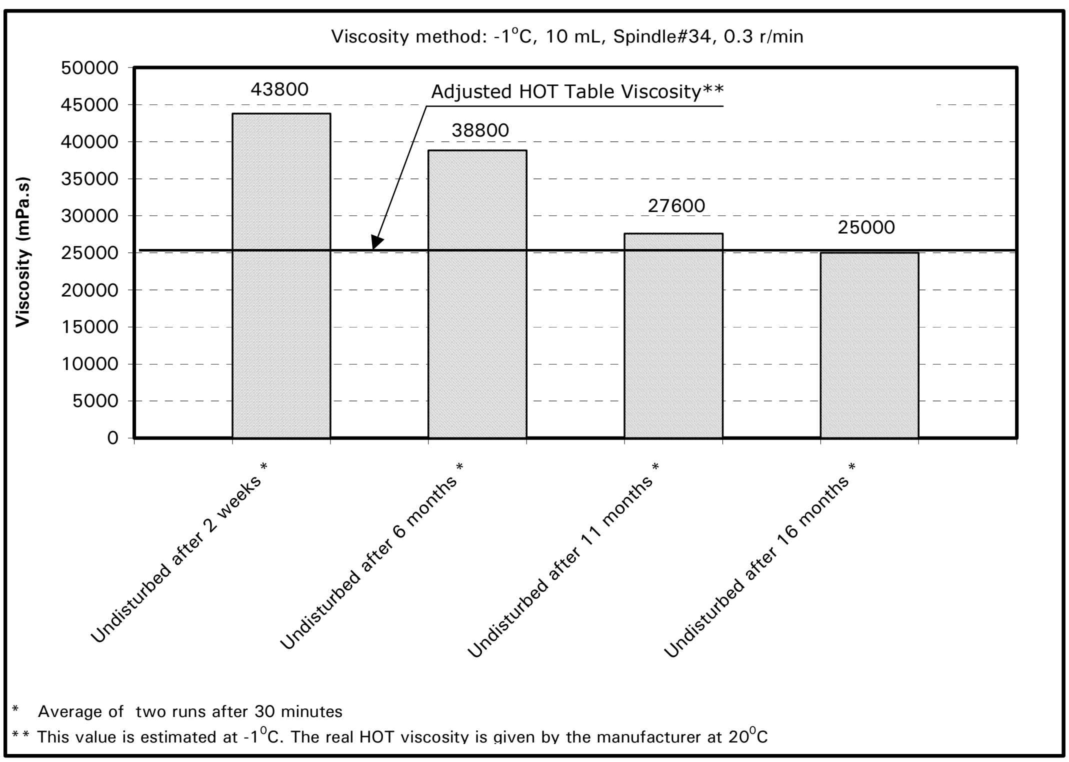

Figure 4.2: Time Effect on Viscosity for Fluid B1 After 16 Months

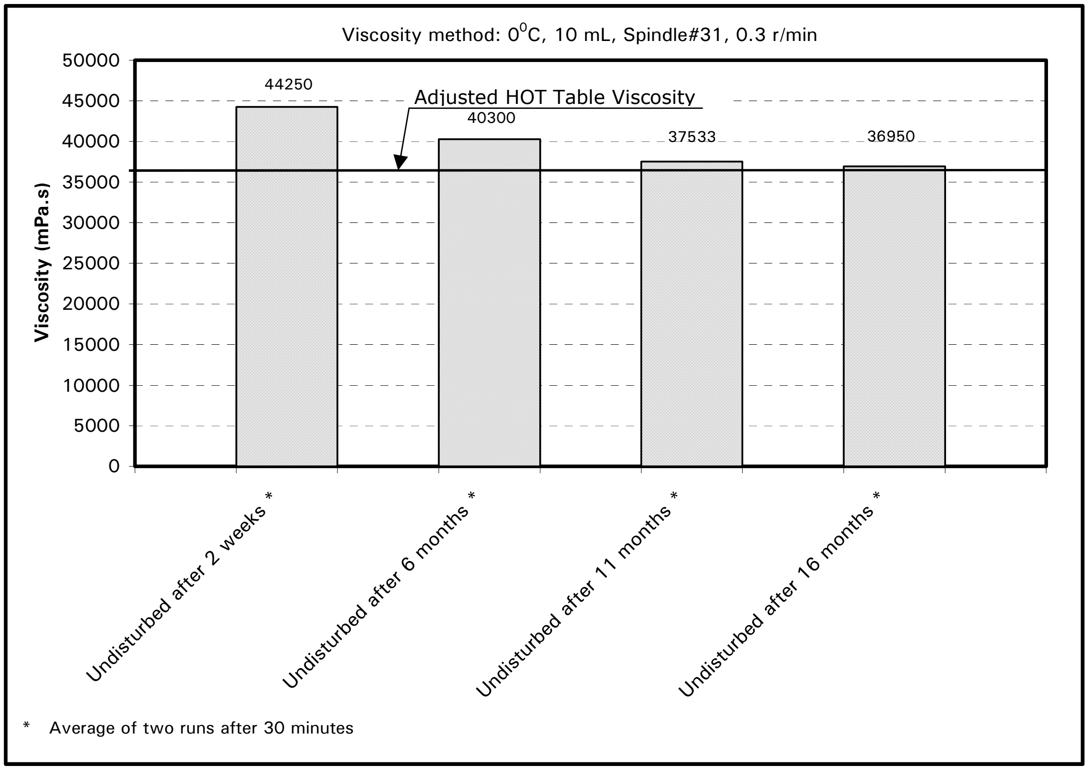

Figure 4.3: Time Effect on Viscosity for Fluid C1 After 16 Months

4.2 Full-Scale Standard Spray Tests

Aircraft wings were sprayed by trained deicing operators using a one-step application method. Fluid samples were collected and the viscosity was then measured. Analysis of the results for the five full-scale standard spray tests is presented in Subsections 4.2.1 to 4.2.5.

4.2.1 Full-Scale Standard Spray Test #1

Figure 4.4 shows comparative viscosity values for Fluid C2 taken from the truck and prior to the standard application. Results for Fluid D1 are presented in Figure 4.5. Elapsed time before viscosity measurement and manipulations of the sample prior to measurement (centrifuged or un-centrifuged) are also indicated.

For the two fluids tested, the viscosity of undisturbed Type IV fluid (taken from the truck), similar to how it would be applied to a plate for holdover time tests, was higher than that of the sprayed fluids collected from the wing. This observation corroborates the results from the preliminary spray tests, giving rise to the same conclusion that the shearing influence depends on the fluid brand.

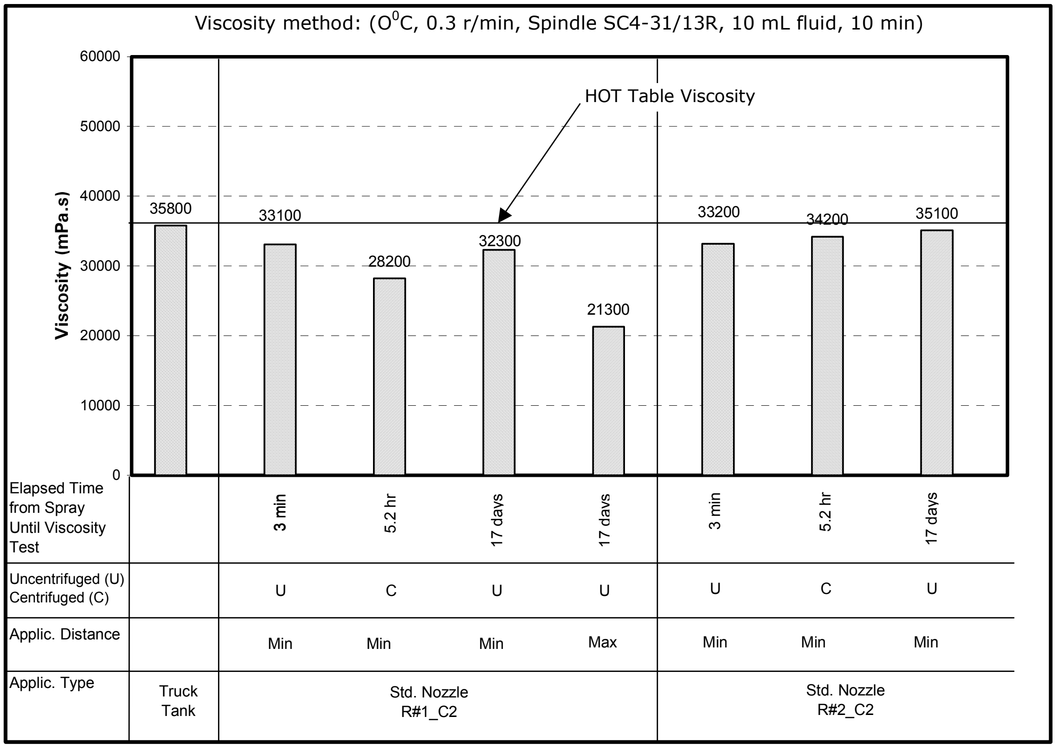

Figure 4.4: Standard Application Effect on Viscosity of Fluid C2: Full-Scale Standard Spray Test #1

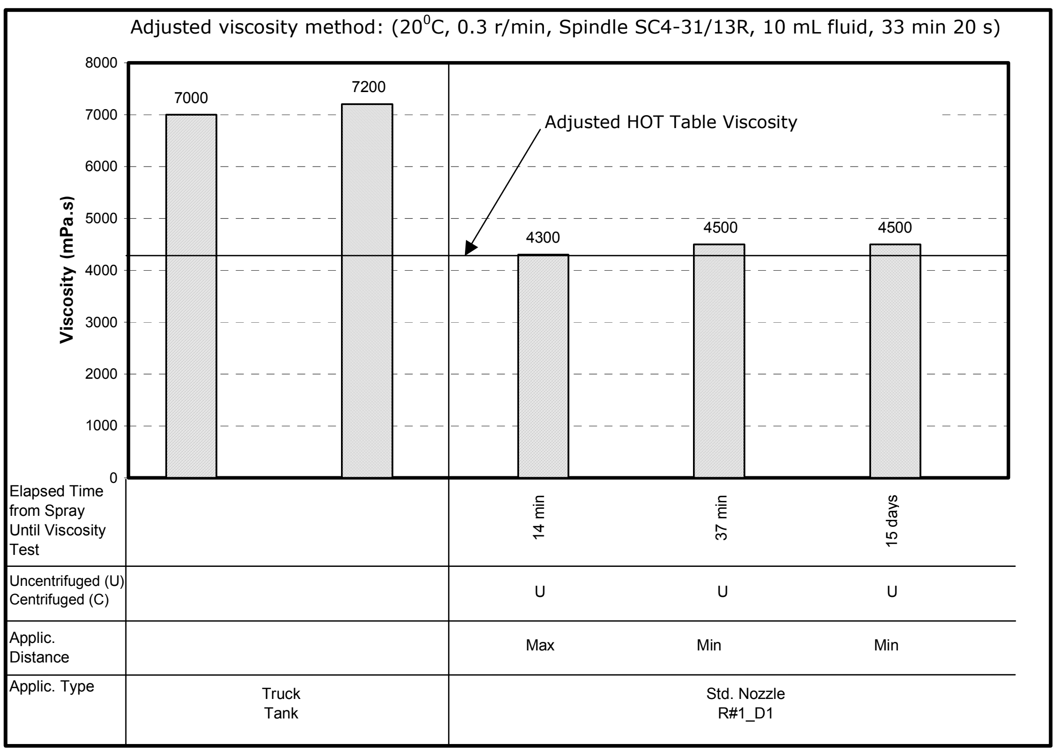

Figure 4.5: Standard Application Effect on Viscosity of Fluid D1: Full-Scale Standard Spray Test #1

As shown in Figure 4.4 and Figure 4.5, Fluid C2 and Fluid D1 were affected by the standard application: their viscosities dropped (average deviation from the truck sample) by approximately 12 and 38 percent, respectively.

4.2.2 Full-Scale Standard Spray Test #2

Two different types of trucks (DVT1 and DVT2) were used in these tests. Fluid B2 was tested only with the DVT1. The effect of both sprayers, fixed and moving (manipulated by an operator), was investigated. Results for the centrifuged samples are summarized in Figure 4.6 and Figure 4.7.

a) After spraying, the viscosity of Fluid B2 decreased but remained higher than the HOT table stated viscosity (compare bars b and c to HOT table viscosity). The moving sprayer seemed to affect the fluid viscosity more than the fixed sprayer (bar b versus bar c);

b) The stated method for Fluid E1 viscosity measurement is 0.3 r/min, 20ºC, Spindle #LV2, 250 mL beaker, 250 mL fluid, 10 min, with the guard leg. The manufacturer also recommended an equivalent method with 10 mL of fluid: 20ºC, 0.3 r/min, Spindle#31, 10 mL fluid, 10 min. Correlation from spindle #31 to spindle #LV2 was provided by the manufacturer. All viscosity measurements for Fluid E1 presented in this report are provided following the method 20ºC, 0.3 r/min, Spindle #31, 10 mL fluid, 10 min.;

c) Fluid E1 viscosity is affected by spraying. For all samples sprayed (bars e, f, and g), the measured viscosities were lower than the HOT table stated value. After spraying, the average spray sample viscosity was about 22 percent below the truck sample;

d) Using the conventional Type IV spray nozzle from a fixed position, the DVT1 truck seemed to affect fluid viscosity more than the DVT2 truck (bar e versus bar g); and

e) In contrast to Fluid B2, the moving sprayer affects the fluid viscosity of Fluid E1 less than the fixed sprayer (bar f versus bar e).

For both fluids tested, the centrifuged samples had a lower viscosity than the un-centrifuged samples (see Table 3.6).

Air trapped in these fluids seems to have decreased their consistency. Alternatively, analysis of Table 3.6 indicates that spraying had no effect on the density of Type IV fluids.

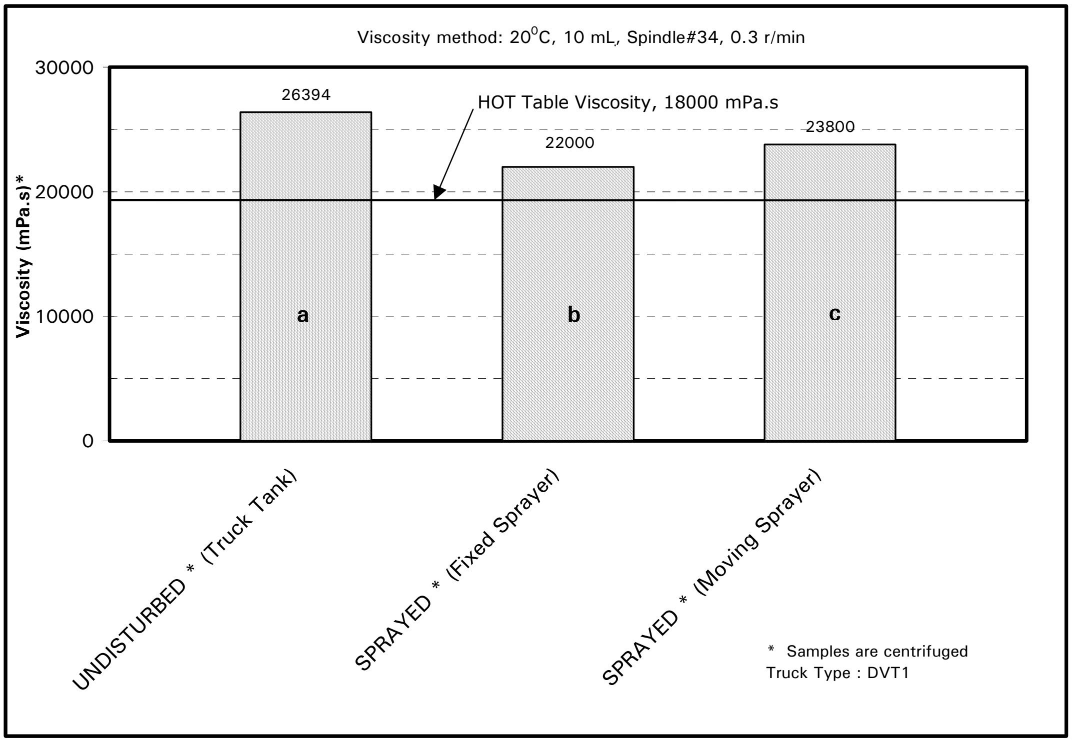

Figure 4.6: Standard Application Effect on Viscosity of Fluid B2: Full-Scale Standard Spray Test #2

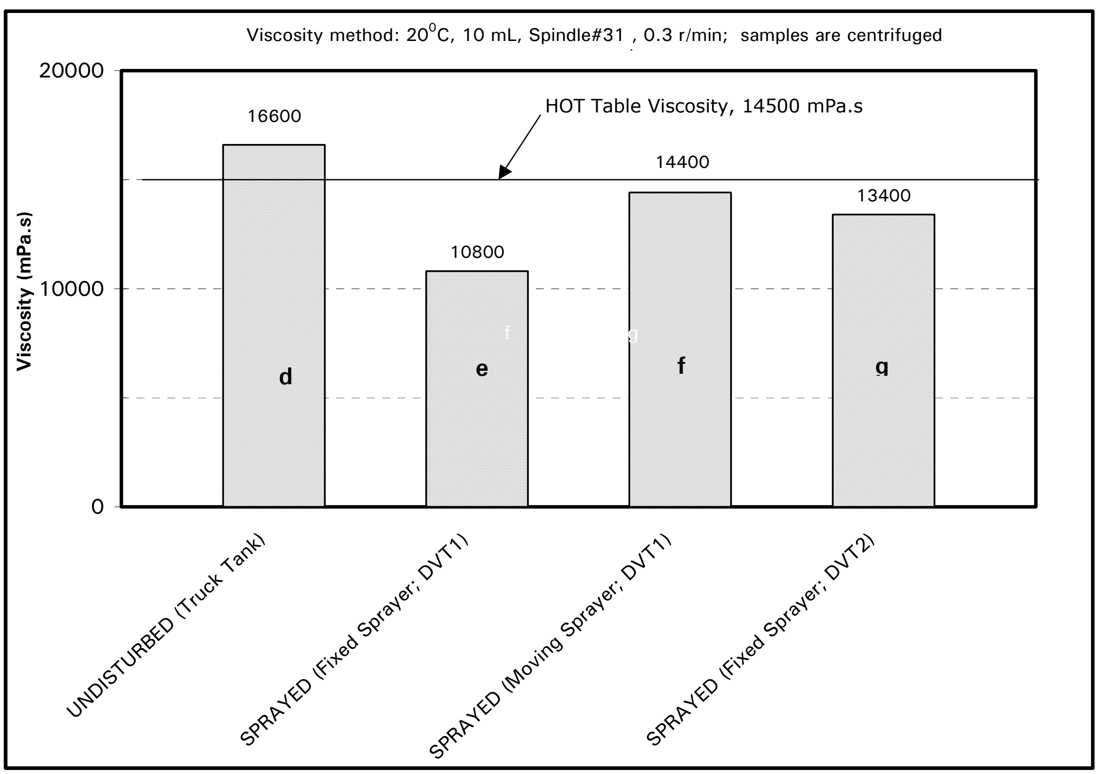

Figure 4.7: Standard Application Effect on Viscosity of Fluid E1: Full-Scale Standard Spray Test #2

4.2.3 Full-Scale Standard Spray Test #3

Fluid B3 was tested using DVT4 truck with a fixed design spray nozzle. The effect of standard application on on-wing viscosity samples is summarized in Figure 4.8.

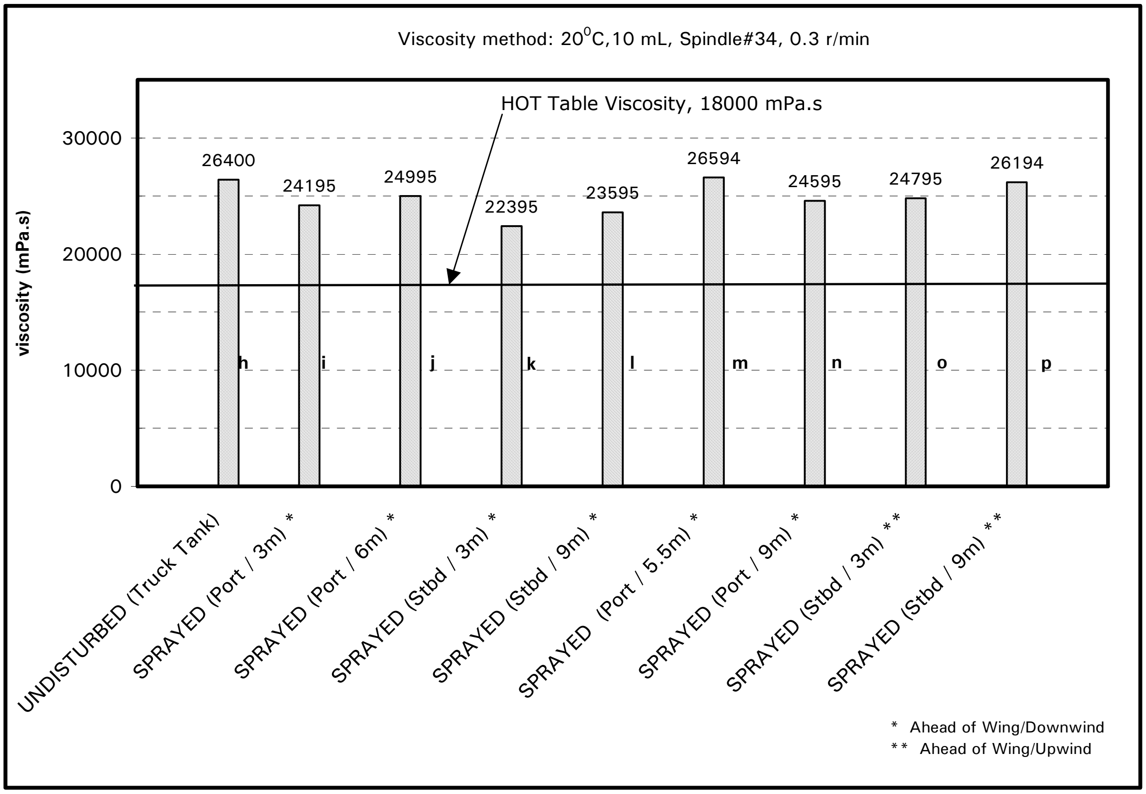

Figure 4.8: Standard Application Effect on Viscosity of Fluid B3: Full-Scale Standard Spray Test #3

The spraying effect was tested on port and starboard wings. Various distances separating the nozzle from the wing were tried. The effect of wind direction when spraying (downwind versus upwind) was tested. All the sprayed fluid samples had a viscosity higher than the values stated in the HOT table. The lowest value measured during these tests was 22 395 mPa.s (bar k). The undisturbed sample was expected to have the highest viscosity (bar h). The difference from the sprayed sample, represented with the "bar m", might be due to experimental errors. There were no substantial variations in fluid viscosity when the distance between nozzle and port wing varied from 3 to 9 m (bars i, j, m and n). This was confirmed on the starboard wing (bars k and l).

The spray direction (upwind versus downwind) did not affect the Type IV fluid viscosity. With an upwind spraying, the viscosity was higher by approximately 10 percent (bars o and p compared to bars k and l). This difference may be due to experimental error. Sprayed fluid behaved roughly the same way on both port and starboard wings (comparing bar j with bar k, and l with n).

With Fluid B3, shearing due to the standard application generally decreased viscosity (with an average of 7 percent). The viscosity range remains acceptable, however, since it is still above that of the fluid used for the endurance time testing. This corroborates results from the full-scale standard spray test #2.

4.2.4 Full-Scale Standard Spray Test #4

Only Fluid C3 was tested during these tests. The results are shown in Figure 4.9. The fluid was applied downwind and the sample was collected from the wing tip. Comparing the undisturbed fluid to the sprayed fluid, shearing did not seem to affect the viscosity as it did with Fluids B2 and E1. The viscosity of the sprayed fluid was still higher than the fluid used for the endurance time tests.

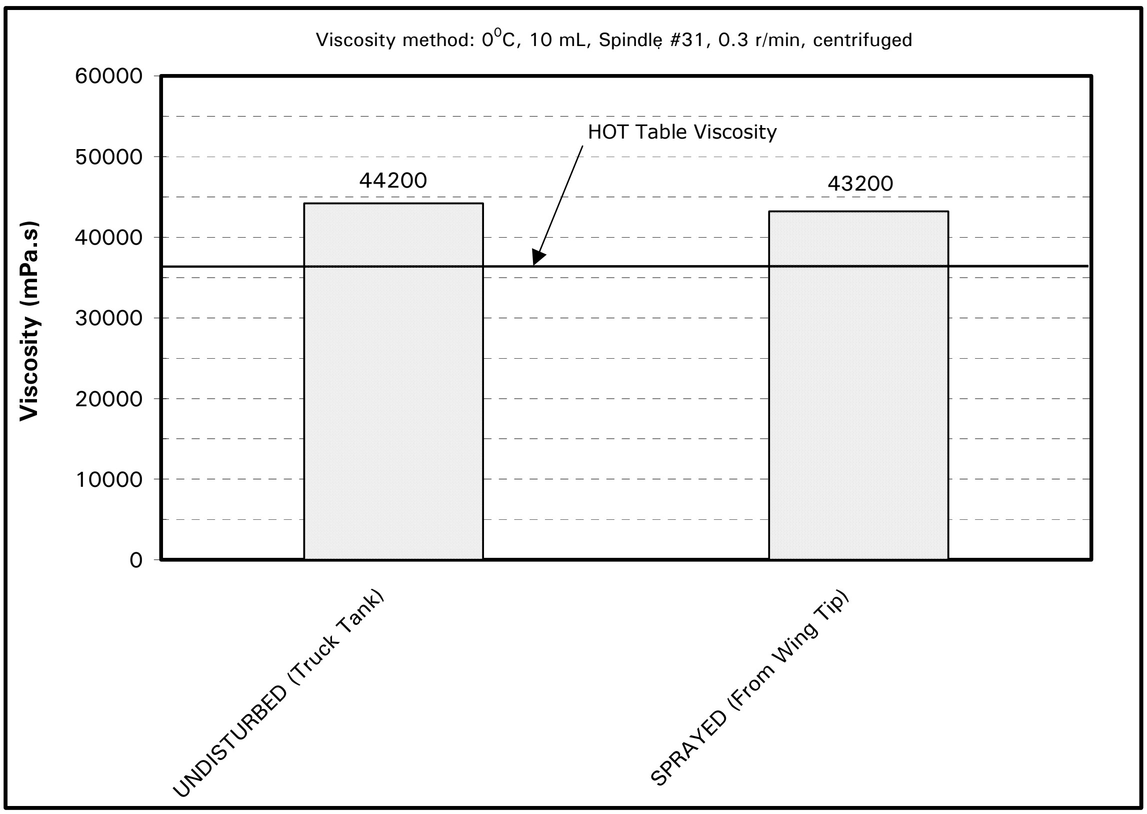

Figure 4.9: Standard Application Effect on Viscosity of Fluid C3: Full-Scale Standard Spray Test #4

4.2.5 Full-Scale Standard Spray Test #5

A total of ten samples of Fluid C4 were collected and tested for viscosity. Results were then compared to the viscosity of undisturbed samples taken from various trucks. All viscosity measurements related to this project are shown in Figure 4.10.

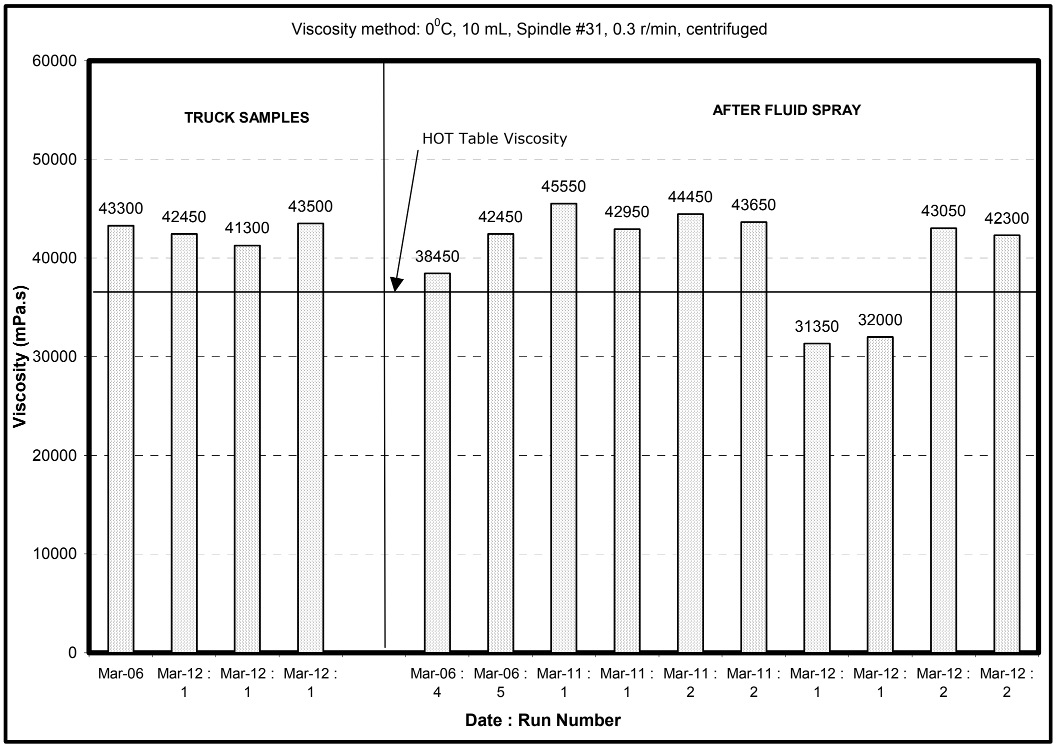

Figure 4.10: Standard Application Effect on Viscosity of Fluid C4: Full-Scale Standard Spray Test #5

Samples collected from all the trucks exhibited an average viscosity of 42 637 mPa.s (see Table 3.9). Table 3.9 shows the percentage of deviation from an average truck sample viscosity. The viscosity of the sample collected from the truck did not change significantly after spraying. However, two samples exhibited a viscosity that was at least 25 percent lower than the undisturbed fluid samples. This reduction is greater than the expected reduction of 15 percent implied in the holdover time table fluid viscosity; no specific reason can be given for this reduction.

In conclusion, it can be inferred that Fluid C4 does not exhibit a critical reduction in viscosity once it is sprayed on a wing by a one-step anti-icing operation. This is consistent with results from the full-scale standard spray test #1, and full-scale standard spray test #4, which are described in Subsections 4.2.1 and 4.2.4.

4.2.6 Summary of the Full-Scale Standard Spray Tests

Based on these full-scale standard spray tests, it is clear that the viscosity of undisturbed (taken from the truck) Type IV fluid, similar to how it would be applied to a plate for holdover time tests, is higher than that of sprayed fluids collected from the wing. Table 4.2 provides a summary of results for the five full-scale standard spray test sessions.

Table 4.2: Summary of the Full-Scale Standard Spray Tests

Test #	Fluid	Undisturbed (From Tank) (mPa.s)	After Spraying (Average) (mPa.s)	Deviation of Sprayed Viscosity from the Undisturbed Viscosity
Test #1	C2	35 800	31 446	-12%
	D1	7 100	4 433	-38%
Test #2	B2	26 394	22 795	-14%
	E1	16 600	12 867	-22%
Test #3	B3	26 400	24 670	-7%
Test #4	C3	44 200	43 200	-2%
Test #5	C4	42 637	40 663	-5%
Average				**14%**

The shearing influence depends on the fluid brand. Viscosity of Fluids C2, C3, and C4 dropped by an average of 12 percent, 2 percent and 5 percent, respectively. Fluid B was tested twice (full-scale standard spray tests #2 and #3) and exhibited a decrease in viscosity of 14 percent (Fluid B2) and 7 percent (Fluid B3). Fluids E1 and D1 were the most affected by the standard application: their viscosities dropped by an average of 22 percent and 38 percent, respectively. After the spray application, the viscosities of fluids E1 and D1 were lower than that of the fluids used for the endurance time tests. Results from full-scale standard spray test #2 indicated that the shearing effect might depend on the spray technique and equipment, including truck type and nozzle used.

4.3 Endurance Time Tests

During this sub-project, a series of ten tests was performed on three test plates. Each test was carried out to learn the effect of fluid application method (spray with or without Type I fluid, versus pouring) on the holdover time of Type IV fluid. By conducting viscosity measurements on fluids collected from each plate, the actual significance of viscosity change on holdover times was evaluated.

The collected data are summarized in Table 3.10. These data are also presented in Figures 4.11 to 4.18. Analysis of each fluid tested is provided in Subsections 4.3.1 to 4.3.4. For easier comparison, viscosity readings and endurance times of the sprayed samples are given in terms of deviation from the poured sample (taken from the drum), and are expressed in percentages.

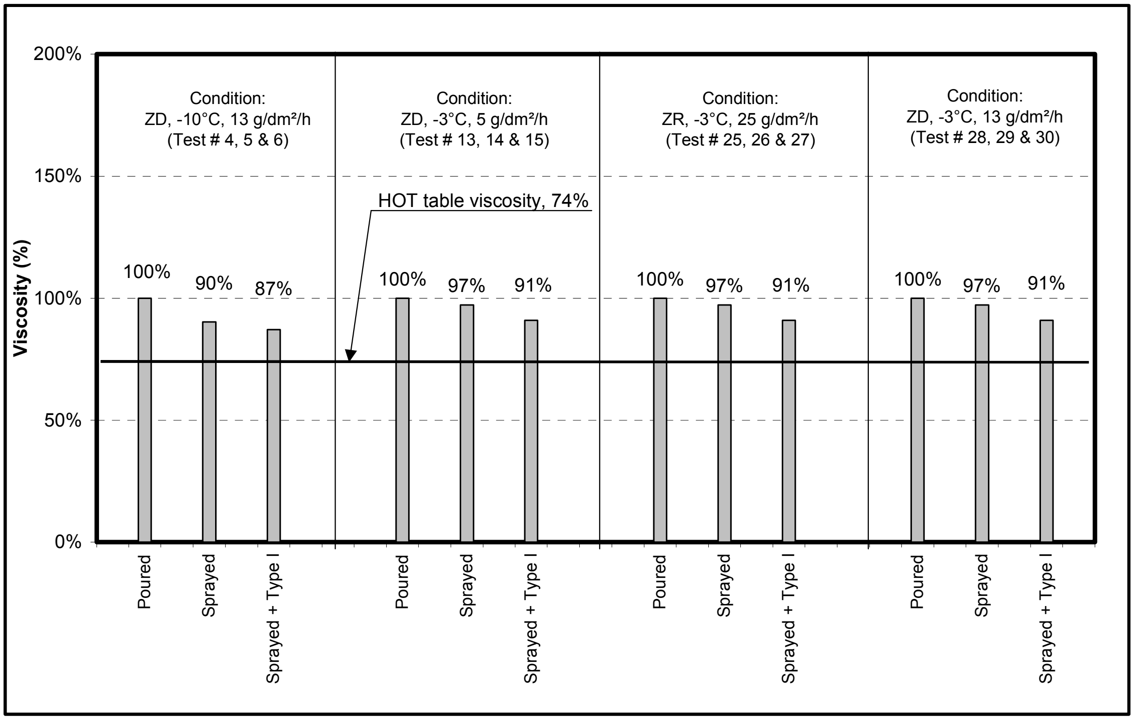

Figure 4.11: Effect of Standard Application on Viscosity for Fluid C5

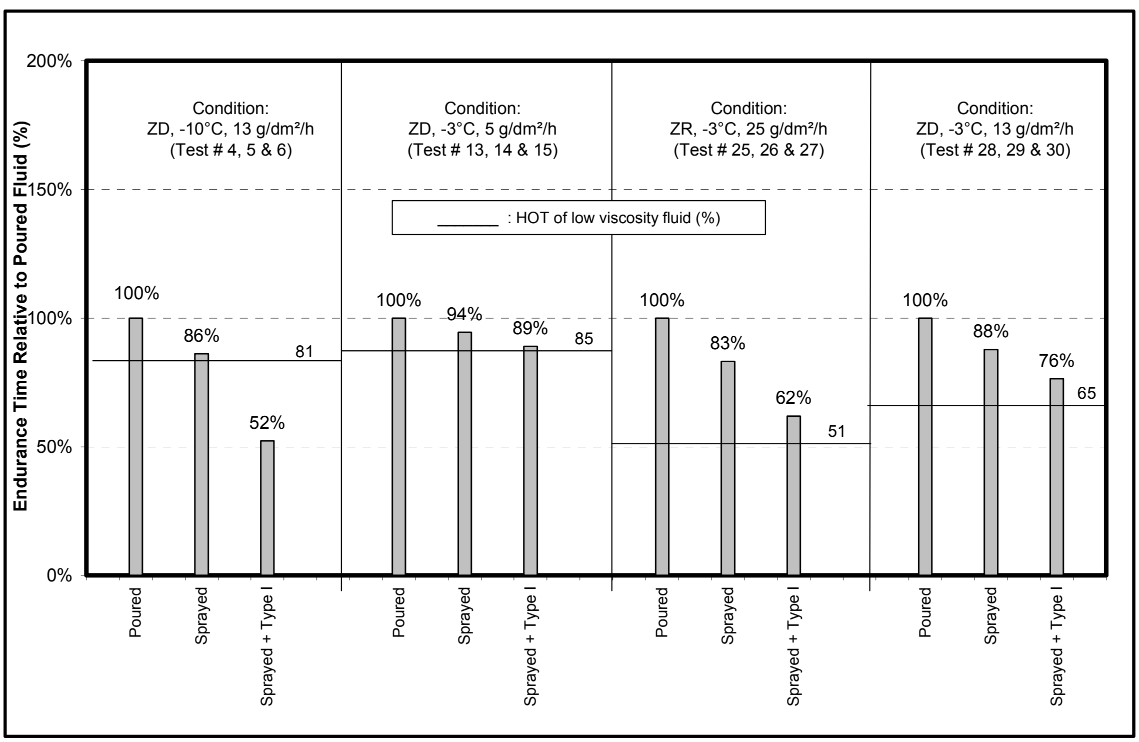

Figure 4.12: Effect of Standard Application on Endurance Time for Fluid C5

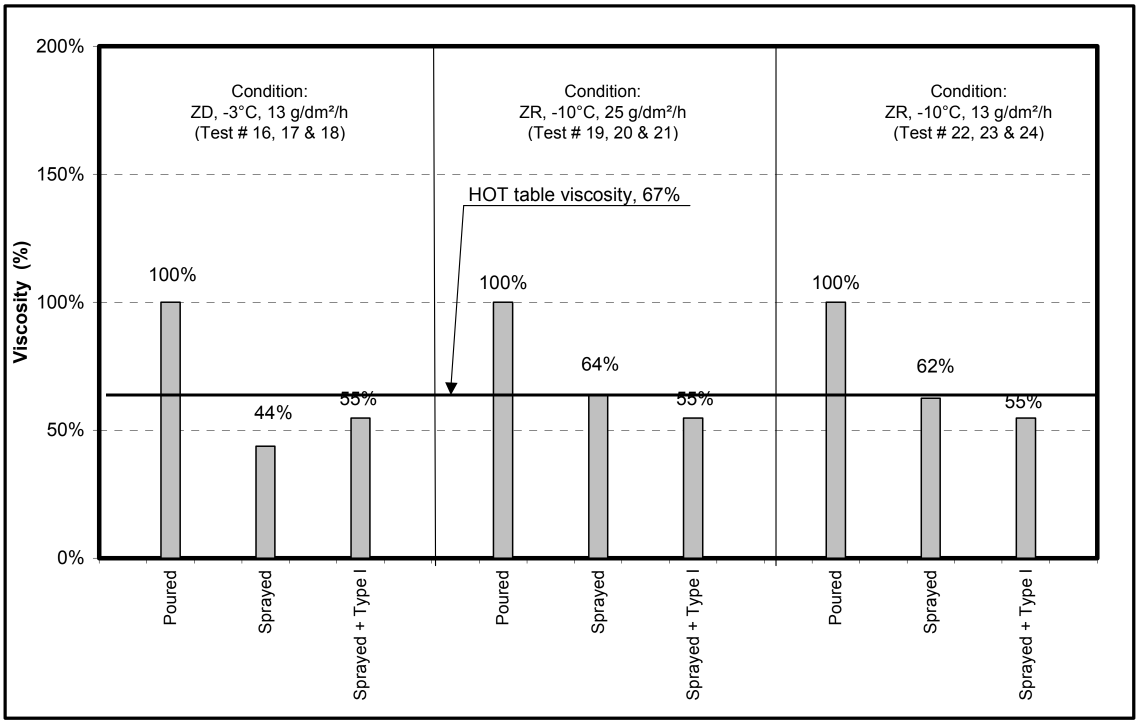

Figure 4.13: Effect of Standard Application on Viscosity for Fluid D2

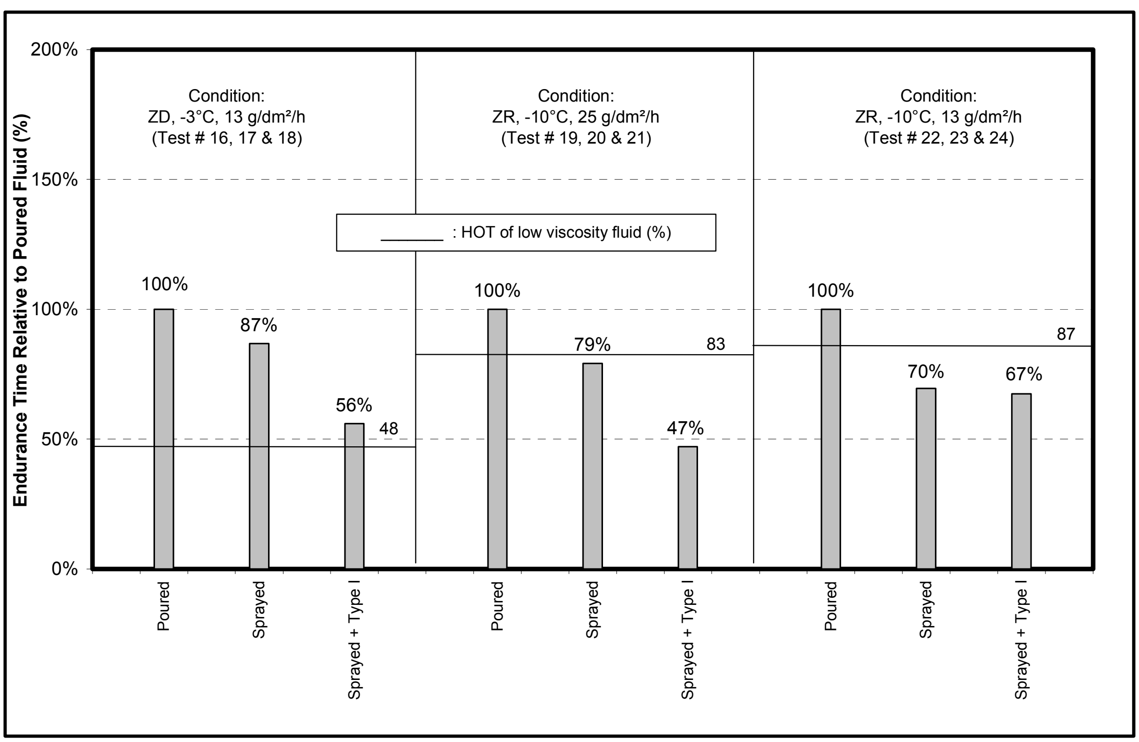

Figure 4.14: Effect of Standard Application on Endurance Time for Fluid D2

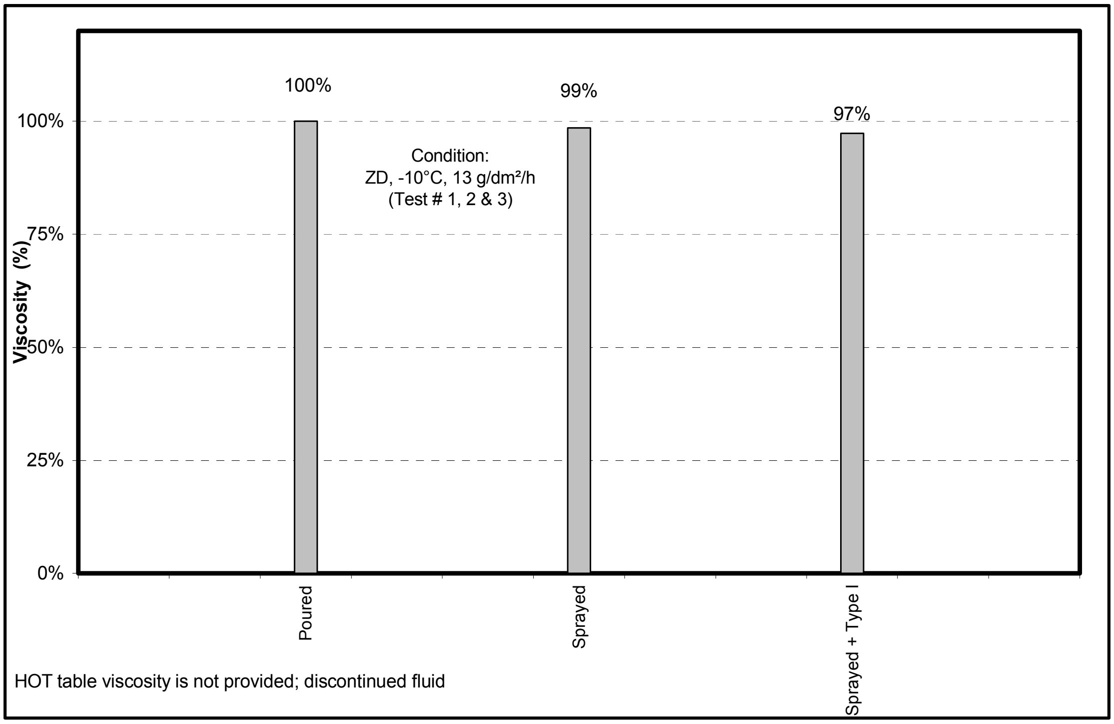

Figure 4.15: Effect of Standard Application on Viscosity for Fluid F

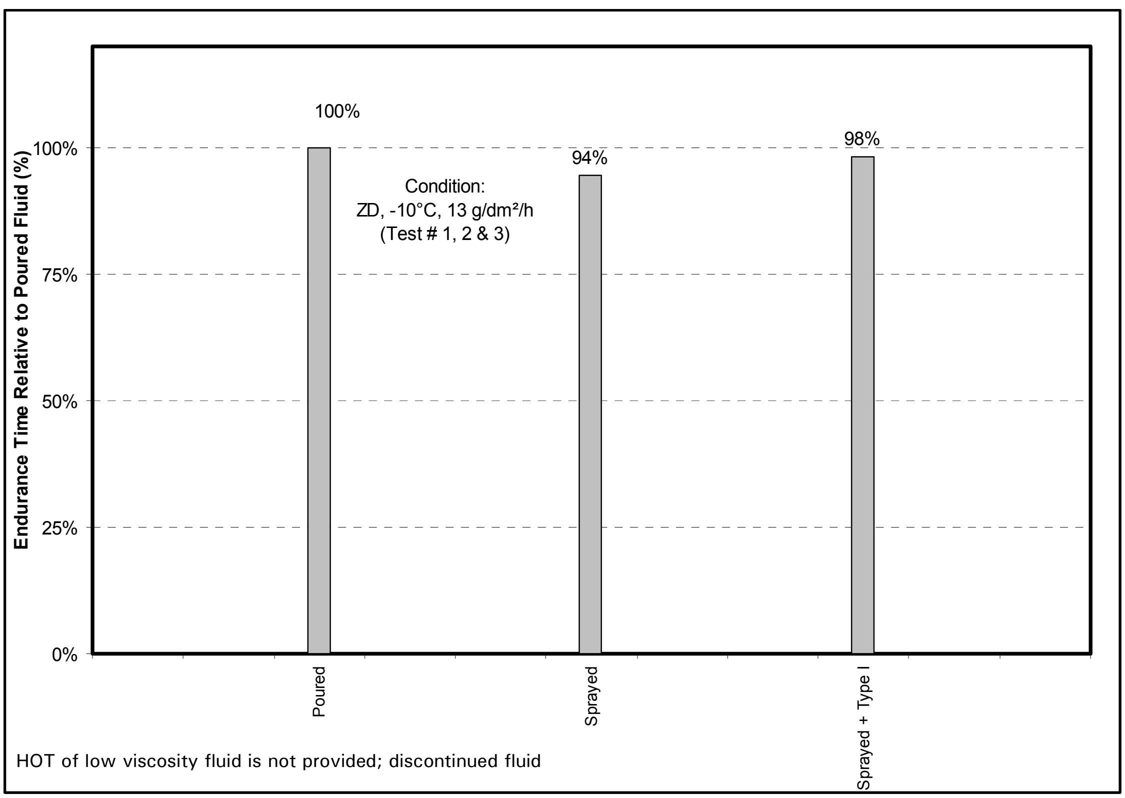

Figure 4.16: Effect of Standard Application on Endurance Time for Fluid F

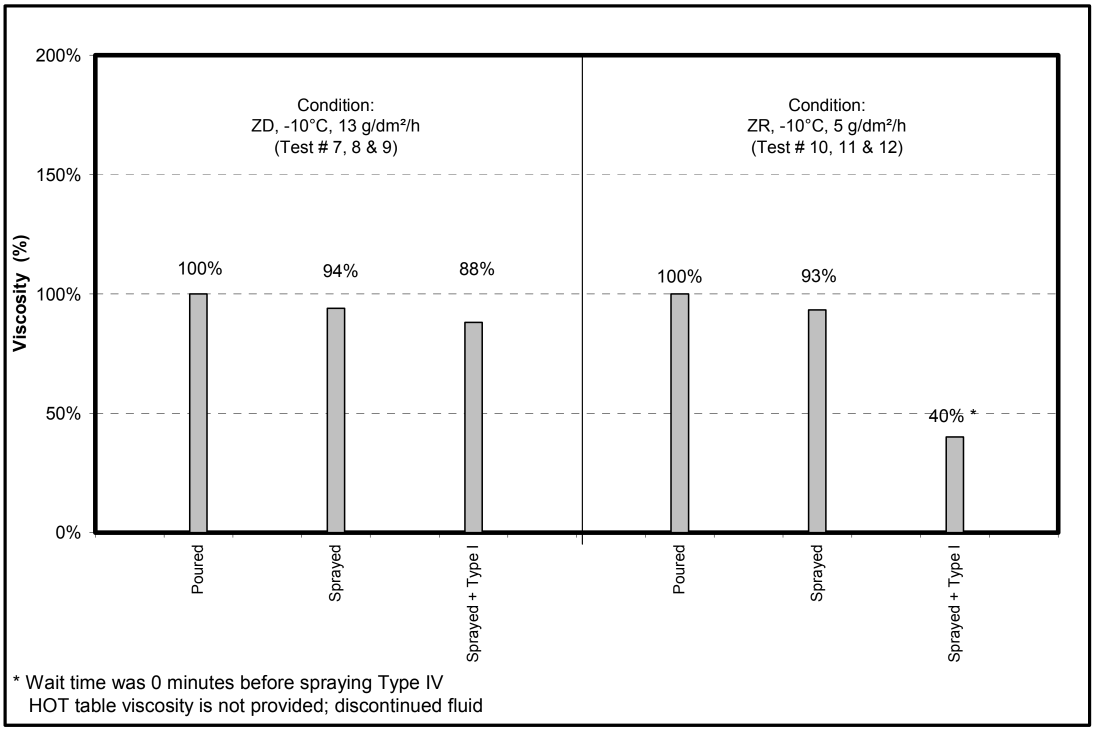

Figure 4.17: Effect of Standard Application on Viscosity for Fluid G

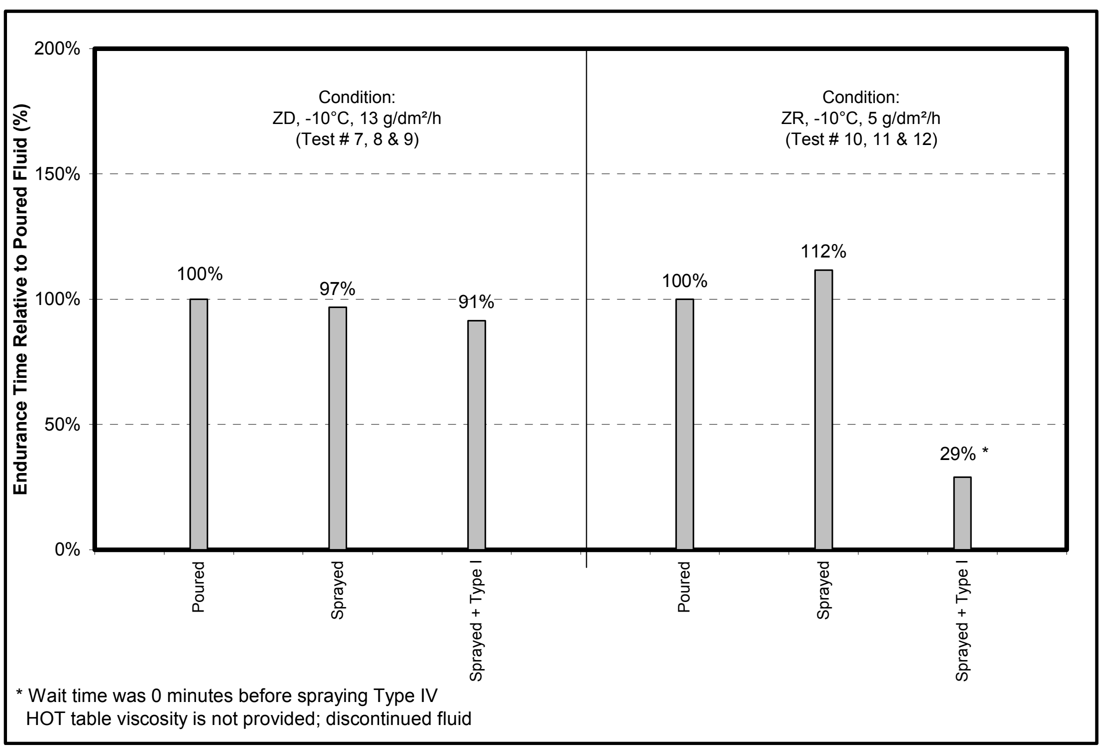

Figure 4.18: Effect of Standard Application on Endurance Time for Fluid G

4.3.1 Endurance Time Tests – Fluid C5

As shown in Figure 4.11, the effect of spraying on fluid viscosity was not significant for all tested conditions. The lowest viscosity recorded was 87 percent of the poured fluid viscosity. When mixed with Type I fluid, the viscosity dropped by 9 to 13 percent. However, all readings are above the critical HOT table viscosity.

For Fluid C5, the spraying effect on the holdover time seemed to follow the same trend (Figure 4.12). The decrease in endurance time (for both sprayed and sprayed with Type I, versus poured) varied between 6 and 48 percent. Based on these tests, Fluid C5 mixed with Type I fluid reached an endurance time relatively close to the critical HOT value of a low viscosity fluid (Tests #6 and #15). The spraying and adding of Type I fluid seem to have more of an effect on endurance time reduction than on viscosity reduction.

4.3.2 Endurance Time Tests – Fluid D2

Results from tests using Fluid D2 indicate that the effect of the spray application and the addition of Type I fluid was more critical than for Fluid C5 (Figure 4.13 and Figure 4.14).

Spraying decreased the drum sample (poured) viscosity by about 37 percent in Tests #20 and #23 (Figure 4.13). Viscosity from Test #17 (at 44 percent) was surprisingly lower (even lower than the sample mixed with Type I) than Tests #20 and #23. Unexpected contamination during the sampling might explain this result.

The spraying effect seems to be critical with Fluid D2. Indeed, all sprayed samples exhibited a viscosity lower than the HOT table value (depicted by a line at 67 percent). This confirms results observed in the full-scale standard spray test #1 discussed in Subsection 4.2.1.

For holdover time, the effect of spraying (without Type I fluid) was also very clear (Figure 4.14). A decrease of 13 to 30 percent was noted when comparing the holdover times of the poured samples to the holdover time of the sprayed fluid (Tests #17, #20 and #23). A decrease of 33 to 53 percent was observed between poured samples and samples sprayed with Type I fluid (Tests #18, #21 and #24). When comparing Fluid D2 endurance times to the holdover time of low viscosity fluid (depicted by lines in Figure 4.14), the results seem critical for Tests #20 and #21, and for Tests #23 and #24.

4.3.3 Endurance Time Tests – Fluid F

For Fluid F, spraying had no tangible effect on sample viscosities and endurance times (Figure 4.15 and Figure 4.16). Surprisingly, even adding Type I fluid did not change the viscosity of the sample taken from the truck. Since only one run was conducted with this fluid, no substantial conclusions were drawn.

4.3.4 Endurance Time Tests – Fluid G

For Tests #7, 8, and 9, the spraying and/or adding of Type I fluid affected neither the viscosity nor the endurance time (Figure 4.17 and Figure 4.18). However, for Tests #10, 11 and 12, a tangible difference was observed on plate #12 (sprayed with Type I). During that test, Type I fluid was poured at ambient temperature, and Type IV fluid was sprayed immediately afterward (unlike Tests #7, 8 and 9, where Type I fluid was poured at 60ºC and Type IV sprayed after 3 minutes). More Type I fluid remained on Plate 12 then on Plate 9, thus leading to a decrease in sample viscosity and endurance time.

Based on these observations, spray application has no affect on the performance of Fluid G.

4.3.5 Summary of Endurance Time Tests

Table 4.3 provides a summary (organized by fluid) of the endurance time tests. Viscosity and endurance time variation results are given as a range, which covers all tested conditions, and as an average.

Table 4.3: Summary of Endurance Time Test Results

Fluid	**Viscosity results:** Range* and average of deviation from the poured sample viscosity		**Endurance time results:** Range* and average of deviation from the poured sample endurance time	
	Sprayed	Sprayed + Type I	Sprayed	Sprayed + Type I
C5	Range: -3 to -10% Average: -7%	Range: -9 to -13% Average: -11%	Range: -6 to -17% Average: -12%	Range: -11 to -48% Average: -30%
D2	Range: -36 to -56% Average: -46%	-45%	Range: -13 to -30% Average: -22%	Range: -33 to -53% Average: -43%
F	-1%	-3%	-6%	-2%
G	Range: -6 to -7% Average: -7%	Range: -12 to -60% Average: -36%	Range: -3 to +12% Average: +8%	Range: -9 to -71% Average: -40%

* Range covers all test conditions

According to Table 4.3, the spraying effect appears to depend on the brand of Type IV fluid. Analysis of the viscosity results showed that Fluid D2 and Fluid G were the most affected by shearing. When these fluids were sprayed on top of Type I fluid, their viscosities decreased by 45 percent and 36 percent, respectively. Their endurance times dropped by 43 percent (for Fluid D2) and 40 percent (for Fluid G).

In general, it can be observed that the holdover time and the viscosity variations are closely dependent. When Fluid C is mixed with Type I fluid, however, spraying appears to affect endurance time variation more than viscosity variation (11 to 48 percent for the ET versus 9 to 13 percent for the viscosity). Other endurance time/viscosity tests with Fluid C should be conducted to confirm this statement.

As shown in Table 4.3, when Type I fluid is poured prior to the anti-icing fluid, it generally decreases the endurance time. The effect of Type I on the endurance time is significant for Fluid D2 and Fluid G (decrease by 43 percent and 40 percent, respectively).

4.4 Summary of Overall Results by Fluid Brand

In this section, a summary of overall results by fluid brand is provided. The results are based on averages obtained in the conduct of the three sub-projects (Table 4.4).

a) For Fluids A, B and C, the degradation over prolonged periods of time decreased their viscosities by 16 to 67 percent;

b) For Fluid C, the application procedure effect reduced the viscosity by 7 percent. When Fluid C was added on top of Type I fluid, endurance time decreased by 30 percent;

c) Fluid D was significantly affected by the application procedures. When it was mixed with Type I fluid, the endurance time dropped by 43 percent;

d) For Fluid E, the shearing due to the spray effect reduced the viscosity by 22 percent.

e) The application effect on Fluid F was not significant; and

f) For Fluid G, the endurance time was reduced by 40 percent when it was sprayed after a Type I fluid application.

Table 4.4: Summary of Overall Results by Fluid Brand

Fluid	**Storage Tests:** Viscosity decrease of undisturbed fluid (16 months versus 2 weeks)	**Full-Scale Standard Application Tests:** Average deviation from the undisturbed viscosity	**Endurance Time Tests**		
			Viscosity deviation from the undisturbed fluid	Endurance Time deviation from the undisturbed fluid	
			Sprayed	Sprayed	Sprayed with Type I
A	-67%	NT	NT	NT	NT
B	-43%	-11%	NT	NT	NT
C	-16%	-6%	-7%	-12%	-30%
D	NT	-38%	-46%	-22%	-43%
E	NT	-22%	NT	NT	NT
F*	NT	NT	-1%	-6%	-2%
G*	NT	NT	-7%	+8%	-40%
Average	**42%**	**19%**	**15%**	**12%**	**29%**

NT: Not Tested
*: Discontinued fluid

5. CONCLUSIONS

The objective of this work was to study the influence of standard application procedure on anti-icing fluids. The following sections describe the conclusions reached from field tests conducted in the 2000-01 and 2001-02 winter seasons.

5.1 Preliminary Spray Tests

Analysis of the data collected during 2000-01 can be subdivided into two parts:

a) Viscosity analysis of the samples collected when both Type I and Type IV fluids were applied on the airfoil; and

b) Viscosity analysis of the degradation of undisturbed fluid over time.

The viscosity analysis of Type IV fluid samples collected from the airfoil (and mixed with Type I fluid) provided inconclusive results. The amount of Type I fluid in relation to Type IV fluid was an uncontrollable variable that skewed the investigation. The shearing effect due to spraying could not be evaluated. Yet the results seem to suggest that there is a significant decrease in viscosity due to both variables (shearing and the addition of Type I fluid). The separate effects of these variables on Type IV fluids were considered in later tests that were carried out in winter 2001/02.

From the viscosity analysis over 16 months of undisturbed fluids, it was concluded that anti-icing fluid performance degrades by an average of 42 percent. The range varies from 16 to 67 percent depending on the fluid brand. Storing some Type IV fluids for a long period could significantly change their characteristics.

5.2 Full-Scale Standard Spray Tests

Analysis of the viscosity samples collected during the five full-scale standard spray tests has led to the conclusion that the viscosity of Type IV fluids sprayed on a wing is lower than that of undisturbed fluids. The decrease is related to the shearing effect. The influence of the application procedure, varying from 6 to 38 percent (average of 19 percent), depends on the brand of the anti-icing fluid. Among the four brands that were tested in this sub-project, Fluid D and Fluid E were the most affected (38 percent decrease for Fluid D1; 22 percent decrease for Fluid E1). The shearing influence on fluid performance may depend on the spray truck and spray nozzle types used.

5.3 Endurance Time Tests

Results from tests conducted during this sub-project indicated that the viscosities of sprayed Type IV fluids collected from the plates were lower by 15 percent than that of undisturbed fluids, which would be applied to a plate for holdover time tests. The viscosity decrease varied between 1 and 46 percent, depending on the fluid brand.

The application procedure and the Type I fluid not only influenced the viscosity, but also the endurance time of the anti-icing fluid, which decreased by an average of 29 percent (the range varied between 2 and 43 percent). In general, these two characteristics are closely dependent. The reduction in endurance time depends on the anti-icing fluid brand.

Among the four brands that were tested, Fluid D was the most affected by the shearing effect, and exhibited a decrease in viscosity and endurance time by 46 percent and 22 percent, respectively.

5.4 Implications of Results to Operational Quality Control of Anti-Icing Fluids

Results from all three sub-projects indicate that spraying Type IV fluid results in a notable change in the performance of fluids with respect to viscosity and endurance time. It can therefore be concluded that operational quality control checks to verify that sprayed anti-icing fluid viscosities are higher than the viscosities identified on the brand-specific tables are necessary. Regulatory bodies should ensure that these procedures are documented by deicing operators and airlines.

5.5 Implications of Results to Proposed SAE Aerospace Standard AS 5485

The outcome of tests conducted using a sprayer and/or by adding Type I fluid prior to spraying demonstrated that different Type IV fluid brands are differently affected in different ways by the change in the test procedure. Some fluids showed a significant reduction in endurance time. This data was also reinforced when these same fluids where tested for viscosity and exhibited a decrease when fluids were sprayed.

It can therefore be concluded that the current test procedures documented in Proposed SAE Aerospace Standard AS 5485 should be re-evaluated. It must also be noted that although some of these fluids did not demonstrate a significant reduction, others did, and therefore the procedures must be further investigated.

6. RECOMMENDATIONS

6.1 Operational Quality Control Implications

From an operational perspective, operators must be vigilant with respect to quality control checks and operational procedures regarding fluid viscosity.

Results from preliminary spray tests showed that there is a significant decrease in fluid viscosity when it is sprayed. The reason behind this reduction was not clear since two parameters were thought to contribute to the reduction in fluid viscosity, namely, the shearing effect due to spraying, and Type I fluid mixing with Type IV fluid in the sample lifted off the wing. In the subsequent year, evidence was gathered as follows to help identify the cause of such a decrease in viscosity:

a) Full-Scale Standard Spray tests, using Type IV fluids without Type I fluids, identified that the shearing effect due to spraying can be attributed to the decrease in viscosity; and

b) Samples collected and analysed for viscosity during Endurance Time spray tests further supported the conclusions drawn from the Full-Scale Standard Spray tests.

In addition, viscosity measurements of undisturbed samples stored over prolonged periods further supported the need to monitor and control fluid condition prior to usage. Finally, based on recent discussions with deicing operators, Type IV fluids may potentially degrade due to repetitive cooling and heating (by exchanging heat with Type I fluid) inside the truck tank, and due to the layering effect caused by long periods of storage in large tanks.

It is therefore recommended that:

a) Due to the nature of anti-icing fluid, quality control checks and operational deicing procedures be strictly adhered to. Regulatory bodies must ensure that adequate guidelines are documented to make sure that quality control checks are conducted on the fluids. An example of such guideline material is available in *Recommendations of Deicing/Anti-Icing of Aircraft on the Ground* published by the Association of European Airlines (AEA) in September 2002 (2); and

b) Exploratory tests be conducted to investigate whether fluid performance is significantly affected by fluid degradation due to repetitive cooling and heating, or by fluid degradation due to layering.

6.2 Implications Related to Proposed SAE Aerospace Standard AS 5485 Endurance Time Test Procedure

From an Endurance Time test perspective, where the question was raised as to the adequacy of the current ET testing procedures to replicate actual operations, it was concluded that there is a notable difference between spraying the fluid when conducting ET tests as opposed to pouring it. ET values in the sprayed tests were slightly lower than ET values in the standard pour test. In one instance, there was a significant difference.

Although a recommendation to change the testing procedure to incorporate the effect of shearing prior to conducting ET tests may seem appropriate, such an approach is impractical and very expensive, and therefore may not be warranted. In addition, it is assumed that the HOT table viscosity stated by the fluid manufacturer is representative of the fluids once they are sprayed in real operations. Therefore, it is up to the manufacturer to further increase, if needed, the viscosity “degradation buffer” to reflect the spraying effect on the fluid. The test results related to spraying the fluid further support the need to ensure that quality control checks be conducted by operators.

Other parameters must be investigated when a study is conducted to recommend the most adequate HOT test procedure. These include the temperature of the fluid and the effect that Type I has on the performance of the anti-icing fluid. It is therefore recommended that:

a) A field survey be conducted at a number of airports to gauge the typical temperature of anti-icing fluid when it is sprayed; and

b) The use of Type I fluid be further investigated in testing of Type II or Type IV fluid for endurance time tests. Temperature of Type I fluid (20 or 60°C), application lag time of Type II or IV fluid (0 or 3 minutes), and the use of cold-soak boxes are some of the parameters that should be studied.

6.3 Full-Scale Tests

In the past, Transport Canada conducted full-scale endurance time tests to investigate and compare the patterns of Type IV fluid failure on an aircraft’s wings to failure patterns on a test plate. Those tests were carried out using ethylene glycol-based fluid only. Since data collected for this research has shown that there is a significant reduction in viscosity and endurance time of certain propylene glycol fluids when they are sprayed, it is recommended that similar full-scale tests that measure and compare fluid failure patterns of aircraft wings to test plates be conducted using propylene glycol-based Type IV fluids.

7. REFERENCES

1. Myers, B., *Aircraft Anti-Icing Fluid Endurance, Holdover, and Failure Times Under Winter Precipitation Conditions: A Glossary of Terms*, Transportation Development Centre, Transport Canada, Montreal, November 2001, TP 13832.

2. Chaput, M., *Aircraft Ground De/Anti-icing Fluid Holdover Time Development Program for the 2000/2001 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, December 2001, TP 13826E.

3. *Recommendations of Deicing/Anti-icing of Aircraft on the Ground,* September 2002, Association of European Airlines.

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APPENDIX A

TERMS OF REFERENCE – PROJECT DESCRIPTION
EXCERPT FROM TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT
(2000-01)

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT – EXCERPT
DC 187
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
2000-01
(January 2001)

5.4 Viscosity of Uncontaminated Type IV Fluids on Wing Surfaces

During the conduct of the Contaminated Aircraft Takeoff Tests during the 1998-99 winter, it was observed that samples of uncontaminated fluid taken from the aircraft wing exhibited a significant reduction in viscosity from typical values expected for delivered fluids. A viscosity lower than the value shown in the holdover time tables could have a negative effect on the fluid protection time.

The contractor shall examine the viscosity of fluids after application on aircraft wings to determine the range of values that are actually experienced during operations. The effect of spray application parameters, including distance from the wing, spray pattern and fluid flow rate, will be examined.

It is expected that a sample fluid will be applied to a test wing from a truck or using a contractor provided fluid pump. The samples will then be collected and the viscosity will be measured on-site. A large number of samples will be collected from each test to allow for future monitoring of the viscosity degradation. Viscosity tests will be performed an hour, a day, a week and a month after fluid collection. Tests will be performed with several makes of Type IV fluids.

5.4.1 Conduct preliminary tests, establish a test procedure and submit to TDC for approval.

5.4.2 Conduct tests at the Dorval Deicing Centre on up to four different occasions. During each of the test sessions, multiple fluid samples will be collected to study the degradation of fluid viscosity over time.

5.4.3 Document all findings in a final technical report and in presentation format.

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APPENDIX B

TERMS OF REFERENCE – PROJECT DESCRIPTION
EXCERPT FROM TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT
(2001-02)

TRANSPORTATION DEVELOPMENT CENTRE

WORK STATEMENT – DC 202
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
WINTER OPERATIONS CONTAMINATED AIRCRAFT – GROUND
2001-02
(March 2002)

5.11 Evaluation of On-Wing Viscosity

5.11.1 Continue viscosity measurements on previously tested fluids to measure the influence of the degradation on fluids over time;

5.11.2 Conduct tests to evaluate the shearing effect of standard truck nozzles on different Type IV fluids. This should be done without Type I fluid when the test opportunity arises from other tests (e.g. Forced Air);

5.11.3 Establish a test procedure and submit it to TDC (already initiated in the previous year);

5.11.4 Conduct endurance time tests on sprayed versus poured Type IV fluids. The effect of Type I fluid on endurance time will be studied and In-situ viscosity will be measured for each fluid. Since these trials will be part of other HOT tests, no extra rental fees will be charged for NRC's CEF; and

5.11.5 Analyze results and document all findings in a final technical report and in a presentation format.

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APPENDIX C

EXPERIMENTAL PROGRAM
MEASUREMENT OF THE VISCOSITY OF UNCONTAMINATED SAE TYPE IV FLUIDS ON WING SURFACES

BM3833.001

MEASUREMENT OF THE VISCOSITY OF UNCONTAMINATED SAE TYPE IV FLUIDS ON WING SURFACES

Winter 2000/2001

Prepared for

Transportation Development Centre
Transport Canada

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Reviewed by: John D'Avirro

APS AVIATION INC.

November 29, 2000
Version 1.0

Editorial Revision
May 4, 2004
Version 1.1

MEASUREMENT OF THE VISCOSITY OF UNCONTAMINATED SAE TYPE IV FLUIDS ON WING SURFACES

Version 1

Winter 2000/2001

1. OBJECTIVE

The objective of this test is to determine the range of viscosity values that are experienced after application of the fluid on aircraft wings and to compare the viscosity versus time progression of the sprayed fluid to that of fluids that are used to measure endurance times.

2. PLAN

During the first session, apply fluid to test surface and immediately monitor the viscosity/time profile of the applied fluid. Refer to Table C-1 for a list of tests conducted during first session. Subsequent tests will be scheduled depending on results. Compare the viscosity versus time profiles of the applied/sprayed fluid versus the undisturbed fluid over time.

3. PROCEDURE

3.1 First Session

- During first session, an initial 1 L sample of the each of the fluids listed in Table C-1 will be taken from the fluid drum. The temperature of the fluid in the drum will be noted. The viscosity of this sample will be measured at the office. Viscosity tests at the office must be conducted at the same fluid temperature as that of the sprayed fluid *after* application.

  Figure C-3 shows the data form to be used when conducting office viscosity tests.

- An APS Aviation Inc. technician, while using Transport Canada's Task Force Tips Nozzle, will conduct two sprays per fluid.

  Spraying:

  - During each spray, the operator will spray the surface to simulate standard two-step deicing operation by spraying the surface from a distance and a nozzle opening similar to that of standard operation. Here we are assuming the surface was previously sprayed with

Type I. (During future sessions, consider changing process to *actual* two step application – pour Type I prior to spraying with Type IV). Nozzle size and opening (fluid flow rate) and distance from wing will be noted.

- Time of spray is noted and temperature of fluid prior to application is measured.
- There is a one-hour interval between each spray.

Sample Collection:

- Immediately after spraying, time is noted and a research assistant will collect a one 0.5 L sample from the test surface using a spatula. Care must be taken not to disturb the fluid's state. The 0.5 L sample will immediately be used at the site for viscosity measurement. Readings will be taken every minute for 60 minutes.

Figure C-1 shows the data form to use while spraying and collecting samples.

Viscosity Measurement:

- The manufacturer's suggested method of testing with regard to spindle number, fluid amount and use of guard leg will be used. Refer to Table C-2 for a list of fluid manufacturer's standards for measuring viscosity. The temperature at which the fluid's viscosity profile over time is monitored will be that of the temperature of the fluid after it has been sprayed. This temperature will be noted and used when conducting viscosity tests of samples taken to office.
- After collection, the sample is immediately placed in the sample adapter, time is noted and measurement process is started. A technician will monitor the digital display on the viscometer and record the fluctuating readings of the viscometer every 60 seconds. The viscosity values will then be taken to the office and the viscosity profile will be plotted against time.
- Time between time of spray and fluid viscosity measurement should be kept to a minimum.

Figure C-2 shows the data form to be used when conducting field viscosity tests.

- The above process is repeated to see whether the process is repeatable and conducted for the fluids listed in Table C-1.

3.2 Subsequent Sessions

Depending on the test results, APS Aviation Inc. may conduct further tests to determine the effects that various methods employed in spraying have on viscosity.

- Three parameters may be examined: distance from the test surface, nozzle opening, and outside air temperature.
- When examining the effect of distance on viscosity the operator will spray using the three distances, one that is standard and two that are farther and closer. Nozzle opening and size will be kept the same.
- When examining the effect of nozzle opening on viscosity the operator will spray using the three nozzle openings, one standard, one wider and one narrower. Distance from the nozzle will be kept the same.
- The same number of fluid samples will be taken, leaving the same time interval between each. The viscosity values will be monitored and noted.

4. PERSONNEL

Two research assistants are required for these tests. One research assistant will monitor time, conduct spraying operations, and collect and label fluid samples. The second research assistant will monitor temperature of the fluid samples and conduct the viscosity tests.

5. DATA FORMS

Each technician on site will use one data form.

Figure C-1 shows the data form to be used while spraying and collecting samples.

Figure C-2 shows the data form to be used when conducting field viscosity tests.

Figure C-3 shows the data form to be used when conducting office viscosity tests.

6. EQUIPMENT

- Task Force Tips nozzle and fluid pump
- Airfoil
- Tarp
- Viscometer
- Stable stand for viscometer
- 3 x 1 L bottles per fluid tested
- Spatula
- Labels
- Generator to operate fluid sprayer pump
- Still camera and/or video camera
- Film/video tape
- Data forms
- Clipboards
- Pencils and pens

7. FLUIDS

Fluid A (neat)
Fluid B (neat)
Fluid C1 (neat)
Fluid D (neat)

8. PRELIMINARY INVESTIGATIONS

Fluid D was used for preliminary investigations to answer some questions concerning the Brookfield DV-1 Viscometer and the behaviour of fluids when viscosity tests where conducted immediately after the fluids were disturbed.

Three tests where conducted using Fluid D:

- Undisturbed Fluid: standard test based on the fluid manufacturer's recommended method.

- Disturbed Fluid: test immediately after the fluid was manually shaken by hand to produce bubbles.

- Sheared Fluid: viscosity test after which the fluid was left to settle for one day, and then placed in an Ostirizer Blender for three one-second intervals at the STIR level.

Conclusions:

1. Brookfield DV-1 Viscometer reads the actual viscosity of the fluid instantaneously. Reference: Emil Cocirla CAN_AM Instruments Ltd.

2. Brookfield DV-1 Viscometer in theory *should* affect the properties of the non-Newtonian fluids. In theory, the process of spindle turning should, in effect, shear the fluid and therefore change its final viscosity reading. Reference: CAN-AM Instruments Ltd.

3. Analysis of the viscosity profiles shown in Figure C-4 indicates that the shearing procedure influences the fluid viscosity.

4. Undisturbed Fluid: Viscometer was giving stable readings after the first 3 minutes of a 30 min. 20 s test. (Average: 5900 mPa.s ± 100).

5. Disturbed Fluid: Viscometer was giving stable readings after the first 6 minutes of a 30 min. 20 s test. Viscometer was allowed to run to see whether there was a significant change in fluid property after a prolonged period of viscosity measurement. No significant change was observed. (Average: 5440 ± 100 mPa.s).

6. Sheared fluid: Viscometer was giving stable readings after the first three minutes of a 30 min. 20 s test. Tests where conducted after a 24-hour period and not conducted at actual test temperature but rather a degree or two lower. (Average: 4060 mPa.s ± 100).

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TABLE C-1

TEST PLAN

Session	Spray Time (hr:min)	Run	Fluid Name	Dilution	Temperature (°C)	Truck	Distance from Surface	Nozzle Opening
1	0:00	1	Fluid C1	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
	1:00	2	Fluid C1	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
	2:30	3	Fluid D	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
	3:30	4	Fluid D	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
	5:00	5	Fluid B1	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
	6:00	6	Fluid B1	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
	7:30	7	Fluid A	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
	8:30	8	Fluid A	Neat	- 5 to -10	Task Force Tips Nozzle	Standard	Standard
2				Details to be determined				
3								
4								

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TABLE C-2

FLUID MANUFACTURER'S STANDARDS FOR MEASURING VISCOSITY

Fluid Name	Temperature (°C)	Speed (rpm)	Spindle	Beaker (mL)	Fluid (mL)	Time (min:sec)	Guard Leg
Fluid C1	0	0.3	SC4-31/13R	10	10	10:00	No
Fluid D	20	0.3	LV1	600	500	33:20	Yes
Fluid B1	20	0.3	SC4-34/13R	10	10	15:00	No
Fluid A	20	0.3	SC4-34/13R	10	10	15:00	No

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FIGURE C-1

DATA FORM FOR THE COLLECTION OF FLUID SAMPLES

Session: ____________________

Location: ____________________

Date: ____________________

OAT: ____________________

Pump Used : ____________________

Spray Technician: ____________________

Fluid Name	Batch Number	Run	Spray Time (hr:min)	Sample Temperature (°C)	SAMPLE LABEL	Location of Viscosity Measurement
Fluid C1		Before Test	NA		R_B-C1	Office
		1			R_1-C1	Test Site
		2			R_2-C1	Test Site
Fluid D		Before Test	NA	NA	R_B-D	Office
		3			R_3-D	Test Site
		4			R_4-D	Test Site
Fluid B1		Before Test	NA	NA	R_B-B1	Office
		5			R_3-B1	Test Site
		6			R_4-B1	Test Site
Fluid A		Before Test	NA	NA	R_B-A	Office
		7			RB-A	Test Site
		8			RB-A	Test Site

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FIGURE C-2

ON WING VISCOSITY FIELD MEASUREMENT DATA FORM

Session: ____________________
Run Number : ____________________
Location: ____________________
Date: ____________________
OAT (°C): ____________________
Pump Used : ____________________
Spray Technician: ____________________

Fluid Name: ____________________
Temp. of Fluid Prior to Spray: ____________________
Time of Spray: ____________________
Temp. of Fluid After Spray: ____________________
Time of Viscosity Measurement: ____________________
Viscosity Technician: ____________________
FLUID LABEL: ____________________

Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	
58:00	
57:00	
56:00	
55:00	
54:00	
53:00	
52:00	
51:00	
50:00	
49:00	
48:00	
47:00	
46:00	
45:00	
44:00	
43:00	
42:00	
41:00	
40:00	
39:00	
38:00	
37:00	
36:00	
35:00	
34:00	
33:00	
32:00	
31:00	
30:00	

Time Left (h:min)	Viscosity Reading (mPa.s)
29:00	
28:00	
27:00	
26:00	
25:00	
24:00	
23:00	
22:00	
21:00	
20:00	
19:00	
18:00	
17:00	
16:00	
15:00	
14:00	
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02:00	
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00:00	

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FIGURE C-3

ON WING VISCOSITY OFFICE MEASUREMENT DATA FORM

Session: ____________ Fluid Name: ____________
Run Number : ____________ Temperature of Fluid* : ____________
Location: ____________ Viscosity Technician: ____________
Date: ____________ FLUID LABEL: ____________

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	
58:00	
57:00	
56:00	
55:00	
54:00	
53:00	
52:00	
51:00	
50:00	
49:00	
48:00	
47:00	
46:00	
45:00	
44:00	
43:00	
42:00	
41:00	
40:00	
39:00	
38:00	
37:00	
36:00	
35:00	
34:00	
33:00	
32:00	
31:00	
30:00	

Time Left (h:min)	Viscosity Reading (mPa.s)
29:00	
28:00	
27:00	
26:00	
25:00	
24:00	
23:00	
22:00	
21:00	
20:00	
19:00	
18:00	
17:00	
16:00	
15:00	
14:00	
13:00	
12:00	
11:00	
10:00	
09:00	
08:00	
07:00	
06:00	
05:00	
04:00	
03:00	
02:00	
01:00	
00:00	

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TABLE C-3

*

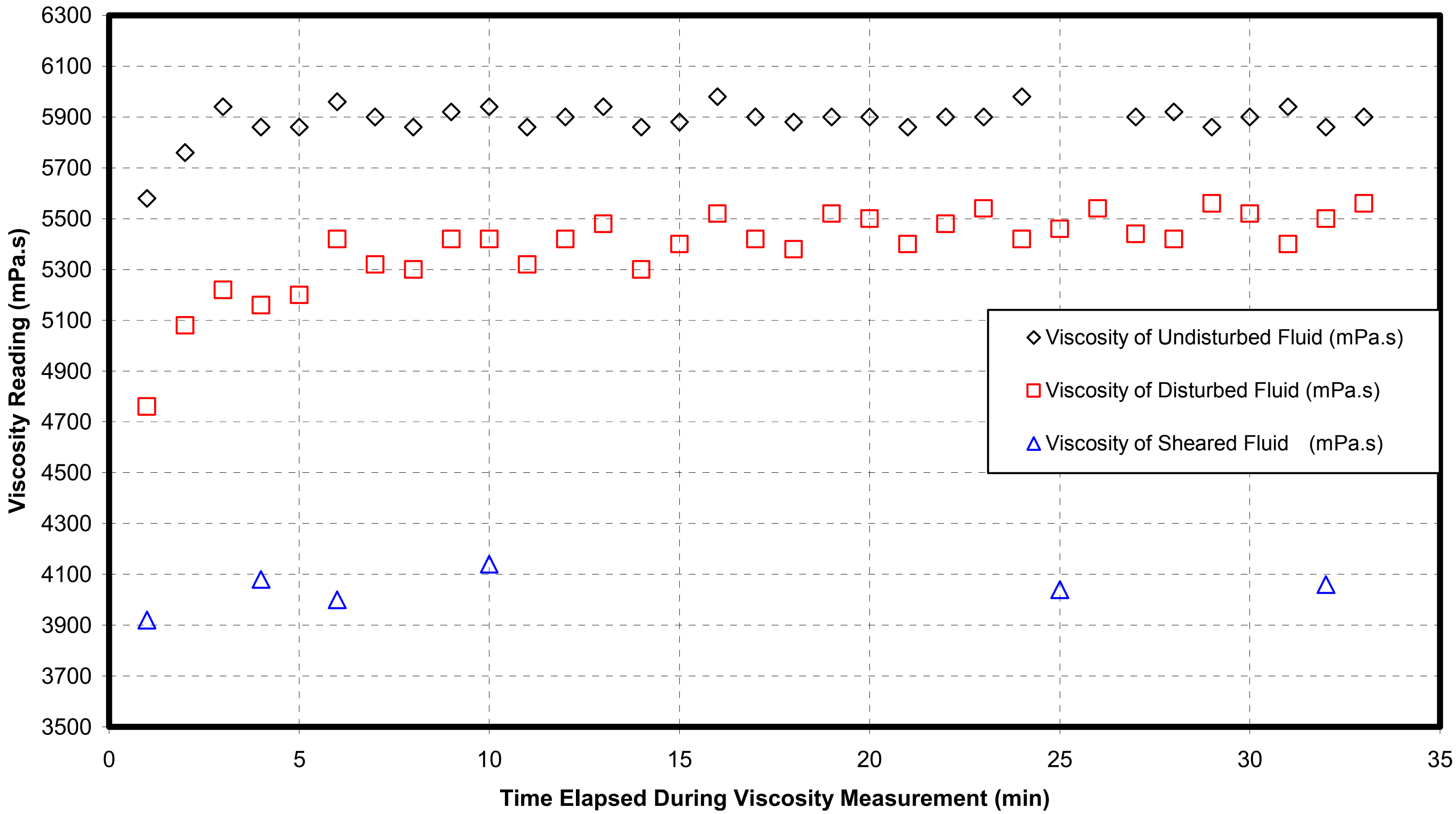
PRELIMINARY OFFICE TESTS
Fluid D

Time elapsed during viscosity measurement (min)	Viscosity of Undisturbed Fluid (mPa.s)	Viscosity of Disturbed Fluid (mPa.s)	Viscosity of Sheared Fluid* (mPa.s)
1	5580	4760	3920
2	5760	5080	
3	5940	5220	
4	5860	5160	4080
5	5860	5200	
6	5960	5420	4000
7	5900	5320	
8	5860	5300	
9	5920	5420	
10	5940	5420	4140
11	5860	5320	
12	5900	5420	
13	5940	5480	
14	5860	5300	
15	5880	5400	
16	5980	5520	
17	5900	5420	
18	5880	5380	
19	5900	5520	
20	5900	5500	
21	5860	5400	
22	5900	5480	
23	5900	5540	
24	5980	5420	
25		5460	4040
26		5540	
27	5900	5440	
28	5920	5420	
29	5860	5560	
30	5900	5520	
31	5940	5400	
32	5860	5500	4060
33	5900	5560	

*Viscosity measurement was conducted after 24 hours of shearing fluid.

FIGURE C-4

Viscosity versus Time Progression
Fluid D



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APPENDIX D

EXPERIMENTAL PROGRAM
INFLUENCE OF TYPE IV FLUID APPLICATION PROCEDURE
ON ENDURANCE TIME

CM1680.001

INFLUENCE OF TYPE IV FLUID APPLICATION PROCEDURE ON ENDURANCE TIME

Winter 2001/2002

Prepared for

Transportation Development Centre
Transport Canada

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APS AVIATION INC.

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1. BACKGROUND

To study the spraying and shearing effect on anti-icing fluids, a research program was undertaken in 2000-2001 to measure the viscosity of Type IV fluids after their application on aircraft wings. The results showed that the viscosity of undisturbed Type IV fluids, applied in a similar way to how it would be applied to a plate for holdover time (HOT) tests, is higher than the viscosity of the sprayed fluids collected from the wing. The noticeable decrease in viscosity of the sprayed fluid after being collected from the wing is likely related to the shearing effect and also to the addition of Type I fluid.

Since the viscosity effect on endurance time is still not understood, the most conclusive way to study the influence of the application procedure will be to conduct a series of tests with Type IV fluids comparing holdover times.

2. OBJECTIVES

The objective of these tests is to determine the effect of the fluid application method (sprayed versus poured) on the endurance times (ET) of Type IV fluids. By measuring the on-wing (on-plate) viscosity, the effect of viscosity change on endurance time will be evaluated. The influence of adding Type I fluid on holdover time will be also tested.

3. TEST REQUIREMENTS

- Trials will be conducted at NRC's Climatic Engineering Facility (CEF) in Ottawa.
- The Type IV fluids must be applied (sprayed or poured) at a constant temperature.
- Type I fluids must be applied at room temperature (20°C ±5°C).
- Five Type IV fluids will be tested in different conditions. In all tests using a two-step fluid application, a Type I fluid of the same glycol base (ethylene glycol or propylene glycol) will be applied to the plate prior to the Type IV application.
- The viscosity of all Type IV fluids to test should be previously measured in the APS laboratory according to the manufacturers' suggested methods.

Freezing Rain and Freezing Drizzle precipitation will be used at high and low rates and at two different air temperatures.

4. FLUIDS

The Type IV fluids to test during these trials are:

- Fluid B4 (propylene based)
- Fluid C5 (ethylene based)
- Fluid D2 (propylene based)
- Fluid F (propylene based)
- Fluid G (ethylene based)

All Type IV fluids are used neat without any water dilution.

Premixed Type I fluids that will be used are:

- Fluid C6 (ethylene glycol-based)
- Fluid C7 (propylene glycol-based)

5. TEST PLAN

A typical run on bare plates will include the following:

- In position 1 on the stand: Type IV is sprayed.
- In position 12: Type I is poured first, and then Type IV is sprayed.
- In position 4: Type IV fluid is poured as per Standard Endurance Time test.
- The rest of the positions on the stand will be used for other projects.

1 Sprayed Type IV	2	3	4 Standard ET test: Poured Type IV	5	6
7	8	9	10	11	12 Poured Type I + Sprayed Type IV

Tests will be carried out with the five fluids (B4, C5, D2, F and G) under the different conditions (precipitation rates/temperatures). These are summarized in Table D-1.

Table D-1: Set Of The Planned Test

Fluid	Condition/Rate (g/dm²/h)/Temperature (˚C)	Set-Up
F	ZD*/13/-10	1
C5	ZD/13/-10	
G	ZD/13/-10	
G	ZD/5/-10	2
C5	ZD/5/-3	3
D2	ZD/13/-3	4
D2	ZR**/25/-10	5
B4	ZR/13/-10	6
C5	ZR/25/-3	7
C5	ZR/13/-3	8

* ZD: Freezing Drizzle
** ZR: Freezing Rain

A detailed test plan is included in Attachment D-I.

6. PERSONNEL

These tests will utilize the same personnel as required for the HOT trials. Two to three extra people are needed:

- One person to spray Type IV fluids.
- One person to sequence the tests, collect the fluid samples and conduct in-situ viscosity measurements.
- If needed, one person will measure and record the Brix and the fluid thickness.

7. EQUIPEMENT

- Task Force Tips Nozzle and fluid pump
- Viscometer
- Centrifuge
- Stable stand for viscometer
- Brixometer
- Thickness gauges to measure fluid thickness on plates

- Spatula to sample fluids
- Pans to collect each Type IV fluid sprayed directly from the Task Force Tips Nozzle (instead of collecting it from plates, it is easier to do it in aluminum pans).
- One litre empty bottles (30) per fluid that will be tested (for sampling).
- Labels
- Data Forms
- The equipment needed for the indoor ET trials is described separately in the HOT procedure found in Appendix C of Transport Canada report TP 13991E.
- When Type IV fluids are sprayed, a skirt (an extension) will be placed on the plates to better simulate the sprayed fluid behavior on a wing. More details about this skirt are given in Attachment D-II.

8. PROCEDURE

If time will allow it, tests will be duplicated to check reproducibility.

Major steps:

1. Ensure the Brix and the viscosity of the undisturbed (non-sprayed) Type IV fluids are previously measured in the APS laboratory.
2. Measure the fluid temperature and the Brix prior to testing.
3. When the rate is stabilized, place two (2) plates on positions 1 and 12. Attach the skirts on these positions. The rate pans should be removed at that time and during all the spraying process to avoid fluid coming in.
4. Select one Type IV fluid.
5. Pour the correspondent Type I fluid on the plate in position 12. Type I fluid will be also poured on the skirt (for further sample collection).
6. Spray Type IV fluid on both skirted plates (in positions 1 and 12; see Figure D-1).

   Task Force Tips Nozzle will be used for this purpose.

   - Nozzle size, opening (fluid flow rate) and distance from plates should be set up similar to that of standard anti-icing operation.
   - Time of spray should be constant for all subsequent fluids.

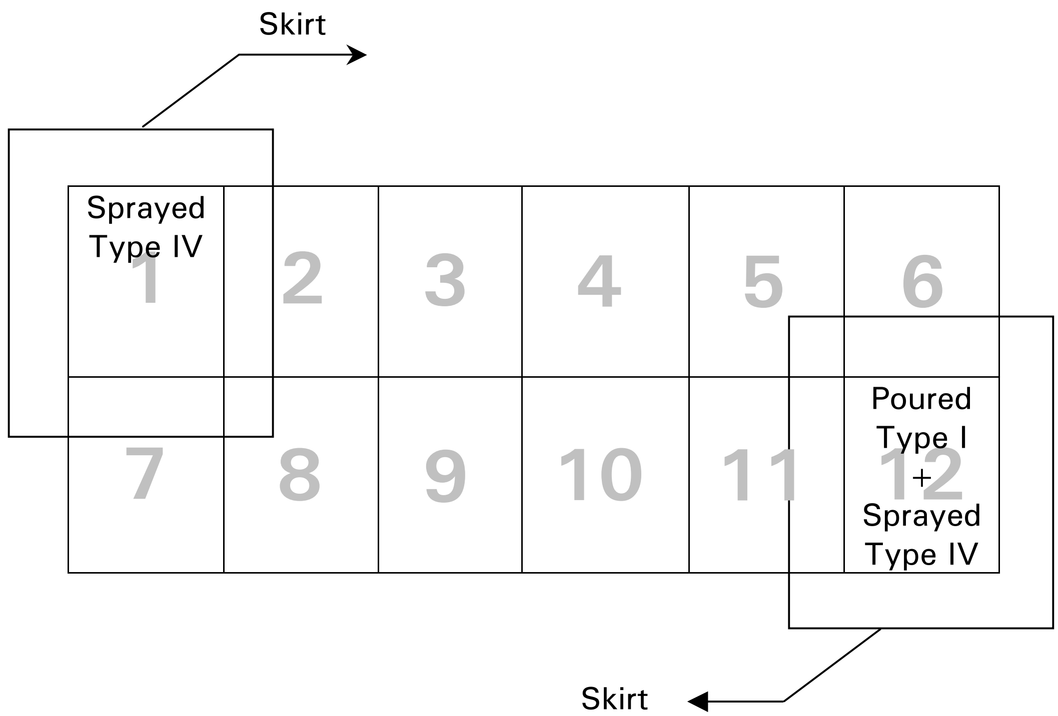

Figure D-1: Plate Positioning on the Stand

7. Type IV fluid will be also sprayed in an empty aluminium pan (easier than collecting it from the skirt). The sheared fluid will be collected in a bottle for further in-situ viscosity runs.

8. The two (2) skirts will be removed. The covering fluids (mixed Type I & Type IV) on the skirt placed on position 12 will be drained with a spatula in a clean bottle.

   The collected samples will be:

   - From step 7: in-situ sheared Type IV fluid.
   - From step 8: in-situ Type I fluid mixed with sprayed Type IV fluid.

9. In-situ viscosity measurements will be conducted following the manufacturer's method. According to the in-situ fluid temperature, the sample will be heated (in a hot water bath) to reach the manufacturer's suggested viscosity temperature. Samples will be centrifuged for 3 min before each viscosity run to avoid bubble effects.

10. The holdover time test will be conducted as per standard procedure.

11. As soon as one of the plates (in position 1 or 12) fails (or if other positions on the stand are free), a clean plate should be placed at that position; Type IV fluid will be poured on it.

12. If a significant difference is noticed in fluid thickness between the poured and the sprayed fluid, fluid thickness will be measured and recorded at the 15 cm (6") line as described in the "Fluid Thickness Profile Test Procedure" found Appendix I of Transport Canada report TP 13991E. Brix will be eventually recorded on the 15 cm line.

The above procedure steps (2 to 12) should be conducted on the other Type IV fluids according to the test plan (Attachment D-I).

9. DATA FORMS

The data forms included at the end of this document are as follows:

Form D-1: De/anti-icing Data Form for Freezing Precipitation;
Form D-2: Brix Measurement Form;
Form D-3: Fluid Thickness Measurement Form; and
Form D-4: In-situ Viscosity Measurement Form.

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Attachment D-I
CEF Detailed Test Plan

Test #	Sequencing Date	Precip Type	Temp. °C	Precip Rate g/dm²/hr	Type IV Fluid Brand	Dilution	Application Procedure	Mixed with Type I	HOT	HOT Est.
1	April 17, (2)	Freezing Drizzle	-10	13	Ely Octagon Type IV	100	Poured	No		
2	April 17, (2)	Freezing Drizzle	-10	13	Ely Octagon Type IV	100	Sprayed	No		
3	April 17, (2)	Freezing Drizzle	-10	13	Ely Octagon Type IV	100	Sprayed	Yes		
4	April 17, (3)	Freezing Drizzle	-10	13	Dow Ultra+	100	Poured	No		
5	April 17, (3)	Freezing Drizzle	-10	13	Dow Ultra+	100	Sprayed	No		
6	April 17, (3)	Freezing Drizzle	-10	13	Dow Ultra+	100	Sprayed	Yes		
7	April 17, (1)	Freezing Drizzle	-10	13	Dow 20-MJM-66	100	Poured	No		
8	April 17, (1)	Freezing Drizzle	-10	13	Dow 20-MJM-66	100	Sprayed	No		
9	April 17, (1)	Freezing Drizzle	-10	13	Dow 20-MJM-66	100	Sprayed	Yes		
10	April 16	Freezing Drizzle	-10	5	Dow 20-MJM-66	100	Poured	No		
11	April 16	Freezing Drizzle	-10	5	Dow 20-MJM-66	100	Sprayed	No		
12	April 16	Freezing Drizzle	-10	5	Dow 20-MJM-66	100	Sprayed	Yes		
13	April 22	Freezing Drizzle	-3	5	Dow Ultra+	100	Poured	No		
14	April 22	Freezing Drizzle	-3	5	Dow Ultra+	100	Sprayed	No		
15	April 22	Freezing Drizzle	-3	5	Dow Ultra+	100	Sprayed	Yes		
16	April 19	Freezing Drizzle	-3	13	Octagon Maxflight	100	Poured	No		
17	April 19	Freezing Drizzle	-3	13	Octagon Maxflight	100	Sprayed	No		
18	April 19	Freezing Drizzle	-3	13	Octagon Maxflight	100	Sprayed	Yes		
19	April 18, (2)	Light Freezing Rain	-10	25	Octagon Maxflight	100	Poured	No		
20	April 18, (2)	Light Freezing Rain	-10	25	Octagon Maxflight	100	Sprayed	No		
21	April 18, (2)	Light Freezing Rain	-10	25	Octagon Maxflight	100	Sprayed	Yes		
22	April 18, (1)	Light Freezing Rain	-10	13	Clariant MP IV 2001	100	Poured	No		
23	April 18, (1)	Light Freezing Rain	-10	13	Clariant MP IV 2001	100	Sprayed	No		
24	April 18, (1)	Light Freezing Rain	-10	13	Clariant MP IV 2001	100	Sprayed	Yes		
25	April 23, (1)	Light Freezing Rain	-3	25	Dow Ultra+	100	Poured	No		
26	April 23, (1)	Light Freezing Rain	-3	25	Dow Ultra+	100	Sprayed	No		
27	April 23, (1)	Light Freezing Rain	-3	25	Dow Ultra+	100	Sprayed	Yes		
28	April 23, (2)	Light Freezing Rain	-3	13	Dow Ultra+	100	Poured	No		
29	April 23, (2)	Light Freezing Rain	-3	13	Dow Ultra+	100	Sprayed	No		
30	April 23, (2)	Light Freezing Rain	-3	13	Dow Ultra+	100	Sprayed	Yes		

Note: tests will be duplicated only if time will allow it.

M:\Groups\Cm1680 (01-02)\Reports\Viscosity\Working Documents\Detailed Test Plan (Attach I)

Attachment D-II
Details About the Skirted Plates

When the Type IV fluid is sprayed, an extension (skirt) needs to be added to the standard plate. A gap of about 1 cm will allow excess fluid to flow off the plate. The skirt will provide a better simulation of fluid application on the wing, i.e. it provides a proper simulation of fluid splashing effects.

The skirt will be placed on the stand (on the fixture). The holes on the skirt are positioned according to Figure D-2.

The skirt can be made of galvanized sheeting, 3.2 mm thick (or thinner sheeting over plywood).

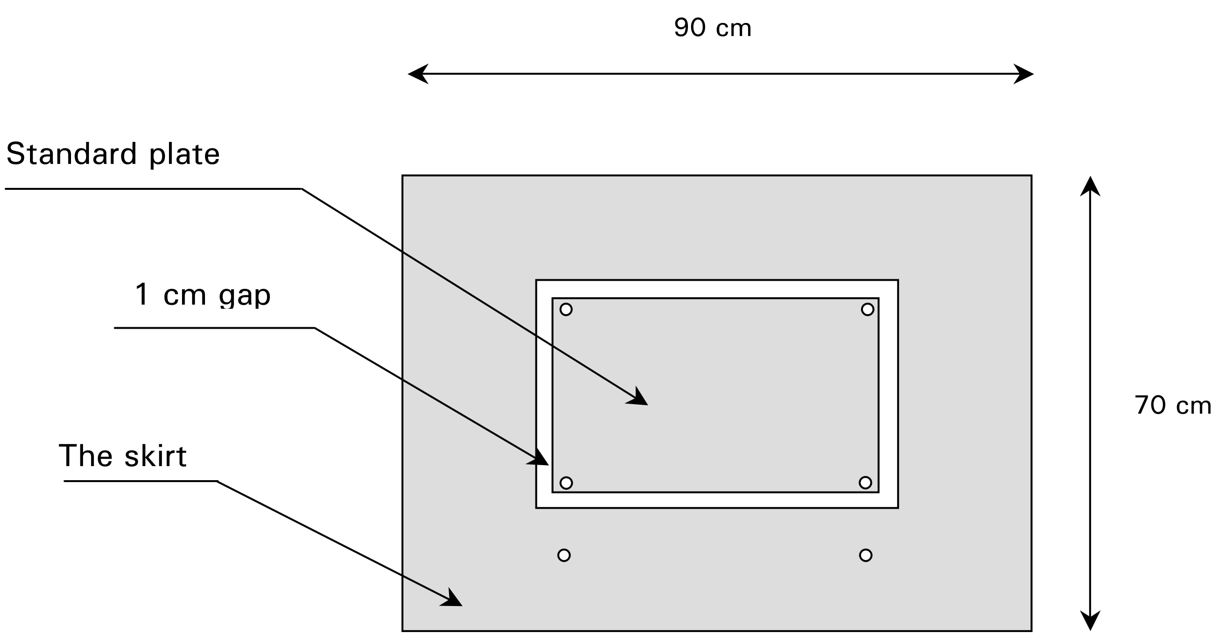

Figure D-2: Simplified Schema for the Skirt Surrounding the Plate to Spray

Form D-1: De/Anti-icing Data Form for Freezing Precipitation

REMEMBER TO SYNCHRONIZE TIME | VERSION 5.0 | 1997/98

LOCATION: CEF (Ottawa) **DATE:** **RUN NUMBER:** **STAND # :**

TIME TO FAILURE FOR INDIVIDUAL CROSSHAIRS (real time)

	Plate 1	Plate 2	Plate 3	Plate 4	Plate 5	Plate 6
Time of Fluid Application:						
Initial Brix						
Initial Fluid Temperatrure						
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
C/FIMS						

	Plate 7	Plate 8	Plate 9	Plate 10	Plate 11	Plate 12
Time of Fluid Application:						
Initial Brix						
Initial Fluid Temperatrure						
FLUID NAME/BATCH						
B1 B2 B3						
C1 C2 C3						
D1 D2 D3						
E1 E2 E3						
F1 F2 F3						
TIME TO FIRST PLATE FAILURE WITHIN WORK AREA						
FAILURE CALL	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy	V. Difficult Difficult. Easy
C/FIMS						

PRECIP: **ZF , ZD , ZR-, MOD** **AMBIENT TEMPERATURE:** ________ **°C**

COMMENTS: ______________________ **FAILURES CALLED BY :** ______________

HAND WRITTTEN BY : ______________ **LEADER:** ______________

*To compare to previous years of testing, subtract "Time of Fluid Application".

I:\Groups\Cm1680 (01-02)\Procedures\Viscosity\Version 1.0\Plate Form Form 2

Form D-2: Fluid Brix Test

DATE: ______________ **PERFORMED BY:** ______________

RUN #: ______________ **WRITTEN BY:** ______________

STAND: ______________ **LOCATION:** ______________

BRIX					
Plate: Fluid:		Plate: Fluid:		Plate: Fluid:	
TIME	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**

I:\Groups\Cm1680 (01-02)\Procedures\Viscosity\Version 1.0\Fluid Brix Test Form

Form D-3: Fluid Thickness Test

DATE: ________________ **TEMPERATURE °C (beg.):** ________________ **PERFORMED BY:** ________________

TEST #: ________ to ________ **WIND SPEED, km/h (beg.):** ________________ **WRITTEN BY:** ________________

STAND: ________________ **LOCATION:** CEF (NRC)

THICKNESS (mil)											
Plate: Run #: Fluid: Application Time:		Plate: Run #: Fluid: Application Time:		Plate: Run #: Fluid: Application Time:		Plate: Run #: Fluid: Application Time:		Plate: Run #: Fluid: Application Time:		Plate: Run #: Fluid: Application Time:	
TIME	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**	**TIME**	**6" LINE**

\M\Groups\Cm1680 (01-02)\Reports\Viscosity\Working Documents\Chart for Appendix D (page d-11).XLS

Form D-4: Data Form for the In-Situ Viscosity Measurement

Temp. before spray (ºC): ____________

Brix Before Spray: ____________

	At APS Lab. (Prior to Testing)	Test Plate Sets *		
		1	2	3
Sample Label				
Type I Applied	No	No	No	Yes
Type IV Application Procedure	N/A	Poured	Sprayed	Sprayed
Spray Time (Sec)	N/A	N/A		
Sample Temperature When Collected (°C)	N/A	N/A		
Brix				
Viscosity Measured (mPa)**		***		

* 2 plates per set if time will allow it.

** Using manufacturer's method.

*** Will be the same measured at APS laboratory (prior to testing).

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APPENDIX E

IN SITU AND LABORATORY VISCOSITY READINGS OF TESTED FLUIDS

Table E-1: On-Wing Viscosity Field Readings for Fluid A (Run #1)

Session:	1	Fluid Name:	Fluid A
Run Number :	1	Temp. of Fluid Prior to Spray:	-8.6 °C
Location:	APS Site	Time of Spray:	49 sec
Date:	1/10/01	Temp. of Fluid After Spray:	-1 °C
OAT (°C):	-13.4 °C	Time of Viscosity Measurement:	18:30:00
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #1-A

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	15400	**29:00**	24400
58:00	26000	**28:00**	24400
57:00	27600	**27:00**	24400
56:00	29800	**26:00**	24200
55:00	30000	**25:00**	23800
54:00	30000	**24:00**	23800
53:00	29800	**23:00**	23800
52:00	29400	**22:00**	23800
51:00	28800	**21:00**	23800
50:00	28400	**20:00**	23800
49:00	27800	**19:00**	23800
48:00	27200	**18:00**	23800
47:00	26800	**17:00**	23800
46:00	26000	**16:00**	23800
45:00	26000	**15:00**	23800
44:00	25600	**14:00**	23800
43:00	25600	**13:00**	23800
42:00	25200	**12:00**	23800
41:00	25200	**11:00**	23800
40:00	25200	**10:00**	23800
39:00	25200	**09:00**	
38:00	25200	**08:00**	
37:00	25000	**07:00**	
36:00	24800	**06:00**	
35:00	24800	**05:00**	
34:00	24600	**04:00**	
33:00	24800	**03:00**	
32:00	24600	**02:00**	
31:00	24600	**01:00**	
30:00	24400	**00:00**	

Table E-2: On-Wing Viscosity Field Readings for Fluid A (Run #2)

Session:	1	Fluid Name:	Fluid A
Run Number :	2	Temp. of Fluid Prior to Spray:	-8.6 °C
Location:	APS Site	Time of Spray:	32 sec
Date:	1/10/01	Temp. of Fluid After Spray:	-1 °C
OAT (°C):	-14.6 °C	Time of Viscosity Measurement:	19:49:00
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #2-A

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	11000	**29:00**	21600
58:00	19000	**28:00**	21600
57:00	21000	**27:00**	21600
56:00	23000	**26:00**	21600
55:00	24000	**25:00**	21400
54:00	25000	**24:00**	21400
53:00	24800	**23:00**	21400
52:00	24600	**22:00**	21400
51:00	24000	**21:00**	21400
50:00	23400	**20:00**	21400
49:00	22800	**19:00**	21400
48:00	22800	**18:00**	21400
47:00	22600	**17:00**	21400
46:00	22400	**16:00**	21400
45:00	22400	**15:00**	21400
44:00		**14:00**	
43:00	21600	**13:00**	
42:00	21200	**12:00**	
41:00	21200	**11:00**	
40:00	21400	**10:00**	
39:00	21400	**09:00**	
38:00	21400	**08:00**	
37:00	21400	**07:00**	
36:00	21400	**06:00**	
35:00	21400	**05:00**	
34:00	21400	**04:00**	
33:00	21600	**03:00**	
32:00	21600	**02:00**	
31:00	21600	**01:00**	
30:00	21600	**00:00**	

Table E-3: On-Wing Viscosity Lab Readings for Fluid A (Run #1) – After 2 Weeks

Session:	1	Fluid Name:	Fluid A
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami + Jeff
Date:	1/24/01	FLUID LABEL:	Run #1-A (+2 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	29600	**29:00**	
58:00	27800	**28:00**	
57:00	27000	**27:00**	
56:00	26400	**26:00**	
55:00	26200	**25:00**	
54:00	26000	**24:00**	
53:00	25800	**23:00**	
52:00	25600	**22:00**	
51:00	25400	**21:00**	
50:00	25200	**20:00**	
49:00	25000	**19:00**	
48:00	25000	**18:00**	
47:00	25000	**17:00**	
46:00	25000	**16:00**	
45:00	25000	**15:00**	
44:00	25000	**14:00**	
43:00	25000	**13:00**	
42:00	25000	**12:00**	
41:00	25000	**11:00**	
40:00	25000	**10:00**	
39:00	25000	**09:00**	
38:00	25000	**08:00**	
37:00	25000	**07:00**	
36:00	25000	**06:00**	
35:00	25000	**05:00**	
34:00	25000	**04:00**	
33:00	25000	**03:00**	
32:00	25000	**02:00**	
31:00	25000	**01:00**	
30:00	25000	**00:00**	

Table E-4: On-Wing Viscosity Lab Readings for Fluid A (Run #2) – After 2 Weeks

Session:	1	Fluid Name:	Fluid A
Run Number :	2	Temperature of Fluid* :	-1 ^{o}C
Location:	APS Office	Viscosity Technician:	Sami + Jeff
Date:	1/24/01	FLUID LABEL:	Run #2-A (+2 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	26000	**29:00**	
58:00	20800	**28:00**	
57:00	20600	**27:00**	
56:00	20600	**26:00**	
55:00	20600	**25:00**	
54:00	20600	**24:00**	
53:00	20400	**23:00**	
52:00	20400	**22:00**	
51:00	20400	**21:00**	
50:00	20400	**20:00**	
49:00	20400	**19:00**	
48:00	20400	**18:00**	
47:00	20400	**17:00**	
46:00	20400	**16:00**	
45:00	20400	**15:00**	
44:00	20400	**14:00**	
43:00	20400	**13:00**	
42:00	20400	**12:00**	
41:00	20400	**11:00**	
40:00	20400	**10:00**	
39:00	20400	**09:00**	
38:00	20400	**08:00**	
37:00	20400	**07:00**	
36:00	20400	**06:00**	
35:00	20400	**05:00**	
34:00		**04:00**	
33:00		**03:00**	
32:00		**02:00**	
31:00		**01:00**	
30:00		**00:00**	

Table E-5: On-Wing Viscosity Lab Readings for Fluid A (Run #1) – After 16 Weeks

Session:	1	Fluid Name:	Fluid A
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	5/4/01	FLUID LABEL:	Run #1-A (+12 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	29600	**29:00**	
58:00	26200	**28:00**	
57:00	25300	**27:00**	
56:00	24200	**26:00**	
55:00	24000	**25:00**	
54:00	23600	**24:00**	
53:00	23400	**23:00**	
52:00	23200	**22:00**	
51:00	23200	**21:00**	
50:00	23200	**20:00**	
49:00	23200	**19:00**	
48:00	23200	**18:00**	
47:00	23200	**17:00**	
46:00	23200	**16:00**	
45:00	23200	**15:00**	
44:00	23200	**14:00**	
43:00	23200	**13:00**	
42:00	23200	**12:00**	
41:00	23200	**11:00**	
40:00	23200	**10:00**	
39:00	23200	**09:00**	
38:00	23200	**08:00**	
37:00	23200	**07:00**	
36:00	23200	**06:00**	
35:00	23200	**05:00**	
34:00	23200	**04:00**	
33:00	23200	**03:00**	
32:00	23200	**02:00**	
31:00	23200	**01:00**	
30:00	23200	**00:00**	

Table E-6: On-Wing Viscosity Lab Readings for Fluid A (Run #2) – After 12 Weeks

Session:	1	Fluid Name:	Fluid A
Run Number :	2	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	5/4/01	FLUID LABEL:	Run #2-A (+12 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	36200	**29:00**	
58:00	29200	**28:00**	
57:00	27600	**27:00**	
56:00	26800	**26:00**	
55:00	26600	**25:00**	
54:00	26400	**24:00**	
53:00	26200	**23:00**	
52:00	26200	**22:00**	
51:00	26000	**21:00**	
50:00	25800	**20:00**	
49:00	25600	**19:00**	
48:00	25400	**18:00**	
47:00	25400	**17:00**	
46:00	25400	**16:00**	
45:00	25200	**15:00**	
44:00	25200	**14:00**	
43:00	25200	**13:00**	
42:00	25200	**12:00**	
41:00	25000	**11:00**	
40:00	25000	**10:00**	
39:00	25000	**09:00**	
38:00	25000	**08:00**	
37:00	25000	**07:00**	
36:00	25000	**06:00**	
35:00	25000	**05:00**	
34:00	25000	**04:00**	
33:00	25000	**03:00**	
32:00	25000	**02:00**	
31:00	25000	**01:00**	
30:00	25000	**00:00**	

Table E-7: On-Wing Viscosity Lab Readings for Fluid A (Undisturbed)

Session:	1	Fluid Name:	Fluid A (Undisturbed)
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami + Jeff
Date:	1/24/01	FLUID LABEL:	Rb-A

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	44600	**29:00**	28800
58:00	36800	**28:00**	28800
57:00	33800	**27:00**	28800
56:00	32400	**26:00**	28800
55:00	31800	**25:00**	28800
54:00	31200	**24:00**	28600
53:00	31000	**23:00**	28600
52:00	30800	**22:00**	28600
51:00	30600	**21:00**	28600
50:00	30600	**20:00**	28600
49:00	30400	**19:00**	28600
48:00	30200	**18:00**	28600
47:00	30200	**17:00**	28600
46:00	30000	**16:00**	28600
45:00	30000	**15:00**	28600
44:00	29800	**14:00**	28600
43:00	29800	**13:00**	28600
42:00	29600	**12:00**	28600
41:00	29600	**11:00**	28600
40:00	29400	**10:00**	28600
39:00	29400	**09:00**	28400
38:00	29200	**08:00**	28400
37:00	29200	**07:00**	28400
36:00	29200	**06:00**	28400
35:00	29000	**05:00**	28400
34:00	29000	**04:00**	28400
33:00	29000	**03:00**	28400
32:00	29000	**02:00**	28400
31:00	29000	**01:00**	28400
30:00	28800	**00:00**	28400

Table E-8: On-Wing Viscosity Field Readings for Fluid B1 (Run #1)

Session:	1	Fluid Name:	Fluid B1
Run Number :	1	Temp. of Fluid Prior to Spray:	-8.6 °C
Location:	APS Site	Time of Spray:	44 sec
Date:	1/10/01	Temp. of Fluid After Spray:	-1 °C
OAT (°C):	-12.8 °C	Time of Viscosity Measurement:	16:44:00
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #1-B1

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	25800	**29:00**	36600
58:00	34200	**28:00**	36600
57:00	36000	**27:00**	36400
56:00	37200	**26:00**	36400
55:00	38200	**25:00**	36400
54:00	39000	**24:00**	36400
53:00	39000	**23:00**	36400
52:00	39000	**22:00**	
51:00	39000	**21:00**	
50:00	39000	**20:00**	
49:00	39000	**19:00**	
48:00	39000	**18:00**	
47:00	39000	**17:00**	
46:00	39000	**16:00**	
45:00	38400	**15:00**	
44:00	38200	**14:00**	
43:00	38000	**13:00**	
42:00	37600	**12:00**	
41:00	37600	**11:00**	
40:00	37600	**10:00**	
39:00	37600	**09:00**	
38:00	37200	**08:00**	
37:00	37200	**07:00**	
36:00	37200	**06:00**	
35:00	37000	**05:00**	
34:00	37000	**04:00**	
33:00	36800	**03:00**	
32:00	36600	**02:00**	
31:00	36600	**01:00**	
30:00	36600	**00:00**	

Table E-9: On-Wing Viscosity Field Readings for Fluid B1 (Run #2)

Session:	1	Fluid Name:	Fluid B1
Run Number :	2	Temp. of Fluid Prior to Spray:	-8.6 °C
Location:	APS Site	Time of Spray:	27 sec
Date:	1/10/01	Temp. of Fluid After Spray:	-1 °C
OAT (°C):	-12.9 °C	Time of Viscosity Measurement:	17:29:00
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #2-B1

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	25000	**29:00**	32000
58:00	28000	**28:00**	32000
57:00	32000	**27:00**	31800
56:00	33000	**26:00**	31800
55:00	34200	**25:00**	31600
54:00	34600	**24:00**	31400
53:00	34600	**23:00**	31400
52:00	34600	**22:00**	31400
51:00	34600	**21:00**	31400
50:00	34600	**20:00**	31200
49:00	34600	**19:00**	31200
48:00	34000	**18:00**	31100
47:00	34000	**17:00**	
46:00	34000	**16:00**	
45:00	34000	**15:00**	
44:00	34000	**14:00**	
43:00	33400	**13:00**	
42:00	33200	**12:00**	
41:00	33200	**11:00**	
40:00	33200	**10:00**	
39:00	33200	**09:00**	
38:00	33200	**08:00**	
37:00	32800	**07:00**	
36:00	32800	**06:00**	
35:00	32600	**05:00**	
34:00	32600	**04:00**	
33:00	32400	**03:00**	
32:00	32200	**02:00**	
31:00	32200	**01:00**	
30:00	32000	**00:00**	

Table E-10: On-Wing Viscosity Lab Readings for Fluid B1 (Run #1) – After 3 Weeks

Session:	1	Fluid Name:	Fluid B1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	2/2/01	FLUID LABEL:	Run #1-B1 (+3 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	41600	**29:00**	36200
58:00	40200	**28:00**	36200
57:00	39000	**27:00**	36200
56:00	38000	**26:00**	36200
55:00	37800	**25:00**	36200
54:00	37400	**24:00**	36200
53:00	37200	**23:00**	36200
52:00	37000	**22:00**	36200
51:00	36800	**21:00**	
50:00	36600	**20:00**	
49:00	36600	**19:00**	
48:00	36600	**18:00**	
47:00	36600	**17:00**	
46:00	36400	**16:00**	
45:00	36400	**15:00**	
44:00	36400	**14:00**	
43:00	36400	**13:00**	
42:00	36400	**12:00**	
41:00	36400	**11:00**	
40:00	36400	**10:00**	
39:00	36400	**09:00**	
38:00	36400	**08:00**	
37:00	36200	**07:00**	
36:00	36200	**06:00**	
35:00	36200	**05:00**	
34:00	36200	**04:00**	
33:00	36200	**03:00**	
32:00	36200	**02:00**	
31:00	36200	**01:00**	
30:00	36200	**00:00**	

Table E-11: On-Wing Viscosity Lab Readings for Fluid B1 (Run #2) – After 3 Weeks

Session:	1	Fluid Name:	Fluid B1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	2/2/01	FLUID LABEL:	Run #2-B1 (+3 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	23400	**29:00**	
58:00	23200	**28:00**	
57:00	23200	**27:00**	
56:00	23200	**26:00**	
55:00	23000	**25:00**	
54:00	23000	**24:00**	
53:00	23000	**23:00**	
52:00	23000	**22:00**	
51:00	23000	**21:00**	
50:00	23000	**20:00**	
49:00	23000	**19:00**	
48:00	23000	**18:00**	
47:00	23000	**17:00**	
46:00	23000	**16:00**	
45:00	23000	**15:00**	
44:00	23000	**14:00**	
43:00	23000	**13:00**	
42:00	23000	**12:00**	
41:00	23000	**11:00**	
40:00	23000	**10:00**	
39:00	23000	**09:00**	
38:00	23000	**08:00**	
37:00		**07:00**	
36:00		**06:00**	
35:00		**05:00**	
34:00		**04:00**	
33:00		**03:00**	
32:00		**02:00**	
31:00		**01:00**	
30:00		**00:00**	

Table E-12: On-Wing Viscosity Lab Readings for Fluid B1 (Run #1) – After 16 Weeks

Session:	1	Fluid Name:	Fluid B1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	4/30/01	FLUID LABEL:	Run #1-B1 (+16 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	33400	**29:00**	32200
58:00	33200	**28:00**	32200
57:00	33000	**27:00**	32200
56:00	32800	**26:00**	32200
55:00	32800	**25:00**	32200
54:00	32600	**24:00**	32200
53:00	32600	**23:00**	32200
52:00	32600	**22:00**	32200
51:00	32600	**21:00**	
50:00	32600	**20:00**	
49:00	32400	**19:00**	
48:00	32400	**18:00**	
47:00	32400	**17:00**	
46:00	32400	**16:00**	
45:00	32400	**15:00**	
44:00	32400	**14:00**	
43:00	32400	**13:00**	
42:00	32200	**12:00**	
41:00	32200	**11:00**	
40:00	32200	**10:00**	
39:00	32200	**09:00**	
38:00	32200	**08:00**	
37:00	32200	**07:00**	
36:00	32200	**06:00**	
35:00	32200	**05:00**	
34:00	32200	**04:00**	
33:00	32200	**03:00**	
32:00	32200	**02:00**	
31:00	32200	**01:00**	
30:00	32200	**00:00**	

Table E-13: On-Wing Viscosity Lab Readings for Fluid B1 (Run #2) – After 16 Weeks

Session:	1	Fluid Name:	Fluid B1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	4/30/01	FLUID LABEL:	Run #2-B1 (+16 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	20800	**29:00**	23000
58:00	22400	**28:00**	23000
57:00	22800	**27:00**	23000
56:00	23000	**26:00**	23000
55:00	23200	**25:00**	23000
54:00	23200	**24:00**	23000
53:00	23200	**23:00**	23000
52:00	23200	**22:00**	23000
51:00	23200	**21:00**	
50:00	23000	**20:00**	
49:00	23000	**19:00**	
48:00	23000	**18:00**	
47:00	23000	**17:00**	
46:00	23000	**16:00**	
45:00	23000	**15:00**	
44:00	23000	**14:00**	
43:00	23000	**13:00**	
42:00	23000	**12:00**	
41:00	23000	**11:00**	
40:00	23000	**10:00**	
39:00	23000	**09:00**	
38:00	23000	**08:00**	
37:00	23000	**07:00**	
36:00	23000	**06:00**	
35:00	23000	**05:00**	
34:00	23000	**04:00**	
33:00	23000	**03:00**	
32:00	23000	**02:00**	
31:00	23000	**01:00**	
30:00	23000	**00:00**	

Table E-14: On-Wing Viscosity Lab Readings for Fluid B1 (Undisturbed)

Session:	1	Fluid Name:	Fluid B1 (Undisturbed)
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	2/1/01	FLUID LABEL:	Rb-B1

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	52200	**29:00**	43800
58:00	48800	**28:00**	43800
57:00	47600	**27:00**	43800
56:00	46800	**26:00**	
55:00	46600	**25:00**	
54:00	46200	**24:00**	
53:00	46000	**23:00**	
52:00	45800	**22:00**	
51:00	45600	**21:00**	
50:00	45600	**20:00**	
49:00	45600	**19:00**	
48:00	45400	**18:00**	
47:00	45000	**17:00**	
46:00	44000	**16:00**	
45:00	44000	**15:00**	
44:00	43800	**14:00**	
43:00	43800	**13:00**	
42:00	43800	**12:00**	
41:00	43800	**11:00**	
40:00	43800	**10:00**	
39:00	43800	**09:00**	
38:00	43800	**08:00**	
37:00	43800	**07:00**	
36:00	43800	**06:00**	
35:00	43800	**05:00**	
34:00	43800	**04:00**	
33:00	43800	**03:00**	
32:00	43800	**02:00**	
31:00	43800	**01:00**	
30:00	43800	**00:00**	

Table E-15: On-Wing Viscosity Field Readings for Fluid C1 (Run #1)

Session:	1	Fluid Name:	Fluid C1
Run Number :	1	Temp. of Fluid Prior to Spray:	9 °C
Location:	APS Site	Time of Spray:	20 sec
Date:	1/10/01	Temp. of Fluid After Spray:	+1 °C
OAT (°C):	-16.6 °C	Time of Viscosity Measurement:	10:02:25
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #1-C1

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00		**29:00**	4200
58:00	100	**28:00**	4200
57:00	200	**27:00**	4200
56:00	300	**26:00**	4200
55:00	600	**25:00**	4500
54:00	800	**24:00**	4500
53:00	900	**23:00**	4500
52:00	1100	**22:00**	4500
51:00	1300	**21:00**	4600
50:00	1400	**20:00**	4600
49:00	2700	**19:00**	4600
48:00	2800	**18:00**	4600
47:00	3000	**17:00**	4700
46:00	3000	**16:00**	4700
45:00	3100	**15:00**	4800
44:00	3200	**14:00**	4800
43:00	3300	**13:00**	4800
42:00	3800	**12:00**	4900
41:00	3800	**11:00**	5500
40:00	3900	**10:00**	5500
39:00	4000	**09:00**	5500
38:00	4000	**08:00**	5500
37:00	4000	**07:00**	5500
36:00	4000	**06:00**	5500
35:00	4000	**05:00**	5500
34:00	4000	**04:00**	5500
33:00	4100	**03:00**	5500
32:00	4100	**02:00**	5500
31:00	4100	**01:00**	5500
30:00	4100	**00:00**	5500

Table E-16: On-Wing Viscosity Field Readings for Fluid C1 (Run #2)

Session:	1	Fluid Name:	Fluid C1
Run Number :	2	Temp. of Fluid Prior to Spray:	8 °C
Location:	APS Site	Time of Spray:	13 sec
Date:	1/10/01	Temp. of Fluid After Spray:	-1 °C
OAT (°C):	-15.7 oC	Time of Viscosity Measurement:	11:37:00
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #2-C1

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00		**29:00**	1300
58:00	-	**28:00**	1300
57:00	-	**27:00**	1400
56:00	-	**26:00**	1500
55:00	100	**25:00**	1500
54:00	400	**24:00**	1500
53:00	600	**23:00**	1600
52:00	600	**22:00**	1600
51:00	600	**21:00**	1600
50:00	800	**20:00**	1600
49:00	800	**19:00**	1600
48:00	800	**18:00**	1600
47:00	800	**17:00**	1600
46:00	800	**16:00**	1700
45:00	800	**15:00**	1700
44:00	800	**14:00**	1800
43:00	800	**13:00**	1800
42:00	900	**12:00**	1800
41:00	900	**11:00**	1900
40:00	1000	**10:00**	1900
39:00	1000	**09:00**	1900
38:00	1000	**08:00**	1900
37:00	1000	**07:00**	-
36:00	1100	**06:00**	-
35:00	1200	**05:00**	2700
34:00	1200	**04:00**	2800
33:00	1300	**03:00**	2800
32:00	1300	**02:00**	2800
31:00	1300	**01:00**	2800
30:00	1300	**00:00**	2800

Table E-17: On-Wing Viscosity Field Readings for Fluid C1 (Run #3)

Session:	1	Fluid Name:	Fluid C1
Run Number :	3	Temp. of Fluid Prior to Spray:	-5 °C
Location:	APS Site	Time of Spray:	13 sec
Date:	1/10/01	Temp. of Fluid After Spray:	-10 °C
OAT (°C):	-14.8 °C	Time of Viscosity Measurement:	12:59:00
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #3-C1

Time Left (h:min)	**Viscosity Reading (mPa.s)**	**Time Left (h:min)**	**Viscosity Reading (mPa.s)**
59:00	11100	**29:00**	
58:00	16400	**28:00**	
57:00	-	**27:00**	
56:00	-	**26:00**	
55:00	28700	**25:00**	
54:00	30900	**24:00**	
53:00	32400	**23:00**	
52:00	33200	**22:00**	
51:00	34900	**21:00**	
50:00		**20:00**	
49:00		**19:00**	
48:00		**18:00**	
47:00		**17:00**	
46:00		**16:00**	
45:00		**15:00**	
44:00		**14:00**	
43:00		**13:00**	
42:00		**12:00**	
41:00		**11:00**	
40:00		**10:00**	
39:00		**09:00**	
38:00		**08:00**	
37:00		**07:00**	
36:00		**06:00**	
35:00		**05:00**	
34:00		**04:00**	
33:00		**03:00**	
32:00		**02:00**	
31:00		**01:00**	
30:00		**00:00**	

Table E-18: On-Wing Viscosity Field Readings for Fluid C1 (Run #4)

Session:	1	Fluid Name:	Fluid C1
Run Number :	4	Temp. of Fluid Prior to Spray:	-5 °C
Location:	APS Site	Time of Spray:	41 sec
Date:	1/10/01	Temp. of Fluid After Spray:	-1 °C
OAT (°C):	-14.4 °C	Time of Viscosity Measurement:	13:28:00
Pump Used :	APS pump	Viscosity Technician:	Alia
Spray Technician:	N. Blais	FLUID LABEL:	Run #4-C1

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	4300	**29:00**	27300
58:00	-	**28:00**	27400
57:00	8000	**27:00**	27800
56:00	11600	**26:00**	28500
55:00	14500	**25:00**	28600
54:00	16800	**24:00**	28600
53:00	18100	**23:00**	28700
52:00	19300	**22:00**	28700
51:00	20800	**21:00**	28800
50:00	21800	**20:00**	28800
49:00	-	**19:00**	28900
48:00	22200	**18:00**	28900
47:00	-	**17:00**	29000
46:00	23400	**16:00**	29100
45:00	-	**15:00**	29300
44:00	-	**14:00**	29300
43:00	24600	**13:00**	29400
42:00	24800	**12:00**	29400
41:00	25000	**11:00**	29500
40:00	25300	**10:00**	29500
39:00	25600	**09:00**	29600
38:00	25700	**08:00**	29700
37:00	25900	**07:00**	29700
36:00	26300	**06:00**	29800
35:00	26500	**05:00**	29800
34:00	-	**04:00**	29800
33:00	26900	**03:00**	29900
32:00	27100	**02:00**	29900
31:00	27100	**01:00**	30100
30:00	27200	**00:00**	30100

Table E-19: On-Wing Viscosity Lab Readings for Fluid C1 (Run #1) – After 2 Weeks

Session:	1	Fluid Name:	Fluid C1
Run Number :	1	Temperature of Fluid* :	+1 ^{o}C
Location:	APS Office	Viscosity Technician:	Sami
Date:	1/22/01	FLUID LABEL:	Run #1-C1 (+2 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	-	**29:00**	5800
58:00	3400	**28:00**	5800
57:00	3900	**27:00**	5800
56:00	4300	**26:00**	5900
55:00	4700	**25:00**	5900
54:00	4800	**24:00**	5900
53:00	5000	**23:00**	5900
52:00	5300	**22:00**	5900
51:00	5300	**21:00**	5900
50:00	5400	**20:00**	6000
49:00	5500	**19:00**	6000
48:00	5500	**18:00**	6000
47:00	5500	**17:00**	6000
46:00	5600	**16:00**	6000
45:00	5600	**15:00**	6000
44:00	5600	**14:00**	6000
43:00	5700	**13:00**	6100
42:00	5700	**12:00**	6000
41:00	5700	**11:00**	6000
40:00	5800	**10:00**	6100
39:00	5800	**09:00**	6100
38:00	5800	**08:00**	6100
37:00	5700	**07:00**	6100
36:00	5800	**06:00**	6100
35:00	5800	**05:00**	6100
34:00	5800	**04:00**	6100
33:00	5800	**03:00**	6100
32:00	5800	**02:00**	6300
31:00	5800	**01:00**	6300
30:00	5800	**00:00**	6400

Table E-20: On-Wing Viscosity Lab Readings for Fluid C1 (Run #2) – After 2 Weeks

Session:	1	Fluid Name:	Fluid C1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	1/22/01	FLUID LABEL:	Run #2-C1 (+2 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	9600	**29:00**	8600
58:00	9200	**28:00**	8600
57:00	8900	**27:00**	8600
56:00	8800	**26:00**	8600
55:00	8700	**25:00**	8600
54:00	8700	**24:00**	8600
53:00	8700	**23:00**	8600
52:00	8600	**22:00**	
51:00	8600	**21:00**	
50:00	8600	**20:00**	
49:00	8600	**19:00**	
48:00	8600	**18:00**	
47:00	8600	**17:00**	
46:00	8600	**16:00**	
45:00	8600	**15:00**	
44:00	8600	**14:00**	
43:00	8600	**13:00**	
42:00	8600	**12:00**	
41:00	8600	**11:00**	
40:00	8600	**10:00**	
39:00	8600	**09:00**	
38:00	8600	**08:00**	
37:00	8600	**07:00**	
36:00	8600	**06:00**	
35:00	8600	**05:00**	
34:00	8600	**04:00**	
33:00	8600	**03:00**	
32:00	8600	**02:00**	
31:00	8600	**01:00**	
30:00	8600	**00:00**	

Table E-21: On-Wing Viscosity Lab Readings for Fluid C1 (Run #3) – After 3 Weeks

Session:	1	Fluid Name:	Fluid C1
Run Number :	1	Temperature of Fluid* :	-10 ^{o}C
Location:	APS Office	Viscosity Technician:	Sami
Date:	2/6/01	FLUID LABEL:	Run #3-C1 (+3 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	55500	**29:00**	48300
58:00	53700	**28:00**	48300
57:00	51400	**27:00**	48300
56:00	50700	**26:00**	48200
55:00	50200	**25:00**	48200
54:00	49800	**24:00**	48200
53:00	49700	**23:00**	48200
52:00	49600	**22:00**	48200
51:00	49300	**21:00**	48200
50:00	49200	**20:00**	48200
49:00	49200	**19:00**	48200
48:00	49100	**18:00**	48200
47:00	49100	**17:00**	48200
46:00	49100	**16:00**	48100
45:00	49100	**15:00**	48100
44:00	48900	**14:00**	48100
43:00	48800	**13:00**	48100
42:00	48800	**12:00**	48100
41:00	48800	**11:00**	48100
40:00	48700	**10:00**	48100
39:00	48700	**09:00**	48100
38:00	48600	**08:00**	48100
37:00	48500	**07:00**	48100
36:00	48500	**06:00**	48000
35:00	48500	**05:00**	48000
34:00	48400	**04:00**	48000
33:00	48400	**03:00**	48000
32:00	48400	**02:00**	48000
31:00	48400	**01:00**	48000
30:00	48300	**00:00**	48000

Table E-22: On-Wing Viscosity Lab Readings for Fluid C1 (Run #4) – After 2 Weeks

Session:	1	Fluid Name:	Fluid C1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	1/23/01	FLUID LABEL:	Run #4-C1 (+2 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	22600	**29:00**	18000
58:00	21100	**28:00**	18000
57:00	19600	**27:00**	18000
56:00	19100	**26:00**	18000
55:00	18900	**25:00**	18000
54:00	18700	**24:00**	18000
53:00	18500	**23:00**	18000
52:00	18500	**22:00**	18000
51:00	18400	**21:00**	18000
50:00	18400	**20:00**	18000
49:00	18300	**19:00**	
48:00	18300	**18:00**	
47:00	18100	**17:00**	
46:00	18100	**16:00**	
45:00	18100	**15:00**	
44:00	18100	**14:00**	
43:00	18100	**13:00**	
42:00	18100	**12:00**	
41:00	18100	**11:00**	
40:00	18000	**10:00**	
39:00	18000	**09:00**	
38:00	18000	**08:00**	
37:00	18000	**07:00**	
36:00	18000	**06:00**	
35:00	18000	**05:00**	
34:00	18000	**04:00**	
33:00	18000	**03:00**	
32:00	18000	**02:00**	
31:00	18000	**01:00**	
30:00	18000	**00:00**	

Table E-23: On-Wing Viscosity Lab Readings for Fluid C1 (Run #1) – After 16 Weeks

Session:	1	Fluid Name:	Fluid C1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	4/30/01	FLUID LABEL:	Run #1-C1 (+16 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	1000	**29:00**	4800
58:00	1800	**28:00**	4800
57:00	2600	**27:00**	4800
56:00	2800	**26:00**	4800
55:00	3600	**25:00**	4800
54:00	3800	**24:00**	4800
53:00	3800	**23:00**	4800
52:00	4000	**22:00**	4800
51:00	4000	**21:00**	4800
50:00	4200	**20:00**	4800
49:00	4200	**19:00**	4800
48:00	4400	**18:00**	4800
47:00	4400	**17:00**	4800
46:00	4400	**16:00**	4800
45:00	4400	**15:00**	4800
44:00	4400	**14:00**	4800
43:00	4400	**13:00**	4800
42:00	4600	**12:00**	4800
41:00	4600	**11:00**	4800
40:00	4600	**10:00**	
39:00	4600	**09:00**	
38:00	4600	**08:00**	
37:00	4600	**07:00**	
36:00	4600	**06:00**	
35:00	4600	**05:00**	
34:00	4800	**04:00**	
33:00	4800	**03:00**	
32:00	4800	**02:00**	
31:00	4800	**01:00**	
30:00	4800	**00:00**	

Table E-24: On-Wing Viscosity Lab Readings for Fluid C1 (Run #2) – After 16 Weeks

Session:	1	Fluid Name:	Fluid C1
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	4/30/01	FLUID LABEL:	Run #2-C1 (+16 weeks)

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	8200	**29:00**	7600
58:00	8000	**28:00**	7600
57:00	7800	**27:00**	7600
56:00	7800	**26:00**	7600
55:00	7800	**25:00**	7600
54:00	7800	**24:00**	7600
53:00	7800	**23:00**	7600
52:00	7600	**22:00**	7600
51:00	7600	**21:00**	7600
50:00	7600	**20:00**	7600
49:00	7600	**19:00**	7600
48:00	7600	**18:00**	
47:00	7600	**17:00**	
46:00	7600	**16:00**	
45:00	7600	**15:00**	
44:00	7600	**14:00**	
43:00	7600	**13:00**	
42:00	7600	**12:00**	
41:00	7600	**11:00**	
40:00	7600	**10:00**	
39:00	7600	**09:00**	
38:00	7600	**08:00**	
37:00	7600	**07:00**	
36:00	7600	**06:00**	
35:00	7600	**05:00**	
34:00	7600	**04:00**	
33:00	7600	**03:00**	
32:00	7600	**02:00**	
31:00	7600	**01:00**	
30:00	7600	**00:00**	

Table E-25: On-Wing Viscosity Lab Readings for Fluid C1 (Undisturbed) at +1°C

Session:	1	Fluid Name:	Fluid C1 (Undisturbed)
Run Number :	1	Temperature of Fluid* :	+1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	1/23/01	FLUID LABEL:	Rb-C1

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	51400	**29:00**	43000
58:00	47900	**28:00**	43000
57:00	45400	**27:00**	43000
56:00	44500	**26:00**	43000
55:00	44200	**25:00**	43000
54:00	43900	**24:00**	43000
53:00	43600	**23:00**	
52:00	43400	**22:00**	
51:00	43300	**21:00**	
50:00	43300	**20:00**	
49:00	43200	**19:00**	
48:00	43200	**18:00**	
47:00	43200	**17:00**	
46:00	43200	**16:00**	
45:00	43100	**15:00**	
44:00	43100	**14:00**	
43:00	43100	**13:00**	
42:00	43100	**12:00**	
41:00	43100	**11:00**	
40:00	43100	**10:00**	
39:00	43000	**09:00**	
38:00	43000	**08:00**	
37:00	43000	**07:00**	
36:00	43000	**06:00**	
35:00	43000	**05:00**	
34:00	43000	**04:00**	
33:00	43000	**03:00**	
32:00	43000	**02:00**	
31:00	43000	**01:00**	
30:00	43000	**00:00**	

Table E-26: On-Wing Viscosity Lab Readings for Fluid C1 (Undisturbed) at -1°C

Session:	1	Fluid Name:	Fluid C1 (Undisturbed)
Run Number :	1	Temperature of Fluid* :	-1 °C
Location:	APS Office	Viscosity Technician:	Sami
Date:	1/23/01	FLUID LABEL:	Rb-C1

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	59800	**29:00**	45400
58:00	57300	**28:00**	45400
57:00	52200	**27:00**	45400
56:00	50600	**26:00**	45400
55:00	49800	**25:00**	45400
54:00	48900	**24:00**	45400
53:00	48500	**23:00**	45400
52:00	48400	**22:00**	45400
51:00	47700	**21:00**	45300
50:00	47300	**20:00**	45300
49:00	47100	**19:00**	45300
48:00	46800	**18:00**	45300
47:00	46600	**17:00**	45300
46:00	46600	**16:00**	45200
45:00	46400	**15:00**	45200
44:00	46300	**14:00**	45200
43:00	46200	**13:00**	45200
42:00	46200	**12:00**	45200
41:00	46000	**11:00**	45100
40:00	45900	**10:00**	45100
39:00	45900	**09:00**	45100
38:00	45800	**08:00**	45100
37:00	45700	**07:00**	45100
36:00	45700	**06:00**	45100
35:00	45700	**05:00**	45100
34:00	45600	**04:00**	45100
33:00	45600	**03:00**	45100
32:00	45500	**02:00**	45100
31:00	45500	**01:00**	45000
30:00	45500	**00:00**	45000

Table E-27: On-Wing Viscosity Lab Readings for Fluid C1 (Undisturbed) at -10°C

Session:	1	Fluid Name:	Fluid C1 (Undisturbed)
Run Number :	1	Temperature of Fluid* :	-10 ^{o}C
Location:	APS Office	Viscosity Technician:	Sami
Date:	2/8/01	FLUID LABEL:	Rb-C1

* Fluid temperature must be equal to field temperature of related test.

Time Left (h:min)	Viscosity Reading (mPa.s)	Time Left (h:min)	Viscosity Reading (mPa.s)
59:00	63400	**29:00**	48800
58:00	59600	**28:00**	48700
57:00	54800	**27:00**	48700
56:00	52800	**26:00**	48700
55:00	52200	**25:00**	48700
54:00	51600	**24:00**	48700
53:00	51200	**23:00**	48700
52:00	51100	**22:00**	48700
51:00	50800	**21:00**	48600
50:00	50600	**20:00**	48600
49:00	50500	**19:00**	48600
48:00	50300	**18:00**	48600
47:00	50100	**17:00**	48600
46:00	49900	**16:00**	48600
45:00	49800	**15:00**	48500
44:00	49700	**14:00**	48500
43:00	49600	**13:00**	48500
42:00	49600	**12:00**	48500
41:00	49500	**11:00**	48500
40:00	49400	**10:00**	48500
39:00	49400	**09:00**	48500
38:00	49400	**08:00**	48500
37:00	49300	**07:00**	48500
36:00	49300	**06:00**	48500
35:00	49200	**05:00**	48500
34:00	49200	**04:00**	48500
33:00	49000	**03:00**	48500
32:00	48900	**02:00**	48500
31:00	48800	**01:00**	48500
30:00	48800	**00:00**	48500

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APPENDIX F

ANALYSIS AND OBSERVATIONS FOR THE PRELIMINARY SPRAY TESTS

ANALYSIS AND OBSERVATIONS FOR THE PRELIMINARY SPRAY TESTS

1. INTRODUCTION

Experimental viscosity-time data that were collected for these preliminary spray tests are shown in Figures F-1 to F-8. In each case, the results are compared to the non-sheared (undisturbed) product. The manufacturer's suggested method of testing with regard to spindle number, fluid amount, and temperature, is indicated in each chart.

2. VISCOSITY TEST RESULTS - FLUID A

2.1 Run #1

Viscosity ranges for this run vary from 23 000 to about 30 000 mPa.s (Figure F-1). According to the in-situ fluid plot, it increases during the first 5 minutes, then decreases, and finally stabilizes at 23 800 mPa.s. This variation may be due to the fluid temperature instability during these first minutes.

While they are subjected to constant shearing, and before reaching their final viscosity value, most of the fluids became less viscous. The in-situ fluid behaved very differently. This may be due to the settled bath temperature used to conduct this test. During the first 5 minutes, the sample temperature may have been higher than the one settled in the bath. By decreasing its temperature, its viscosity increased until it reaches the bath temperature (variation **x** to **y** on Figure F-1). Then, the fluid became less viscous (variation **y** to **z** on Figure F-1). Entrained air (bubbles) created during the spraying may explain this variation. In fact, big and/or unstable bubbles disappeared mainly during the first minutes, thus affecting fluid viscosity. Hence, the entrainment seemed to decrease the viscosity of Fluid A.

The fluid stabilized after 15 minutes. By that time, the whole sample reached a steady temperature, and bubbling led to stable viscosity.

Before stabilizing, readings for the undisturbed fluid and readings after 2 and 12 weeks (samples collected after 30 min on the wing and measured after 2 and 12 weeks) became less viscous (Figure F-1). This was because the fluid had initially been very resistant to flow; for the first 5 minutes, significant friction between the fluid layers led to high viscosity.

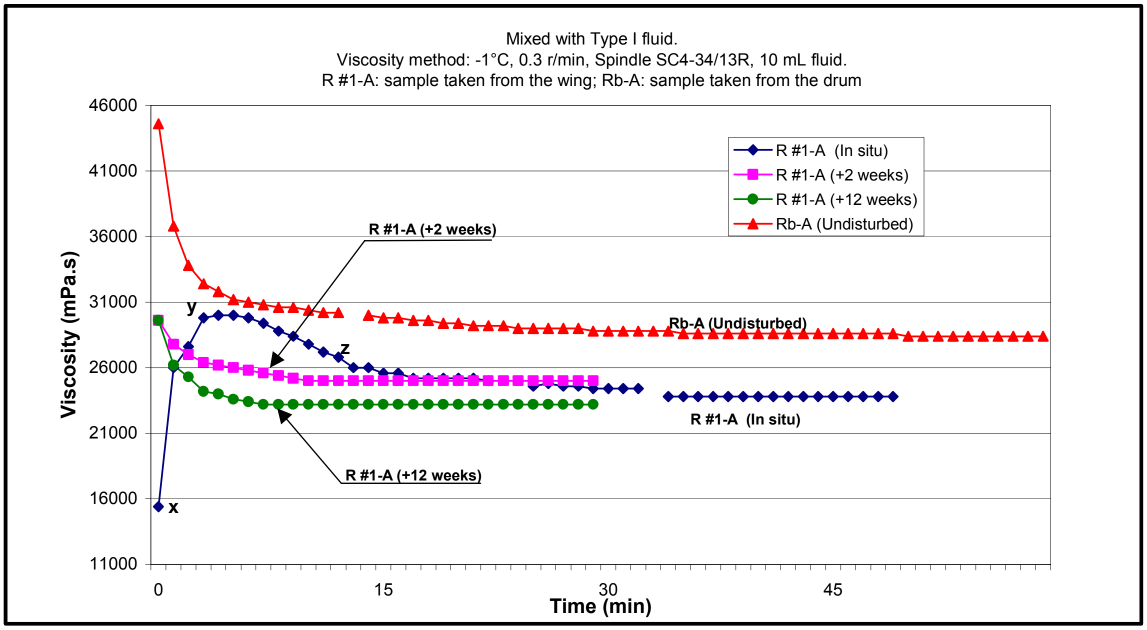

Figure F-1: Viscosity Change Over Time – Fluid A (Run #1)

Once stabilized, the final viscosity values in situ reached almost the same level as the sample collected and measured after two weeks.

The slight difference may have been due to the viscometer's experimental error (around 7%). During these two weeks, the fluid did not really change.

Readings for the sample collected and measured after 12 weeks decreased slightly. During that time, the fluid stabilized by losing bubbles. Hence, we can presume that air entrainment decreased the viscosity of Fluid A.

The sprayed fluid collected in-situ (coded "R #1-A") was less viscous then the non-sheared (undisturbed) Type IV sample (coded "Rb-A"). The difference (about 6 000 mPa.s) was due mainly to the fact that the collected sample was sheared and was a mix of the Type I and Type IV fluids (Type I is less viscous than Type IV). In fact, the composition of a material is a determining factor of its viscosity. When the composition is altered, either by changing the proportions of the component substances or by adding other materials, a change in viscosity is expected.

2.2 Run #2

The overall behaviour of this sample was comparable to the previous one. The variation in viscosity ranges between this run and Run #1 may be due to the difference in quantity of Type I fluid that was collected.

Viscosity decreased by about 8 000 mPa.s (from 30 000 to 22 000 mPa.s), compared with the undisturbed Type IV samples (Rb-A).

Although the in-situ readings for Run #1 levelled at 23 800 mPa.s (Figure F-1; R #1-A), the one for Run #2 levelled at 21 400 mPa.s (Figure F-2; R #2-A). This difference may be due to the amount of Type I fluid, which was not easy to keep the same for each run. Most likely, more Type I fluid was collected in Run #2 than in Run #1.

After 12 weeks, we found that the sample behaviour in the two runs was different (see R #1-A (+12 weeks) in Figure F-1 and R #2-A (+12 weeks) in Figure F-2). The viscosity was much lower in Run #2, probably due to the amount of Type I fluid.

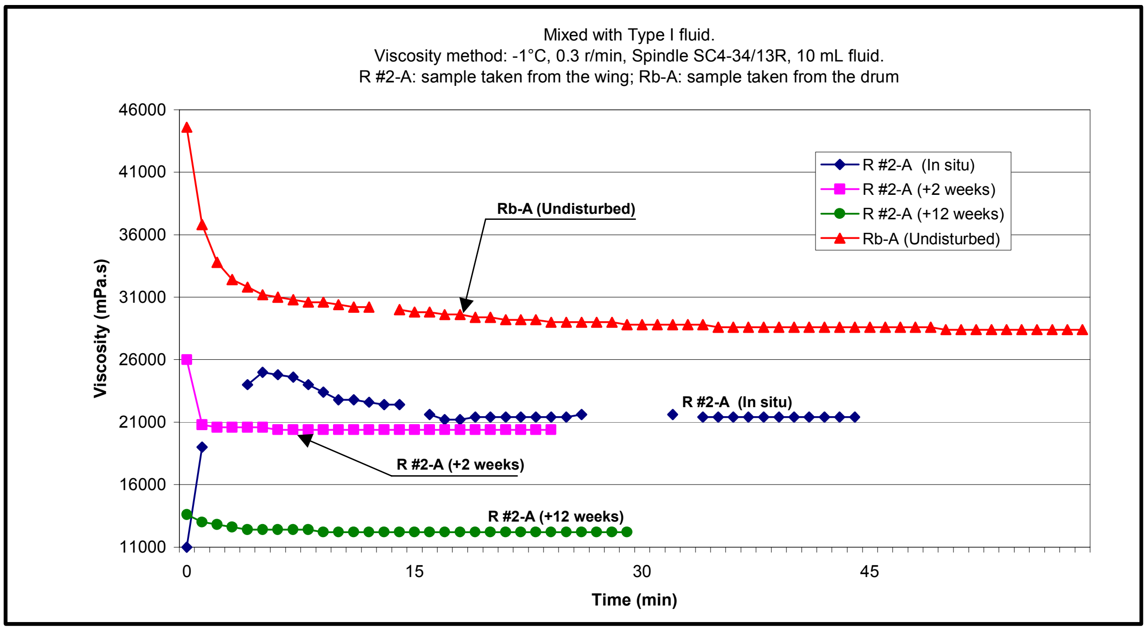

Figure F-2: Viscosity Change Over Time - Fluid A (Run #2)

3. VISCOSITY TEST RESULTS - FLUID B1

3.1 Run #1

The viscosity range was between 32 000 and 43 000 mPa.s (Figure F-3). According to the in-situ plot (R #1-B1 (in-situ)), viscosity went up during the first 5 minutes and levelled off later at 36 400 mPa.s. The explanation for this increase is the same as that mentioned in Section 2.1.

After 3 weeks, the viscosity measurement conducted on the fluid collected on-wing levelled off at the same value as the one collected in-situ. As in the case of Fluid A, Fluid B1 did not change much after three weeks.

After 16 weeks, having lost the air bubbles created during spraying, the fluid became much less viscous (plot R #1-B1 (+16 weeks)).

The difference between the undisturbed fluid (Rb-B1) and the one sampled in-situ (R #1-B1 (in-situ)) is probably due to the fact that the latter was actually a mix of Type I and Type IV.

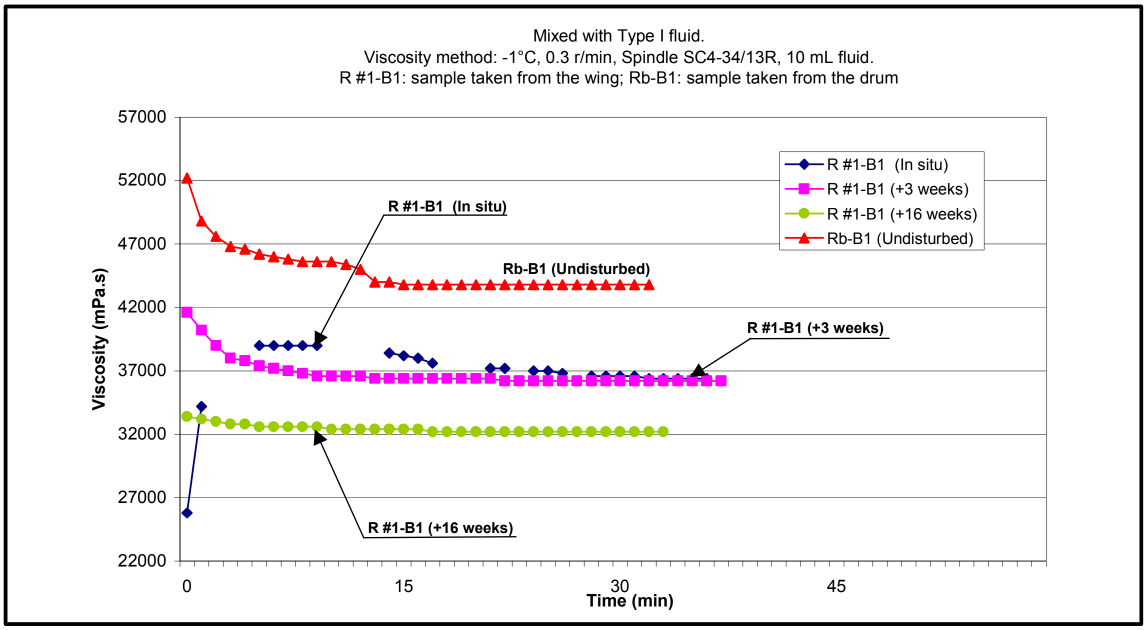

Figure F-3: Viscosity Change Over Time - Fluid B1 (Run #1)

3.2 Run #2

Viscosity readings varied between 23 000 and 43 000 mPa.s (Figure F-4). The average of the in-situ viscosity (R #2-B1 (in-situ)) was around 5 000 mPa.s lower than that of the first run. More Type I fluid may have been collected during this run than during the previous one. In-situ viscosity values (R #2-B1) were noticeably lower than those of the undisturbed fluid (Rb-B1).

For this run, the fluid sample taken on-wing and tested after three weeks was clearly less viscous than the one measured in-situ. We suspect that the spraying was not well done (the nozzle opening being too big), which eventually introduced larger bubbles than the small ones introduced in Run #1. Consequently, it did not take the fluid more than three weeks to lose nearly all of its entrained air and stabilize. This assumption is consistent with the insignificant difference between the readings taken after 3 and 16 weeks. Time may not have affected the sample viscosity.

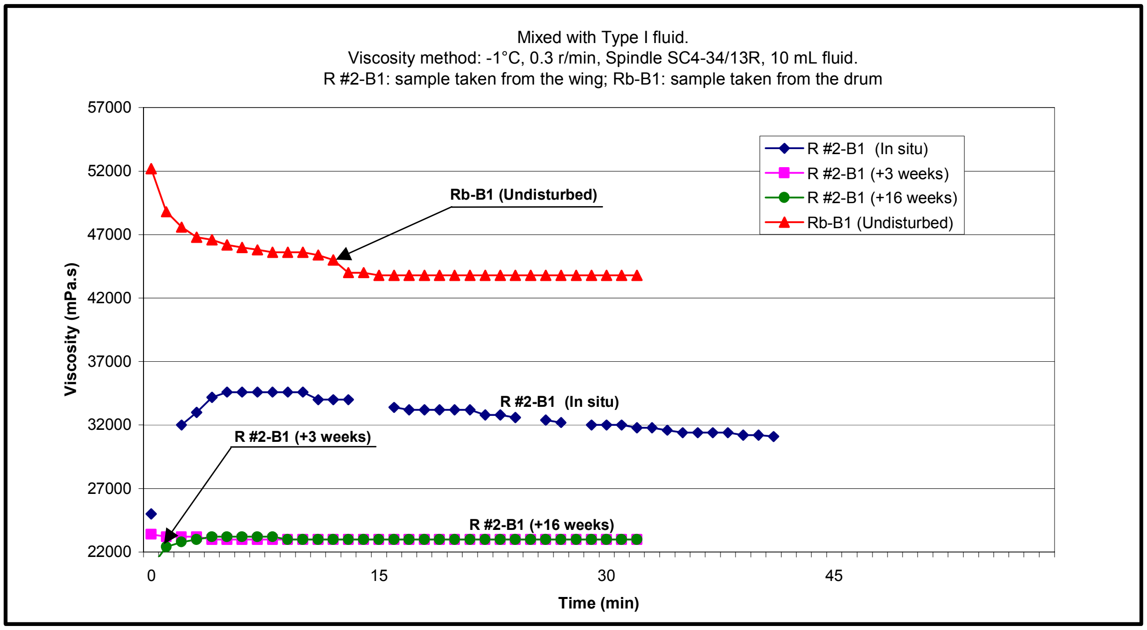

Figure F-4: Viscosity Change Over Time - Fluid B1 (Run #2)

4. VISCOSITY TEST RESULTS - FLUID C1

4.1 Run #1

It took about 10 minutes for the tested fluid to reach stable viscosity readings. The average viscosity during this run ranged between 5 500 and 43 000 mPa.s (Figure F-5).

According to the in-situ viscosity plot (R #1-C1 (in-situ)), during the first minutes, Fluid C1 did not become much more viscous than Fluids A and B1. This means that the settled bath temperature and the fluid temperature measured immediately after sampling might have been very close. Thus, the tested fluid levelled off quickly.

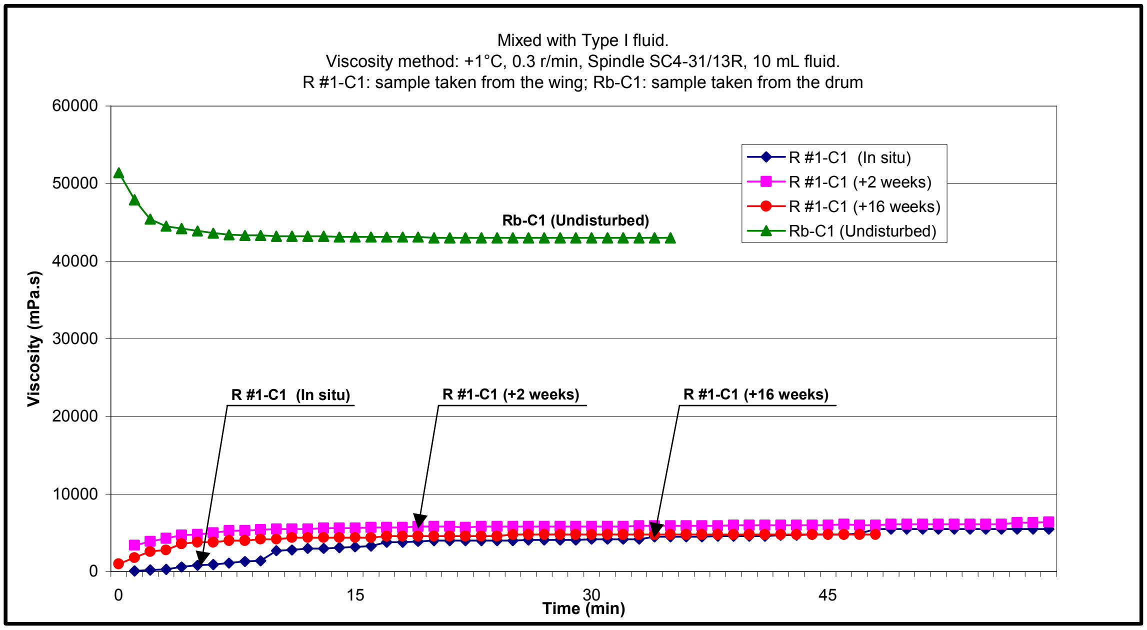

Figure F-5: Viscosity Change Over Time - Fluid C1 (Run #1)

The difference between the undisturbed fluid (Rb-C1) and the one sampled in-situ (R #1-C1 (in-situ)) is most likely due to mixture with Type I fluid.

For this run, the in-situ readings and the ones taken for the same fluid after 2 and 16 weeks had almost the same profile. The viscosity levelled off (clearly after about 30 min) at almost 5 000 mPa.s. The slight difference may be due to the viscometer's experimental error (around 7%). The sample from the wing seemed to stabilize after about 1 hour; time did not affect the fluid viscosity.

4.2 Run #2

During this run, the in-situ readings and the ones taken after 2 and 16 weeks levelled off relatively (to fluids A and B1) fast (Figure F-6). This fact may prove the stability of this sample compared to that of the previously tested fluids (A and B1). Air entrainment may have been less noticeable with Fluid C1.

The viscosity readings of this sample, taken after 2 and 16 weeks, were surprisingly higher (compared to Fluids A and B1) than the ones taken in-situ (Figure F-6). One possible reason is that the entrained air, unlike that of Fluids A and B1, decreased viscosity instead of increasing it.

Since Run #1 was conducted at +1°C and Run #2 at -1°C (because the sampled fluids were at different temperatures), no constructive comparison could be made between the runs. As expected, the viscosity range of each plot was effectively higher in the second run (at lower temperature).

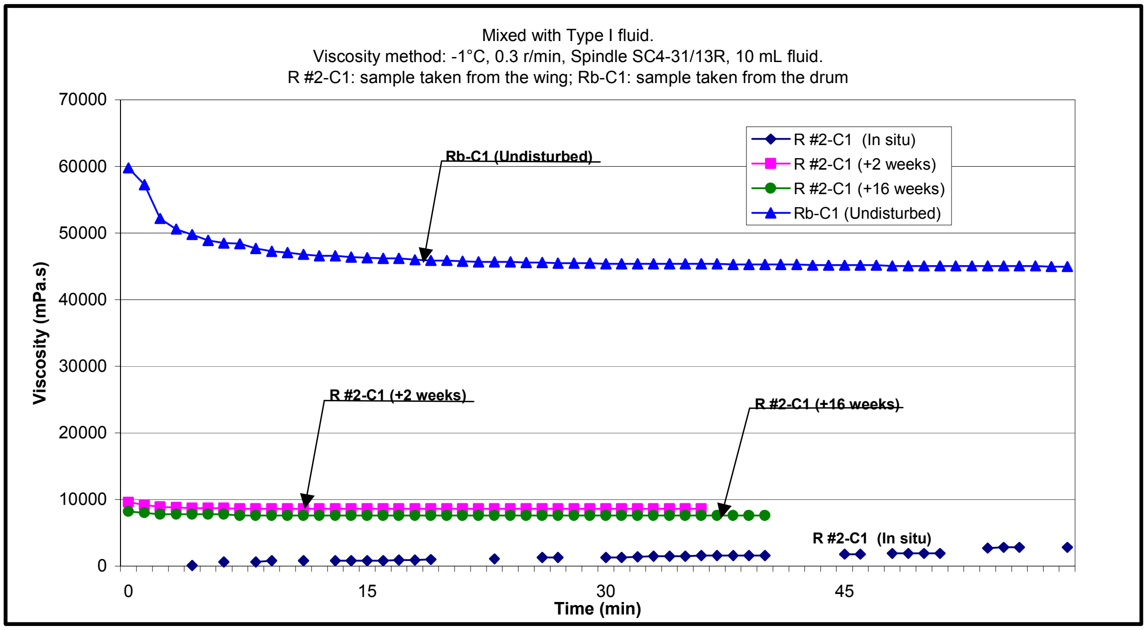

Figure F-6: Viscosity Change Over Time - Fluid C1 (Run #2)

4.3 Run #3

This run was specifically conducted with <u>no Type I fluid</u> (Figure F-7). The viscosity was measured at -10°C (lower than the previous runs, as it was not mixed with hot Type I fluid). Since this run was not really planned for this session, the in-situ viscosity readings were stopped after 10 minutes.

Comparing the viscosity readings of the sample taken from the wing and tested after four weeks (R #3-C1 (+4 weeks)) with the undisturbed fluid readings (Rb-C1), we find that the profile is almost identical. This proves that after four weeks, entrained air is no longer present, which produces a stable fluid comparable to the undisturbed one.

When compared with Run #1 and Run #2, this run also shows the remarkable effect that Type I fluid has on the viscosity of the on-wing fluid mix.

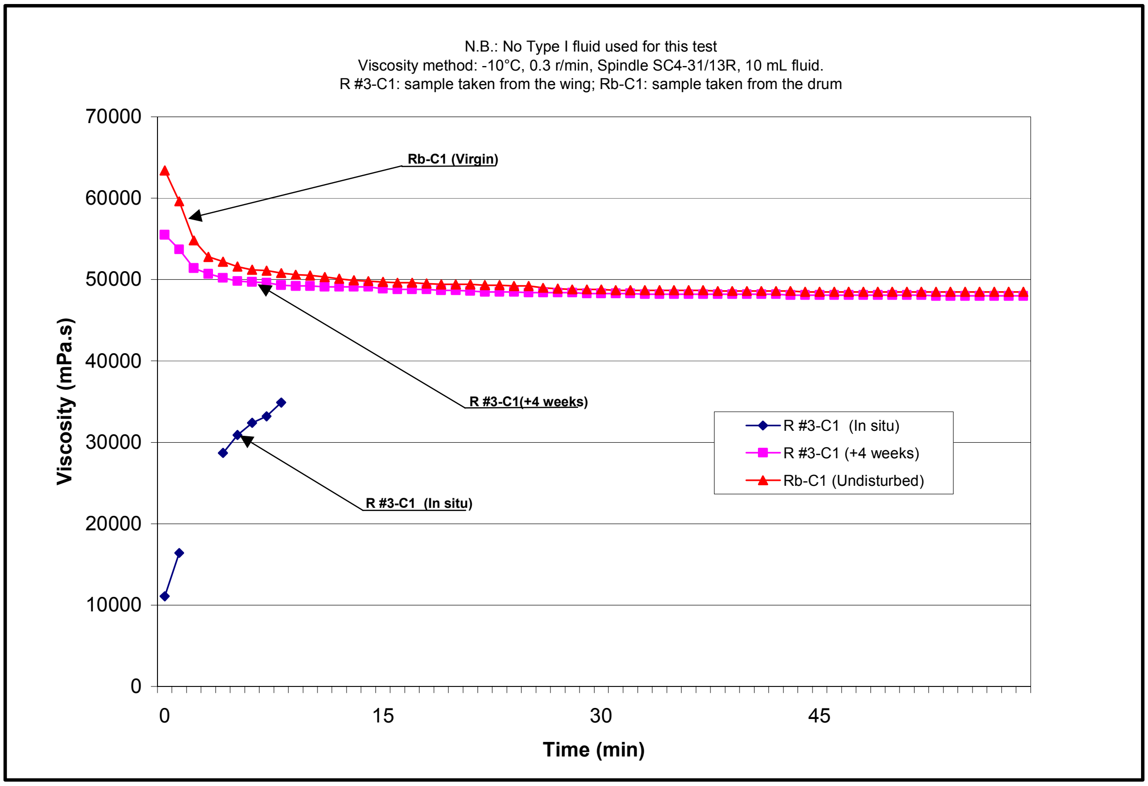

Figure F-7: Viscosity Change Over Time - Fluid C1 (Run #3)

4.4 Run #4

According to Figure F-8, the difference between the undisturbed fluid (Rb-C1) and the one sampled in-situ (R #4-C1 (in-situ)) is about 15 000 mPa.s (from 30 000 to 45 000 mPa.s). When compared to Run #2, carried out at the same bath temperature, this difference is remarkable (from 3 000 to 45 000 mPa.s; see Figure F-6). We might suspect that in Run #4, the sample collected from the wing contained less Type I fluid than the one in Run #2. Also, unlike Run #2, the viscosity readings of the sample taken after 2 weeks during Run #4 were surprisingly lower than those taken in-situ (Figure F-8).

Since it was reported during Run #4 that the "spraying was not well done", it is suspected that the air entrainment was the reason for this difference.

As opposed to Fluids A and B1, the entrained air might decrease the viscosity of fluid C1 instead of increasing it.

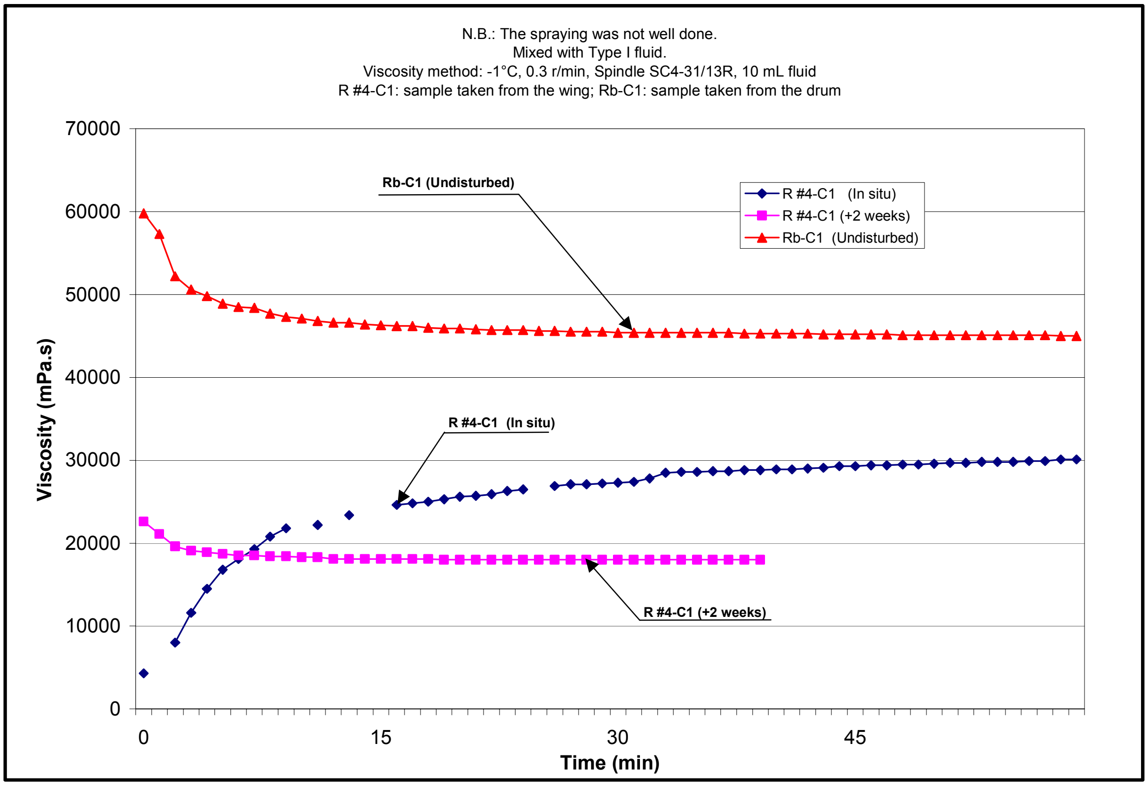

Figure F-8: Viscosity Change Over Time - Fluid C1 (Run #4)

4.5 General Observations for Fluid C1

Compared with viscosity readings of the undisturbed Fluid C1, those of the in-situ sample decreased considerably by about 37 000 mPa.s (from 43 000 to 6 000 mPa.s; see Figure F-6). The difference was more noticeable with Fluid C1 than with Fluid A and Fluid B1. This was probably because Fluid C1, which is ethylene-based (compared to Fluid A and Fluid B1, which are propylene-based) was mixed with propylene-based Type I fluid. Therefore, the behaviour of the mix should be expected to be different. On the other hand, compared with Fluid A and Fluid B1, Fluid C1 was taken from a drum filled by an AéroMag truck. It was therefore subjected to an extra shearing that may have caused an additional decrease in viscosity.

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