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

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Transportation Development Centre

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APS Aviation Inc.

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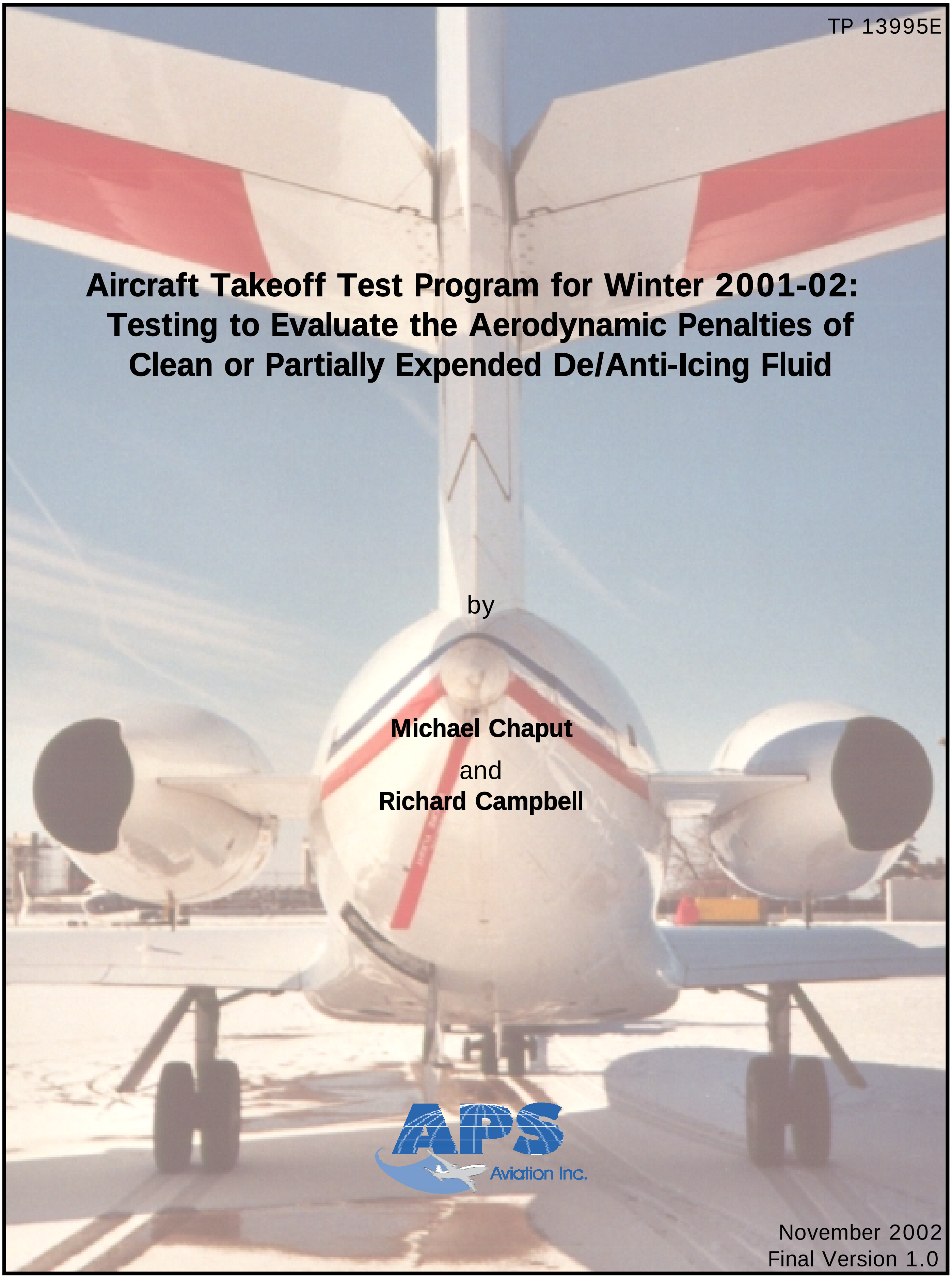

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by

Michael Chaput

and

Richard Campbell

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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 with 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 Test 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 Three Aircraft Ground Icing Research Activities During the 2001-02 Winter.

This report, TP 13995E, has the following objective:

- To further evaluate the flow of contaminated fluid from the wing of an aircraft during simulated takeoff runs.

This objective was met by performing a series of takeoff tests using the NRC Falcon 20 aircraft in March 2002.

ACKNOWLEDGEMENTS

This research has been funded by Transport Canada. This program could not have been accomplished without the participation of many organizations. APS would therefore like to thank the Civil Aviation Directorate and the Transportation Development Centre of Transport Canada, the U.S. Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada (formerly known as Atmospheric Enviroment 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

The objective of this study was to ascertain whether there is an aerodynamic penalty on an aircraft due to the presence of partially expended anti-icing fluid on the wings. To satisfy this objective, takeoff tests were performed with a National Research Council Falcon 20 research aircraft at the Ottawa Airport. Three different types of tests were performed in 2001-02: baseline tests with clean, bare wings; tests with clean, undiluted Type IV fluid, and tests with partially diluted Type IV fluid.

APS Aviation Inc. coordinated and provided support for the Falcon 20 tests. NRC flight crews flew the aircraft. APS personnel recorded all non-flight related test data. The NRC project management team performed analysis of the Falcon 20 flight data.

The test wings were treated with an ethylene glycol-based Type IV fluid either in a one-step or two-step de/anti-icing operation. In the tests involving two-step operations, the wings were first cleaned with an ethylene glycol-based Type I prior to the application of Type IV. Simulated light freezing rain was then sprayed over the test fluid until specified levels of contamination were achieved. Data such as fluid thickness, wing temperatures, and fluid freeze points were recorded. The aircraft was then operated through a takeoff run, including aircraft rotation and climb-out. The behaviour of the fluid during the takeoff run was documented with hand-held video cameras from the cabin.

Fluid thickness values on the leading edge were recorded prior to the takeoff of the aircraft.

The fluid present on the wings was nearly completely eliminated during the takeoff. In general, a small film of fluid remained on certain wing surfaces, most notably on the trailing edge of the aircraft. The leading edge surfaces occasionally had residual fluid following the takeoff. Preliminary analysis by NRC of the flight data suggests that a significant lift penalty may be attributed to the presence of neat or diluted anti-icing fluid on the wings of the Falcon 20.

Tests performed in 2001-02 with the Falcon 20 were conducted as part of a three-year test program. It is recommended that testing to investigate the residual effects of PG SAE Type IV continue in the upcoming year.

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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

L'étude avait pour objectif de déterminer si la présence, sur les ailes d'un avion, d'un fluide antigivre partiellement contaminé entraîne une perte d'aérodynamisme. Des essais de décollage ont été menés en 2001-2002 avec un avion de recherche Falcon 20 du Conseil national de recherches du Canada (CNRC), à l'aéroport d'Ottawa. Trois types d'essais ont été réalisés, selon que les ailes étaient propres et nues (essais de référence), qu'elles étaient revêtues d'un fluide de type IV intact, sans contamination, ou qu'elles étaient revêtues d'un fluide de type IV présentant un certain degré de contamination.

APS Aviation Inc. (APS) a coordonné les essais et en a assuré le soutien. Le Falcon 20 était piloté par des équipages du CNRC. Le personnel d'APS a enregistré toutes les données d'essai autres que les données de vol. L'équipe de gestion du projet du CNRC a procédé à l'analyse des données de vol.

Les ailes ont été revêtues d'un fluide de type IV à base d'éthylèneglycol, au cours d'opérations de dégivrage/antigivrage à une seule étape ou à deux étapes. Les opérations à deux étapes consistaient à d'abord nettoyer les ailes à l'aide d'un fluide de type I à base d'éthylèneglycol, pour ensuite appliquer le fluide de type IV. C'est alors que les ailes étaient exposées à des précipitations artificielles de pluie verglaçante légère, jusqu'à ce que le fluide présente divers degrés de contamination. Différents paramètres étaient notés, comme l'épaisseur du fluide, la température des ailes et le point de congélation du fluide. L'avion effectuait alors un décollage, y compris les phases de rotation et de montée. Des caméras vidéo portables placées dans la cabine filmaient le comportement du fluide.

Avant le décollage, l'épaisseur du fluide sur le bord d'attaque était consignée.

Le décollage avait pour effet de chasser presque tout le fluide présent sur les ailes. Une mince pellicule de fluide subsistait généralement sur certaines surfaces des ailes, en particulier sur le bord de fuite. Il est aussi arrivé que du fluide résiduel ait été trouvé sur le bord d'attaque après le décollage. L'analyse préliminaire des données de vol faite par le CNRC donne à penser que la présence de fluide antigivre, intact ou contaminé, sur les ailes du Falcon 20 conduit à une importante perte d'aérodynamisme.

Les essais réalisés en 2001-2002 avec le Falcon 20 s'inscrivaient dans le cadre d'un programme triennal d'essais. Il est recommandé de mener l'an prochain d'autres essais pour étudier les effets de fluides résiduels de type IV à base de propylèneglycol (PG) de la Society of Automotive Engineers.

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC) of Transport Canada, APS Aviation Inc. has undertaken a research program to examine the potential aerodynamic penalties resulting from the presence of diluted and undiluted anti-icing fluid on aircraft wings.

Aircraft departure regulations in icing conditions require that no takeoff be attempted as long as any form of contamination (ice, frost, snow or slush) is adhering to the critical surfaces of an aircraft. The method of identifying that some form of contamination exists on the aircraft surface relies on visual indications, as perceived by personnel on the ground or by flight crew from flight decks and/or aircraft cabins. When fluid failure is visually identified, the basic assumption is that it is adhering.

Previous Testing

During the 1997-98 and 1998-99 winter test seasons, several simulated takeoff runs were conducted using a National Research Council Canada (NRC) Falcon 20 aircraft to examine the issue of removal of contaminated fluid from aircraft wings during a simulated takeoff run. These tests were intended to fill an information gap left unresolved by either theoretical analysis or wind tunnel laboratory research. These tests were reported in Transport Canada reports TP 13316E, *Contaminated Aircraft Takeoff Tests for the 1997-98 Winter* (1), and TP 13479E, *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter* (2).

The 1997-98 and 1998-99 series of simulated takeoff runs provided an initial level of understanding of the issue and proved useful in gaining a more complete understanding of contaminated fluid elimination.

Anti-icing fluid, when diluted by ongoing precipitation, often begins to fail in the upper fluid layers, forming slush. However, because a layer of fluid is always present below, no adherence to the aircraft surface is initially possible; the airflow at takeoff should remove the contamination along with the fluid. Up to 10 percent coverage of the wing by slush is generally accepted before holdover time ends. In addition, NRC open circuit wind tunnel tests showed that the presence of residual fluid caused a small loss of lift at rotation. Results from full-scale flight tests by Boeing and SAAB have also indicated reductions in lift due to residual fluid.

2001-02 Testing

In 2001-02, TDC initiated a three-year study to examine the aerodynamic penalties resulting from the presence of diluted and undiluted fluid on aircraft

wings. The long-term goal of this research program is to determine the effects of a limited level of unabsorbed winter precipitation present in or on an anti-icing fluid while maintaining a safe takeoff condition below the protection time limit for the fluid. In other words, the wing is to be maintained aerodynamically “clean” even though it may not be visually clean.

The role of APS in the test program was to coordinate and provide support services for the Falcon 20 tests. The aircraft is owned and operated by NRC, and was flown by NRC flight crews. The NRC project team performed analysis of the Falcon 20 flight data.

The test program undertaken during winter 2001-02 using the NRC Falcon 20 aircraft addressed the effects of residual anti-icing fluid on aircraft takeoff performance. Testing was conducted to ascertain whether there is an aerodynamic penalty on the aircraft due to the presence of neat or partially expended anti-icing fluid on the wings. One ethylene glycol-based Type IV fluid was examined for this purpose.

To satisfy the objective of the test program, simulated takeoff runs were performed with an NRC Falcon 20 research aircraft. Three different types of tests were performed:

- Baseline tests with clean, bare wings;
- Tests using clean, undiluted Type IV fluid; and
- Tests using partially diluted Type IV fluid (with simulated precipitation).

The test wings were treated with the Type IV fluid either in a one- or two-step de/anti-icing operation. In the tests involving two-step operations, the wings were first cleaned with an ethylene glycol-based Type I fluid prior to the application of the Type IV fluid. Simulated freezing rain was then sprayed over the test fluid until specified levels of contamination were achieved. Data such as fluid thickness, wing temperatures, and fluid freeze points were recorded.

The aircraft was subsequently operated through a takeoff run, including aircraft rotation and climb-out. The aircraft then performed a circuit of the airport and returned. During the takeoff run, the fluid behaviour was recorded with hand-held video cameras from the cabin. Upon the aircraft’s return to the inspection pad, the wing condition was again examined and documented.

APS coordinated and provided support for testing with the Falcon 20 to evaluate the aerodynamic penalties of clean or partially expended de/anti-icing fluid. APS personnel recorded all related test data.

Conclusions

Fluid thickness values on the leading edge recorded prior to the takeoff of the aircraft were in the range of 0.2 mm to 0.6 mm, although measurements of up to 2.0 mm were recorded in some locations near the leading edge slat-to-wing interface. Fluid thickness values on the mid-wing section recorded prior to the takeoff of the aircraft were in the range of 0.8 mm to 2.4 mm, although measurements as low as 0.3 mm and as high as 3.6 mm were recorded in some sections. Fluid thickness values on the trailing edge recorded prior to the takeoff of the aircraft were generally in the range of 0.7 mm to 1.2 mm, although measurements as low as 0.2 mm and as high as 2.4 mm were recorded in some tests.

The test results show that uncontaminated fluid was nearly completely eliminated from the wing surface during takeoff. In general, a small film of fluid, usually in the range of less than 0.1 mm to 0.3 mm, remained on certain wing surfaces, most notably on the trailing edge of the aircraft. The leading edge surfaces occasionally had residual fluid after the takeoff run. The thickness of the fluid film never measured more than 0.1 mm.

Preliminary analysis of the NRC flight data suggests that a significant lift penalty may be attributed to the presence of neat or diluted anti-icing fluid on the wings of the Falcon 20.

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SOMMAIRE

À la demande du Centre de développement des transports (CDT) de Transports Canada, APS Aviation Inc. a entrepris un programme de recherche qui visait à examiner plus avant la perte d'aérodynamisme susceptible de résulter de la présence de fluides antigivre, contaminés et intacts, sur les ailes d'un avion.

Les règles sur le décollage dans des conditions givrantes interdisent aux pilotes de décoller lorsqu'une forme ou l'autre de contamination (glace, givre, neige ou neige fondante) adhère aux surfaces critiques de l'avion. La façon de déterminer la présence de contamination sur les surfaces de l'avion est l'observation visuelle, par le personnel au sol ou par l'équipage de conduite, depuis le poste de pilotage et/ou la cabine de l'avion. Lorsque la perte d'efficacité du fluide est constatée visuellement, il faut conclure que la contamination adhère aux surfaces.

Essais antérieurs

Au cours des saisons d'essai 1997-98 et 1998-99, plusieurs simulations de décollage d'un avion Falcon 20 du Conseil national de recherches du Canada (CNRC) ont eu lieu. Ces essais avaient pour but d'examiner si le fluide contaminé devenu inefficace était chassé pendant la course au décollage. Il s'agissait de répondre à une question laissée en suspens aussi bien par une analyse théorique que par des essais en soufflerie. Ces essais sont documentés par les rapports TP 13316E, *Contaminated Aircraft Takeoff Tests for the 1997-98 Winter* (1) et TP 13479E, *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter* (2) de Transports Canada.

Les séries de décollages simulés réalisés en 1997-98 et en 1998-99 ont tout de même permis de défricher le terrain et de mieux comprendre le phénomène d'élimination du fluide contaminé.

Lorsque le fluide antigivre est dilué par une précipitation, sa perte d'efficacité commence souvent à se manifester dans ses couches supérieures, sous forme de ce qui ressemble à de la neige fondante. Cependant, comme il subsiste toujours, dessous, une couche de fluide, la contamination ne peut adhérer à la surface : l'écoulement d'air au décollage élimine normalement la contamination en même temps que le fluide. On accepte généralement une couverture de 10 p. 100 de l'aile par de la neige fondante avant de déclarer la perte d'efficacité du fluide. De plus, les essais réalisés dans la soufflerie à circuit ouvert du CNRC ont révélé que la présence de fluide résiduel entraînait une faible diminution de la portance au moment du cabrage de l'avion. Les essais en vraie grandeur menés par Boeing et SAAB ont aussi révélé des diminutions de la portance due à la présence de fluide résiduel.

Essais de 2001-02

En 2001-02, le CDT lançait une étude triennale dont l'objectif était d'examiner la perte d'aérodynamisme attribuable à la présence, sur les ailes d'un avion, de fluide contaminé et intact. L'objectif à long terme de ce programme de recherche est de déterminer si la présence, dans ou sur un fluide antigivre, d'une petite quantité de précipitation hivernale non absorbée, influe sur la sûreté d'un décollage fait dans les limites de la durée d'efficacité établie pour le fluide. Autrement dit, il faut que l'aile soit «propre» du point de vue aérodynamique, même si elle n'est pas propre visuellement.

Le rôle d'APS dans l'étude a été de coordonner les essais et d'en assurer le soutien. Le CNRC étant propriétaire et exploitant du Falcon 20, les équipages de conduite provenaient du CNRC. C'est aussi l'équipe de projet du CNRC qui a analysé les données de vol du Falcon 20.

Les essais de 2001-02 mettant en jeu l'avion Falcon 20 portaient sur les effets de la présence de fluide antigivre résiduel sur le comportement au décollage d'un avion. L'objectif était de déterminer si la présence, sur les ailes d'un avion, d'un fluide antigivre intact ou partiellement contaminé conduit à une perte d'aérodynamisme. Un seul fluide de type IV à base d'éthylèneglycol a été étudié.

Pour atteindre l'objectif assigné au programme, des décollages ont été effectués avec un avion de recherche Falcon 20 du CNRC. Trois types d'essais ont été réalisés :

- essais de référence – ailes propres et nues;
- essais utilisant un fluide de type IV intact, non contaminé;
- essais utilisant un fluide de type IV partiellement contaminé (par des précipitations artificielles).

Les ailes ont été revêtues d'un fluide de type IV à base d'éthylèneglycol, au cours d'opérations de dégivrage/antigivrage à une seule étape ou à deux étapes. Les opérations à deux étapes consistaient à d'abord nettoyer les ailes à l'aide d'un fluide de type I à base d'éthylèneglycol, pour ensuite appliquer le fluide de type IV. C'est alors que les ailes étaient exposées à des précipitations artificielles de pluie verglaçante légère, jusqu'à ce que le fluide présente divers degrés de contamination. Différents paramètres étaient notés, comme l'épaisseur du fluide, la température des ailes et le point de congélation du fluide.

L'avion effectuait alors un décollage, y compris les phases de rotation et de montée. Après avoir décrit un circuit autour de l'aéroport, il revenait se poser. Des caméras vidéo portables placées dans la cabine filmaient le comportement du fluide. Au retour de l'avion au poste d'inspection, l'aile était de nouveau examinée et les résultats consignés.

APS a coordonné les essais du Falcon 20 et apporté son soutien aux travaux, qui visaient à évaluer la perte d'aérodynamisme associée à un fluide antigivre intact ou partiellement contaminé. Le personnel d'APS a enregistré toutes les données reliées aux essais.

Conclusions

Les valeurs d'épaisseur du fluide sur le bord d'attaque enregistrées avant le décollage allaient de 0,2 mm à 0,6 mm, voire jusqu'à 2,0 mm à certains endroits près de la jonction entre le bec du bord d'attaque et l'aile. Les épaisseurs enregistrées sur l'aile médiane étaient de l'ordre de 0,8 mm à 2,4 mm, malgré des valeurs aussi faibles que 0,3 mm et aussi élevées que 3,6 mm enregistrées à certains endroits. Sur le bord de fuite, les valeurs enregistrées oscillaient généralement entre 0,7 mm et 1,2 mm, même si certains essais ont donné des valeurs aussi faibles que 0,2 mm et aussi élevées que 2,4 mm.

Les résultats des essais révèlent que le fluide intact était presque complètement chassé de la surface des ailes au cours du décollage. Une mince pellicule de fluide, habituellement de moins de 0,1 mm à 0,3 mm d'épaisseur, subsistait généralement sur certaines surfaces, en particulier sur le bord de fuite. Il est aussi arrivé que du fluide résiduel ait été trouvé sur le bord d'attaque après la course au décollage. L'épaisseur de la pellicule ne dépassait jamais 0,1 mm.

Une analyse préliminaire des données de vol du CNRC laisse penser que la présence de fluide antigivre, intact ou contaminé, sur les ailes du Falcon 20 a un effet défavorable significatif sur l'aérodynamisme de l'aéronef.

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GLOSSARY

APS	APS Aviation Inc.
CSA	Canadian Space Agency
DND	Department of National Defence
EG	Ethylene Glycol
GPS	Global Positioning System
ILS	Instrument Landing System
MLS	Microwave Landing System
MSC	Meteorological Service of Canada (formerly known as Atmospheric Environmental Services (AES))
NASA	National Aeronautics and Space Administration (U.S.)
NRC	National Research Council Canada
PG	Propylene Glycol
SAE	Society of Automotive Engineers
TDC	Transportation Development Centre
VOR	VHF Omnidirectional Range
YOW	MacDonald Cartier International Airport

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1. INTRODUCTION

Under contract to the Transportation Development Centre (TDC) of Transport Canada, APS Aviation Inc. (APS) has undertaken a research program to examine the potential aerodynamic penalties resulting from the presence of clean and diluted anti-icing fluid on aircraft wings.

1.1 Background

Aircraft departure regulations for icing conditions require that takeoff is prohibited as long as any form of contamination (ice, frost, snow or slush) is adhering to the critical surfaces of an aircraft. The method for identifying whether some form of contamination exists on the aircraft surface is generally reliant on visual indications, as perceived by personnel on the ground or by flight crew from flight decks and/or aircraft cabins. When fluid failure is visually identified, it is assumed to be adhering.

In some situations a tactile test may be conducted, either in response to regulations or as a voluntary practice to provide additional information on the wing condition. This test consists of passing the bare hand over an area of the wing surface, such as the leading edge, or scraping the surface with the fingernails to identify the presence of a very thin ice film.

1.1.1 1997-98 Testing

During the winter of 1997-98, several simulated takeoff runs were conducted using a National Research Council Canada (NRC) Falcon 20 aircraft. The issue of removing contaminated fluid from aircraft wings during takeoff was examined. These tests were intended to fill an information gap not yet resolved by theoretical analysis or wind tunnel laboratory research. The tests were reported in TP 13316E, *Contaminated Aircraft Takeoff Tests for the 1997-98 Winter* (1).

The series of simulated takeoff runs conducted (up to but not including rotation) in 1997-98 provided an elementary understanding of the issue and proved to be useful in gaining a more complete understanding of elimination of contaminated fluid. Several observations were drawn from the tests:

a) The first documented evidence anti-icing fluid elimination from the wings of a contaminated aircraft was obtained;

b) In some cases, the contaminated fluid failed to adhere to the wing surface and yet showed freedom of movement (though it continued to stay on the wing);

c) In general, contamination was not completely eliminated from the wing surface during acceleration of the aircraft to rotation speed in the simulated takeoff run; and

d) These tests identified the need to conduct a further series of tests at takeoff speeds up to and including rotation to verify the results.

1.1.2 1998-99 Testing

As other avenues of research had yet to provide resolution to the issue of contaminated fluid from aircraft wings, it was decided to conduct additional simulated takeoff runs during the winter of 1998-99. A perceived shortcoming of the series of runs conducted in 1997-98 was that although aircraft speed was increased to normal takeoff speed, the aircraft was not rotated at takeoff speed and therefore offered an incomplete representation of true takeoff conditions. It was proposed that the second series of tests examine ways to include rotation at takeoff speed as part of the simulation, and that both ethylene and propylene glycol-based SAE Type IV fluids be tested. These tests were reported in TP 13479E, *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter* (2).

The observations and conclusions from the 1998-99 tests were as follows:

a) Uncontaminated fluid, both ethylene glycol-based (EG) and propylene glycol-based (PG), was nearly completely eliminated from the wing surface during the takeoff run;

b) In tests with EG SAE Type IV fluid, ice formations existing prior to the takeoff run continued to exist following takeoff and was independent of adhesion or lack of adhesion to the wing skin prior to the takeoff run;

c) PG SAE Type IV fluid was completely eliminated when a reasonable level of contaminated fluid was tested;

d) For similar exposure times, PG Type IV fluid gave the visual appearance of being contaminated to a greater extent than EG fluid. Conversely, contamination developed on the PG Type IV was completely eliminated from the wing during the takeoff run, whereas contamination on the EG fluids remained; and

e) Rotation of the aircraft at normal rotation speed during the takeoff run failed to eliminate the frozen contamination remaining on the wing.

1.1.3 Planned Testing in 1999-2000 and 2000-01

Tests were again planned for the 1999-2000 and 2000-01 winter test seasons. Due to a lack of suitable weather in the period allotted for testing in each year, no tests were conducted. The procedures for the 1999-2000 tests with the Falcon 20 were included in TP 13666E, *Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures* (3).

1.2 2001-02 Testing

The risk of a catastrophic aircraft accident at takeoff caused by ongoing winter precipitation may be regarded as the product of the probabilities of:

a) Anti-icing fluid failing to prevent contamination adhering to the aircraft;

b) Fluid failure going undetected and a decision being made to take off; and

c) Contamination of aerodynamic surfaces being sufficient to cause significant loss of lift and/or loss of control.

When diluted by ongoing precipitation, anti-icing fluids often begins to fail in the upper fluid layers forming slush. Because a layer of fluid is always present below the slush, the failed fluid does not adhere to the lift-critical parts of the aircraft initially, and the airflow at takeoff removes the frozen contamination along with the fluid. Up to ten percent coverage of the wing by slush is generally accepted before holdover time ends; although aircraft tests by TDC have shown that this figure may vary considerably. In addition, NRC open circuit wind tunnel tests showed that the presence of unshed fluid caused a small loss of lift at rotation. Results from full-scale flight tests by Boeing and SAAB have also indicated reductions in lift due to unshed fluid.

In 2001-02, TDC undertook a three-year study to examine the aerodynamic penalties resulting from the presence of diluted and undiluted fluid on aircraft wings. The long-term goal of this research program is to determine the effects of a limited level of unabsorbed winter precipitation present in or on an anti-icing fluid while maintaining a safe takeoff condition below the protection time limit for the fluid. In other words, the wing is to be maintained aerodynamically “clean” even though it may not be visually clean.

The role of APS in the test program was to coordinate and provide support for the Falcon 20 tests. The aircraft is owned and operated by NRC, and was flown by NRC flight crews. Analysis of the Falcon 20 flight data was performed by the NRC project team.

The test program undertaken during the winter of 2001-02 using the NRC Falcon 20 aircraft addressed the effects of unshed anti-icing fluid on aircraft takeoff performance. The aerodynamic penalty on the aircraft due to presence of clean anti-icing fluid and also partially expended anti-icing fluid on the wings were examined for one ethylene glycol-based Type IV fluid.

1.3 Program Objectives

The three-year test program will address the following objectives:

a) To ascertain whether there is an aerodynamic penalty on the aircraft due to presence of clean or partially expended anti-icing fluid on the wings;

b) To determine the effects of a limited level of unabsorbed frozen contamination present in or on an anti-icing fluid while maintaining a safe takeoff condition below the holdover time limit for the fluid; and

c) To determine the level of contamination of anti-icing fluid (caused by winter precipitation) at which the airflow at takeoff fails to remove the resultant slush.

In 2001-02, testing was conducted to address objective (a), as mentioned above. To satisfy this objective, simulated takeoff runs were performed with an NRC Falcon 20 research aircraft. Three different tests were performed:

a) Baseline tests with clean, bare wings;
b) Tests with clean, undiluted Type IV fluid; and
c) Tests with partially diluted Type IV fluid.

One ethylene glycol-based Type IV fluid was tested. The test wing was treated with the Type IV fluid either in a one-step or a two-step de/anti-icing operation. In the tests involving two-step operations, the wings were first cleaned with an ethylene glycol-based Type I fluid prior to the application of the Type IV fluid. Simulated freezing rain was then sprayed over the test fluid until specified levels of contamination were achieved. Data such as fluid thickness, wing temperatures, and fluid freeze points were recorded.

The aircraft was subsequently operated through a takeoff run, including aircraft rotation and climb-out. The aircraft then performed a circuit of the airport and returned. The visual behaviour of the fluid during the takeoff run was recorded with hand-held video cameras. Upon the aircraft's return to the inspection pad, the wing condition was again examined and documented.

1.4 Work Statement

Appendix A presents an excerpt from the project description in the work statement for the APS Aviation 2001-02 winter research program.

1.5 Report Format

The following list provides short descriptions of subsequent sections of this report:

- Section 2 describes the test conditions and methodologies used, as well as equipment and personnel requirements necessary to carry out testing;
- Section 3 describes the data collected and the different conditions in which data were collected;
- Section 4 presents the data analysis and the overall results of the testing;
- Section 5 presents conclusions derived from testing; and
- Section 6 lists recommendations for future testing.

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2. METHODOLOGY

This section describes the test conditions and experimental methodologies followed in the 2001-02 testing with the Falcon 20 aircraft, as well as the equipment and the personnel requirements.

The issue of clarity when discussing fluid failure is significant. Therefore common terminology definitions have been included in Section 2.1. 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 (4).

2.1 Icing Definitions

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.

Failure adhesion
The initial bonding of ice crystals in a fluid to the surface resulting from the diluted fluid freezing point rising above the surface temperature at a nucleation site on the surface.

Nucleation site
The site at which an ice crystal is stimulated to form from supercooled water.

Protection time
The period that an anti-icing treatment protects aerodynamically critical surfaces from the adhesion of contamination and the resulting roughness that could cause a premature stall or result in loss of control and prevent the crew from safely operating the aircraft.

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.

Holdover time guidelines
Guidelines for holdover times as a function of specific weather conditions established by the SAE G-12 holdover time committee and based on endurance time test results.

Standard test plate
The standard test plate, for the purpose of this document, is restricted to the plate used in endurance time testing. It is an aluminum alloy plate 50 cm (20 in.) long and 30 cm (12 in.) wide adopted by SAE for the evaluation and certification of de/anti-icing fluid performance. For testing it is mounted at 10° to the horizontal. Along the top and two sides a line is marked 2.5 cm (1 in.) from the edge; ice crystals commencing in these zones are ignored as outside the test area. The bottom edge is a special case because the fluid is held back and is excessively thick there. The test area of the test plate is about 75 percent of the total area. The plate is marked with horizontal lines parallel to the top edge at 7.5 cm (3 in.), 15 cm (6 in.), 22.5 cm (9 in.), 30 cm (12 in.), and 37.5 cm (15 in.). On each of these lines are marked three cross hairs, one in the middle of the line and the other two evenly spaced 7.5 cm (3 in.) each side of it for a total of 15 crosshair sites.

Standard plate failure

Failure is established as a visual failure of one third of the test surface based on the observation of conditions on full-scale aircraft. This usually occurs when the failure front on the plate crosses the 15 cm (6 in.) line. However, in outside snow tests, because there is usually wind, the start point may be anywhere on the plate and the progression in any direction. Under these conditions, visual failure may be estimated. Alternatively, when contamination is visible on five of the 15 cross hairs, the plate is determined to be one third covered and therefore visually failed.

For the purposes of this report the following have been defined:

An artificial product is one that represents the product in its physical form, ie. "look and feel" (but does not necessarily simulate the effect of the real thing).

A simulation should simulate the way the product interacts with a particular environment having the same effect (but does not need to have the look and feel of the real thing).

2.2 Test Site

The 2001-02 series of takeoff tests was performed at MacDonald Cartier International Airport in Ottawa (YOW) using an NRC Falcon 20 aircraft (see Photo 2.1). The NRC Flight Research Laboratory is located at the airport in Ottawa and, for this reason, NRC personnel selected YOW as the airport of choice. Figure 2.1 provides a schematic of the airport showing the runways and the location of the deicing centre.

The tests were carried out over three days in March 2002. Prior to APS involvement in the tests, the NRC flight crew conducted baseline tests (without fluid on the wings) in February 2002.

2.3 Description of Test Procedures

The procedures for 2001-02 tests with the Falcon 20 aircraft are shown in Appendix D.

Test dates were selected based on weather forecast and availability of the test aircraft. Desired weather conditions for the tests were dry, with sub-freezing outside air temperatures. Overcast skies were preferred, to reduce surface warming of the wing surfaces under test. For safety purposes, it was necessary that runway conditions were clear and dry. Actual test conditions are reported in Section 3.

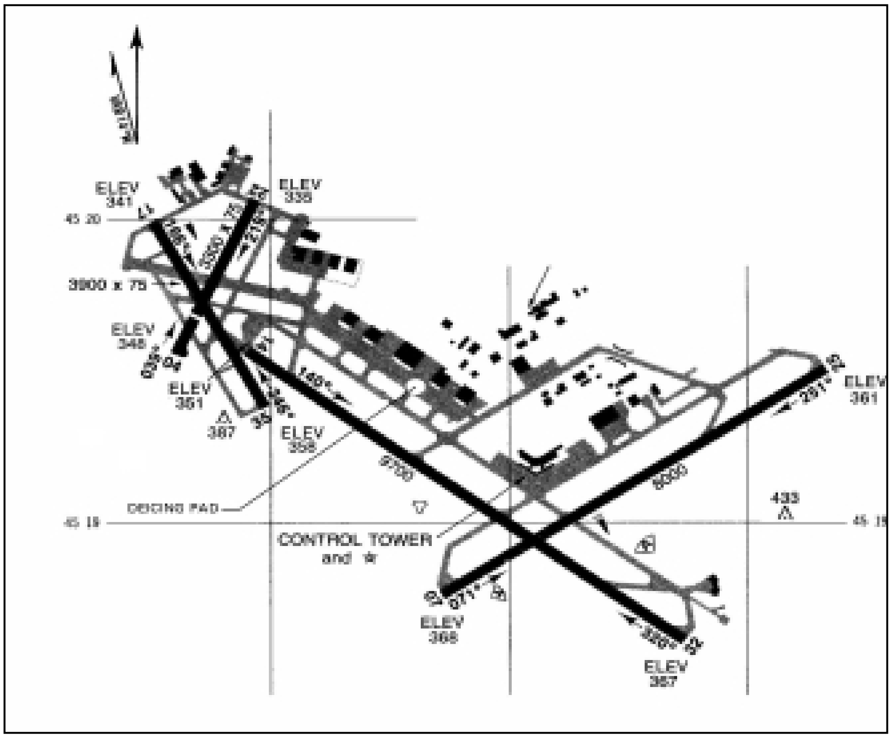


Figure 2.1: Schematic of Ottawa Airport

Prior to testing, NRC personnel used markers to draw a grid with dimensions of 0.61 m x 0.61 m (2 ft. x 2 ft.) grid just inboard the fence on each wing of the Falcon 20 (see Photo 2.2). Smaller boxes with dimensions of 5.1 cm x 5.1 cm (2 in. x 2 in.) were then drawn inside the larger grid, perpendicular to the fence and not parallel to the leading edge of the aircraft (see Photo 2.3). This grid was used to facilitate visual observations of the fluid behaviour when shearing off the wing during takeoff tests.

In 1997-98 and 1998-99 testing with the Falcon 20 aircraft, a single area on the port wing just inboard of the fence was selected to serve as the test surface on the Falcon 20 research aircraft. Because the 2001-02 tests aimed to determine the effects of neat or diluted fluid on the overall lift generated by the aircraft, the test area was increased to include the entire surface area of both wings. The current tests involve takeoff and therefore to reduce the effects of aerodynamic asymmetry similar quantities of fluid were applied to each wing and the fluids were diluted down to the same freeze point using the freezing rain sprayer on each wing.

Prior to the application of fluids to the wing, the wing temperatures at several locations were recorded using hand-held temperature probes.

GlobeGround personnel conducted the application of deicing and anti-icing fluids at the central deicing facility at Ottawa Airport. The first three tests in

March 2002 used two-step deicing and anti-icing operations (Type IV fluid over Type I fluid). All remaining tests were conducted without the application of Type I fluid.

Fluid samples were collected from each deicing vehicle prior to the fluid application process. Fluids samples were again gathered from the wing following the fluid application using spatulas (see Photo 2.4). The fluid samples were transported to APS Aviation's laboratory and subjected to viscosity testing.

The thickness of the Type IV fluid film was measured using octagonal thickness gauges at nine locations along two chords of each wing, for a total of 36 thickness measurement locations for each test. Table 2.1 provides the data form used to record fluid thickness measurements, and also shows the chords and thickness locations that were selected for testing. Fluid thickness was measured after a delay of about 2 minutes to allow the fluid thickness to stabilize following application. The spray application and the appearance of the resulting fluid film on the wing surface were photographed and videotaped. The fluid thickness was then measured prior to the departure of the aircraft from the deicing pad.

For tests involving dilution of the fluid on the wings, precipitation in the form of light freezing rain was applied with the use of custom designed hand-held sprayers by operators located in the buckets of the deicing trucks (see Photo 2.5). Artificial freezing rain was applied until a level of dilution had reached a predetermined level, based on measurements of the refractive index of the fluid at several points on the wing.

Once the fluid had reached the desired level of dilution, the state of the fluid was again photographed and videotaped by observers located on the ground and in the aircraft, and thickness measurement data and wing temperature data were recorded. Fluid samples at selected locations were also collected.

The aircraft then departed the deicing pad for the runway. Thickness measurements were again recorded at the runway threshold just prior to the takeoff of the aircraft.

The hand-held video cameras filmed the appearance of the fluid contaminant mixture from inside the cabin throughout the taxi phase (see Photo 2.6), the takeoff run (see Photo 2.7), the climb-out of the aircraft (see Photo 2.8), and the subsequent return to the inspection pad at the central deicing facility. During the takeoff run, the First Officer read off the ground speed from aircraft instrumentation for the audio track on the videotape.

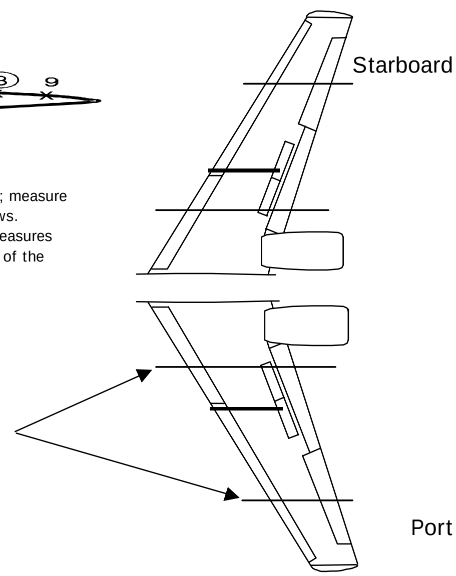
Table 2.1: Thickness Measurement Data Form Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
INBOARD	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								

M:\Groups\Cm1680 (01-02)\Reports\Falcon 20\Working Documents\Table 2.1

Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows.
Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



Location of inboard and outbourd test denoted by lines.

Upon return to the deicing facility, the nature and condition of the fluid remaining on the wing was then re-examined and documented.

Wing skin temperatures were measured at several locations after the takeoff run. Fluid thickness was recorded again (see Photo 2.9), and fluid samples of the remaining fluid on the wings collected for viscosity analysis.

The test plan for 2001-02 testing with the Falcon 20 aircraft is shown in Table 2.2. Modifications were made to the original test plan based on discussions with TDC. Further modifications were made to the test plan during conduct of the tests, and the table containing the actual tests performed is given in Section 3 (Table 3.1).

Table 2.2: Test Plan for Falcon 20 Tests in 2001-02

TEST #	OAT °C	Fluid	Type of Contamination	Level of Contamination
1	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
2	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
3	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
4	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
5	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +
6	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +
7	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +
8	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +

2.4 Data Forms

Several different forms were used to facilitate the documentation of the various data collected in these tests. These forms include:

a) General Form (Every Test);
b) General Form (Once per Session);
c) Fluid Failure Pattern Form – Port Wing;
d) Fluid Failure Pattern Form – Starboard Wing;
e) Fluid Sampling and Brix Form – Port Wing;
f) Fluid Sampling and Brix Form – Starboard Wing;
g) Adherence and Wing Temperature Form – Port Wing;
h) Adherence and Wing Temperature Form – Starboard Wing;
i) Fluid Thickness on Aircraft;
j) Rain/Snow Quantity Form; and
k) Log of Ice Detection Sensor Form.

Copies of these forms are provided in the test procedure given in Appendix D.

2.5 Equipment

A considerable array of test equipment was required to perform these tests, some of which are worthy of comment.

2.5.1 Falcon 20 Research Aircraft

The aircraft used for testing was a Dassault Falcon 20 twin-engine, mid-size business jet, operated by NRC (see Photo 2.1). The aircraft is a multi-purpose platform that has been used in recent years for two major research programs:

a) The testing and evaluation of precision instrument approaches using augmented Global Positioning Systems (GPS) for guidance; and

b) The determination of aircraft performance characteristics on runways contaminated by winter precipitation.

With an extensive onboard data acquisition system including a Litton 92 inertial navigation system, the aircraft can also be used for airborne geoscience studies, avionics research, and aircraft based sensor research.

NRC acquired the Falcon 20 from the Department of National Defence (DND) in 1991. In partnership with the Canadian Space Agency (CSA) and Transport Canada, NRC originally instrumented the aircraft to support micro-gravity research and curved path (area navigation) capabilities and procedures. These capabilities still exist with the modified aircraft fuel and hydraulic systems still in place to allow the aircraft to fly “zero” G parabolic manoeuvres, and the modified aircraft guidance systems available to fly curved path precision approaches using GPS-based receivers.

In partnership with Transport Canada, NASA, and DND, the NRC Falcon 20 was used in a five-year research program directed at standardizing runway friction reporting procedures for winter contaminated runways, and determining aircraft landing and takeoff performance changes as a result of runway contaminant.

2.5.1.1 Falcon 20 design characteristics

A three-view diagram of the Falcon 20 aircraft has been included in Figure 2.2. Some of the pertinent dimensions of the Falcon 20 are noteworthy:

a) Wing span: 16.32 m (53 ft. 7 in.);
b) Wing surface area (both wings): 41 m^2 (441.33 $ft.^2$); and
c) Length: 17.15 m (56 ft. 3 in.).

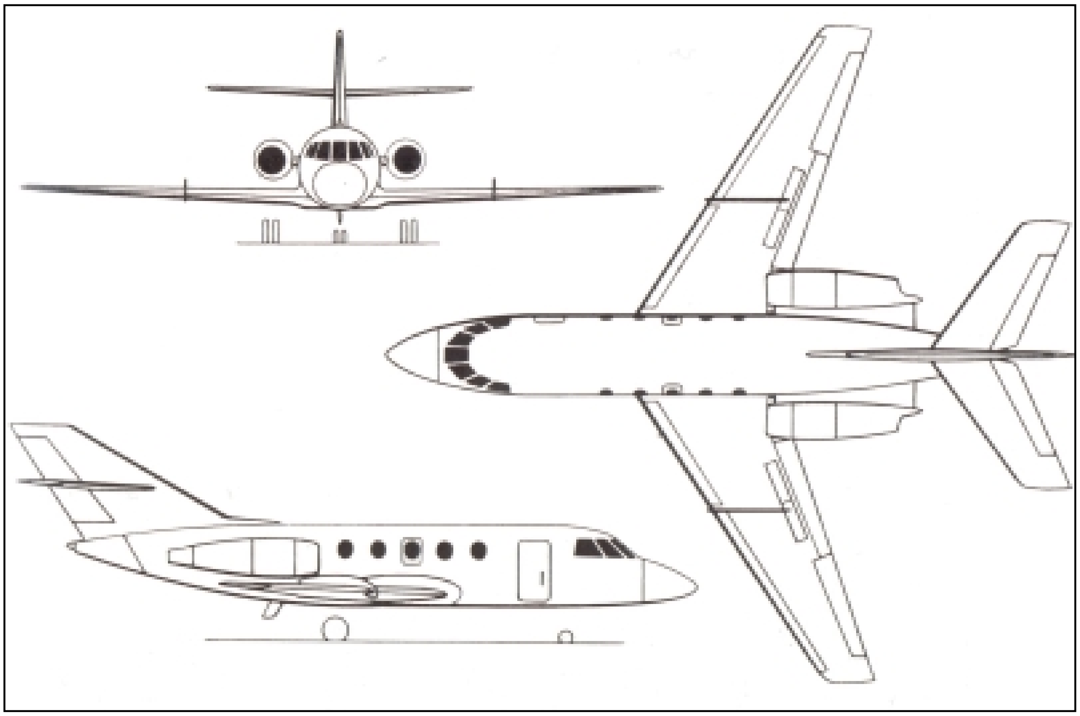


Figure 2.2: Schematic View of Dassault Falcon 20

The Falcon 20 has slotted slats outboard of the fence on each wing; the wing section inboard of the fence contains no moveable devices.

2.5.1.2 Falcon 20 on-board installations

The NRC Falcon 20 research aircraft is equipped with the following on-board installations:

a) Engineering workstation containing PC computer with GPS receiver card, display and interface with the data acquisition system;

b) Data acquisition system based on LSI 11/73 digital computer, with DAT tape and/or hard disk recording medium;

c) Multiple navigation sensors including VHF Omnidirectional Range (VOR), Instrument Landing System (ILS), Microwave Landing System (MLS), Global Positioning System (GPS), flight test differential GPS, Litton 92 Inertial Navigation System (INS) and a modified flight director; and

d) Cockpit mounted CDU to initiate GPS approaches and monitor selected test parameters.

2.5.1.3 Falcon 20 measurement capabilities

The NRC Falcon 20 research aircraft has the following measurement capabilities:

a) Three-axis accelerations and rates;
b) Aircraft attitude and heading;
c) Three-dimensional positions and velocities;
d) Static and dynamic pressures;
e) Outside air temperature; and
f) Flight director system signals.

2.5.2 Fluid Application Equipment

The ethylene glycol-based Type I and Type IV fluids sprayed on the wings of the Falcon 20 were applied by GlobeGround personnel. The GlobeGround deicing vehicles were manufactured by Superior, model 1045, and were equipped with Task Force Tips spray nozzles, model # BH-Type 2 (see Photo 2.10).

During the three-year test program with the Falcon 20 aircraft, tests are intended to be performed with both ethylene and propylene glycol-based fluids. Because most deicing operators only carry and spray fluid of one glycol base, a suitable fluid sprayer unit was developed by APS for this project.

The mobile sprayer system was designed to enable outdoor and indoor testing in all conditions using different Type IV fluids as required. It comprises three interrelated components: a fluid reservoir, a fluid pump, and a fluid application nozzle. The components of the mobile sprayer are described below:

a) A non-shearing fluid pump, identical to those installed in deicing vehicles, forces the 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 monitors 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 is connected to the pump with a pressure-resistant rubber hose fitted with locking couplings.

The mobile sprayer system weighs approximately 315 kg (not including the generator) and can be easily transported with a pickup truck although a winch is required for loading (see Photo 2.11). The generator required for previous tests with the mobile sprayer was a large portable unit mounted on its own trailer as shown in Photo 2.12.

Although this unit was made available for testing in 2001-02, it was not used, because only ethylene fluids, which were dispensed by GlobeGround, were tested.

2.5.3 Fluid Dilution Equipment

The objective of the three-year test program with the Falcon 20 research aircraft is to ascertain the aerodynamic penalty on the aircraft due to the presence of partially expended anti-icing fluid on the wings of the aircraft. Fluid diluted by snow and freezing rain will be examined as part of this research program. For 2001-02 testing, only one method of fluid dilution was required, although APS also investigated methods for simulating snow using the NCAR artificial snowmaker.

2.5.3.1 Snow delivery system

Previous attempts to simulate natural snow have provided inadequate results. In March 2000, APS made arrangements with a Montreal firm, MTN Snow Equipment Inc., for use of a Lenko 950 snow gun for aircraft hot water deicing tests. The snow produced by the Lenko gun at -5°C was in the form of a pellet with a diameter of about 1.5 mm, and was slightly wet resulting in immediate and strong adherence to the wing skin. Furthermore, since the gun had to be positioned at a great distance from the aircraft to achieve the desired rates of snowfall, the use of the technology would result in the accumulation of snow over a large part of the test aircraft and not only on the designated wing test area (see Transport Canada Report, *Hot Water Deicing of Aircraft: Phase 2,* TP 13663E (5)).

In February 2002, APS examined the possibility of using sifters to dispense natural snow onto the wings of the Falcon 20 aircraft. The snow sifter tested was a plastic frame containing a series of mesh filters at the bottom of the crate to break up the snow and provide improved distribution.

Calibration tests with the snow sifter were conducted at the central deicing facility at Dorval Airport using the Lockheed JetStar wing (see Photo 2.13). Rate pans were placed at several locations on the wing to determine whether the desired rate of precipitation over the entire wing surface (approximately 25 g/dm^2/h) could be obtained. A known weight of snow was placed in the sifter, and the sifter was provided to an operator in a boom truck.

It soon became apparent that this method for dispensing snow would be inappropriate for large-scale tests with the Falcon 20 aircraft. The snow that fell from the sifter was very clumpy and only covered a small section of the wing. To dilute the fluid over the entire surface area of the Falcon 20 wing span, many boom trucks and several operators with snow sifters would be required, possibly as many as 4 operators and boom trucks per wing. This would create disorder around the aircraft during testing and would give rise to due to safety concerns.

New methods for dispensing snow on the Falcon 20 need to be examined. One method in particular, produced by Buccheri Industries of Australia, may hold some promise. This method will be examined further to determine its feasibility for future tests in snow.

2.5.3.2 Freezing rain sprayer unit

A water sprayer to produce artificial freezing rain was designed by APS for the 1997-98 and 1998-99 Falcon 20 tests. Because only a small section of one wing was contaminated in those tests, only a single spray bar was required.

One of the requirements of the tests conducted in 2001-02 was to dilute the fluid on the entire wing surface area. A new sprayer, based largely on the original sprayer, was designed to accomplish this task.

The sprayer system included several principal elements:

a) A liquid pumping unit;
b) An air compressor;
c) A portable generator;
d) A 1000 L ice bath/water reservoir; and
e) Two hand-held spray bars.

System controls and the overall system installation in the rented van are shown in Photos 2.14. The freezing rain sprayer equipped with the spray hoses is shown in Photo 2.15.

Each spray bar unit was equipped with three spray heads that accepted hypodermic needles of various gauges as used at NRC's Climatic Engineering Facility to produce different droplet sizes. In this application, 20 gauge hypodermic needles were installed to produce droplet sizes appropriate to light freezing rain.

Evaluation tests of the freezing rain sprayer were conducted at the NRC Flight Research Laboratory on March 7, 2002, using the Falcon 20 as a test bed (see Photo 2.16). These tests demonstrated that rates typical of freezing rain could be achieved using the portable unit, provided the wind conditions were adequately low. Because the spray bars are hand-held and manipulated by an operator to provide coverage over the surface of the wing, the rates and consistency of coverage may be operator dependent. For this reason, it is important that spray personnel are familiar with the operation of the spray apparatus prior to testing.

In tests with the freezing rain sprayer, operators were positioned in deicing vehicle buckets. Depending on the intensity of the wind, the spray bar was positioned anywhere from approximately 1.2 m to 2.4 m (4 ft. to 8 ft.) above the wing surface.

The water temperature in the fluid reservoir in the van was approximately 5°C and the droplet size of the light freezing rain was approximately 1 mm. Rates of precipitation were measured using plate pans positioned on the wings of the Falcon 20 prior to the start of testing. After the fluid dilution process, the rate pans were weighed and the ice catch determined.

The operation manual for the freezing rain sprayer has been included in Appendix E.

2.5.4 Fluid Adhesion Measurement Unit

During the 1997-98 study characterising the nature of aircraft anti-icing fluids during the process of contamination, a qualitative method of determining the extent of adhesion failure dimensionality and degree of bonding was developed (refer to Transport Canada report, TP13317E, *Characteristics Of Aircraft Anti-Icing Fluids Subjected To Precipitation* (6)). This method was based on the use of an electric dental floss device (Photo 2.17).

In operation (Photo 2.10), a thread of "floss" was spun by the device. A floss segment extended radially about 3 to 4 mm from the tip of the unit, and upon spinning could carve out a circle (if adhesion had occurred) with a radius of 3 to 4 mm on a failed surface element. In a layer of non-adhered fluid, the force of the spinning floss was sufficient to expose the surface of the test plate.

Because the rotation speed of the unit was fixed, the applied force was constant for all tests. This provided a basis of comparison among various test conditions, and between different stages of contamination for individual tests. Use of this device provided a satisfactory approach to establish areas that had undergone bonding of contamination to the substrate and gave a measure of the strength of the bond formed.

An analysis of the effective shearing force exerted by this instrument determined it to be in the range of 1.2×10^{-4} to 2.0×10^{-4} MPa. This shear force value is possibly in a range similar to the wind shear developed on a wing during takeoff.

This device was made available for 2001-02 testing with the Falcon 20, even though no contamination was to be present in the fluid on the wings. This device will be used in subsequent testing with the Falcon 20.

2.5.5 Fluid Viscometer

Fluid samples for viscosity tests were gathered from various points within the wing test area and were stored in small wide-mouth glass bottles with screw caps. Viscosity measurements of these samples were carried out using a Brookfield viscometer (Model DV-1+, Photo 2.18) fitted with a thermostatted re-circulating fluid bath and microsampling option.

2.5.6 Hand-Held Video Camera

In 1997-98 and 1998-99 tests, a video camera was installed on the Falcon 20. This camera was mounted in a temporary structure, which replaced the normal aircraft emergency exit hatch. The camera was fixed in position, and was focused on the forward portion of the test area, including the leading edge. Because the takeoff and climb of the aircraft were not examined in these tests, it was possible to remove the window and to replace it with a temporary structure.

For tests conducted in 2001-02 with the Falcon 20, the aircraft was rotated and then flown for a circuit of the airport prior to its return. The temporary door used for mounting the video camera in previous tests was not airworthy and an alternate solution was needed to enable the recording of video documentation of the condition of the wing during takeoff. After much debate, it was decided that APS personnel would be positioned in the cabin over the wings of the Falcon 20 with hand-held video cameras.

2.5.7 Other Equipment

Octagonal wet film thickness gauges, shown in Figure 2.3, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thickness (0.01 mm to 10.2 mm) for Type IV fluids. The rectangular gauge shown in the figure has a finer scale and was used in some cases when the fluid film was less thick (toward the end of a test). Thickness values, as read off directly from the thickness gauge, were used in this report. These values were not adjusted.

Fluid freeze points on the wing were measured using a hand-held Misco refractometer with a Brix scale.

Wing temperatures were measured using hand-held Wahl surface temperature probes.

A full list of equipment is provided in Appendix D.

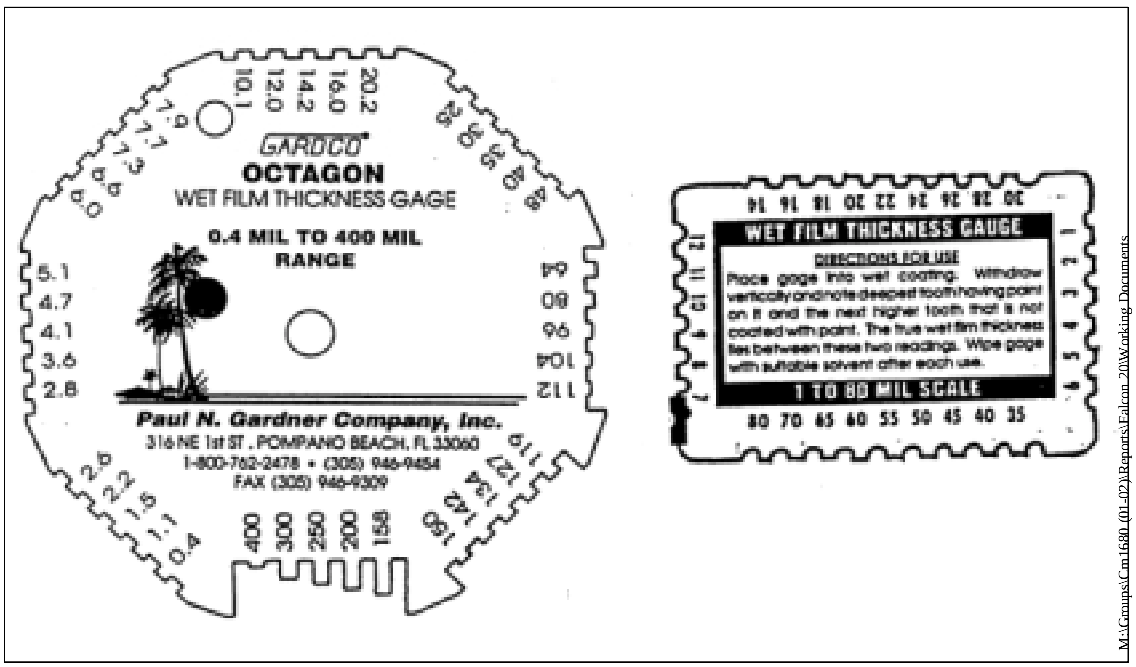


Figure 2.3: Thickness Gauges

2.6 Fluids

Two fluids were used in the Falcon 20 tests:

a) Dow Chemical UCAR XL54 Type I fluid; and
b) Dow Chemical UCAR Ultra+ Type IV fluid.

The UCAR fluids were dispensed by GlobeGround personnel at the central deicing facility in Ottawa.

The Brix values of the neat Dow Ultra+ fluid dispensed by GlobeGround ranged from 40° to 42°.

2.7 Personnel

The NRC Falcon 20 research aircraft was operated by the NRC crew out of Ottawa, Ontario.

Representatives from TDC provided direction in testing and participated as observers.

GlobeGround conducted aircraft spray operations in conformance with their standard procedures.

Nine APS personnel were required for the conduct of the Falcon 20 tests. A complete list of task descriptions for each personnel is included in Attachment III of the test procedure provided in Appendix D.

Photo 2.1: NRC Falcon 20

Photo 2.2: Drawing of Grid on Falcon 20 Wing

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Photo 2.3: Finished Grid on the Starboard Wing

Photo 2.4: Sample Collection for Viscosity Analysis

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Photo 2.5: Freezing Rain Sprayed on Falcon 20

Photo 2.6: Appearance of Type IV Fluid During Taxi

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Photo 2.7: Appearance of Type IV Fluid During Takeoff

Photo 2.8: Appearance of Wing During Climb-Out

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Photo 2.9: Thickness Measurement Following Takeoff Run

Photo 2.10: GlobeGround Deicing Vehicle

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Photo 2.11: Mobile Type IV Fluid Sprayer Unit

Photo 2.12: Mobile Type IV Fluid Sprayer Unit and Generator

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Photo 2.13: Snow Sifter Used in Snow Calibration Tests

Photo 2.14: Freezing Rain Sprayer in Rental Van

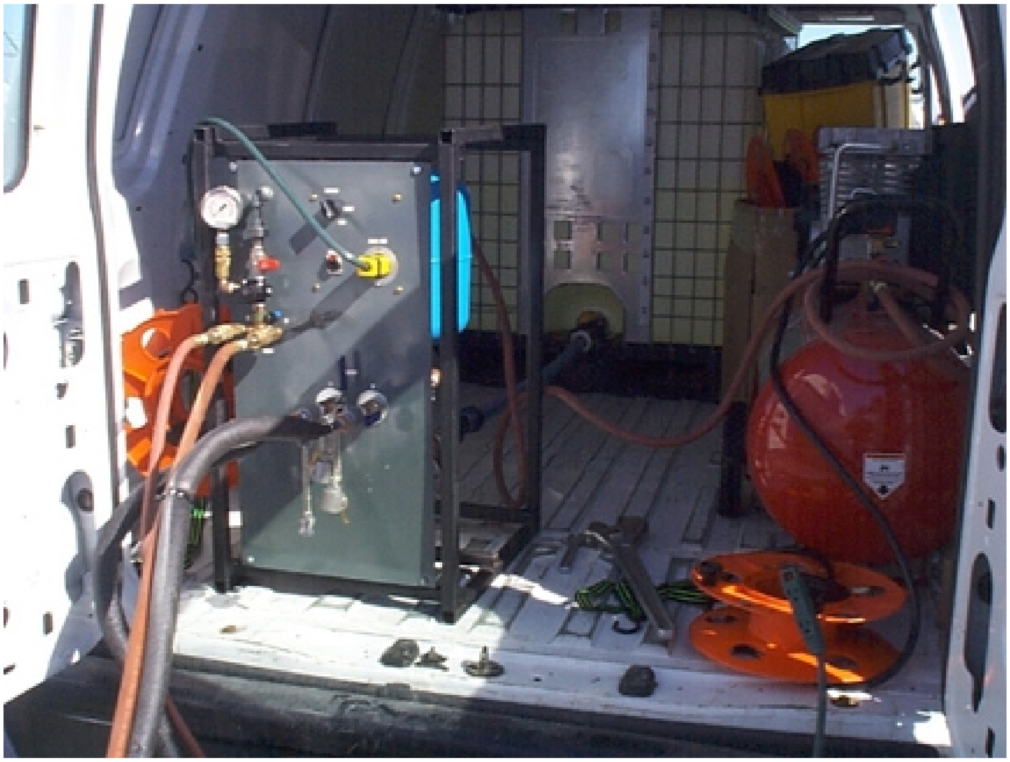

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Photo 2.15: Freezing Rain Sprayer with Hoses

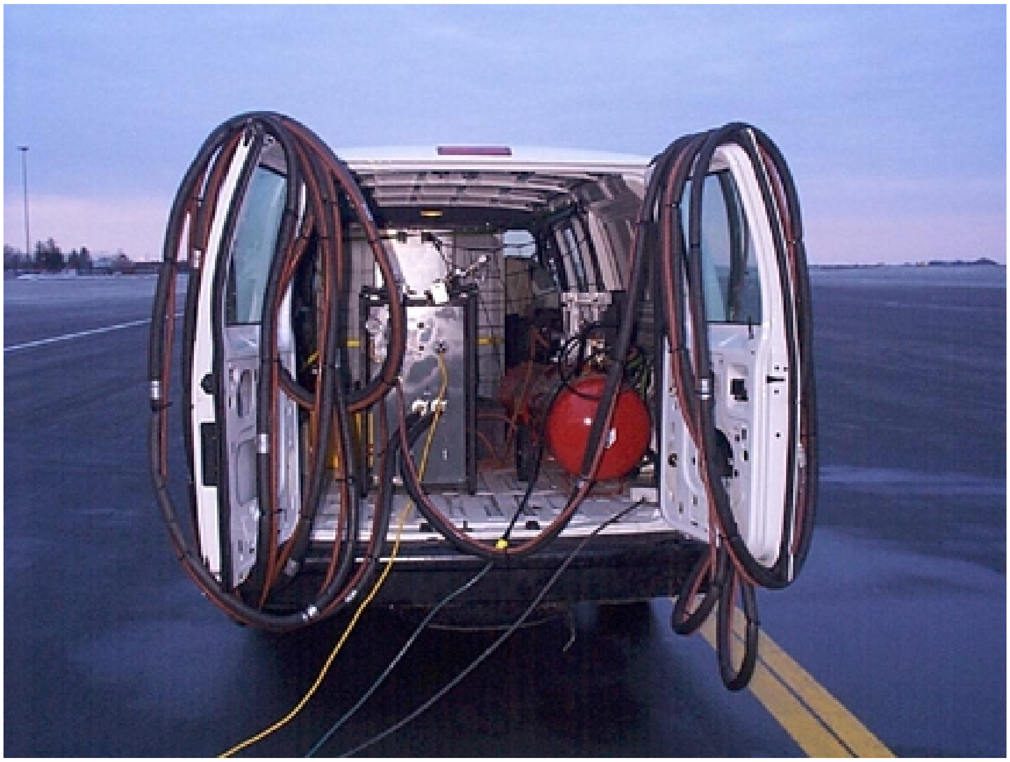

Photo 2.16: Calibration Tests with Freezing Rain Sprayer at NRC

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Photo 2.17: Device Used to Test Adherence

Photo 2.18: Brookfield Digital Viscometer Model DV-1+ and Temperature Bath

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3. DESCRIPTION AND PROCESSING OF DATA

3.1 Overview of Tests

This series of takeoff tests was conducted on three occasions at MacDonald Cartier International Airport in Ottawa, Ontario:

a) The clean wing calibration tests were conducted by NRC on February 20, 2002. No APS personnel were present for these tests;

b) Clean fluid tests (no dilution) were conducted on March 6, 2002; and

c) Diluted fluid tests were conducted on March 11 and 12, 2002.

The NRC Falcon 20 research aircraft was made available for testing at 6:00 a.m. on each day of testing. A briefing was held on each day of testing at the NRC Flight Testing Laboratory at 6:00 a.m., and the aircraft was then taxied over to the central deicing facility from there, and tests commenced immediately.

A summary of the tests conducted during the winter of 2001-02 is shown in Table 3.1. A more detailed summary of the pertinent information for each test is presented in Subsections 3.1.1 to 3.1.9.

Table 3.1: Summary of 2001-02 Testing with Falcon 20

DATE	RUN	FLUID	ZR- APPLIED
6-Mar-02	1	Type IV / Type I	No
6-Mar-02	2	Type IV / Type I	No
6-Mar-02	3	Type IV / Type I	No
6-Mar-02	4	Type IV	No
6-Mar-02	5	Type IV	No
11-Mar-02	1	Type IV	No
11-Mar-02	2	Type IV	Yes
12-Mar-02	1	Type IV	Yes
12-Mar-02	2	Type IV	Yes

3.1.1 Run 1, March 6, 2002

- Ambient temperature: -8°C
- Wind direction/speed: 190/3 knots
- Sky condition: Broken clouds at 5000 feet
- Runway used: 14
- Fluid spray start time (port wing): 7:32
- Fluid spray end time (port wing): 7:34
- Fluid spray start time (starboard wing): 7:35
- Fluid spray end time (starboard wing): 7:37
- Fluid spray quantities (port wing): 41 L Type I, 41 L Type IV
- Fluid spray quantities (starboard wing): 42 L Type I, 51 L Type IV
- Departure time from deicing pad: 7:53
- Start of takeoff run: 8:03:20
- Time of landing: 8:07:20
- Return time to deicing pad: 8:10:30

3.1.2 Run 2, March 6, 2002

- Ambient temperature: -7°C
- Wind direction/speed: 230/3 knots
- Sky condition: Overcast at 4000 feet
- Runway used: 14
- Fluid spray start time (port wing): 8:27:40
- Fluid spray end time (port wing): 8:30:50
- Fluid spray start time (starboard wing): 8:32:10
- Fluid spray end time (starboard wing): 8:34:20
- Fluid spray quantities (port wing): 42 L Type I, 68 L Type IV
- Fluid spray quantities (starboard wing): 43 L Type I, 52 L Type IV
- Departure time from deicing pad: 8:53:45
- Start of takeoff run: 9:03:20
- Time of landing: 9:07:30
- Return time to deicing pad: 9:11:30

3.1.3 Run 3, March 6, 2002

- Ambient temperature: -4°C
- Wind direction/speed: 240/4 knots
- Sky condition: Overcast at 4000 feet
- Runway used: 14
- Fluid spray start time (port wing): 9:31:20
- Fluid spray end time (port wing): 9:33:10

- Fluid spray start time (starboard wing): 9:35:15
- Fluid spray end time (starboard wing): 9:37:20
- Fluid spray quantities (port wing): 31 L Type I, 53 L Type IV
- Fluid spray quantities (starboard wing): 28 L Type I, 46 L Type IV
- Departure time from deicing pad: 9:55:40
- Start of takeoff run: 10:03:45
- Time of landing: 10:07:10
- Return time to deicing pad: 10:10:40

3.1.4 Run 4, March 6, 2002

- Ambient temperature: -3°C
- Wind direction/speed: 250/2 knots
- Sky condition: Overcast, very light snow
- Runway used: 14
- Fluid spray start time (port wing): 10:59:15
- Fluid spray end time (port wing): 11:03:15
- Fluid spray start time (starboard wing): 11:02:45
- Fluid spray end time (starboard wing): 11:03:15
- Fluid spray quantities (port wing): 55 L Type IV
- Fluid spray quantities (starboard wing): 54 L Type IV
- Departure time from deicing pad: 11:19
- Start of takeoff run: 11:27:30
- Time of landing: 11:30:45
- Return time to deicing pad: 11:33:40

3.1.5 Run 5, March 6, 2002

- Ambient temperature: -3°C
- Wind direction/speed: 265/2 knots
- Sky condition: Overcast, very light snow
- Runway used: 14
- Fluid spray start time (port wing): 11:56:45
- Fluid spray end time (port wing): 11:58:15
- Fluid spray start time (starboard wing): 11:59
- Fluid spray end time (starboard wing): 12:00
- Fluid spray quantities (port wing): 60 L Type IV
- Fluid spray quantities (starboard wing): 65 L Type IV
- Departure time from deicing pad: 12:16
- Start of takeoff run: 12:25
- Time of landing: 12:28:50
- Return time to deicing pad: 12:31:30

3.1.6 Run 1, March 11, 2002

- Ambient temperature: -11°C
- Wind direction/speed: 270/15 knots
- Sky condition: Partially clear
- Runway used: 25
- Fluid spray start time (port wing): 7:56
- Fluid spray end time (port wing): 7:57:30
- Fluid spray start time (starboard wing): 7:55
- Fluid spray end time (starboard wing): 7:56:30
- Fluid spray quantities (port wing): 65 L Type IV
- Fluid spray quantities (starboard wing): 47 L Type IV
- Departure time from deicing pad: 9:00
- Start of takeoff run: 9:13
- Time of landing: 9:22
- Return time to deicing pad: 9:25:15

3.1.7 Run 2, March 11, 2002

- Ambient temperature: -8°C
- Wind direction/speed: 270/15 knots
- Sky condition: Partially clear
- Runway used: 25
- Fluid spray start time (port wing): 9:52
- Fluid spray end time (port wing): 9:53:15
- Fluid spray start time (starboard wing): 9:51
- Fluid spray end time (starboard wing): 9:52:30
- Fluid spray quantities (port wing): 48 L Type IV
- Fluid spray quantities (starboard wing): 40 L Type IV
- Rate of precipitation (port wing): 7 $g/dm^2/h$
- Rate of precipitation (starboard wing): 16 $g/dm^2/h$
- Light freezing rain spray application time: 17 minutes
- Departure time from deicing pad: 10:44
- Start of takeoff run: 10:57
- Time of landing: 11:03
- Return time to deicing pad: 11:07

3.1.8 Run 1, March 12, 2002

- Ambient temperature: -3°C
- Wind direction/speed: 160/5 knots
- Sky condition: Partially clear

- Runway used: 14
- Fluid spray start time (port wing): 6:58
- Fluid spray end time (port wing): 6:59
- Fluid spray start time (starboard wing): 7:01
- Fluid spray end time (starboard wing): 7:02:30
- Fluid spray quantities (port wing): 29 L Type IV
- Fluid spray quantities (starboard wing): 37 L Type IV
- Rate of precipitation (port wing): 16 g/dm^2/h
- Rate of precipitation (starboard wing): 15 g/dm^2/h
- Light freezing rain spray application time: 58 minutes
- Departure time from deicing pad: 8:36
- Start of takeoff run: 8:51
- Time of landing: 9:00
- Return time to deicing pad: 9:04

3.1.9 Run 2, March 12, 2002

- Ambient temperature: 3°C
- Wind direction/speed: 275/11 knots
- Sky condition: Partially clear
- Runway used: n/a (no takeoff)
- Fluid spray start time (port wing): 9:27
- Fluid spray end time (port wing): 9:29
- Fluid spray start time (starboard wing): 9:27
- Fluid spray end time (starboard wing): 9:28:45
- Fluid spray quantities (port wing): 35 L Type IV
- Fluid spray quantities (starboard wing): 39 L Type IV
- Rate of precipitation (port wing): 17 g/dm^2/h
- Rate of precipitation (starboard wing): 8 g/dm^2/h
- Light freezing rain spray application time: 38 minutes
- Departure time from deicing pad: n/a (no takeoff)
- Start of takeoff run: n/a (no takeoff)
- Time of landing: n/a (no takeoff)
- Return time to deicing pad: n/a (no takeoff)

3.2 Description of Data Collected and Analysis Methodology

For every test, the same method of data collection was followed at each of the three (or four) distinct stages in the test progression. This data collection procedure enabled comparison of the nature of fluid on the wing and the level of contamination at each stage. These stages were:

a) Following application of fluid and prior to application of artificial freezing rain;

b) Following dilution of the fluid to the desired level (if light freezing rain was applied to the wings);

c) Following the taxi of the aircraft to the runway threshold and prior to the to takeoff run; and

d) Immediately following landing.

Data for each test run, including fluid thickness, fluid viscosity, fluid freeze point, and wing temperature are discussed in Section 4, where data values obtained are compared before and after takeoff runs.

The videotape documentation of fluid appearance on the wing during the takeoff run as provided by the onboard camera was reviewed for each test. This videotape documented the behaviour of the fluid as it was eliminated from the wing, and provided some insight regarding the relationship between fluid elimination and aircraft speed. Observations related to fluid elimination are presented in Section 4.

3.2.1 Fluid Thickness

For each test, the quantity of anti-icing fluid remaining on either wing at various points during the test was determined by measuring the fluid film thickness at nine locations on two different chords of each wing and taking the average of the 18 positions.

3.2.2 Fluid Freeze Points

Brix values of the Dow UCAR Ultra+ Type IV fluid used for tests were obtained using hand-held refractometers. The freeze points of the various fluid samples were then determined using the conversion curve shown in Figure 3.1, produced by the Dow Chemical.

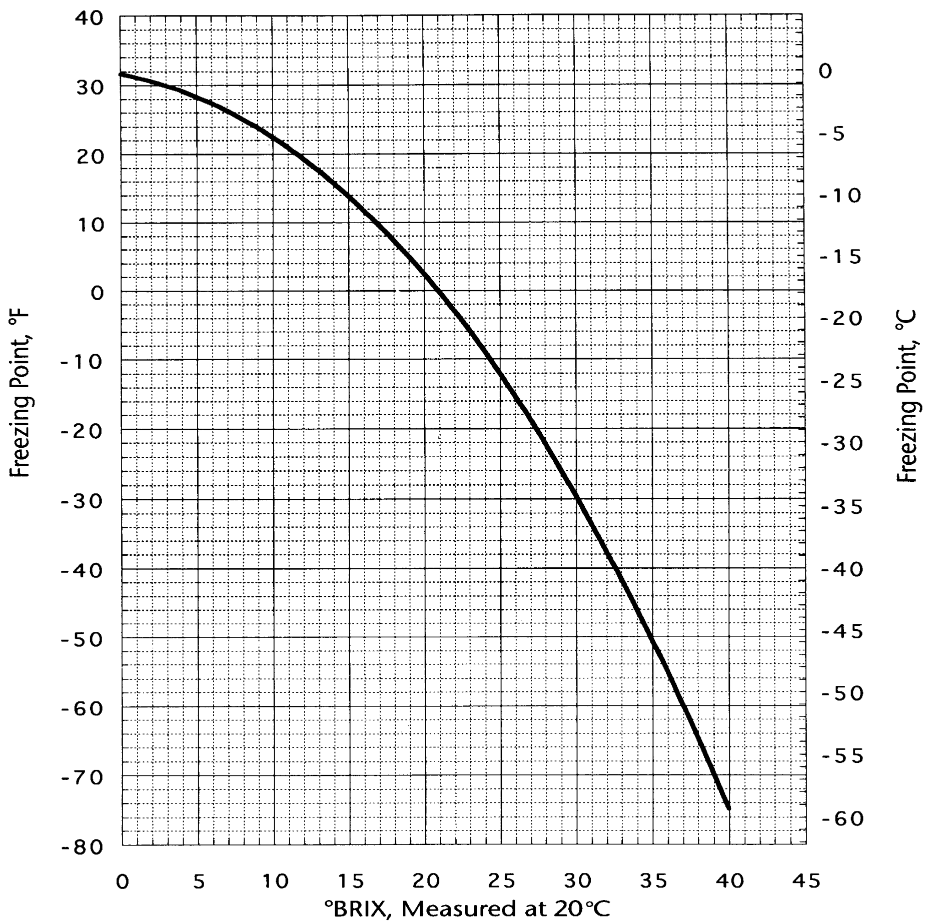

Figure 3.1: Freeze Point vs. Brix of Aqueous Solutions of Dow UCAR Ultra+

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4. ANALYSIS AND OBSERVATIONS

In this section, data collected and observations made prior to and following each takeoff are discussed for each test. Remarks on the fluid viscosity are based on measurements of the fluid samples recovered during the tests. The viscosity measurements were made after the conclusion of the tests, and the results of the viscometric analysis are presented in Table 4.1.

4.1 March 6, 2002 – Run 1; Type IV over Type I; No Dilution

4.1.1 Prior to Departure from the Deicing Bay

4.1.1.1 Fluid thickness measurements

This test was conducted in the absence of artificial freezing rain. The profile of fluid thickness along the two chords (inboard and outboard) of both wings was typical of the Type IV fluid applications observed in previous tests. Pre-stabilized and stabilized ethylene glycol-based Type I and Type IV fluid thickness values are documented in a 1995-96 study of fluid thickness on wing surfaces (see TP 12900E, *Evaluation of Fluid Thickness to Locate Representative Surfaces* (7)).

In this test, the fluid thickness before departure of the aircraft from the deicing bay took on a range of values (Table 4.2):

a) 0.4 mm to 1 mm for the outboard chord on the port wing (average 0.8 mm);

b) 0.5 mm to 2 mm for the inboard chord of the port wing (average 1.2 mm);

c) 0.2 mm to 1 mm for the outboard chord of the starboard wing (average 0.4 mm); and

d) 0.4 mm to 1 mm for the inboard chord of the starboard wing (average 0.6 mm).

In general, the thickness measurements in this run were lower than those of the other test runs conducted with the Falcon 20 aircraft, especially the film thickness values on the starboard wing. It is noteworthy that the port wing in this run was re-sprayed with Type IV fluid due to an incomplete coverage with the first application.

The volume of fluid that fell to the ground at various stages during the Falcon 20 tests has been included in Appendix F.

Table 4.1: Viscosity Measurements for Falcon 20 Samples Using Dow/UCAR

TRUCK SAMPLES	Bottle #	DATE	RUN #	VISCOSITY (cP)*
TRUCK SAMPLE	24	Mar-06-02	5	43 300
GENERAL TRUCK SAMPLE	25	Mar-11-02	1+2	43 500
STARBOARD TRUCK SAMPLE	26	Mar-12-02	1 + 2	41 300
PORT TRUCK SAMPLE	27	Mar-12-02	1 + 2	42 450

AFTER FLUID SPRAY (BEFORE ZR PRECIP)	Bottle #	DATE	RUN #	VISCOSITY (cP)*
AFTER FLUID SPRAY	1	Mar-6-02	1**	15 650
AFTER FLUID SPRAY	3	Mar-6-02	3**	32 950
AFTER FLUID SPRAY	4	Mar-6-02	4	38 450
AFTER FLUID SPRAY	5	Mar-6-02	5	42 450
PORT, AFTER FLUID SPRAY	16	Mar-11-02	1	45 550
STARBOARD, AFTER FLUID SPRAY	8	Mar-11-02	1	42 950
PORT, AFTER FLUID SPRAY	10	Mar-11-02	2	44 450
STARBOARD, AFTER FLUID SPRAY	12	Mar-11-02	2	43 650
PORT, AFTER FLUID SPRAY	14	Mar-12-02	1	31 350
STARBOARD, AFTER FLUID SPRAY	17	Mar-12-02	1	32 000
PORT, AFTER FLUID SPRAY	20	Mar-12-02	2	43 050
STARBOARD, AFTER FLUID SPRAY	22	Mar-12-02	2	42 300

AFTER ZR CONTAMINATION	Bottle #	DATE	RUN #	VISCOSITY (cP)*
PORT, AFTER CONTAMINATION / BEFORE TAKEOFF	11	Mar-11-02	2	40 950
STARBOARD, AFTER CONTAMINATION / BEFORE TAKEOFF	13	Mar-11-02	2	36 050
PORT, AFTER CONTAMINATION / BEFORE TAKEOFF	15	Mar-12-02	1	7 400
STARBOARD, AFTER CONTAMINATION / BEFORE TAKEOFF	18	Mar-12-02	1	100
PORT, AFTER CONTAMINATION / BEFORE TAKEOFF	21	Mar-12-02	2	17 950
STARBOARD, AFTER CONTAMINATION / BEFORE TAKEOFF	23	Mar-12-02	2	13 500

AFTER ROTATION	Bottle #	DATE	RUN #	VISCOSITY (cP)*
AFTER ROTATION / AFTER TAKEOFF RUN	2	Mar-06-02	1**	9 700
PORT AFTER ROTATION / AFTER TAKEOFF RUN	7	Mar-11-02	1	19 750
STARBOARD AFTER ROTATION / AFTER TAKEOFF RUN	9	Mar-11-02	1	46 150
PORT AFTER ROTATION / AFTER TAKEOFF RUN	16	Mar-12-02	1	24 000
STARBOARD AFTER ROTATION / AFTER TAKEOFF RUN	19	Mar-12-02	1	0

*method: 0.3r/min, 0°C, Spindle SC4-31, 10 mL, 10 min, centrifuged
**Two-step operations: Type IV over Type I
ZR

M:\Groups\Cm1680 (01-02)\Reports\Falcon 20\Working Documents\Viscosity Meas.

Table 4.2: Thickness Measurements (mm) for Run 1, March 6, 2002
Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.4		0.3		0.2		0.2	
	2	0.8		0.3		0.2		0.2	
	3	0.8		0.3		0.2		0.2	
	4	1.0		1.0		0.5		0.5	
	5	0.9		0.9	0.0	1.0		1.2	
	6	1.0		0.6	0.1	0.5		0.4	0.1
	7	0.4		0.4	0.2	0.2		0.3	0.1
	8	1.0		0.8	0.2	0.4		0.4	0.1
	9	1.0		0.8	0.2	0.4		0.4	0.1
INBOARD	1	0.8		0.5		0.4		0.4	
	2	1.2		1.0		0.4		0.4	
	3	1.6		1.2		0.4		0.4	
	4	1.6		1.0		0.6		0.9	
	5	2.0		2.0		1.0		1.2	
	6	1.2		0.9		1.0		0.4	
	7	0.5		0.3		0.4		0.4	
	8	0.5		0.5	0.3	0.4		0.4	0.1
	9	0.6		0.6		0.4		0.4	0.1

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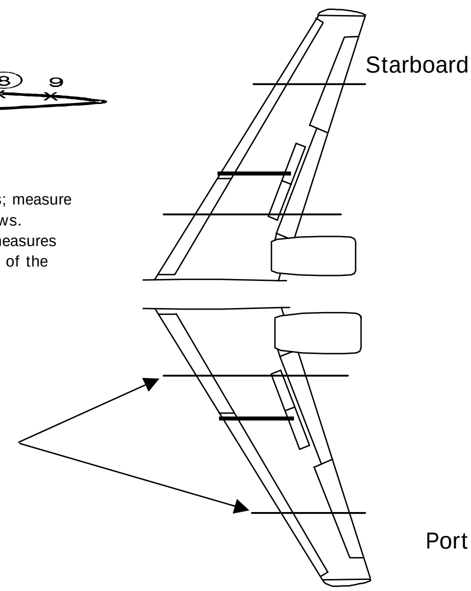
Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows.
Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



Location of inboard and outboard test denoted by lines.

4.1.1.2 *Wing temperatures*

Prior to the departure of the Falcon 20 from the deicing pad, the wing temperatures ranged from -7.4°C to -8°C (see Figure 4.1). The ambient air temperature at the start of testing was -8°C.

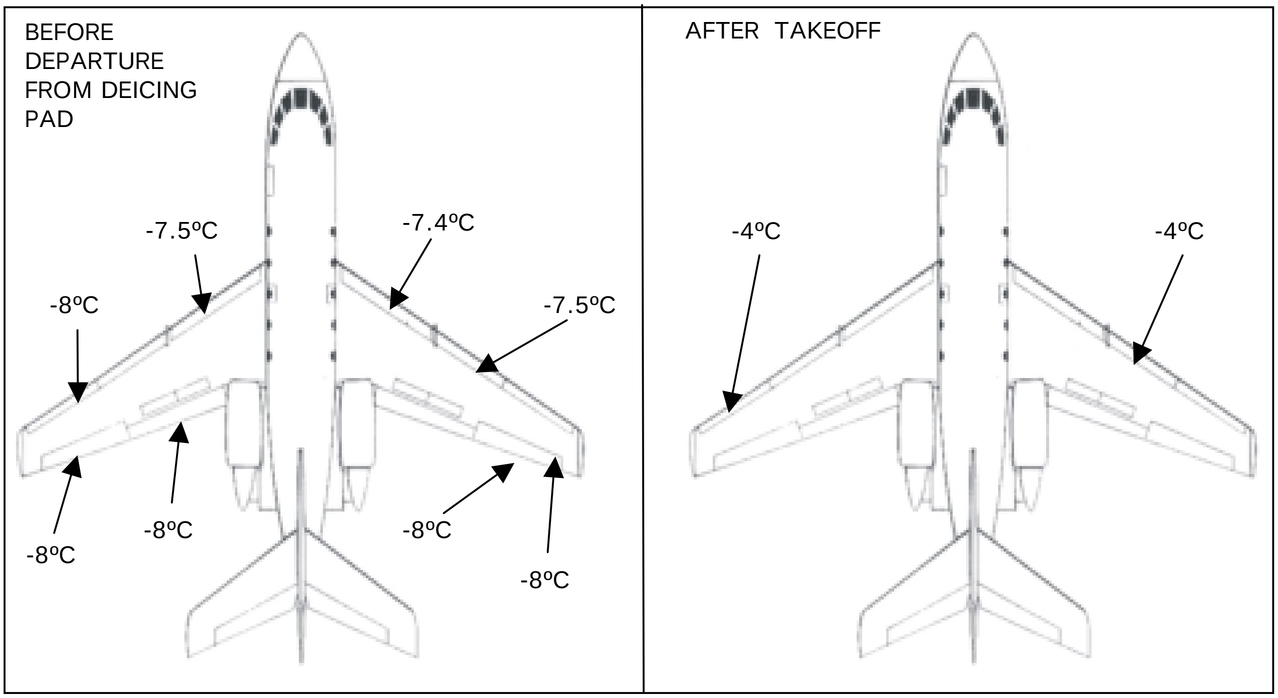


Figure 4.1: Wing Skin Temperatures (ºC) – March 6, 2002 – Run 1, Before/After Takeoff Run

4.1.2 Prior to Takeoff Run

4.1.2.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff of the aircraft at the threshold of Runway 14, after the aircraft was taxied from the deicing bay.

In this test, the fluid thickness (before takeoff) took on a range of values (Table 4.2):

a) 0.3 mm to 1 mm for the outboard chord on the port wing (average 0.6 mm);

b) 0.3 mm to 2 mm for the inboard chord of the port wing (average 0.9 mm);

c) 0.2 mm to 1.2 mm for the outboard chord of the starboard wing (average 0.4 mm); and

d) 0.4 mm to 1.2 mm for the inboard chord of the starboard wing (average 0.5 mm).

4.1.3 Following the Takeoff Run

4.1.3.1 Fluid thickness measurements

Following the takeoff run (see Table 4.2), the fluid had been largely removed from the wings. A very thin film of fluid remained, but in most cases the thickness was immeasurable (less than 0.1 mm). Some pooling of remaining fluid was observed toward the trailing edge of the aircraft. This fluid measured between 0.1 and 0.3 mm.

4.1.3.2 Fluid viscosity

GlobeGround applied the fluid with a deicing vehicle manufactured by Superior and equipped with a Task Force Tips spray nozzle. A sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck and used in testing following the last run on March 6, 2002 (see Table 4.1). The viscosity of this sample measured 43 300 cP.

Once applied to the wing over Type I fluid, the Type IV fluid had a measured viscosity of 15 650 cP. It is assumed that the Type I and Type IV fluids had combined, resulting in this significantly reduced viscosity value.

After the aircraft had returned to the deicing bay following the takeoff run and flight, a final sample was collected on the trailing edge of the aircraft. The viscosity of the after-flight sample was 9 700 cP.

4.1.3.3 Wing temperatures

Following the takeoff run of the Falcon 20, the wing temperatures had warmed to -4°C (see Figure 4.1).

4.2 March 6, 2002 – Run 2; Type IV over Type I; No Dilution

4.2.1 Prior to Departure From the Deicing Bay

4.2.1.1 Fluid thickness measurements

In this test, the stabilized fluid thickness (before departure from the deicing bay) took on a range of values (Table 4.3):

a) 0.6 mm to 2.6 mm for the outboard chord on the port wing (average 1.6 mm);

b) 0.4 mm to 2.4 mm for the inboard chord of the port wing (average 1.7 mm);

c) 0.5 mm to 2 mm for the outboard chord of the starboard wing (average 1.2 mm); and

d) 0.8 mm to 3.8 mm for the inboard chord of the starboard wing (average 1.8 mm).

Table 4.3: Thickness Measurements (mm) for Run 2, March 6, 2002 Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.6		0.6		0.5		0.5	0.0
	2	1.0		0.6	0.0	1.0		0.5	0.0
	3	1.2		0.5		1.2		0.4	0.0
	4	2.0		2.4		1.6		1.2	0.1
	5	2.6		n/a	0.1	2.0		2.0	0.1
	6	2.6		2.0	0.1	1.6		1.2	0.1
	7	0.9		0.8	0.1	0.9		0.9	0.2
	8	1.6		1.2	0.1	1.2		1.2	0.1
	9	2.0		1.6	0.1	1.2		1.2	0.2
INBOARD	1	0.8		0.8		0.8		0.4	0.0
	2	1.6		1.2		1.6		1.2	0.0
	3	2.0		1.6		2.0		2.0	0.0
	4	2.4		1.6		2.4		2.0	0.0
	5	2.4		2.0		3.8		3.2	0.1
	6	0.4				2.0			
	7	2.0		0.9	0.1	1.6		0.4	0.1
	8	1.6		1.0	0.4	1.0		0.8	0.1
	9	2.0		1.0	0.1	1.0		0.6	0.1

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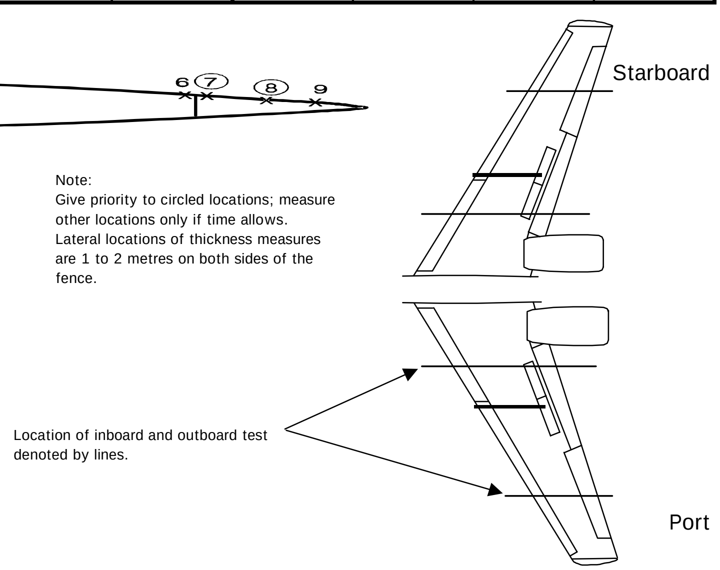
Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows. Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



4.2.1.2 Wing temperatures

Prior to the departure of the Falcon 20 from the deicing pad, the wing surface temperature was -4°C (see Figure 4.2). The ambient temperature at the start of testing was -7°C.

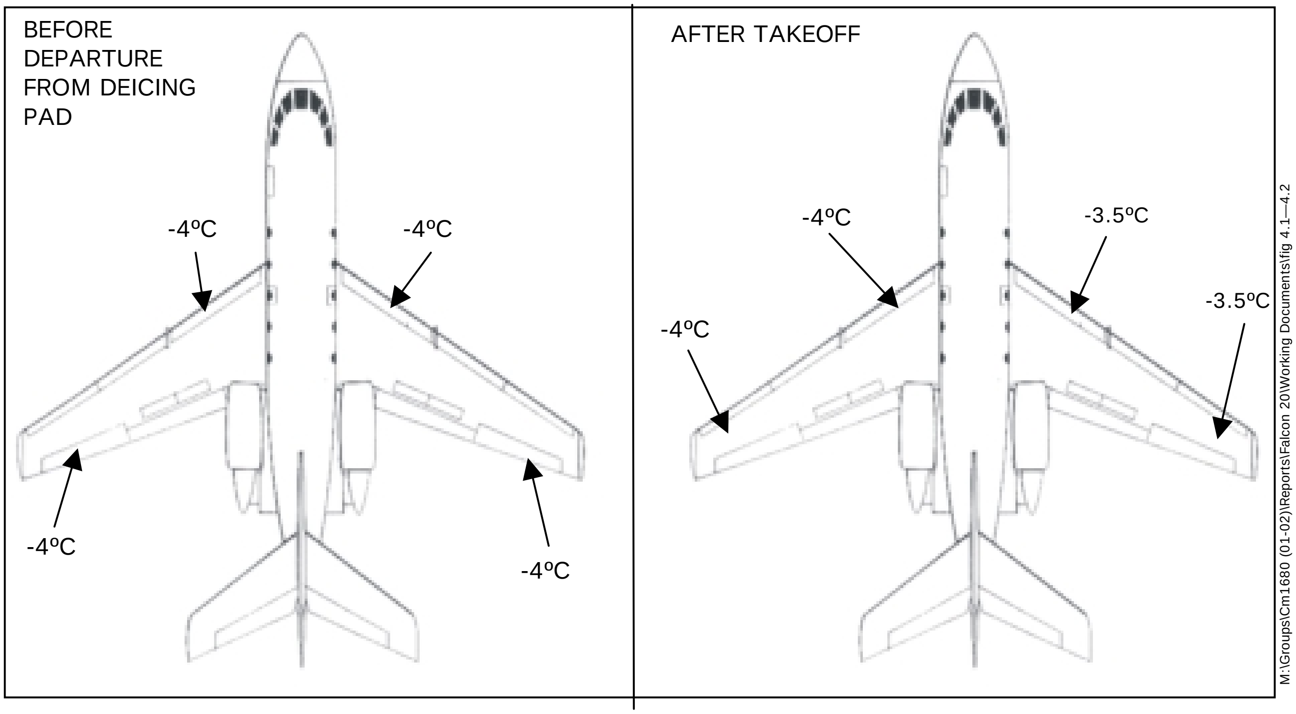


Figure 4.2: Wing Skin Temperatures (ºC) – March 6, 2002 – Run 2, Before/After Takeoff Run

4.2.2 Prior to Takeoff Run

4.2.2.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff run of the aircraft at the threshold of Runway 14, following the taxi of the aircraft from the deicing bay.

In this test, the stabilized fluid thickness (before takeoff) took on a range of values (Table 4.3):

a) 0.5 mm to 2.4 mm for the outboard chord on the port wing (average 1.2 mm);

b) 0.8 mm to 2 mm for the inboard chord of the port wing (average 1.3 mm);

c) 0.4 mm to 2 mm for the outboard chord of the starboard wing (average 1.0 mm); and

d) 0.4 mm to 3.2 mm for the inboard chord of the starboard wing (average 1.3 mm).

4.2.3 Following the Takeoff Run

4.2.3.1 Fluid thickness measurements

Following the takeoff run (see Table 4.3), only a very thin film of fluid remained, but in most cases the thickness was immeasurable (less than 0.1 mm). Some puddling of remaining fluid was seen farther back toward the trailing edge of the aircraft. The thickness of this fluid layer measured between 0.1 and 0.4 mm. The 0.4 mm of fluid was measured on the flap of the port wing.

4.2.3.2 Fluid viscosity

A sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck used for the tests following the last run on March 6, 2002 (see Table 4.1). The viscosity of this sample measured 43 300 cP.

No samples were collected during this run immediately following the application of the fluid to the wing or after the return of the aircraft to the deicing bay.

4.2.3.3 Wing temperatures

Following the takeoff run of the Falcon 20, the skin temperatures of the Falcon 20 ranged from -3.5°C to -4°C (see Figure 4.2).

4.3 March 6, 2002 – Run 3; Type IV over Type I; No Dilution

4.3.1 Prior to Departure from the Deicing Bay

4.3.1.1 Fluid thickness measurements

In this test, the fluid thickness (before departure from the deicing bay) took on a range of values (Table 4.4):

a) 0.5 mm to 2 mm for the outboard chord on the port wing (average 1.2 mm);

b) 0.9 mm to 3 mm for the inboard chord of the port wing (average 1.9 mm);

c) 0.6 mm to 3 mm for the outboard chord of the starboard wing (average 1.4 mm); and

d) 0.6 mm to 4 mm for the inboard chord of the starboard wing (average 1.6 mm).

Table 4.4: Thickness Measurements (mm) for Run 3, March 6, 2002 Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.5		0.8		0.6		0.6	
	2	1.0		0.6	0.0	1.2		0.6	0.0
	3	1.2		0.9	0.0	1.2		0.6	0.0
	4	1.6		1.6	0.0	1.6		1.2	0.1
	5	2.0		1.6	0.1	3.0		2.8	0.1
	6	1.6		1.2	0.1	2.0		1.2	0.1
	7	1.0		0.9	0.1	0.8		0.8	0.1
	8	0.8		1.0	0.1	1.2		1.0	0.1
	9	0.9		0.8	0.1	1.0		1.0	0.1
INBOARD	1	0.9		0.5		0.6		0.4	
	2	1.6		1.2	0.0	1.2		1.2	0.0
	3	2.0		1.6	0.0	1.6		1.6	0.1
	4	2.0		1.6	0.1	1.6		1.6	0.1
	5	3.0		2.4	0.1	4.0		4.0	0.1
	6								
	7	1.6		0.8	0.1	1.2		0.5	0.0
	8	2.0		1.0	0.3	1.6		0.6	0.0
	9	2.0		1.0	0.3	1.2		0.6	0.1

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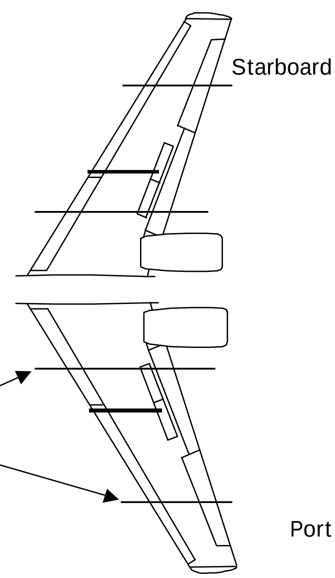
Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows.
Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



Location of inboard and outboard test denoted by lines.

4.3.1.2 Wing temperatures

Prior to the departure of the Falcon 20 from the deicing pad, the wing surface temperature ranged from -2°C to -3.2°C (see Figure 4.3). The ambient temperature at the start of testing was -4°C.

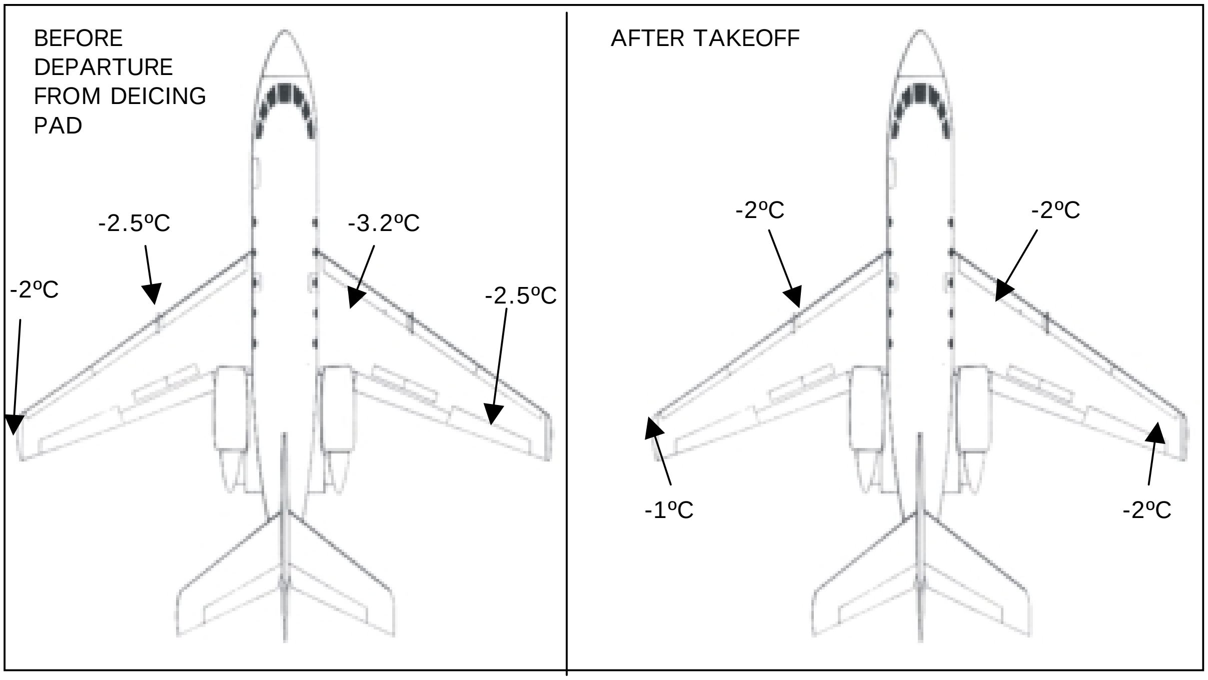


Figure 4.3: Wing Skin Temperatures (ºC) – March 6, 2002 – Run 3, Before/After Takeoff Run

4.3.2 Prior to Takeoff Run

4.3.2.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff run of the aircraft at the threshold of Runway 14, following the taxi of the aircraft from the deicing bay.

In this test, the stabilized fluid thickness (before takeoff run) took on a range of values (Table 4.4):

a) 0.6 mm to 1.6 mm for the outboard chord on the port wing (average 1 mm);

b) 0.5 mm to 2.4 mm for the inboard chord of the port wing (average 1.3 mm);

c) 0.6 mm to 2.8 mm for the outboard chord of the starboard wing (average 1.1 mm); and

d) 0.4 mm to 4 mm for the inboard chord of the starboard wing (average 1.3 mm).

4.3.3 Following the Takeoff Run

4.3.3.1 Fluid thickness measurements

Following the takeoff run (see Table 4.4), only a very thin film of fluid remained, but in most cases the thickness was immeasurable (less than 0.1 mm). Some puddling of remaining fluid was seen farther back toward the trailing edge of the aircraft. The thickness of the fluid layer was between 0.1 and 0.3 mm. On the starboard wing, 0.1 mm of fluid was measured on the leading edge, 2.54 cm (1 in.) from the joint between the leading edge and the main wing, on both the inboard and outboard chords.

4.3.3.2 Fluid viscosity

A sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck used for the in tests following the last run on March 6, 2002 (see Table 4.1). The viscosity of this sample measured 43 300 cP.

Once applied to the wing over Type I fluid, the Type IV fluid in this run had a measured viscosity of 32 950 cP. It is assumed that the Type I and Type IV fluids had combined, resulting in this significantly reduced viscosity value.

No sample was collected when the aircraft was returned to the deicing bay following the takeoff and flight.

4.3.3.3 Wing temperatures

The wing temperatures following the takeoff run ranged from -1°C to -2°C (see Figure 4.3).

4.4 March 6, 2002 – Run 4; Type IV; No Dilution

4.4.1 Prior to Departure from the Deicing Bay

4.4.1.1 Fluid thickness measurements

In this test the fluid thickness (before departure from the deicing bay) took on a range of values (Table 4.5):

a) 0.9 mm to 3 mm for the outboard chord on the port wing (average 1.7 mm);

b) 0.6 mm to 2 mm for the inboard chord of the port wing (average 1.5 mm);

c) 0.6 mm to 2.6 mm for the outboard chord of the starboard wing (average 1.6 mm); and

d) 0.9 mm to 3.8 mm for the inboard chord of the starboard wing (average 2.2 mm).

Table 4.5: Thickness Measurements (mm) for Run 4, March 6, 2002
Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.9		0.5		0.6		0.4	
	2	1.2		0.5	0.0	1.2		0.5	0.1
	3	1.2		0.4	0.1	1.6		0.4	0.1
	4	1.6		1.6	0.1	2.0		2.4	0.1
	5	2.8		2.8	0.1	2.6		2.4	0.1
	6	3.0		2.0		1.2		1.6	0.2
	7	1.0		0.9	0.2	1.2		1.2	0.2
	8	1.6		1.6	0.3	2.0		1.6	0.2
	9	2.4		1.6	0.1	2.0		1.6	0.2
INBOARD	1	0.6		0.5		0.9		0.4	
	2	1.2		1.2		2.0		1.2	0.1
	3	1.6		1.6	0.0	2.4		2.0	0.1
	4	2.0		1.6	0.1	2.6		2.0	0.1
	5	2.0		2.0	0.1	3.8		3.6	0.1
	6				0.1				
	7	1.6		0.6	0.1	2.0		1.0	0.2
	8	1.6		1.0	0.1	1.6		0.9	0.2
	9	1.6		1.0	0.1	2.0		0.9	0.2

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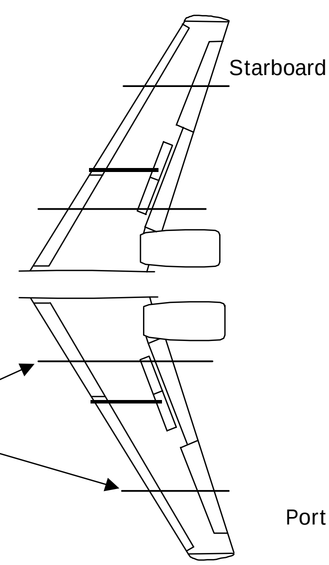
Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows.
Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



Location of inboard and outboard test denoted by lines.

4.4.1.2 Wing temperatures

The wing temperatures prior to departure from the deicing bay ranged from -1°C to -1.5ºC (see Figure 4.4). The ambient temperature at the start of testing was -3°C.

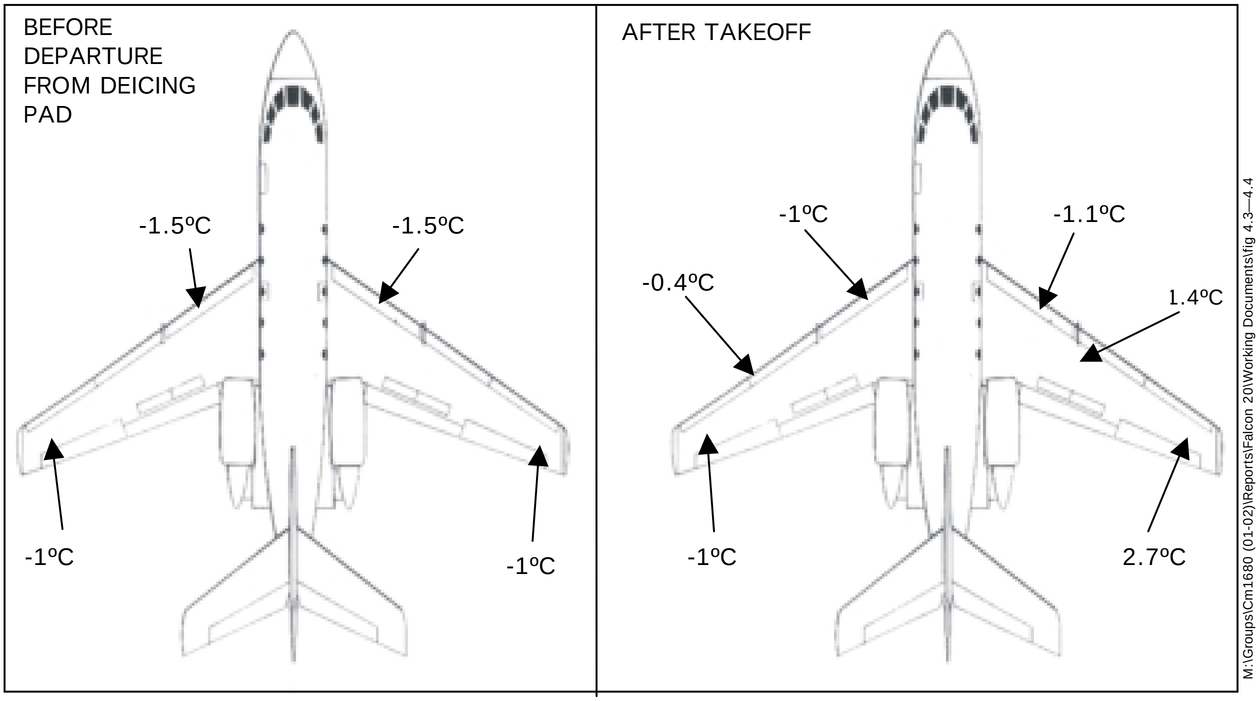


Figure 4.4: Wing Skin Temperatures (ºC) – March 6, 2002 – Run 4, Before/After Takeoff Run

4.4.2 Prior to Takeoff Run

4.4.2.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff run of the aircraft at the threshold of Runway 14, following the taxi of the aircraft from the deicing bay.

In this test, the stabilized fluid thickness (before takeoff run) took on a range of values (Table 4.5):

a) 0.4 mm to 2.8 mm for the outboard chord on the port wing (average 1.3 mm);

b) 0.5 mm to 2 mm for the inboard chord of the port wing (average 1.2 mm);

c) 0.4 mm to 2.4 mm for the outboard chord of the starboard wing (average 1.3 mm); and

d) 0.4 mm to 3.6 mm for the inboard chord of the starboard wing (average 1.5 mm).

4.4.3 Following the Takeoff Run

4.4.3.1 Fluid thickness measurements

Following the takeoff run (see Table 4.5), only a very thin film of fluid remained; in most areas the thickness was below 0.2 mm. Some pooling of remaining fluid was seen farther back toward the trailing edge of the aircraft. The thickness of the fluid layer measured between 0.1 and 0.3 mm. On the leading edge of both wings, up to 0.1 mm of fluid was measured.

4.4.3.2 Fluid viscosity

After termination of the final run on March 6, 2002, a sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck used in testing (see Table 4.1). The viscosity of this sample measured 43 300 cP.

Once applied to the wing, the Type IV fluid in this run had a measured viscosity of 38 485 cP.

No sample was collected when the aircraft returned to the deicing bay.

4.4.3.3 Wing temperatures

The wing temperatures following the takeoff run ranged from 2.7°C to -1.1°C (see Figure 4.4).

4.5 March 6, 2002 – Run 5; Type IV; No Dilution

4.5.1 Prior to Departure from the Deicing Bay

4.5.1.1 Fluid thickness measurements

In this test, the fluid thickness (before departure from the deicing bay) took on a range of values (Table 4.6):

a) 0.6 mm to 3.2 mm for the outboard chord on the port wing (average 1.7 mm);

a) 0.8 mm to 2.6 mm for the inboard chord of the port wing (average 1.9 mm);

b) 0.5 mm to 3 mm for the outboard chord of the starboard wing (average 1.9 mm); and

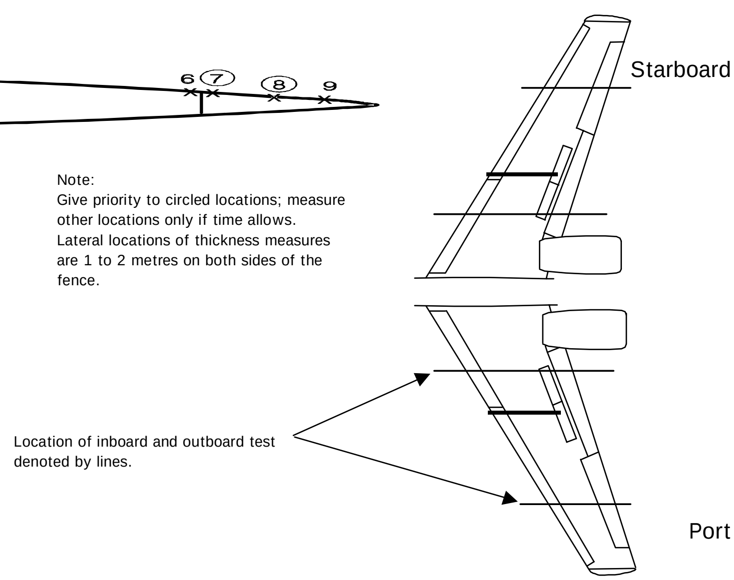
c) 0.6 mm to 3.2 mm for the inboard chord of the starboard wing (average 1.9 mm).

Table 4.6: Thickness Measurements (mm) for Run 5, March 6, 2002 Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.6		1.0		0.5		0.5	
	2	1.2		0.9	0.0	1.0		0.6	0.0
	3	1.2		0.6	0.1	1.6		0.4	0.1
	4	2.0		2.0	0.1	1.6		1.6	0.1
	5	2.6		3.0	0.1	2.0		2.0	0.1
	6	3.2		2.6	0.1	3.0		2.4	0.1
	7	0.9		1.0	0.1	2.0		1.6	0.1
	8	2.0		1.6	0.1	2.4		1.6	0.1
	9	2.0		1.6	0.1	2.6		2.0	0.2
INBOARD	1	0.8		0.5		0.6		0.4	
	2	1.2		1.2	0.0	1.2		1.2	0.0
	3	2.0		1.6	0.0	1.6		1.6	0.1
	4	1.6		1.6	0.0	2.0		2.0	0.1
	5	2.0		2.0	0.1	3.2		3.4	0.1
	6								
	7	2.6		1.0	0.2	2.4		1.2	0.1
	8	2.6		1.2	0.3	2.0		1.2	0.1
	9	2.4		1.2	0.1	2.4		1.2	0.1

Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows. Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



4.5.1.2 Wing temperatures

The temperatures of the Falcon 20 wing ranged from 6.4°C to -1.1°C prior to the departure of the aircraft from the deicing pad. The sun was poking through the broken cloud layer and warmed the wing (see Figure 4.5). The ambient temperature at the start of testing was -3°C.

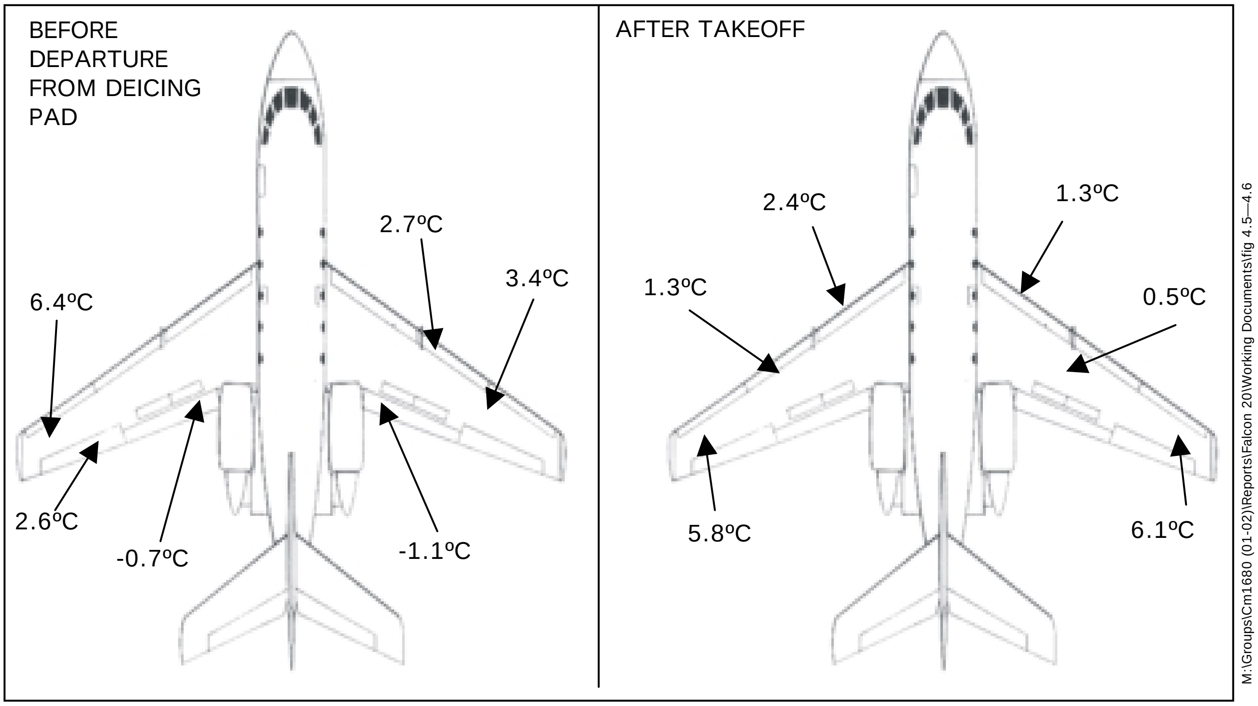


Figure 4.5: Wing Skin Temperatures (ºC) – March 6, 2002 – Run 5, Before/After Takeoff Run

4.5.2 Prior to Takeoff Run

4.5.2.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff run of the aircraft at the threshold of Runway 14, following the taxi of the aircraft from the deicing bay.

In this test the stabilized fluid thickness (before takeoff run) took on a range of values (Table 4.6):

a) 0.6 mm to 3 mm for the outboard chord on the port wing (average 1.6 mm);

b) 0.5 mm to 2 mm for the inboard chord of the port wing (average 1.3 mm);

c) 0.4 mm to 2.4 mm for the outboard chord of the starboard wing (average 1.4 mm); and

d) 0.4 mm to 3.4 mm for the inboard chord of the starboard wing (average 1.5 mm).

4.5.3 Following the Takeoff Run

4.5.3.1 Fluid thickness measurements

Following the takeoff run (see Table 4.6), only a very thin film of fluid remained: in most areas the thickness was below 0.2 mm. Some pooling of remaining fluid was seen farther back toward the trailing edge of the aircraft. The thickness of the fluid layer measured between 0.1 and 0.3 mm. On the leading edge of both wings, up to 0.1 mm of fluid was measured.

4.5.3.2 Fluid viscosity

After termination of the last run on March 6, 2002, a sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck used in testing (see Table 4.1). The viscosity of this sample measured 43 300 cP.

Once applied to the wing, the Type IV fluid in this run had a measured viscosity of 42 450 cP.

No sample was collected when the aircraft returned to the deicing bay.

4.5.3.3 Wing temperatures

The temperatures following the takeoff run in Run #5 ranged between 0.5°C and 6.1°C (see Figure 4.5). The sun was breaking through the overcast sky and warmed the wing.

4.6 March 11, 2002 – Run 1; Type IV; No Dilution

4.6.1 Prior to Departure from the Deicing Bay

4.6.1.1 Fluid thickness measurements

In this test the fluid thickness (before departure from the deicing bay) took on a range of values (Table 4.7):

a) 0.8 mm to 3.2 mm for the outboard chord on the port wing (average 1.9 mm);

b) 0.9 mm to 3.6 mm for the inboard chord of the port wing (average 2.1 mm);

c) 1 mm to 2 mm for the outboard chord of the starboard wing (average 1.5 mm); and

d) 0.9 mm to 2.8 mm for the inboard chord of the starboard wing (average 1.5 mm).

Table 4.7: Thickness Measurements (mm) for Run 1, March 11, 2002 Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.8		0.5	0.0	1.0		0.5	0.0
	2	1.0		0.8	0.0	1.0		0.5	0.0
	3	1.0		0.5	0.0	1.2		0.4	0.0
	4	2.0		1.6	0.0	2.0		1.6	0.0
	5	2.0		2.0	0.0	2.0		2.0	0.1
	6	3.2		2.8	0.1	2.0		2.0	0.1
	7	1.6		1.6	0.1	1.0		1.0	0.1
	8	2.6		2.4	0.1	1.6		1.2	0.1
	9	2.8		2.4	0.1	1.6		1.2	0.1
INBOARD	1	0.9		0.5	0.0	0.9		0.6	0.0
	2	1.6		1.2	0.0	1.2		1.0	0.0
	3	2.4		0.9	0.0	1.6		1.2	0.0
	4	2.4		3.0	0.0	1.6		1.6	0.1
	5	3.6		3.4		2.8		3.0	0.1
	6	2.4							0.0
	7	2.0		0.9	0.1	1.6		0.8	0.0
	8	2.0		0.7	0.2	1.0		0.9	0.1
	9	2.0		1.2	0.2	1.6		0.9	0.1

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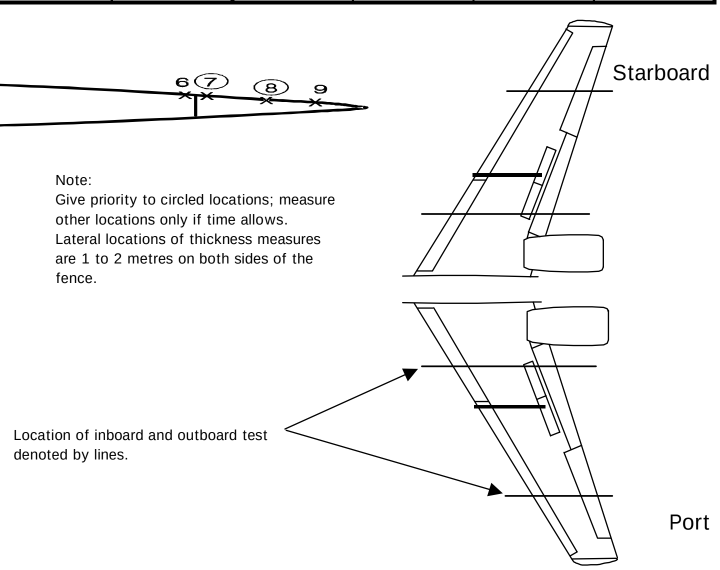
Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows. Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



4.6.1.2 Wing temperatures

The wing temperatures prior to takeoff run ranged from -7.8°C to -10°C (see Figure 4.6). The ambient temperature at the start of testing was -11°C.

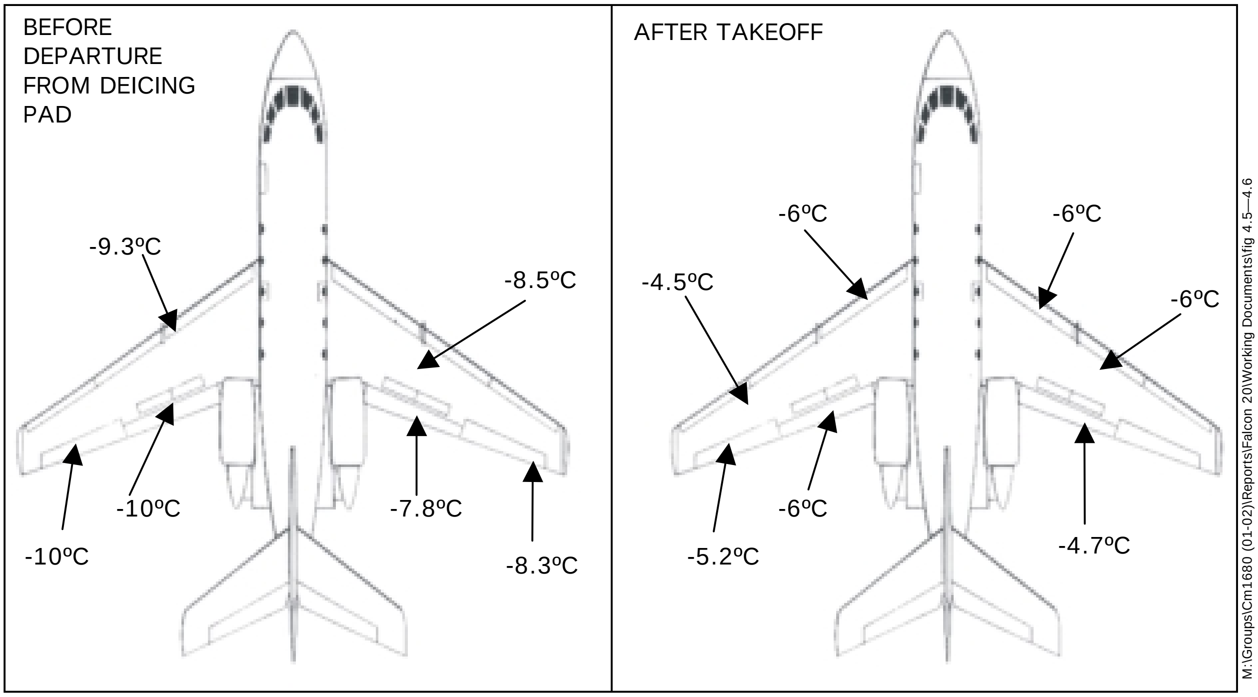


Figure 4.6: Wing Skin Temperatures (ºC) – March 11, 2002 – Run 1, Before/After Takeoff Run

4.6.2 Prior to Takeoff Run

4.6.2.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff run of the aircraft at the threshold of Runway 25, following the taxi of the aircraft from the deicing bay.

In this test, the fluid thickness (before takeoff run) took on a range of values (Table 4.7):

a) 0.5 mm to 2.8 mm for the outboard chord on the port wing (average 1.6 mm);

b) 0.5 mm to 3.4 mm for the inboard chord of the port wing (average 1.5 mm);

c) 0.4 mm to 2 mm for the outboard chord of the starboard wing (average 1.2 mm); and

d) 0.6 mm to 3 mm for the inboard chord of the starboard wing (average 1.3 mm).

4.6.3 Following the Takeoff Run

4.6.3.1 Fluid thickness measurements

Following the takeoff run (see Table 4.7), only a very thin film of fluid remained; in most areas the thickness was below 0.2 mm. Some pooling of remaining fluid was seen farther back toward the trailing edge of the aircraft. The thickness of the fluid layer measured between 0.1 and 0.2 mm.

4.6.3.2 Fluid viscosity

A sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck used in testing on March 11, 2002 (see Table 4.1). The viscosity of this sample measured 43 500 cP.

Once applied to the wing, the Type IV fluid in this run had a measured viscosity of 45 550 cP on the port wing, and 42 950 cP on the starboard wing.

After the takeoff run and flight, fluid samples were collected from the trailing edges of both Falcon 20 wings. On the port wing, the sample recovered had a viscosity of 19 750 cP; on the starboard wing, the sample recovered had a viscosity of 46 150 cP.

4.6.3.3 Wing temperatures

The wing temperatures following the takeoff measured between -4.5°C and -6°C (see Figure 4.6).

4.7 March 11, 2002 – Run 2; Type IV; Light Freezing Rain Applied

4.7.1 Prior to Application of Light Freezing Rain

4.7.1.1 Fluid thickness measurements

In this test the fluid thickness (before application of the light freezing rain) took on a range of values (Table 4.8):

a) 1 mm to 3 mm for the outboard chord on the port wing (average 1.9 mm);

b) 1.2 mm to 2.6 mm for the inboard chord of the port wing (average 1.8 mm);

c) 0.5 mm to 2.4 mm for the outboard chord of the starboard wing (average 1.2 mm); and

d) 0.6 mm to 2.4 mm for the inboard chord of the starboard wing (average 1.4 mm).

Table 4.8: Thickness Measurements (mm) for Run 2, March 11, 2002 Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	1.0	0.5	0.4		0.5	0.4	0.4	
	2	1.2	1.2	0.5		0.9	0.9	0.4	
	3	1.6	1.6	0.4		1.2	1.2	0.5	
	4	2.4	2.6	2.0	0.0	1.6	1.6	1.6	
	5	3.0	3.0	3.0	0.0	2.4	2.4	2.0	
	6	3.0	2.6	2.6	0.1	1.2	1.2	1.2	0.1
	7	1.0	0.9	0.8	0.1	1.2	1.2	0.9	0.1
	8	2.0	2.0	2.0	0.1	1.2	1.2	0.7	0.1
	9	2.0	2.4	2.0	0.0	0.9	0.8	1.0	0.1
INBOARD	1	1.2	0.5	0.4		0.6	1.0	0.5	
	2	2.0	1.2	1.2		1.2	1.2	1.2	
	3	2.0	2.4	2.0		1.6	2.0	1.6	
	4	2.6	1.6	2.6		2.0	2.0	2.0	0.1
	5	1.6	2.0	2.0		2.4	2.4	2.0	
	6	1.6							
	7	1.6	1.2	1.0		1.2	1.6	0.6	0.1
	8	2.0	1.6	1.2	0.2	1.6	1.6	1.0	0.1
	9	1.6	2.6	1.6	0.2	0.6	0.8	1.0	0.1

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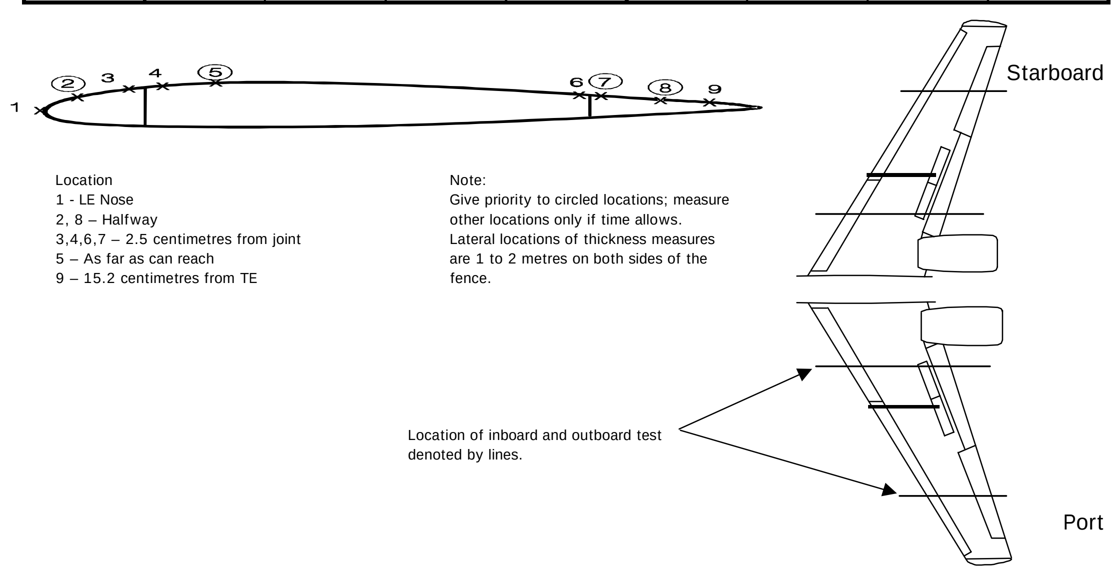

4.7.2 After Application of Light Freezing Rain

The rates of precipitation captured by the two rate pans on the port and starboard wings were 7.1 g/dm^2/h and 15.8 g/dm^2/h, respectively. It was very windy (15 knots), and the spray was very difficult to apply to the wing area, especially on the port wing. The spray application lasted 17 minutes.

4.7.2.1 Fluid thickness measurements

In this test, the fluid thickness after the application of the freezing precipitation took on a range of values (Table 4.8):

a) 0.5 mm to 3.0 mm for the outboard chord on the port wing (average 1.9 mm);
b) 0.5 mm to 2.6 mm for the inboard chord of the port wing (average 1.6 mm);
c) 0.4 mm to 2.4 mm for the outboard chord of the starboard wing (average 1.2 mm); and
d) 0.8 mm to 2.4 mm for the inboard chord of the starboard wing (average 1.6 mm).

4.7.2.2 Wing temperatures

The skin temperatures of the wing ranged between -1.9°C and -4.9°C (see Figure 4.7). The ambient temperature at the start of this test was -8°C.

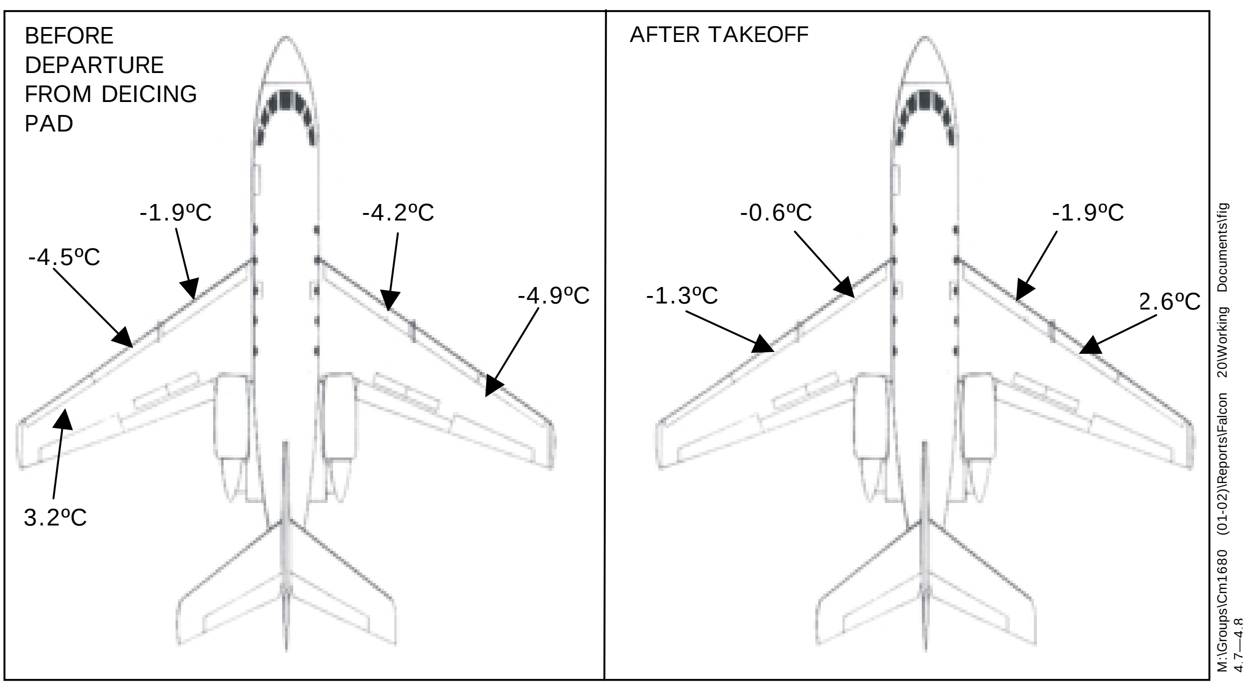

Figure 4.7: Wing Skin Temperatures (ºC) – March 11, 2002 – Run 2, Before/After Takeoff Run

4.7.2.3 Fluid freeze points

The freeze points of the Type IV fluid prior to the takeoff run are shown in Figure 4.8. Because of the wind, dilution of the fluids was difficult, and the lowest Brix value recorded in this run was 37.5, which represents a freeze point of approximately -52°C.

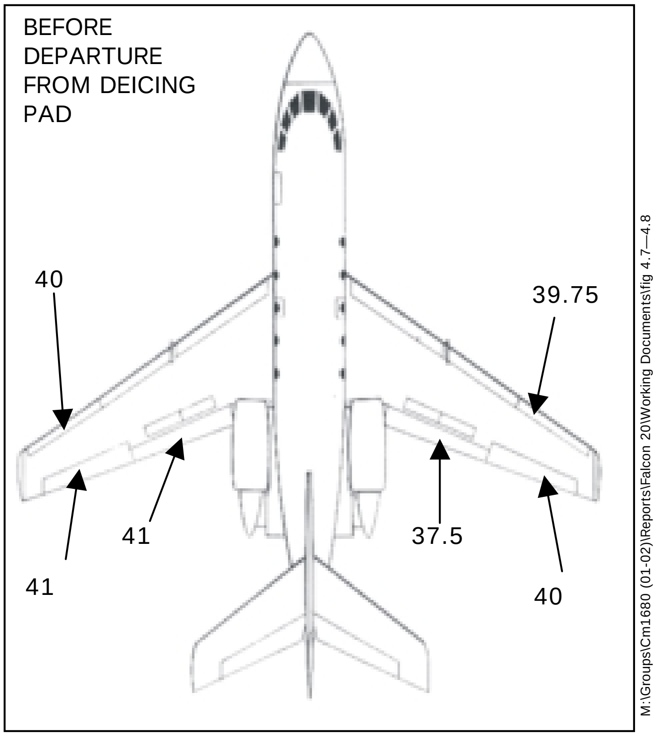

Figure 4.8: Fluid Freeze Point Measurements (ºBrix) – March 11, 2002 – Run 2

4.7.3 Prior to Takeoff Run

4.7.3.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff run of the aircraft at the threshold of Runway 25, following the taxi of the aircraft from the deicing bay.

In this test, the stabilized fluid thickness (before takeoff) took on a range of values: (Table 4.8)

a) 0.4 mm to 3 mm for the outboard chord on the port wing (average 1.5 mm);

b) 0.4 mm to 2.6 mm for the inboard chord of the port wing (average 1.5 mm);

c) 0.4 mm to 2 mm for the outboard chord of the starboard wing (average 1 mm); and

d) 0.5 mm to 2 mm for the inboard chord of the starboard wing (average 1.2 mm).

4.7.4 Following the Takeoff Run

4.7.4.1 Fluid thickness measurements

Following the takeoff run (see Table 4.7), only a very thin film of fluid remained; in most areas the thickness was immeasurable (less than 0.1 mm). Some puddling of remaining fluid was seen farther back toward the trailing edge of the aircraft. The thickness of the fluid film measured between 0.1 and 0.2 mm.

4.7.4.2 Fluid viscosity

A sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck used in testing on March 11, 2002 (see Table 4.1). The viscosity of this sample measured 43 500 cP.

Once applied to the wing, the Type IV fluid in this run had a measured viscosity of 44 450 cP on the port wing and 43 650 cP on the starboard wing. Following the application of light freezing rain to the wings, the viscosities of the fluids on the port and starboard wings measured 40 950 cP and 36 050 cP, respectively.

After the takeoff run and flight, no fluid samples were collected for this run.

4.7.4.3 Wing temperatures

After the takeoff run, the temperatures on the wing ranged between -0.6°C and -2.6°C (see Figure 4.7).

4.8 March 12, 2002 – Run 1; Type IV; Light Freezing Rain Applied

4.8.1 Prior to Application of Light Freezing Rain

4.8.1.1 Fluid thickness measurements

In this test, the fluid thickness (before application of the freezing rain) took on a range of values (Table 4.9):

a) 0.5 mm to 2 mm for the outboard chord on the port wing (average 1.2 mm);

b) 0.4 mm to 2 mm for the inboard chord of the port wing (average 1.2 mm);

c) 0.5 mm to 1.6 mm for the outboard chord of the starboard wing (average 1.1 mm); and

d) 0.6 mm to 2.0 mm for the inboard chord of the starboard wing (average 1.3 mm).

Table 4.9: Thickness Measurements (mm) for Run 1, March 12, 2002 Before/After Takeoff Run

		PORT				STARBOARD			
	Wing Position	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.5	0.2	0.2	0.0	0.5	0.3	0.2	0.0
	2	1.0	0.4	0.4	0.0	0.6	0.4	0.2	0.0
	3	1.2	0.4	0.2	0.0	1.0	0.5	0.3	0.0
	4	1.6	0.6	0.8	0.0	1.6	0.6	0.6	0.0
	5	2.0	1.6	1.6	0.0	1.2	1.2	1.2	0.0
	6	2.0	1.2	0.8	0.0	1.6	0.8	0.8	0.1
	7	1.0	0.3	0.2	0.1	1.2	0.4	0.3	0.1
	8	1.0	0.4	0.4	0.0	1.6	0.5	0.5	0.0
	9	0.5	0.9	1.0	0.1	1.0	0.6	0.4	0.1
INBOARD	1	0.4	0.2	0.2	0.0	0.6	0.3	0.2	0.0
	2	1.2	0.2	0.2	0.0	1.6	0.5	0.4	0.0
	3	1.6	0.4	0.4	0.0	2.0	0.6	0.5	0.0
	4	1.6	0.4	0.4	0.0	2.0	0.6	0.6	0.0
	5	2.0	2.0	1.6	0.0	1.6	1.6	1.2	0.0
	6	1.2			0.0	1.2			0.0
	7	1.0	0.3	0.2	0.1	0.9	0.4	0.2	0.0
	8	0.9	0.6	0.5	0.1	0.8	0.4	0.2	0.0
	9	0.6	0.8	0.5	0.1	0.8	0.4	0.2	0.1

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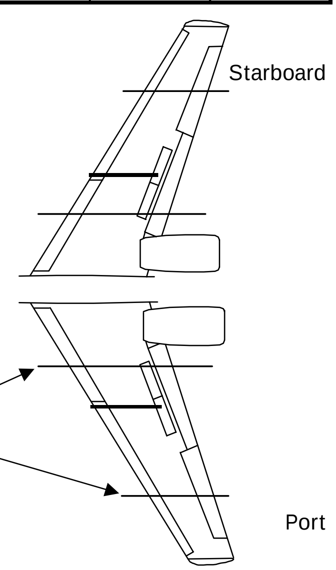
Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows.
Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



4.8.2 After Application of Light Freezing Rain

The rates of precipitation captured by the rate pans on the port and starboard wings wing were 16.1 g/dm^2/h and 15.5 g/dm^2/h, respectively. The spray application lasted approximately 58 minutes.

4.8.2.1 Fluid thickness measurements

In this test the fluid thickness after the application of the freezing precipitation took on a range of values (Table 4.9):

a) 0.2 mm to 1.6 mm for the outboard chord on the port wing (average 0.7 mm);
b) 0.2 mm to 2 mm for the inboard chord of the port wing (average 0.6 mm);
c) 0.3 mm to 1.2 mm for the outboard chord of the starboard wing (average 0.6 mm); and
d) 0.3 mm to 1.6 mm for the inboard chord of the starboard wing (average 0.6 mm).

4.8.2.2 Wing temperatures

The wing temperatures on the Falcon 20 prior to the departure of the aircraft from the deicing pad ranged from 0.7°C to -0.6°C (see Figure 4.9). The ambient temperature at the start of testing was -3°C.

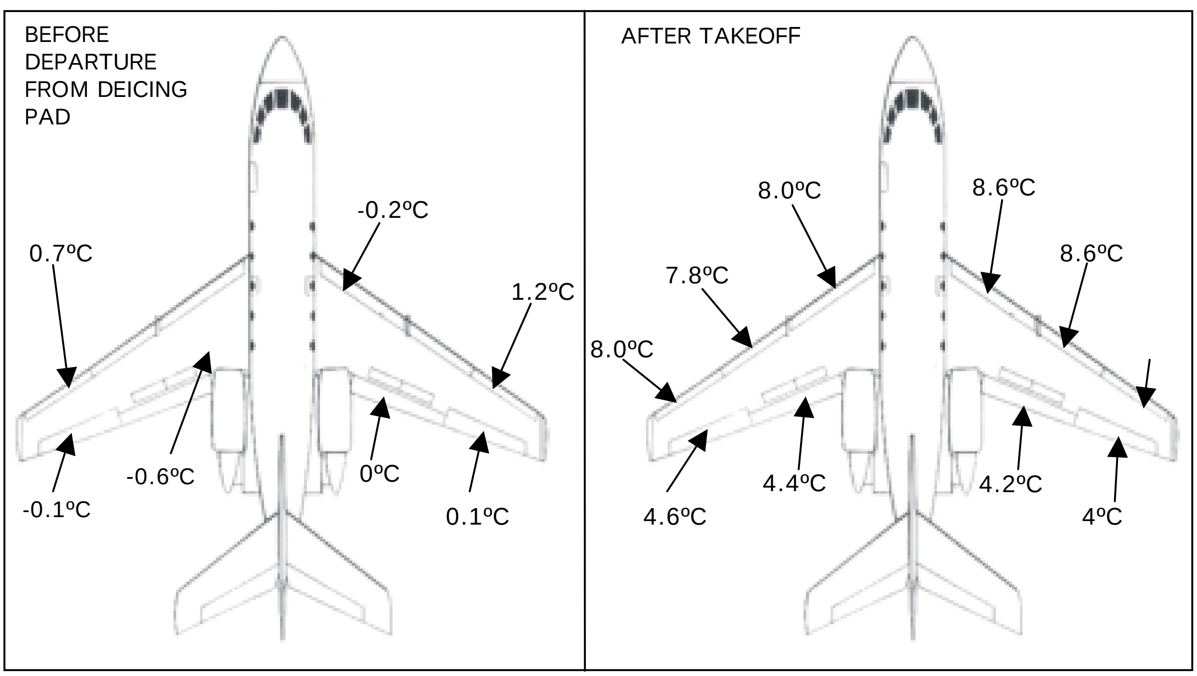


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Figure 4.9: Wing Skin Temperatures (ºC) – March 12, 2002 – Run 1, Before/After Takeoff Run

4.8.2.3 Fluid freeze points

The fluid freeze point distribution over both wings after dilution of the fluid and prior to the takeoff run is shown in Figure 4.10.

On the port wing, the fluid freeze points ranged from -47°C (36.5º Brix) on the inboard leading edge to -10°C (15.5 Brix) on the aileron.

On the starboard wing, the fluid freeze points ranged from -38°C (31.5º Brix) on the wing tip to -6°C (11º Brix) on the inboard flap.

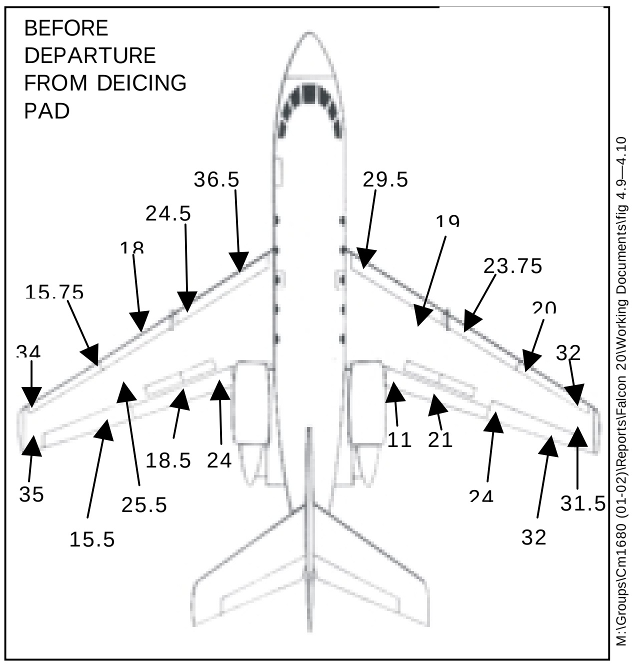

Figure 4.10: Fluid Freeze Point Measurements (ºBrix) – March 12, 2002 – Run 1

4.8.3 Prior to Takeoff Run

4.8.3.1 Fluid thickness measurements

Fluid thickness measurements were taken again just prior to the takeoff run of the aircraft at the threshold of Runway 14, following the taxi of the aircraft from the deicing bay.

In this test, the fluid thickness (before takeoff run) took on a range of values (Table 4.9):

a) 0.2 mm to 1.6 mm for the outboard chord on the port wing (average 0.6 mm);

b) 0.2 mm to 1.6 mm for the inboard chord of the port wing (average 0.5 mm);

c) 0.2 mm to 1.2 mm for the outboard chord of the starboard wing (average 0.5 mm); and

d) 0.2 mm to 1.2 mm for the inboard chord of the starboard wing (average 0.4 mm).

4.8.4 Following the Takeoff Run

4.8.4.1 Fluid thickness measurements

Following the takeoff run (see Table 4.9), only a very thin film of fluid remained; in most areas the thickness was immeasurable. Some pooling of remaining fluid was seen farther back toward the trailing edge of the aircraft, but on this run it measured less than 0.1 mm.

4.8.4.2 Fluid viscosity

A sample of the uncontaminated Dow UCAR Ultra+ fluid was recovered from the deicing truck used in testing on March 11, 2002 (see Table 4.1). The viscosity of this sample measured 43 500 cP.

Once applied to the wing, the Type IV fluid in this run had a measured viscosity of 31 350 cP on the port wing and 32 000 cP on the starboard wing. Following the application of light freezing rain to the wings, the viscosities of the fluids on the port and starboard wings measured 7 400 cP and 100 cP, respectively.

After the takeoff and flight, fluid samples were collected from the trailing edges of both wings. On the port wing, the sample recovered had a viscosity of 24,000 cP; on the starboard wing, the sample recovered had a viscosity of 0 cP.

4.8.4.3 Wing temperatures

After the takeoff, the wing temperatures had dramatically increased, and ranged from 4°C to 8.6°C (see Figure 4.9).

4.9 March 12, 2002 – Run 2; Type IV; Light Freezing Rain Applied

4.9.1 Prior to Application of Light Freezing Rain

4.9.1.1 Fluid thickness measurements

In this test, the fluid thickness (before application of the freezing rain) took on a range of values (Table 4.10):

a) 0.5 mm to 1.6 mm for the outboard chord on the port wing (average 1.2 mm);

b) 0.6 mm to 1.6 mm for the inboard chord of the port wing (average 1.3 mm);

c) 0.4 mm to 2.0 mm for the outboard chord of the starboard wing (average 1.1 mm); and

d) 0.5 mm to 2.0 mm for the inboard chord of the starboard wing (average 1.4 mm).

Table 4.10: Thickness Measurements (mm) for Run 2, March 12, 2002 Before/After Takeoff Run

	Wing Position	PORT				STARBOARD			
		BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF	BEFORE RAIN SPRAY	AFTER RAIN SPRAY	BEFORE TAKEOFF	AFTER TAKEOFF
OUTBOARD	1	0.5	0.2	DID NOT TAKE OFF		0.4	0.2	DID NOT TAKE OFF	
	2	1.2	0.4			1.0	0.4		
	3	1.2	0.5			1.2	0.6		
	4	1.6	1.6			1.6	0.6		
	5	1.6	2.0			1.6	2.0		
	6	1.6	1.2			2.0	1.6		
	7	1.2	0.5			0.9	0.2		
	8	1.6	1.6			1.0	0.8		
	9	0.6	1.0			0.6	0.9		
INBOARD	1	0.6	0.1			0.5	0.1		
	2	1.2	0.5			1.0	0.2		
	3	1.6	1.2			1.2	0.4		
	4	1.6	1.6			1.6	0.5		
	5	1.6	1.6			2.0	2.4		
	6		1.6			1.6	0.8		
	7	1.6	0.9			1.2	0.6		
	8	1.6	1.2			1.6	0.6		
	9	0.8	1.6			1.6	1.6		

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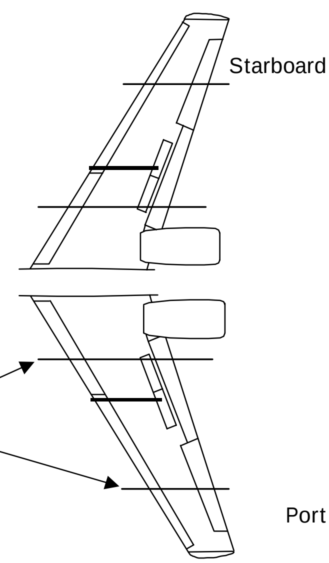
Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 2.5 centimetres from joint
5 – As far as can reach
9 – 15.2 centimetres from TE

Note:
Give priority to circled locations; measure other locations only if time allows.
Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



Location of inboard and outboard test denoted by lines.

4.9.2 After Application of Light Freezing Rain

The rates of precipitation captured by the pans on the port and starboard wings were 17.1 and 8.4 g/dm^2/h, respectively. The spray application period lasted approximately 38 minutes. The wind increased to 11 knots during this run, making spray application to the starboard wing difficult.

4.9.2.1 Fluid thickness measurements

In this test the fluid thickness after the application of the freezing precipitation took on a range of values (Table 4.10):

a) 0.2 mm to 2.0 mm for the outboard chord on the port wing (average 1 mm);

b) 0.1 mm to 1.6 mm for the inboard chord of the port wing (average 1.1 mm);

c) 0.2 mm to 2.0 mm for the outboard chord of the starboard wing (average 0.8 mm); and

d) 0.1 mm to 2.4 mm for the inboard chord of the starboard wing (average 0.8 mm).

4.9.2.2 Wing temperatures

The wing skin temperatures on the Falcon 20 prior to departure from the deicing pad ranged from 5.1°C to 8.6°C (see Figure 4.11). The ambient temperature at the start of testing was 3°C under partially sunny skies.

4.9.2.3 Fluid freeze points

The fluid freeze point distribution over both wings of the Falcon 20 after dilution of the fluid is shown in Figure 4.12.

On the port wing, the fluid freeze points ranged from -58°C (41.25º Brix) on the wing tip to -20°C (22º Brix) on the mid-wing section inboard of the fence.

On the starboard wing, the fluid freeze points ranged from -52°C (37.5º Brix) on the wing tip to -22°C (23.25º Brix) on the outboard leading edge.

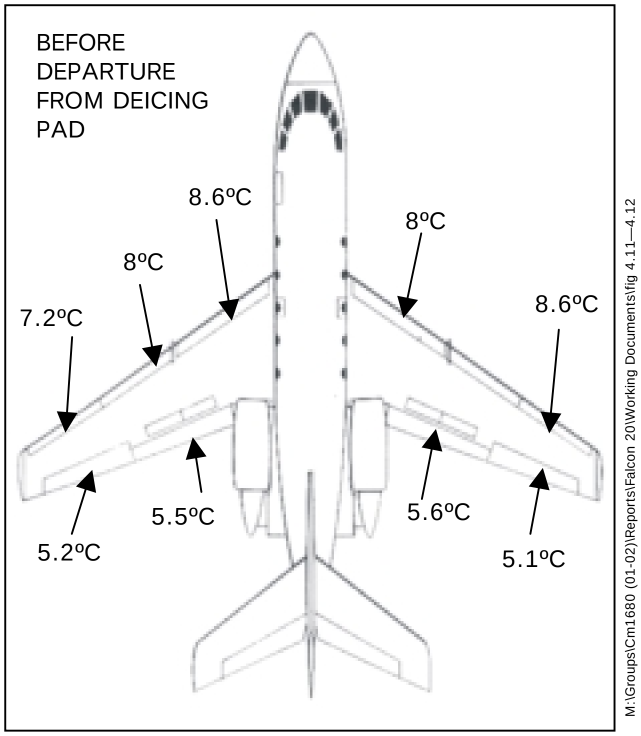


Figure 4.11: Wing Skin Temperatures (ºC) – March 12, 2002 – Run 2

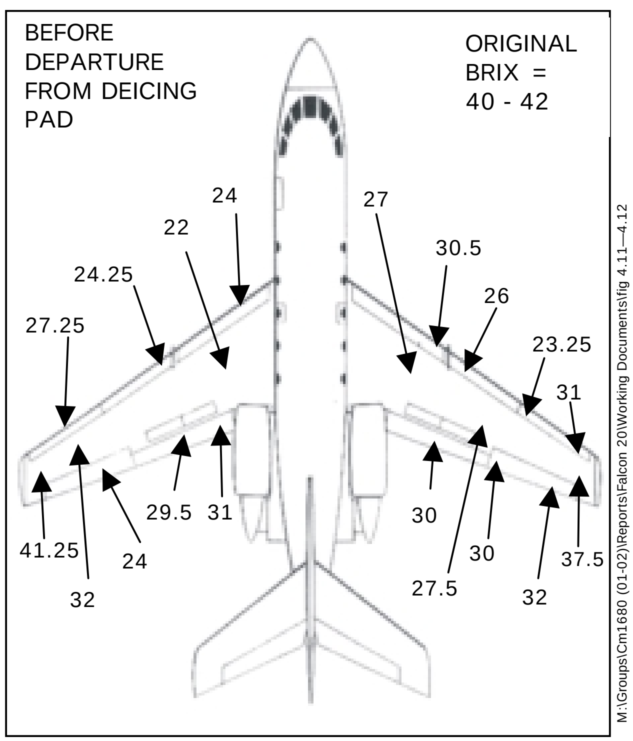


Figure 4.12: Fluid Freeze Point Measurements (ºBrix) – March 12, 2002 – Run 2

4.9.3 End of Testing

Due to problems with the data acquisition systems onboard the Falcon 20, Run #2 conducted on March 12, 2002 was never completed, and the aircraft never left the deicing pad for the departure runway. No further data were collected.

4.10 Volume of Anti-Icing Fluid Sheared Off the Falcon 20 Aircraft During Takeoff Run and Location(s) Where the Anti-Icer is Deposited

Fluid thickness measurements were recorded by APS personnel at various times:

a) Shortly after the Type IV fluid application and prior to the application of freezing precipitation to dilute the fluid on the wings;

b) Immediately following the fluid dilution process, and prior to the taxi of the aircraft;

c) Just prior to the aircraft taking position on the runway for departure; and

d) Following the return of the aircraft to the deicing facility after a short flight.

Fluid thickness measurements were recorded at 34 locations on the wings just prior to takeoff of the aircraft. These measurements allowed for a calculation of the volume of anti-icing fluid that was present on the wings of the Falcon 20 prior to the departure of the aircraft.

The results from the eight Falcon tests showed that, on average, 46 percent of the Type IV fluid applied to the wings of the Falcon 20 was present prior to the takeoff of the aircraft.

During the takeoff run, the majority of the fluid on the wing was sheared off and lands on the airfield. Some residual fluid was observed on the wings following the takeoff and during the climb-out, but this film was incredibly thin. Some residual fluid was measured on the trailing edge of the Falcon 20 following the return of the aircraft to the deicing bay. This quantity was mostly immeasurable but localized areas with thicknesses of 0.3 mm of fluid were observed.

For each test, hand-held video cameras were employed to monitor the shearing of the de/anti-icing products from the moment the brakes were released to beyond the rotation of the aircraft. Furthermore, aircraft runway markers and cockpit voice recordings were used to determine the speed at which the fluid was being removed from the wing and where on the runway it was being deposited.

Examination of the video documentation from the Falcon 20 tests showed that the Type IV fluid was sheared from the wing within seconds of the aircraft approaching 80 knots at ground speed. At rotation, only a very thin film was observed on the wing.

Figure 4.13 shows the percentage of visible fluid loss on the wings of the Falcon 20 as a function of runway distance and ground speed. The values provided in Figure 4.13 are based on estimates provided by APS personnel viewing the takeoff video documentation. Estimates of the variance on the visible fluid remaining on the wing have also been included within Figure 4.13.

Figure 4.13 shows that when the aircraft reached 80 knots of ground speed, approximately 75 percent of the Type IV fluid on the wing had been removed. This occurred in the first 305 metres (1000 ft.) of the takeoff run. In the following 610 metres (2000 ft.) of runway, an additional 20 percent of the fluid had come off the wing. This scenario may be significantly different, however, for other aircraft. The Falcon 20 was light, carried no cargo, and had very little fuel on board. Furthermore, the Falcon 20 requires a shorter takeoff run than larger, heavier aircraft. While the fluid present on the wings of a larger aircraft would undoubtedly begin to shear off at speeds similar to those shown in Figure 4.13, it would take these larger and heavier aircraft more time and runway length to attain these ground speeds, thus altering the patterns of glycol dispersion over the runway. Also, aircraft size and wingspan would affect the dispersal patterns since some portion of the fluid would be carried by the vortices generated by the different aircraft.

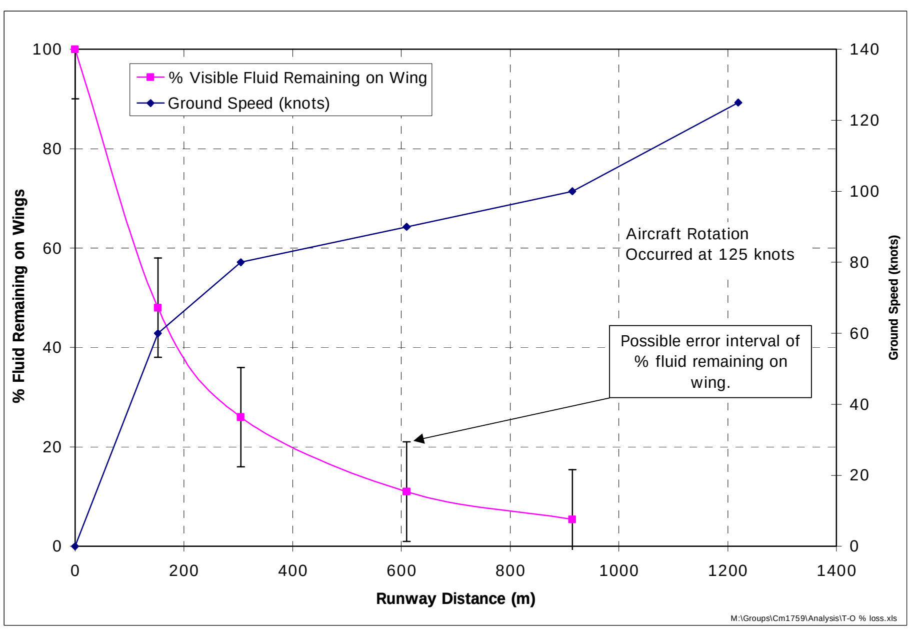


Figure 4.13: Fluid Remaining on the Wings of the Falcon 20 During the Takeoff Run

Industry focus over the past five years has concentrated on centralized deicing practices to alleviate the environmental impacts of glycol deicing and anti-icing. While this has significantly improved the collection of fluids within the application areas, based on the information presented in this study, it appears that a significant amount of Type IV fluid – perhaps as high as 50 percent – is being dispersed over the runway and airfield as a result of the shearing of fluids during the takeoff run. This appears to present be a problem, particularly with thickened fluids. Most of the Type I fluid applied to a wing falls to the ground in the application area, so the amounts that come off during the takeoff run may be insignificant.

It is noteworthy that the 50 percent value of dispersion over the runway and airfield would be lower during periods of ongoing precipitation. The fluids on the wing would be diluted during the taxi of the aircraft to the departure runway, dispersing them in greater quantity over the taxiways. Regardless, the containment of removed de/anti-icing fluids on the runway appears to be the greatest challenge for airports using thickened anti-icing fluids.

4.11 Summary of Falcon 20 Tests

4.11.1 Fluid Thickness

EG-based Type IV fluid was applied to both wings of the Falcon 20 aircraft at the central deicing facility in Ottawa.

Fluid thickness values on the leading edge (thickness locations 1 to 3 in Tables 4.2 to 4.10) recorded prior to the takeoff of the aircraft were generally in the range of 0.2 mm to 0.6 mm, although measurements up to 2.0 mm were recorded in some cases near the leading edge joint.

Fluid thickness values on mid-wing sections (thickness locations 4 to 6 in Tables 4.2 to 4.10) recorded prior to the takeoff of the aircraft were generally in the range of 0.8 mm to 2.4 mm, although measurements as low as 0.3 mm and measurements as high as 3.6 mm were recorded at some locations.

Fluid thickness values on the trailing edge (thickness locations 7 to 9 in Tables 4.2 to 4.10) recorded prior to the takeoff of the aircraft were generally in the range of 0.7 mm to 1.2 mm, although measurements as low as 0.2 mm and as high as 2.4 mm were recorded in some tests.

Fluid thickness measurements were recorded at 34 locations on the wings after the fluid application, prior to the start of the taxi, and just prior to takeoff of the aircraft. Consequently, the volume of anti-icing fluid that fell to the ground inside the application area, outside the application area as a result of the taxi of the aircraft, and on the runway as a result of the shear forces exerted during the takeoff run, could easily be determined.

Table 4.11 contains the summary of the eight runs conducted with the Falcon 20. The final run (Run #2, March 12, 2002) was omitted from the table since no takeoff was performed.

Table 4.11: Summary of Falcon 20 Aircraft Tests

Date	Run	Wing	Spray Quantity (litres)	Amount on Wing after Application (litres)	Amount on Wing after Dilution (litres)	Amount on Wing after Taxi (litres)
March 6	1	Port	41	20.5		15.4
March 6	1	Starboard	51	10.3		10.3
March 6	2	Port	68	34		26.7
March 6	2	Starboard	52	30.8		24.6
March 6	3	Port	53	32.8		24
March 6	3	Starboard	46	30.8		24
March 6	4	Port	55	32.8		26.7
March 6	4	Starboard	54	39		28.7
March 6	5	Port	60	36.9		30.8
March 6	5	Starboard	62	39		30.8
March 11	1	Port	65	41		32.8
March 11	1	Starboard	47	30.8		26.8
March 11	2	Port	48	39	36.9	30.8
March 11	2	Starboard	40	28.7	28.7	22.6
March 12	1	Port	29	24.6	14.4	12.3
March 12	1	Starboard	32	24.6	12.3	10.3

The results of the eight tests showed that:

a) On average, 38 percent of the Type IV fluid applied to the wings of the Falcon 20 aircraft fell to the ground within the application area. These measurements were typically completed within 7-10 minutes of the spray application;

b) On average, 11 percent of the fluid that was present on the wings of the Falcon 20 aircraft prior to leaving the deicing bay came off as a result of the taxi of the aircraft to the departure runway; and

c) On average, 46 percent of the Type IV fluid applied to the wings of the Falcon 20 was present prior to the takeoff of the aircraft.

4.11.2 Wing Temperatures

A summary of the wing temperatures from the Falcon 20 tests is shown in Table 4.12.

Table 4.12: Summary of Falcon 20 Wing Temperatures Before/After Takeoff Run

Date	Run	OAT		Before Takeoff (ºC)		After Takeoff (ºC)	
				Port	Starboard	Port	Starboard
March 6	Run 1	-8ºC	*Avg*	-7.9	-7.7	-4.0	-4.0
			Min	-8.0	-8.0	-4.0	-4.0
			Max	-7.5	-7.4	-4.0	-4.0
March 6	Run 2	-7ºC	*Avg*	-4.0	-4.0	-4.0	-3.5
			Min	-4.0	-4.0	-4.0	-3.5
			Max	-4.0	-4.0	-4.0	-3.5
March 6	Run 3	-4ºC	*Avg*	-2.0	-2.9	-1.5	-2.0
			Min	-2.0	-3.2	-2.0	-2.0
			Max	-2.0	-2.5	-1.0	-2.0
March 6	Run 4	-3ºC	*Avg*	-1.3	-1.3	-0.8	0.1
			Min	-1.5	-1.5	-1.0	-1.4
			Max	-1.0	-1.0	-0.4	2.7
March 6	Run 5	-3ºC	*Avg*	2.8	1.7	3.2	2.6
			Min	-0.1	-1.1	1.3	0.5
			Max	6.4	3.4	5.8	6.1
March 11	Run 1	-11ºC	*Avg*	-9.8	-8.2	-5.4	-5.6
			Min	-10.0	-8.5	-6.0	-6.0
			Max	-9.3	-7.8	-4.5	-4.7
March 11	Run 2	-8ºC	*Avg*	-3.2	-4.6	-1.0	-2.3
			Min	-4.5	-4.9	-1.3	-2.6
			Max	-1.9	-4.2	-0.6	-1.9
March 12	Run 1	-3ºC	*Avg*	0.0	0.3	6.6	6.8
			Min	-0.6	-0.2	4.4	4.0
			Max	0.7	1.2	8.0	8.6
March 12	Run 2	3ºC	*Avg*	6.9	6.8	no data	no data
			Min	5.2	5.1		
			Max	8.6	8.6		

4.11.3 Fluid Viscosity

A summary of the viscosity results from the Falcon 20 tests was previously shown in Table 4.1.

In general, the viscosity values from the Falcon 20 tests followed an expected trend. The samples collected from the deicing vehicles had viscosity values in the manufacturer's production range. Once applied to the wing, the viscosities of the UCAR Ultra+ fluid were similar to the truck values, although a few values were significantly lower. When light freezing rain was applied to the Type IV fluid on the wings, the viscosities diminished to varying degrees, based largely on exposure to the light freezing rain.

Following the takeoff run and flight of the Falcon 20, samples of the residual fluid on the trailing edge of the aircraft were collected. Although the results have been deemed largely inconclusive, in most cases the collected samples had viscosities inferior to those collected prior to the takeoff run.

4.12 Fluid Freeze Point

Three tests were conducted with diluted Type IV fluid in 2001-02.

In Run #2 on March 11, 2002, the anti-icing fluid was exposed to light freezing rain for only 17 minutes, resulting in the fluid being diluted only slightly to a 42°C buffer.

In Run #1 on March 12, 2002, the anti-icing fluid was exposed to light freezing rain for 58 minutes, resulting in the fluid being diluted to a 7°C buffer on the port wing, and a 3°C buffer on the starboard wing.

In Run #2 on March 12, 2002, the anti-icing fluid was exposed to light freezing rain for 38 minutes, resulting in the fluid being diluted to a 23°C buffer on the port wing, and a 25°C buffer on the starboard wing.

In all three tests, the fluid across the wing was not diluted to the same levels as indicated above, and the buffer was that of the most diluted wing section. In general, the fluid across the entire wing surface was less diluted than at the selected locations.

4.13 Summary of NRC Flight Test Data

A preliminary analysis of the flight data recorded by the NRC flight team revealed that a significant degradation in lift occurs as a result of the presence of neat (undiluted) anti-icing fluid on the wings of the Falcon 20. No differences were noted in tests conducted with diluted anti-icing fluid.

The complete set of NRC flight test results will be prepared by NRC and published in a separate report for TDC.

5. CONCLUSIONS

Tests performed in 2001-02 with the Falcon 20 were conducted as the first year's tests part one-year test component of a three-year test program. The following sections describe the conclusions reached from field tests conducted in the 2001-02 winter season.

5.1 Test Coordination and Provision of Support

APS coordinated and provided support for tests aimed to quantify the aerodynamic penalties associated with the presence of neat or diluted anti-icing fluids on the wings of the NRC Falcon 20. The test methodologies employed for the application of light freezing rain and the collection of fluid thickness, fluid viscosity, wing temperature, and fluid freeze point data were satisfactory.

5.2 Fluid Thickness Measurements

5.2.1 Fluid Thickness Data Prior to Takeoff Run

Fluid thickness values on the leading edge recorded prior to the takeoff of the aircraft were generally in the range of 0.2 mm to 0.6 mm. Measurements of up to 2.0 mm were recorded in some locations near the leading edge slat to wing interface.

Fluid thickness values on the mid-wing section recorded prior to the takeoff run of the aircraft were generally in the range of 0.8 mm to 2.4 mm, although measurements as low as 0.3 mm and as high as 3.6 mm were recorded in some sections.

Fluid thickness values on the trailing edge recorded prior to the takeoff run of the aircraft were generally in the range of 0.7 mm to 1.2 mm, although measurements as low as 0.2 mm and as high as 2.4 mm were recorded in some tests.

5.2.2 Quantities of Fluid that Remain on the Wing After the Fluid Spray

The results of the eight tests involving takeoff showed that:

a) Approximately 40 percent of the Type IV fluid applied to the wings of the Falcon 20 aircraft fell to the ground within the application area.

b) Approximately 10 percent of the fluid that was present on the wings of the Falcon 20 aircraft prior to leaving the deicing bay came off as a result of the taxi of the aircraft to the departure runway; and

c) Approximately 50 percent of the Type IV fluid applied to the wings of the Falcon 20 was present prior to the takeoff of the aircraft.

5.3 Elimination of Neat and Diluted Fluids

Only one ethylene glycol-based Type IV fluid, UCAR Ultra+ was tested in a neat state to observe the process of fluid elimination from the wing surface during takeoff.

The videotape of the fluid surface during the takeoff run showed that the majority of the fluid had been eliminated from the wing surface by the time the aircraft speed had reached 80 knots. A small film of fluid was observed, receding toward the trailing edge of the aircraft, at the time of rotation.

Measurements following flight showed that the fluid underwent near complete elimination, leaving only a very thin film of residual fluid. The remaining fluid film was less than 0.1 mm when present on leading edge surfaces, but ranged from 0.1 mm to 0.3 mm on the trailing edge.

No differences were noted in tests conducted with diluted fluids.

5.4 Aerodynamic Penalties Due to the Presence of Diluted or Undiluted Fluid

Preliminary analysis of the NRC flight data shows that a significant lift penalty may be attributed to the presence of neat or diluted anti-icing fluid on the wings of the Falcon 20.

NRC will prepare a report of the aerodynamic data for TDC.

6. RECOMMENDATIONS

Tests conducted to examine the lift penalties associated with the presence of neat or diluted anti-icing fluid on the wings of the NRC Falcon 20 aircraft were conducted in 2001-02 as the first year of a three-year test program.

Several recommendations can be put forth from the results of this testing:

a) Further takeoff tests should be conducted using different fluid formulations. All tests conducted in 2001-02 used the same ethylene glycol-based Type IV fluid. It is recommended that future tests utilize propylene glycol-based products, since the fluid dilution and failure characteristics of the PG fluids are significantly different than those of EG fluids;

b) Further takeoff tests should be conducted using snow precipitation. The objective of these tests would be to evaluate whether snow provides results similar to freezing rain with respect to the elimination of diluted fluid from aircraft wings;

c) Further takeoff tests should be conducted using higher levels of dilution and even possibly contamination. (The tests conducted in 2001-02 employed fluid with freeze point buffers ranging from 3°C to 42°C, and no contamination whatsoever in the fluid film);

d) A preliminary measurement of the relationship between viscosity and refractive index should be performed for all test fluids at different levels of dilution and at different temperatures; and

e) Clean wing takeoff tests should be performed during a natural rain occurrence to use as a baseline for comparison with anti-icing fluid tests.

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APPENDIX A

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

TRANSPORTATION DEVELOPMENT CENTRE

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

5.3 Flow of Contaminated Fluid from Aircraft Wings During Takeoff

Previous trials of simulated takeoff runs provided an improved understanding of the behaviour of contaminated fluid on aircraft wings during this critical phase of the takeoff run. Those trials demonstrated that, with ethylene glycol- (EG-) based fluids, any ice formations that existed prior to the takeoff run, remained following the run, regardless of whether the ice had adhered to the wing surface or not. Many ice formations underwent adhesion during the run. With the propylene glycol- (PG-) based fluid, a contamination level of 100 percent was completely eliminated from the wing during the takeoff run. The purpose of the tests is to evaluate the flow of contaminated fluid from the wing of a Falcon 20 aircraft during simulated takeoff runs.

5.3.1 Develop a test plan jointly with NRC staff, who operate the aircraft

5.3.2 Conduct tests at Mirabel airport over a period of three days.

5.3.3 Produce a professional quality video record of fluid behaviour on the wing during the takeoff run.

5.3.4 Conduct the trials in appropriate weather conditions. Overcast skies are especially important to avoid the heating of wing surfaces caused by sun radiation. Ambient air temperatures from -5º to -10ºC are required. During at least one session, natural snow recovered from previous snowfalls will be applied to simulate natural snowfall contamination of the fluids.

5.3.5 Depending on the runway in operation, and if deemed necessary, intercept the aircraft on the return taxi to allow the state of fluid on the wing to be examined immediately after the takeoff run.

5.3.6 Arrange for the use one or more ice contamination sensors to assist in documenting contamination levels before and after the takeoff runs. It is assumed that the manufacturers will participate and will provide the sensors for testing. The sensors will be positioned at an orientation, height, and distance from the wing to simulate an end-of-runway scanning configuration.

5.3.7 Determine the adherence of fluid to the wing.

5.3.8 Explore with NRC the possibility of installing instrumentation on the wing surface in the form of a rake of pitot-tubes (costs to be established).

5.3.9 Collect the following data during these trials:

- Type of fluid applied;
- Record of type and rate of contamination applied;
- Extent of fluid contamination prior to and following the takeoff run;
- Measurements of thickness, concentration, viscosity, and adherence of clean and contaminated fluid at various stages in the test;
- Observations on fluid appearance and behaviour, photography and videotape records, and ice sensor records; and
- Specifics (speed, aircraft configuration, etc.) during the takeoff runs will be obtained from NRC personnel.

5.3.10 Co-ordinate all test activities, initiating tests in conjunction with NRC staff based on forecast weather and aircraft availability. The Contractor shall analyze the results and document the findings in a final technical report.

APPENDIX B

TERMS OF REFERENCE – PROJECT DESCRIPTION
EXCERPT FROM TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT
(2001-03)

TRANSPORTATION DEVELOPMENT CENTRE

EXCERPT FROM WORK STATEMENT – DC 202
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
WINTER OPERATIONS CONTAMINATED AIRCRAFT – GROUND
2001-03
(March 2002)

5.14 Flow of Contaminated Fluid from Aircraft Wings During Takeoff

5.14.1 Develop a test plan jointly with NRC staff who operate the aircraft;

5.14.2 Plan for and co-ordinate the application of SAE Type IV fluid (ethylene and propylene-based) at Ottawa airport over a period of three days;

5.14.3 Plan for and co-ordinate the application of controlled amounts of snow and /or freezing rain contamination on the applied fluids;

5.14.4 Document the appearance of fluids on the wing and adherence of fluid to the wing prior to departure of the aircraft for the test flight;

5.14.5 Collect the following data during the trials:

a) Type and amount of fluid applied;
b) Record of type and rate of contamination applied;
c) Extent of fluid contamination prior to the takeoff run; and
d) Measurements of thickness, concentration, viscosity, and adherence of clean and contaminated fluid prior to departure for the flight test;

5.14.6 Co-ordinate the ground aspect of test activities and initiate tests in conjunction with NRC staff based on forecast weather and aircraft availability; and

5.14.7 Document collected data from the ground aspect of testing for inclusion in the analysis and report.

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APPENDIX C

TERMS OF REFERENCE – PROJECT DESCRIPTION FROM TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT WINTER 2001-02

TERMS OF REFERENCE – PROJECT DESCRIPTION
TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT

CONTAMINATED AIRCRAFT DYNAMIC TESTS – DC195

(Winter 01/02)

1. INTRODUCTION

The risk of a catastrophic aircraft accident at takeoff caused by ongoing winter precipitation may be regarded as the product of the probabilities of

(1) anti-icing fluid failing to prevent contamination adhering to the aircraft;
(2) fluid failure being undetected and a decision made to takeoff; and,
(3) contamination of the aerodynamic surfaces being sufficient to cause significant loss of lift and/or loss of control.

Anti-icing fluid, when diluted by ongoing precipitation, begins to fail at the top surface forming slush but, because a layer of fluid is always present below, no adherence is initially possible and the airflow at takeoff should remove it along with the fluid. Although up to 10 percent coverage of the wing by such slush is accepted before holdover time ends, aircraft tests by TDC have shown that this may not be the case. Also, NRC open circuit wind tunnel tests showed that the presence of unshed fluid caused a small loss of lift at rotation. Full scale flight tests by Boeing and SAAB have also indicated reductions in lift due to unshed fluid.

The long-term goal of this program of research is to determine the effects of a limited level of unabsorbed winter precipitation present in or on an anti-icing fluid while maintaining a safe takeoff condition below the protection time limit for the fluid. I.e. the wing is to be maintained aerodynamically “clean” even though it may not be visually clean.

The test program planned for winter 2001-02 using the NRC Falcon aircraft will address the effects of unshed anti-icing fluid on aircraft takeoff performance. As a first step it is proposed to ascertain whether there is an aerodynamic penalty on the aircraft due to presence of clean anti-icing fluid and also partially expended anti-icing fluid on the wings. The limiting condition of the fluid would be when it can no longer absorb frozen contamination, but unabsorbed precipitation is not present on the fluid surface. Tests for this latter condition will use artificial precipitation and a simulated distribution of precipitate over the surface, which will approximate “real world” conditions.

2. PROGRAM OBJECTIVE

Take an active and participatory role to advance aircraft ground deicing/anti-icing technology.

3. PROGRAM SUB-OBJECTIVE

3.1 Develop international standards for de/anti-icing technology.

3.2 Develop more reliable methods of predicting anti-icing Holdover times.

3.3 Develop guidance material for remote and runway-end deicing facilities.

3.4 Encourage development of systems that can allow pilots to assess the external state of the aircraft from within the flight deck.

3.5 Establish weather conditions significant to winter operations.

4. PROJECT OBJECTIVE – THREE-YEAR PROJECT

4.1 To ascertain whether there is an aerodynamic penalty on the aircraft due to presence of partially expended anti-icing fluid on the wings.

4.2 To determine the effects of a limited level of unabsorbed frozen contamination present in or on an anti-icing fluid while maintaining a safe takeoff condition below the endurance time limit for the fluid.

4,3 To determine at what level of contamination of anti-icing fluid by winter precipitation the airflow at take off does not remove the resultant slush.

5. DETAILED STATEMENT OF WORK – YEAR 1

5.1 Co-ordination and Review

TDC acting directly or through a contractor will coordinate and provide support services for the conduct of tests. A contact person (or persons) will be nominated, and will provide services and liaison as identified below. An advisory group will be formed to review planned tests, conduct of tests and comment on results. The group will be formed from representatives of government and industry.

5.2 Planning and Preparation

In co-operation with NRC, the contractor will prepare a detailed work-plan and schedule for review with the TDC project officer.

5.3 **Aircraft and Services to be provided**

NRC shall provide the Falcon 20 Research Aircraft and flight crew.

A three-year program of tests to measure comparative aircraft takeoff performance under winter operating conditions is anticipated;

a) Reference tests with clean, dry (uncontaminated) wings;
b) Tests with clean (uncontaminated) anti-icing fluid on the wings
c) Tests with contaminated fluid (simulating a fluid just prior to loss of ability to absorb further freezing precipitation) on the wings; and
d) Tests with fluid unable to absorb further freezing precipitation ('small' area of unabsorbed contamination near or at the trailing edge) prior to end of holdover time.

Alternatively tests (b) and (c) may be replaced by a single diluted fluid condition for each of two fluids.

The number of runs to be performed and the condition of the aircraft for test to be agreed upon by NRC and TDC.

The tests for the first year of the program are covered by the present Work Statement.

5.4 **Schedule**

The project will involve three series of tests:

- conduct of dry aircraft reference tests – January or February, '02 (Specific date at NRC discretion);
- tests with clean fluid on the wings – week of 11 February, '02; and
- tests with contaminated fluid on the wings – week of 04 March, '02.

Priority will be accorded to the dry aircraft reference tests, followed by the tests with clean fluid on the wings.

Preparations to start any time after December '01, test work to be completed prior to March 31, 2002; the estimated overall project duration is ten months, ending September 30, 2002.

5.5 **Airport Selection**

NRC shall select the airfield for conduct of the tests.

Ottawa airport is the preferred location. Mirabel is the alternative location.

Deicing/anti-icing should be performed as close to runway for start of takeoff runs as is practical. The contractor shall make appropriate arrangements.

5.6 **Test Procedures**

Detail test procedures will be developed jointly by NRC and TDC.

At the start of each set of tests the aircraft will perform a "standard" takeoff run through rotation and lift-off.

In successive runs the angle of attack at rotation will be increased to obtain data to develop a curve of lift versus angle of attack (the C_L curve), up to a safe maximum, based on measurement of velocity and angle at lift-off for known aircraft weight, and acceleration/roll distance.

The C_L curve will be developed for:

a) the dry aircraft. This will be done during the first week of tests.
b) the aircraft with clean fluid on the wings, and
c) the aircraft with diluted fluid on the wings.

The clean fluid test will be repeated prior to each contaminated fluid test.
Subject to findings, the runs will then be repeated for minor levels of unabsorbed precipitation on the fluid (e.g. 315 sq.cm x 0,5mm thick).
Accuracy of measurement will be such that repeated runs will be required to ensure availability of meaningful data.
Sixteen hours of flight time are estimated for this first year of the test program.

5.7 Fluid Application

'Fluid' refers to Type IV anti-icing fluid. Application will follow standard procedures, i.e. application of Type I deicing fluid followed by the Type IV fluid.
The contractor will apply fluids to the entire aircraft wing surface areas.
The wings will be treated symmetrically.
The extent of surface coverage will be determined in co-operation with the pilot. The largest possible coverage is desired in order to facilitate measurement of the effects of interest.

5.8 Instrumentation and Measurements

NRC shall co-ordinate with TDC and the contractor for use of instrumentation, aircraft data and provide advice as necessary.
A video camera or other means will record airspeed and time and shall be synchronised to other possible fluid recording devices. Before and after a ground roll the contractor will measure the depth and dilution of the fluid at several chord-wise locations, at one span-wise station; NRC will arrange how this might best be accomplished safely.

5.9 Meteorological Conditions

Tests conducted shall be performed under overcast skies, preferably with no natural precipitation, and at sub-freezing temperatures, preferably above -7^{0}C, and ideally between -3^{0}C and 0^{0}C.
The "clean wing" base line tests may be conducted at any ambient temperature. Wind speed should not exceed 10 kts.

5.10 **Data Analysis and Recommendations**
Data analysis will be performed by NRC
The methodology for data analysis, format of output, and development of recommendations will be reviewed jointly by NRC and TDC, and may be reviewed by the Advisory Group.

5.11 **Presentations of test program results**
Prepare and present preliminary findings to the Transport Canada Standing Committee on Operations, as agreed.

6. ROLE OF OTHER PARTIES

TDC, through its contractor APS Aviation Inc, shall provide support to the testing including the provision of test fluids, their application and the application of simulated winter precipitation. APS will also measure the state of the fluid and its contamination both before and after the takeoff runs. for test implementation. The APS contract for this work is in place.

7. SPECIAL INSTRUCTIONS

7.1 NRC is encouraged to publicise the research: however all publicity should be co-ordinated with the Project Officer, and credit should be given to the project sponsor, Transport Canada, as instructed. (See also Appendix ‘B’).

7.2 Suitable opportunities for visual material creation should be sought during the course of the contract in the form of slides, photographs, drawings or videotapes.

7.3 A presentation by NRC to the TC/JAA/FAA Cooperative R&D - Ground Icing Working Group should be anticipated for June 2002, in Montreal.

7.4 Intellectual Property Rights, as detailed in appendix B.

8. PROJECT ADMINISTRATION

The Executive Director, Transportation Development Centre (TDC) has appointed Barry Myers to manage the project on behalf of TDC. A progress review committee will be convened to counsel the Project Officer, to monitor progress and comment on the work.

9. REPORTING REQUIREMENTS

9.1 Progress Reports
None

9.2 Final Reports and Publication Standards
[Conform to TDC principles, including a Transport Canada publication number (TP number) and Publication Data Form (PDF), and produce in electronic format.]

9.3 Publication Schedule

9.3.1 NRC shall assist the TDC contractor in preparing a yearly presentation and a written report on the methodology, conduct of the test and observations.

9.3.2 For control purposes, all reports, except progress reports, shall be delivered to:

Office Services Supervisor
Transportation Development Centre
800 Rene Levesque Blvd. W., Suite 600
Montreal, Quebec. H3B 1X9

10. DISPOSAL OF EQUIPMENT

10.1 All equipment procured or constructed at the expense of TDC during the contract shall be delivered or disposed of in agreement with TDC at the completion of work.

10.2 All equipment provided on loan from TDC in the course of the work will be maintained and all legal charges paid by the loan recipient, and furthermore such equipment shall be returned as directed by TDC.

10.3 Copies of source code for software developed under this contract specifically for TDC shall be delivered on magnetic media along with a hard copy program listing.

10.4 All software licenses procured at the expense of and for TDC during the contract shall be transferred to TDC at the completion of work unless otherwise agreed to; the arrangements necessary to accomplish this transfer shall be made with the licensee at the time of purchase.

10.5 Any software developed by a third party for use in this project should be free from any encumbrances.

APPENDIX D

EXPERIMENTAL PROGRAM
FIELD TRIALS TO EXAMINE
REMOVAL OF DILUTED FLUID FROM AIRCRAFT WINGS
DURING THE TAKEOFF RUN

CM1680.001

EXPERIMENTAL PROGRAM
FIELD TRIALS TO EXAMINE REMOVAL OF DILUTED FLUID FROM AIRCRAFT WINGS DURING THE TAKEOFF RUN

Winter 2001-02

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Michael Chaput

Reviewed by: John D'Avirro

March 8, 2002
Version 3.0

APS AVIATION INC.

FIELD TRIALS TO EXAMINE REMOVAL OF DILUTED FLUID FROM AIRCRAFT WINGS DURING THE TAKEOFF RUN

Version 3.0

Winter 2001-02

Previous trials to examine the elimination of failed SAE Type IV fluid from aircraft wings during takeoff were conducted during the 1997-98 and 1998-99 winter seasons. Those trials, based on simulated takeoff runs using a National Research Council Falcon 20 aircraft, provided an improved understanding of the subject and showed that the selected test approach was a viable one. Additional trials were planned for the 1999-2000 and 2000-01 winter test seasons, however these trials were not conducted due to lack of suitable weather conditions in the limited time that the aircraft and crew were available for testing.

The test program planned for winter 2001-02 using the NRC Falcon 20 will address the effects of unshed anti-icing fluid on aircraft takeoff performance. As a first step it is proposed to ascertain whether there is an aerodynamic penalty on the aircraft due to presence of clean anti-icing fluid and also partially expended anti-icing fluid on the wings. The limiting condition of the fluid would be when it can no longer absorb frozen or freezing precipitation, but unabsorbed precipitation is not present on the fluid surface. Tests for this latter condition will use artificial precipitation and a simulated distribution of precipitate over the surface that will approximate “real world” conditions.

These trials will be co-ordinated and reported by APS. They will be conducted at Ottawa International Airport (YOW) on a Falcon 20 research aircraft owned and piloted by the National Research Council Canada.

This document provides the detailed procedures and equipment required to support these trials.

1. OBJECTIVE

This project addresses the following objective:

- To ascertain whether there is an aerodynamic penalty on the aircraft due to presence of partially expended anti-icing fluid on the wings.

2. TEST REQUIREMENTS

APS will co-ordinate and plan test activities and prepare a final report as well as present results at industry deicing meetings.

APS will provide support to these tests for instrumentation, fluid application, and artificial precipitation application. A high-quality digital videotape record of fluid behaviour on aircraft wings during the takeoff run is required and will be recorded by observers in the Falcon 20 cabin.

Desired weather conditions are dry, with subfreezing outside air temperature. Tests will be limited to a maximum of 10kts crosswind. At least one test session will be conducted at warm temperatures, near -3°C. Trials at ambient temperatures near -7°C are also planned, to study the effect of the different mechanisms of fluid failure at that temperature. Overcast skies are very important to avoid overheating of aircraft wings from exposure to the sun. Runway conditions are to be clean and dry.

For tests involving precipitation, freezing rain or snow will be applied untilthe fluid condition is such that a 3°C buffer exists between the FFP and the air temperature. The condition will be measured at three locations on control surfaces.

Freezing rain and snow equipment will be calibrated to support delivery near 25g/dm^2/h. Precipitation will be measured during the trials.

An ice detection sensor from Goodrich Aerospace will be used to assist in documenting contamination levels before and after the takeoff run.

Attachment I provides a description of test procedures. Table I provides a plan overview of the different tests.

Table 1: Test Plan – Removal of Diluted Fluid from Aircraft Wings During Takeoff Run

TEST #	OAT °C	Fluid	Type of Contamination	Level of Contamination
1*	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
2*	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
3*	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
4*	-3	Type IV EG Neat	Freezing Rain	Clean Fluid
5*	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +
6	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +
7*	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +
8*	-3	Type IV EG Neat	Freezing Rain	Up to 3°C buffer +

* Denotes duplicate tests
\+ Or prior to the onset of first failure being detected on the wing

Note: Consider testing in the event of natural precipitation.

3. EQUIPMENT AND FLUIDS

3.1 Equipment

Equipment to be employed is shown in Attachment II.

3.2 Fluids

SAE Type I UCAR ADF EG fluid and Type IV UCAR Ultra+ EG fluid will be used in 2001-02 trials.

4 PERSONNEL

Up to eleven APS staff members are required for tests on aircraft at Ottawa airport.

The Falcon 20 aircraft will be sprayed by Globe Ground personnel at the central deicing facility in Ottawa.

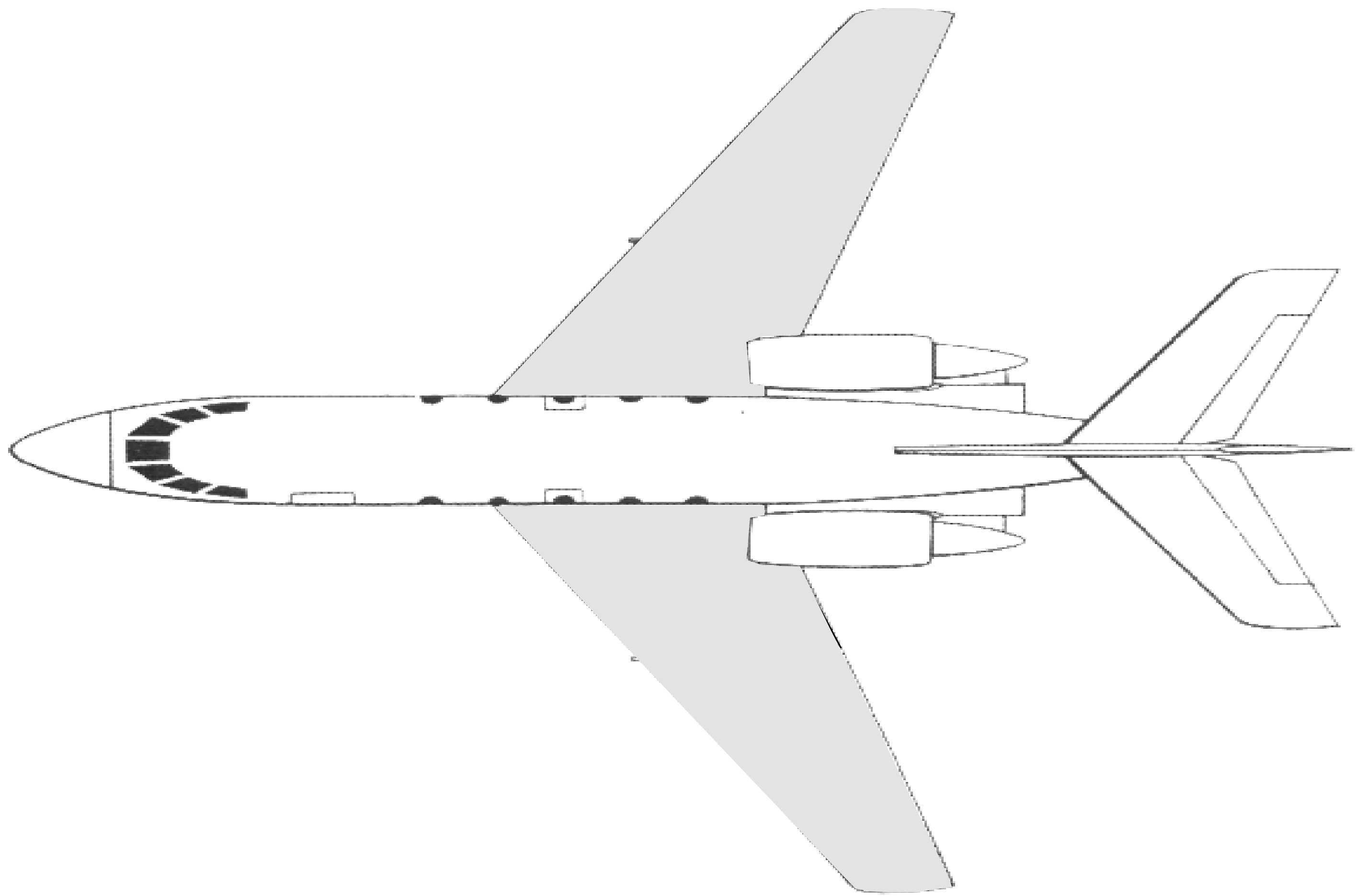
National Research Council flight crews will operate the National Research Council aircraft.

Attachment III provides task assignments.

5 DATA FORMS

Figure 1 Wing Test Area for Takeoff Run Trials
Figure 2 General Form (Every Test)
Figure 2a General Form (Once per Session)
Figure 3 Fluid Failure Pattern Form – Port Wing
Figure 3a Fluid Failure Pattern Form – Starboard Wing
Figure 4 Fluid Sampling and Brix form – Port Wing
Figure 4a Fluid Sampling and Brix Form – Starboard Wing
Figure 5 Wing Temperature Form – Port Wing
Figure 5a Wing Temperature Form – Starboard Wing
Figure 6 Fluid Thickness on Aircraft
Figure 7 Rain/Snow Quantity Form
Figure 8 Log of Ice Detection Sensor Form

FALCON 20



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Form 1

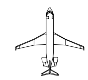
Figure 1: Wing Test Area for Takeoff Run Trials

GENERAL FORM (EVERY TEST)
(TO BE FILLED IN BY OVERALL COORDINATOR)

DATE: ______________________ **AIRCRAFT TYPE:** FALCON 20

RUN #: ______________________

DIRECTION OF AIRCRAFT: ________ DEGREES **DRAW DIRECTION OF WIND AT DEICING CENTRE WRT AIRCRAFT:**



DEPARTURE TIME FROM DE-ICING BAY: ______________

START OF TAKE-OFF ROLL: ______________

TIME OF LANDING: ______________

RETURN TO DEICING BAY: ______________

FLUID APPLICATION - PORT WING

Actual Start Time: ______________ **am / pm** **Actual End Time:** ______________ **am / pm**

Amount of Type I: ______________ **L / gal** **Amount of Type IV:** ______________ **L / gal**

Fluid Sample Collected from Truck or Barrel: **Y / N**

FLUID APPLICATION - STARBOARD WING

Actual Start Time: ______________ **am / pm** **Actual End Time:** ______________ **am / pm**

Amount of Type I: ______________ **L / gal** **Amount of Type IV:** ______________ **L / gal**

Fluid Sample Collected from Truck or Barrel: **Y / N**

CONTAMINANT SPRAY APPLICATION

Actual Start Time (port wing): ______________ **am / pm** **Actual End Time:** ______________ **am / pm**

Actual Start Time (starboard wing): ______________ **am / pm** **Actual End Time:** ______________ **am / pm**

End of Test Time: ______________ (hr:min:ss) am/pm

COMMENTS: ______________________________

MEASUREMENTS BY: ______________________

HANDWRITTEN BY: ______________________

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Form 2

Figure 2: General Form (Every Test)

GENERAL FORM (ONCE PER SESSION)

(TO BE FILLED IN BY OVERALL COORDINATOR)

AIRPORT: YMX YOW

AIRCRAFT TYPE: FALCON 20

EXACT PAD LOCATION OF TEST: ______________________

AIRLINE: ______________

DATE: ______________

FIN #: ______________

APPROX. AIR TEMPERATURE: ______ ºC

FUEL LOAD: ______________ **LB / KG**

TYPE I FLUID APPLICATION	***TYPE IV FLUID APPLICATION***
TYPE I FLUID TEMP: ______ ºC	**TYPE IV FLUID TEMP:** ______ ºC
Type I Truck #: ______	**Type IV Truck #:** ______
Type I Fluid Nozzle Type: ______	**Type IV Fluid Nozzle Type:** ______

COMMENTS: ______________________

MEASUREMENTS BY: ______________

HANDWRITTEN BY: ______________

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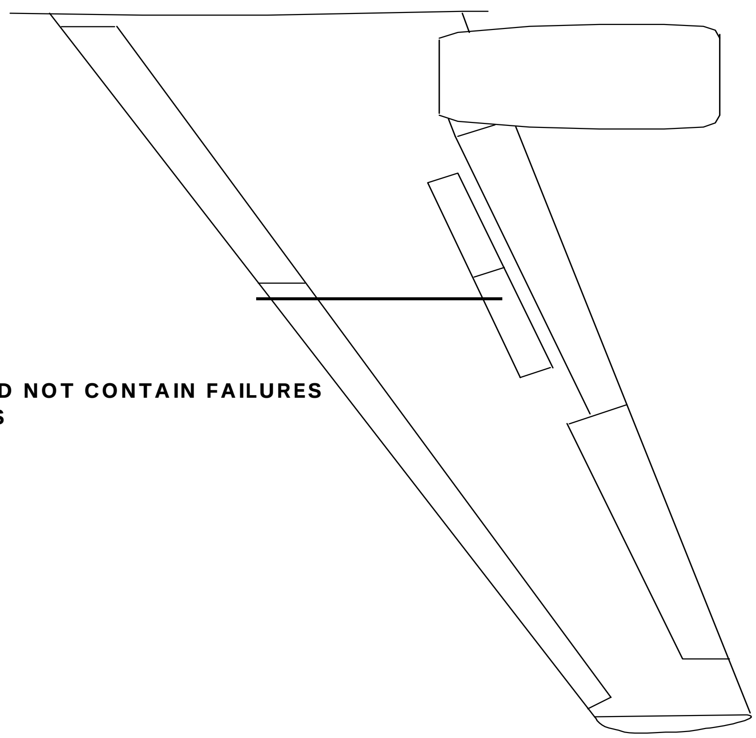
Form 2a

Figure 2a: General Form (Once per session)

Date: ________	**Time:** ________	**Run Number** ________
Failure Contours: Before Takeoff ________ After Takeoff ________	**Location of Observer:** Cabin ________ Wing ________	**Fluid Type:** ________

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE



NOTE: WING SHOULD NOT CONTAIN FAILURES FOR 2001-02 TRIALS

Wing Observer
measure and indicate on wing form the test area subjected to snow or rain contamination.

Area = _______m²

Amount of Contaminant

Applied = _____ kg

Plate Failure Times

Initial = ___________ (hr:mm:ss)

Plate = ___________ (hr:mm:ss)

COMMENTS: ____________________

____

____

____

OBSERVER: ____________________

ASSISTED BY: ____________________

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Form 3

Figure 3: Fluid Failure Pattern Form – Port Wing

Date: __________________ **Time:** __________________ **Run Number** _________

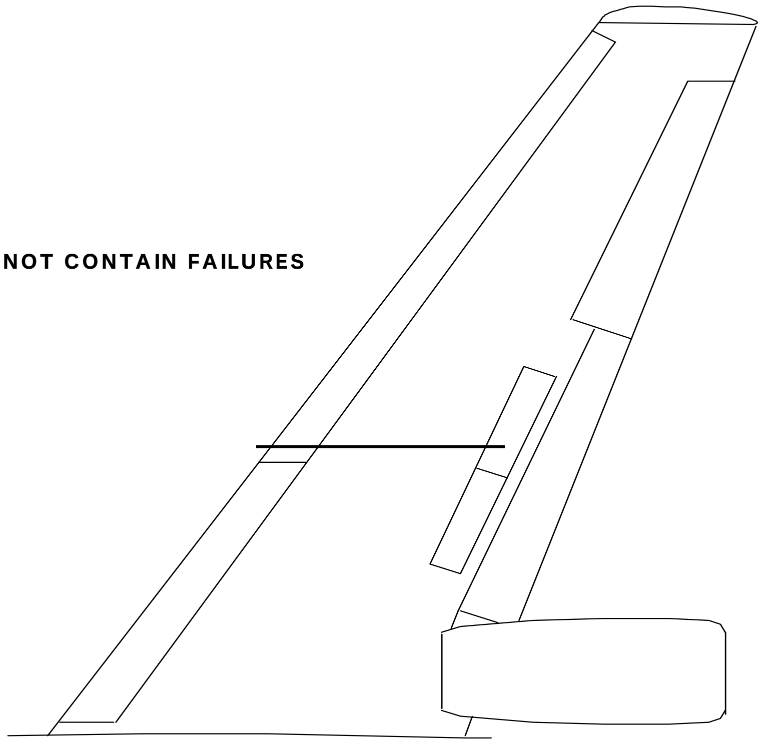
Failure Contours: Before Takeoff _________ After Takeoff _________

Location of Observer: Cabin _________ Wing _________

Fluid Type: __________________

DRAW FAILURE CONTOURS ACCORDING TO THE PROCEDURE

NOTE: WING SHOULD NOT CONTAIN FAILURES IN 2001-02 TRIALS



Wing Observer
measure and indicate on wing form the test area subjected to snow or rain contamination.

Area = _______m²

Amount of Contaminant

Applied = _____ kg

Plate Failure Times

Initial = ___________ (hr:mm:ss)

Plate = ___________ (hr:mm:ss)

COMMENTS: ____

OBSERVER: ______________________

ASSISTED BY: ______________________

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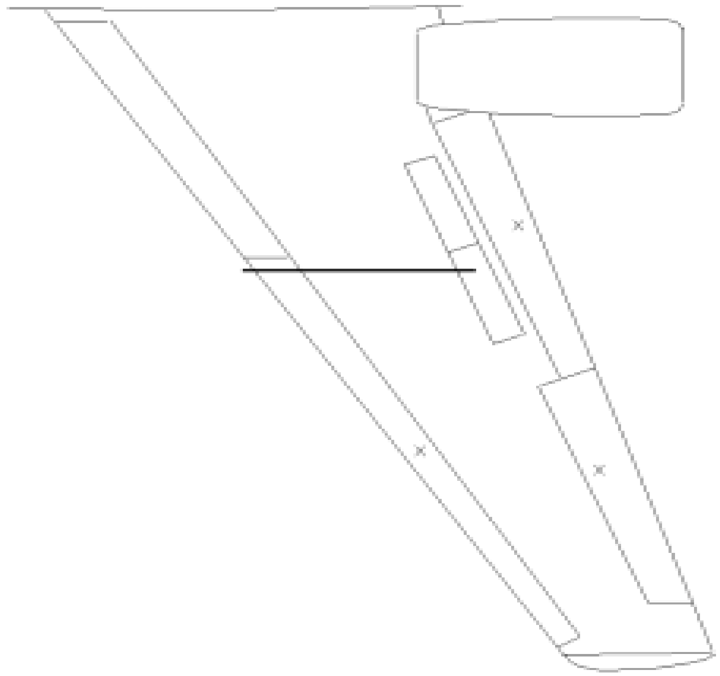
Form 3a

Figure 3a: Fluid Failure Pattern Form – Starboard Wing

Date: ________________ **Time:** ________________ **Run Number** __________

Test Phase: A- before contamination ☐ B- after contamination ☐ C- after takeoff ☐



Constantly monitor Brix at 3 locations "x" and stop precipitation when one location reaches 3°C buffer.

UCAR ULTRA+	
FFP (°C)	Brix
-2	5.5
-4	8.8
-6	11.2
-8	13.3
-10	15.1
-12	16.8
-14	18.3
-16	19.7

Sample ID Protocol
F for Falcon
1,2 for Run #
A, B or C for test phase
1, 2 etc for sample #
Show location of sample # on wing form.

Example:
F2B3

COMMENTS: ____

OBSERVER: ______________________

ASSISTED BY: ______________________

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Form 4

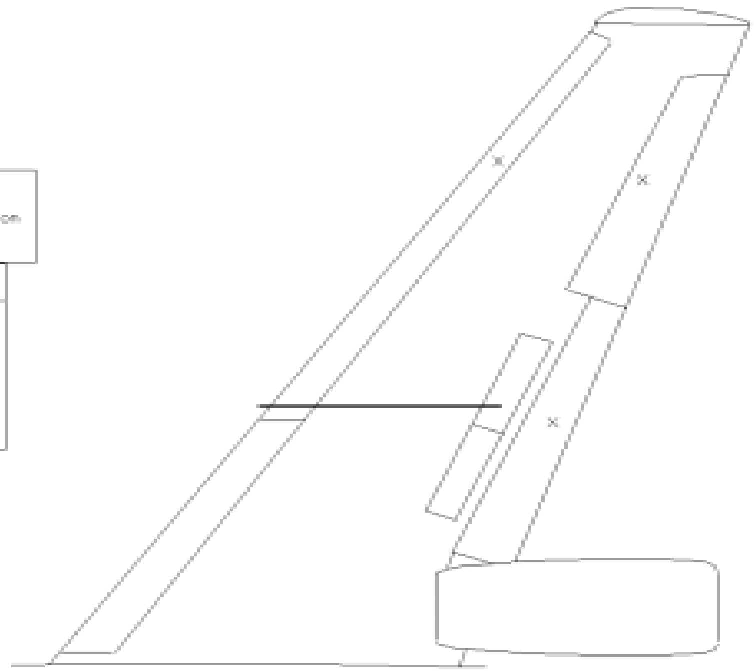
Figure 4: Fluid Sampling And Brix Form – Port Wing

Date: ____________ Time: ____________ Run Number ________

Test Phase: A- before contamination [ ] B- after contamination [ ] C- after takeoff [ ]

Constantly monitor Brix at 3 locations "x" and stop precipitation when one location reaches 3°C buffer.

UCAR ULTRA+	
FFP (°C)	Brix
-2	5.6
-4	8.8
-6	11.2
-8	13.3
-10	15.1
-12	16.8
-14	18.3
-16	19.7



Sample ID Protocol
F for Falcon
1, 2 for Run #
A, B or C for test phase
1, 2 etc for sample #
Show location of sample # on wing form.

Example:
F2B3

COMMENTS: ____________________

OBSERVER: ____________________

ASSISTED BY: ____________________

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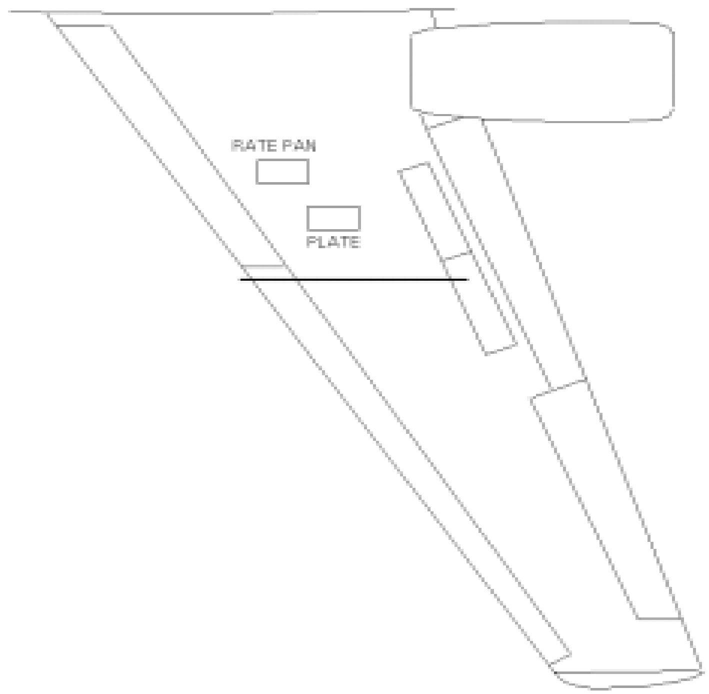
Form 4a

Figure 4a: Fluid Sampling And Brix Form – Starboard Wing

Date: ____________ **Time:** ____________ **Run Number** ________

Test Phase: A- before contamination ☐ B- before taxi ☐ C- after takeoff ☐



Skin Temperature
Record Temperature and Time at several points in test area, include shaded and sun areas.
Show location on wing form

Rate Pan
Precipitation = ________g

During Takeoff Run:

OAT = ______ °C
Wind = ______ kph
RH = ______ %
Sky Condition: ____________

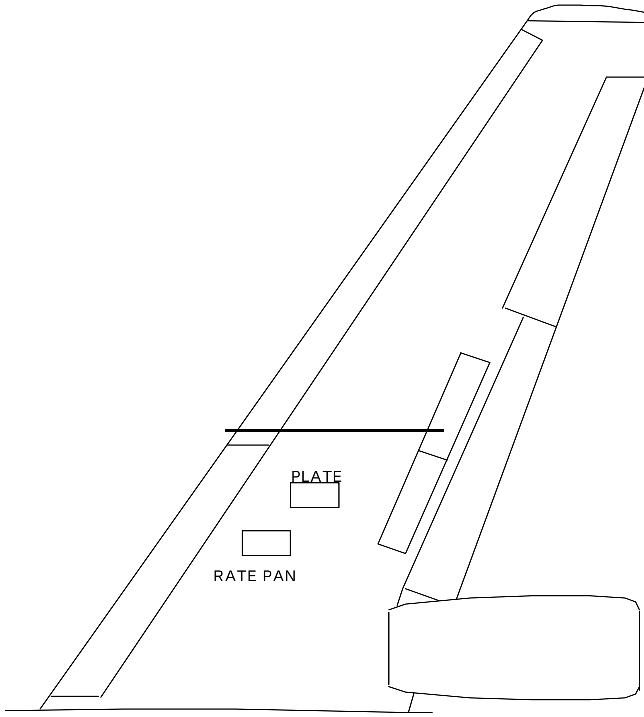
OBSERVER: ____________________

ASSISTED BY: ____________________

Figure 5: Adherence And Wing Temperature Form – Port Wing

Date: ______________ **Time:** ______________ **Run Number** ________

Test Phase: A- before contamination ☐ B- before taxi ☐ C- after takeoff ☐



Skin Temperature
Record Temperature and Time at several points in test area, include shaded and sun areas.
Show location on wing form

Rate Pan

Precipitation = ________g

During Takeoff Run:

OAT = ______ °C

Wind = ______ kph

RH = ______ %

Sky Condition: ____________________

OBSERVER: ______________________________

ASSISTED BY: ______________________________

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Form 5a

Figure 5a: Adherence and Wing Temperature Form – Starboard Wing

	Wing Position	PORT BEFORE RAIN SPRAY	PORT AFTER RAIN SPRAY	PORT BEFORE TAKEOFF	PORT AFTER TAKEOFF	STARBOARD BEFORE RAIN SPRAY	STARBOARD AFTER RAIN SPRAY	STARBOARD BEFORE TAKEOFF	STARBOARD AFTER TAKEOFF
OUTBOARD	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								
INBOARD	1								
	2								
	3								
	4								
	5								
	6								
	7								
	8								
	9								

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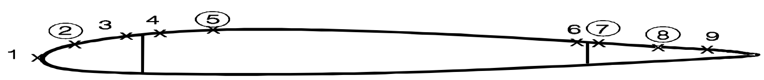
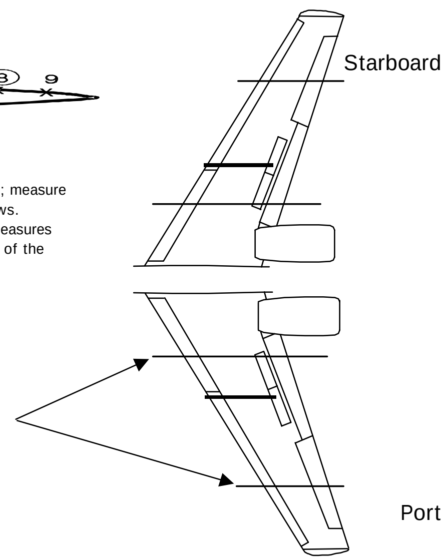


Location
1 - LE Nose
2, 8 – Halfway
3,4,6,7 – 1" From joint
5 – As far as can reach
9 – 6" From TE

Note:
Give priority to circled locations; measure other locations only if time allows.
Lateral locations of thickness measures are 1 to 2 metres on both sides of the fence.



Location of inboard and outbourd test denoted by lines.

Figure 6: Fluid Thickness on Aircraft

Date: ___________

Time Before	Time After	Run	ZR- or Snow	Container Weight (kg)	
				Before	After

Measured by: ____________________

Handwritten by: ____________________

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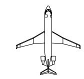
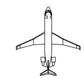
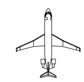
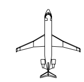
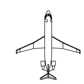
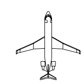
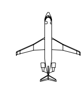
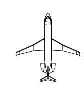
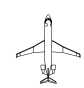
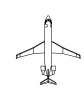
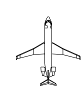
Form 7

Figure 7: Rain/Snow Quantity Form

Date: _______

Time	Run	Before or After (B/A)	Cox or BFG (C/B)	Water or Snow (W/S)	Horizontal Distance from Wing Test Area (m)	Height Above Ground (m)	Orientation Relative to Aircraft
							
							
							
							
							
							
							
							
							
							
							

Measured by: ____________________

Handwritten by: ____________________

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Form 8

Figure 8: Log of Ice Detection Sensor Form

Attachment I
Test Procedures

1. PRE-TEST SETUP

- Co-ordinate with Globe Ground for de/anti-icing fluid, and access to deicing pad (MC).
- Co-ordinate with Ottawa Airport Authority and NavCan (MC).
- Co-ordinate with Goodrich for availability of ice detection sensors. Arrange for vehicle with mast, to mount camera(s) (MC).
- Arrange for security escorts and passes. A number of visiting observers may be present and will require security passes and escort (MC).
- Find video specialists and photographers in Ottawa to record behaviour of fluid on the aircraft during the precipitation phase, taxi and takeoff of the Falcon 20 (AC).
- Prepare freezing rain sprayer (NB).
- Conduct trials on the JetStar wing in Montreal to calibrate the rate of delivery of the freezing rain sprayer. Target rate is $25 g/dm^2/h$ (NB).
- Develop apparatus and procedure to apply natural snow from the environment with a snow spreader. Calibrate rate of delivery. Target rate is $25 g/dm^2/h$ (2002-03).
- Hotels and advances for APS personnel (AC/CD).
- Arrange personnel travel arrangements.
- Transport equipment to Ottawa.

2. CONDUCT FREEZING RAIN TESTS

- Brief team, including Globe Ground.
- Synchronise times on all test instruments and watches.
- Mount test plates and rate pans on wing surfaces at position indicated in Figures 5 and 5a.
- Ensure all cameras and instruments are ready for tests.

For Type IV fluids tests:

- Spray the wings using standard procedures for two-step fluid application.
- Measure fluid thickness at several points following the fluid application.
- Collect Type IV fluid samples for viscosity tests prior to and following precipitation.
- Apply the freezing rain over the two wings. Record the start of the precipitation application process and measure the amount of precipitation applied.
- When the desired level of precipitation (up to 3°C buffer measured at three

locations in Figure 4) has been applied to the wings, the wing observer will call for the end of the precipitation application process. Identify and record the condition of the wing on the data sheet, and by ice detection sensor. Measure thickness and dilution of fluid (Brix) at several locations along the chord. Two chord locations should be used for thickness; one on each side (1 to 2 meters) of the aerodynamic “fence”. Measure wing skin temperature on leading edge and main wing; note temperature and locations measured on wing form.

- Photograph and videotape the appearance of the fluid on the wing.

Takeoff Run:

- Remove test plate and rate pan from wing surface.
- With test crew onboard, perform the takeoff run and climb. Videotape the behaviour of the fluid on the wing during the takeoff run and climb, capturing any movement of fluid.
- With a third video camera, record readings from the air speed indicator.
- During the takeoff run, record OAT, wind, RH and sky condition.
- Examine the wing as soon as possible after the aircraft has returned to the deicing bay. Document fluid condition. Measure thickness and Brix of any fluid remaining, and temperature of wing skin at locations measured before the takeoff run. Photograph any remnants of fluid still on the wing and, if possible, scan the area with the ice detection sensor. Lift Type IV fluid samples for later viscosity measurement.

Attachment II
Adherence of Contaminated Fluid
Test Equipment Checklist

TASK **Logistics for Every Test**	***STATUS***
Monitor Forecast	
Coordinate test initiation with NRC, TDC	
Alert APS test Personnel	
Rent 2 boom trucks or rolling scaffolding for fluid dispensing	
Rent Cube Truck for rain sprayer	
Rent portable generators (10 KW, 220V 30 AMPS twist lock 4 prungs)	
Rent Personnel Van for APS team to/from Montreal to YOW	
Rent Mast truck for Goodrich sensor mounting	
Rent Cube van for equipment delivery	
Advise Globe Ground; arrange for Deicing Truck with Types I and IV	
Advise YOW Airport Operations	
Advise Goodrich	
Advise sensor truck operator	
Advise Security agency, confirm number of passes and escorts	
TEST EQUIPMENT	
Producing Precipitation	
Freezing Rain Sprayer with needles for freezing rain	
Water for rain sprayer	
APS Generator	
Sensor Support	
Goodrich Sensor & support, plus TV and VCR with videotape	
Generator (s) to Support Sensor	
Table and 3 chairs for Goodrich setup in cube van	
Dish heater for cube van	
Lights for cube van	
Aircraft Support	
Generator to support aircraft heating	
220 volt extension cable for Falcon heater with correct plug	
Pylons	
Aluminum test plate and rate pan on legs, to mount on wing	
Camera Equipment	
Digital video camera for a/c over-wing exit	
Digital still camera	
General Support Equipment	
Fuel for generators	
Large tape measure	
Step Ladders – Short + Tall	
Electrical extension cables (heavy gauge extension 25 ft – compressor)	
Radios X 2 (walkie-talkies)	

Inverter	
Fire Extinguisher	
First Aid Kit	
Test Equipment	
Test Procedures	
Data Forms	
Clipboards	
Pencils	
Pencil Sharpener	
Wing markers for sample locations and solvent	
Tape measures; long survey tape plus standard carpenters tapes.	
Thickness Gauges	
Thermometer Probe and spare batteries	
Brixometer X 3	
Devices for lifting fluid samples for Brix tests	
Devices to lift fluid samples for viscosity	
Sample bottles for viscosity measurement	
Vaisala Meter for OAT and RH	
Wind gauge	
Personnel Equipment	
Hearing Protectors (yellow foam)	
Coffee Pot/ Coffee/ Milk and Sugar	
Drinking water and for making coffee	
Binoculars	
Security passes	

ATTACHMENT III
APS Staff Task Description
Aircraft Trials at Ottawa Airport

Co–ordinator (MC)

- Initiate test with NRC, TDC, Globe Ground.
- Advise all other agencies, including security and sensor manufacturers.
- Advise APS test team.
- Ensure that all required equipment is available and functional.
- Provide direction as required during the tests.
- Maintain General Form for every test (Figure 2).
- Maintain General Form for every session (Figure 2a).
- Ensure all data are collected and recorded, and that all test records submitted.
- Record start and end of precipitation on each wing.
- Announce end-of-precipitation according to test plan for each wing;
- Record fluid failure time on test plates mounted on wings (failures should not occur).
- Record amount of precipitation applied (get from spray team).
- Examine and record fluid remaining after the aircraft returns.

Photographer – Outside Aircraft (YOW)

- Ensure time stamp operating and accurately set.
- Photograph all test set-up, outside and onboard the aircraft.
- Videotape and photograph fluid on wings "before and after" each run, ensuring constant viewing angles are used, to facilitate comparisons.

Video – Onboard Aircraft – Port Wing and Starboard Wing (YOW)

- Ensure time stamp operating and accurately set.
- Videotape fluid on wings "before and after" each run and during climb, ensuring constant viewing angles are used, to facilitate comparisons.

Fluid Thickness, Brix and Fluid Samples – Port Wing (RC)

- Collect samples of Type IV fluid for subsequent viscosity tests; and
- Record specifics for each sample.
- Take 2 fluid samples of each fluid used in tests
  - Type IV from deicing vehicle
  - Type I from deicing vehicle

Sampling Protocol during Test

a) Before Precipitation

Take 2 samples on each wing; note locations on Fluid Sampling and Brix Form (Figure 4).

b) After Contamination

Take one fluid sample (attempting to avoid collecting ice formations in the sample) at a location as directed by MC or JD; note location on form.

c) After Takeoff

Take one sample of any fluid remaining (attempting to avoid collecting ice formations in the sample) on each wing. Note location on sampling form.

- Measure thickness and brix of fluid on wing at selected chord-wise locations. Record Brix on Fluid Sampling and Brix Form (Figure 4) and fluid thickness on Fluid Thickness on Aircraft form (Figure 6).

Fluid Thickness, Brix and Fluid Samples – Starboard Wing (SC)

- Collect samples of Type IV fluid for subsequent viscosity tests; and
- Record specifics for each sample.
- Take 2 fluid samples of each fluid used in tests
  - Type IV from deicing vehicle
  - Type I from deicing vehicle

Sampling Protocol during Test

d) Before Precipitation

Take 2 samples on each wing; note locations on Fluid Sampling and Brix Form (Figure 4).

e) After Contamination

Take one fluid sample (attempting to avoid collecting ice formations in the sample) at a location as directed by MC or JD; note location on form.

f) After Takeoff

Take one sample of any fluid remaining (attempting to avoid collecting ice formations in the sample) on each wing. Note location on sampling form.

- Measure thickness and Brix of fluid on wing at selected chord-wise locations. Record Brix on Fluid Sampling and Brix Form (Figure 4) and fluid thickness on Fluid Thickness on Aircraft form (Figure 6).

Rates, Wing Temperature (PP)

- Set-up scale in cube van for weighing precipitation.
- Set-up Vaisala meter.
- Install test plates and rate pans on wings prior to each test.
- Record data Wing Temperature Form (Figure 5).

- Weigh and record the amount of precipitation collected during the test in the rate pan mounted on the wings.
- Measure temperature of wing surface before and after takeoff run. Record temperature and indicate points measured on the wing plan in Figure 5. Note condition of sky.
- Remove test plates and rate pans from wings following each test, prior to starting the engines.
- Record OAT and RH from the Vaisala meter and Wind speed with the handheld anemometer during each takeoff run.

Freezing Rain Sprayer Manager (NB) and Assistants 1 (RP) and 2 (HR) and Drivers (RT) and (AC)

- Responsible to ensure proper functioning of rain sprayer equipment, giving attention to preventing lines from freezing between tests.
- Responsible for spraying freezing rain over the wings until advised by the *wing observer* that the desired amount of precipitation has been dispensed.
- Responsible for overall equipment operation including re-fuelling portable generators.

Ice Detection Sensor Operator (DD)

- Responsible to provide support to the operation of the two ice detection systems.
- Responsible to ensure that the wings are scanned by the ice detection sensor at the time that the wing observer calls end of precipitation, and following the takeoff run.
- Responsible to document the sensor camera positions relative to the wing test area, for each scan using Log of Ice Detection Sensor Form (Figure 8).
- Responsible to retrieve data from the sensor system databases.

APPENDIX E

ARTIFICIAL RAIN SPRAYER OPERATION MANUAL
MODEL 110-40
2002 EDITION

- **GENERAL**
- **DIMENSIONS AND WEIGHTS**
- **CAPACITIES**
- **OPERATION PROCEDURES**

GENERAL DESCRIPTION

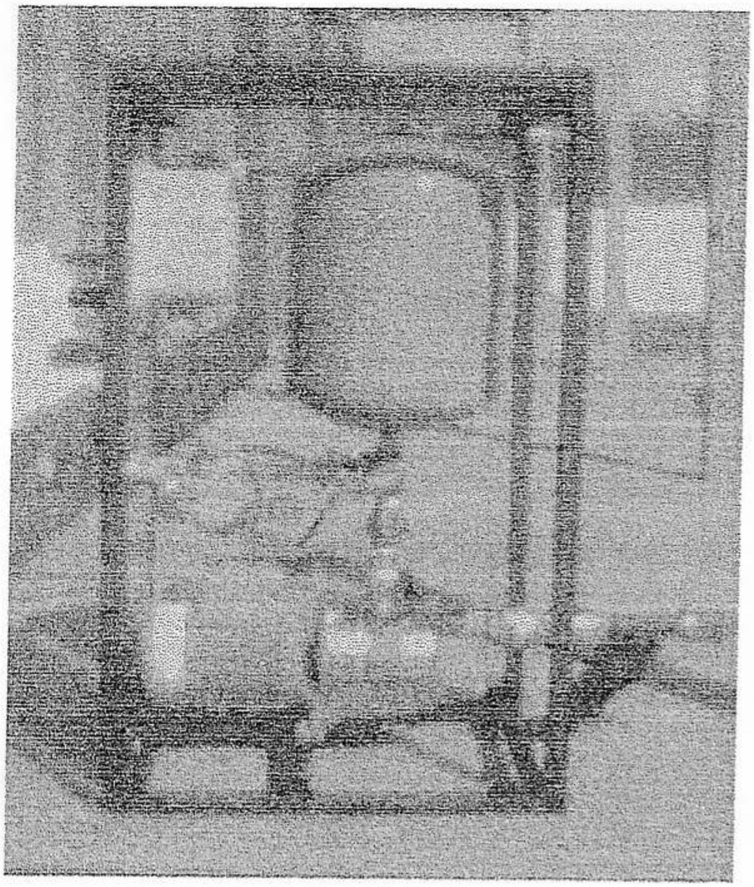


Fig.1 110-40 Artificial Rain Sprayer

The 110-40 Artificial Rain Sprayer is a portable water sprayer. It is designed to reproduce natural freezing rain precipitation under sub-zero air temperature conditions.

The 110-40 Artificial Rain Sprayer is a research tool, mainly to be used in the aircraft de-icing and anti-icing field.

GENERAL 1-2

SYSTEM DIAGRAM

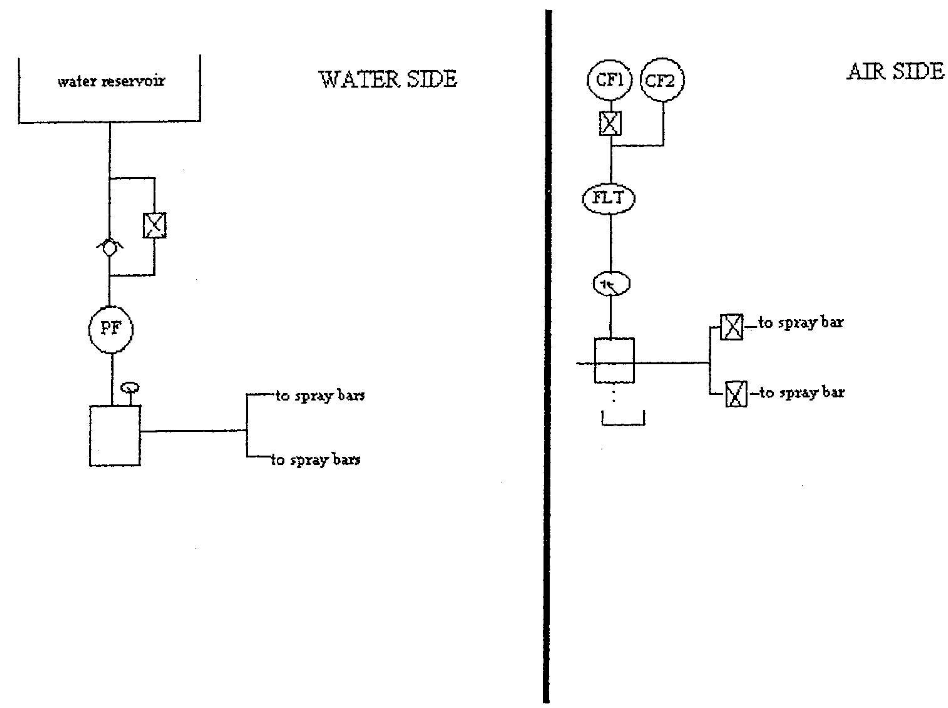


Fig.2 System Diagram

DIMENSION AND WEIGHTS 2-1

AIR COMPRESSOR --------------------40" x 36" x 20", 125lbs.

AIR AND WATER CONDUITS ------- 50', 30lbs (per pair).

SPRAY BARS ---------------------------- 25'' X 9'' X 3", 5lbs.

SPRAYER CONTROL UNIT ---------- 32" X 18" X 20", 85lbs.

WATER RESERVOIR ------------------ 4' x 4' x 40", 175lbs.

CAPACITIES 3-1

AIR COMPRESSOR

AIR TANK------------------- 30 US gals.
AIR PUMP------------------- 7.2 SCFM @ 40PSI
MOTOR ---------------------- 15 AMPS @ 125PSI
AIR PUMP OIL SUMP----- 473.2ml

WATER RESERVOIR

RESERVOIR ----------------- 275 US gals.

WATER PUMP

PUMP ---------------------------- 675 US gals. / Hr @ 10'
MOTOR-------------------------- 8 AMPS RUN, 15 AMPS START.
WATER ACCUMULATOR--- 4.5 US GALS.

WATER RESERVOIR FILLING 4-1

The water reservoir consists of a 275 US gal square plastic tank. It is protected around by a metal cage, attached to a plastic base support.

The reservoir has a top access cover for filling and a 2 inches drain valve, full port ball type, located in the centre off one of the side walls of the reservoir, at the lowest point of the wall.

Filling of the reservoir is done by adding water to the reservoir thru the top access. Cap is removed by turning it counterclockwise. Putting cap back is the reverse action.

Note: Only clean water should be introduced in the reservoir, an special care should be taken not to drop any kind of dirt or debris in reservoir.

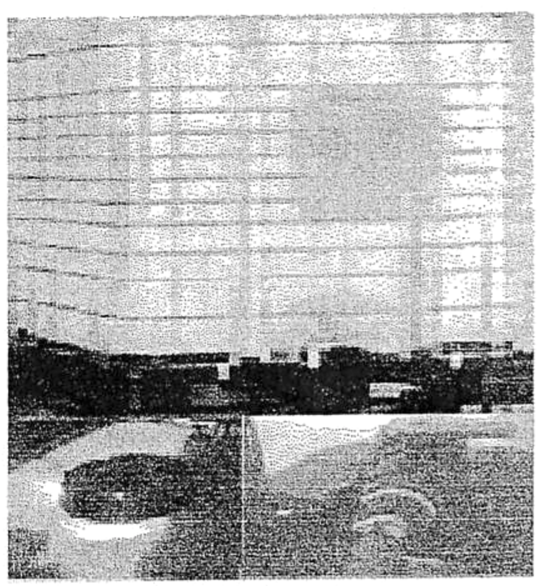


Fig.3 Water Reservoir, Filler cap and Drain valve

SPRAYER CONTROL UNIT CONNECTION 4-2

The sprayer control unit is the heart of the artificial freezing rain system. It divides in two main branches: the air side and the water side.

The air side consists of an inlet connection for the air compressor, air filter an a twin air pressure control, linked to two air outlets.

The water side consists of a water inlet, a water filter, a water pump and pressure reservoir, a water temperature link and a twin water flow shut-off control, linked to two water outlets.

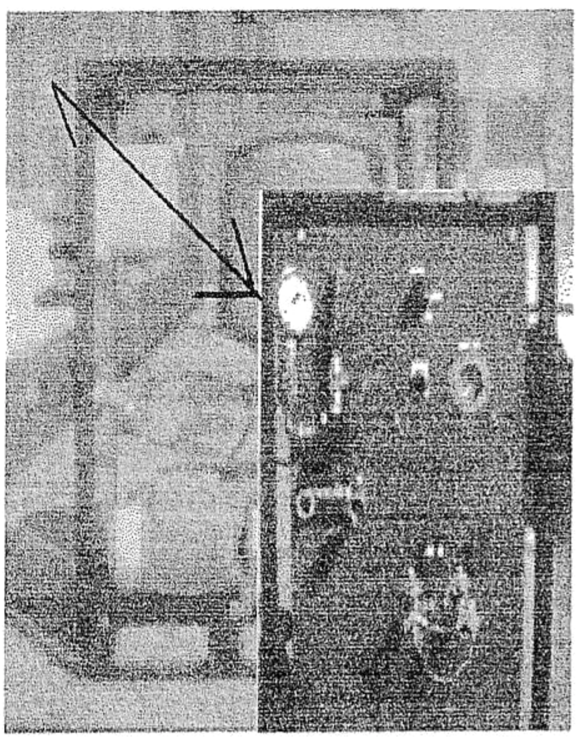


Fig.4 Sprayer control unit (s.c.u) and its Control panel

SPRAYER CONTROL UNIT CONNECTION 4-2-1

Connection of the sprayer control unit is done by first connecting the water, then the air, and finally the electrical power to the unit.

Water connection: Connect the water reservoir to the s.c.u.(sprayer control unit) by connecting the water transfer pipe first to the 2" quick connector on the water reservoir and then to the 1" quick connector on the s.c.u. water pump inlet. *Make sure water reservoir drain valve is closed.*

Fig.5 Water transfer pipe linking the Water reservoir and the s.c.u. Water pump inlet

SPRAYER CONTROL UNIT CONNECTION 4-2-2

Air connection: Connect each air compressor to one of the two s.c.u. air inlet, located at the top back section of the s.c.u., with a compressor air hose. Air shut-off valves on compressors should be opened.

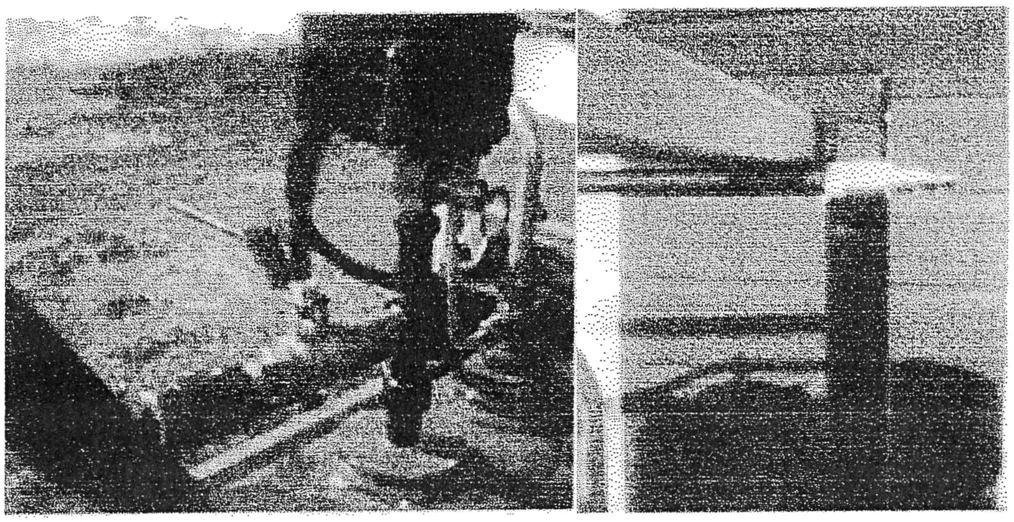


Fig.6 Air compressor shut-off valve and s.c.u. air inlet

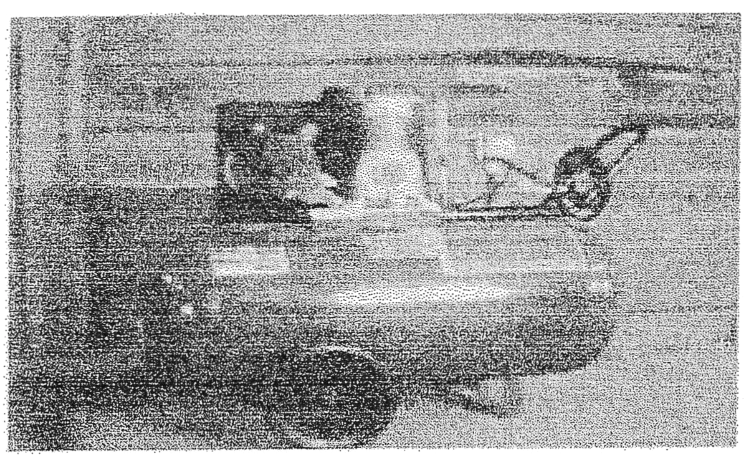


Fig.7 Air compressor

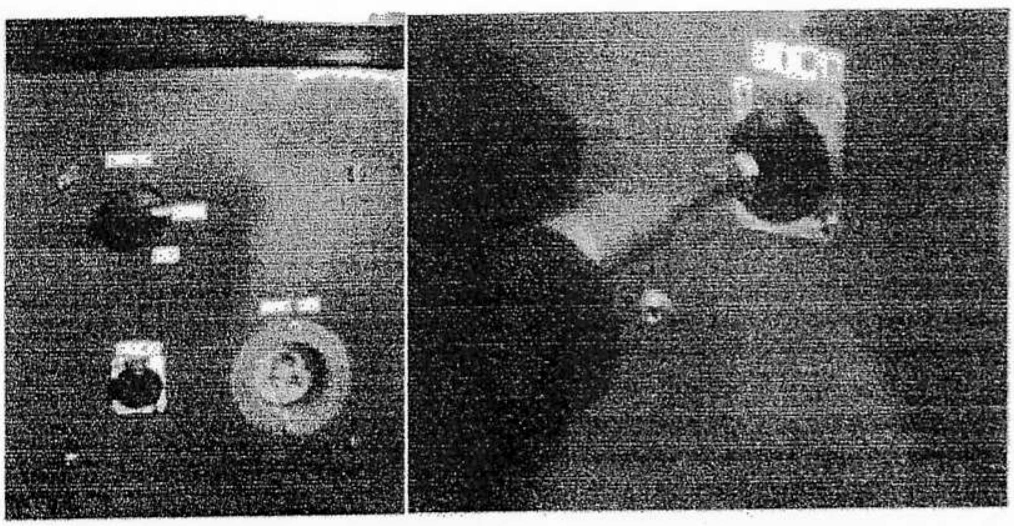
SPRAYER CONTROL UNIT CONNECTION 4-2-3

Electrical connections: power is required for both the s.c.u.(to run the water pump) and the compressors.

First, use a 16 gauge extension cord(or heavier) with a 110V 15A supply to feed the s.c.u. Connection port for the s.c.u. is the same type as a household outlet and is located on the control panel of the s.c.u. On/Off of s.c.u. water pump is controlled thru the water pump power switch, on the s.c.u. control panel.

Then, use a 10 gauge extension cord(or heavier) with a 110v 30A supply to feed each compressor. Supplies must be separate circuits for each compressor. Connection of each compressor is done thru their respective inlet cords, wich are the same type of connector as a normal household appliance.

The thermistor outlet provides a way to monitor water temperature coming out of the s.c.u. water pump. A ¼ " stereo jack extension linking the s.c.u. and a thermistor logger should be used.



Fig…. (left) s.c.u. control panel - electrical
Fig…. (right) water temperature thermistor jack

SPRAY BARS CONNECTION 4-3

The artificial freezing rain system is capable of operating two 3 nozzles heads spray bars simultaneously. They are individually linked to the s.c.u. by their respective Air/Water hoses bundle.

To connect the spray bars to the s.c.u., first make sure all air and water shut-off valves on the s.c.u. panel are closed. Then, connect each Air/Water hoses bundle to their respective air and water quick connectors outlets on the s.c.u. panel. Also, connect the bundles opposite side to their respective air and water quick connectors on the spray bars.

Finally, install 3 water needles on each spray bar. The needle socket on each nozzle head is a luer-lock type socket and only a ¼ to ½ turn clockwise is required to secure the needle to the socket after its insertion into the socket. Removal is the opposite.

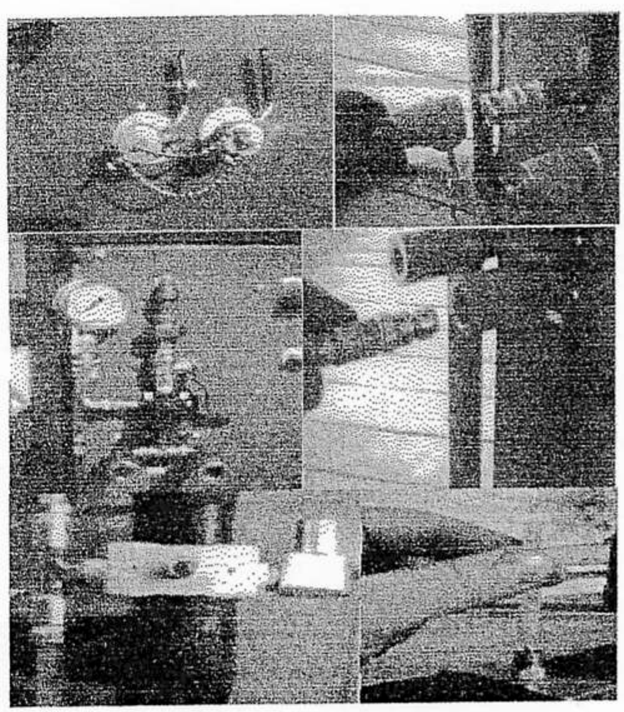


Fig.10 (top row) Water shut-off valves and water lines connectors
Fig.11 (middle row) Air supply control and Air lines connectors
Fig.12 (bottom row) Spray bar nozzle head and needle installation

PRIMING THE S.C.U 4-3-1

When all main components are connected to the s.c.u., the operator should be ready to start the s.c.u. mainly for priming the water pump before any spray bar adjustment.

Note that the air portion of the s.c.u. does not need any special attention, but to let the air compressors normally build up their air tank pressure before any test is done with the artificial freezing rain sprayer.

STARTING THE S.C.U.

1- Open water reservoir 2" drain valve. Let water flow thru system for 2 min. Make sure the top filler cap is not closed tight. Some air must pass to maintain a positive air pressure in reservoir.

2- Make sure s.c.u. water shut-off valves are closed.

3- Turn s.c.u. pump on/off control to the "on" position. Wait until water flows thru spray bar needles. When flow at needles as stabilized, close s.c.u. water shut-off valves. Water pressure is now available at spray bar.

4- Open s.c.u. air inlet divider valve (located near s.c.u. air inlet) and leave the outlet valve (located on s.c.u. control panel) closed. Air pressure is now available at spray bar.

5- When ready for adjustments before testing, open both the s.c.u. air and water shut-off valves (located on s.c.u. control panel). Air and water should be flowing thru spray bar nozzles. Make necessary adjustments by working with the air or water pressure regulators. (See section 4-4)

SYSTEM OPERATION 4-4

To simplify the operation of the system, only two things have to be kept in mind:

1- **water flow** is controlled by water pressure regulators located on each spray bar. The water flow will determine how much water is delivered thru each trio of nozzles of a spray bar. Adjustment is possible for the operator by simply setting the pressure desired on the spray bar water pressure gauge by an action of the spray bar regulator control knob.

2- **droplet size and spray pattern** is controlled by a main air pressure control located on the s.c.u. control panel. Adjustments to the desired air pressure is done by an action on the air pressure regulator knob. Selected pressure can be read on the nozzles pressure gauge, also located on the s.c.u. control panel. Alike the water control, air pressure for spray bars cannot be individually set to respective air pressure. When a selection for a certain nozzle air pressure is made, it will be the setting for both spray bars.

Note: adjusting air pressure will allow variation of droplet size to only a certain extent. A wider range of variation can be reached by selecting a different water needle gauge.

SYSTEM OPERATION 4-4-1

Water flow

The water flow is adjusted by the spray operator. It can be done on the ground or from the spray position in the truck basket, by rotating the water pressure regulator control knob. Rotation clockwise will allow more water to flow thru nozzles as rotation counterclockwise will restraint the flow thru nozzles. Monitoring of flow by operator is done by looking at the water pressure gauge on the spray bars.

The starting pressure should be between 3 and 10 psi.

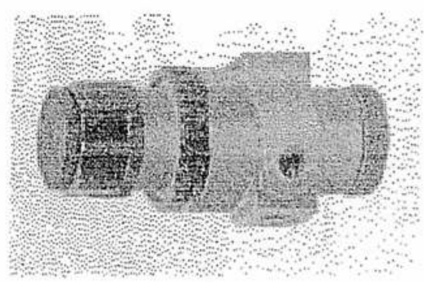


Fig.13 Typical pressure regulator adjustable thru rotation of knob(black). Each spray bar has its own water pressure regulator, coupled with a pressure gauge as a indirect indication of the water flow.

Droplet size and spray pattern

Droplet size and spray pattern are controlled by varying the air pressure at the nozzle head. Adjustments of the air pressure is done at the s.c.u. control panel, by turning the air pressure regulator knob clockwise to increase air pressure or counterclockwise to reduce it. Alike the water delivery system of the s.c.u. to the spray bars, the air delivery system cannot be individually adjusted for a particular spray bar and every change in pressure setting at the s.c.u. will affect both spray bars nozzle heads air pressure. The air shut-off valve is either kept open for spraying or closed for maintenance purposes.

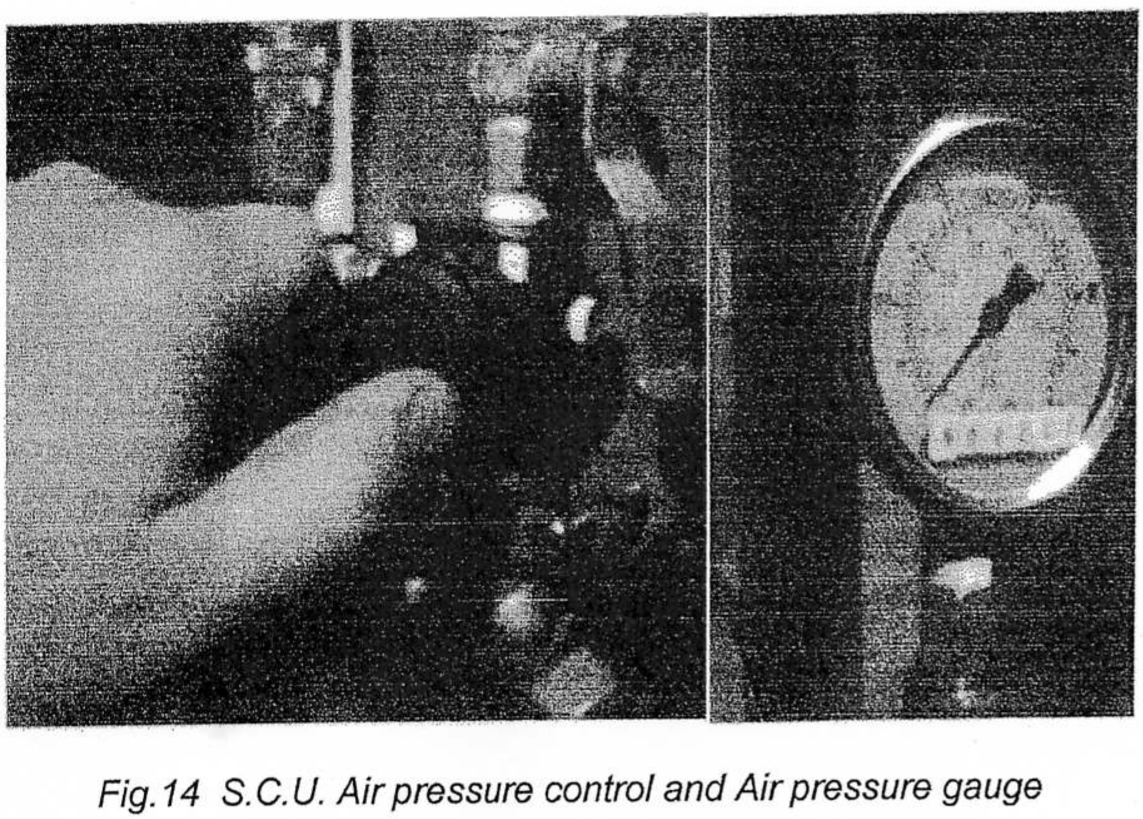


Fig.14 S.C.U. Air pressure control and Air pressure gauge

AFTER OPERATION DRAINAGE AND STORAGE 4-5

Making sure your system is completely drained and adequately lubricated will prevent any damage resulting from freezing and corrosion. Simple actions need to be done every time the artificial freezing rain unit is stored.

DRAINAGE

Operators should make sure of completely draining the following from any residual water left from testing with this equipment:

1- Water reservoir: drain thru drain valve. Tip reservoir slightly to get all water out. Leave drain valve open. Replace dirt cap. See fig.
2- S.c.u. connection pipe. Drain and replace dirt caps. See fig.
3- s.c.u. water pump and water pressure tank. Drain thru s.c.u. control panel water outlets, thru water pump drain plug and thru water filter drain valve. Leave all valves open. Replace dirt caps.
4- spray bars and connection hose bundles: using air-water crossfeed connector, blow air from s.c.u. air outlets thru water hoses in each bundle, leaving the spray bars connected to their respective hose bundle. When no sign of water exist at each spray bar water needle, shut-off air pressure, remove needle, disconnect spray bars, hose bundles. Replace all dirt caps.
5- Drain the s.c.u. air filter.

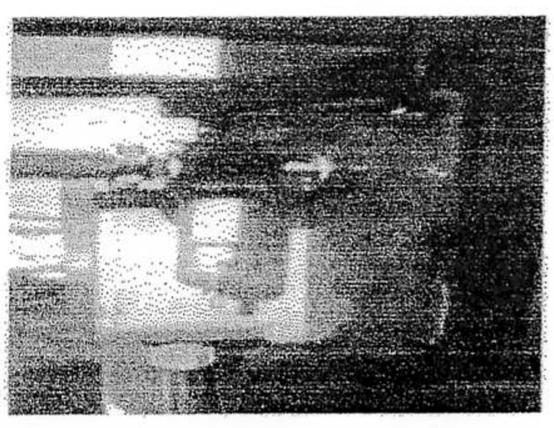


Fig.15 S.C.U. Air filter

AFTER OPERATION DRAINAGE AND STORAGE 4-5-1

LUBRICATION

All air quick connectors need lubrication before long term storage, i.e. after a winter test season. Use LPS2 lubricant in spray to lightly coated each air connector.

The air compressors need their oil to be changed with appropriate air compressor oil. Refer to manufacturer recommendations for the oil change procedure.

WATER PRESSURE RESERVOIR AIR PRE-CHARGE

According to manufacturer specifications, the water pressure reservoir air pre-charge should be verified at regular intervals and set to 18 psi of air pressure. Water pressure tank air inlet is located on top of the tank and is a standard car wheel valve type.

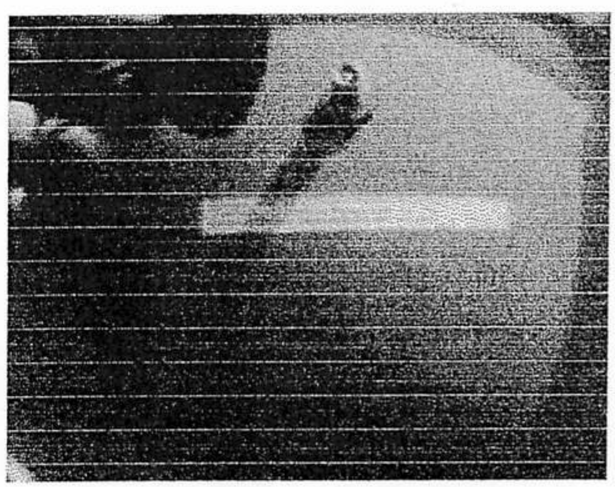


Fig.16 Water pressure tank air inlet

AFTER OPERATION DRAINAGE AND STORAGE 4-5-2

WATER FILTER CLEAN-UP

Water filter should be removed, cleaned and replaced in its cartrige each test . To remove filter from its cartrige, turn bottom part of cartrige counterclockwise. When the cartrige separates, pull on filter and it should break away easily. Rince in water wellto eliminate any contaminant. Replace filter in its cartrige.

Fig.17 Water filter

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APPENDIX F

VOLUME OF FLUID THAT FELL TO THE GROUND AT VARIOUS STAGES DURING THE FALCON 20 TESTS

VOLUME OF FLUID THAT FELL TO THE GROUND AT VARIOUS STAGES DURING THE FALCON 20 TESTS

1. MARCH 6, 2002 – RUN 1; TYPE IV OVER TYPE I; NO DILUTION

1.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

The volume of fluid that has fallen to the ground within the application area during the Falcon 20 tests can be approximated for each wing at any time during the thickness decay period using the following formula:

V = Q – (t x a)
Where

V = Volume of fluid that falls to the ground in the application area (litres)
Q = Fluid application quantity (litres)
t = Average fluid thickness on wing (mm)
a = surface area of the wing = 20.5 m^2

For the port wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1 mm. As such, the approximate volume of fluid remaining on this wing would be 20.5 L. Since 41 L of Type IV fluid were applied to the wing, it can be deduced that about 20.5 L fell to the ground in the deicing bay as a result of overspray and dripping.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 0.5 mm, which is incredibly low. The approximate volume of fluid remaining on this wing was 10.3 L. Since 51 L of Type IV fluid was applied to the wing, it can be assumed that 40.7 L fell to the ground at the deicing bay.

It could also be assumed that all of the Type I fluid applied, 41 L on the port wing and 51 L on the starboard wing, were displaced by the Type IV fluid application and fell to the ground within the application area.

1.2 Volume of Type IV Fluid that Fell to the Ground on the Taxiways

The volume of fluid that had fallen to the ground on the taxiways during the

Falcon 20 tests could be approximated for each wing using the following formula:

V = Q – (t x a)
Where

V = Volume of fluid that falls to the ground on the taxiways (litres)
Q = Quantity of fluid on wing prior to leaving the deicing bay (litres)
t = Average fluid thickness on wing (mm)
a = surface area of the wing = 20.5 m^2

For the port wing, the average fluid thickness on the wing before takeoff was 0.75 mm. As such, the approximate volume of fluid remaining on the port wing was 15.4 L. Since 20.5 L of Type IV fluid were present on the wing when it departed from the deicing pad, it can be deduced that 5.1 L, fell to the ground on the taxiways.

For the starboard wing, the average fluid thickness on the wing before takeoff was 0.5 mm. In this case, the approximate volume of fluid remaining on the wing following the taxi to the runway threshold, 10.3 L, equaled the amount present on the wing when the aircraft left the deicing bay. This appears to be an anomaly.

2. MARCH 6, 2002 – RUN 2; TYPE IV OVER TYPE I; NO DILUTION

2.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay in Run #2 was 1.7 mm. The approximate volume of fluid remaining on this wing was 34 L. Since 68 L of Type IV fluid were applied to the wing, it can be assumed that roughly 34 L fell to the ground at the deicing bay as a result of overspray and dripping.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.5 mm. As such, the approximate volume of fluid remaining on this wing was 30.8 L. Because 52 L of Type IV fluid was applied to the wing, it can be deduced that 21.2 L fell to the ground at the deicing bay.

It could also be assumed that all of the Type I fluid applied – 42 L on the port wing and 43 L on the starboard wing – was displaced by the Type IV fluid application and fell to the ground within the application area.

2.2 Volume of Fluid that Fell to the Ground on the Taxiways

For the port wing, the average fluid thickness on the wing before takeoff was 1.3 mm, and 26.7 L of fluid remained on the wing. Since 34 L of Type IV fluid were present on the wing when the aircraft departed the deicing pad, it can be deduced that 7.4 L fell to the ground on the taxiways.

For the starboard wing, the average fluid thickness on the wing before takeoff was 1.2 mm. In this case, the approximate volume of fluid remaining on the wing was 24.6 L. Since 30.8 L of Type IV fluid was present on the wing when the aircraft left the deicing bay, it can be deduced that 6.2 L of fluid fell to the ground on the taxiways.

3. MARCH 6, 2002 – RUN 3; TYPE IV OVER TYPE I; NO DILUTION

3.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.6 mm, which corresponds to approximately 32.8 L of fluid remaining on this wing. Since 53 L of Type IV fluid were applied to the wing, it can be assumed that 20.2 L fell to the ground at the deicing bay as a result of overspray and dripping.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.5 mm. The approximate volume of fluid remaining on this wing was 30.8 L. Since 46 L of Type IV fluid was applied to the wing, it can be deduced that 15.3 L fell to the ground at the deicing bay.

It could also be assumed that most, if not all, of the Type I fluid applied – 31 L on the port wing and 28 L on the starboard wing – were displaced by the Type IV application and fell to the ground within the application area.

3.2 Volume of Fluid that Fell to the Ground on the Taxiways

For the port wing, the average fluid thickness on the wing before takeoff was 1.2 mm. Approximately 24 L of fluid remained on this wing. Since 32.8 L of Type IV fluid were present on the wing when it departed the deicing pad, it can be deduced that 8.8 L fell to the ground on the taxiways.

For the starboard wing, the average fluid thickness on the wing before takeoff was 1.2 mm. In this case, the approximate volume of fluid remaining on the wing was 24 L. Since 30.8 L of Type IV fluid was present on the wing when the aircraft left the deicing bay, it can be deduced that 6 L of fluid fell to the ground on the taxiways.

4. MARCH 6, 2002 – RUN 4; TYPE IV; NO DILUTION

4.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the aircraft departure from the deicing bay in Run #4 was 1.6 mm. The approximate volume of fluid remaining on this wing was 32.8 L. Since 55 L of Type IV fluid were applied to the wing, it can be deduced that 22.2 L fell to the ground at the deicing bay as a result of overspray and dripping.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.9 mm. The approximate volume of fluid remaining on this wing was 39 L. Since 54 L of Type IV fluid was applied to the wing, it can be deduced that 15 L fell to the ground at the deicing bay.

No Type I fluid was applied in this run prior to the application of Type IV fluid.

4.2 Volume of Fluid that Fell to the Ground on the Taxiways

For the port wing, the average fluid thickness on the wing before takeoff was 1.3 mm. The approximate volume of fluid remaining on this wing was 26.7 L. Since 32.8 L of Type IV fluid were present on the wing when it departed the deicing pad, it can be deduced that 6.2 L fell to the ground on the taxiways.

For the starboard wing, the average fluid thickness on the wing before takeoff was 1.4 mm. The approximate volume of fluid remaining on the wing was 28.7 L. Since 39 L of Type IV fluid was present on the wing when the aircraft left the deicing bay, it can be deduced that 10.3 L of fluid fell to the ground on the taxiways.

5. MARCH 6, 2002 – RUN 5; TYPE IV; NO DILUTION

5.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay in Run #5 was 1.8 mm. The approximate volume of fluid remaining on this wing was 36.9 L. Since 60 L of Type IV fluid were applied to the wing, it can be deduced that 23.1 L fell to the ground at the deicing bay as a result of overspray and drippage.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.9 mm. The approximate volume of fluid remaining on this wing was 39 L. Since 62 L of Type IV fluid was applied to the wing, it can be deduced that 23 L fell to the ground at the deicing bay.

5.2 Volume of Fluid that Fell to the Ground on the Taxiways

For the port wing, the average fluid thickness on the wing before takeoff was 1.5 mm. The approximate volume of fluid remaining on this wing was 30.8 L. Since 36.9 L of Type IV fluid were present on the wing when it departed the deicing pad, it can be deduced that 6.2 L fell to the ground on the taxiways.

For the starboard wing, the average fluid thickness on the wing before takeoff was again was 1.5 mm. The approximate volume of fluid remaining on this wing was 30.8 L. Since 39 L of Type IV fluid was present on the wing when the aircraft left the deicing bay, it can be deduced that 8.2 L of fluid fell to the ground on the taxiways.

6. MARCH 11, 2002 – RUN 1; TYPE IV; NO DILUTION

6.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 2 mm. The approximate volume of fluid remaining on this wing was 41 L. Since 65 L of Type IV fluid were applied to the wing, it can be deduced that 24 L fell to the ground at the deicing bay as a result of overspray and drippage.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.5 mm. The approximate volume of fluid remaining on this wing was 30.8 L. Since 47 L of Type IV fluid was applied to the wing, it can be deduced that 16.2 L fell to the ground at the deicing bay.

6.2 Volume of Fluid that Fell to the Ground on the Taxiways

For the port wing, the average fluid thickness on the wing before takeoff was 1.6 mm. The approximate volume of fluid remaining on this wing was 32.8 L. Since 41 L of Type IV fluid were present on the wing when it departed the deicing pad, it can be deduced that 8.2 L fell to the ground on the taxiways.

For the starboard wing, the average fluid thickness on the wing before takeoff was again was 1.3 mm. The approximate volume of fluid remaining on this wing was 26.7 L. Since 30.8 L of Type IV fluid was present on the wing when the aircraft left the deicing bay, it can be deduced that 4.2 L of fluid fell to the ground on the taxiways.

7. MARCH 11, 2002 – RUN 2; TYPE IV; LIGHT FREEZING RAIN APPLIED

7.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the application of light freezing rain was 1.9 mm. The approximate volume of fluid remaining on this wing was 39 L. Since 48 L of Type IV fluid were applied to the wing, it can be deduced that 9 L fell to the ground at the deicing bay as a result of overspray and drippage.

For the starboard wing, the average fluid thickness on the wing prior to the application of light freezing rain was 1.3 mm. The approximate volume of fluid remaining on this wing was 26.7 L. Since 40 L of Type IV fluid was applied to the wing, it can be deduced that 13.3 L fell to the ground at the deicing bay.

7.2 Volume of Type IV Fluid that Fell to the Ground Within the Application Area Due to Dilution of the Fluid

For the port wing, the average fluid thickness on the wing after the application of freezing rain was 1.8 mm. The approximate volume of fluid remaining on this wing was 36.9 L. Since 39 L of Type IV fluid remained on the wing prior to the application of the freezing rain, it can be deduced that only 2.1 L fell during the dilution period. The only locations on the port wing with significant reductions in thickness due to dilution were on the leading edge. The rate of precipitation on this wing was 7.1 $g/dm^2/h$.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.4 mm. The approximate volume of fluid remaining on this wing was 28.7 L. This is more fluid than was present on the wing prior to the application of freezing rain to the wing. There were slight increases in fluid thickness after the application of the freezing rain at several locations on the starboard wing saw. The rate of precipitation on this wing was 15.8 $g/dm^2/h$.

7.3 Volume of Fluid that Fell to the Ground on the Taxiways

For the port wing, the average fluid thickness on the wing before takeoff was 1.5 mm. The approximate volume of fluid remaining on this wing was 30.8 L. Since 36.9 L of Type IV fluid were present on the wing when it departed from the deicing pad, it can be deduced that 6.1 L fell to the ground on the taxiways.

For the starboard wing, the average fluid thickness on the wing before takeoff was 1.1 mm. The approximate volume of fluid remaining on this wing was 22.6 L. Since 28.7 L of Type IV fluid were present on the wing when the aircraft left the deicing bay, it can be deduced that 6.2 L of fluid fell to the ground on the taxiways.

8. MARCH 12, 2002 – RUN 1; TYPE IV; LIGHT FREEZING RAIN APPLIED

8.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the application of light freezing rain was 1.2 mm. The approximate volume of fluid remaining on this wing was 24.6 L. Since 29 L of Type IV fluid were applied to the wing, it can be deduced that 4.4 L fell to the ground at the deicing bay as a result of overspray and drippage.

For the starboard wing, the average fluid thickness on the wing prior to the application of light freezing rain was 1.2 mm. The approximate volume of fluid remaining on this wing was 24.6 L. Since 37 L of Type IV fluid was applied to the wing, it can be deduced that 12.4 L fell to the ground at the deicing bay.

8.2 Volume of Type IV Fluid that Fell to the Ground Within the Application Area Due to Dilution of the Fluid

For the port wing, the average fluid thickness on the wing after the application of freezing rain was 0.7 mm. The approximate volume of fluid remaining on this wing was 14.4 L. Since 24.6 L of Type IV fluid remained on the wing prior to the application of the freezing rain, it can be deduced that only 10.2 L fell during the dilution period. The only locations on the port wing to see significant reductions in thickness due to dilution were on the leading edge.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 0.6 mm. The approximate volume of fluid remaining on this wing was 12.3 L. Since 24.6 L of fluid was present on the wing prior to the application of freezing rain, it can be deduced that 12.3 L fell during the dilution process.

8.3 Volume of Fluid that Fell to the Ground on the Taxiways

For the port wing, the average fluid thickness on the wing before takeoff was 0.6 mm. The approximate volume of fluid remaining on this wing was 12.3 L. This was the same amount of fluid measured on the wing following the application of the freezing rain spray.

For the starboard wing, the average fluid thickness on the wing before takeoff was again was 0.5 mm. The approximate volume of fluid remaining on this wing was 10.3 L. Since 12.3 L of Type IV fluid were present on the wing when the aircraft left the deicing bay, it can be deduced that 2 L of fluid fell to the ground on the taxiways.

9. March 12, 2002 – Run 2; Type IV; Light Freezing Rain Applied

9.1 Volume of Type IV Fluid that Fell to the Ground Within the Application Area

For the port wing, the average fluid thickness on the wing prior to the application of freezing rain was 1.3 mm. The approximate volume of fluid remaining on this wing was 26.7 L. Since 35 L of Type IV fluid were applied to the wing, it can be deduced that 8.4 L fell to the ground at the deicing bay as a result of overspray and drippage.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 1.3 mm. The approximate volume of fluid remaining on this wing was 26.7 L. Since 39 L of Type IV fluid was applied to the wing, it can be deduced that 12.3 L fell to the ground at the deicing bay.

9.2 Volume of Type IV Fluid that Fell to the Ground Within the Application Area Due to Dilution of the Fluid

For the port wing, the average fluid thickness on the wing after the application of freezing rain was 1.1 mm. The approximate volume of fluid remaining on this wing was 22.6 L. Since 26.7 L of Type IV fluid remained on the wing prior to the application of the freezing rain, it can be deduced that only 4.1 L fell during the dilution period. The only locations on the port wing with significant reductions in thickness due to dilution were on the leading edge.

For the starboard wing, the average fluid thickness on the wing prior to the departure of the aircraft from the deicing bay was 0.8 mm. The approximate volume of fluid remaining on this wing was 16.4 L. Since 26.7 L of fluid was present on the wing prior to the application of freezing rain, 10.3 L fell during the dilution process. There were slight increases in fluid thickness after the application of the freezing rain at several locations on the starboard wing.

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