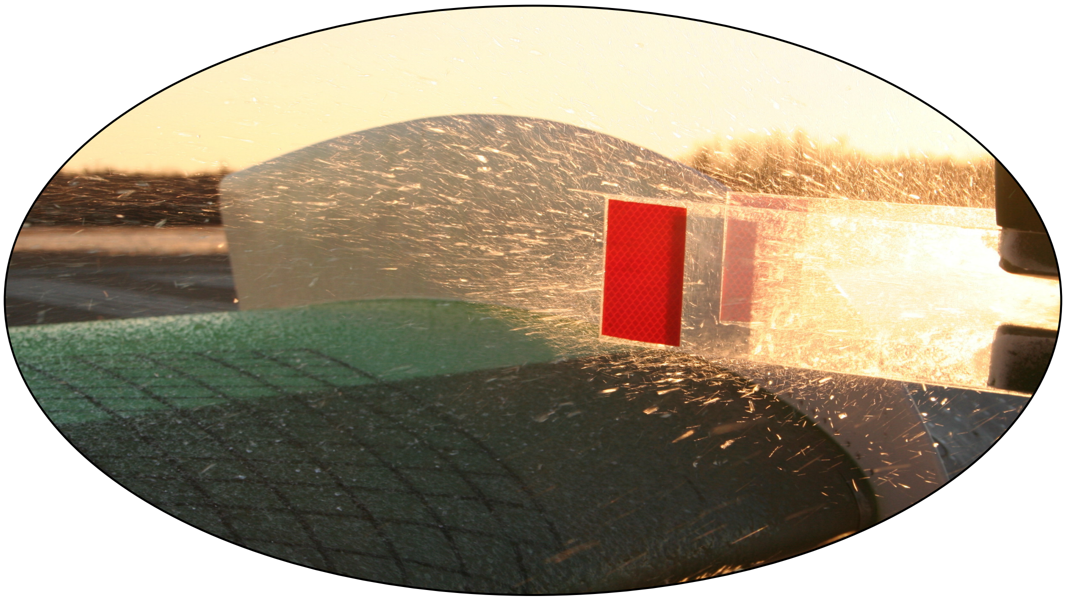
TP 14716E

Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets



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In cooperation with

Civil Aviation
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

December 2006
Final Version 1.0

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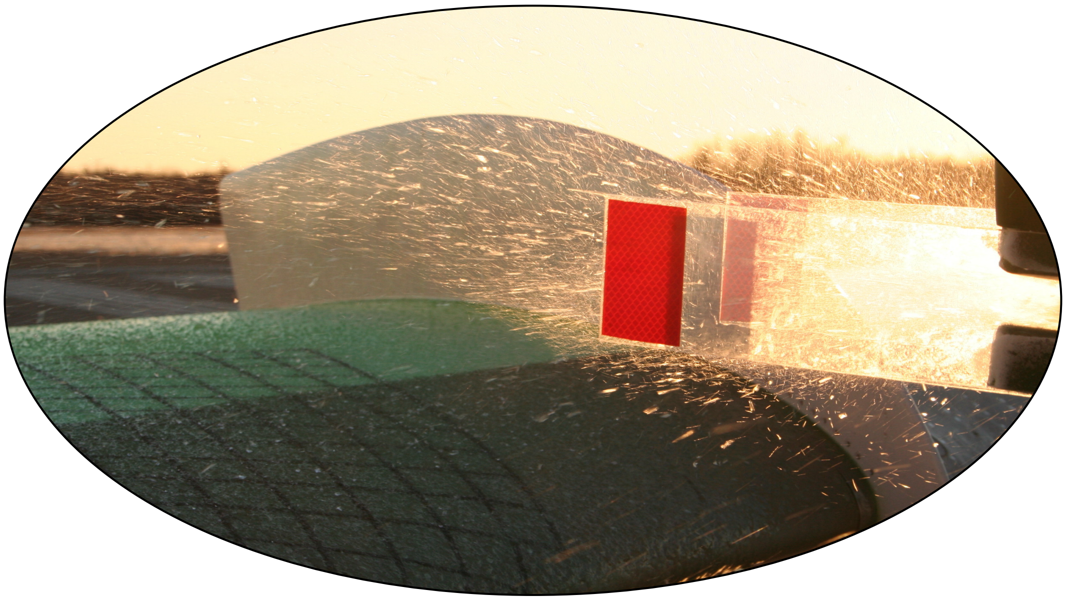

by:

Geroge Balaban

APS Aviation Inc.

December 2006
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The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

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

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Un sommaire français se trouve avant la table des matières.

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PREFACE

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

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To evaluate whether holdover times should be developed for ice pellet conditions;
- To examine the effect of heated fluids on Type II, III and IV fluid endurance times;
- To evaluate if it is appropriate to apply fluid with a -3°C buffer (fluid with a freeze point 3°C above the ambient temperature) for the 1st step of a two-step application;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To assist in the testing of flow of contaminated fluid from aircraft wings during takeoff;
- To validate the laboratory snow test protocol with Type II and IV fluids;
- To develop performance specifications for an integrated weather system that measures holdover time;
- To provide support for the development of a standard that evaluates remote on-ground ice detection systems;
- To conduct general and exploratory de/anti-icing research;
- To conduct endurance time tests on non-aluminum plates; and
- To conduct endurance time tests in frost on various test surfaces.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2005-06 are documented in nine reports. The titles of the reports are as follows:

- TP 14712E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2005-06 Winter;
- TP 14713E Aircraft Deicing Research in Natural and Simulated Ice Pellet Conditions;
- TP 14714E Evaluation of Fluid Freeze Points in First-Step Application of Type I Fluids;
- TP 14715E Winter Weather Impact on Holdover Time Table Format (1995-2006);
- TP 14716E Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets;
- TP 14717E Endurance Time Testing in Snow: Comparison of Indoor and Outdoor Data for 2005-06;
- TP 14718E Preliminary Endurance Time Testing in Simulated Ice Pellet Conditions;
- TP 14719E Aircraft Ground Icing General Research Activities During the 2005-06 Winter; and
- TP 14720E Effect of Heat on Fluid Endurance Times Using Composite Surfaces.

In addition, the following three interim reports are being prepared:

- *Implementation of Holdover Time Determination Systems*;
- *Effect of Heat on Endurance Times of Anti-Icing Fluids; and*
- *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions.*

This report, TP 14716E, has the following objective:

- To determine the maximum amount of ice pellet contamination that will flow off an anti-iced aircraft at takeoff.

This objective was met by performing a series of takeoff tests using the National Research Council Canada Falcon 20 aircraft in March 2006.

PROGRAM ACKNOWLEDGEMENTS

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

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: George Balaban, Katrina Bell, Kim Bendickson, Stephanie Bendickson, Nicolas Blais, Michael Chaput, Sami Chebil, John D'Avirro, Jan Goraczkowski, Chris McCormack, Rob Petermann, Marco Ruggi, Joey Tiano, Larry Turner, and David Youssef.

Special thanks are extended to Barry Myers, Frank Eyre and Yagusha Bodnar, who on behalf of the Transportation Development Centre, have participated, contributed and provided guidance in the preparation of these documents.

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APS Aviation Inc. would like to acknowledge the contributions of the following organization to this project: National Research Council Canada for providing the Falcon 20 research aircraft and support personnel.

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15. Supplementary Notes (Funding programs, titles of related publications, etc.)

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

16. Abstract

The objective of this study was to determine the maximum amount of ice pellet contamination that will flow off an anti-iced aircraft at takeoff. To satisfy this objective, simulated takeoff runs were performed with the National Research Council (NRC) Falcon 20 research aircraft at the Ottawa Airport. Nine runs were performed with simulated precipitation rates ranging from 25 g/dm^2/h to 167 g/dm^2/h. Eight runs were conducted with Type IV anti-icing fluids and one run was completed with an ethylene glycol-based Type I deicing fluid.

The testing was completed by APS Aviation Inc. (APS) and personnel from the NRC. The NRC provided the Falcon 20 aircraft and flight crews and collected the Falcon 20 flight data. APS coordinated and provided support for the Falcon 20 tests. APS personnel recorded all non-flight related test data.

The test wings were treated with de/anti-icing fluids using a one-step operation. Simulated ice pellets were then applied 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 simulated takeoff run. The behaviour of the fluid during the takeoff run was documented with high-speed digital still cameras and video cameras.

The contamination present on the wings was almost completely eliminated during the simulated takeoffs. In general, a small film of fluid remained on certain wing surfaces, most notably on the trailing edge of the aircraft. The leading edge was cleared of any contamination during the takeoff run, even at very high precipitation rates. Some contamination was observed on the trailing edge during one run at a very high precipitation rate (136 g/dm^2/h). The Type I EG run showed a small amount of ice had adhered to the wing surface at the end of the simulated takeoff.

Further testing is recommended as a result of the observations made during the tests. It is recommended takeoff tests be conducted in natural snow and mixed precipitation as a comparison for the ice pellet tests. It is also recommended tests be conducted in the wind tunnel if feasible.

17. Key Words Anti-icing, deicing, deicing fluid, holdover times, precipitation, endurance times, Type I, Type II, Type III, Type IV, aircraft, ground, test, winter	18. Distribution Statement Limited number of copies available from the Transportation Development Centre

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

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

16. Résumé

L'objectif de cette étude était de déterminer la quantité maximale de contaminants sous forme de granules de glace qui ruissellerait de la surface d'un aéronef traité au moyen d'un liquide d'antigivrage au moment du décollage. Pour atteindre cet objectif, des simulations de course de décollage ont été effectuées avec l'aéronef expérimental Falcon 20 du Conseil national de recherches Canada (CNRC) à l'aéroport d'Ottawa. Neuf essais ont été réalisés avec des taux de précipitations simulées allant de 25 g/dm2/h à 167 g/dm2/h; huit essais ont été menés avec du liquide d'antigivrage de type IV, et le neuvième, avec du liquide de dégivrage de type I à base d'éthylène glycol.

Les essais ont été réalisés par APS Aviation Inc. (APS) et le personnel du CNRC. Le CNRC a fourni l'aéronef Falcon 20 et les membres de l'équipage en plus de recueillir les données de vol de l'appareil. APS a coordonné les essais sur le Falcon 20 et en a assuré le soutien. Le personnel d'APS a consigné toutes les données d'essais non liées au vol.

Les ailes soumises aux essais ont été traitées au moyen de liquides de dégivrage et d'antigivrage à l'aide d'une méthode en une étape. Des granules de glace artificiels ont ensuite été appliqués par-dessus le liquide jusqu'à ce que les taux de contamination déterminés soient atteints. Des données telles que l'épaisseur et le point de congélation du liquide et la température des ailes ont été recueillies. L'aéronef a ensuite réalisé une simulation de course de décollage. Le comportement du liquide a été documenté durant la course au moyen d'appareils photographiques et de caméras vidéo numériques à grande vitesse.

La contamination présente sur les ailes a presque complètement été éliminée durant les simulations de décollage. En général, une mince pellicule de liquide demeurait sur certaines surfaces des ailes, principalement sur le bord de fuite. Le bord d'attaque était quant à lui exempt de toute contamination durant la course de décollage, même à des taux de précipitations très élevés. Une certaine contamination a été observée sur le bord de fuite lors d'un essai à un taux de précipitations très élevé, soit de 136 g/dm2/h. Lors de l'essai réalisé avec du liquide de type I à base d'éthylène glycol, une petite quantité de glace avait adhéré à la surface de l'aile à la fin du décollage simulé.

En raison des résultats observés, il est recommandé de procéder à des essais supplémentaires. Des essais de décollage devraient être menés dans des conditions de neige naturelle et de précipitations mixtes pour servir de point de comparaison aux essais sur les granules de glace. Des essais devraient aussi être réalisés dans la soufflerie, si possible.

17. Mots clés Antigivrage, dégivrage, liquide de dégivrage, durées d'efficacité, précipitation, temps d'endurance, Type I, Type II, Type III, Type IV, aéronef, sol, essai, hiver	18. Diffusion Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

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EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), with support from the Federal Aviation Administration (FAA), and several fluid manufacturers, APS Aviation Inc. (APS) has undertaken a testing and research program to further advance aircraft ground de/anti-icing technology. The program has a number of objectives, and work completed to address these objectives is documented in a series of related reports. The objective of the project documented in this report was to examine the behaviour of ice pellet-contaminated anti-icing fluid at takeoff.

Background and Objective

Although holdover times currently do not exist in ice pellet conditions, aircraft can depart during ice pellet conditions following aircraft deicing and a pre-takeoff contamination check. This protocol is feasible for common air carrier aircraft that provide access to emergency exit windows overlooking the leading edge of the aircraft wings; however, it poses a significant problem for cargo aircraft that have limited visibility of the wings from the cabin.

The objective of the 2005-06 Falcon 20 tests was to determine the amount of ice pellet contamination that will flow off an anti-iced aircraft at takeoff. This objective was met by performing a series of simulated takeoff tests with the Falcon 20 aircraft in March 2006.

The simulated takeoff runs were performed with the National Research Council (NRC) Falcon 20 research aircraft at the Ottawa Airport. Nine runs were performed with simulated precipitation rates ranging from 25 g/dm^2/h to 167 g/dm^2/h. The majority of runs were conducted with Type IV anti-icing fluid; one run was completed with an ethylene glycol-based Type I deicing fluid.

Data Collection and Testing

The testing was completed by APS and personnel from the NRC. The NRC provided the Falcon 20 aircraft and flight crews and collected the Falcon 20 flight data. APS coordinated and provided support for the Falcon 20 tests. APS personnel recorded all non-flight related test data.

At the start of each run, the test wing was treated with de/anti-icing fluid using a one-step operation. Simulated ice pellets were then applied 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 simulated takeoff run. The behaviour of the fluid during the simulated takeoff was documented with high-speed digital still cameras and video cameras.

Conclusions

The contamination present on the wings was almost completely eliminated during the simulated takeoffs. In general, a small film of fluid remained on certain wing surfaces, most notably on the trailing edge of the aircraft. The leading edge was cleared of any contamination during the takeoff run, even at very high precipitation rates. Some contamination was observed on the trailing edge during one run at a very high precipitation rate (136 g/dm^2/h). The Type I run showed that a small amount of ice had adhered to the wing surface at the end of the simulated takeoff.

Recommendations

Further testing is recommended as a result of the observations made during the 2005-06 tests. It is recommended that takeoff tests be conducted in natural snow and mixed precipitation as a comparison for the ice pellet tests. It is also recommended that wind tunnel tests be conducted if feasible.

SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports (CDT) de Transports Canada (TC), avec l'appui de la Federal Aviation Administration (FAA) et de plusieurs fabricants de liquides, APS Aviation Inc. (APS) a entrepris des essais et un programme de recherches visant à approfondir la technologie de dégivrage et d'antigivrage d'aéronefs au sol. Le programme poursuivait plusieurs objectifs et les travaux effectués pour atteindre ces objectifs sont documentés dans une suite de rapports connexes. Le projet dont il est question dans le présent rapport avait pour objectif d'examiner le comportement de liquides d'antigivrage contaminés par des granules de glace au moment du décollage.

Contexte et objectif

Bien qu'il n'existe actuellement aucune ligne directrice sur les durées d'efficacité dans des conditions de granules de glace, les aéronefs peuvent tout de même décoller dans de telles conditions après avoir été soumis à un dégivrage et à une inspection de contamination avant le décollage. Ce protocole est acceptable pour les aéronefs de transporteurs publics équipés de fenêtres d'issues de secours au-dessus du bord d'attaque des ailes ; il pose toutefois un problème important pour les aéronefs cargos offrant une visibilité limitée des ailes à partir de la cabine.

L'objectif des essais de 2005-2006 sur le Falcon 20 était de déterminer la quantité maximale de contaminants sous forme de granules de glace qui ruissellerait d'un aéronef traité au moyen d'un liquide d'antigivrage au moment du décollage. Pour ce faire, une série de simulations de décollage a été réalisée en mars 2006 à l'aide d'un aéronef Falcon 20.

Les simulations de course de décollage ont été effectuées avec l'aéronef expérimental Falcon 20 du Conseil national de recherches Canada (CNRC) à l'aéroport d'Ottawa. Neuf essais ont été réalisés avec des taux de précipitations simulés allant de 25 g/dm^2/h à 167 g/dm^2/h. La majorité des essais ont été menés avec du liquide d'antigivrage de type IV ; un essai a été mené avec du liquide de dégivrage de type I à base d'éthylène glycol.

Collecte de données et essais

Les essais ont été réalisés par APS et le personnel du CNRC. Le CNRC a fourni l'aéronef Falcon 20 et les membres de l'équipage en plus de recueillir les données de vol de l'appareil. APS a coordonné les essais sur le Falcon 20 et en a assuré le soutien. Le personnel d'APS a consigné toutes les données d'essais non liées au vol.

Avant chaque course de décollage, l'aile soumise à l'essai était traitée au moyen d'un liquide de dégivrage ou d'antigivrage à l'aide d'une méthode en une étape. Des granules de glace artificiels ont ensuite été appliqués par-dessus le liquide jusqu'à ce que les taux de contamination déterminés soient atteints. Des données telles que l'épaisseur et le point de congélation du liquide et la température des ailes ont été recueillies. L'aéronef a ensuite réalisé une simulation de course de décollage. Le comportement du liquide a été documenté durant la course au moyen d'appareils photographiques et de caméras vidéo numériques à grande vitesse.

Conclusions

La contamination présente sur les ailes a presque complètement été éliminée durant les simulations de décollage. En général, une mince pellicule de liquide demeurait sur certaines surfaces des ailes, principalement sur le bord de fuite. Le bord d'attaque était quant à lui exempt de toute contamination durant la course de décollage, même à des taux de précipitations très élevés. Une certaine contamination a été observée sur le bord de fuite lors d'un essai à un taux de précipitations très élevé, soit de 136 $g/dm^2/h$. Lors de l'essai réalisé avec du liquide de type I, une petite quantité de glace avait adhéré à la surface de l'aile à la fin du décollage simulé.

Recommandations

En raison des résultats observés durant les essais de 2005-2006, il est recommandé de procéder à des essais supplémentaires. Des essais de décollage devraient être menés dans des conditions de neige naturelle et de précipitations mixtes pour servir de point de comparaison aux essais sur les granules de glace. Des essais devraient aussi être réalisés dans la soufflerie, si possible.

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GLOSSARY

APS	APS Aviation Inc.
CDU	Cockpit Display Unit
CSA	Canadian Space Agency
DAU	Data Acquisition Unit
DND	Department of National Defence
EG	Ethylene Glycol
FAA	Federal Aviation Administration
GPS	Global Positioning System
ILS	Instrument Landing System
MLS	Microwave Landing System
MSC	Meteorological Service of Canada
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
PG	Propylene Glycol
SAE	Society of Automotive Engineers
TC	Transport Canada
TDC	Transportation Development Centre
UPS	United Parcel Service
VOR	VHF Omnidirectional Range
YOW	MacDonald-Cartier International Airport

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1. INTRODUCTION

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

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

Under contract to the TDC, with financial support from the FAA, APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology.

As part of a larger research program examining aircraft operations in ice pellets, APS conducted tests with the NRC Falcon 20 in 2005-06 to determine the maximum amount of ice pellet contamination that will flow off an anti-iced aircraft at takeoff.

1.1 Background

Although holdover times currently do not exist in ice pellet conditions, aircraft can depart during ice pellet conditions following aircraft deicing and a pre-takeoff contamination check. This protocol is feasible for common air carrier aircraft that provide access to emergency exit windows overlooking the leading edge of the aircraft wings; however, it poses a significant problem for cargo aircraft that have limited visibility of the wings from the cabin.

On December 22, 2004, United Parcel Service (UPS) aircraft in Louisville were grounded for several hours due to extended ice pellet conditions. Due to cargo aircraft configuration, pre-takeoff contamination checks by the onboard crew were not possible. Fed-Ex had been faced with similar problems in Memphis.

As a result of this costly incident, UPS set out to obtain experimental data to provide guidance and allow operations to continue in ice pellet conditions. In 2005, aerodynamic and endurance time testing were conducted in simulated ice pellet conditions. Based on the preliminary data, an allowance of 20 minutes in light ice pellet conditions was proposed.

1.2 Program Objectives

A test program was developed for the winter of 2005-06 in an attempt to better understand the issues described above. A series of test procedures was developed to carry out tests in support of this objective in the winter of 2005-06. These test procedures are listed below:

1. Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets;
2. Wind Tunnel Tests to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets;
3. Video Documentation of Pilot's Perspective in Ice Pellets;
4. Dissolving Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid;
5. Dissolving Time Outdoors: Video Documentation of Ice Pellets and Snow Dissolving in Fluid;
6. Photography of Ice Pellets on Black Felt; and
7. Endurance Time Testing in Natural Ice Pellets.

This report documents the 2005-06 Falcon 20 tests that were conducted using the first procedure listed above. The objective of the Falcon 20 tests was to determine the maximum amount of ice pellet contamination that will flow off an anti-iced aircraft at takeoff. The work statement for these tests is provided in Appendix A.

Wind tunnel tests to examine fluid contaminated with ice pellets removed from aircraft during takeoff were planned for February 2006 using the second procedure listed above; however, the tests were cancelled due to a scheduling problem with the NRC wind tunnel facility. The procedure developed in support of these tests has been included in Appendix B for reference.

1.3 Previous Full-Scale Testing

Previous trials to examine the elimination of failed Society of Automotive Engineers (SAE) Type IV fluid from aircraft wings during takeoff were conducted during the 1997-98 and 1998-99 winter seasons. These trials, based on simulated takeoff runs using the NRC Falcon 20 aircraft, showed that the test approach was a viable one. The Falcon 20 test program conducted during the winters of 2001-02 and 2002-03 addressed the effects of unshed anti-icing fluid on aircraft takeoff performance.

This research is documented in detail in a series of five reports written by APS for TC:

1. TP 13316E, *Contaminated Aircraft Takeoff Test for the 1997/98 Winter* (1);
2. TP 13479E, *Contaminated Aircraft Takeoff Tests for the 1998-99 Winter* (2);
3. TP 13666E, *Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures* (3);
4. 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* (4); and
5. TP 14147E, *Aircraft Takeoff Test Program for Winter 2002-03: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid* (5).

1.4 Report Format

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

a) Section 2 describes the methodology used in testing, as well as equipment and personnel requirements necessary to carry out testing;
b) Section 3 describes the data collected and the different conditions in which data were collected;
c) Section 4 includes the analysis of the data and the overall results of testing;
d) Section 5 presents conclusions derived from testing; and
e) Section 6 lists recommendations for future testing.

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2. METHODOLOGY

This section describes the test methodologies followed.

2.1 Test Site

The 2005-06 Falcon 20 tests were performed at MacDonald-Cartier International Airport (YOW) in Ottawa. Figure 2.1 provides a schematic of the airport showing the runways and the location of the NRC hangar and apron.

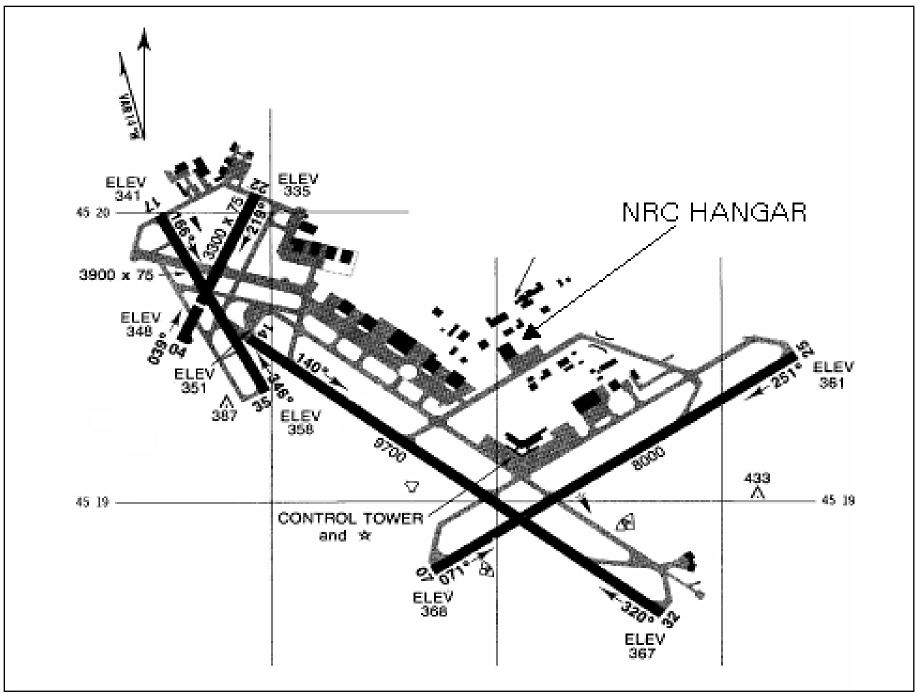

Figure 2.1: Schematic of Ottawa Airport

2.2 Test Schedule

Testing was scheduled for the period of March 9-17, 2006. March 7 and 8 were scheduled as setup days. A test plan was completed that allowed for modifications during the test period according to observations made during initial tests. The following tests were completed:

a) Baseline tests: ethylene glycol (EG) and propylene glycol (PG) Type IV fluids contaminated with ice pellets representing a rate of 25 g/dm^2/h for 20 minutes;

b) Subsequent tests: Subsequent tests were carried out with increasing ice pellet mass until a run was conducted in which the contaminated fluid was not removed during the simulated takeoff; and

c) Additional test: A test with EG Type I fluid, not included in the initial test plan, was performed.

The test preparation went according to schedule and the first run took place on March 9, 2006. Mild weather made subsequent testing possible only in the last of the scheduled test days, March 15-17, 2006. Table 2.1 presents the calendar of Falcon 20 tests performed in 2006.

Table 2.1: Calendar of Tests

Date	Number of Test Runs	Run Numbers
March 9	2	1 and 2
March 10-14	No tests	N/A
March 15	2	3 and 4
March 16	3	5, 6, and 7
March 17	2	8 and 9

2.3 Procedure

To satisfy the program objective, simulated takeoff runs were performed with the NRC Falcon 20 research aircraft, and different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests.

The procedure for each run was as follows:

a) A designated test area on the port wing was treated with Type IV fluid, poured in a one-step operation outside the NRC hangar. In the last run, Type I EG fluid was applied heated in a one-step operation at the runway button;

b) Manufactured ice pellets were transported in the aircraft in a temperature-controlled cooler and applied on the test area at the runway button using hand-held dispersers; and

c) The aircraft was subsequently operated through a simulated takeoff run, excluding climb-out. The behaviour of the contaminated fluid during the takeoff run was recorded with digital video cameras and digital high-speed still cameras.

Tests with increasing ice pellet quantities and different ice pellet sizes were carried out as described in Subsection 2.2.

2.4 Equipment

A considerable amount of test equipment was required to perform these tests. Key items are described in the following subsections; a full list of equipment is provided in the test procedure, which is included in Appendix C.

2.4.1 Falcon 20 Research Aircraft

The aircraft used for testing was a Dassault Falcon 20 twin-engine, mid-size business jet, operated by the 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, 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 Defense (DND) in 1991. In partnership with the Canadian Space Agency (CSA) and TC, 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 in place to allow the aircraft to fly "zero-G" parabolic manoeuvres and with the modified aircraft guidance systems available to fly curved path precision approaches using GPS-based receivers.

In partnership with TC, National Aeronautics and Space Administration (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 at determining aircraft landing and takeoff performance changes as a result of runway contaminants.

2.4.1.1 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:

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.).

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

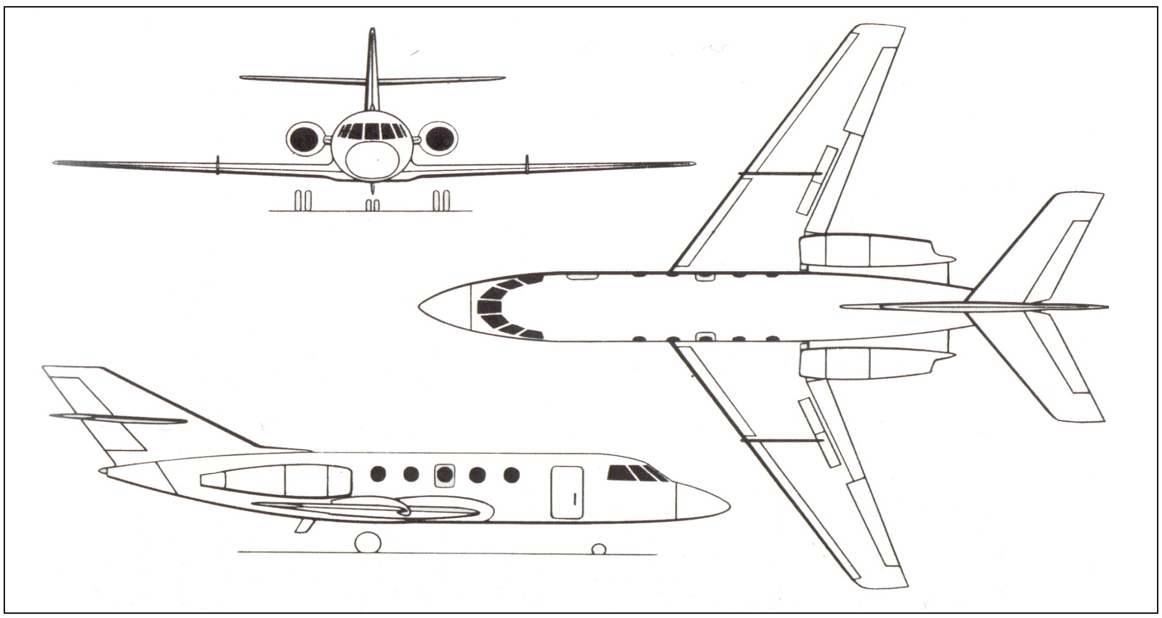

Figure 2.2: Schematic View of Dassault Falcon 20

2.4.1.2 Falcon 20 Onboard Installations

The NRC Falcon 20 research aircraft is equipped with the following onboard installations:

a) Engineering workstation containing 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), GPS, flight test differential GPS, and modified flight director; and
d) Cockpit mounted Cockpit Display Unit (CDU) to initiate GPS approaches and monitor selected test parameters.

2.4.1.3 Falcon 20 Measurement Capabilities

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

a) 3-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.

2.4.2 Type IV Fluid Application Equipment

Type IV fluids were applied to the Falcon 20 using several PVC pouring devices (Photo 2.2) manufactured for this purpose. Each 2.5 L device was fitted with pouring, refill, and breather holes, which permitted uniform fluid flow.

2.4.3 Ice Pellet Related Equipment

The tests required that ice pellets be manufactured and dispersed over the test area. Ice pellets were manufactured from ice cubes inside a rented refrigerated truck. The process required the use of blenders, calibrated sieves, colourant, and large Styrofoam containers.

Once produced, the ice pellets were stored in Styrofoam containers. They were applied over the test area using the special hand-held dispensers shown in Photo 2.3.

2.4.4 Video and Photo Equipment

Two Canon Digital Rebel XT digital still cameras were used to obtain high-speed, high-resolution photographs of the testing. The 8 mega-pixel resolution cameras are capable of taking up to three pictures per second in continuous shooting mode. The cameras were used with two different lenses:

a) 18-55 mm standard lens for wide angle pictures; and
b) 105 mm macro lens for close-ups.

Two Sony video cameras were provided and operated by NRC personnel. The still cameras and video cameras are shown in Photo 2.4.

2.4.5 Viscometer

Viscosity measurements were carried out using a Brookfield viscometer (Model DV-1+, shown in Photo 2.5) fitted with a recirculating fluid bath and small sample adapter.

2.4.6 Fluid Freezing Point and Temperature Gauges

Fluid freezing points were measured using a hand-held Misco refractometer with a Brix scale.

Wing temperatures were measured using hand-held Wahl surface temperature probes. An extension for the temperature probe was made to allow measurements in areas not reachable by hand.

2.4.7 Thickness Gauges

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 (0.1 mm to 10.2 mm) for Type IV fluids. The rectangular gauge shown in Figure 2.3 has a finer scale and was used in some cases when the fluid film was thinner (toward the end of a test).

2.5 Fluids

Three fluids were used in these tests: Dow Chemical UCAR Ultra+, Kilfrost ABC-S, and UCAR ADF XL 54. The pertinent characteristics of these fluids are given in Table 2.2.

The Type IV fluids were received from the manufacturers in either 200 L drums or 20 L containers and were dispensed by APS personnel. The Type I fluid, which was mixed to a 10°C buffer, was provided at no cost by AéroMag 2000.

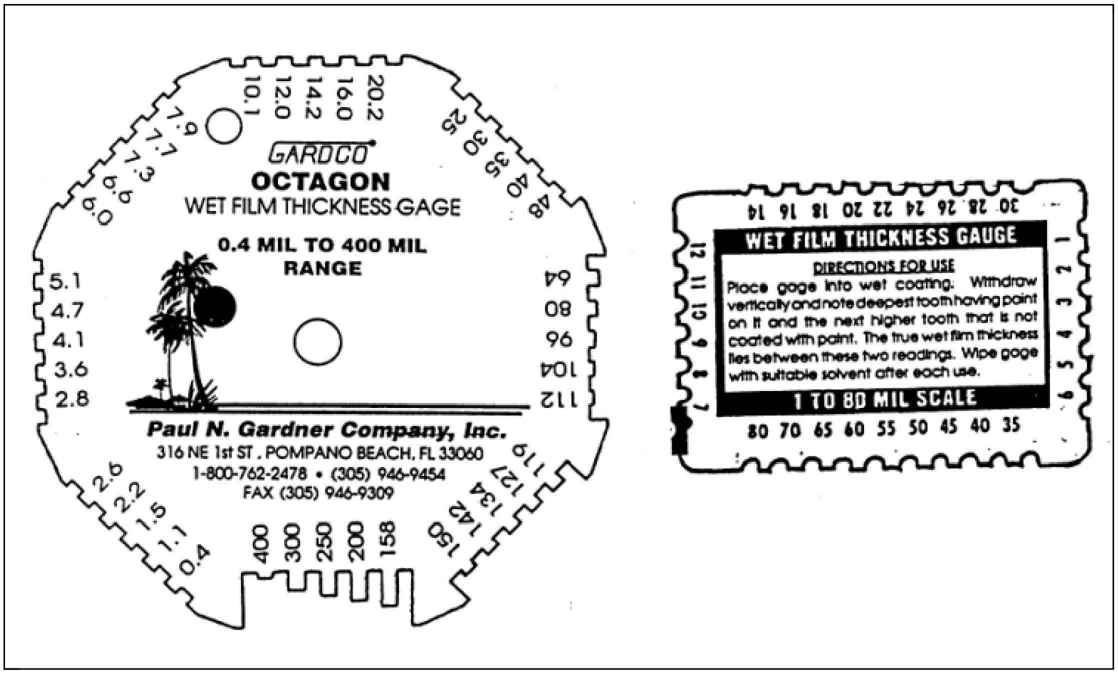

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Figure 2.3: Thickness Gauges

Table 2.2: Test Fluids

Fluid Name	Batch #	Type	Formulation	Brix	Viscosity (mPa.s)
Dow Chemical UCAR Ultra+	UA2555S3DY	IV	EG	40.0°	41,400[1]
Kilfrost ABC-S	14506	IV	PG	36.0°	24,500[2]
UCAR ADF XL 54	AéroMag 2000	I	EG	22.5°	n/a

[1]Spindle SC4-31, 10 mL of fluid, 10 minutes, 0.3 rpm, 0°C
[2]Equivalent to: Spindle LV-2, 150 mL of fluid, 10 minutes, 0.3 rpm, 20°C

2.6 Personnel

NRC personnel operated the Falcon 20 aircraft. Four APS staff members were required to conduct the tests, and four additional persons from Ottawa were hired to manufacture ice pellets. A professional photographer was retained to record digital images of the test setup and test runs. Representatives from the TDC and the FAA provided direction in testing and participated as observers.

2.7 Test Area

A single area on the port wing just inboard of the fence was selected to serve as the test surface on the Falcon 20. The test area was made large enough to be representative of the entire wing and, at the same time, to enable an ice pellet production rate that was reasonably achievable.

2.7.1 Test Area for Runs 1 to 4

The initial test area established was situated on the port wing. This area covers 1.4 m of the leading edge, inboard of the fence and the entire chord of the wing, as illustrated in Figure 2.4. The test surface had an area of 3.6 m^2 and was used for the first four runs.

2.7.2 Test Area for Runs 5 to 9

As the quantity of ice pellets required from test to test increased, the test area was reduced from 3.6 m^2 to 2.7 m^2 in order to achieve the required precipitation rate in the current ice pellet production conditions. The new test area, also presented in Figure 2.4, measured 1.1 m inboard from the fence and was used in the last five runs.

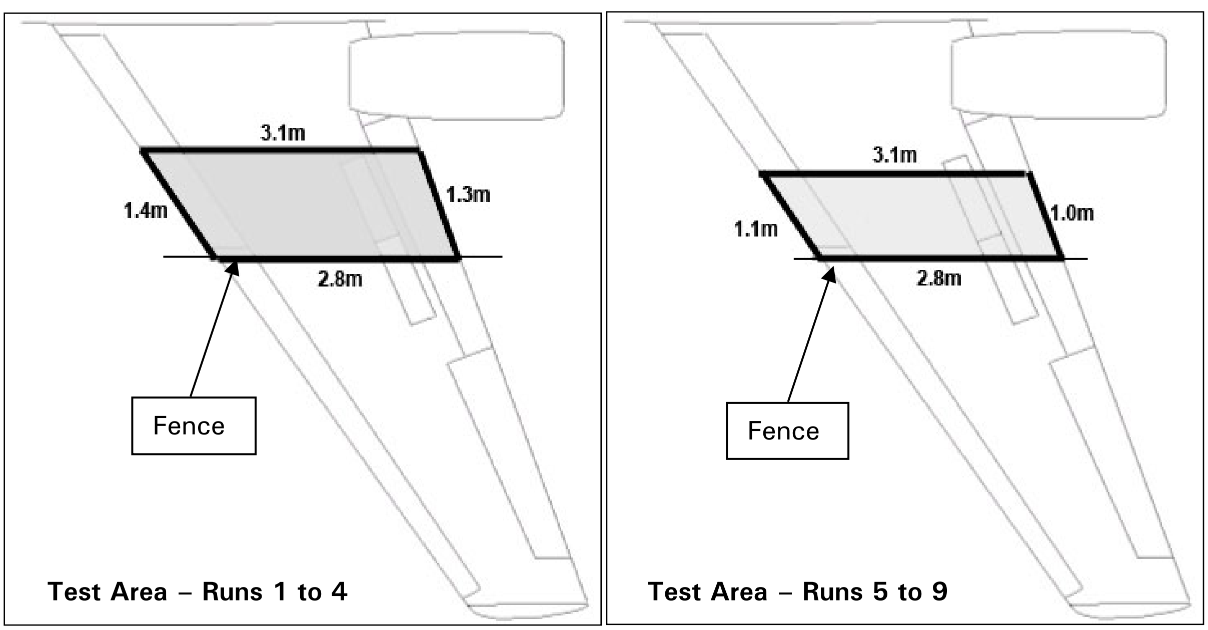


Figure 2.4: Test Areas

2.7.3 Test Area Grid

Prior to the March 2006 testing, NRC personnel used markers to draw a grid with dimensions of 0.61 m x 0.61 m (2 ft. x 2 ft.) just inside the fence on the port wing of the Falcon 20. Smaller grids with dimensions of 5.1 cm x 5.1 cm (2 in. x 2 in.) were then drawn inside the larger grid, perpendicular and parallel to the fence (see Photo 2.6). In two of these small grids, horizontal lines were drawn 2 mm apart to facilitate estimating the size of ice pellets embedded in fluid using macro photography. The grid was used to facilitate observations of the fluid shearing off the wing and the movement of ice pellets during takeoff.

2.8 Artificial Contamination

In a previous analysis of natural ice pellet events, the diameter of ice pellets was measured. It was found that the ice pellets generally ranged from 1 mm to 3 mm. During moderate to heavy ice pellet conditions, the diameter of the ice pellets measured up to 5 mm. Based on this observation, three ice pellet size ranges were produced for the Falcon 20 tests:

- Large (3.35 mm to 4.75 mm in diameter): used to represent the large ice pellet size observed during natural events. They were also used because the tests involved long delays between precipitation application and takeoff during which the melting process reduced their size;
- Small (1.0 mm to 3.35 mm in diameter): used to represent the most common ice pellet size observed during natural events; and
- Small unprocessed (0 mm to 3.35 mm in diameter): used to represent small ice pellets mixed with snow.

The ice pellets were manufactured inside a refrigerated truck (see Photo 2.7). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.8) to obtain the required ice pellets size ranges. A typical sample of ice pellets created using this method is illustrated in Photo 2.9. Hand-held dispensers (Photo 2.3) were used to dispense the ice pellets. The ice pellets were applied to the leading and trailing edges of the wing at the same time.

On February 8, 2006, APS performed preliminary testing to determine the efficiency of the ice pellet dispensers. Four tests were conducted on an airfoil with similar dimensions to the test area selected for the Falcon tests; between 77 and 84 percent of the ice pellets dispensed fell in the test area.

Following these preliminary tests, it was estimated that the dispensers had an efficiency of approximately 80 percent. This factor was considered throughout the tests when establishing the quantity of ice pellets necessary to achieve the required level of contamination. When considering the large surface area of the test section, variability in the efficiency of the dispensers did not significantly affect the average amount of contamination applied throughout the test section.

For observation purposes, colouring dye was used to tint about 10 percent of the ice pellets. These served as tracers when observing the movement of the precipitation exposed to the airflow at takeoff.

2.8.1 Fluid Application and Collection

2.8.1.1 Type IV Fluid Application

The Type IV fluids were kept at ambient temperature and applied to the aircraft outside the NRC hangar. The fluids were poured rather than sprayed so that application would not change the fluid viscosity. This methodology was appropriate given the relatively small test area and the goal of minimizing the amount of fluid flowing off the wing. Several pouring devices were manufactured for this purpose (see Subsection 2.4.2).

2.8.1.2 Type I Fluid Application

The last run (Run 9) was performed with Type I fluid. For this run only, the fluid was heated to 80°C and poured using the hand-held devices manufactured to apply the Type IV fluids.

2.8.1.3 Waste Fluid Collection

A glycol mitigation plan was prepared for the Ottawa Airport Authority prior to the March 2006 tests. This plan is shown in Appendix D.

Using a relatively small test area and applying the fluids by pouring minimized the amount of fluid falling off the aircraft wing. APS personnel used a vacuum to collect the fluid that did reach the ground immediately following the departure of the aircraft from the application area.

2.9 Measurement of Test Parameters

2.9.1 Fluid Viscosity

Virgin fluid samples were collected at the beginning of the test period. Fluid samples were also collected from the wing following Runs 4 and 8. These runs were selected in order to compare the effect of a low precipitation rate (25 $g/dm^2/h$ – Run 4) and a higher precipitation rate (136 $g/dm^2/h$ – Run 8) on the viscosity of one fluid (Kilfrost ABC-S). The samples were transported to the APS laboratory and subjected to viscosity testing.

2.9.2 Fluid Thickness

For each test, the fluid thickness of the anti-icing fluid was measured at five locations along the centreline of the test area (see Photo 2.10). Four measurements were taken in a typical test run:

a) After fluid application;
b) Before the ice pellet application;
c) After the ice pellet application; and
d) After the simulated takeoff run.

The fluid thickness and Brix data form that was used to record the fluid thickness data is shown in Figure 2.5. The locations designated for thickness measurement, identified in the data form, were the following:

- Wing Position 1: On the leading edge;
- Wing Position 2: Halfway between the leading edge and the joint;
- Wing Position 5: As far as could be reached from the leading edge;
- Wing Position 7: Trailing edge – 2.5 cm from the joint; and
- Wing Position 8: Halfway between the trailing edge and the joint.

For each location, the observer in the field recorded an uncorrected thickness value (in mils), as read directly from the thickness gauge. These values were then converted to a corrected thickness in mm using the Film Thickness Conversion Table shown in Table 2.3.

Form 4A

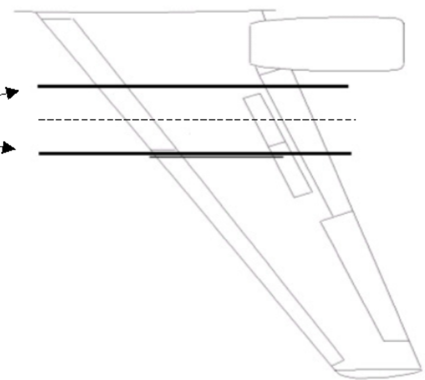
FLUID THICKNESS AND BRIX FORM (PORT WING)

Date: ____________________ Run Number: _______

FLUID THICKNESS				
Wing Position	After fluid application	Before IP Application	After IP Application	After Takeoff Run
1				
2				
5				
7				
8				
TIME				

FLUID BRIX							
After fluid application (lead./trail.)	Wing Position	Before IP Application (lead./trail.)	Wing Position	After IP Application (lead./trail.)	Wing Position	After Takeoff Run (lead./trail.)	Wing Position
Time:		time:		time:		time:	

Test area denoted by lines



Location: 1 - LE nose
2,8 - Halfway
3,4,6,7 - 1" form joint
5 - As far as can reach
9 - 6" from TE

Notes: - Measure thickness along centerline indicated in the diagram.
- Give priority to circled locations; measure other locations only if time allows.

Comments ______________________________

OBSERVER: ____________________

ASSISTED BY: ____________________

Figure 2.5: Fluid Thickness and Brix Form

Table 2.3: Film Thickness Conversion Table

RECTANGULAR GAUGE			OCTAGON GAUGE		
Reading*	Calculated Thickness		Reading*	Calculated Thickness	
(mil)	(mil)	(mm)	(mil)	(mil)	(mm)
			0.4	0.8	0.0
1.0	1.5	0.0	1.1	1.3	0.0
			1.5	1.9	0.0
2.0	2.5	0.1	2.2	2.4	0.1
			2.6	2.7	0.1
3.0	3.5	0.1	2.8	3.2	0.1
			3.6	3.9	0.1
4.0	4.5	0.1	4.1	4.4	0.1
			4.7	4.9	0.1
5.0	5.5	0.1	5.1	5.6	0.1
6.0	6.4	0.2	6.0	6.4	0.2
			6.6	7.0	0.2
7.0	7.5	0.2	7.3	7.5	0.2
8.0	8.5	0.2	7.7	7.8	0.2
9.0	9.5	0.2	7.9	9.0	0.2
10	11	0.3	10	11	0.3
11	12	0.3			
12	13	0.3	12	13	0.3
14	15	0.4	14	15	0.4
16	18	0.4	16	18	0.4
18	19	0.5			
20	21	0.5	20	23	0.6
22	23	0.6			
24	25	0.6	25	28	0.7
26	27	0.7			
28	29	0.7			
30	33	0.8	30	33	0.8
35	38	1.0	35	38	1.0
40	43	1.1	40	43	1.1
45	48	1.2			
50	53	1.3	48	56	1.4
55	58	1.5			
60	63	1.6			
65	68	1.7	64	72	1.8
70	73	1.8			
75	78	2.0			
80	88	2.2	80	88	2.2
			96	100	2.5
			104	108	2.7
			112	116	2.9
			119	123	3.1
			127	131	3.3
			134	138	3.5
			142	146	3.7
			150	154	3.9
			158	179	4.5
			200	225	5.7
			250	275	7.0
			300	350	8.9
			400	400	10.2

* Reading of last wetted tooth.

2.9.3 Fluid Freezing Points

Fluid freezing points were measured at the leading edge (Wing Position 2) and the trailing edge (Wing Position 8) using hand-held refractometers (Photo 2.11) at four stages of the Type IV runs:

a) After fluid application;

b) Before ice pellet application;

c) After ice pellet application; and

d) After the simulated takeoff.

The freezing points of the various fluid samples were determined using the conversion curve or table provided to APS by their respective fluid manufacturer. The Kilfrost ABC-S table is shown in Table 2.4, and the Dow Ultra+ curve is shown in Figure 2.6.

Table 2.4: Freezing Point vs. Brix of Aqueous Solutions of Kilfrost ABC-S

Conc. (% vol)	BRIX (20°C)	Freezing Point (20°C)	RI (20°C)		Conc. (% vol)	BRIX (20°C)	Freezing Point (20°C)	RI (20°C)		Conc. (% vol)	BRIX (20°C)	Freezing Point (20°C)	RI (20°C)
20%	8.20	1.345	-3.4		**50%**	**18.90**	**1.362**	**-10.6**		80%	29.40	1.380	-23.1
21%	8.59	1.345	-3.6		51%	19.26	1.363	-11.1		81%	29.73	1.380	-23.7
22%	8.98	1.346	-3.8		52%	19.62	1.364	-11.6		82%	30.06	1.381	-24.2
23%	9.37	1.346	-4.0		53%	19.98	1.364	-12.0		83%	30.36	1.382	-24.8
24%	9.76	1.347	-4.2		54%	20.34	1.365	-12.4		84%	30.72	1.382	-25.4
25%	10.15	1.348	-4.4		55%	20.70	1.365	-12.8		85%	31.05	1.383	-26.0
26%	10.54	1.348	-4.6		56%	21.06	1.366	-13.1		86%	31.38	1.383	-26.7
27%	10.93	1.349	-4.9		57%	21.42	1.366	-13.4		87%	31.71	1.384	-27.3
28%	11.32	1.349	-5.1		58%	21.78	1.367	-13.8		88%	32.04	1.384	-28.0
29%	11.71	1.350	-5.3		59%	22.14	1.368	-14.1		89%	32.37	1.385	-28.6
30%	12.10	1.351	-5.5		60%	22.50	1.368	-14.5		90%	32.70	1.386	-29.3
31%	12.43	1.351	-5.8		61%	22.85	1.369	-14.9		91%	33.02	1.386	-30.1
32%	12.76	1.352	-6.0		62%	23.20	1.369	-15.2		92%	33.34	1.387	-30.8
33%	13.09	1.352	-6.3		63%	23.55	1.370	-15.7		93%	33.66	1.387	-31.5
34%	13.42	1.353	-6.5		64%	23.90	1.371	-16.0		94%	33.98	1.388	-32.2
35%	13.75	1.354	-6.8		65%	24.25	1.371	-16.4		95%	34.30	1.389	-33.0
36%	14.08	1.354	-7.0		66%	24.60	1.372	-16.8		96%	34.62	1.389	-33.8
37%	14.41	1.355	-7.3		67%	24.95	1.372	-17.2		97%	34.94	1.390	-34.6
38%	14.74	1.355	-7.6		68%	25.30	1.373	-17.6		98%	35.26	1.391	-35.4
39%	15.07	1.356	-7.9		69%	25.65	1.373	-18.0		99%	35.58	1.391	-36.2
40%	15.40	1.356	-8.1		70%	26.00	1.374	-18.4		**100%**	**35.90**	**1.392**	**-37.0**
41%	15.75	1.357	-8.4		71%	26.34	1.375	-18.9					
42%	16.10	1.358	-8.7		72%	26.68	1.375	-19.3					
43%	16.45	1.358	-9.0		73%	27.02	1.376	-20.0					
44%	16.80	1.359	-9.3		74%	27.36	1.376	-20.7					
45%	17.15	1.359	-9.5		**75%**	**27.70**	**1.377**	**-21.4**					
46%	17.50	1.360	-9.8		76%	28.04	1.378	-21.7					
47%	17.85	1.361	-10.0		77%	28.38	1.379	-22.0					
48%	18.20	1.361	-10.2		78%	28.72	1.379	-22.3					
49%	18.55	1.362	-10.4		79%	29.06	1.379	-22.6					

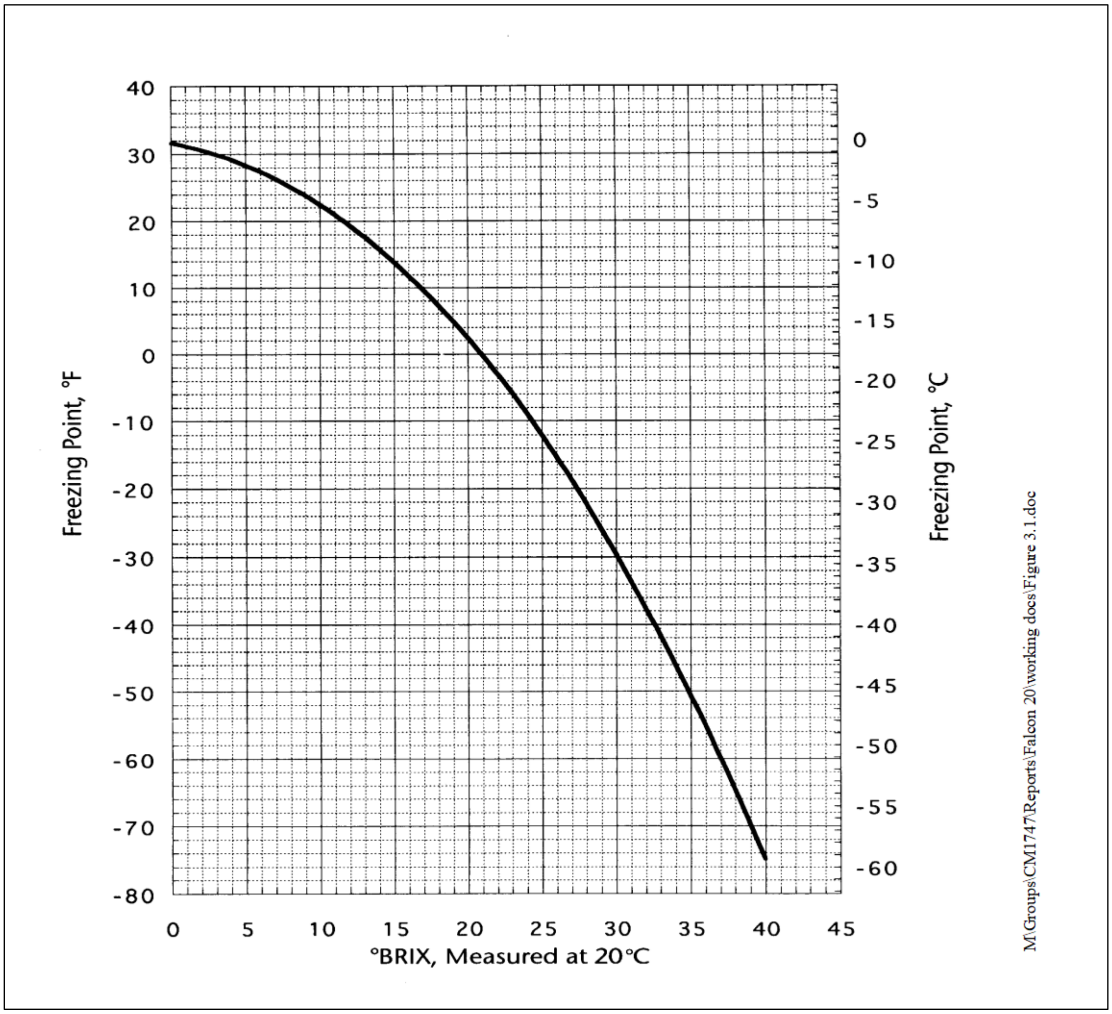


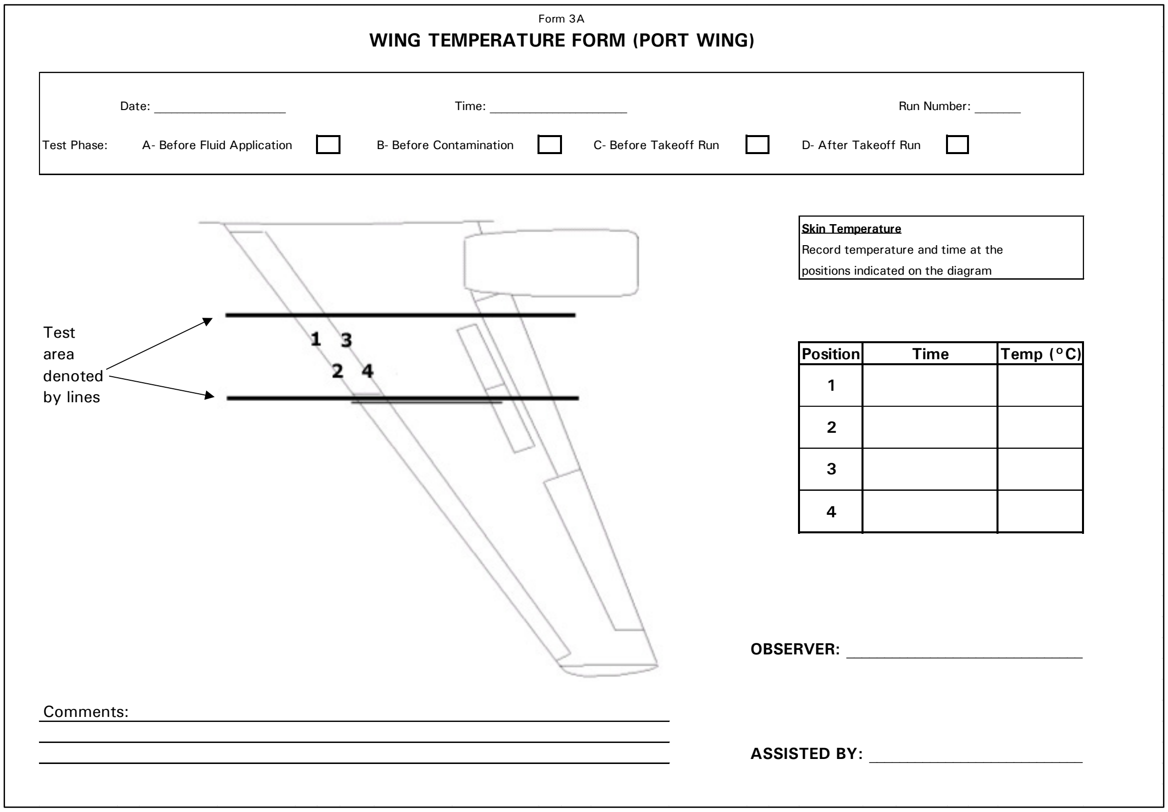
Figure 2.6: Freezing Point vs. Brix of Aqueous Solutions of Dow UCAR Ultra+

2.9.4 Wing Skin Temperature

Wing temperatures were measured at eight locations across the test area both before and after the simulated takeoff run:

- Positions 1 and 2: On the leading edge;
- Positions 3 and 4: On the leading edge, 2.5 cm (1 in.) from the joint;
- Positions 5 and 6: Approximately at the middle of the cord; and
- Positions 7 and 8: Halfway between the trailing edge and the joint.

Wing temperatures were read directly off the temperature probe (Photo 2.12) and recorded on the appropriate data form (Figure 2.7). The data form also shows the location of each measurement position.


Form 3A

WING TEMPERATURE FORM (PORT WING)

Date: ________________ Time: ________________ Run Number: ______

Test Phase: A- Before Fluid Application ☐ B- Before Contamination ☐ C- Before Takeoff Run ☐ D- After Takeoff Run ☐

Test area denoted by lines

1 3

2 4

<u>Skin Temperature</u>

Record temperature and time at the positions indicated on the diagram

Position	Time	Temp (°C)
1		
2		
3		
4		

OBSERVER: ______________________

Comments: ______________________

ASSISTED BY: ______________________

Figure 2.7: Wing Temperature Data Form

2.10 Video and Photo Recording

Digital video and still cameras were used to record visual observations of the testing. To create a consistent and stable setup for the cameras and video cameras, NRC personnel replaced one of the emergency exit doors of the Falcon 20 with a temporary structure that had camera-mounting capability (see Photo 2.13).

Two digital video cameras were initially mounted on the temporary structure replacing the door. One of the cameras provided a wide-angle view of the test area, while the second was zoomed in on a section of the grid. Following the second run, a digital still camera fitted with a macro lens replaced one of the video cameras. The video camera and the still camera were zoomed in to observe the behaviour of the fluid and contamination on the wing.

In addition to the images obtained from the cameras mounted on the aircraft, a professional photographer used a digital still camera to take pictures of the test setup and all phases of the takeoff runs.

2.11 Data Forms

Several different forms were used to facilitate the documentation of the various data collected in the Falcon 20 tests. These forms include:

a) Form 1: Fluid Receipt Form;

b) Form 2: General Form (every test);

c) Form 3A: Wing Temperature Form (Port Wing);

d) Form 4A: Fluid Thickness and Brix Form (Port Wing);

e) Form 5A: Test Results Form (Port Wing);

f) Form 6: Time Record of Operations; and

g) Form 7: Nominal Test Conditions.

Copies of these forms are provided in the test procedure, which is included in Appendix C.

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Photo 2.1: Falcon 20 Aircraft

Photo 2.2: Fluid Application Using PVC Pouring Devices

Photo 2.3: Ice Pellet Dispenser

Photo 2.4: Canon Still Camera and Sony Video Camera

Photo 2.5: Brookfield Digital Viscometer Model DV-1+

Photo 2.6: Grid on the Test Area

Photo 2.7: Refrigerated Truck Used for Manufacturing Ice Pellets

Photo 2.8: Calibrated Sieves Used to Obtain Desired Size Distribution

Photo 2.9: Typical Ice Pellets Sample

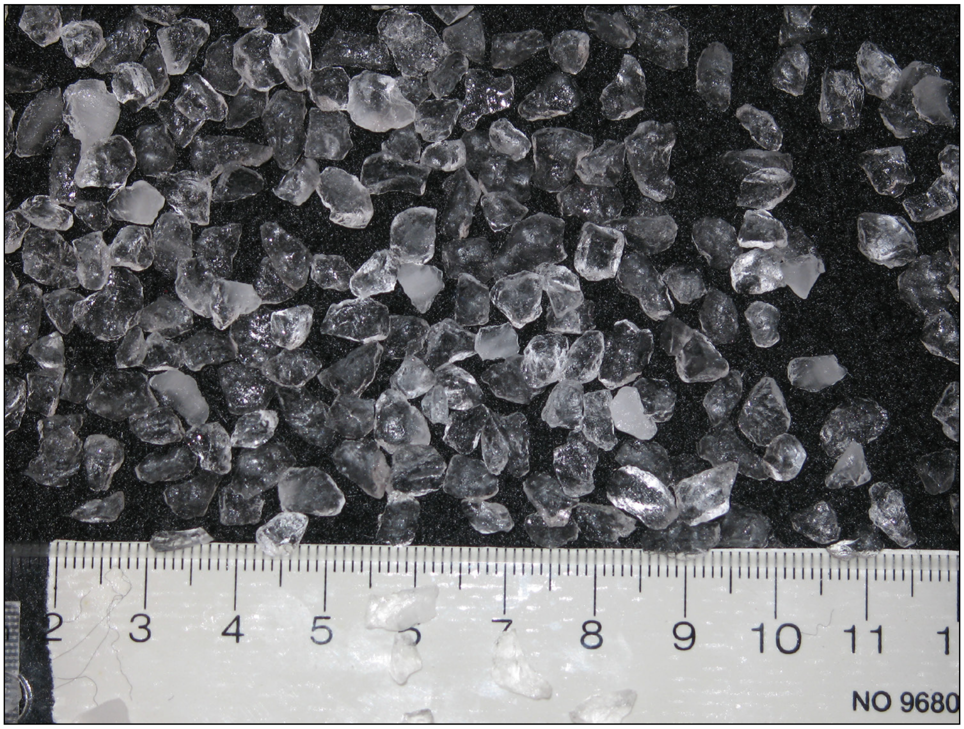

Photo 2.10: Fluid Thickness Measurement Using Wet Film Thickness Gauge

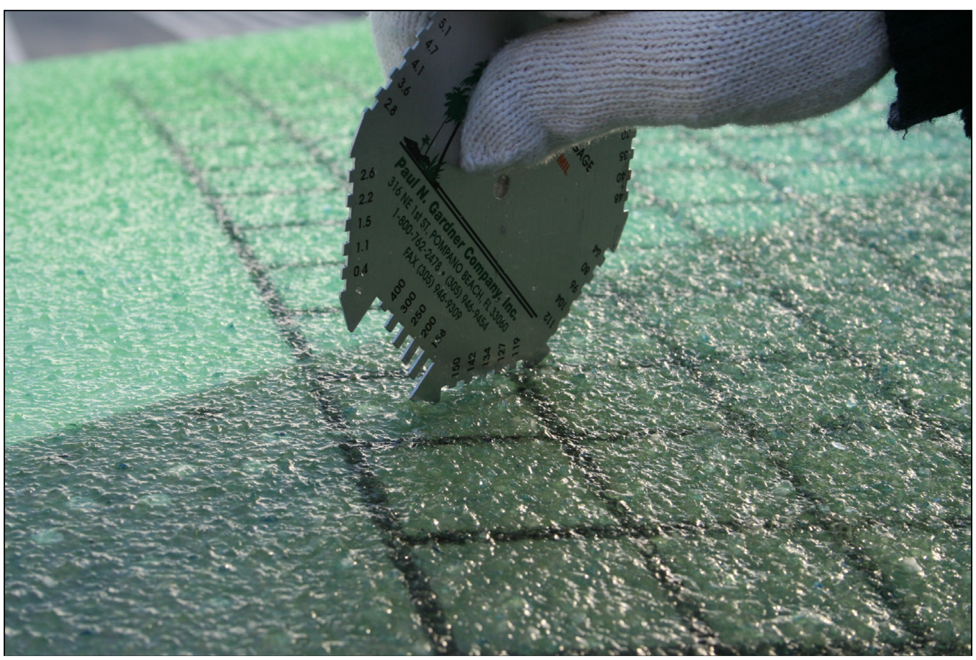

Photo 2.11: Fluid Freezing Point Measurement Using Hand-held Refractometer

Photo 2.12: Wing Surface Temperature Measurement

Photo 2.13: Temporary Structure Fitted with Camera-Mounting Capability

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3. DESCRIPTION AND PROCESSING OF DATA

This section provides an overview of each run conducted as part of the test program. The parameters for each run are detailed, and a description of the data collected during each run is provided.

3.1 Overview of Tests

A summary of the tests conducted is shown in Table 3.1. More detailed summaries of the pertinent parameters for each run are provided in Subsections 3.1.1 to 3.1.9.

Table 3.1: Summary of 2005-06 Testing with Falcon 20

RUN NUMBER	1	2	3	4	5	6	7	8	9
Date	09-Mar-06	09-Mar-06	15-Mar-06	15-Mar-06	16-Mar-06	16-Mar-06	16-Mar-06	17-Mar-06	17-Mar-06
Fluid	Ultra +	ABC-S	ABC-S	ABC-S	ABC-S	Ultra +	Ultra +	ABC-S	Type I EG
Fluid Dilution	100%	100%	100%	100%	100%	100%	100%	100%	10°C buffer
Pellets Size [mm]	3.35 - 4.75	3.35 - 4.75	3.35 - 4.75	1.0 - 3.35	1.0 - 3.35	1.0 - 3.35	<3.35 unprocessed	<3.35 unprocessed	1.0 - 3.35
Actual Precip. Rate for 20 min (T-IV) and 11 min (T-I) [g/dm^2/h]	24.8	N/A	24.8	24.8	83.5	83.5	167.0	136.3	33.0
Approx Avg Wing Temp before Fluid Application [°C]	-2.7	-2.9	-5	-3.5	-8.2	-3.2 to -7.1	-3.7 to -5.5	-9.5	-9
OAT [°C]	-5	-4	-6	-6	-8	-8	-7	-9	-10
Wind Direction/Speed	105/12 kt	105/10 kt	270/16 kt	300/17 kt	305/12 kt	315/18 kt	315/14 kt	335/12 kt	335/14 kt
Sky Condition	Overcast	Overcast	Overcast	Mostly overcast	Scatted clouds	Mostly sunny	Mostly sunny	Clear (sunrise)	Sunny
Precipitation	Nil	-ZR	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Video Camera (mounted on window)	Wide / Zoom	Wide / Zoom	Zoom	Zoom	Zoom	Zoom	Zoom	Zoom	Zoom
Still Camera (mounted on window)	Nil / Nil	Nil / Nil	Zoom	Zoom	Zoom / N/A	Zoom	Zoom	Zoom	Zoom
Remarks		Test aborted due to freezing rain		Brakes seized after test	Still camera N/A		Emergency of other A/C caused delayed T/O. Precip. melted after exposure to direct sunlight	Slush remained aft of approx 20% LE	Small spots of ice adhered, fluid app method not representative of ops; more heat would have generated more adhesion

3.1.1 Run 1 – March 9, 2006

- Fluid and dilution: Ultra+ (100%)
- Ice pellets size: 3.35 mm – 4.75 mm
- Test area: 3.6 m^2
- Quantity of ice pellets dispensed: 3.75 kg
- Quantity of ice pellets applied to test area: 3 kg
- Simulated precipitation rate: 24.8 $g/dm^2/h$
- Dyed pellets used: No
- Pellets application: Leading and Trailing Edge
- Approximate test start time: 07:10:00
- Average Wing Temperature: -2.7ºC
- Ambient temperature: -5ºC
- Wind direction / speed: 105º / 12 knots
- Sky condition: Overcast
- Runway used: 07
- Fluid application start time: 07:18:00
- Fluid application end time: 07:24:00
- Fluid quantity applied: 16 L Type IV EG
- Departure time from deicing pad: 07:45:00
- Ice pellets application start time: 08:03:00
- Ice pellets application end time: 08:05:00
- Start of takeoff roll: 08:06:37
- End of acceleration: 08:06:59
- Return time to deicing pad: 08:13:00

Figure 3.1 shows the velocity of the aircraft in knots (y-axis) as a function of time in seconds (x-axis) during Run 1. This data was provided by NRC.

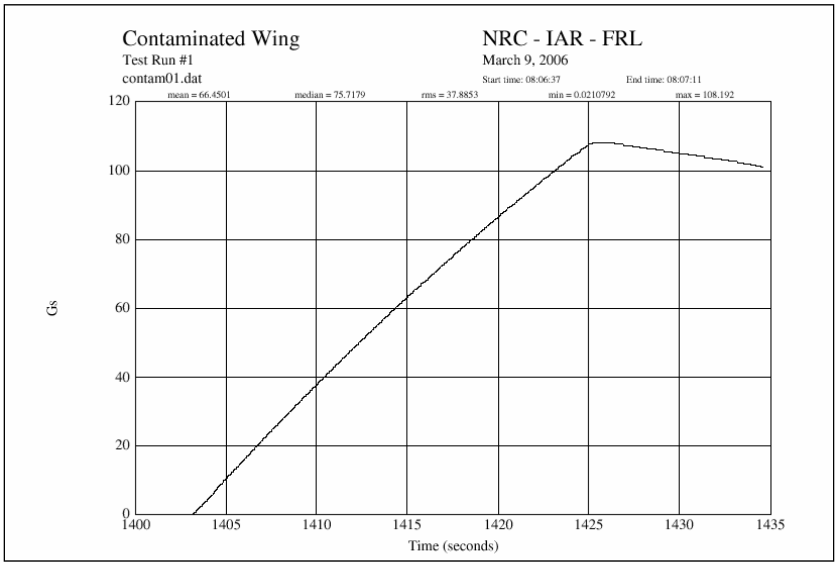


Figure 3.1: Run 1 – March 9, 2006

3.1.2 Run 2 – March 9, 2006

- Fluid and dilution: ABC-S (100%)
- Ice pellets size: 3.35 mm – 4.75 mm
- Test area: 3.6 m^2
- Quantity of ice pellets dispensed: N/A
- Quantity of ice pellets applied to test area: N/A
- Simulated precipitation rate: N/A
- Dyed pellets used: N/A
- Pellets application: N/A
- Approximate test start time: 08:54:00
- Average Wing Temperature: -2.9ºC
- Ambient temperature: -4ºC
- Wind direction / speed: 105º / 10 knots
- Sky condition: Overcast / Freezing Rain
- Runway used: N/A
- Fluid application start time: 08:54:00
- Fluid application end time: 09:00:30
- Fluid quantity applied: 15.5 L Type IV PG

- Departure time from deicing pad: N/A
- Ice pellets application start time: N/A
- Ice pellets application end time: N/A
- Quantity of ice pellets applied to test area: N/A
- Equivalent precipitation rate: N/A
- Start of takeoff roll: N/A
- End of acceleration: N/A
- Return time to deicing pad: N/A

Remark: Test aborted due to freezing rain.

3.1.3 Run 3 – March 15, 2006

- Fluid and dilution: ABC-S (100%)
- Ice pellets size: 3.35 mm – 4.75 mm
- Test area: 3.6 m^2
- Quantity of ice pellets dispensed: 3.75 kg
- Quantity of ice pellets applied to test area: 3 kg
- Simulated precipitation rate: 24.8 $g/dm^2/h$
- Dyed pellets used: Yes
- Pellets application: Leading and Trailing Edge
- Approximate test start time: 07:05:00
- Average Wing Temperature: -5ºC
- Ambient temperature: -6ºC
- Wind direction / speed: 270º/ 16 knots
- Sky condition: Overcast
- Runway used: 25
- Fluid application start time: 07:05:00
- Fluid application end time: 07:09:30
- Fluid quantity applied: 20 L Type IV PG
- Departure time from deicing pad: 07:22:00
- Ice pellets application start time: 07:36:00

- Ice pellets application end time: 07:38:00
- Start of takeoff roll: 07:46:00
- End of acceleration: 07:46:26
- Return time to deicing pad: 07:54:30

Figure 3.2 shows the velocity of the aircraft during Run 3.

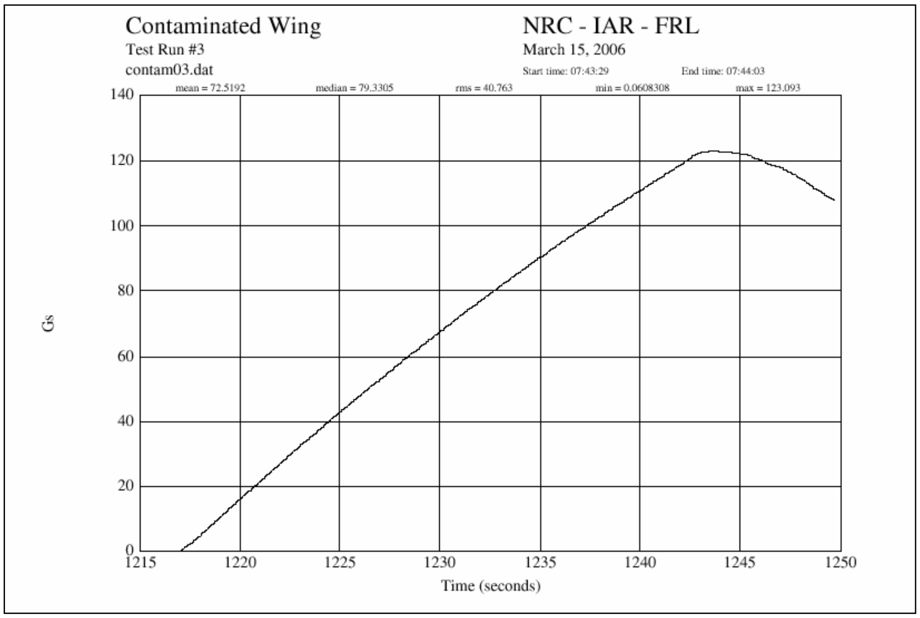


Figure 3.2: Run 3 – March 15, 2006

3.1.4 Run 4 – March 15, 2006

- Fluid and dilution: ABC-S (100%)
- Ice pellets size: 1.0 mm – 3.35 mm
- Test area: 3.6 m^2
- Quantity of ice pellets dispensed: 3.75 kg
- Quantity of ice pellets applied to test area: 3 kg
- Simulated precipitation rate: 24.8 $g/dm^2/h$
- Dyed pellets used: Yes
- Pellets application: Leading and Trailing Edge
- Approximate test start time: 08:03:00
- Average Wing Temperature: -3.5°C

- Ambient temperature: -6ºC
- Wind direction / speed: 300º / 17 knots
- Sky condition: Mostly overcast
- Runway used: 25
- Fluid application start time: 08:03:30
- Fluid application end time: 08:07:20
- Fluid quantity applied: 20 L Type IV PG
- Departure time from deicing pad: 08:13:00
- Ice pellets application start time: 08:19:00
- Ice pellets application end time: 08:21:00
- Start of takeoff roll: 08:26:00
- End of acceleration: 08:26:24
- Return time to deicing pad: 10:30:00

Remark: Brakes seized after the takeoff run. Aircraft was not operational for the rest of the day. NRC replaced the brakes, and the Falcon was ready for the following day.

Figure 3.3 shows the velocity of the aircraft during Run 4.

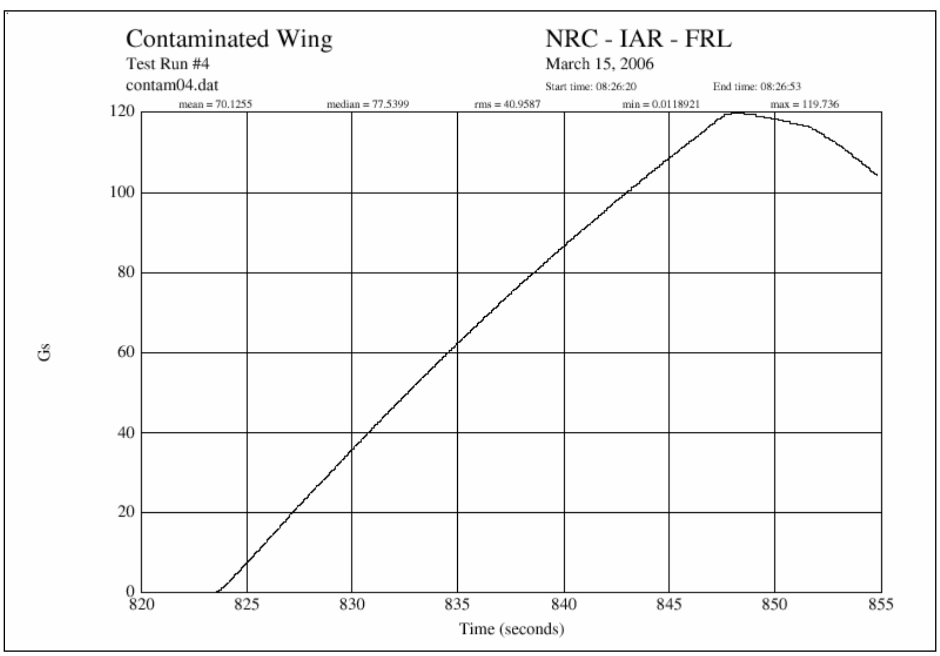


Figure 3.3: Run 4 – March 15, 2006

3.1.5 Run 5 – March 16, 2006

- Fluid and dilution: ABC-S (100%)
- Ice pellets size: 1.0 mm – 3.35 mm
- Test area: 2.7 m^2
- Quantity of ice pellets dispensed: 9.5 kg
- Quantity of ice pellets applied to test area: 7.6 kg
- Simulated precipitation rate: 83.5 $g/dm^2/h$
- Dyed pellets used: Yes
- Pellets application: Leading and Trailing Edge
- Approximate test start time: 07:05:00
- Average Wing Temperature: -8.2ºC
- Ambient temperature: -8ºC
- Wind direction / speed: 305º / 12 knots
- Sky condition: Scattered clouds
- Runway used: 25
- Fluid application start time: 07:07:00
- Fluid application end time: 07:11:00
- Fluid quantity applied: 20 L Type IV PG
- Departure time from deicing pad: 07:30:30
- Ice pellets application start time: 07:39:15
- Ice pellets application end time: 07:44:10
- Start of takeoff roll: 07:49:15
- End of acceleration: 07:49:42
- Return time to deicing pad: 08:10:00

Figure 3.4 shows the velocity of the aircraft during Run 5.

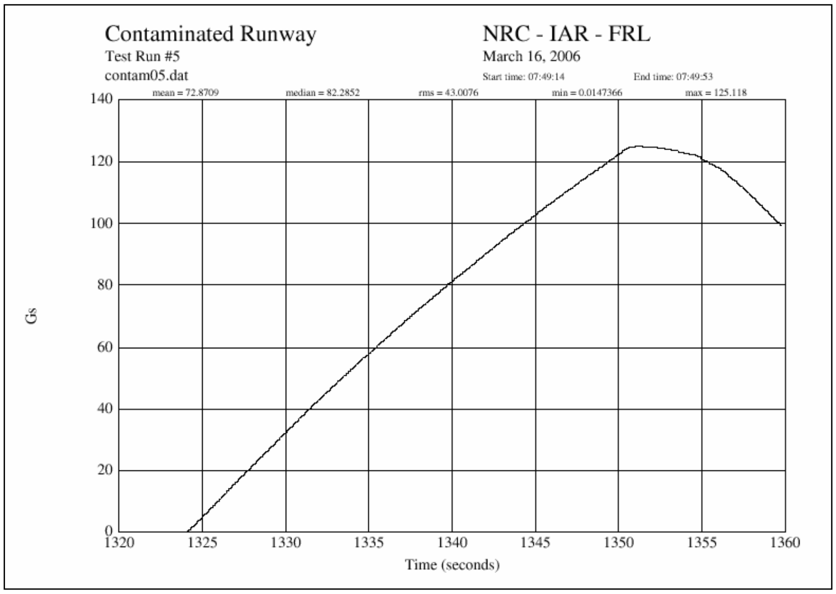


Figure 3.4: Run 5 – March 16, 2006

3.1.6 Run 6 – March 16, 2006

- Fluid and dilution: Ultra+ (100%)
- Ice pellets size: 1.0 mm – 3.35 mm
- Test area: 2.7 m^2
- Quantity of ice pellets dispensed: 9.5 kg
- Quantity of ice pellets applied to test area: 7.6 kg
- Simulated precipitation rate: 83.5 $g/dm^2/h$
- Dyed pellets used: Yes
- Pellets application: Leading and Trailing Edge
- Approximate test start time: 08:15:00
- Average Wing Temperature: -3.2 to -7.1ºC
- Ambient temperature: -8ºC
- Wind direction / speed: 315º / 18 knots
- Sky condition: Mostly sunny
- Runway used: 25
- Fluid application start time: 08:22:00
- Fluid application end time: 08:28:45
- Fluid quantity applied: 20 L Type IV EG

- Departure time from deicing pad: 08:48:40
- Ice pellets application start time: 08:55:45
- Ice pellets application end time: 09:00:00
- Start of takeoff roll: 09:06:00
- End of acceleration: 09:06:24
- Return time to deicing pad: 09:20:00

Figure 3.5 shows the velocity of the aircraft during Run 6.

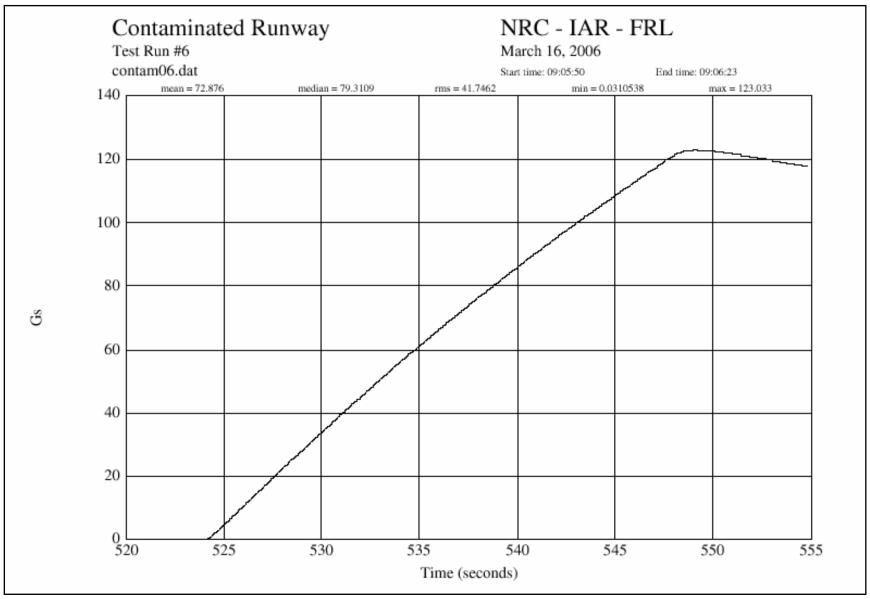


Figure 3.5: Run 6 – March 16, 2006

3.1.7 Run 7 – March 16, 2006

- Fluid and dilution: Ultra+ (100%)
- Ice pellets size: less than 3.35 mm
- Test area: 2.7 m^2
- Quantity of ice pellets dispensed: 19 kg
- Quantity of ice pellets applied to test area: 15.2 kg
- Simulated precipitation rate: 167 $g/dm^2/h$
- Dyed pellets used: Yes
- Pellets application: Leading and Trailing Edge
- Approximate test start time: 09:24:00
- Average Wing Temperature: -3.7 to -5.5°C

- Ambient temperature: -7ºC
- Wind direction / speed: 315º / 14 knots
- Sky condition: Mostly Sunny
- Runway used: 25
- Fluid application start time: 09:24:00
- Fluid application end time: 09:27:45
- Fluid quantity applied: 20 L Type IV EG
- Departure time from deicing pad: 09:33:00
- Ice pellets application start time: 09:40:00
- Ice pellets application end time: 09:48:00
- Start of takeoff roll: 10:10:00
- End of acceleration: 10:10:23
- Return time to deicing pad: 10:26:00

Remark: Takeoff run delayed by the emergency declared by another aircraft. The takeoff roll started approximately 22 minutes after ice pellet application. During this time, the aircraft was exposed to direct sunlight and, as a result, a significant part of the simulated precipitation melted.

Figure 3.6 shows the velocity of the aircraft during Run 7.

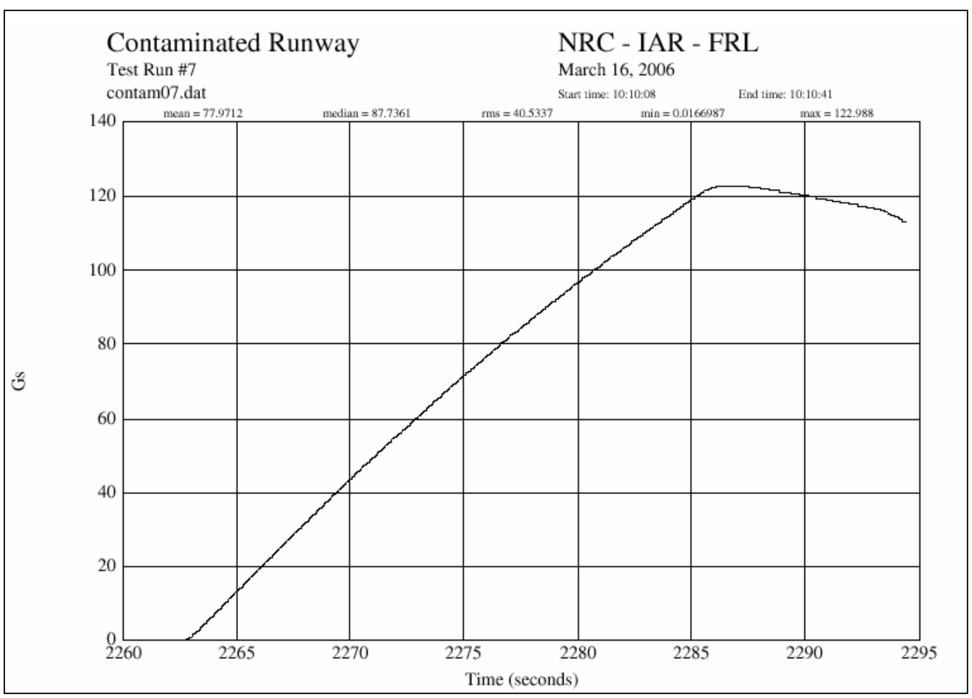


Figure 3.6: Run 7 – March 16, 2006

3.1.8 Run 8 – March 17, 2006

- Fluid and dilution: ABC-S (100%)
- Ice pellets size: less than 3.35 mm
- Test area: 2.7 m^2
- Quantity of ice pellets dispensed: 15.5 kg
- Quantity of ice pellets applied to test area: 12.4 kg
- Simulated precipitation rate: 136.3 $g/dm^2/h$
- Dyed pellets used: Yes
- Pellets application: Leading and Trailing Edge
- Approximate test start time: 06:04:00
- Average Wing Temperature: -9.5ºC
- Ambient temperature: -9ºC
- Wind direction / speed: 335º / 12 knots
- Sky condition: Clear
- Runway used: 25
- Fluid application start time: 06:06:00
- Fluid application end time: 06:10:30
- Fluid quantity applied: 20 L Type IV PG
- Departure time from deicing pad: 06:29:00
- Ice pellets application start time: 06:38:00
- Ice pellets application end time: 06:53:00
- Start of takeoff roll: 07:02:00
- End of acceleration: 07:02:25
- Return time to deicing pad: 07:17:00

Figure 3.7 shows the velocity of the aircraft during Run 8.

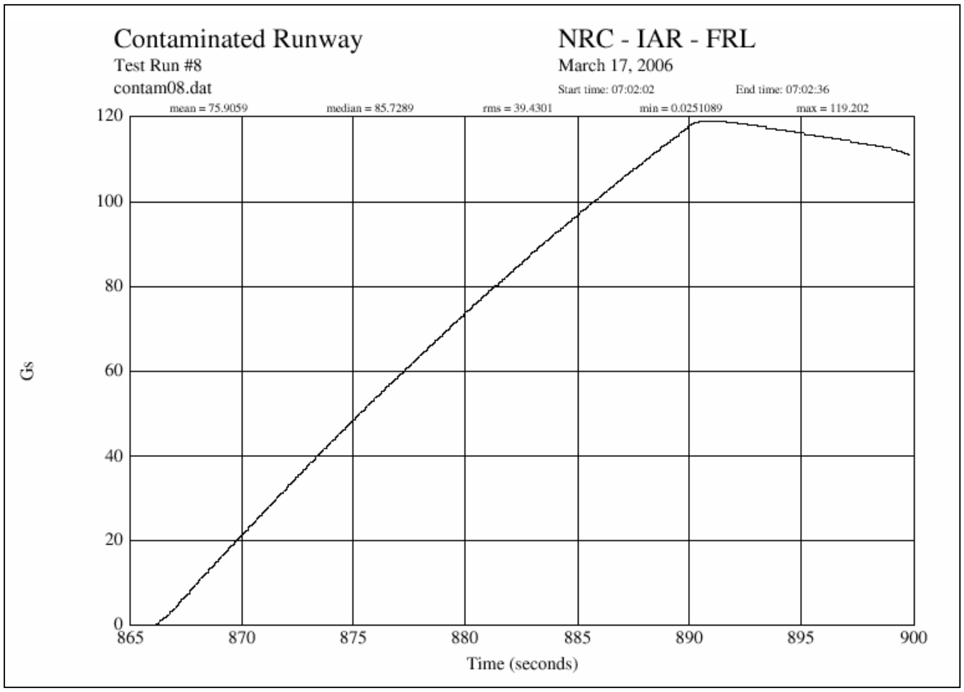


Figure 3.7: Run 8 – March 17, 2006

3.1.9 Run 9 – March 17, 2006

• Fluid and dilution:	Type I EG (10ºC buffer)
• Ice pellets size:	1.0 mm – 3.35 mm
• Test area:	2.7 m^2
• Quantity of ice pellets dispensed:	2.1 kg
• Quantity of ice pellets applied to test area:	1.7 kg
• Simulated precipitation rate:	33 $g/dm^2/h$
• Dyed pellets used:	Yes
• Pellets application:	Leading and Trailing Edge
• Approximate test start time:	07:43:00
• Average Wing Temperature:	-9ºC
• Ambient temperature:	-10ºC
• Wind direction / speed:	335º / 14 knots
• Sky condition:	Sunny
• Runway used:	25
• Fluid application start time:	08:00:00

- Fluid application end time: 08:01:30
- Fluid quantity applied: 4 L Type I EG @ 80ºC
- Departure time from deicing pad: 07:54:15
- Ice pellets application start time: 08:01:00
- Ice pellets application end time: 08:02:45
- Start of takeoff roll: 08:08:05
- End of acceleration: 08:08:30
- Return time to deicing pad: 08:21:00

Remark: Type I EG fluid heated to 80°C was applied at the runway button.

Figure 3.8 shows the velocity of the aircraft during Run 9.

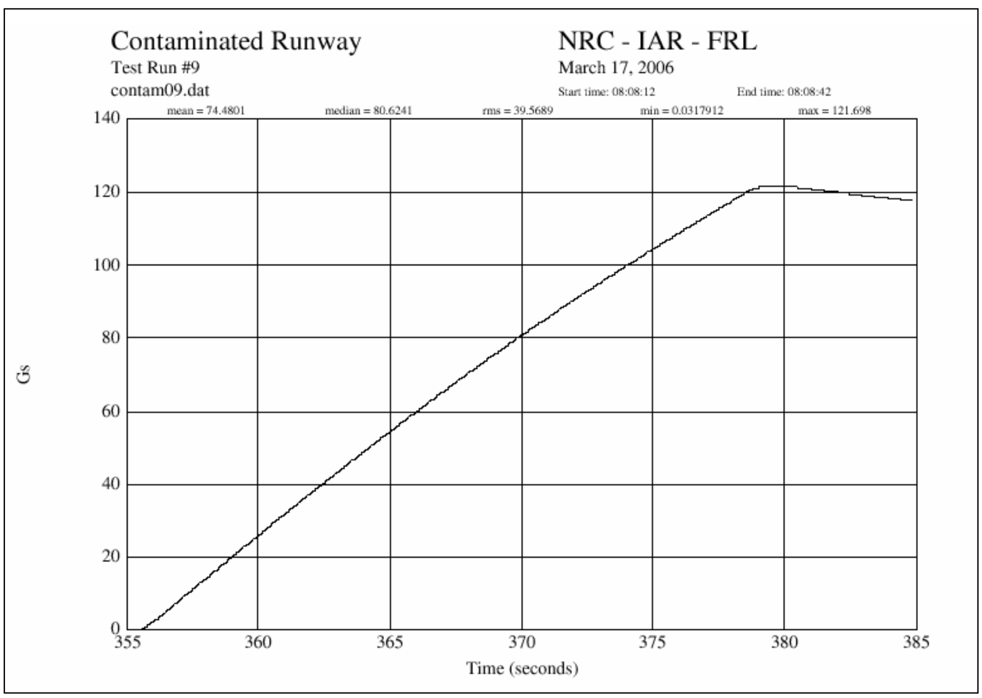


Figure 3.8: Run 9 – March 17, 2006

3.2 Timing of Operations

Figure 3.9 and Table 3.2 summarize the timing of the most important operations taking place during each run.

Table 3.2: Time Log of Events for Falcon 20 2005-06 Tests

OPERATION	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9
Date	09-Mar-06	09-Mar-06	15-Mar-06	15-Mar-06	16-Mar-06	16-Mar-06	16-Mar-06	17-Mar-06	17-Mar-06
Pilots Board	7:30:00		7:02:00		7:05:00		on board	6:04:00	7:43:00
Start Engines			7:11:00		7:17:30		eng on	6:19:00	7:46:00
Fluid Application Start	7:18:00	8:54:00	7:05:00	8:03:30	7:07:00	8:22:00	9:24:00	6:06:00	8:00:00[3]
Fluid Application Complete	7:24:00	9:00:30	7:09:30	8:07:20	7:11:00	8:28:45	9:27:45	6:10:30	8:01:30[3]
Measure Fluid and Air Temperature	7:26:00	9:04:00	7:14:00	8:09:00	7:05:00	8:33:00	9:31:00	6:10:00	7:41:00
Close Door			7:19/7:24[1]	8:12:00	7:15:00	8:40:00	9:32:00	6:17:00	7:43:00
Ready to Roll					7:30:00				7:51:00
Start Taxi	7:45:00		7:22:00	8:13:00	7:30:30	8:48:40	9:33:00	6:29:00	7:54:15
Arrive Runway Hold			7:32:00	8:16:45	7:35:50	8:54:00	9:37:00	6:34:00	7:58:15
Door Open			7:33:00	8:17:00	7:36:30	8:54:00	9:37:00	6:34:00	7:58:45
Measure Fluid Thickness, Brix and Temperature	8:02:00			8:10:20	7:38:00	8:55:30	9:40:00	6:16:00	
Pellet Application Start	8:03:00		7:36:00	8:19:00	7:39:15	8:55:45	9:40:00	6:38:00	8:01:00
Pellet Application Complete	8:05:00		7:38:00	8:21:00	7:44:10	9:00:00	9:48:00	6:53:00	8:02:45
Measure Fluid Thickness, Brix and Temperature			7:41:00	8:24:00	7:45:00	9:02:45	9:48:00	6:56:00	
Door Closed			7:41:00	8:24:00	7:47:20	9:03:30	9:49:00	6:57:00	8:04:00
Taxi to Take Off	8:05:00				7:49:00		10:06:00	7:02:00	
Start Cameras					7:49:15				8:07:50
Start Take Off Roll	8:06:37		7:46:00	8:26:00	7:49:15	9:06:00	10:10:00	7:02:00	8:08:05
End Acceleration	8:06:59		7:46:26	8:26:24	7:49:42	9:06:24	10:10:23	7:02:24	8:08:27
End Take Off Roll	8:07:30		7:46:36	8:26:45	7:50:10	9:06:40	10:11:00	7:02:45	8:09:02
Look for Remaining Pellets and Record	8:13:00		7:48:00	8:30:30	7:52:00	9:11:00	10:13:00	7:09:00	8:10:30
Arrive at Hanger	8:13:00		7:54:30	10:30:00[2]	8:10:00	9:20:00	10:26:00	7:17:00	8:21:00
Engine Shut Down	8:13:00			10:31:00	8:12:00		10:26:00	7:18:00	8:21:50
Door Open	8:13:00		7:55:00	10:32:00	8:13:00	9:21:00	10:26:00	7:18:00	8:22:10
Measure Fluid Thickness, Brix and Temperature	8:17:00		7:48:00	8:30:30	7:55:00	9:12:00	10:14:00	7:10:00	
Record Wing Condition	8:17:00		7:48:00	8:31:00	7:58:00	9:12:00	10:14:00	7:10:00	8:15:00
Remarks		Run aborted due to ZR	[1]Second pilot arrived at 7:24	[2]Brake problems	Still camera N/A	No engine shut down after run	Takeoff delayed by other A/C emergency		[3]Fluid applied at button

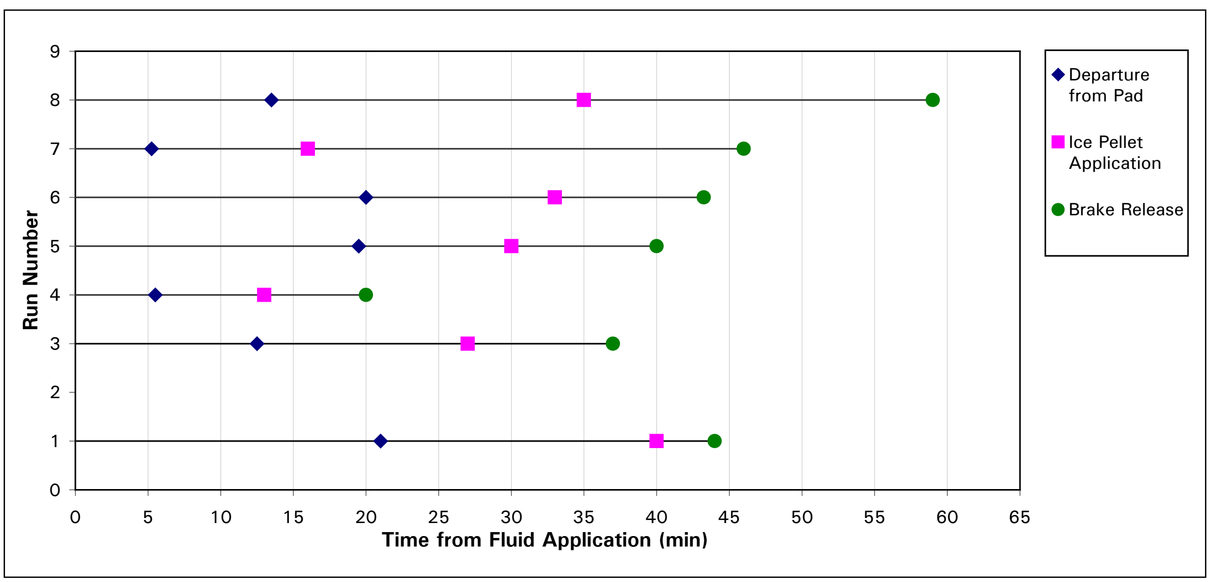


Figure 3.9: Timing of Major Operations from Fluid Application for Runs 1 to 8

3.3 Discussion of the Effective Precipitation Rate

The methodology of testing was discussed in Section 2. In that section, it was noted that a controlled quantity of ice pellets was applied at the runway button for each run. Following application of the ice pellets, a variable period of time was required to take measurements, board the aircraft, and position the aircraft for the simulated takeoff run. The timing of these events for each run was shown in Subsection 3.2.

The variation in time delays encountered throughout the test runs required a normalization of the precipitation rate data. The precipitation rate data can be presented in three different forms:

- Actual ice pellet application rate ($R_{actual\ appl}$): accounts for the quantity of ice pellets applied, the test area, and the actual ice pellet application time;
- Ice pellet application to takeoff precipitation rate ($R_{IP\text{-}takeoff}$): accounts for the quantity of ice pellets applied, the test area, and the time between the ice pellet application and the beginning of the takeoff run; and
- Effective precipitation rate ($R_{effective}$): normalized precipitation rate assuming a 20-minute effective time between ice pellet application and takeoff run for Type IV fluids and an 11-minute time for the Type I fluid.

Table 3.3 presents the three precipitation rates for each run. The effective precipitation rate ($R_{effective}$) is used throughout the report to illustrate the amount of ice pellets applied to the test area.

Table 3.3: Precipitation Rates Achieved for Each Run

Run No.	$\Delta t_{IP\ Appl.}$ (min)	$R_{actual\ Appl.}$ ($g/dm^2/h$)	$\Delta t_{IP\text{-}takeoff}$ (min)	$R_{IP\text{-}takeoff}$ ($g/dm^2/h$)	$\Delta t_{Effective}$ (min)	$R_{Effective}$ ($g/dm^2/h$)
1	2.0	252	3.6	138	20	25
2	-	-	-	-	-	-
3	2.0	252	10.0	50	20	25
4	2.0	252	7.0	71	20	25
5	4.9	343	10.0	170	20	84
6	4.3	396	10.3	165	20	84
7	8.0	423	30.0	112	20	167
8	5.0	553	24.0	114	20	136
9	1.8	216	7.0	54	11	33

3.4 Description of Data Collected for Each Run

During each run, data was collected for the following variables:

a) Fluid thickness;
b) Wing skin temperature; and
c) Fluid freezing point.

The data collected during each run for each of these variables is discussed in Subsections 3.4.1 to 3.4.9.

A series of photos was also taken during each run to visually document the testing. The Run 4 and Run 8 photos have been included in Appendix E. Photos for the other runs are available upon request.

3.4.1 Run 1 – March 9, 2006

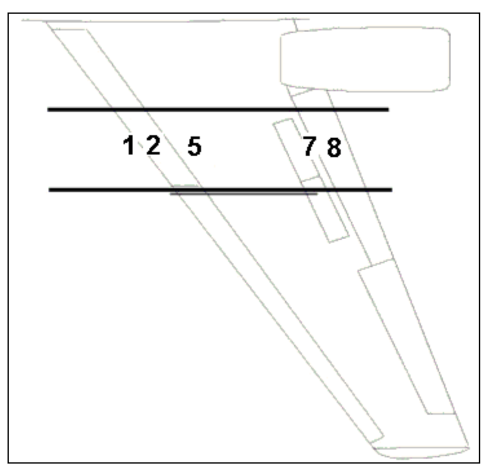
Run 1 was conducted with Neat EG Type IV fluid poured on the 3.6 m^2 test area on the port wing. A total of 3 kg of ice pellets (3.35 mm to 4.75 mm in diameter) were applied to the test area at the runway button, yielding an effective precipitation rate of 24.8 $g/dm^2/h$.

3.4.1.1 Fluid Thickness Measurements

Fluid thickness measurements were recorded at five positions along the centreline of the test area. The measurements were taken after fluid application, before ice pellet application, after ice pellet application, and after the simulated takeoff run. Measurements for Run 1 are shown in Table 3.4.

Table 3.4: Fluid Thickness Measurements for Run 1

Wing Position (see diagram)	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	0.8	0.7	0.7	0.0
2	1.3	1.2	1.3	0.0
5	4.5	4.5	5.7	0.2
7	2.2	1.8	1.8	0.4
8	2.5	0.8	0.6	0.2

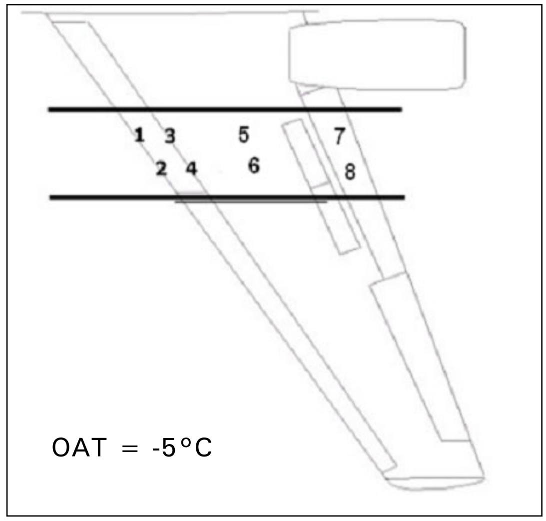


3.4.1.2 Wing Skin Temperatures

Wing skin temperatures were recorded at eight positions on the test area. The first run measurements were taken before the takeoff roll only. Wing temperatures for Run 1 are shown in Table 3.5.

Table 3.5: Wing Temperature Measurements for Run 1

Wing Position (see diagram)	Wing Temperature Before Takeoff Run (°C)	Wing Temperature After Takeoff Run (°C)
1	-1.9	N/A
2	-2.3	N/A
3	-2.5	N/A
4	-2.7	N/A
5	-3.3	N/A
6	-3.0	N/A
7	-2.8	N/A
8	-2.8	N/A



Prior to takeoff, the wing temperatures ranged from -3.3°C to -1.9°C (see Table 3.5). The readings were taken at the NRC pad following the fluid application. The ambient air temperature at the start of testing was -5°C; the sky condition was overcast.

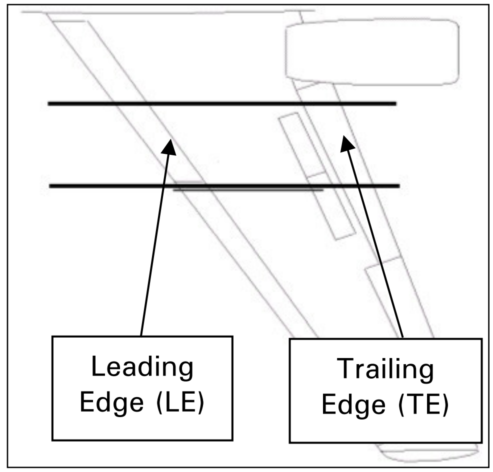
3.4.1.3 Fluid Freezing Point Measurements

Fluid freezing points were measured on the leading and trailing edges of the test area. The measurements were taken after fluid application, before the ice pellet application, after the ice pellet application, and after the simulated takeoff run.

The fluid freezing points were read directly off the refractometer (in °Brix) and converted to a freezing point in degrees Celsius using the Dow Ultra+ conversion chart (see Figure 2.6). The freezing points of the fluid on the wings of the Falcon 20 at the departure runway are shown in Table 3.6.

Table 3.6: Fluid Freezing Point Measurements for Run 1

Wing Position (see diagram)	Fluid Freezing Points (ºC)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
Leading Edge	-60	-60	-54	-49
Trailing Edge	-60	-60	-44	-49



3.4.2 Run 2 – March 9, 2006

Run 2 was to be conducted with neat PG Type IV fluid poured on the 3.6 m^2 test area on the port wing. A total of 3 kg of ice pellets (3.35 mm to 4.75 mm in diameter) were prepared for application on the test area at the runway button, yielding an effective precipitation rate of 24.8 g/dm^2/h.

Run 2 was not completed as freezing rain precipitation occurred at the beginning of the test. NRC flight crew considered the runway too slippery for the successful completion of the run.

3.4.3 Run 3 – March 15, 2006

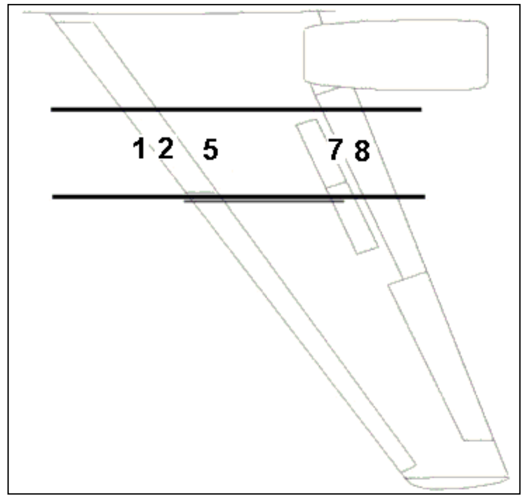
Run 3 was conducted with Neat PG Type IV fluid poured on the 3.6 m^2 test area on the port wing. A total of 3 kg of ice pellets (3.35 mm to 4.75 mm in diameter) were applied to the test area at the runway button, yielding an effective precipitation rate of 24.8 g/dm^2/h.

3.4.3.1 Fluid Thickness Measurements

Fluid thickness measurements were recorded at five positions along the centreline of the test area. The measurements were taken after fluid application, before ice pellet application, after ice pellet application, and after the simulated takeoff run. Measurements for Run 3 are shown in Table 3.7.

Table 3.7: Fluid Thickness Measurements for Run 3

Wing Position (see diagram)	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	0.7	0.6	1.1	0.1
2	1.8	2.2	2.9	0.2
5	5.7	4.5	4.5	0.2
7	1.8	1.5	2.7	0.2
8	2.2	0.7	2.5	0.2

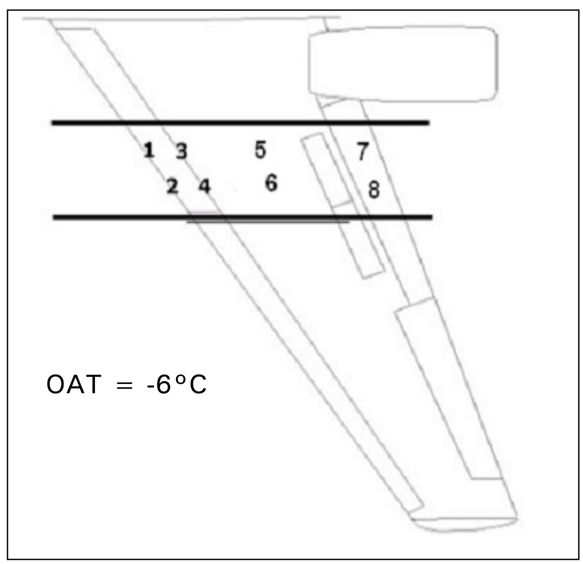


3.4.3.2 Wing Skin Temperatures

Wing skin temperatures were recorded at eight positions on the test area. The measurements were taken before and after the takeoff roll. Temperatures for Run 3 are shown in Table 3.8.

Table 3.8: Wing Temperature Measurements for Run 3

Wing Position (see diagram)	Wing Temperature Before Takeoff Run (°C)	Wing Temperature After Takeoff Run (°C)
1	-5.2	N/A
2	-5.0	N/A
3	-4.6	-4.2
4	-4.7	-4.2
5	-4.5	-5.2
6	-4.7	-5.2
7	-5.5	N/A
8	-5.5	N/A



Prior to the simulated takeoff, the wing temperatures ranged from -4.5°C to -5.5°C. At the end of the run, they varied between -4.2°C and -5.2°C. The readings were taken at the NRC pad after the fluid application and immediately after the takeoff roll. The ambient air temperature at the start of testing was -6°C. The test conditions were ideal: the sky was overcast, minimizing the solar radiation heating the wing surface.

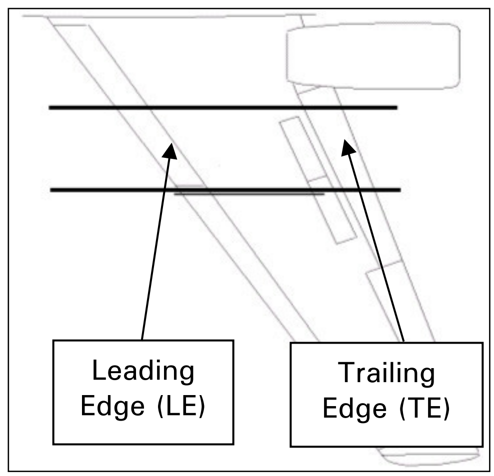
3.4.3.3 Fluid Freezing Point Measurements

Fluid freezing points were measured on the leading and trailing edges of the test area. The measurements were taken after fluid application, before the ice pellet application, after the ice pellet application, and after the simulated takeoff run.

The fluid freezing points were read directly off the refractometer (in °Brix) and converted to a freezing point in degrees Celsius using the Kilfrost ABC-S conversion table (see Table 2.4). The freezing points of the fluid on the wings at the departure runway are shown in Table 3.9.

Table 3.9: Fluid Freezing Point Measurements for Run 3

Wing Position (see diagram)	Fluid Freezing Points (°C)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
Leading Edge	-37	-37	-35	-26
Trailing Edge	-37	-37	-30	-30



3.4.4 Run 4 – March 15, 2006

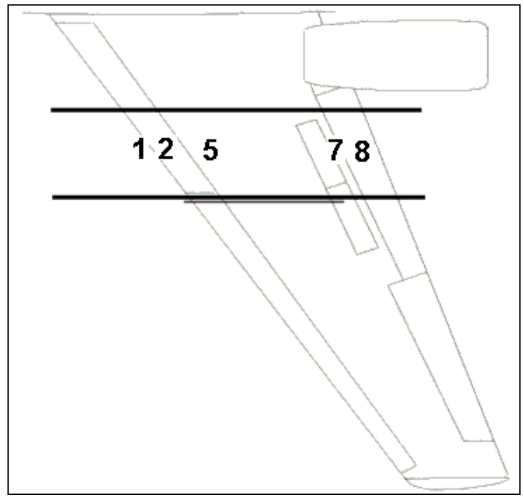
Run 4 was conducted with Neat PG Type IV fluid poured on the 3.6 m^2 test area on the port wing. A total of 3 kg of ice pellets (1.0 mm to 3.35 mm in diameter) were applied to the test area at the runway button, yielding an effective precipitation rate of 24.8 $g/dm^2/h$.

3.4.4.1 Fluid Thickness Measurements

Fluid thickness measurements were recorded at five positions along the centreline of the test area. The measurements were taken after fluid application, before ice pellet application, after ice pellet application, and after the simulated takeoff run. Measurements for Run 4 are shown in Table 3.10.

Table 3.10: Fluid Thickness Measurements for Run 4

Wing Position (see diagram)	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.1	0.7	1.1	0.1
2	2.2	1.7	2.5	0.1
5	4.5	3.9	4.5	0.2
7	2.5	1.8	2.2	0.2
8	1.5	1.1	1.8	0.2



3.4.4.2 Wing Skin Temperatures

Wing skin temperatures were recorded at eight positions on the test area. On the fourth run, measurements were taken before the takeoff roll only. Temperatures for Run 4 are shown in Table 3.11.

Prior to the simulated takeoff, the wing temperatures ranged from -3.8°C to -3.6°C (see Table 3.11). The readings were taken at the NRC pad following the fluid application. The ambient air temperature at the start of testing was -6°C. The sky condition was overcast, which minimized solar radiation.

3.4.4.3 Fluid Freezing Point Measurements

Fluid freezing points were measured on the leading and trailing edges of the test area. The measurements were taken after fluid application, before the ice pellet application, after the ice pellet application, and after the simulated takeoff run.

The fluid freezing points were read directly off the refractometer (in ºBrix) and converted to a freezing point in degrees Celsius using the Kilfrost ABC-S conversion table (see Table 2.4). The freezing points of the fluid on the wings at the departure runway are shown in Table 3.12.

Table 3.11: Wing Temperature Measurements for Run 4

Wing Position (see diagram)	Wing Temperature Before Takeoff Run (°C)	Wing Temperature After Takeoff Run (°C)
1	-3.6	N/A
2	-3.6	N/A
3	-3.5	N/A
4	-3.5	N/A
5	-3.7	N/A
6	-3.7	N/A
7	-3.8	N/A
8	-3.7	N/A

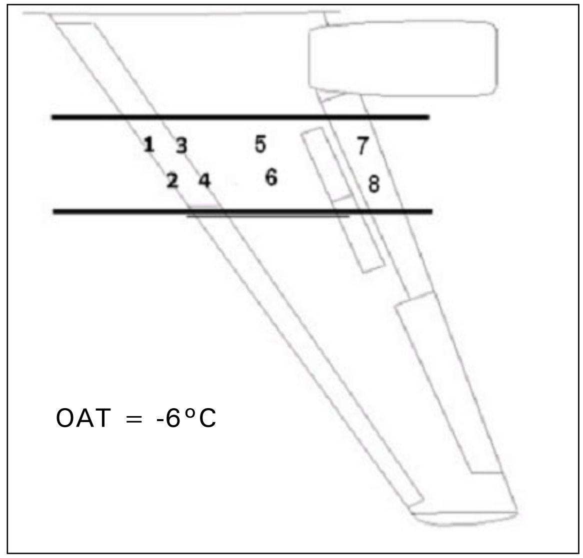
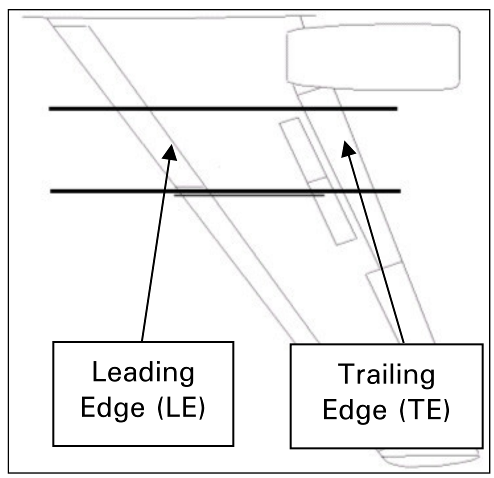


Table 3.12: Fluid Freezing Point Measurements for Run 4

Wing Position (see diagram)	Fluid Freezing Points (°C)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
Leading Edge	-37	-37	-24	-16
Trailing Edge	-37	-37	-20	-22



3.4.5 Run 5 – March 16, 2006

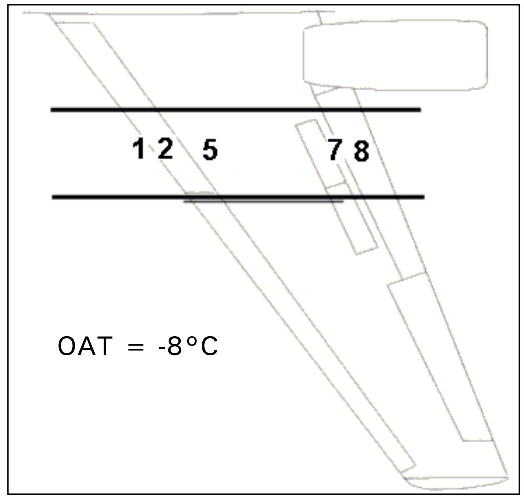
Run 5 was conducted with Neat PG Type IV fluid poured on the test area. The test surface was decreased from 3.6 m^2 to 2.7 m^2. A total of 7.6 kg of ice pellets (1.0 mm to 3.35 mm in diameter) were applied to the test area at the runway button, yielding an effective precipitation rate of 83.5 $g/dm^2/h$.

3.4.5.1 Fluid Thickness Measurements

Fluid thickness measurements were recorded at five positions along the centreline of the test area. The measurements were taken after fluid application, before ice pellet application, after ice pellet application, and after the simulated takeoff run. Measurements for Run 5 are shown in Table 3.13.

Table 3.13: Fluid Thickness Measurements for Run 5

Wing Position (see diagram)	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.0	0.5	1.1	0.1
2	2.2	1.0	2.9	0.2
5	5.7	4.5	4.5	0.2
7	2.2	1.1	3.5	0.3
8	2.7	0.8	1.8	0.2



3.4.5.2 Wing Skin Temperatures

Wing skin temperatures were recorded at eight positions on the test area. The measurements were taken before and after the takeoff roll. Temperatures for Run 5 are shown in Table 3.14.

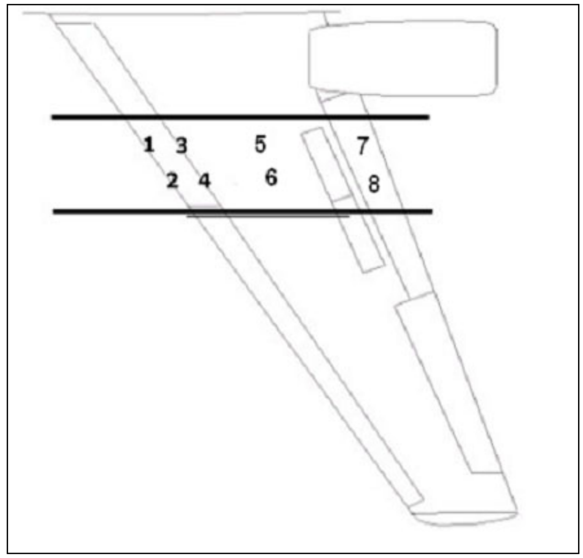
Prior to the simulated takeoff, the wing temperatures ranged from -8.6ºC to -8.0ºC (see Table 3.14). At the end of the run, they varied from -8.2ºC to -7.4ºC. The readings were taken at the NRC pad before the fluid application and immediately after the takeoff roll. The ambient air temperature at the start of testing was -8ºC; the sky condition was scattered clouds.

3.4.5.3 Fluid Freezing Point Measurements

Fluid freezing points were measured on the leading and trailing edges of the test area. The measurements were taken after fluid application, before the ice pellet application, after the ice pellet application, and after the simulated takeoff run.

Table 3.14: Wing Temperature Measurements for Run 5

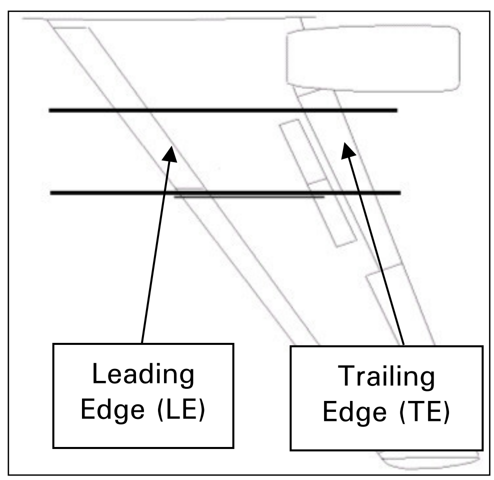
Wing Position (see diagram)	Wing Temperature Before Takeoff Run (ºC)	Wing Temperature After Takeoff Run (ºC)
1	-8.2	-7.4
2	-8.3	-8.2
3	-8.2	-7.8
4	-8.0	-7.8
5	-8.1	N/A
6	-8.3	N/A
7	-8.6	-8.2
8	-8.3	-8.2



The fluid freezing points were read directly off the refractometer (in ºBrix) and converted to a freezing point in degrees Celsius using the Kilfrost ABC-S conversion table (see Table 2.4). The freezing points of the fluid on the wings at the departure runway are shown in Table 3.15.

Table 3.15: Fluid Freezing Point Measurements for Run 5

Wing Position (see diagram)	Fluid Freezing Points (ºC)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
Leading Edge	-37	-37	-24	-16
Trailing Edge	-37	-37	-19	-18



3.4.6 Run 6 – March 16, 2006

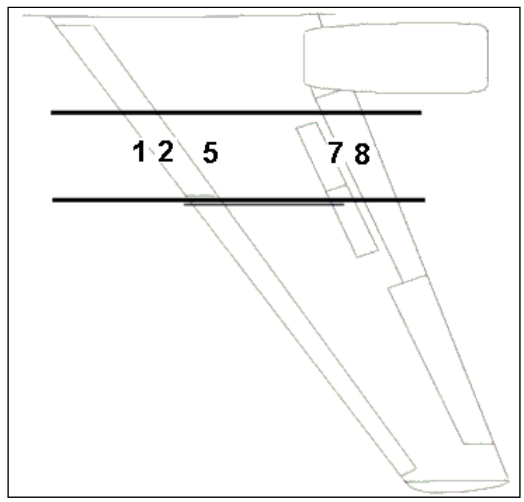
Run 6 was conducted with Neat EG Type IV fluid poured on the 2.7 m^2 test area on the port wing. A total of 7.6 kg of ice pellets (1.0 mm to 3.35 mm in diameter) were applied to the test area at the runway button, yielding an effective precipitation rate of 83.5 g/dm^2/h.

3.4.6.1 Fluid Thickness Measurements

Fluid thickness measurements were recorded at five positions along the centreline of the test area. The measurements were taken after fluid application, before ice pellet application, after ice pellet application, and after the simulated takeoff run. Measurements for Run 6 are shown in Table 3.16.

Table 3.16: Fluid Thickness Measurements for Run 6

Wing Position (see diagram)	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	0.7	0.7	0.3	0.0
2	1.8	2.2	1.8	0.0
5	4.5	4.5	5.7	0.2
7	1.8	1.5	3.5	0.2
8	1.1	1.1	1.6	0.2



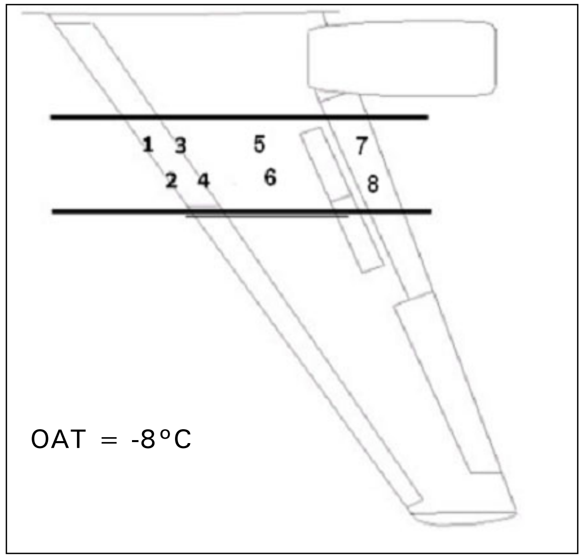
3.4.6.2 Wing Skin Temperatures

Wing skin temperatures were recorded at eight positions on the test area. The measurements were taken before and after the simulated takeoff. Temperatures for Run 6 are shown in Table 3.17.

Prior to takeoff, the wing temperatures ranged from -7.1ºC to -3.2ºC (see Table 3.17). The readings were taken at the NRC pad following the fluid application. At this location, the inboard half of the test area where measurements 1, 3, 5, and 7 were taken was in the shadow of the fuselage, while the outboard half was exposed to solar radiation. The ambient air temperature at the start of testing was -8°C; the sky condition was mostly sunny. Even though the wing skin temperatures measured at the NRC hangar had a wide range, the temperature throughout the wing surface equalized during the taxi and takeoff run. The temperature range measured after the run, -6.6ºC to -4.5ºC, confirms this.

Table 3.17: Wing Temperature Measurements for Run 6

Wing Position (see diagram)	Wing Temperature Before Takeoff Run (°C)	Wing Temperature After Takeoff Run (°C)
1	-6.7	-5.2
2	-3.3	-5.9
3	-6.4	-4.5
4	-3.2	-5.2
5	-5.8	N/A
6	-4.2	N/A
7	-7.1	-6.6
8	-5.4	-5.8



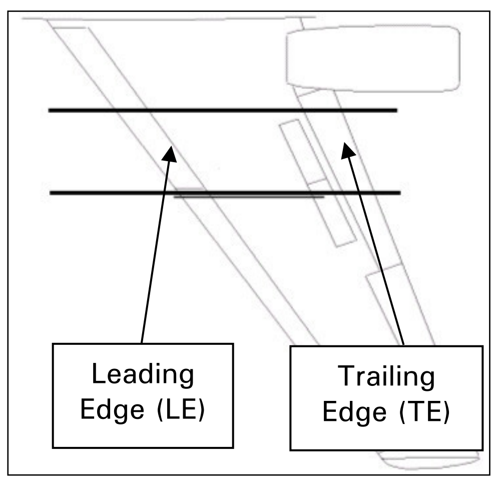
3.4.6.3 *Fluid Freezing Point Measurements*

Fluid freezing points were measured on the leading and trailing edges of the test area. The measurements were taken after fluid application, before the ice pellet application, after the ice pellet application, and after the simulated takeoff run.

The fluid freezing points were read directly off the refractometer (in °Brix) and converted to a freezing point in degrees Celsius using the Dow Ultra+ conversion chart (see Figure 2.6). The freezing points of the fluid on the wings at the departure runway are shown in Table 3.18.

Table 3.18: Fluid Freezing Point Measurements for Run 6

Wing Position (see diagram)	Fluid Freezing Points (°C)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
Leading Edge	-60	-60	-18	-39
Trailing Edge	-60	-60	-19	-41



3.4.7 Run 7 – March 16, 2006

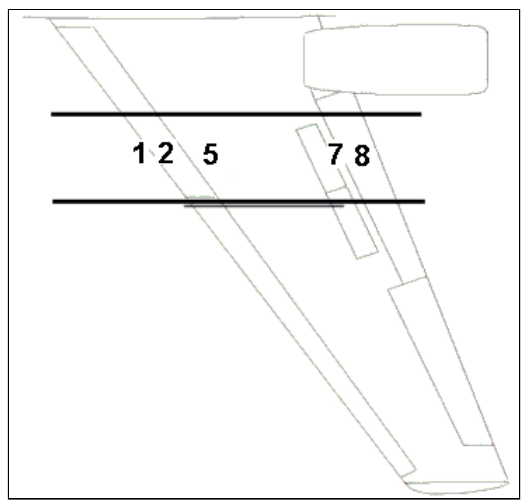
Run 7 was conducted with Neat EG Type IV fluid poured on the 2.7 m^2 test area on the port wing. A total of 15.2 kg of precipitation (unprocessed ice pellets, less than 3.35 mm in diameter) were applied to the test area at the runway button, yielding an effective precipitation rate of 167 g/dm^2/h.

3.4.7.1 Fluid Thickness Measurements

Fluid thickness measurements were recorded at five positions along the centerline of the test area. The measurements were taken after fluid application, before ice pellet application, and after the simulated takeoff run. No measurement was taken after the ice pellet application, as the pilot was required to clear the runway due to an emergency declared by another aircraft. Measurements for Run 7 are shown in Table 3.19.

Table 3.19: Fluid Thickness Measurements for Run 7

Wing Position (see diagram)	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.2	0.7	N/A	0.0
2	1.8	1.8	N/A	0.0
5	4.5	4.5	N/A	0.0
7	2.5	2.2	N/A	0.2
8	1.2	1.1	N/A	0.1



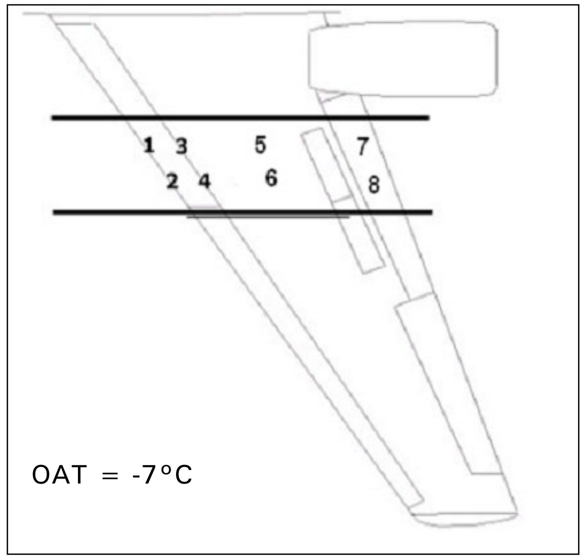
3.4.7.2 Wing Skin Temperatures

Wing skin temperatures were recorded at eight positions on the test area. The measurements were taken before and after the takeoff roll. Temperatures for Run 7 are shown in Table 3.20.

Prior to the simulated takeoff, the wing temperatures ranged from -5.2ºC to -3.7ºC (see Table 3.20). At the end of the run, they varied from -4.3ºC to -2.6ºC. The readings were taken at the NRC pad before the fluid application. A reading was taken immediately after the application of ice pellets as well. For Run 7, the wing temperature just after contamination decreased to -9.5°C. The ambient air temperature at the start of testing was -7°C; the sky condition was sunny.

Table 3.20: Wing Temperature Measurements for Run 7

Wing Position (see diagram)	Wing Temperature Before Takeoff Run (°C)	Wing Temperature After Takeoff Run (°C)
1	-5.2	N/A
2	-4.2	-3.2
3	-5.0	N/A
4	-3.7	-2.6
5	-5.5	N/A
6	-4.5	-4.2
7	N/A	-4.2
8	N/A	-4.3



3.4.7.3 Fluid Freezing Point Measurements

Fluid freezing points were measured on the leading and trailing edges of the test area. The measurements were taken after fluid application, before the ice pellet application, and after the simulated takeoff run. No measurement was taken after the ice pellet application.

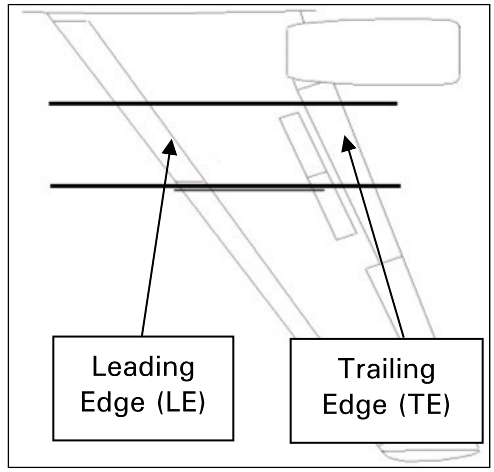
The fluid freezing points were read directly off the refractometer (in °Brix) and converted to a freezing point in degrees Celsius using the Dow Ultra+ conversion chart (see Figure 2.6). The freezing points of the fluid on the wings at the departure runway are shown in Table 3.21.

3.4.8 Run 8 – March 17, 2006

Run 8 was conducted with Neat PG Type IV fluid poured on the 2.7 m^2 test area on the port wing. A total of 12.4 kg of precipitation (unprocessed ice pellets, less than 3.35 mm in diameter) were applied to the test area at the runway button, yielding an effective precipitation rate of 136.3 $g/dm^2/h$.

Table 3.21: Fluid Freezing Point Measurements for Run 7

Wing Position (see diagram)	Fluid Freezing Points (ºC)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
Leading Edge	-60	-60	N/A	-32
Trailing Edge	-60	-60	N/A	-39

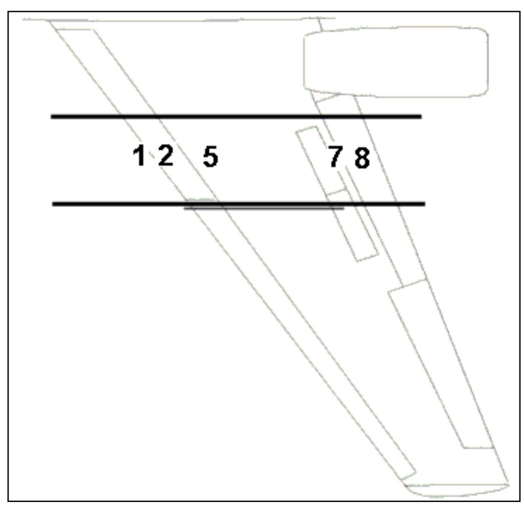


3.4.8.1 Fluid Thickness Measurements

Fluid thickness measurements were recorded at five positions along the centreline of the test area. The measurements were taken after fluid application, before ice pellet application, after ice pellet application, and after the simulated takeoff run. Measurements for Run 8 are shown in Table 3.22.

Table 3.22: Fluid Thickness Measurements for Run 8

Wing Position (see diagram)	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.1	0.6	0.8-1.8	0.0
2	2.2	1.5	3.1	0.1
5	5.7	1.8	4.5-5.7	0.4
7	1.8	1.2	4.5	1.0
8	2.2	0.6	3.3	1.0

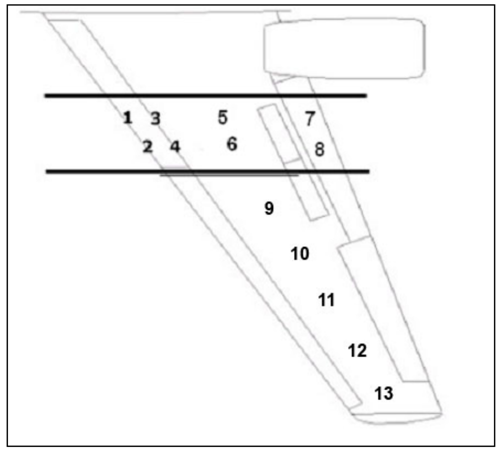


3.4.8.2 Wing Skin Temperatures

Wing skin temperatures were recorded at several positions on the test area. The measurements were taken before and after the ice pellet application, as well as after the takeoff roll. Temperatures for Run 8 are shown in Table 3.23. Temperature readings were taken at 13 locations. The extra measurements were taken to verify the amount of fuel present in the wing and to characterize the temperature profile of the entire wing.

Table 3.23: Wing Temperature Measurements for Run 8

Wing Position (see diagram)	Wing Temp. Before IP Appl. (ºC)	Wing Temp. After IP Appl. (ºC)	Wing Temp. After Takeoff Run (ºC)
1	N/A	N/A	N/A
2	-9.1	-11.6	-10.1
3	N/A	N/A	N/A
4	-9.1	-11.1	-10.0
5	N/A	N/A	N/A
6	-9.6	-12.6	-11.0
7	N/A	N/A	N/A
8	-9.8	N/A	-11.0
9	N/A	N/A	-10.4
10	N/A	N/A	-10.4
11	N/A	N/A	-10.4
12	N/A	N/A	-9.7
13	N/A	N/A	-9.7



Prior to the simulated takeoff (after ice pellet application), the wing temperatures ranged from -12.6ºC to -11.1ºC (see Table 3.23). At the end of the run, the test area temperatures varied between -11.0ºC and -10.1ºC. The readings were taken at the runway button before and after the takeoff run. The ambient air temperature at the start of testing was -9ºC; the sky condition was clear.

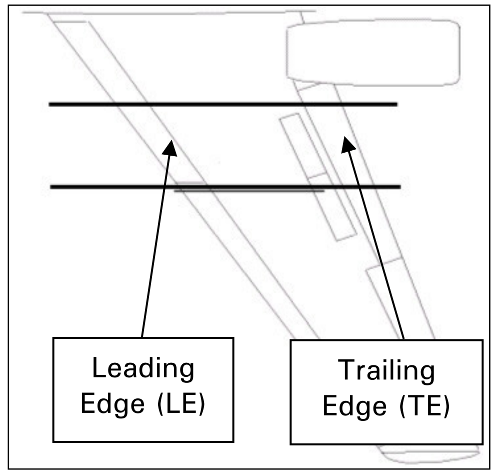
3.4.8.3 Fluid Freezing Point Measurements

Fluid freezing points were measured on the leading and trailing edges of the test area. The measurements were taken after fluid application, before the ice pellet application, after the ice pellet application, and after the simulated takeoff run.

The fluid freezing points were read directly off the refractometer (in ºBrix) and converted to a freezing point in degrees Celsius using the Kilfrost ABC-S conversion table (see Table 2.4). The freezing points of the fluid on the wings at the departure runway are shown in Table 3.24.

Table 3.24: Fluid Freezing Point Measurements for Run 8

Wing Position (see diagram)	Fluid Freezing Points (°C)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
Leading Edge	-37	-37	-12	-21
Trailing Edge	-37	-37	-9	-10



3.4.9 Run 9 – March 17, 2006

A test run with Type I fluid was proposed after the behaviour of Type IV fluids was observed. Run 9 was conducted with Type I EG fluid mixed to a 10ºC buffer (Brix of 22.5º). Four litres of fluid heated to 80ºC and stored inside the aircraft in thermoses were poured on the wing test area at the runway button. A total of 1.7 kg of ice pellets (1.0 mm to 3.35 mm in diameter) were then applied to the test area at the runway button, yielding an effective precipitation intensity of 33 g/dm^2/h.

3.4.9.1 Fluid Thickness and Freezing Point Measurements

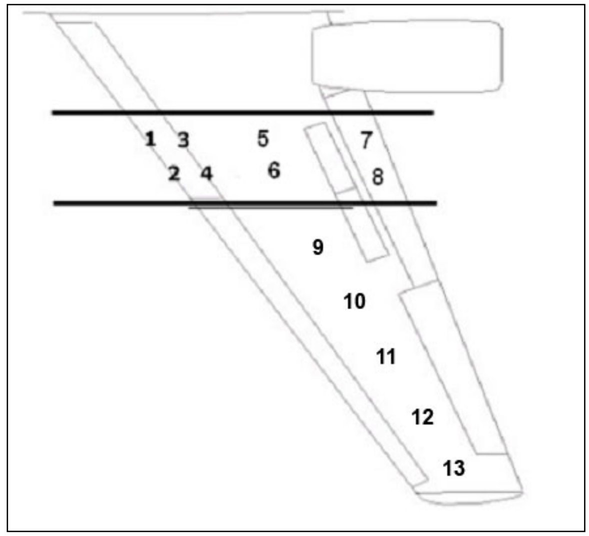
No fluid thickness or Brix measurements were taken for this run.

3.4.9.2 Wing Skin Temperatures

Wing skin temperatures were recorded at several positions on the test area. The measurements were taken before and after the takeoff roll. Temperatures for Run 9 are shown in Table 3.25.

Table 3.25: Wing Temperature Measurements for Run 9

Wing Position (see diagram)	Wing Temperature Before Takeoff Run (ºC)	Wing Temperature After Takeoff Run (ºC)
1	N/A	-8.7
2	N/A	N/A
3	-10.6	-8.9
4	-10.6	N/A
5	-8.7	-8.7
6	-8.7	N/A
7	-10.4	-10.0
8	-10.4	N/A
9	-11.2	-9.1
10	-10.1	N/A
11	-9.0	-9.2
12	-7.8	-7.5
13	-7.9	-7.1



Prior to the simulated takeoff run, the test area temperatures ranged from -10.6ºC to -8.7ºC (see Table 3.25). At the end of the run, the test area temperatures varied from -10.0ºC to -8.7ºC. The readings were taken at the runway button before and after the takeoff run. The ambient air temperature at the start of testing was -10ºC; the sky condition was sunny.

3.5 Fluid Viscosity

At the beginning of the test session, fluid samples were collected for viscosity testing. Fluid samples were also collected for viscosity measurements following Runs 4 and 8. These two runs were selected based on two premises:

- Both runs were conducted with the same fluid (ABC-S); and

- Run 4 was conducted with the baseline precipitation rate, while Run 8 was conducted with the highest precipitation rate for the ABC-S fluid tests.

A summary of the viscosity measurements is shown in Table 3.26. The manufacturer method was used to measure the Dow Ultra+ samples (spindle SC4-31, 10 mL of fluid, 10 minutes, 0.3 rpm, 0°C). The ABC-S fluid samples were tested with spindle SC4-31. The results were then converted to the equivalent manufacturer method (spindle LV-2, 150 mL of fluid, 10 minutes, 0.3 rpm, 20°C) values using a conversion curve provided by Kilfrost.

Table 3.26: Viscosity Log for March 2006 Falcon 20 Tests

Fluid	Sample Collection Time	Sample Location	Viscosity (mPa.s)
Dow Ultra+	Before test session (virgin sample)	N/A	41,400
Kilfrost ABC-S	Before test session (virgin sample)	N/A	24,500
Kilfrost ABC-S	After Run 4	Random location in test area	20,900
Kilfrost ABC-S	After Run 8	Leading edge	3,700
Kilfrost ABC-S	After Run 8	Trailing edge	9,100

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4. ANALYSIS AND OBSERVATIONS

In this section, observations and analysis are made for each test run and for each test parameter (fluid thickness, wing temperature, and fluid freezing point).

4.1 Run 1 Observations

In Run 1, the fluid and contamination were removed from the wing of the Falcon 20 during the simulated takeoff. A very thin film of fluid remained on the wing surface. The fluid did reach 0.4 mm on the trailing edge; however, this is explained by the fact that the pilots used the spoilers at the end of the run, which caused the fluid to accumulate in this area. No ice pellets remained on the test area following the run. An example of the residual fluid that remained at the end of a typical test is shown in Photo 4.1.

The acceleration of the Falcon 20 during the first run is illustrated in Figure 4.1. The y-axis represents the speed of the aircraft in knots recorded by the aircraft data acquisition unit (DAU) as a function of time, in seconds, shown on the x-axis. The first simulated takeoff run lasted 22 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 110 knots.

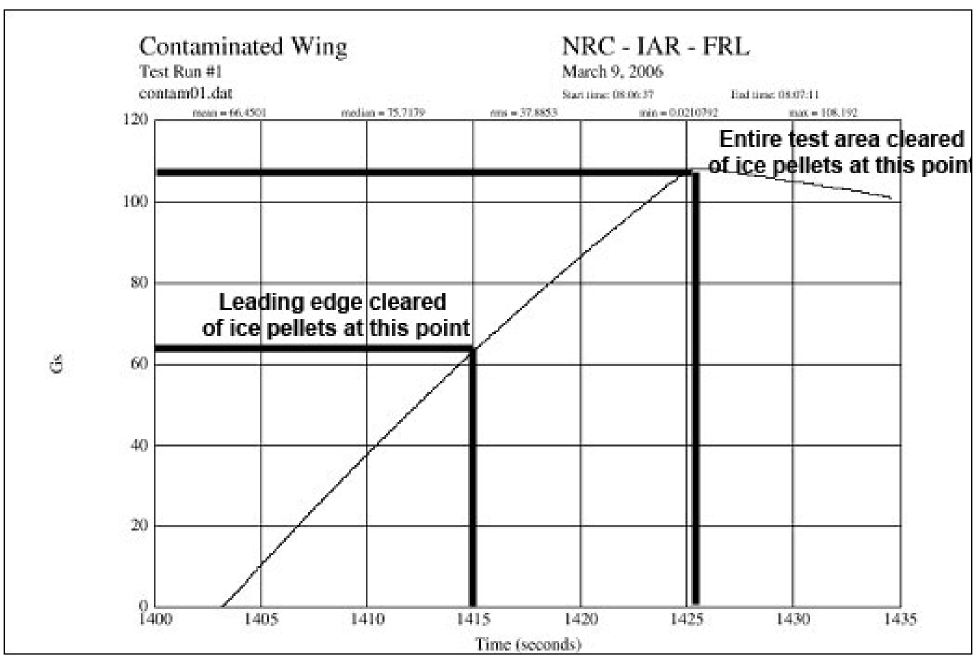

Figure 4.1: Acceleration of the Falcon 20 – Run 1

The leading edge of the test area was cleared of contamination 12 seconds after the start of the run. For this run only, a still camera was focused on the trailing edge. It showed that towards the end of the acceleration, the entire test area, including the trailing edge, was cleared of ice pellets. No ice pellets remained on the test area following the run.

4.2 Run 2 Observations

Run 2 was not completed, as freezing rain precipitation occurred at the beginning of the test. NRC flight crew considered the taxiway and runway too slippery to complete the run.

4.3 Run 3 Observations

In Run 3, the fluid and contamination were removed from the wing of the Falcon 20 during the simulated takeoff. A very thin film of fluid remained on the wing surface, but the thickness was less than 0.2 mm. No ice pellets remained on the test area at the completion of the run.

The acceleration of the Falcon 20 aircraft during the third run is illustrated in Figure 4.2. The y-axis represents the speed of the aircraft in knots recorded by the aircraft DAU as a function of time, in seconds, shown on the x-axis.

The third simulated takeoff run lasted 26 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 122 knots.

The leading edge of the test area was cleared of contamination 12 seconds after the start of the run, as the aircraft reached 70 knots. No ice pellets remained on the test area following the run.

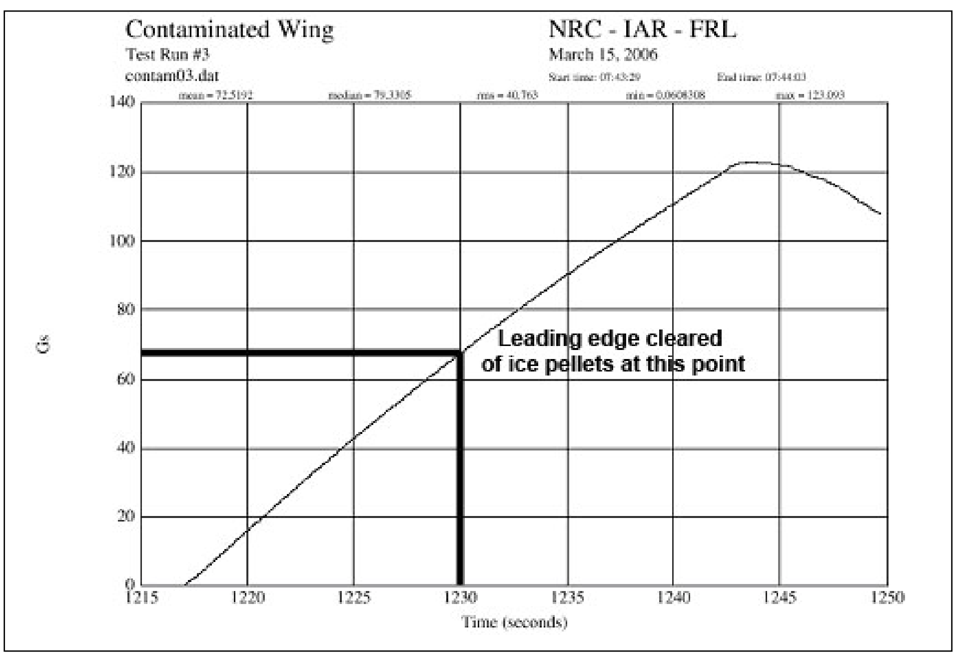

Figure 4.2: Acceleration of the Falcon 20 – Run 3

4.3.1 Speed of Ice Pellet Removal

High-resolution photography permitted the evaluation of the speed of the ice pellets being removed from the test area. The movement of an ice pellet during the third run is illustrated in Photos 4.2 through 4.5.

Position 1 (Photo 4.2) presents the ice pellet 8 seconds into the takeoff run. At this point the Falcon 20 was travelling with a velocity of 45 knots. Position 4 (Photo 4.5) shows the same ice pellet 2 seconds later as the aircraft reached 60 knots.

In the 2-second period between positions 1 and 4, the ice pellet travelled approximately 10 cm (the side of a grid square is 5.1 cm). Therefore, the average speed at which the ice pellet moved was 5 cm/s (0.10 knots).

4.4 Run 4 Observations

In Run 4, the fluid and contamination were removed from the wing of the Falcon 20 during the simulated takeoff. A very thin film of fluid remained on the wing surface, but the thickness was less than 0.2 mm. No ice pellets remained on the test area at the completion of the run.

The acceleration of the Falcon 20 aircraft during the fourth run is illustrated in Figure 4.3. The y-axis represents the speed of the aircraft in knots recorded by the aircraft DAU as a function of time, in seconds, shown on the x-axis.

The fourth simulated takeoff run lasted 24 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 120 knots.

The leading edge of the test area was cleared of contamination 16 seconds into the run, as the aircraft approached 90 knots. No ice pellets remained on the test area following the run.

Run 4 is visually documented in a series of photos included in Appendix E.

4.4.1 Speed of Ice Pellet Removal

High-resolution photography permitted the evaluation of the speed of the ice pellets being removed from the test area. The movement of two ice pellets during the fourth run is shown in Photos 4.6 to 4.10.

Position 1 (Photo 4.6) shows the ice pellets 4.5 seconds into the takeoff run. At this point, the Falcon 20 was travelling with a velocity of 30 knots. Position 5

(Photo 4.10) shows the same ice pellets 3.5 seconds later as the aircraft reached 45 knots.

In the 3.5-second period between positions 1 and 5, the ice pellets travelled approximately 5.1 cm (the side of a grid square is 5.1 cm). Therefore, the average speed at which the ice pellets moved was 1.5 cm/s (0.03 knots).

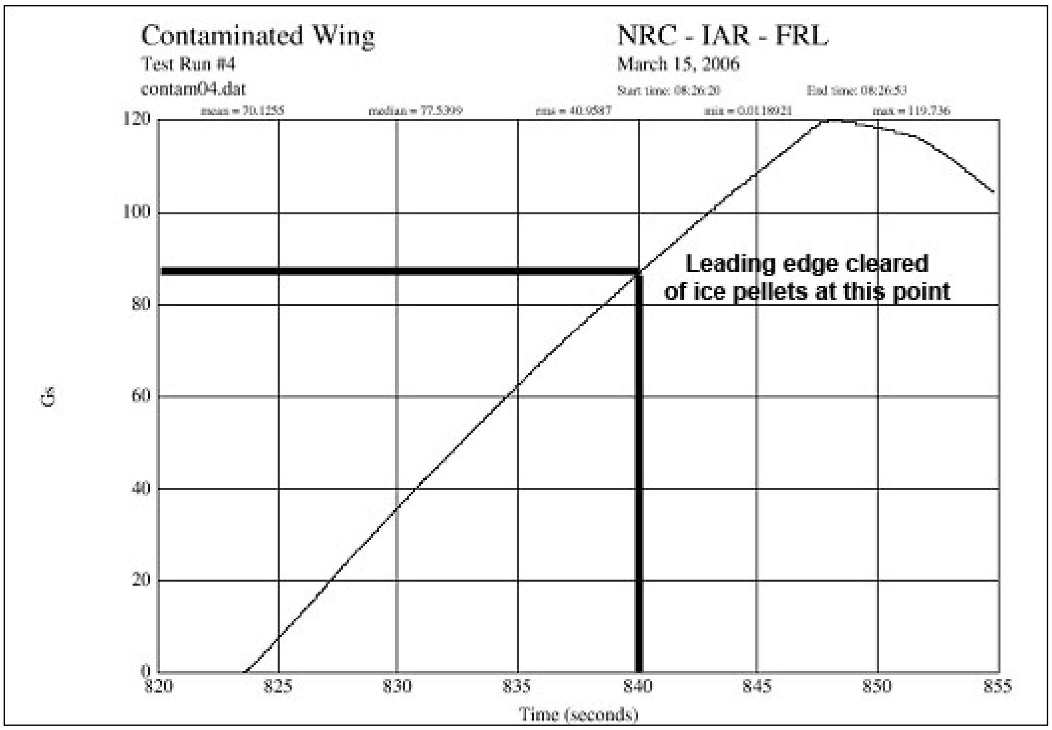

Figure 4.3: Acceleration of the Falcon 20 – Run 4

4.5 Run 5 Observations

In Run 5, the fluid and contamination were largely removed from the wing of the Falcon 20 during the simulated takeoff. A very thin film of fluid remained on the wing surface. Some traces of ice pellets were noted on the trailing edge only. The residual fluid thickness was less than 0.3 mm.

The acceleration of the Falcon 20 aircraft during the fifth run is illustrated in Figure 4.4. The y-axis represents the speed of the aircraft in knots recorded by the aircraft DAU as a function of time, in seconds, shown on the x-axis.

The fifth simulated takeoff run lasted 27 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 125 knots. No ice pellets remained on the test area following the run. Due to a malfunction of the digital camera, no still images of the run were available at the end of the test. The video images of this run do not provide sufficient detail to estimate the displacement of the contamination. For these reasons, no estimation of the time required to clear the leading edge of ice pellets was possible for Run 5.

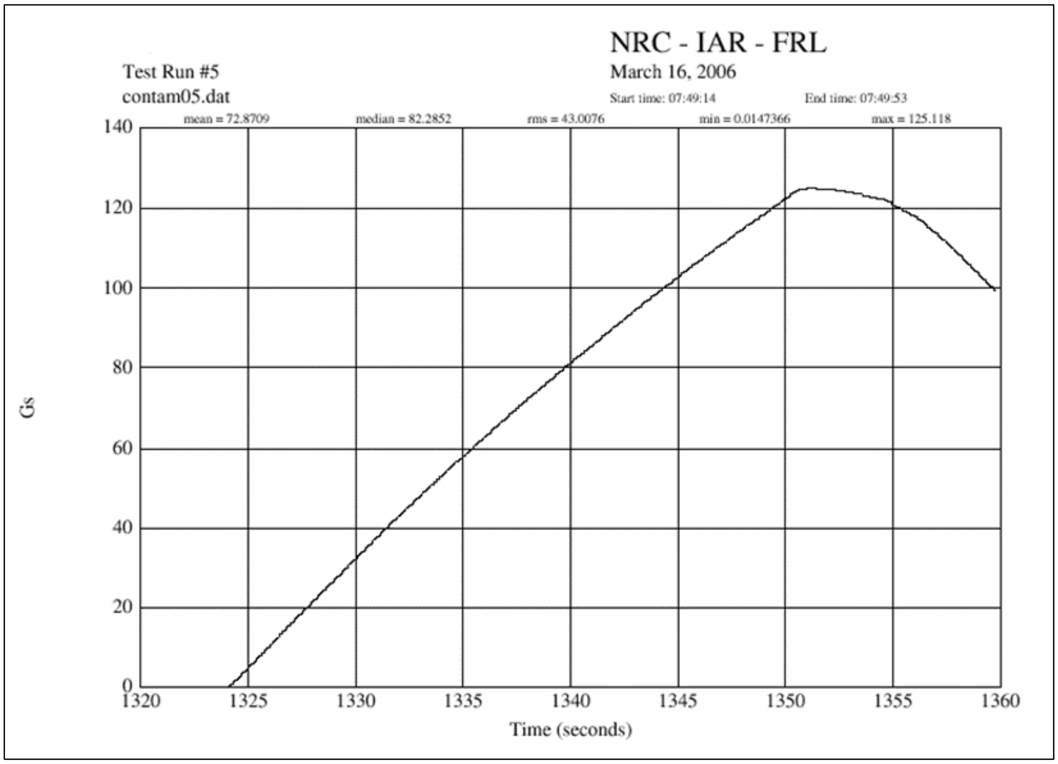

Figure 4.4: Acceleration of the Falcon 20 – Run 5

4.6 Run 6 Observations

In Run 6, the fluid and contamination were removed from the wing of the Falcon 20 during the simulated takeoff. A very thin film of fluid remained on the wing surface, but the thickness was less than 0.2 mm. No ice pellets remained on the test area at the completion of the run.

The acceleration of the Falcon 20 aircraft during the sixth run is illustrated in Figure 4.5. The y-axis represents the speed of the aircraft in knots recorded by the aircraft DAU as a function of time, in seconds, shown on the x-axis.

The sixth simulated takeoff run lasted 24 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 122 knots. The leading edge of the test area was cleared of contamination after 14 seconds from the start of the run, as the aircraft reached 80 knots. No ice pellets remained on the test area following the run.

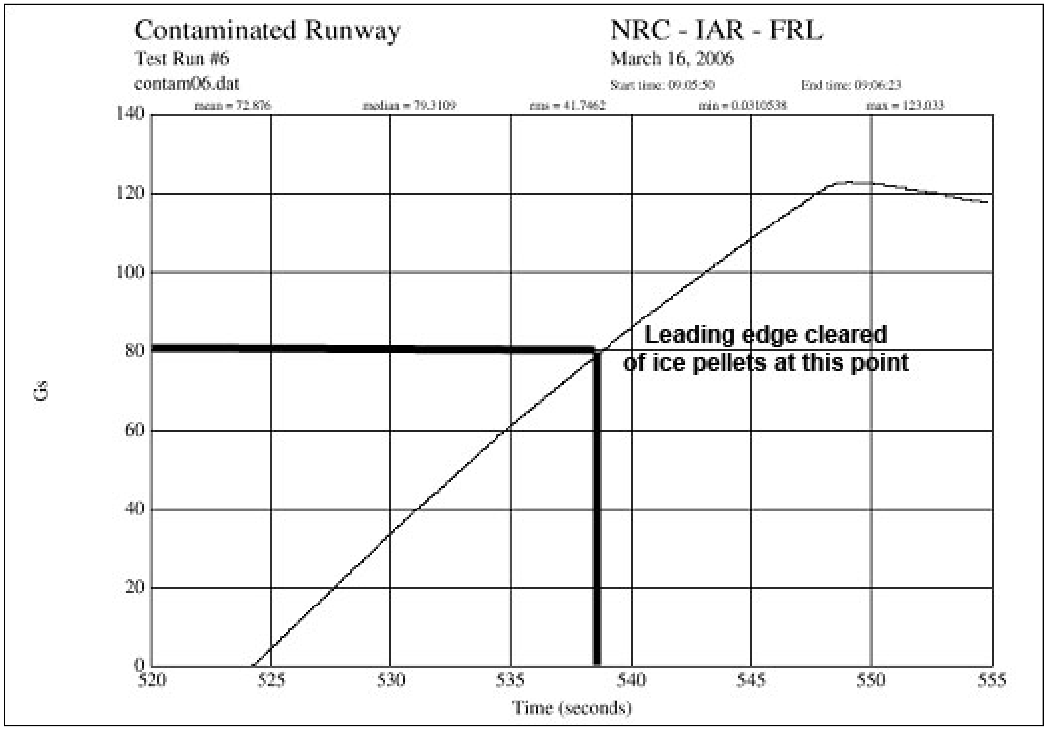

Figure 4.5: Acceleration of the Falcon 20 – Run 6

4.7 Run 7 Observations

In Run 7, the fluid and contamination were removed from the wing of the Falcon 20 during the simulated takeoff. A very thin film of fluid remained on the wing surface, but the thickness was less than 0.2 mm. No ice pellets remained on the test area at the completion of the run.

The acceleration of the Falcon 20 aircraft during the seventh run is illustrated in Figure 4.6. The y-axis represents the speed of the aircraft in knots recorded by the aircraft DAU as a function of time, in seconds, shown on the x-axis. The seventh simulated takeoff run lasted 23 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 122 knots.

The leading edge of the test area was cleared of 14 seconds into the run, as the aircraft reached 80 knots. No ice pellets remained on the test area following the run.

This takeoff run was delayed by the emergency declared by another aircraft. Given this delay, and subsequent melting of the contamination, it was unclear if the results could be considered conclusive. Another run was therefore conducted at a very high precipitation rate the following day with Kilfrost ABC-S in place of Dow Ultra+.

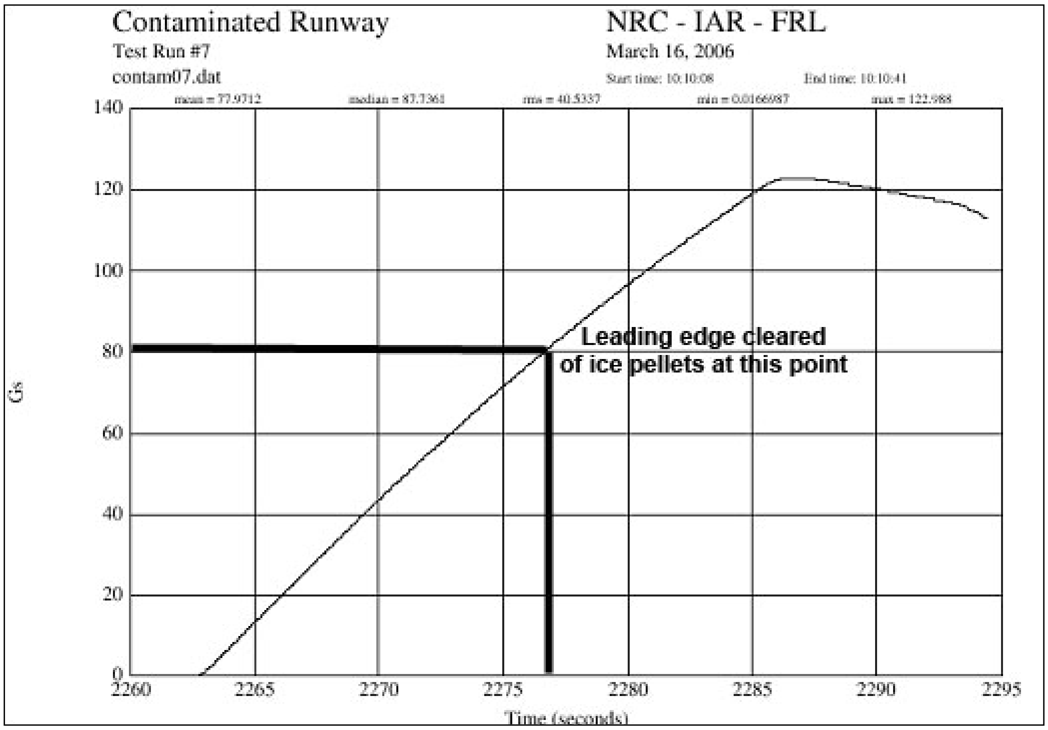

Figure 4.6: Acceleration of the Falcon 20 – Run 7

4.8 Run 8 Observations

In Run 8, the fluid and contamination were removed from the leading edge of the Falcon 20 wing during the simulated takeoff. A very thin film of fluid remained on the leading edge, but the thickness was less than 0.1 mm. No ice pellets remained on this part of the test area following the run.

A small quantity of ice pellets, however, remained in the mid-section of the test area, and the quantity of contaminated fluid present following the simulated takeoff increased towards the trailing edge.
A considerable quantity of ice pellets was present on the trailing edge half of the test area. An example of the residual fluid that remained on the wings of the Falcon 20 at the end of the run is shown in Photo 4.11. In this section of the test area, the residual fluid thickness was as high as 1.0 mm.

The acceleration of the Falcon 20 during the eighth run is illustrated in Figure 4.7. The y-axis represents the speed of the aircraft in knots recorded by the aircraft DAU as a function of time, in seconds, shown on the x-axis.

The eighth simulated takeoff run lasted 25 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 119 knots. The leading edge of the test area was cleared of contamination 24 seconds into the run, at the end of the acceleration. No ice pellets remained on the leading edge following the run, but contaminated fluid was still visible on the trailing edge.

Run 8 is visually documented in a series of photos included in Appendix E.

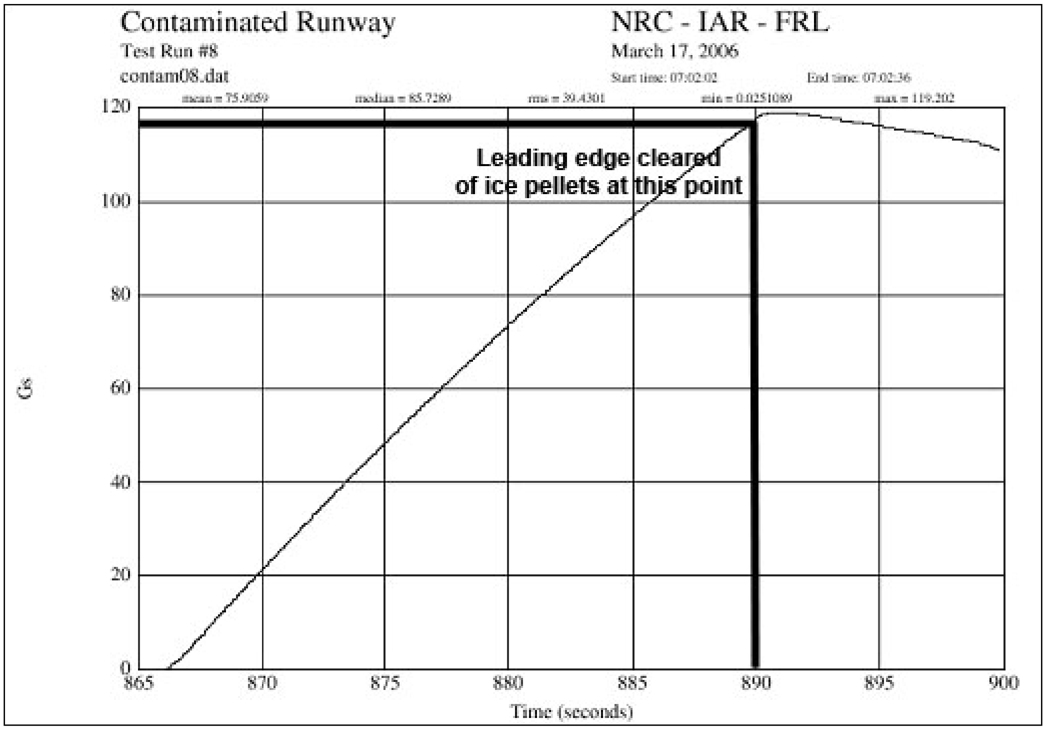

Figure 4.7: Acceleration of the Falcon 20 – Run 8

4.9 Run 9 Observations

Run 9 was completed with Type I fluid. No thickness or Brix measurements were taken for this run. After the simulated takeoff was completed, the fluid film on the wing was almost nonexistent and the contamination had been removed. A few very small spots in the test area showed some ice adhered to the wing surface. The area of each small ice cluster was less than that of a 25-cent coin. Photo 4.12 shows some of the ice pellets adhered to the wing surface after the run.

The acceleration of the Falcon 20 aircraft during the ninth run is illustrated in Figure 4.8. The y-axis represents the speed of the aircraft in knots recorded by the aircraft DAU as a function of time, in seconds, shown on the x-axis.

The ninth simulated takeoff run lasted 25 seconds from brake release to the end of acceleration. The Falcon 20 reached a maximum speed of 121 knots.

The leading edge of the test area was cleared of ice pellets 23 seconds into the run, as the Falcon 20 reached 120 knots. No ice pellets remained on the leading edge following the run.

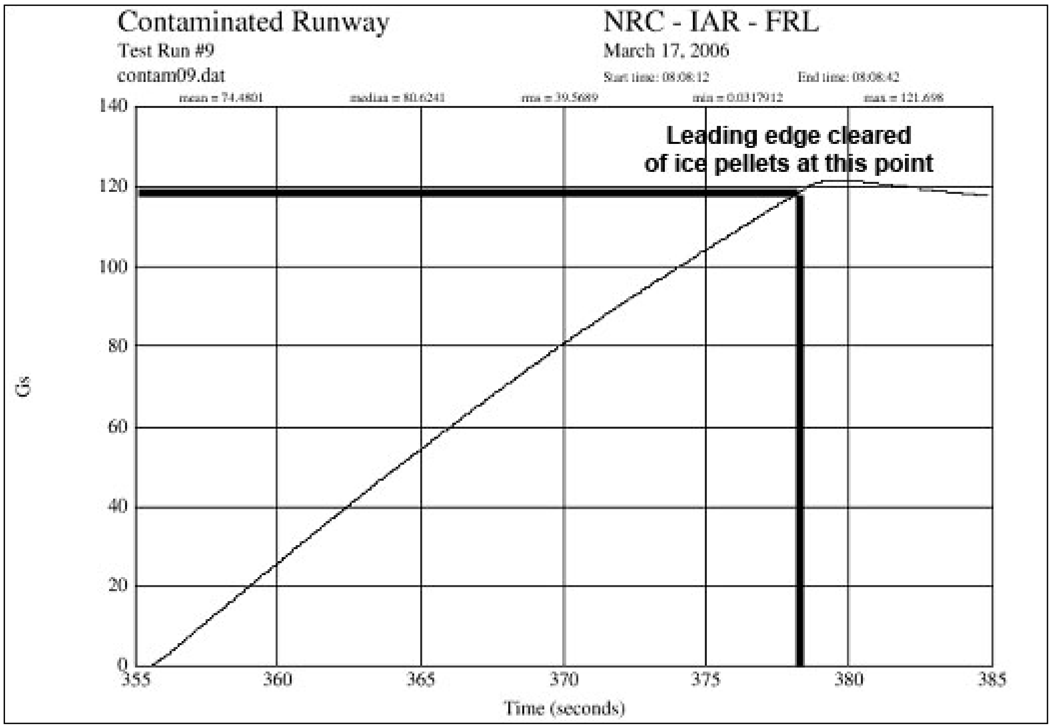

Figure 4.8: Acceleration of the Falcon 20 – Run 9

4.10 Summary of Results

4.10.1 Fluid Thickness

A summary of the thickness measurements recorded for Runs 1 to 8 is presented in Table 4.1. Run 2 is not included in this analysis as the takeoff run was aborted.

Table 4.1: Summary of Falcon 20 Thickness Tests

RUN 1: Ultra+, 25 g/dm²/h, Large IP, OAT=-5°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	0.8	0.7	0.7	0.0
2	1.3	1.2	1.3	0.0
5	4.5	4.5	5.7	0.2
7	2.2	1.8	1.8	0.4
8	2.5	0.8	0.6	0.2

RUN 3: ABC-S, 25 g/dm²/h, Large IP, OAT=-5°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	0.7	0.6	1.1	0.1
2	1.8	2.2	2.9	0.2
5	5.7	4.5	4.5	0.2
7	1.8	1.5	2.7	0.2
8	2.2	0.7	2.5	0.2

RUN 4: ABC-S, 25 g/dm²/h, Small IP, OAT=-4°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.1	0.7	1.1	0.1
2	2.2	1.7	2.5	0.1
5	4.5	3.9	4.5	0.2
7	2.5	1.8	2.2	0.2
8	1.5	1.1	1.8	0.2

RUN 5: ABC-S, 84 g/dm²/h, Small IP, OAT=-8°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.0	0.5	1.1	0.1
2	2.2	1.0	2.9	0.2
5	5.7	4.5	4.5	0.2
7	2.2	1.1	3.5	0.3
8	2.7	0.8	1.8	0.2

RUN 6: Ultra+, 84 g/dm²/h, Small IP, OAT=-8°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	0.7	0.7	0.3	0.0
2	1.8	2.2	1.8	0.0
5	4.5	4.5	5.7	0.2
7	1.8	1.5	3.5	0.2
8	1.1	1.1	1.6	0.2

RUN 7: Ultra+, 167 g/dm²/h, UnPr IP, OAT=-7°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.2	0.7	N/A	0.0
2	1.8	1.8	N/A	0.0
5	4.5	4.5	N/A	0.0
7	2.5	2.2	N/A	0.2
8	1.2	1.1	N/A	0.1

RUN 8: ABC-S, 136 g/dm²/h, UnPr IP, OAT=-9°C				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	Before IP Appl.	After IP Appl.	After Takeoff Run
1	1.1	0.6	0.8-1.8	0.0
2	2.2	1.5	3.1	0.1
5	5.7	1.8	4.5-5.7	0.4
7	1.8	1.2	4.5	1.0
8	2.2	0.6	3.3	1.0

Wing Position Locations

1: Leading edge
2: Halfway between the leading edge and joint
5: As far as could be reached from the leading edge
7: Trailing edge, 2.5 cm from the joint
8: Halfway between the trailing edge and joint

4.10.1.1 Fluid Thickness on the Leading Edge

The leading edge (Wing Positions 1 and 2 in Table 4.1) is a critical area to analyse. Table 4.1 shows that fluid thickness on the leading edge before contamination was consistent for all the runs.

When contamination was applied, the EG and PG Type IV fluids showed different behaviour in terms of thickness measurements on the leading edge. The thickness of the diluted EG Type IV fluid (Dow Ultra+) was approximately the same or less than the thickness of the fluid before contamination. The thickness of the diluted PG Type IV fluid (Kilfrost ABC-S) increased with the application of contamination.

For both EG and PG Type IV fluids, the airflow at takeoff removed the contaminated fluid from the leading edge, leaving only a very thin film of fluid – less than 0.1 mm (Position 1) – even at very high precipitation rates.

4.10.1.2 Fluid Thickness on the Trailing Edge

The PG and EG fluids behaved similarly in terms of fluid thickness on the trailing edge (Wing Positions 7 and 8 in Table 4.1) after the takeoff run. The contamination was cleared from the trailing edge for precipitation rates as high as 84 g/dm^2/h. The fluid thickness on the trailing edge after the run ranged from 0.2 mm to 0.4 mm for the first six runs.

When the simulated precipitation rate was increased to 136 g/dm^2/h, the airflow failed to remove all contamination. Following Run 8, the fluid thickness on the trailing edge was 1.0 mm.

4.10.2 Wing Temperatures

A summary of the wing temperatures measured before and after the simulated takeoff runs is shown in Table 4.2.

It can be noted that:

- Generally, the average wing temperatures before and after the run were within 1°C; and
- The sky condition was a significant influence:
  - Overcast sky conditions provided wing temperature equilibrium throughout the tests;

- Sunny conditions showed large variations of temperatures across the test area relative to exposure to the sun (Run 6). Precipitation exposed directly to solar radiation was subject to premature melting; and
- The ambient and wing temperatures were very close when the sky was overcast.

Table 4.2: Summary of Falcon 20 Wing Temperatures

Run No.	Fluid	OAT (°C)	Sky Condition	Wing Temp. Range (°C)		Avg. Wing Temp. (°C)	
				Before Run	After Run	Before Run	After Run
1	Ultra+	-5	overcast	-1.9 to -3.3	N/A	-2.7	N/A
2	ABC-S	-4	overcast	N/A	N/A	N/A	N/A
3	ABC-S	-6	overcast	-4.5 to -5.5	-4.2 to -5.2	-5.0	-4.7
4	ABC-S	-6	mostly overcast	-3.5 to -3.7	N/A	-3.6	N/A
5	ABC-S	-8	scattered clouds	-8.0 to -8.6	-7.4 to -8.2	-8.2	-7.9
6	Ultra+	-8	mostly sunny	-3.2 to -7.1	-4.5 to -6.6	-5.3	-5.5
7	Ultra+	-7	mostly sunny	-3.7 to -5.5	-2.6 to -4.3	-4.7	-3.7
8	ABC-S	-9	clear	-9.1 to -9.8	-10.0 to -11.0	-9.4	-10.5
9	Type I EG	-10	sunny	-8.7 to -10.6	-8.7 to -10.0	-9.9	-9.1

4.10.3 Fluid Freezing Points

The freezing points of the virgin Ultra+ and ABC-S samples were measured to be -60°C and -37°C, respectively. No change was recorded in the fluid freezing point following the fluid application and taxi to the runway button. A summary of the fluid freezing points measured before and after the simulated takeoffs are shown in Table 4.3.

It can be noted that only in Run 8 did the fluid freezing point decrease to near the ambient temperature after the ice pellet application. On the trailing edge, both the fluid freezing point and the outside air temperature were -9°C before the simulated takeoff run. The test results showed that in this area (trailing edge) the airflow at takeoff failed to remove the contaminated fluid entirely.

Table 4.3: Summary of Falcon 20 Fluid Freezing Points

Run No.	Fluid	OAT (°C)	LE and TE Freezing Points (°C)		Avg. Freezing Point (°C)	
			Before Run, After IP App.	After Run	Before Run, After IP App.	After Run
1	Ultra+	-5	-54 & -44	-49 & -49	-49	-49
2	ABC-S	-4	N/A	N/A	N/A	N/A
3	ABC-S	-6	-35 & -30	-26 & -30	-33	-28
4	ABC-S	-6	-24 & -20	-16 & -22	-22	-19
5	ABC-S	-8	-24 & -19	-16 & -18	-22	-17
6	Ultra+	-8	-18 & -19	-39 & -41	-19	-40
7	Ultra+	-7	N/A	-32 & -39	N/A	-36
8	ABC-S	-9	-12 & -9	-21 & -10	-11	-16
9	Type I EG	-10	N/A	N/A	N/A	N/A

4.10.4 Contamination Removal Time

The time from brake release and the speed required to clear the leading edge of contamination are illustrated in Figure 4.9 and Table 4.4 for the runs where digital photography data was available to estimate the ice pellet removal.

Run 7 was not included in this analysis because the contamination was exposed to direct solar radiation during a delay and consequently melted prior to the simulated takeoff.

Generally, for precipitation rates of approximately 25 g/dm^2/h, the airflow cleared the leading edge of contamination as the aircraft reached 60 knots. As the precipitation rate was increased to values in the 80 g/dm^2/h range, the Falcon 20 reached 80 knots before the contamination from the leading edge came off. Finally, for the very high precipitation rate test (Run 8, over 130 g/dm^2/h), the entire 24 seconds of the takeoff run were required to clear the leading edge of any precipitation. In this case, some contamination remained on the trailing edge.

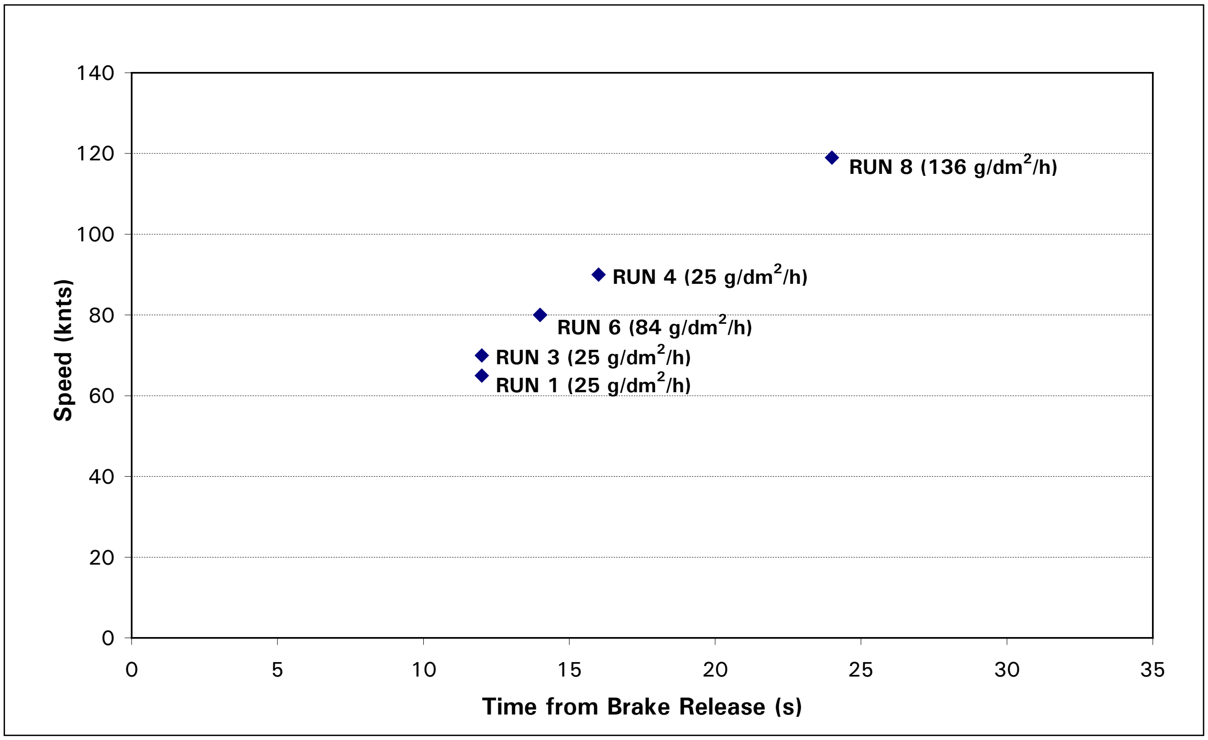

Figure 4.9: Time and Speed Required to Clear the Leading Edge of Contamination

Table 4.4: Time and Speed Required to Clear the Leading Edge of Contamination

Run Number	Effective Precip. Rate (g/dm^2/h)	Time from Brake Release (s)	Ground Speed (knots)
1	24.8	12	65
3	24.8	12	70
4	24.8	16	90
6	83.5	14	80
8	136.3	24	119

4.10.5 Speed of Ice Pellet Removal

The use of high-resolution digital photography made it possible to evaluate the ice pellet speed when removed by the airflow. It was noted that the ice pellets and the fluid appear to be moving at the same speed. It was remarked that the ice pellets moved with an average speed of 0.015 m/s (0.03 knots) when the Falcon 20 was accelerating from 30 knots to 45 knots. It was also noted that the contamination moved with a velocity of 0.05 m/s (0.10 knots) when the aircraft accelerated from 45 knots to 60 knots. After 60 knots, the observation of ice pellets left on the wing was difficult, as most of the contamination had been removed. From the observation of individual ice pellets being removed, it was noticed that the contamination appeared to move with a constant acceleration, but slightly slower than that of the aircraft.

4.11 Implication of Ice Pellet Tests on Current Holdover Times

During the winters of 2002-03 and 2003-04, APS conducted a study of the adhesion of contaminated Type II/IV fluids on aluminum surfaces [see TC report, TP 14377E, *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces* (6)]. It was concluded that for natural snow, adhesion failure occurs after extended periods of time. In the same report, the occurrence of adherence was observed under all other freezing precipitation conditions. Typically, adhesion was observed shortly after standard plate failure for freezing precipitation.

The 2006 Falcon 20 tests showed that ice pellets did not adhere to the wing surface. In addition, tests on flat plates with ice pellets alone also did not show signs of adhesion, similar to what was observed in the previous work in natural snow conditions. We can therefore conclude that:

- It is possible that the current holdover times in snow are conservative for Type II/IV fluids; and
- If time to adhesion is a true measure of holdover time, then published holdover times in many conditions may be conservative.

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Photo 4.1: Typical Residual Fluid Left After Runs 1 to 7

Photo 4.2: Ice Pellet Velocity Estimate for Run 3 (Position 1)

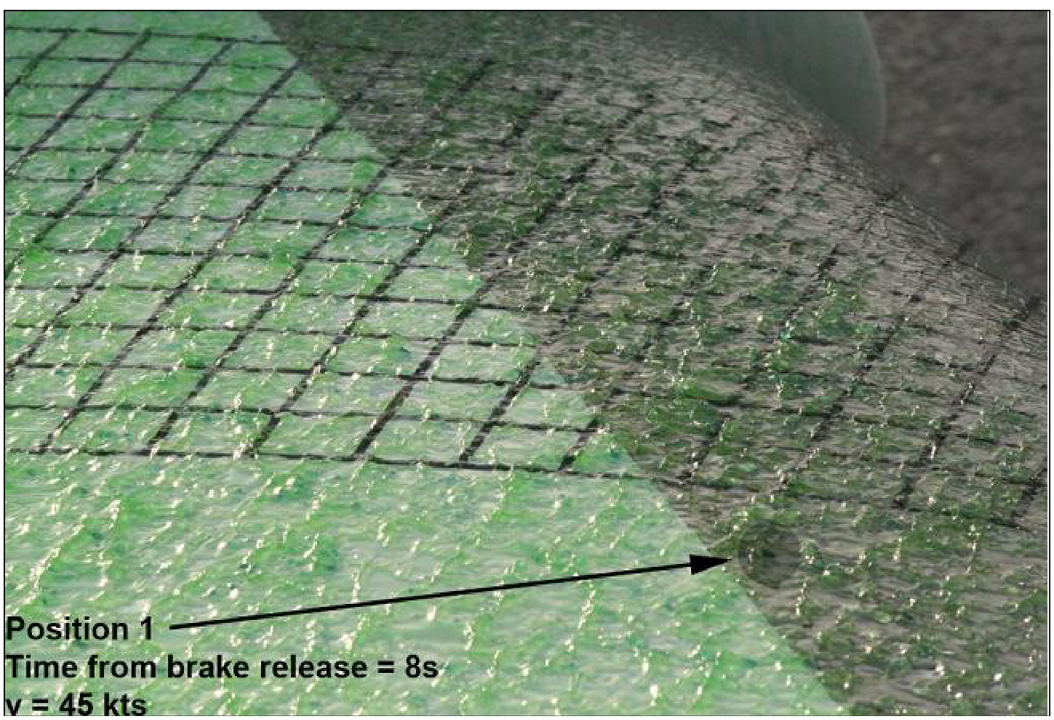

Photo 4.3: Ice Pellet Velocity Estimate for Run 3 (Position 2)

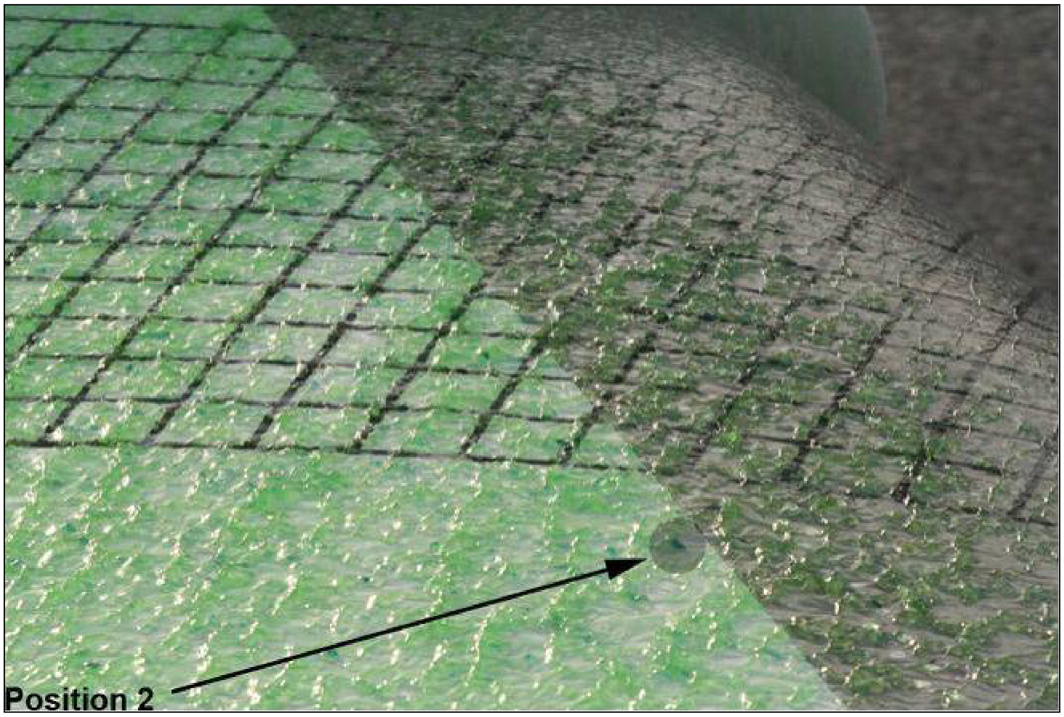

Photo 4.4: Ice Pellet Velocity Estimate for Run 3 (Position 3)

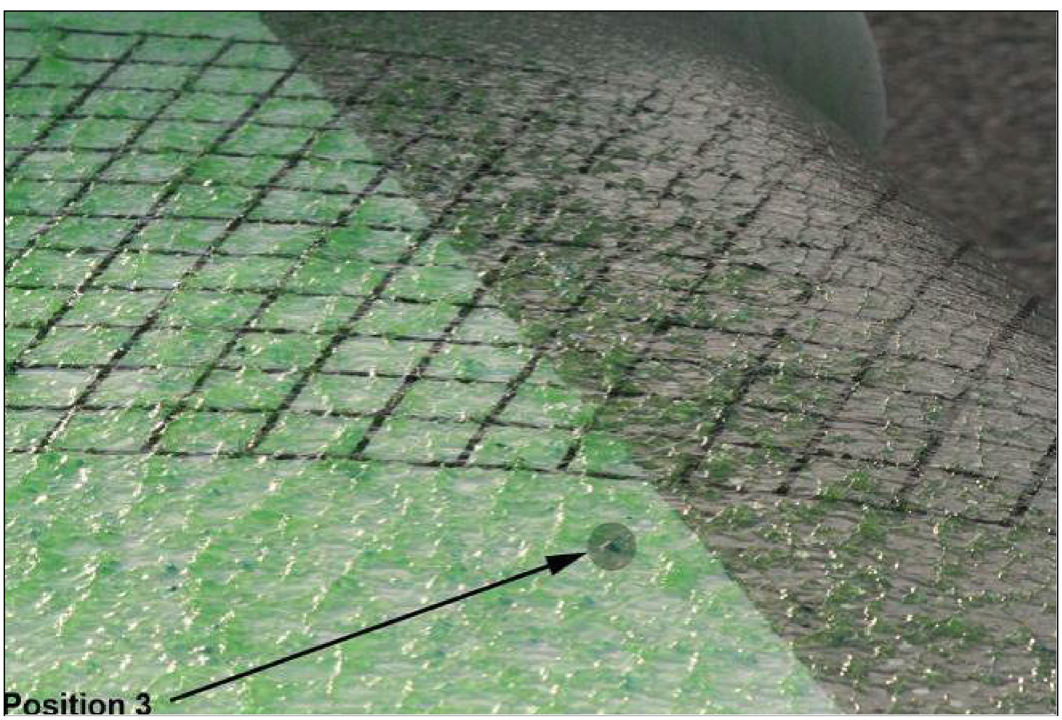

Photo 4.5: Ice Pellet Velocity Estimate for Run 3 (Position 4)

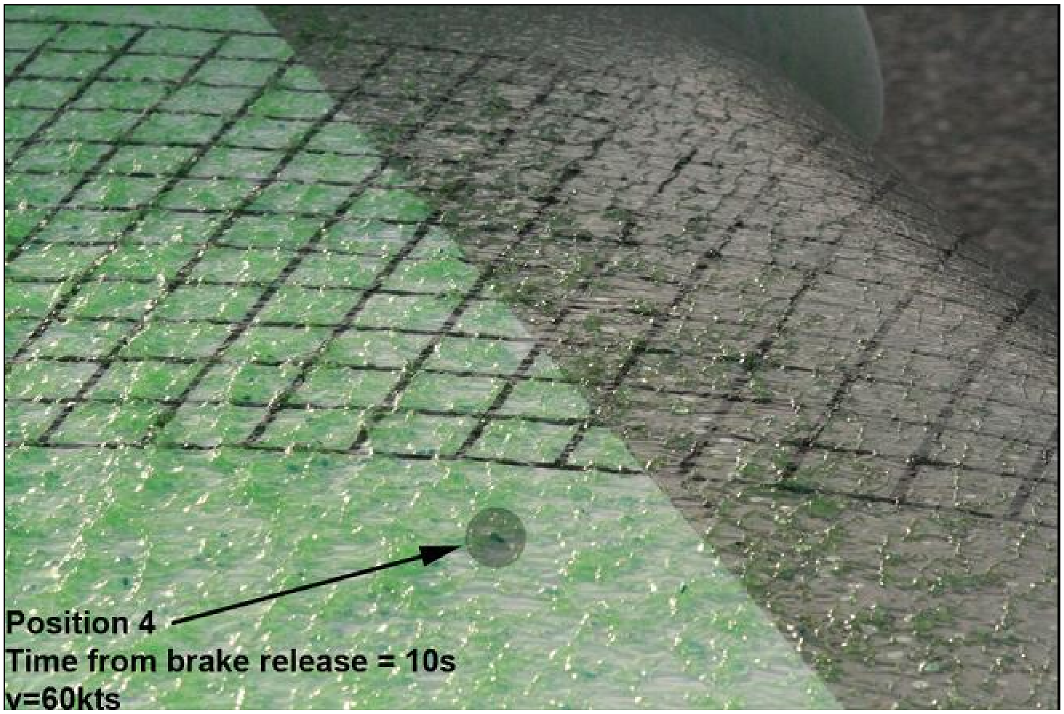

Photo 4.6: Ice Pellet Velocity Estimate for Run 4 (Position 1)

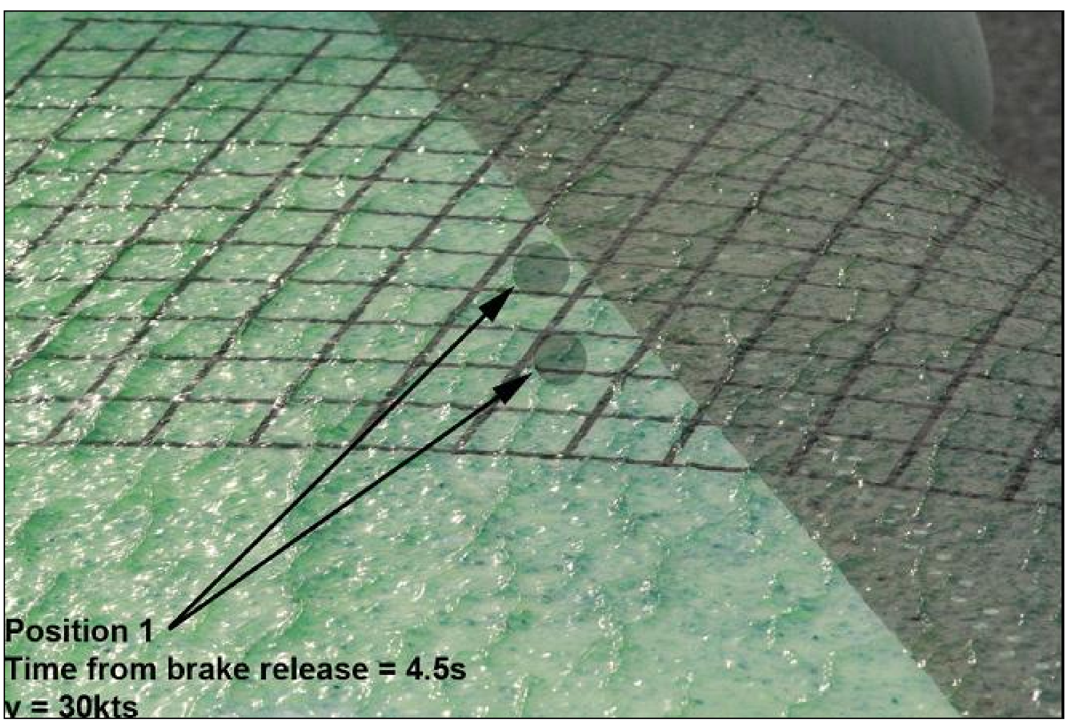

Photo 4.7: Ice Pellet Velocity Estimate for Run 4 (Position 2)

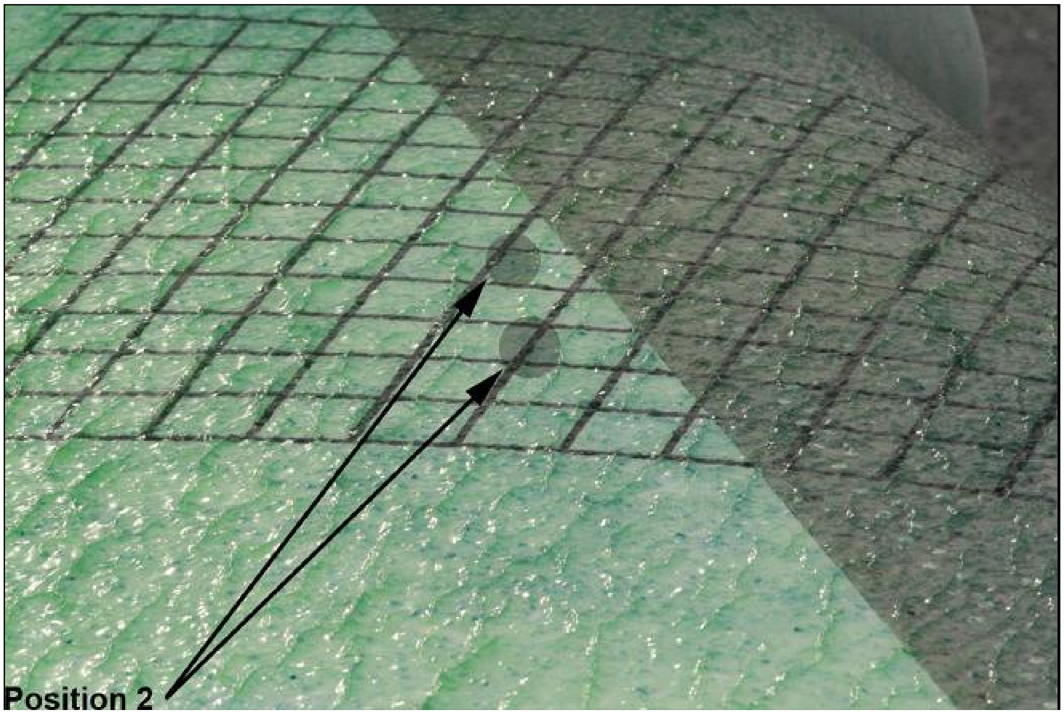

Photo 4.8: Ice Pellet Velocity Estimate for Run 4 (Position 3)

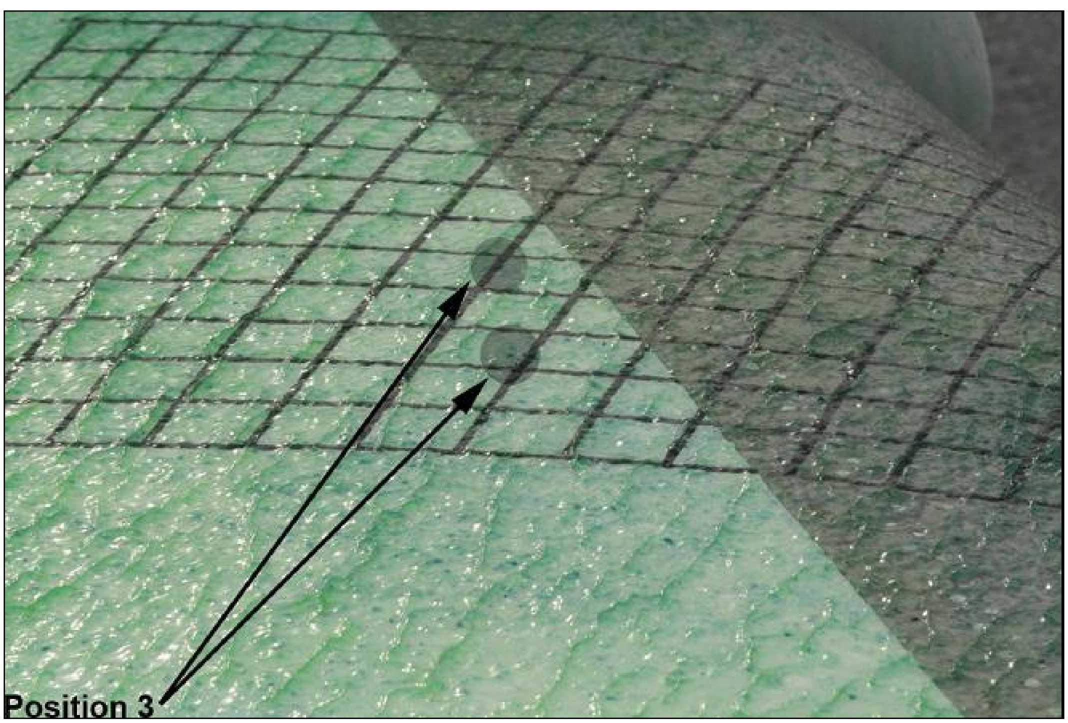

Photo 4.9: Ice Pellet Velocity Estimate for Run 4 (Position 4)

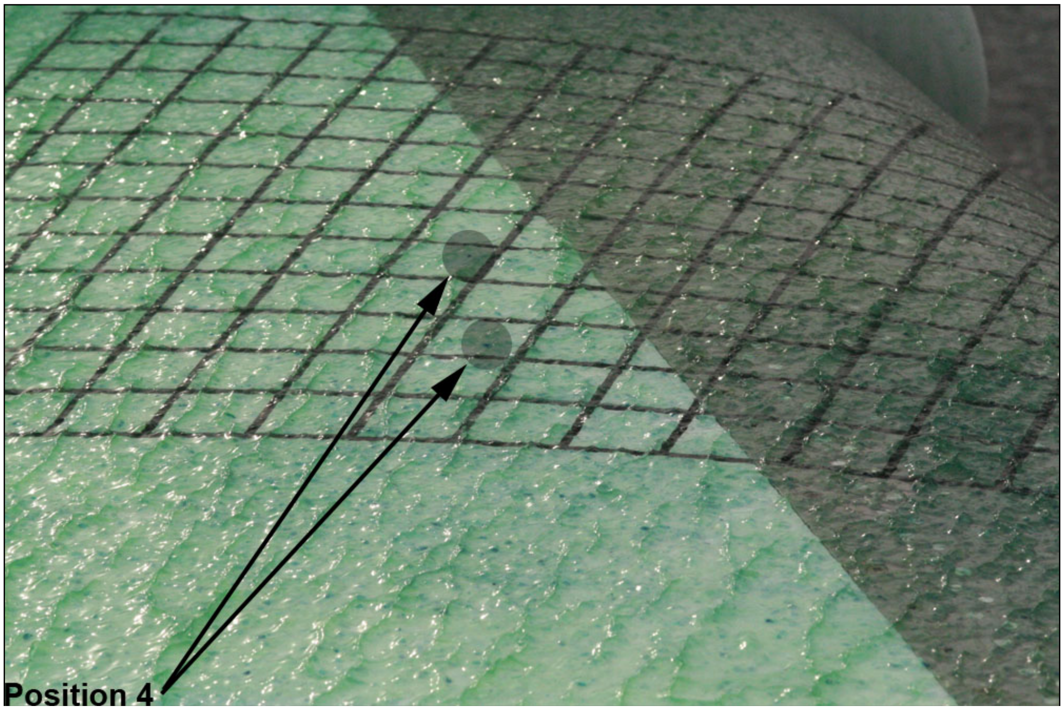

Photo 4.10: Ice Pellet Velocity Estimate for Run 4 (Position 5)

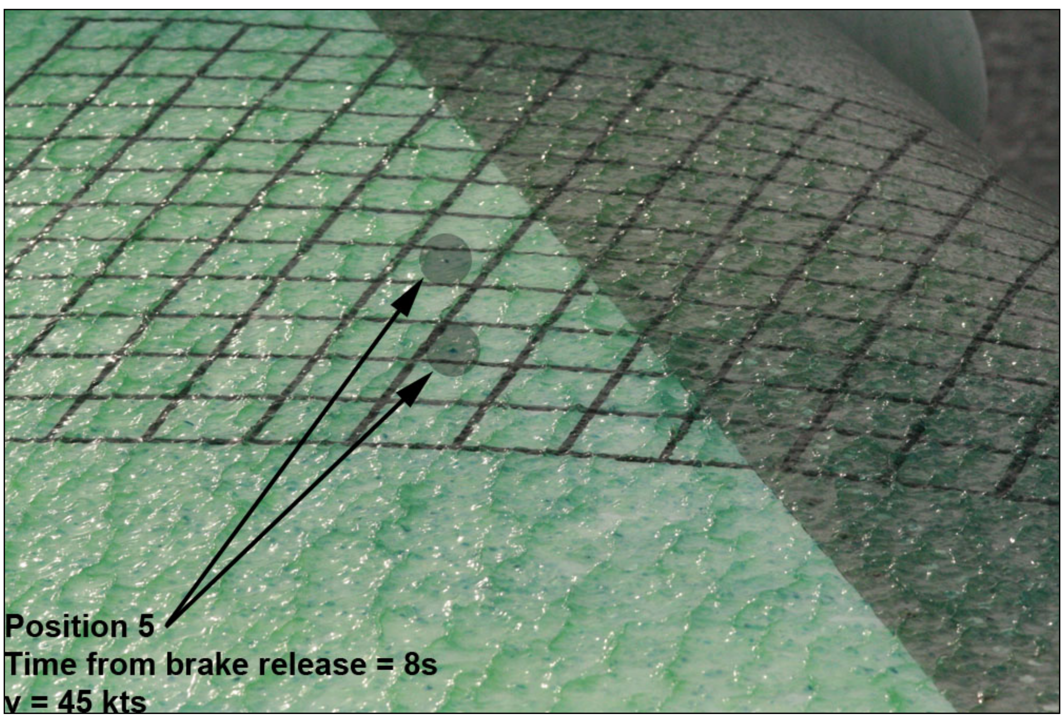

Photo 4.11: Residual Fluid on Trailing Edge after Run 8

Photo 4.12: Residual Fluid and Ice Pellets Adhering to the Trailing Edge After Run 9

5. CONCLUSIONS

Tests performed in 2005-06 with the Falcon 20 studied the amount of ice pellet contamination that will flow off an anti-iced aircraft at takeoff. The following sections describe the conclusions reached from the field tests conducted.

5.1 Test Coordination and Provision of Support

APS coordinated and provided support for tests with the NRC Falcon 20 aircraft. The test methodologies employed for the application of ice pellets and the collection of fluid thickness, fluid viscosity, wing temperature, and fluid freezing point data were satisfactory.

5.2 Elimination of Contaminated Fluids

For Type IV fluid tests, a controlled quantity of ice pellets was applied at the runway button. The baseline was chosen to represent an effective precipitation rate of 25 g/dm^2/h over a period of 20 minutes. The quantity of ice pellets applied was increased until the airflow failed to remove all the contamination.

For both EG and PG Type IV fluids, the airflow at takeoff removed ice pellet-contaminated anti-icing fluid from the leading edge, leaving only a very thin film of fluid even at very high precipitation rates. In one case, at a very high precipitation rate (effective rate of 136 g/dm^2/h), the entire 24 seconds of the takeoff run were required to clear the leading edge of any precipitation. In this case, some contamination (up to 1 mm) remained on the trailing edge.

A test with Type I EG fluid showed some adhesion of ice to the wing surface due to heat transferred from the fluid to the wing surface. As seen in previous tests, heat transferred to test surfaces may have the effect of allowing the melted contaminant to dilute the Type I fluid to water before the surface temperature drops to 0ºC [TP 14377E (6)]. When freezing finally occurs, the resulting ice may adhere to the surface. The fluid application method in this test was not representative of actual operations. Normal deicing operations may transfer more heat, which may generate more adhesion. Adhesion of Type I fluids in ice pellet conditions was also observed in previous tests on flat plates that were conducted at the NRC climate chamber. These tests are reported in the TC report, TP 14713E, *Aircraft Deicing Research in Natural and Simulated Ice Pellet Conditions* (7).

5.3 Implication of Ice Pellet Tests on Current Holdover Times

The ice pellet tests performed in 2006 show that it is possible that the current holdover times in snow are conservative for Type II/IV fluids. If time to adhesion is a true measure of holdover time, then the endurance times in many conditions may be conservative. Previous work performed by APS [documented in TP 14377E (6)] provides some insight in this area.

6. RECOMMENDATIONS

Several recommendations can be made from the results of this testing:

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

b) Further takeoff tests should be conducted using mixed precipitation (e.g., freezing rain mixed with ice pellets);

c) Further takeoff tests should be conducted with lower rotation speed aircraft;

d) Further takeoff tests should be conducted with aircraft that have slatted leading edges; and

e) Further wind tunnel tests are recommended for the ease of control of the test variables.

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3. Dawson, P., *Contaminated Aircraft Simulated Takeoff Tests for the 1999-2000 Winter: Preparation and Procedures*, APS Aviation Inc., Transportation Development Centre, Montreal, August 2000, TP 13666E, 18.

4. Campbell, R., Chaput, M., *Aircraft Takeoff Test Program for Winter 2001-02: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid,* APS Aviation Inc., Transportation Development Centre, Montreal, November 2002, TP 13995E, 92.

5. Chaput, M., *Aircraft Takeoff Test Program for Winter 2002-03: Testing to Evaluate the Aerodynamic Penalties of Clean or Partially Expended De/Anti-Icing Fluid,* APS Aviation Inc., Transportation Development Centre, Montreal, November 2003, TP 14147E, 92.

6. Moc, N., *Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces,* APS Aviation Inc., Transportation Development Centre, Montreal, December 2004, TP 14377E, 104.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2005-06

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID
WINTER TESTING 2005-06

5.3 Aircraft Performance Research

5.3.1 Flow of Contaminated Fluid from Aircraft Wings During Takeoff

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

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

c) Plan and co-ordinate the application of controlled amounts of ice pellets, snow and/or freezing rain contamination on the applied fluids;

d) 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;

e) Spot deicing: Evaluate how deicing fluid on one wing only (spot deicing) affects the flying capabilities of the aircraft. Low viscosity fluids (such as Type I or Type III) should be used. The fluids will be sprayed only on one wing of the aircraft, and the aircraft will be rotated, taking care to prevent complete takeoff;

f) Collect the following data during the tests:

   i) Type and amount of fluid applied;

   ii) Type and rate of contamination applied;

   iii) Extent of fluid contamination prior to the takeoff run;

   iv) Document the appearance of fluid on the wings during the takeoff run and climb of the aircraft by analyzing the video records; and

   v) Measurements of thickness, concentration, viscosity, and adherence of clean and contaminated fluid prior to departure for the flight test.

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

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

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APPENDIX B

PROCEDURE:
WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

CM2020.002 (05-06)

This document, *Wind Tunnel Tests to Examine Fluid Removed from Aircraft during Takeoff with Ice Pellets,* provides the procedures and equipment required to support the wind tunnel tests aimed to study the effects of simulated ice pellets on a Cessna Caravan wing during takeoff. The wind tunnel tests scheduled for February-March 2006 were cancelled due to a scheduling problem with the National Research Council wind tunnel facility in Ottawa.

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: For George Balaban

Reviewed by: John D'Avirro

March 14, 2006
Version 1.0

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

1. BACKGROUND

This document, *Wind Tunnel Tests to Examine Fluid Removed from Aircraft during Takeoff with Ice Pellets,* provides the procedures and equipment required to support the wind tunnel tests aimed to study the effects of simulated ice pellets on a Cessna Caravan wing during takeoff. The wind tunnel tests scheduled for February-March 2006 were cancelled due to a scheduling problem with the National Research Council wind tunnel facility in Ottawa.

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 (NRC) Falcon 20 aircraft, showed that the test approach was a viable one. The test program conducted during winter 2001-02 and 2002-03 addressed the effects of unshed anti-icing fluid on aircraft take-off performance.

Ice pellets represent a type of precipitation consisting of transparent or translucent pellets of ice, 5 mm or less in diameter. The effects of (simulated) ice pellets on the wing of Falcon 20 aircraft during takeoff and on a Cessna Caravan wing section subjected to takeoff conditions in a wind tunnel are currently studied. Since ice pellets embedded in the fluid were not adhering according to previous tests, it is not known whether this contamination in the fluid would come off during aircraft rotation. As a result, the FAA has issued a notice that prevents operations from departing in ice pellet conditions.

The 2005-06 winter season tests will address the effects of deicing fluid contaminated with ice pellets that the airflow at takeoff fails to remove.

This document provides the procedures and equipment required to support the wind tunnel tests scheduled for February-March 2006. These trials will be coordinated and reported by APS. They will be conducted at the National Research Council wind tunnel in Ottawa on a Cessna Caravan wing section.

In an attempt to better understand the issues described above, a series of procedures using both photography and videography were developed for testing in ice pellet conditions.

1. Video Documentation of Pilot's Perspective in Ice Pellets;
2. Dissolving Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid;
3. Dissolving Time Outdoors: Video Documentation of Ice Pellets and Snow Dissolving in Fluid;
4. Photography of Ice Pellets on Black Felt; and
5. Endurance Time Testing in Natural Ice Pellets.

During the course of the winter season, more procedures may be developed based upon results from initial testing and discussions with the industry. In addition to the above five procedures, other procedures may be developed for the ongoing study of ice pellets.

This procedure, *Wind Tunnel Tests to Examine Fluid Removed from Aircraft during Takeoff with Ice Pellets,* is described in this document; the other procedures are described in separate documents.

Preliminary testing was conducted at the PMG research facility. Endurance time testing was conducted during simulated ice pellet conditions on a standard test plate and on an airfoil. The wind tunnel tests described in this procedure will be followed by tests performed on a Falcon 20 aircraft owned and operated by NRC. This procedure is described in a separate document.

2. OBJECTIVES

The objective of this procedure is to determine the level of contamination of anti-icing fluid caused by ice pellets at which the airflow at takeoff fails to remove the resultant slush. The experiment will also review the effects of uncontaminated anti-icing fluid on the aerodynamic of the wing at takeoff.

To satisfy these objectives, a Cessna Caravan wing section will be subjected to a series of tests in the NRC wind tunnel..

3. TEST REQUIREMENTS

APS will co-ordinate the planned 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 and still pictures of fluid on the wing are required.

The tests will be performed in the NRC wind tunnel in Ottawa. The tests are independent of the weather conditions.

The wind tunnel tests scheduled for February-March 2006 will study the behavior of fluids at a precipitation rate of 25 $g/dm^2/h$. Attachment I presents the quantities of ice pellets required to achieve this rate as well as the holdover time (HOT) tables for the fluids used in the tests. Two sizes of ice pellets will be used throughout the tests. These sizes are yet to be determined.

Four sets of tests will be performed in February-March 2006:

- Tests with clean, uncontaminated anti-icing ethylene fluid (2 tests);
- Tests with clean, uncontaminated anti-icing propylene fluid (1 test);
- Tests with ice pellets dispersed over the anti-icing ethylene fluid on the wing section (13 tests); and
- Tests with ice pellets dispersed over the anti-icing propylene fluid on the wing section (4 tests).

A test schedule is presented in Attachment II.

A list of safety issues that must be considered when testing is shown in Attachment III.

4. EQUIPMENT AND FLUIDS

4.1 Equipment

Equipment to be employed is shown in Attachment IV

4.2 Fluids

Ethylene glycol-based UCAR Ultra+ Type IV and propylene glycol-based Kilfrost ABC-S Type IV will be used in February-March 2006 trials.

5. PROCEDURE

The test procedures are shown in Attachment V.

6. PERSONNEL

Four APS staff members are required for tests at the NRC wind tunnel. Two additional persons will be required from Ottawa for making and dispersing the ice pellets. One additional person will be required from Ottawa to record images of the testing.

Fluid and ice pellets applications will be performed by APS personnel at the NRC wind tunnel. Waste fluid clean-up and recovery will be performed by APS personnel. National Research Council personnel will operate the NRC wind tunnel.

Attachment VI provides task assignments.

7. DATA FORMS

The following data forms are required for the February-March 2006 wind tunnel tests:

- Attachment VII – Fluid Receipt Form;
- Attachment VIII – General Form (Every Test);
- Attachment IX – Wing Temperature Form (Port);
- Attachment X – Wing Temperature Form (Starboard);
- Attachment XI – Fluid Thickness on Wing (Port);
- Attachment XII – Fluid Thickness on Wing (Starboard);
- Attachment XIII – Test Results Form (Port); and
- Attachment XIV – Test Results Form (Starboard).

ATTACHMENT I
Ice Pellets Requirements for Tests with DOW UCAR ADF/AAF ULTRA+

1. DOW UCAR ADF/AAF ULTRA+

1.1 Rate of Precipitation

The rate of precipitation studied in the March 2006 wind tunnel tests is 25 g/dm^2/h.

1.2 Holdover Time for Ultra+

From the HOT table attached (see Attachment I), Ultra+ has a HOT of 30 minutes in *light freezing rain conditions* at a rate of precipitation of 25 g/dm^2/h, in temperatures between -3°C and -14°C. The current regulations provide a HOT of 20 minutes, which is consistent with the HOT in *light freezing rain* conditions.

1.3 Quantity of Ice Pellets Required

The calculation of the quantity of ice pellets required for a test takes into account the precipitation rate, test area and the estimated HOT of the fluid.

Precipitation rate: 25 g/dm^2/h
Test Area: 4 m^2 = 400 dm^2
Estimated HOT: 0.3 h

$Q_{Ice\ Pellets}$ = Rate X Test Area X Time = 3000 g = 3.3 kg

1.4 Quantity of Ice Pellets Dispersed

The ice pellets will be dispersed over the test area using handheld dispersers. Trials performed at the Dorval test site in February 2006 showed that the efficiency of the ice pellets disperser is 80%.

Therefore, the quantity required for one test is:

$Q_{dispersed}$ = $Q_{ice\ pellets}$ / 0.8 = 3.3 kg / 0.8 = 4.2 kg

2. KILFROST ABC-S

The quantity of Kilfrost ABC-S required for the tests is the same as for Ultra+ for a HOT of 20 minutes. Since the HOT in light freezing rain conditions is highly dependent on temperature, adjustments may be necessary depending on the test conditions.

ATTACHMENT I (cont.)

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2005-2006[1] UCAR™ ADF/AAF ULTRA+

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

Outside Air Temperature		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	**Degrees Fahrenheit**		**Active Frost**	**Freezing Fog**	**Snow or Snow Grains**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing**	**Other[2]**
-3 and above	27 and above	100/0	12:00	1:35 – 3:35	0:35 – 1:15	0:45 – 1:35	0:25 – 0:40	0:10 – 1:20	CAUTION: No holdover time guidelines exist
		75/25							
		50/50							
below -3 to -14	below 27 to 7	100/0	12:00	1:25 – 3:00	0:25 – 0:55	0:45 – 1:25[3]	0:30 – 0:45[3]		
		75/25							
below -14 to -25	below 7 to -13	100/0	12:00[5]	0:40 – 2:10[5]	0:20 – 0:45[5]				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met.[5] Consider use of Type I when Type IV fluid cannot be used.						

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 These holdover times only apply to outside air temperatures to -24°C (-11°F).

CAUTIONS

- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT I (cont.)

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2005-2006[1]
ABC-S

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

Outside Air Temperature		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	Degrees Fahrenheit		Active Frost	Freezing Fog	Snow or Snow Grains	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	100/0	12:00	2:35 – 4:00	1:00 – 1:40	1:20 – 1:50	1:00 – 1:25	0:20 – 1:15	
		75/25	5:00	1:05 – 1:45	0:30 – 0:55	0:45 – 1:10	0:35 – 0:50	0:10 – 0:50	
		50/50	3:00	0:20 – 0:35	0:05 – 0:15	0:15 – 0:20	0:05 – 0:10	CAUTION: No holdover time guidelines exist	
below -3 to -14	below 27 to 7	100/0	12:00	0:45 – 2:05	0:45 – 1:20	0:20 – 1:00[3]	0:10 – 0:30[3]		
		75/25	5:00	0:25 – 1:00	0:25 – 0:50	0:20 – 1:10[3]	0:10 – 0:35[3]		
below -14 to -25	below 7 to -13	100/0	12:00	0:20 – 0:40	0:15 – 0:30				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met. Consider use of Type I when Type IV fluid cannot be used.						

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

CAUTIONS

- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT II
Test Plan Wind Tunnel Tests in 2005-06

Test #	OAT°C	Fluid	Precipitation	Wing Condition
1	<-3	UCAR Ultra+	None	Clean wing
2	<-3	UCAR Ultra+	None	Clean wing
3	<-3	UCAR Ultra+	None	Ice pellets contamination
4	<-3	UCAR Ultra+	None	Ice pellets contamination
5	<-3	UCAR Ultra+	None	Ice pellets contamination
6	<-3	UCAR Ultra+	None	Ice pellets contamination
7	<-3	UCAR Ultra+	None	Ice pellets contamination
8	<-3	UCAR Ultra+	None	Ice pellets contamination
9	<-3	UCAR Ultra+	None	Ice pellets contamination
10	<-3	UCAR Ultra+	None	Ice pellets contamination
11	<-3	UCAR Ultra+	None	Ice pellets contamination
12	<-3	UCAR Ultra+	None	Ice pellets contamination
13	<-3	UCAR Ultra+	None	Ice pellets contamination
14	<-3	UCAR Ultra+	None	Ice pellets contamination
15	<-3	UCAR Ultra+	None	Ice pellets contamination
16	<-3	Kilfrost ABC-S	None	Clean wing
17	<-3	Kilfrost ABC-S	None	Ice pellets contamination
18	<-3	Kilfrost ABC-S	None	Ice pellets contamination
19	<-3	Kilfrost ABC-S	None	Ice pellets contamination
20	<-3	Kilfrost ABC-S	None	Ice pellets contamination

ATTACHMENT III
Safety Issues

- All personnel must be familiar with Material Safety Data Sheets (MSDS) for fluids;
- When in controlled areas, ensure correct procedures and make sure escorts are available;
- When wind tunnel is operating, no loose objects should be used;
- When wind tunnel is operating, ensure ear plugs are worn and keep safe distances;
- When working on ladders, ensure equipment is stable;
- Appropriate footwear and clothing for frigid temperatures are to be worn by all personnel;
- If fluid comes into contact with skin, rinse hands under running water; and
- If fluid comes into contact with eyes, flush with the portable eye wash station.

Attachment IV
Test Equipment Checklist

TASK	STATUS
Logistics for Every Test	
Coordinate test initiation with NRC	
Fluid pouring device	
Fluid recovery containers	
Vacuum and tarps for fluid collection	
Test Equipment	
Camera Equipment	
Digital video camera	
Digital still camera	
General Support Equipment	
Large tape measure	
Step Ladders – Short + Tall	
Test Equipment	
Test Procedures, data forms	
Clipboards, pencils, wing markers for sample locations and solvent	
Sartorius weigh scale	
Thickness Gauges	
Temperature Probe x 2 and spare batteries	
Devices to lift fluid samples for viscosity	
Sample bottles for viscosity measurement	
Ice Pellets Fabrication Equipment	
Refrigerated Truck	
Ice pellets containers	
Ice pellets dispersers	
Ice bags	
Ice bags storage freezer	
Blenders	
Ice pellets filters	
Folding tables	
Personnel Equipment	
Hearing Protectors (yellow foam)	

Attachment V
Test Procedures

1. PRE-TEST SETUP

- Co-ordinate with NRC wind tunnel personnel;
- Find video/photo specialist in Ottawa to record behaviour of fluid on the Cessna Caravan wing during wind tunnel tests;
- Hotels and advances for APS personnel;
- Arrange for vehicles to transport fluid and ice pellets fabrication and dispersion material;
- Arrange personnel travel to Ottawa;
- Ensure proper functioning of mobile equipment;
- Ensure proper functioning of ice pellets dispersers;
- Mark wing data collection locations;
- Ensure NRC personnel draws grid on the wing;
- Prepare and arrange for transport of equipment to Ottawa;
- Co-ordinate fabrication of ice pellets;
- Ensure the quantity of ice pellets is sufficient for the test;
- Arrange for storage and transportation of ice pellets.

2. CONTACT LIST

- NRC Institute of Aerospace Research: Myron Oleskiw (613) 993-5339;

3. CONDUCT TESTS

3.1 Tests # 1, 2 and 16

3.1.1 Prior to Fluid Application:

- Record ambient conditions of the test (Attachment VIII);
- Collect virgin samples of Type IV fluid for viscosity tests;
- Record wing temperature (Attachments IX and X).

3.1.2 Fluid Application (Pour)

- Pour fluid over the test area;
- Record fluid application times (Attachment VIII);
- Record fluid application quantities (Attachment VIII);

- Let fluid settle for 5 minutes;
- Measure fluid thickness at pre-determined locations on the wing (Attachments XI and XII);
- Measure fluid Brix value (Attachments XI and XII);
- Photograph and videotape the appearance of the fluid on the wing; and
- Collect the excess fluid.

3.1.3 During the Wind Tunnel Test:

- Take still pictures/videotape the behaviour of the fluid on the wing during the simulated takeoff run, capturing any movement of fluid; and
- Record wind tunnel operation parameters.

3.1.4 After the Wind Tunnel Test:

- Collect Type IV fluid samples on wings (if any) for later viscosity measurement;
- Measure thickness and Brix values (Attachments XI and XII); and
- Record observations (Attachments XIII and XIV).

3.2 Tests # 3 –15 and 17-20

3.2.1 Prior to Fluid Application:

- Record ambient conditions of the test (Attachment VIII);
- Collect virgin samples of Type IV fluid for viscosity tests;
- Record wing temperature (Attachments IX and X).

3.2.2 Fluid Application (Pour):

- Pour fluid over the test area;
- Record fluid application times (Attachment VIII);
- Record fluid application quantities (Attachment VIII);
- Let fluid settle for 5 minutes;
- Measure fluid thickness at pre-determined locations on the wing (Attachments XI and XII);
- Measure fluid Brix value (Attachments XI and XII);
- Photograph and videotape the appearance of the fluid on the wing; and
- Collect the excess fluid.

3.2.3 Ice Pellets Application:

- Spread the ice pellets evenly over the test area using the handheld dispenser;
- Record quantity of ice pellets dispersed (Attachment VIII);
- Record application times (Attachment VIII);
- Measure fluid thickness (Attachments XI and XII);
- Measure fluid Brix value (Attachments XI and XII);
- Photograph and videotape the appearance of the fluid on the wing.

3.2.4 Prior to Wind Tunnel Test:

- Measure fluid thickness at the pre-determined locations on the wing (Attachments XI and XII);
- Measure fluid Brix value (Attachments XI and XII);
- Record wing temperatures (Attachments IX and X);
- Record start time of test (Attachment VIII).

3.2.5 During Wind Tunnel Test:

- Take still pictures/videotape the behaviour of the fluid on the wing during the takeoff run, capturing any movement of fluid/ice pellets; and
- Record wind tunnel operation parameters.

3.2.6 After the Wind Tunnel Test:

- Collect Type IV fluid samples from wings (if any) for later viscosity measurement;
- Measure thickness and Brix value (Attachments XI and XII); and
- Observe and record the status of the fluid/ice pellets (Attachments XIII and XIV).

3.3 After Each Test Session

APS personnel will collect the waste solution.
APS will collect EG and PG-based Type IV fluids in separate containers to ensure the waste solutions are properly separated.

3.4 Typical Wind Tunnel Test

Below is a description of a typical Wind Tunnel test, assuming the test starts at 08:00:00.

TIME	TASK
08:00:00	START OF THE TEST. ALL EQUIPMENT READY.
08:00:00	Record test conditions.
08:00:00	Collect fluid samples for subsequent tests.
08:05:00	Prepare wing for fluid application (clean wing, etc).
08:15:00	Pour fluid over test area.
08:30:00	Measure Brix, thickness. Photograph test area.
08:35:00	Disperse ice pellets over test area.
08:45:00	Measure Brix, thickness. Photograph test area.
08:50:00	Clear area and start wind tunnel
09:05:00	Wind tunnel stopped
09:10:00	Measure Brix, thickness. Photograph test area. Record test observations
09:15:00	END OF TEST

ATTACHMENT VI
APS Staff Task Description

Overall Co-ordinator (JD/MC)

- Co-ordinate tests with NRC; and
- Provide direction as required during the tests.

Co-ordinator 1 (GB)

- Ensure that all required equipment is available and functional;
- Maintain General Form for every test (Attachment VIII);
- Ensure all data are collected and recorded, and that all test records submitted;
- Measure temperature of the wing (Attachment IX and X) and Brix (Attachment XI and XII);
- Pour fluid over test area;
- Disperse ice pellets over the test area using the handheld disperser;
- Note the observed wing condition after each run (Attachments XIII and XIV);
- Communicate safety concerns.

Co-ordinator 2 (JG)

- Pour fluid over test area;
- Measure thickness measurements (Attachments XI and XII);
- Disperse ice pellets over the test area using the handheld disperser; and
- Note the observed wing condition after each run (Attachment XIII and XIV).

Data collection (DY)

- Complete the Fluid Receipt Form (Attachment VII) for each fluid;
- Record temperature measurements (Attachment IX and X);
- Record brix and thickness measurements (Attachment XI and XII);
- Record start and end of fluid application (Attachment VIII);
- Record start and end of ice pellets application (Attachment VIII);
- Record amount of ice pellets applied (Attachment VIII).
- Collect samples of fluid for viscosity tests:
  - Virgin Type IV prior to application;
  - Type IV fluid on wing applied by pouring;
  - Type IV fluid remaining on trailing edge following takeoff run; and

- Record the specifics for each sample on the bottle in permanent marker.

Videographer/Photographer (from Ottawa)

- Ensure time stamps are operating and accurately set;
- Videotape fluid on wing "before and after" each run and during wind tunnel test, ensuring constant viewing angles are used, to facilitate comparisons;
- Photograph all test set-up; and
- Photograph the condition of wing with ice pellets at specified times.

Ice Pellets Makers (2-4 persons from Ottawa)

- Responsible for the fabrication of ice pellets;
- One ice pellet maker will operate the blender; and
- One ice pellet maker will filter the crushed ice.

Ice Pellets Co-ordinator (JT/MR)

- Supervise the production of ice pellets;
- Supply the ice pellet makers with raw ice;
- Ensure that the quantity of ice pellets produced is sufficient for the test requirements;
- Ensure proper storage of ice pellets and raw ice;
- Transport ice pellets to the test site; and
- Assist with ice pellets application

ATTACHMENT VII: Fluid Receipt Form

RECEIVING LOCATION:	DATE OF RECEIVING:	SAMPLE COLLECTED FROM BARREL: Y / N

GENERAL

Manufacturer: ________ Fluid Name: ________ APS Code: ________ Fluid Type: ____ Batch #: ________

Certificates of Conformance acc. to SAE AMS 1424: ☐
(check the box if received)

Fluid Freeze Point Curves (FP vs. Dilution & FP vs. Refraction): ☐
(for Type I Fluids only; check the box if received)

Lowest Operational Use Temperature: ☐
(check the box if received)

WSET Done by the Certification Agency: ☐
(check the box if received)

Date of Production: ________ Quantity: ___,___,___(L) Fluid Dilution: ________ (100/75/50 or Neat)(%)

Manufacturer stated BRIX: ________ APS Measured BRIX: ________ MSDS Sheets Received: ☐

Manufacturer's Authorization to Proceed with Endurance Time Testing: ☐
(check the box if received)

Authorized by: ________
(PRINT NAME)

on: ________
(DATE)

TYPE IV FLUIDS

Manufacturers stated VISCOSITY: ☐ mPa*s (cP)
(VALUE)

APS Measured VISCOSITY: ☐ mPa*s (cP)
Using Manufacturer's Method (VALUE)

Viscosity shall be determined using the same Brookfield spindle/sample size combination as used for the AMS 1428 certification (most current).

Attachment VIII: General Form (every Test)

DATE: ____________ FLUID APPLIED: ____________ RUN #: ____________

TEST START TIME: ____________ TEST END TIME: ____________

AIR TEMPERATURE (°C) BEFORE TEST: ____________ AIR TEMPERATURE (°C) AFTER TEST: ____________

FLUID APPLICATION	
Actual start time: ____________	Actual End Time: ____________
Fluid Brix: ____________	Amount of Fluid: ____________
Fluid Temperature: ____________	Fluid Application Method: ____________
Fluid Sample Collected from Barrel: Y / N	

ICE PELLETS APPLICATION	
Actual start time: ____________	Actual End Time: ____________
Quantity of Ice Pellets Applied: ____________	Ice Pellets Size: ____________

COMMENTS

____

MEASUREMENTS BY: ____________ **HANDWRITTEN BY:** ____________

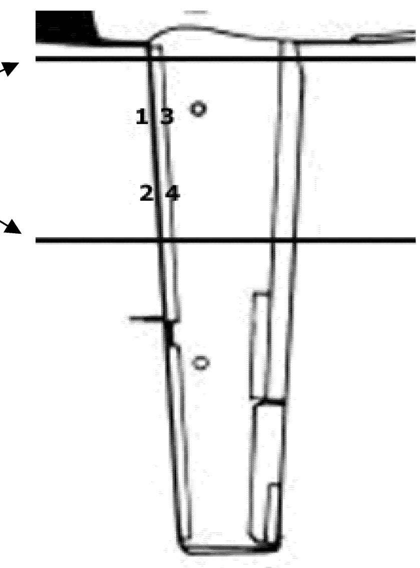
WIND TUNNEL TESTS ***TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS***

Attachment IX: Wing Temperature Form (Port)

Date: ____________________ Time: ____________________ Run Number: _______

Test Phase: A- Before Fluid Application ☐ B- Before Contamination ☐ C- After Contamination ☐ D- After Wind Tunnel Run ☐

Test area denoted by lines



Skin Temperature
Record temperature and time at the positions indicated on the diagram

Position	Time	Temp (°C)
1		
2		
3		
4		

OBSERVER: ____________________________

Comments: ____

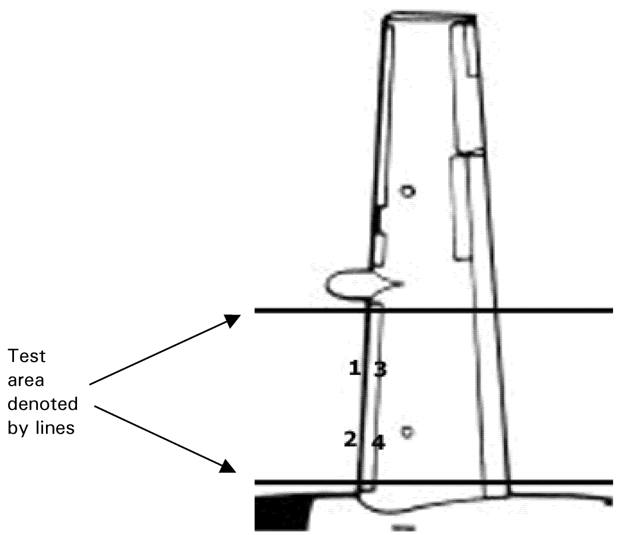
ASSISTED BY: __________________________

Attachment X: Wing Temperature Form (Starboard)

Date: ____________________ Time: _____________________ Run Number: _______

Test Phase: A- Before Fluid Application ☐ B- Before Contamination ☐ C- After Contamination ☐ D- After Wind Tunnel Run ☐

Skin Temperature
Record temperature and time at the positions indicated on the diagram



Position	Time	Temp (°C)
1		
2		
3		
4		

OBSERVER: ____________________________

Comments: ____

ASSISTED BY: ___________________________

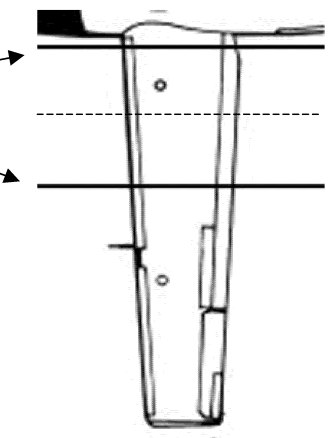
Attachment XI: Fluid Thickness on Wing (Port)

Date: ____________________ Time: ____________________ Run Number: _______

FLUID THICKNESS				
Wing Position	Before IP Application	After IP Application	Before Wind Tunnel Run	After Wind Tunnel Run
1				
2				
3				
4				
5				
6				
7				
8				
9				

FLUID BRIX							
Before IP Application	Wing Position	After IP Application	Wing Position	Before Wind Tunnel Run	Wing Position	After Wind Tunnel Run	Wing Position

Test area denoted by lines



Location: 1 - LE nose
2,8 - Halfway
3,4,6,7 - 1" form joint
5 - As far as can reach
9 - 6" from TE

Notes: - Measure thickness along centerline indicated in the diagram.
- Give priority to circled locations; measure other locations only if time allows.

Comments: ________________________________

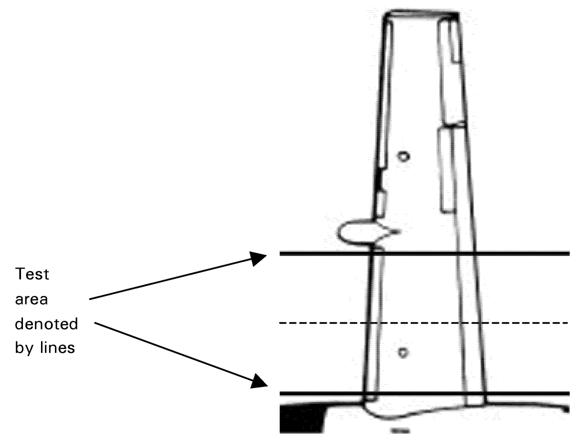
OBSERVER: ____________________
ASSISTED BY: ____________________

Attachment XII: Fluid Thickness on Wing (Starboard)

Date: ____________________ Time: ____________________ Run Number: _______

FLUID THICKNESS				
Wing Position	Before IP Application	After IP Application	Before Wind Tunnel Run	After Wind Tunnel Run
1				
2				
3				
4				
5				
6				
7				
8				
9				

FLUID BRIX							
Before IP Application	Wing Position	After IP Application	Wing Position	Before Wind Tunnel Run	Wing Position	After Wind Tunnel Run	Wing Position



Location: 1 - LE nose
2,8 - Halfway
3,4,6,7 - 1" form joint
5 - As far as can reach
9 - 6" from TE

Notes: - Measure thickness along centerline indicated in the diagram.
- Give priority to circled locations; measure other locations only if time allows.

Comments: ____________________

____

____

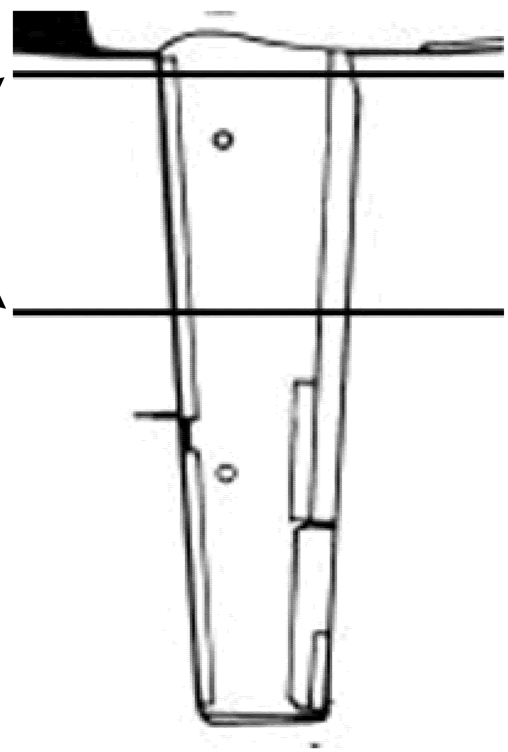
OBSERVER: ____________________

ASSISTED BY: ____________________

Attachment XIII: Test Results Form (Port)

Date: ____________________ Time: _____________________ Run Number: _______

Test area denoted by lines



Observations: ____

____

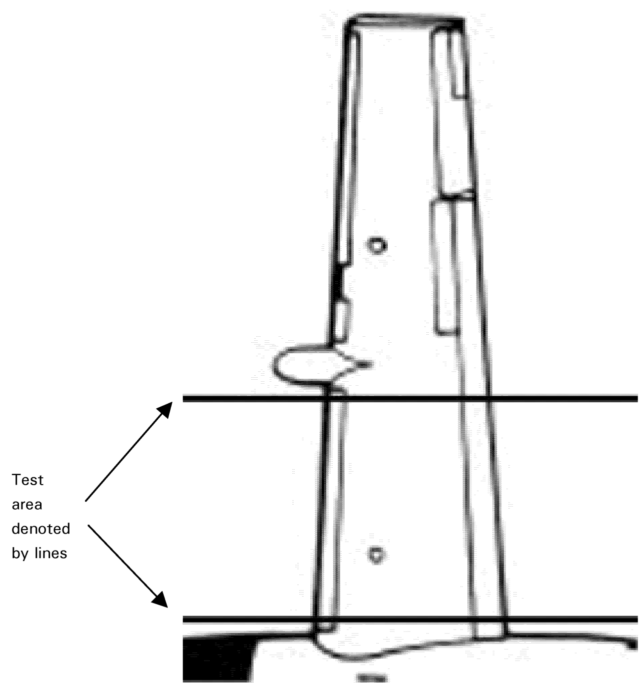
____

OBSERVER: ______________________________

ASSISTED BY: ______________________________

Attachment XIV: Test Results Form (Starboard)

Date: ____________________ Time: _____________________ Run Number: _______



Observations: ______________________________
____
____
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OBSERVER: ______________________________

ASSISTED BY: ______________________________

APPENDIX C

PROCEDURE:
FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT WINGS DURING TAKEOFF WITH ICE PELLETS

CM2020.002 (2006)

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: George Balaban

Reviewed by: John D'Avirro

APS Aviation Inc.

March 13, 2006
Version 3.0

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

1. BACKGROUND

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 (NRC) Falcon 20 aircraft, showed that the test approach was a viable one. The test program conducted during winter 2001-02 and 2002-03 addressed the effects of unshed anti-icing fluid on aircraft take-off performance.

Ice pellets represent a type of precipitation consisting of transparent or translucent pellets of ice, 5mm or less in diameter. The effects of (simulated) ice pellets on the wing of a Falcon 20 aircraft during takeoff will be studied. Since ice pellets embedded in the fluid were not adhering according to previous tests, it is not known whether this contamination in the fluid would come off during aircraft rotation. As a result, the FAA has issued a notice that prevents operations from departing in ice pellet conditions.

The 2005-06 winter season tests will address the effects of deicing fluid contaminated with ice pellets that the airflow at takeoff fails to remove.

This document provides the procedures and equipment required to support the Falcon 20 tests scheduled for March 2006. These trials will be coordinated and reported by APS. They will be conducted at Ottawa International Airport (YOW) on a Falcon 20 research aircraft owned and operated by the NRC

In an attempt to better understand the issues described above, a series of procedures using both photography and videography have been developed for testing in ice pellet conditions. These procedures were developed separately and are listed below.

1. Video Documentation of Pilot's Perspective in Ice Pellets;
2. Dissolving Time Indoors: Video Documentation of Simulated Snow and Ice Pellets Dissolving in Fluid;
3. Dissolving Time Outdoors: Video Documentation of Ice Pellets and Snow Dissolving in Fluid;
4. Photography of Ice Pellets on Black Felt; and
5. Endurance Time Testing in Natural Ice Pellets.

During the course of the winter season, more procedures may be developed based upon results from initial testing and discussions with the industry. In addition to the above procedures, other procedures may be developed for the ongoing study of ice pellets.

The procedure *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets* is described in this document; the other procedures are described in separate documents.

Preliminary testing was conducted at the PMG research facility. Endurance time testing was conducted during simulated ice pellet conditions on a standard test plate and on an airfoil.

2. OBJECTIVES

The objective of this procedure is to determine the level of contamination of anti-icing fluid caused by ice pellets at which the airflow at takeoff fails to remove the resultant slush. The experiment will also review the effects of uncontaminated anti-icing fluid on the aerodynamic of the wing at takeoff.

To satisfy these objectives, a series of simulated takeoff runs will be performed with the NRC Falcon 20 research aircraft.

3. TEST REQUIREMENTS

APS will co-ordinate the planned 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 and still pictures of fluid on aircraft wings during the takeoff run are required.

Desired weather conditions are dry, with subfreezing outside air temperature. Tests will be limited to a maximum of 10 kts crosswind. Overcast skies are very important to avoid overheating the aircraft wings from exposure to the sun. Runway conditions are to be clean and dry.

The Falcon 20 tests scheduled for March 2006 will study the behaviour of fluids at a precipitation rate of 25 g/dm^2/h. Attachment I presents the quantities of ice pellets required to achieve this rate as well as the holdover time (HOT) tables for the fluids used in the tests. Two sizes of ice pellet will be used throughout the tests. The ice pellet size is yet to be determined.

Four sets of tests will be performed in March 2006:

- Tests with clean, uncontaminated anti-icing type IV ethylene fluid on the wing inboard area (2 test);
- Tests with clean, uncontaminated anti-icing type IV propylene fluid on the wing inboard area (1 test);
- Tests with ice pellets dispersed over the anti-icing type IV ethylene fluid on the wing inboard area (10 tests); and
- Tests with ice pellets dispersed over the anti-icing type IV propylene fluid on the wing inboard area (3 tests).

A test schedule is presented in Attachment II. Attachment XIV (Nominal Test Conditions) will be used to schedule the Falcon 20 test runs.

A list of safety issues that must be considered when testing is shown in Attachment III.

A glycol mitigation plan will be prepared for the Ottawa Airport Authority prior to requesting the approval for the conduct of test at YOW. The mitigation plan is shown in Attachment IV.

4. EQUIPMENT AND FLUIDS

4.1 Equipment

Equipment to be employed is shown in Attachment V.

4.2 Fluids

Ethylene glycol-based UCAR Ultra+ Type IV and propylene glycol-based Kilfrost ABC-S Type IV will be used in March 2006 trials.

5. PROCEDURE

The test procedures are shown in Attachment VI.

6. PERSONNEL

Four APS staff members are required for tests at the airport. Two additional persons will be required from Ottawa for making and dispersing the ice pellets. One additional person will be required from Ottawa to record images of the testing. Waste fluid clean-up and recovery will be performed by APS personnel.

Fluid and ice pellets applications will be performed by APS personnel at the NRC hangar. NRC flight crews will operate the NRC aircraft.

Attachment VII provides task assignments.

7. DATA FORMS

The following data forms are required for the Falcon 20 tests to be conducted in February and March 2006:

- Attachment VIII – Fluid Receipt Form;
- Attachment IX – General Form (Every Test);
- Attachment X – Wing Temperature Form (Port Wing);
- Attachment XI – Fluid Thickness on Wing (Port Wing);
- Attachment XII – Test Results Form (Port Wing);
- Attachment XIII – Time Record of Operations;
- Attachment XIV – Nominal Test Conditions.

ATTACHMENT I
Ice Pellets Requirements for Tests with DOW UCAR ADF/AAF ULTRA+

1. DOW UCAR ADF/AAF ULTRA+

1.1 Rate of Precipitation

The rate of precipitation studied in the March 2006 Falcon 20 tests is 25 g/dm^2/h.

1.2 Holdover Time for Ultra+

From the HOT table attached (see Attachment I), Ultra+ has a HOT of 30 minutes in *light freezing rain conditions* at a rate of precipitation of 25 g/dm^2/h, in temperatures between -3°C and -14°C. The current regulations provide a HOT of 20 minutes, which is consistent with the HOT in *light freezing rain* conditions.

1.3 Quantity of Ice Pellets Required

The calculation of the quantity of ice pellets required for a test takes into account the precipitation rate, test area and the estimated HOT of the fluid.

Precipitation rate: 25 g/dm^2/h
Test Area: 3.6 m^2 = 360 dm^2
Estimated HOT: 0.3 h

$Q_{\text{Ice Pellets}}$ = Rate X Test Area X Time = 3000 g = 3 kg

1.4 Quantity of Ice Pellets Dispersed

The ice pellets will be dispersed over the test area using handheld dispersers. Trials performed at the Dorval test site in February 2006 showed that the efficiency of the ice pellets disperser is 80%.

Therefore, the quantity required for one test is:

$Q_{\text{dispersed}}$ = $Q_{\text{ice pellets}}$ / 0.8 = 3 kg / 0.8 = 3.75 kg

2. KILFROST ABC-S

The quantity of Kilfrost ABC-S required for the tests is the same as for Ultra+ for a HOT of 20 minutes. Since the HOT in light freezing rain conditions is highly dependent on temperature, adjustments may be necessary depending on the test conditions.

ATTACHMENT I (cont.)

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2005-2006[1] UCAR™ ADF/AAF ULTRA+

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

Outside Air Temperature		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	Degrees Fahrenheit		Active Frost	Freezing Fog	Snow or Snow Grains	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	100/0	12:00	1:35 – 3:35	0:35 – 1:15	0:45 – 1:35	0:25 – 0:40	0:10 – 1:20	CAUTION: No holdover time guidelines exist
		75/25							
		50/50							
below -3 to -14	below 27 to 7	100/0	12:00	1:25 – 3:00	0:25 – 0:55	0:45 – 1:25[3]	0:30 – 0:45[3]		
		75/25							
below -14 to -25	below 7 to -13	100/0	12:00[5]	0:40 – 2:10[5]	0:20 – 0:45[5]				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met.[5] Consider use of Type I when Type IV fluid cannot be used.						

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 These holdover times only apply to outside air temperatures to -24°C (-11°F).

CAUTIONS

- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT I (cont.)

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2005-2006[1]
ABC-S

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

Outside Air Temperature		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	Degrees Fahrenheit		Active Frost	Freezing Fog	Snow or Snow Grains	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[2]
-3 and above	27 and above	100/0	12:00	2:35 – 4:00	1:00 – 1:40	1:20 – 1:50	1:00 – 1:25	0:20 – 1:15	CAUTION: No holdover time guidelines exist
		75/25	5:00	1:05 – 1:45	0:30 – 0:55	0:45 – 1:10	0:35 – 0:50	0:10 – 0:50	
		50/50	3:00	0:20 – 0:35	0:05 – 0:15	0:15 – 0:20	0:05 – 0:10		
below -3 to -14	below 27 to 7	100/0	12:00	0:45 – 2:05	0:45 – 1:20	0:20 – 1:00[3]	0:10 – 0:30[3]		
		75/25	5:00	0:25 – 1:00	0:25 – 0:50	0:20 – 1:10[3]	0:10 – 0:35[3]		
below -14 to -25	below 7 to -13	100/0	12:00	0:20 – 0:40	0:15 – 0:30				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the outside air temperature and the aerodynamic acceptance criteria are met. Consider use of Type I when Type IV fluid cannot be used.						

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Heavy snow, snow pellets, ice pellets, moderate and heavy freezing rain, and hail.
3 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.

CAUTIONS

- **The only acceptable decision criteria time is the shortest time within the applicable holdover time table cell.**
- **The time of protection will be shortened in heavy weather conditions, heavy precipitation rates, or high moisture content.**
- **High wind velocity or jet blast may reduce holdover time.**
- **Holdover time may be reduced when aircraft skin temperature is lower than outside air temperature.**
- **Fluids used during ground deicing/anti-icing do not provide in-flight icing protection.**

ATTACHMENT II
Test Plan for Falcon 20 Tests in 2005-06

Test #	OAT°C	Fluid	Precipitation	Wing Condition
1	<-3	UCAR Ultra+	None	Clean wing
2	<-3	UCAR Ultra+	None	Clean wing
3	<-3	UCAR Ultra+	None	Ice pellets contamination
4	<-3	UCAR Ultra+	None	Ice pellets contamination
5	<-3	UCAR Ultra+	None	Ice pellets contamination
6	<-3	UCAR Ultra+	None	Ice pellets contamination
7	<-3	UCAR Ultra+	None	Ice pellets contamination
8	<-3	UCAR Ultra+	None	Ice pellets contamination
9	<-3	UCAR Ultra+	None	Ice pellets contamination
10	<-3	UCAR Ultra+	None	Ice pellets contamination
11	<-3	UCAR Ultra+	None	Ice pellets contamination
12	<-3	UCAR Ultra+	None	Ice pellets contamination
13	<-3	Kilfrost ABC-S	None	Clean wing
14	<-3	Kilfrost ABC-S	None	Ice pellets contamination
15	<-3	Kilfrost ABC-S	None	Ice pellets contamination
16	<-3	Kilfrost ABC-S	None	Ice pellets contamination

ATTACHMENT III
Safety Issues

- All personnel must be familiar with Material Safety Data Sheets (MSDS) for fluids;
- When in controlled airport areas, ensure correct procedures and make sure escorts are available;
- When engines are operating, no loose objects should be used around the engines;
- When engines are operating, ensure ear plugs are worn and keep safe distances;
- When working on ladders, ensure equipment is stable;
- Appropriate footwear and clothing for frigid temperatures are to be worn by all personnel;
- The test area must be cleared of snow and ice before testing;
- If fluid comes into contact with skin, rinse hands under running water; and
- If fluid comes into contact with eyes, flush with the portable eye wash station.

ATTACHMENT IV

GLYCOL MITIGATION PLAN

APS AVIATION INC.

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS OTTAWA, ONTARIO (YOW) MARCH 9-17, 2006

1. CORPORATE PROFILE

APS Aviation Inc. (APS), member of the ADGA Group of companies, is a worldwide leader in aircraft de-icing research and development. Since 1990, APS has been contracted by the Transportation Development Centre (TDC) of Transport Canada to further advance aircraft pre-flight de/anti-icing technology.

2. BACKGROUND

At the request of the TDC of Transport Canada, 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.

Previous trials to examine the aerodynamic elimination of failed Type IV fluid from aircraft wings during takeoff were conducted on behalf of Transport Canada during the 1997-98 and 1998-99 and winter seasons at Mirabel Airport. Those trials, based on simulated takeoff runs using a National Research Council Falcon 20 aircraft, provided an improved understanding of the subject matter and demonstrated that the selected test approach was a viable one.

During the winter of 2001-02 and 2002-03, flight tests were performed at Ottawa International Airport (YOW). Tests were performed with one ethylene glycol-based Type IV fluid, Dow Ultra+, in neat and diluted form. Fluid was applied at the central de-icing pad at YOW by GlobeGround personnel.

The effects of (simulated) ice pellets on the wing of Falcon 20 aircraft during takeoff are currently studied. Since ice pellets embedded in the fluid were not adhering according to previous tests, it is not known whether this contamination in the fluid would come off during aircraft rotation. As a result, the FAA has issued a notice that prevents operations from departing in ice pellet conditions.

The March 2006 tests at YOW will address the effects of deicing fluid contaminated with ice pellets that the airflow at takeoff fails to remove.

This document describes the glycol mitigation plan for the planned tests as follows:

- The fluid application procedures;
- The locations designated for fluid application;
- The anticipated fluid quantities to be sprayed; and
- The fluid recovery plan.

3. FLUID APPLICATION PROCEDURES

In previous tests conducted at YOW with ethylene fluid, GlobeGround personnel applied the Dow Ultra+ Type IV fluid to the wings of the Falcon 20 at the central deicing pad. The GlobeGround deicing vehicles were manufactured by Superior, model 1045, and were equipped with Task Force Tips spray nozzles, model # BH–Type 2. All deicing fluid that fell to the ground within the application area was properly recovered.

In March 2006, tests will be conducted at YOW with ethylene and propylene glycol-based Type IV fluids.

APS personnel are highly experienced in aircraft deicing matters, and attempts will be made to limit the quantities of fluid applied to the aircraft. The fluids will be applied to a 3.5 square-meter section of the aircraft wing by pouring, thus limiting the amount of fluid that falls on the ground after application.

The fluid application will be performed by APS personnel at the NRC pad.

All Type IV fluids will be applied unheated to the wings of the Falcon 20. No Type I fluid will be applied prior to the Type IV.

4. LOCATIONS DESIGNATED FOR FLUID APPLICATION

The fluid application will be performed by APS personnel at the NRC pad.

Fluid applications at the NRC pad will be conducted in close proximity to the NRC hangar. Two separate areas will be assigned, one for ethylene applications, the other for propylene applications. NRC personnel will determine the precise locations prior to testing. The aircraft will not be positioned near the stormwater catch basins located on the southern edge of the NRC apron.

5. ANTICIPATED FLUID QUANTITIES TO BE SPRAYED

Sixteen tests are anticipated for March 2006 at YOW. Of this total, twelve will be performed with Dow Ultra+ (ethylene) and four will be performed with Kilfrost ABC-S (propylene).

Based on preliminary testing, the estimated maximum amount of fluid required for the conduct of these tests will be 240 liters (180 of ethylene glycol and 60 of propylene glycol base). Of this quantity, roughly 20% falls to the ground immediately following application.

6. FLUID RECOVERY PLAN

The method of application, pouring, minimizes the fluid that is applied to the wing section and the fluid falling on the ground immediately after application. APS personnel will collect the excess fluid immediately after application using fluid collection containers, tarps and a powerful vacuum.

The waste solutions will be recovered and stored separately to prevent cross-contamination of the products. APS will incur the costs of these fluid recovery services.

7. ADDITIONAL REPORTS

A subsequent report will be provided by APS to the airport authority following the conduct of tests at YOW to provide the quantities of fluid used in testing.

ATTACHMENT V
Test Equipment Checklist

TASK	*STATUS*
Logistics for Every Test	
Monitor Forecast	
Coordinate test initiation with NRC, TDC	
Advise YOW Airport Operations	
Advise Security agency	
Fluid pouring device	
Fluid recovery containers	
Vacuum and tarps for fluid collection	
Test Equipment	
Camera Equipment	
Digital video camera for over-wing position	
Digital still camera	
General Support Equipment	
Fuel for generators	
Large tape measure	
Step Ladders – Short + Tall	
Test Equipment	
Test Procedures, data forms	
Rate pan with Type IV fluid	
Clipboards, pencils, wing markers for sample locations and solvent	
Weigh scale	
Thickness Gauges	
Temperature Probe x 2 and spare batteries	
Devices to lift fluid samples for viscosity	
Sample bottles for viscosity measurement	
Ice Pellets Fabrication Equipment	
Refrigerated Truck	
Ice pellets containers	
Ice pellets dispersers	
Ice bags	
Ice bags storage freezer	
Blenders	
Ice pellets filters	
Folding tables ***Personnel Equipment***	
Hearing Protectors (yellow foam)	
Security passes	

ATTACHMENT VI
Test Procedures

1. PRE-TEST SETUP

- Co-ordinate with Ottawa Airport Authority;
- Arrange for security escorts and passes, if required;
- Find video/photo specialist in Ottawa to record behaviour of fluid on the aircraft during the precipitation phase, taxi and simulated takeoff run of the Falcon 20;
- Hotels and advances for APS personnel;
- Arrange for vehicles to transport fluid and ice pellets fabrication and dispersion material;
- Arrange personnel travel to Ottawa;
- Ensure proper functioning of mobile equipment;
- Ensure proper functioning of ice pellets dispersers;
- Mark aircraft data collection locations;
- Ensure NRC personnel draw grid on aircraft wings;
- Prepare and arrange for transport of equipment to Ottawa;
- Co-ordinate fabrication of ice pellets;
- Ensure the quantity of ice pellets is sufficient for the test;
- Arrange for storage and transportation of ice pellets; and
- Order fluids.

2. CONTACT LIST

- NRC Flight Research Laboratory: Matthew Bastian (613) 998-3337;
- Security escorts: Harvey Airfield: Doug Harvey (613) 794-6884; and
- Ottawa Airport Authority: Yvon Larochelle (613) 248-2000 ext. 1157.

3. CONDUCT TESTS

3.1 Tests # 1, 2 and 13

3.1.1 Prior to Fluid Application:

- Record OAT, wind speed, direction and sky condition (Attachment IX);
- Collect virgin samples of Type IV fluid for viscosity tests; and
- Measure wing temperature (Attachment X).

3.1.2 Fluid Application (Pour)

- Pour fluid over the test area at the NRC hangar;
- Record fluid application times (Attachment IX);
- Record fluid application quantities (Attachment IX);
- Let the fluid settle for 5 minutes;
- Measure fluid thickness at pre-determined locations on the wing (Attachment XI);
- Measure fluid Brix value (Attachment XI);
- Photograph and videotape the appearance of the fluid on the wing; and
- Collect the excess fluid.

3.1.3 Prior to Simulated Takeoff Run (at runway button):

- Measure fluid thickness at the pre-determined locations on the wing (Attachment XI);
- Measure fluid Brix value (Attachment XI);
- Record wing temperatures on the leading edge (Attachment X);
- Record departure runway, wind speed and direction (Attachment IX); and
- Record time of departure (Attachment IX).

3.1.4 During Simulated Takeoff Run:

- Take still pictures/videotape the behaviour of the fluid on the wing during the simulated takeoff run, capturing any movement of fluid; and
- With a second camera, record readings from the air speed indicator (NRC to perform).

3.1.5 Upon Return to the De-icing Pad:

- Collect Type IV fluid samples on wings (if any) for later viscosity measurement;
- Measure thickness and Brix value (Attachment XI); and
- Record observations (Attachment XII).

3.2 Tests # 3 –12 and 14-16

3.2.1 Prior to Fluid Application:

- Record OAT, wind speed, direction and sky condition;
- Collect virgin samples of Type IV fluid for viscosity tests; and

- Measure wing temperature (Attachment X).

3.2.2 Fluid Application (Pour):

- Pour fluid at NRC hangar;
- Record fluid application times (Attachment IX);
- Record fluid application quantities (Attachment IX);
- Let the fluid settle for 5 minutes;
- Measure thickness and Brix value (Attachment XI);
- Collect Type IV fluid samples for viscosity tests;
- Photograph and videotape the appearance of the fluid on the wing; and
- Collect the excess fluid.

3.2.3 Ice Pellets Application:

- Spread the ice pellets evenly over the test area using the handheld dispenser;
- Record quantity of ice pellets dispersed (Attachment IX);
- Measure fluid thickness on the leading edge (Attachment XI);
- Measure fluid Brix value (Attachment XI); and
- Photograph and videotape the appearance of the fluid on the wing.

3.2.4 Prior to Simulated Takeoff Run (at runway button):

- Record wing temperatures on the leading edge (Attachment X);
- Measure fluid thickness on the leading edge (Attachment XI);
- Measure fluid Brix value (Attachment XI);
- Record departure runway, wind speed and direction (Attachment IX); and
- Record time of departure (Attachment IX).

3.2.5 During Simulated Takeoff Run:

- Take still pictures/videotape the behaviour of the fluid on the wing during the takeoff run, capturing any movement of fluid/ice pellets; and
- With a second camera, record readings from the air speed indicator (NRC to perform).

3.2.6 Upon Return to the De-icing Pad:

- Collect Type IV fluid samples from wings (if any) for later viscosity measurement;

- Measure thickness and Brix value (Attachment XI); and
- Observe and record the status of the fluid/ice pellets (Attachment XII).

3.3 After Each Test Session

APS personnel will collect the waste solution from the NRC apron. APS will apply EG and PG-based Type IV fluids at different locations on the NRC apron to ensure the waste solutions are properly separated.

3.4 Typical Falcon 20 Test: Anticipating Timing

Below is a description of a typical Falcon 20 test, assuming the test starts at 08:00:00.

APPROX. TIME	TASK
08:00:00	START OF THE TEST. ALL EQUIPMENT READY.
08:00:00	Record test conditions (OAT, wind, RH, sky condition, etc).
08:00:00	Collect fluid samples for subsequent tests.
08:05:00	Prepare wing for fluid application (clean wing, etc).
08:15:00	Pour fluid over test area and let settle for 5 minutes
08:30:00	After 5 minutes measure Brix, thickness. Photograph test area.
08:35:00	Disperse ice pellets over test area.
08:45:00	Measure Brix, thickness. Photograph test area.
08:50:00	Start aircraft engines. Pilots follow standard pre-departure procedures
09:05:00	Aircraft starts to taxi towards runway. Waste fluid collected and pad prepared for next test.
09:15:00	Aircraft is positioned for the simulated takeoff run. Measure Brix, thickness. Photograph test area.
09:25:00	Start of the simulated takeoff run.
09:35:00	Aircraft returns to the deicing pad.
09:45:00	Measure Brix, thickness. Photograph test area. Record test observations
10:00:00	END OF TEST

ATTACHMENT VII
APS Staff Task Description

Overall Co-ordinator (JD/MC)

- Co-ordinate tests with NRC, TDC;
- Advise all other agencies, including security; and
- Provide direction as required during the tests.

Co-ordinator 1 (GB)

- Ensure that all required equipment is available and functional;
- Maintain General Form for every test (Attachment IX);
- Ensure all data are collected and recorded, and that all test records submitted;
- Measure temperature of the wing (Attachment X) and Brix (Attachment XI);
- Pour fluid over test area;
- Disperse ice pellets over the test area using the handheld disperser;
- Note the observed wing condition after each run (Attachment XII);
- Communicate safety concerns.

Co-ordinator 2 (JG)

- Pour fluid over test area;
- Measure thickness measurements (Attachments XI);
- Disperse ice pellets over the test area using the handheld disperser; and
- Note the observed wing condition after each run (Attachment XII);

Data collection (DY)

- Complete the Fluid Receipt Form (Attachment VIII) for each fluid;
- Record temperature measurements (Attachment X);
- Record brix and thickness measurements (Attachment XI);
- Record start and end of fluid application (Attachment IX);
- Record start and end of ice pellets application (Attachment IX);
- Record amount of ice pellets applied (Attachment IX).
- Collect samples of fluid for viscosity tests:
    - Virgin Type IV prior to application;
    - Type IV fluid on wing applied by pouring;
    - Type IV fluid remaining on trailing edge following takeoff run; and

- Record the specifics for each sample on the bottle in permanent marker.

Videographer/Photographer (from Ottawa)

- Ensure time stamps are operating and accurately set;
- Videotape fluid on wing "before and after" each run and during takeoff run, ensuring constant viewing angles are used, to facilitate comparisons; and
- Photograph all test set-up, outside and onboard the aircraft;
- Photograph the condition of wing with ice pellets at specified times.

Ice Pellets Makers (2-4 persons from Ottawa)

- Responsible for the fabrication of ice pellets;
- One ice pellet maker will operate the blender; and
- One ice pellet maker will filter the crushed ice.

Ice Pellets Co-ordinator (JT/MR)

- Supervise the production of ice pellets;
- Supply the ice pellet makers with raw ice;
- Ensure that the quantity of ice pellets produced is sufficient for the test requirements;
- Ensure proper storage of ice pellets and raw ice;
- Transport ice pellets to the test site; and
- Assist with ice pellets application

Falcon 20 Observer

- One person seated inside the Falcon 20 during tests will keep a time record of operations (Attachment XIII).

ATTACHMENT VIII: Fluid Receipt Form

RECEIVING LOCATION: **DATE OF RECEIVING:** **SAMPLE COLLECTED FROM BARREL: Y / N**

GENERAL

Manufacturer: ________________ **Fluid Name:** ________________________ **APS Code:** ________________________ **Fluid Type:** _____ **Batch #:** ______________________

Certificates of Conformance acc. to SAE AMS 1424: ☐
(check the box if received)

Fluid Freeze Point Curves (FP vs. Dilution & FP vs. Refraction): ☐
(for Type I Fluids only; check the box if received)

Lowest Operational Use Temperature: ☐
(check the box if received)

WSET Done by the Certification Agency: ☐
(check the box if received)

Date of Production: ______________ **Quantity:** ____,____,____(L) **Fluid Dilution:** __________ (100/75/50 or Neat)(%)

Manufacturer stated BRIX: ______________ **APS Measured BRIX:** ______________ **MSDS Sheets Received:** ☐

Manufacturer's Authorization to Proceed with Endurance Time Testing: ☐
(check the box if received)

Authorized by: _________________________
(PRINT NAME)

on: _________________________
(DATE)

TYPE IV FLUIDS

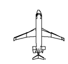
Manufacturers stated VISCOSITY: ☐ mPa*s (cP)
(VALUE)

APS Measured VISCOSITY: Using Manufacturer's Method ☐ mPa*s (cP)
(VALUE)

Viscosity shall be determined using the same Brookfield spindle/sample size combination as used for the AMS 1428 certification (most current).

ATTACHMENT IX: General Form (Every Test)

DATE:	______	AIRCRAFT TYPE:	Falcon 20
RUN #:	______	AIRPORT:	YOW
OAT BEFORE TEST:	______ (°C)	OPERATOR:	NRC
WIND SPEED / DIRECTION:	______	FIN #:	______
EXACT PAD LOCATION OF TEST:	______	FUEL LOAD:	______
FLUID APPLIED:	______	DIRECTION OF AIRCRAFT:	______ degrees
FLUID BRIX:	______	DRAW DIRECTION OF WIND WRT AIRCRAFT	



FLUID APPLICATION - PORT / STARBOARD WING

ACTUAL START TIME:	______	ACTUAL END TIME:	______
FLUID TEMPERATURE	______ (°C)	AMOUNT OF FLUID:	______
FLUID APPLICATION METHOD:	______		

ICE PELLETS APPLICATION - PHOTOGRAPH SAMPLE

ACTUAL START TIME:	______	ACTUAL END TIME:	______
QUANTITY OF ICE PELLETS APPLIED	______ kg	ICE PELLETS SIZE:	______

DEPARTING TIME FROM DEICING BAY:	______	PILOTS READY/DOOR CLOSED:	______
START TIME OF TAKE-OFF ROLL:	______	ARRIVE AT IP APPLICATION ZONE:	______
END TIME OF TAKE-OFF ROLL:	______	OPEN DOOR/APPLY IP:	______
RETURN TO THE DEICING BAY:	______	CLOSE DOOR AFTER IP APPLICATION:	______
OAT AFTER TEST:	______ (°C)	COMMENTS:	______
SKY CONDITIONS:	______		

MEASUREMENTS BY: ______

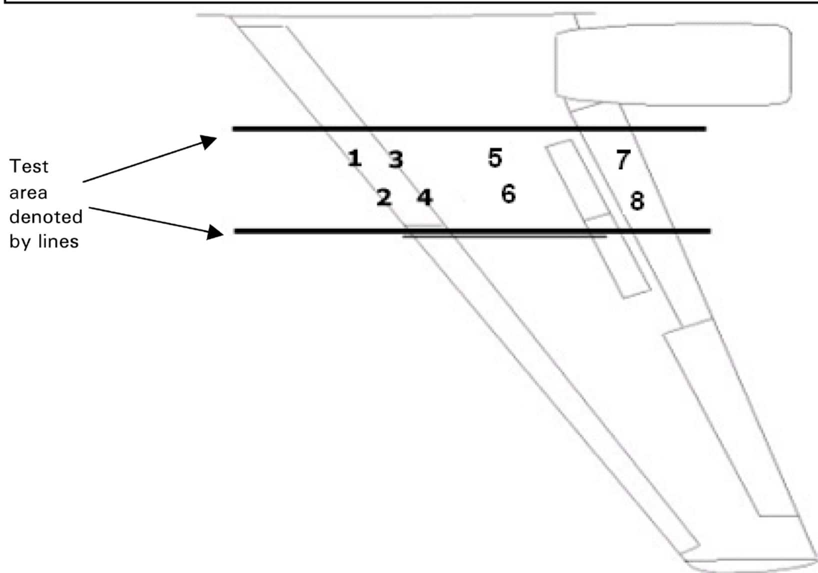
HANDWRITTEN BY: ______

M:/Groups/PM 2020 (TC-Deicing 05-06)/Procedures/Data Forms/General Form - Falcon 20 v3.0

ATTACHMENT X: Wing Temperature Form (Port Wing)

Date: ____________________ Time: ____________________ Run Number: _______

Test Phase: A- Before Fluid Application ☐ B- Before Contamination ☐ C- Before Takeoff Run ☐ D- After Takeoff Run ☐



~~**Skin Temperature**~~
Record temperature and time at the positions indicated on the diagram

Position	Time	Temp (°C)
1		
2		
3		
4		
5		
6		
7		
8		

Comments: ____

OBSERVER: ______________________

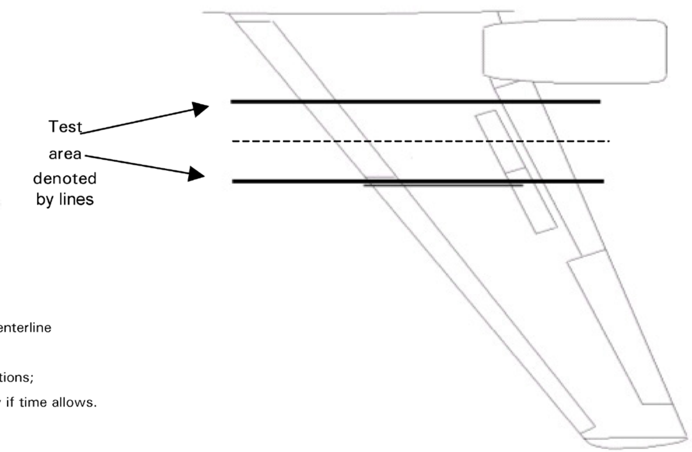
ASSISTED BY: ______________________

ATTACHMENT XI: Fluid Thickness on Wing (Port Wing)

Date: ____________________ Run Number: _______

FLUID THICKNESS				
Wing Position	After fluid application	Before IP Application	After IP Application	After Takeoff Run
1				
2				
5				
7				
8				
TIME				

FLUID BRIX							
After fluid application (lead./trail.)	Wing Position	Before IP Application (lead./trail.)	Wing Position	After IP Application (lead./trail.)	Wing Position	After Takeoff Run (lead./trail.)	Wing Position
Time:		time:		time:		time:	



Location: 1 - LE nose
2,8 - Halfway
3,4,6,7 - 1" form joint
5 - As far as can reach
9 - 6" from TE

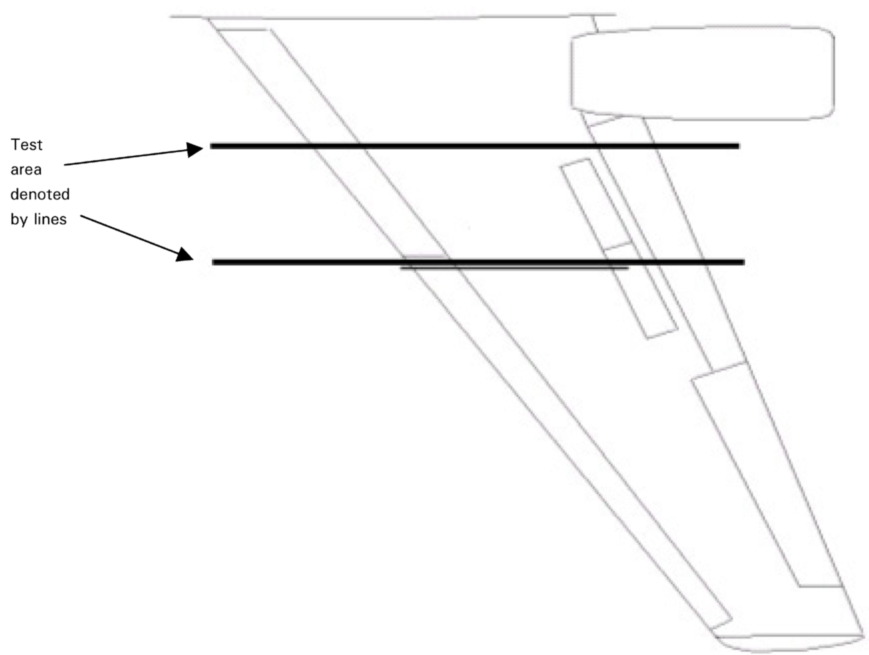
Notes: - Measure thickness along centerline indicated in the diagram.
- Give priority to circled locations; measure other locations only if time allows.

Comments: ____
____
____

OBSERVER: ____________________
ASSISTED BY: ____________________

ATTACHMENT XII: Test Results Form (Port Wing)

Date: ____________________ Time: ____________________ Run Number: _______



Observations: ____________________

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OBSERVER: ____________________

ASSISTED BY: ____________________

ATTACHMENT XIII: Time Record of Operations

Run Number __________________

Date _________________________

OPERATION	TIME / OBSERVATION
Pilots Bboard	
Start Engines	
Systems Rready	
Fluid Application Start	
Fluid Application Completed	
Measure Ffluid and Air Temperature	
Close Ddoor	
Ready to Roll	
Start Taxi	
Arrive Runway Hold	
Door Open	
Measure Aair Temperature	
Measure Fluid Thickness Brix and Temperature	
Start Pellet Application	
Complete Pellet Application	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	
Start Cameras	
Start Take Off Roll	
End Acceleration	
End Take Off Roll	
Look for Remaining Pellets and Record	
Arrive at Hanger	
Engine Shut Down	
Door Open	

ATTACHMENT XIV: Nominal Test Conditions

TEST NO	1	2	3	4	5
Date	9-Mar-06	9-Mar-06			
Fluid	Ultra +	ABCS			
Pellets size [mm]	3.35 - 4.75	3.35 - 4.75			
Pellet Application Rate [g/dm ^{2}]	8	N/A			
Total Pellet Weight Applied [kg]	3	N/A			
Dyed Pellets	N/A	N/A			
Pellets Applied	LE & TE	N/A			
Test Start Time	7:10	8:54			
Runway in Use	07	N/A			
OAT [C]	-5	-4			
Average Wing Temp [C]	-2.7	2.9			
Relative Humidity	N/A	N/A			
Wind Condition	105 / 12 kt	105 / 10 kt			
Sky Condition	Overcast	Overcast			
Precipitation	NIL	-ZR			
Flight Time					
Remarks		Test aborted due to freezing rain			

APPENDIX D

GLYCOL MITIGATION PLAN

GLYCOL MITIGATION PLAN

APS AVIATION INC.

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS OTTAWA, ONTARIO (YOW) MARCH 9-17, 2006

1. CORPORATE PROFILE

APS Aviation Inc. (APS), member of the ADGA Group of companies, is a worldwide leader in aircraft de-icing research and development. Since 1990, APS has been contracted by the Transportation Development Centre (TDC) of Transport Canada to further advance aircraft pre-flight de/anti-icing technology.

2. BACKGROUND

At the request of the TDC of Transport Canada, 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.

Previous trials to examine the aerodynamic elimination of failed Type IV fluid from aircraft wings during takeoff were conducted on behalf of Transport Canada during the 1997-98 and 1998-99 and winter seasons at Mirabel Airport. Those trials, based on simulated takeoff runs using a National Research Council Falcon 20 aircraft, provided an improved understanding of the subject matter and demonstrated that the selected test approach was a viable one.

During the winter of 2001-02 and 2002-03, flight tests were performed at Ottawa International Airport (YOW). Tests were performed with one ethylene glycol-based Type IV fluid, Dow Ultra+, in neat and diluted form. Fluid was applied at the central deicing pad at YOW by GlobeGround personnel.

The effects of (simulated) ice pellets on the wing of Falcon 20 aircraft during takeoff are currently studied. Since ice pellets embedded in the fluid were not adhering according to previous tests, it is not known whether this contamination in the fluid would come off during aircraft rotation. As a result, the FAA has issued a notice that prevents operations from departing in ice pellet conditions.

The March 2006 tests at YOW will address the effects of deicing fluid contaminated with ice pellets that the airflow at takeoff fails to remove.

This document describes the glycol mitigation plan for the planned tests as follows:

- The fluid application procedures;
- The locations designated for fluid application;
- The anticipated fluid quantities to be sprayed; and
- The fluid recovery plan.

3. FLUID APPLICATION PROCEDURES

In previous tests conducted at YOW with ethylene fluid, GlobeGround personnel applied the Dow Ultra+ Type IV fluid to the wings of the Falcon 20 at the central deicing pad. The GlobeGround deicing vehicles were manufactured by Superior, model 1045, and were equipped with Task Force Tips spray nozzles, model # BH–Type 2. All deicing fluid that fell to the ground within the application area was properly recovered.

In March 2006, tests will be conducted at YOW with ethylene and propylene glycol-based Type IV fluids.

APS personnel are highly experienced in aircraft deicing matters, and attempts will be made to limit the quantities of fluid applied to the aircraft. The fluids will be applied to a 3.5 square-meter section of the aircraft wing by pouring, thus limiting the amount of fluid that falls on the ground after application.

The fluid application will be performed by APS personnel at the NRC pad.

All Type IV fluids will be applied unheated to the wings of the Falcon 20. No Type I fluid will be applied prior to the Type IV.

4. LOCATIONS DESIGNATED FOR FLUID APPLICATION

The fluid application will be performed by APS personnel at the NRC pad.

Fluid applications at the NRC pad will be conducted in close proximity to the NRC hangar. Two separate areas will be assigned, one for ethylene applications, the other for propylene applications. NRC personnel will determine the precise locations prior to testing. The aircraft will not be positioned near the stormwater catch basins located on the southern edge of the NRC apron.

5. ANTICIPATED FLUID QUANTITIES TO BE SPRAYED

Sixteen tests are anticipated for March 2006 at YOW. Of this total, twelve will be performed with Dow Ultra+ (ethylene) and four will be performed with Kilfrost ABC-S (propylene).

Based on preliminary testing, the estimated maximum amount of fluid required for the conduct of these tests will be 240 liters (180 of ethylene glycol and 60 of propylene glycol base). Of this quantity, roughly 20% falls to the ground immediately following application.

6. FLUID RECOVERY PLAN

The method of application, pouring, minimizes the fluid that is applied to the wing section and the fluid falling on the ground immediately after application. APS personnel will collect the excess fluid immediately after application using fluid collection containers, tarps and a powerful vacuum.

The waste solutions will be recovered and stored separately to prevent cross-contamination of the products. APS will incur the costs of these fluid recovery services.

7. ADDITIONAL REPORTS

A subsequent report will be provided by APS to the airport authority following the conduct of tests at YOW to provide the quantities of fluid used in testing.

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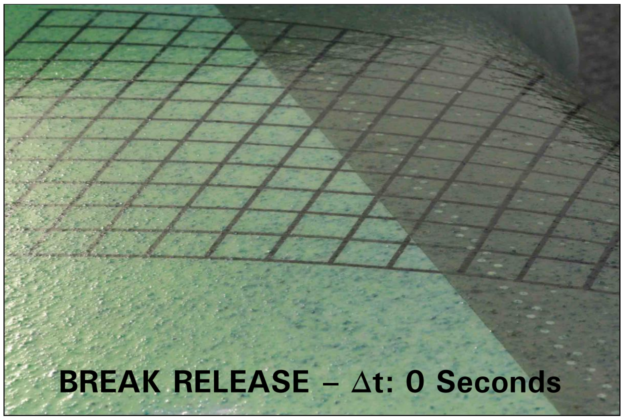
APPENDIX E

PHOTO DOCUMENTATION OF RUN 4 AND RUN 8

RUN 4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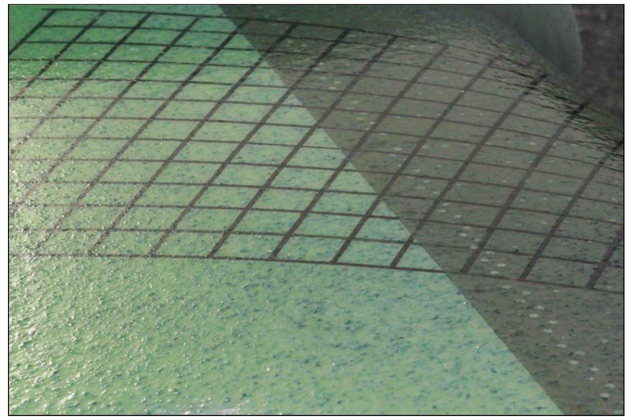

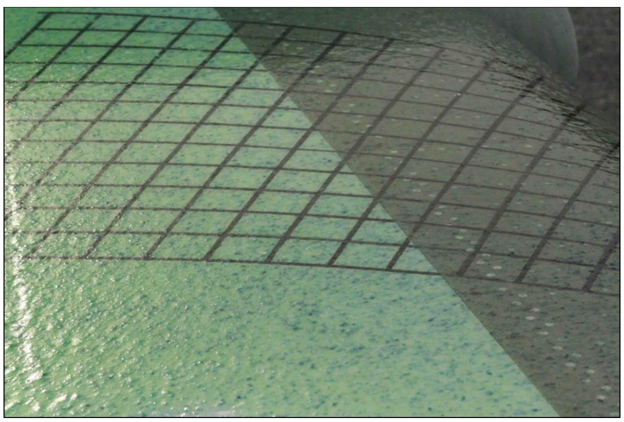

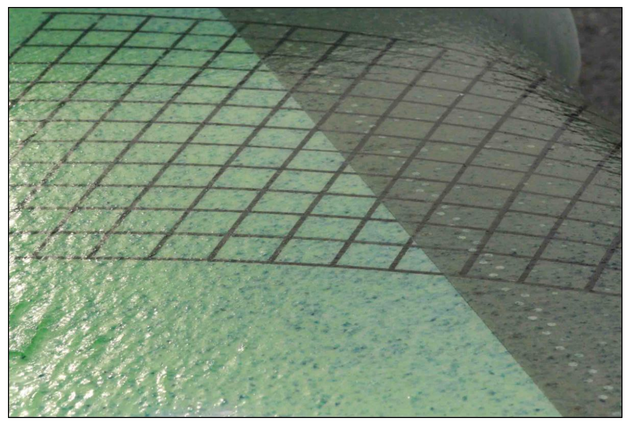

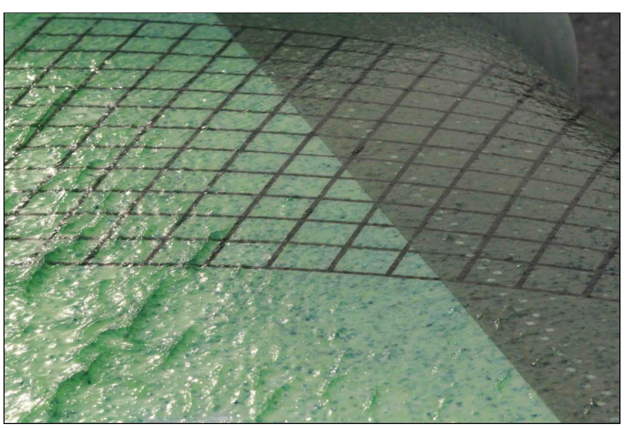

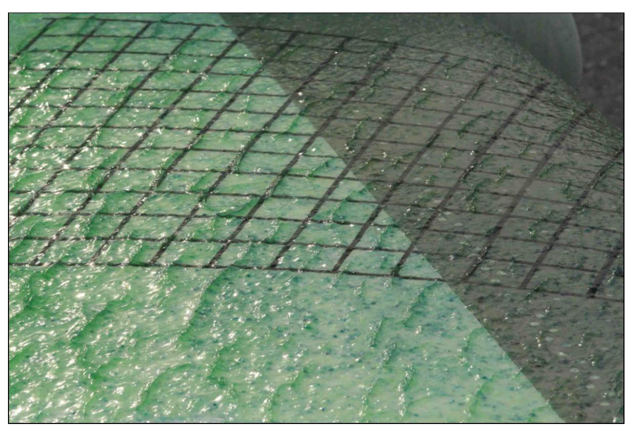

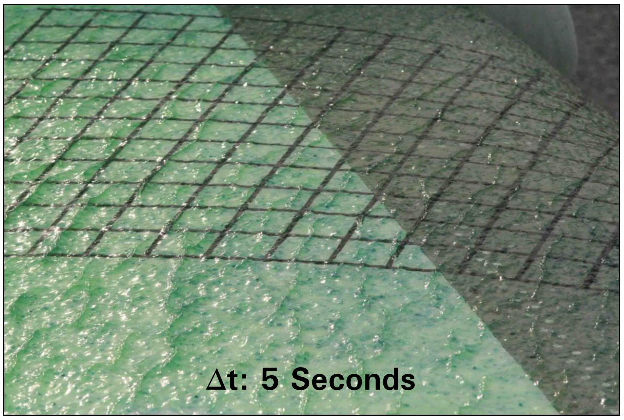
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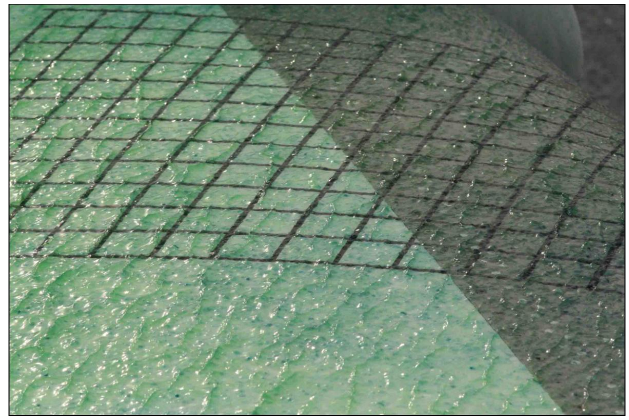

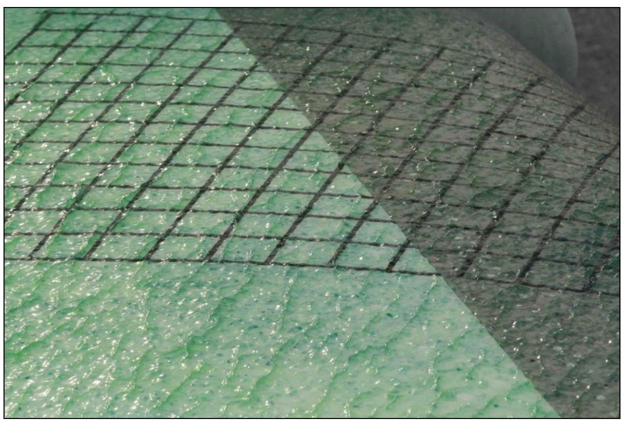

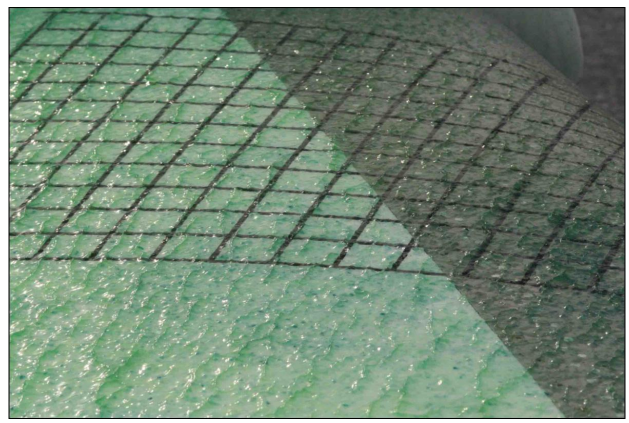

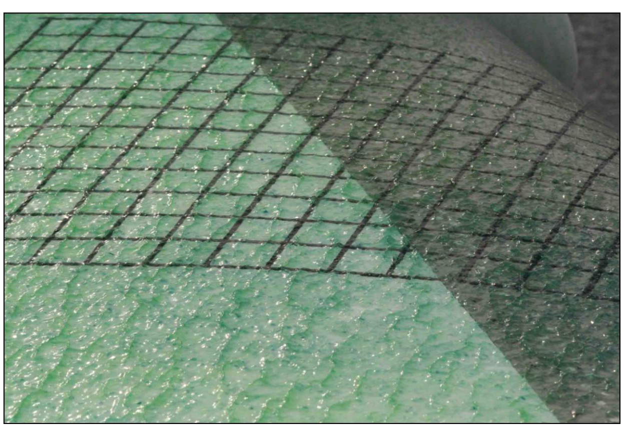

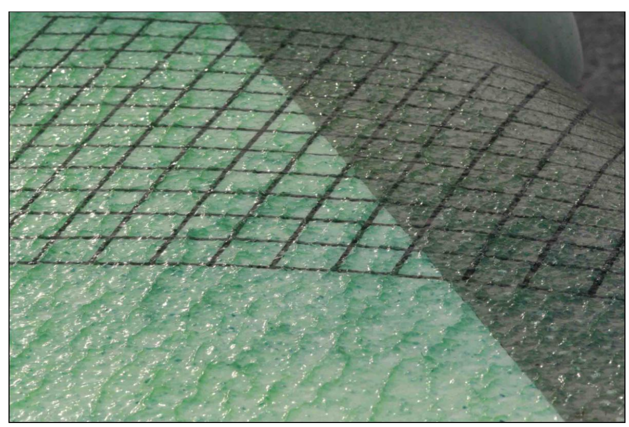

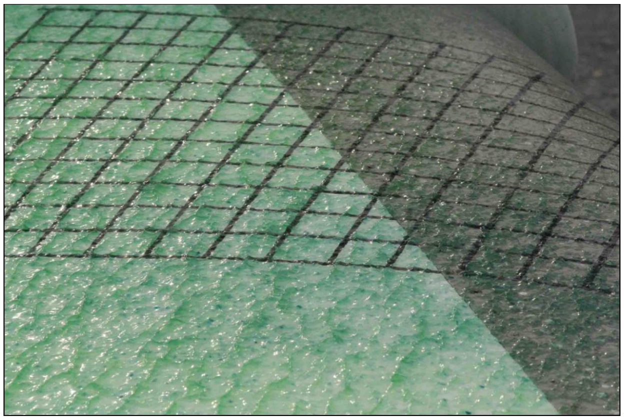

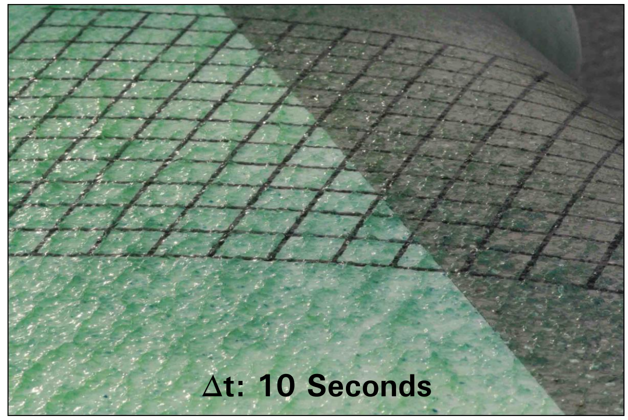
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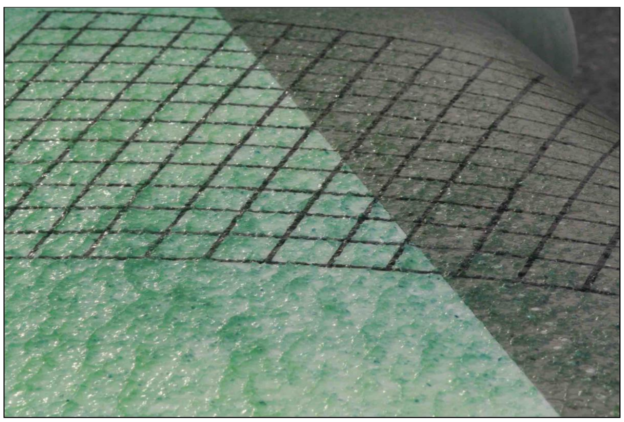
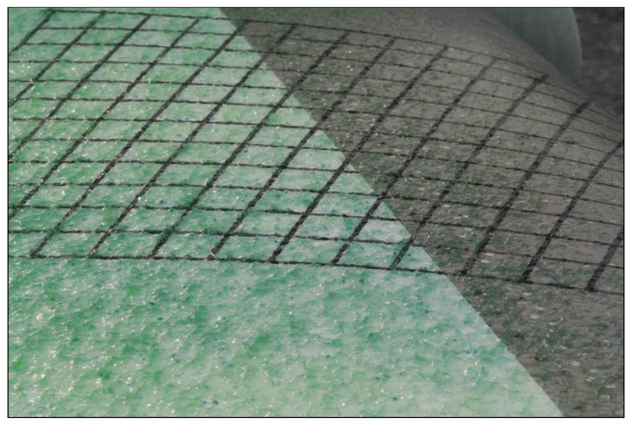
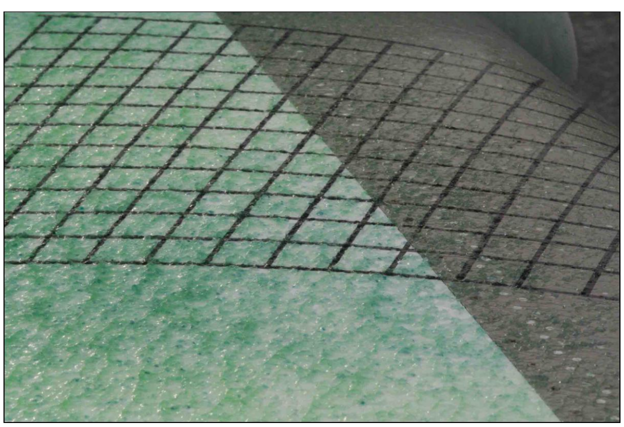
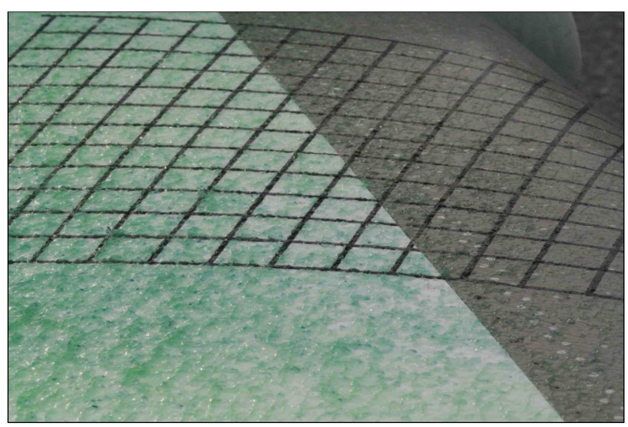
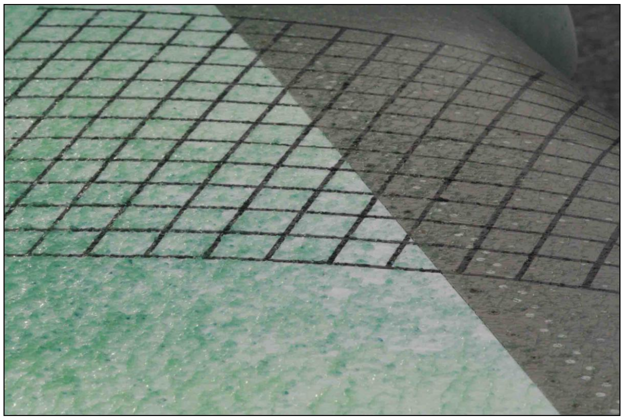
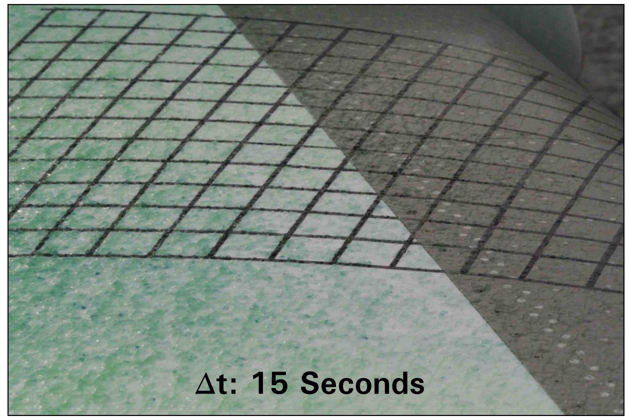


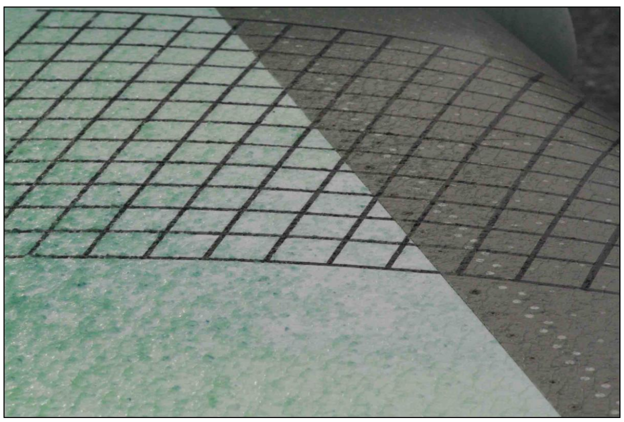


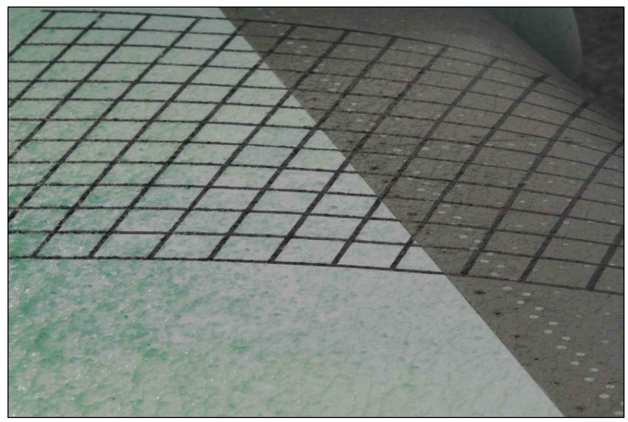


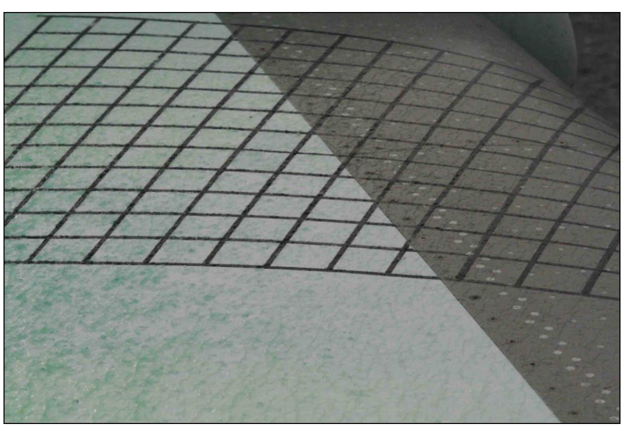


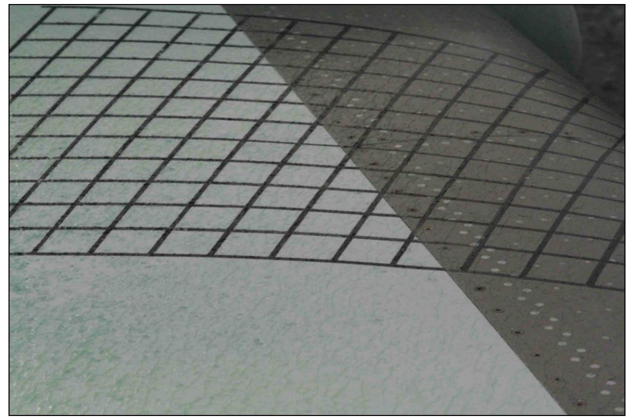


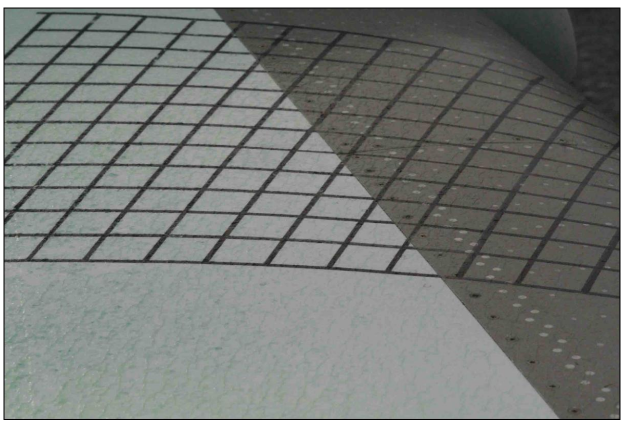

Δt: 15 Seconds

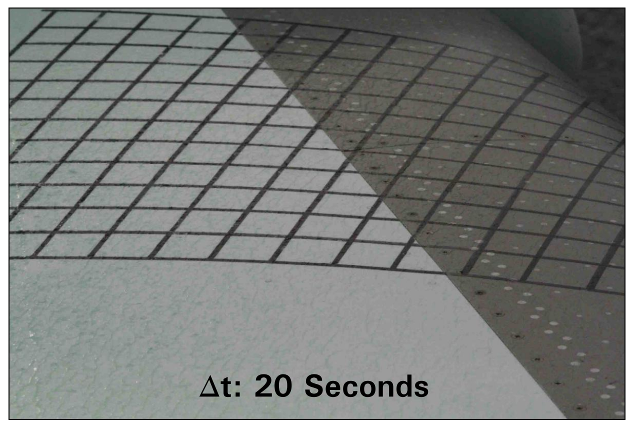








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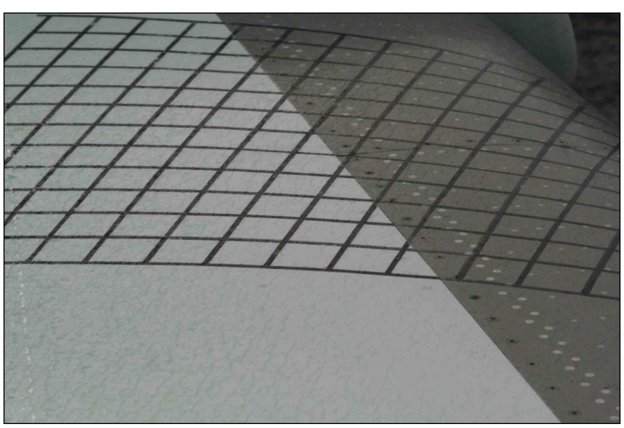
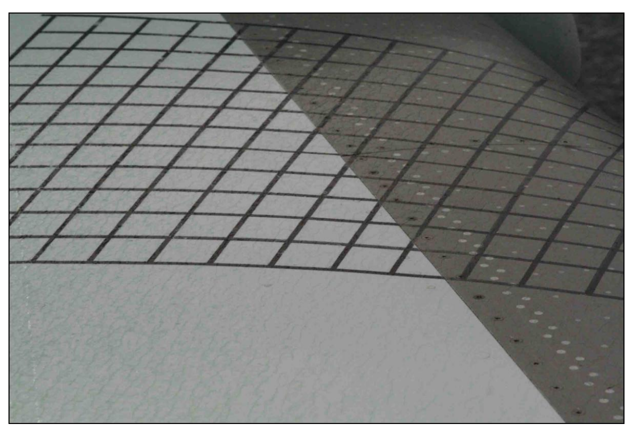
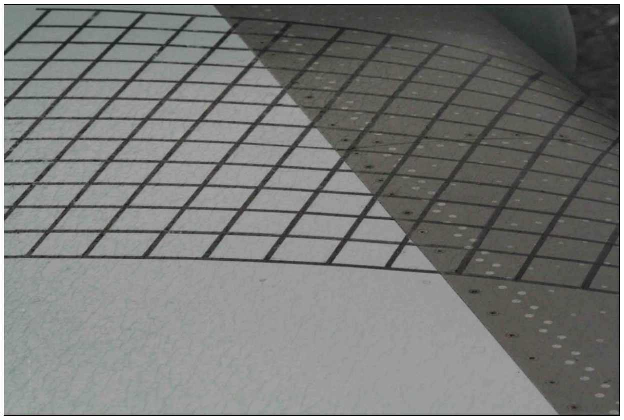
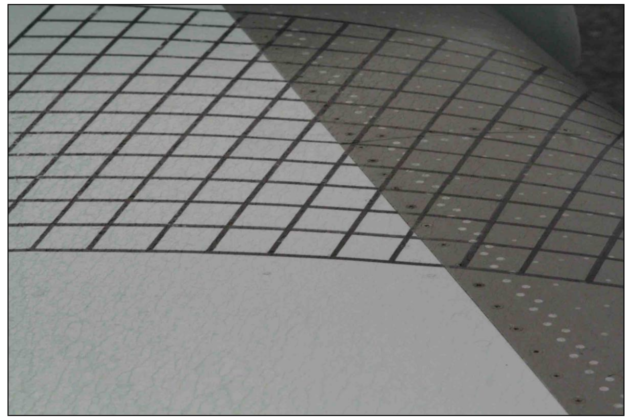
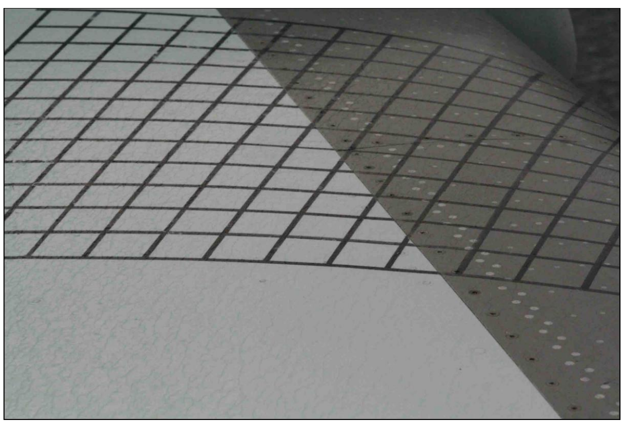
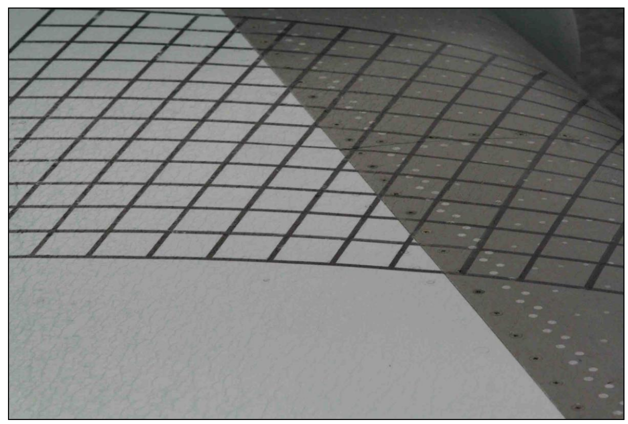


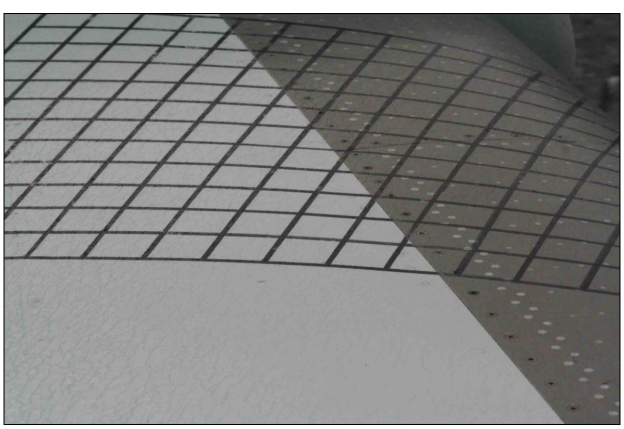


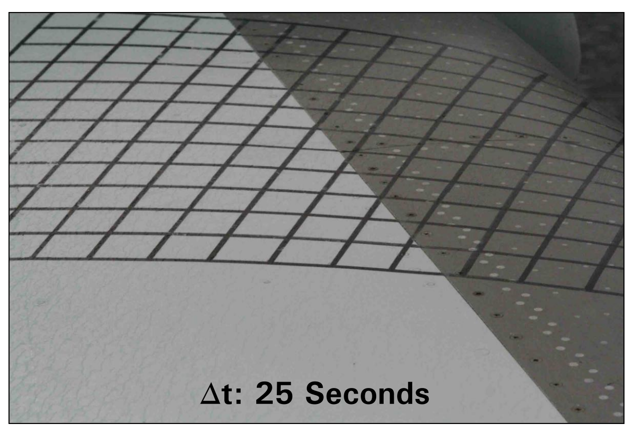


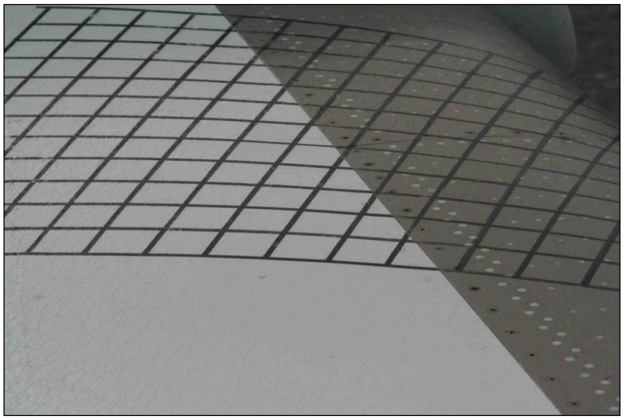


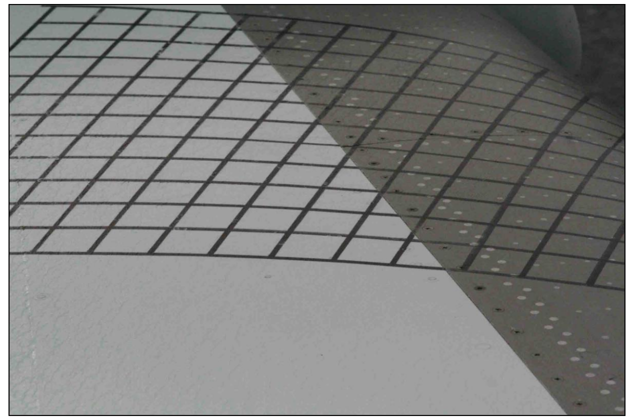


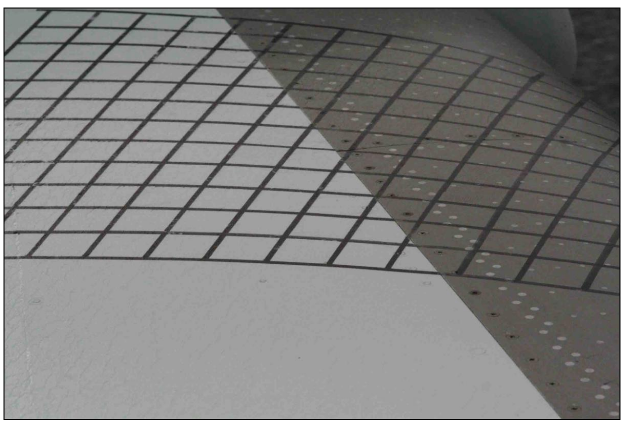


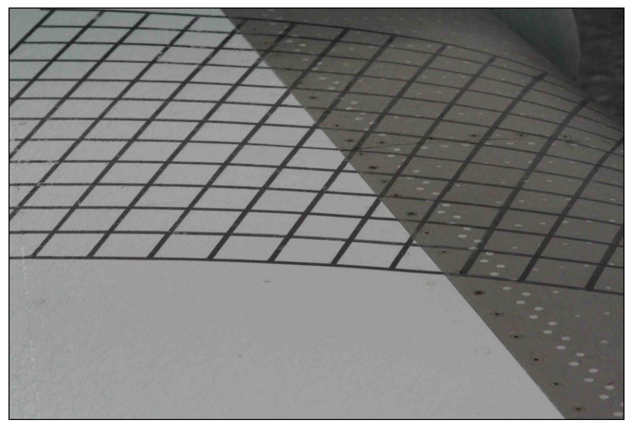


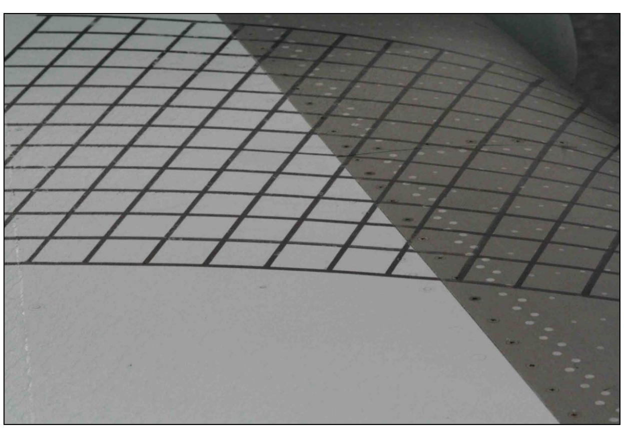

Δt: 25 Seconds

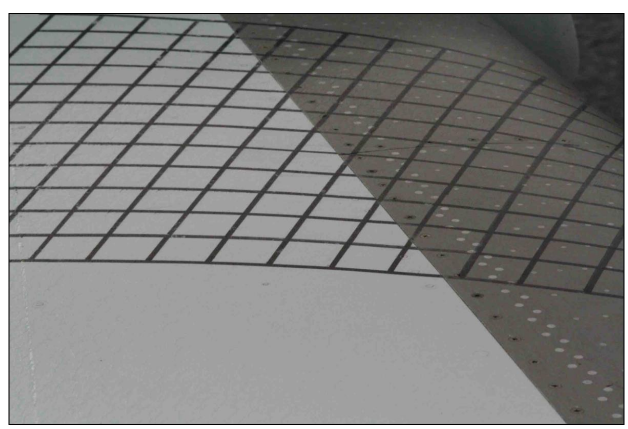


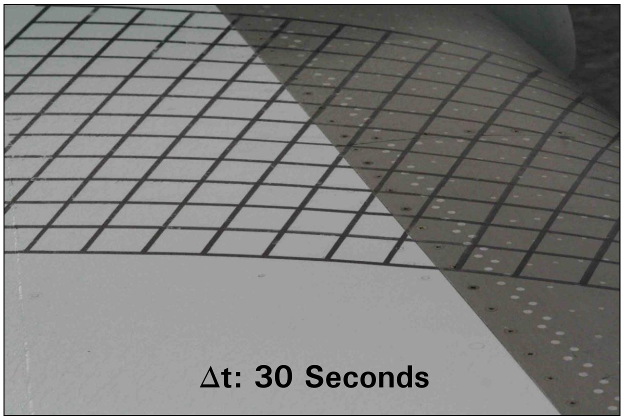








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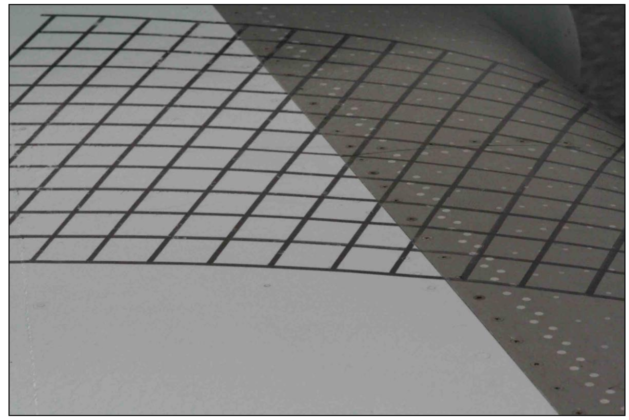

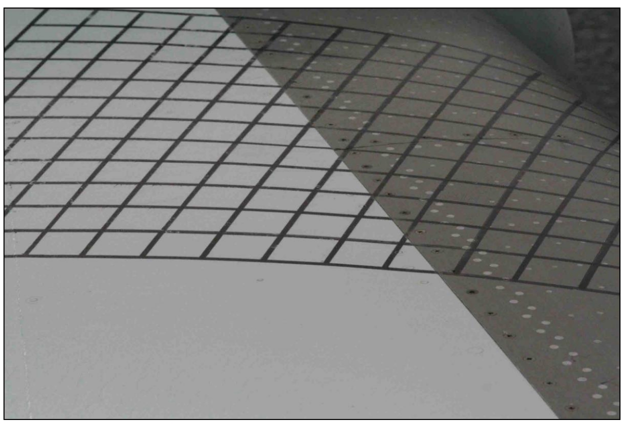

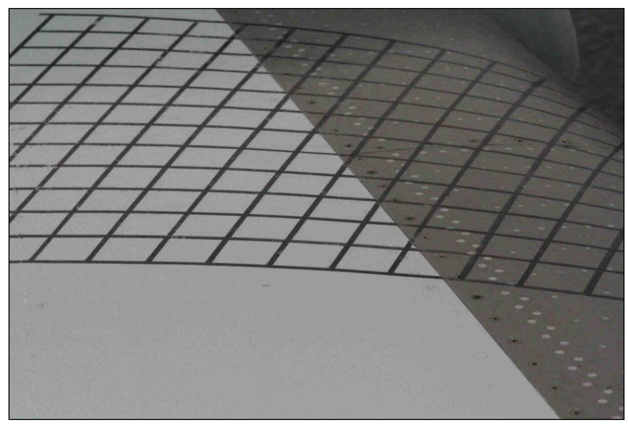

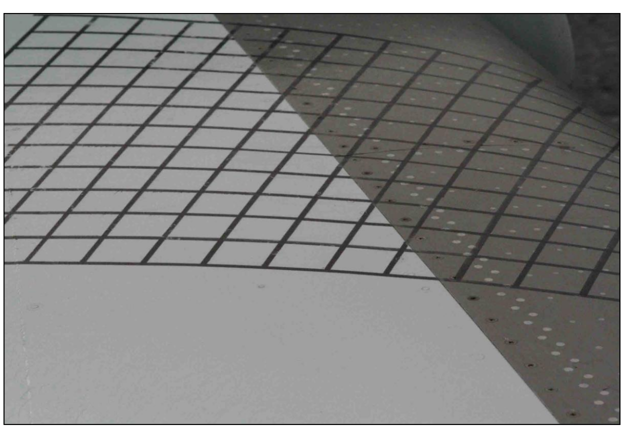

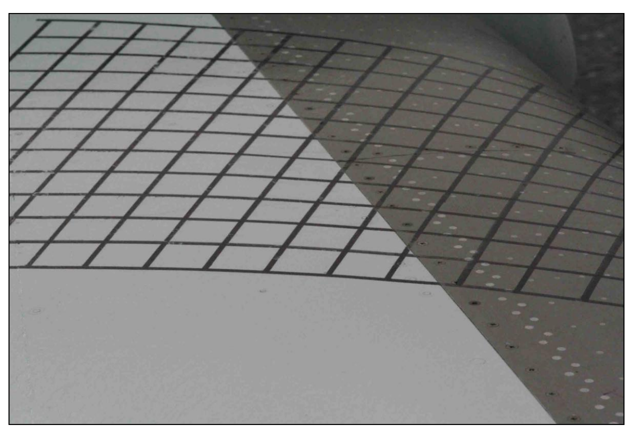

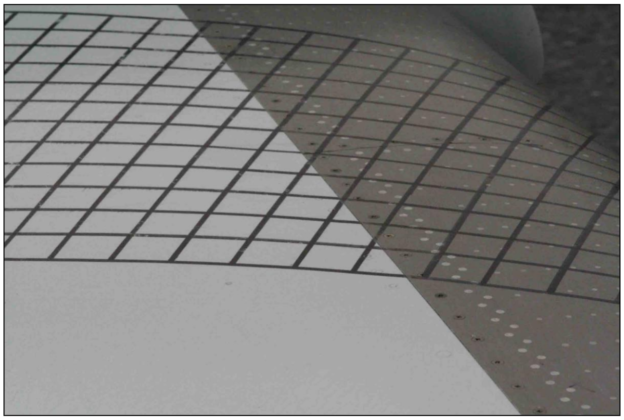
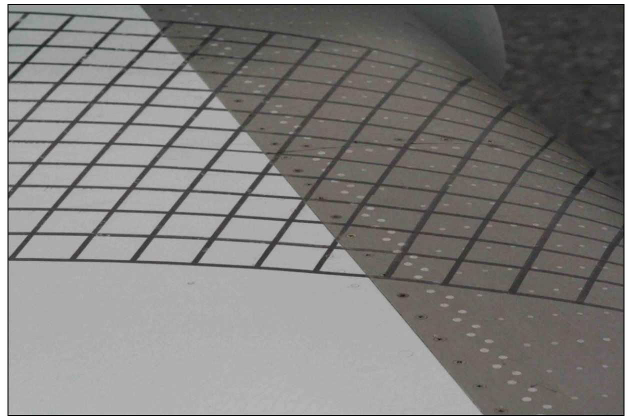
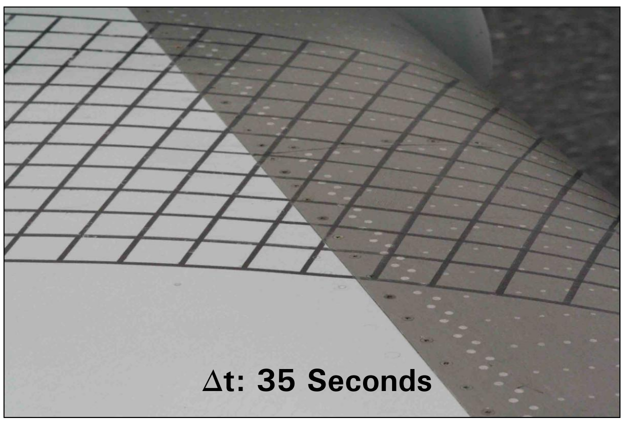
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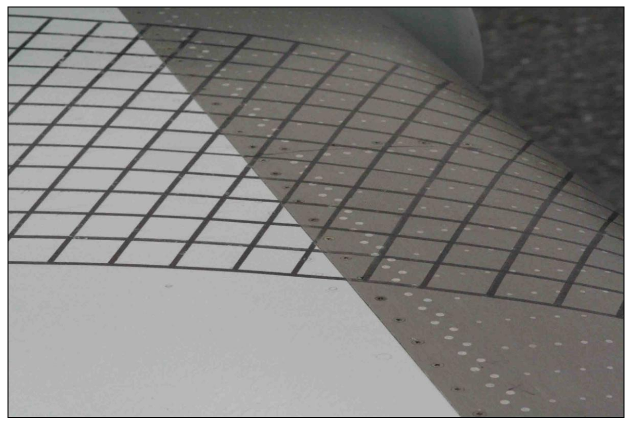
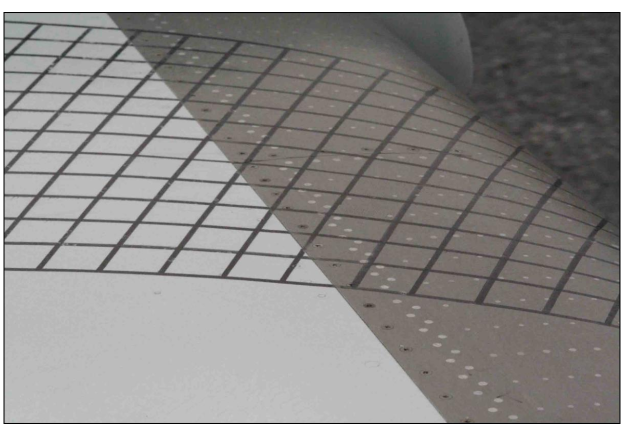
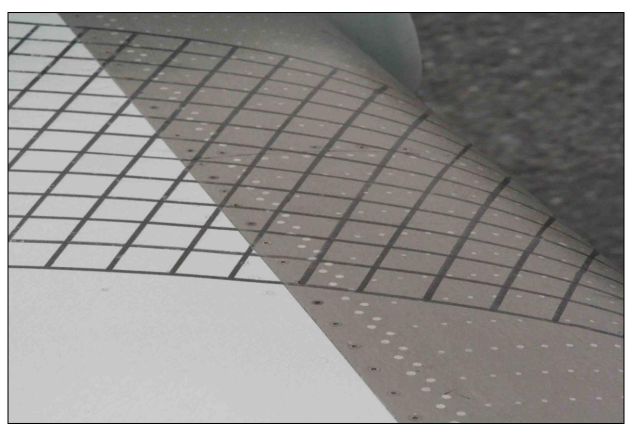

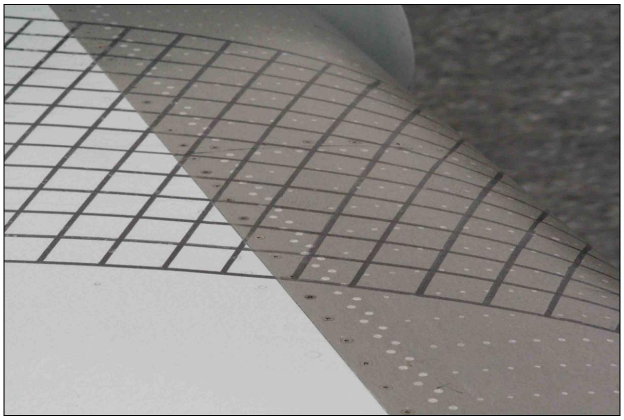

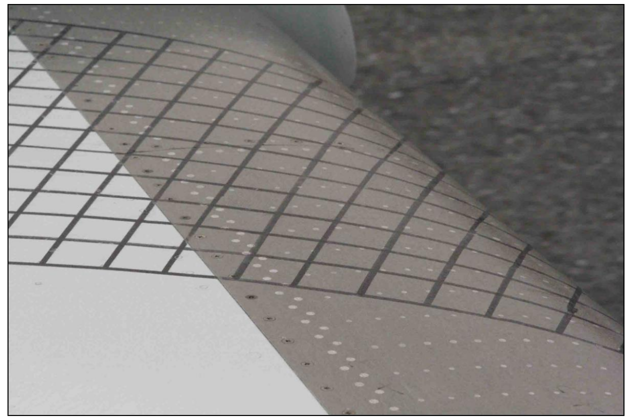

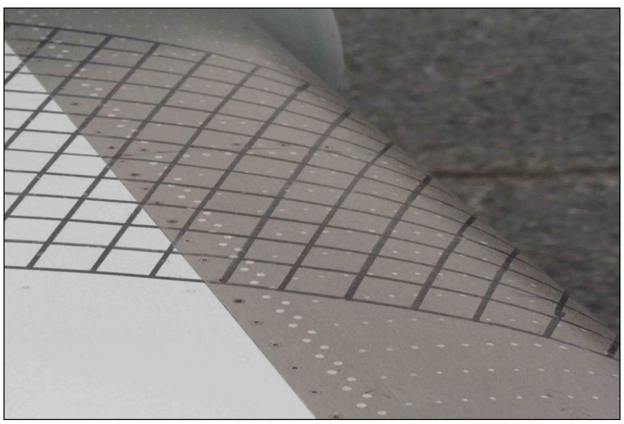

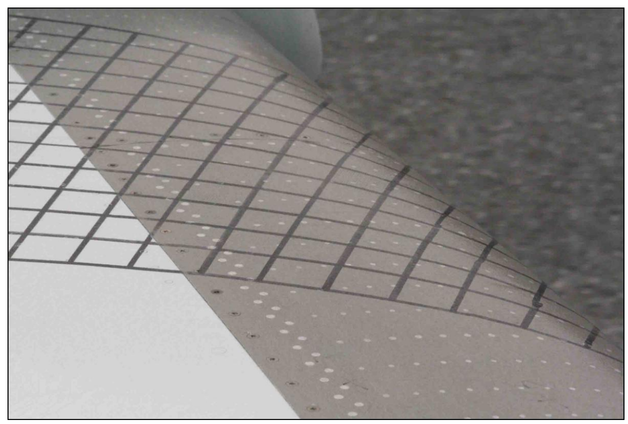

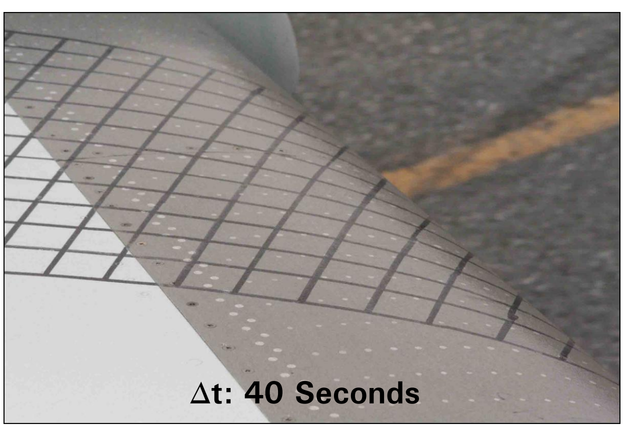
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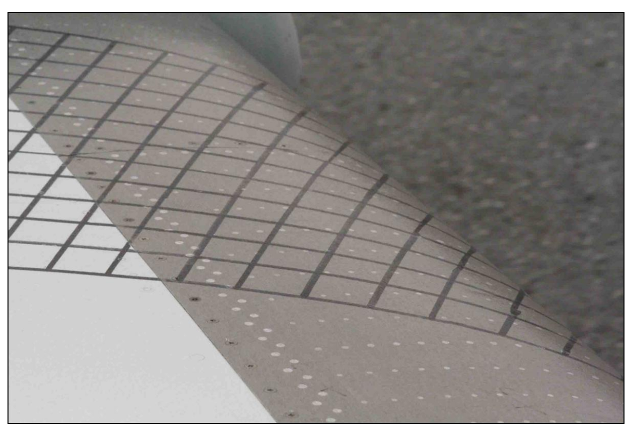
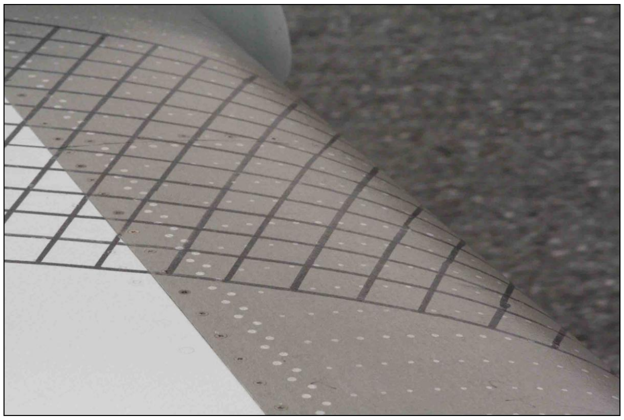
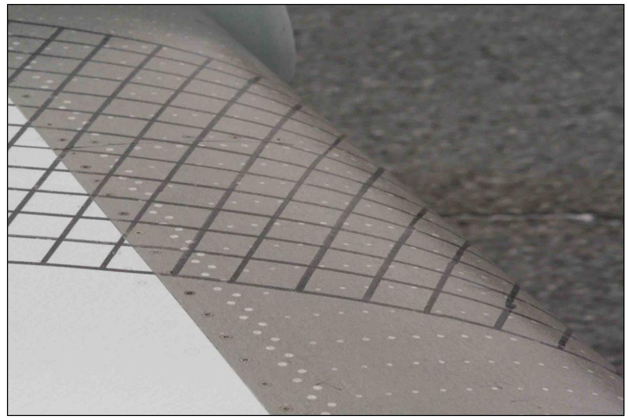
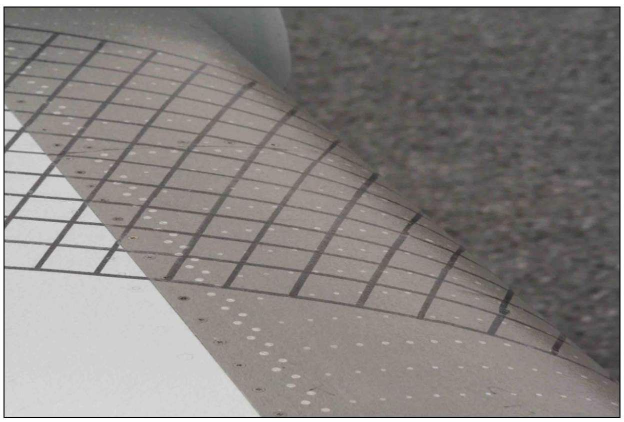
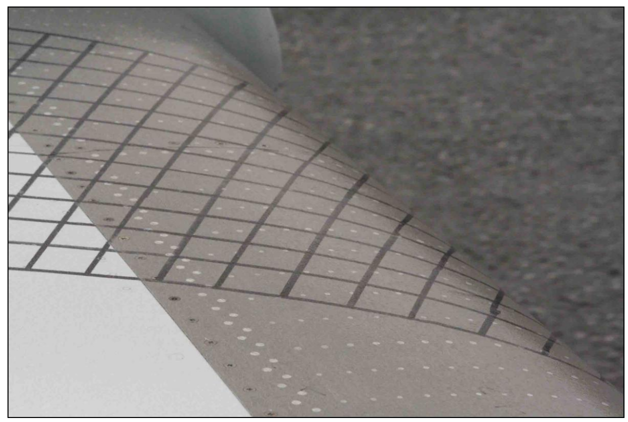
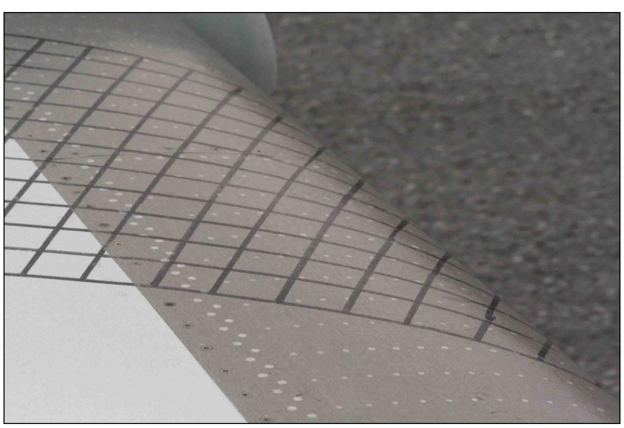


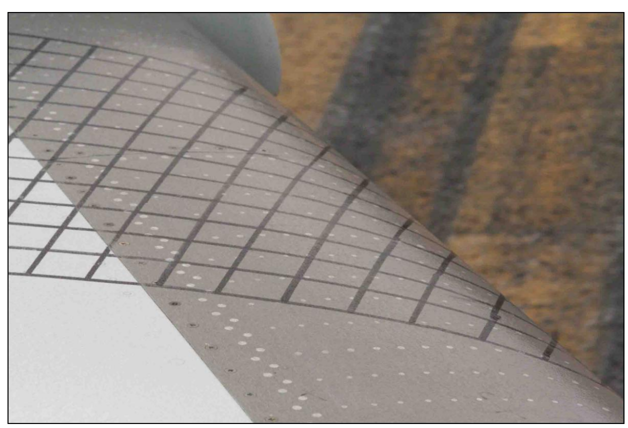


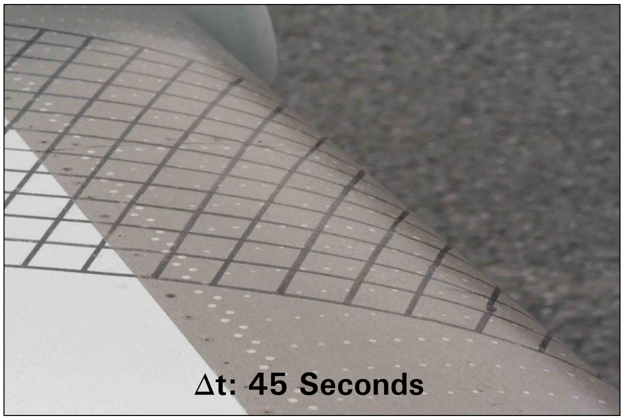


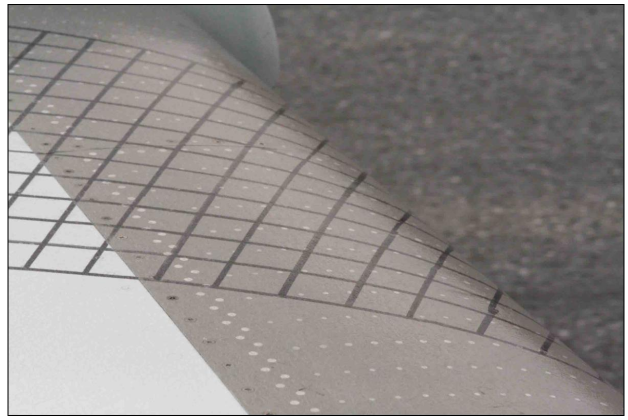


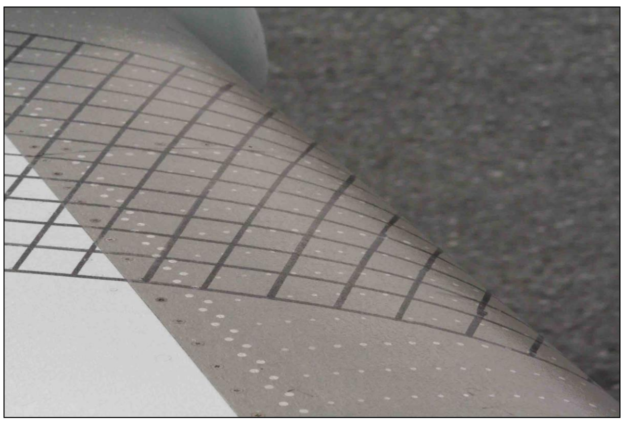


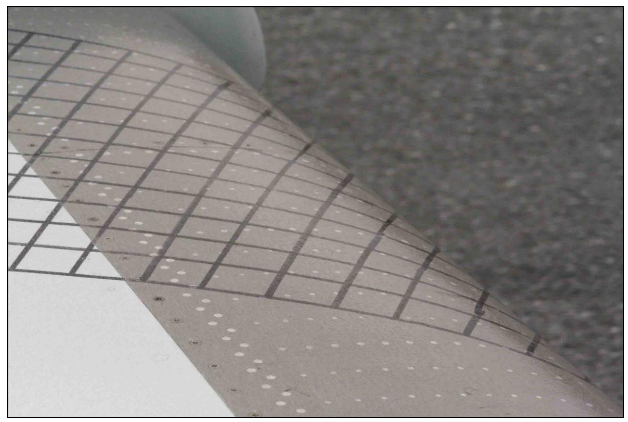


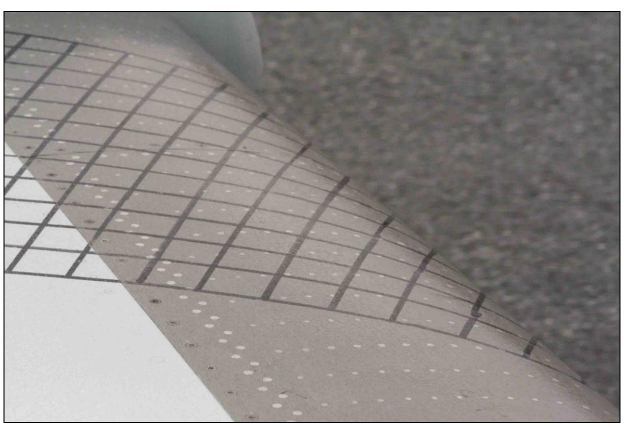


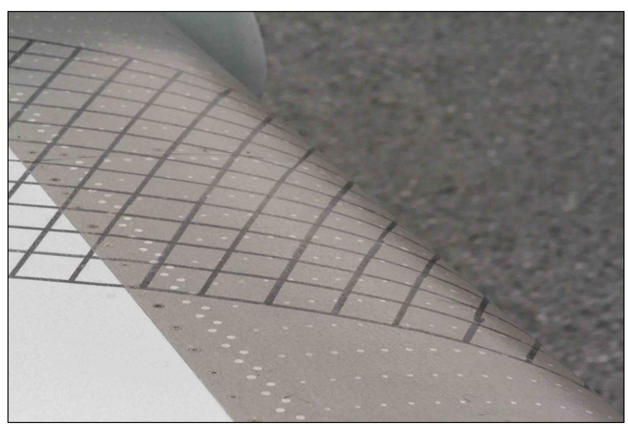

Δt: 45 Seconds

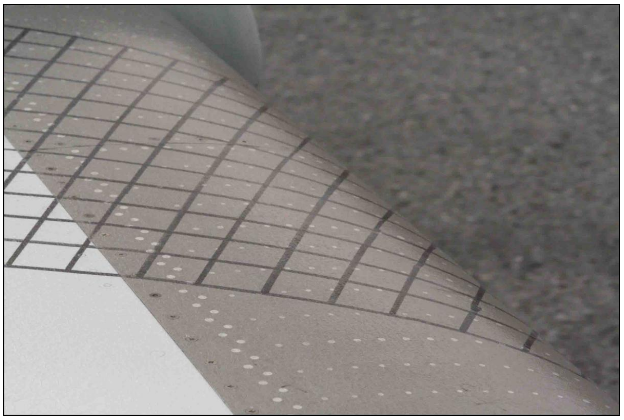


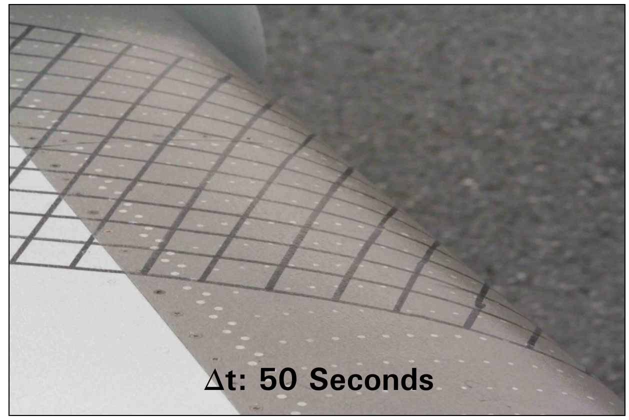


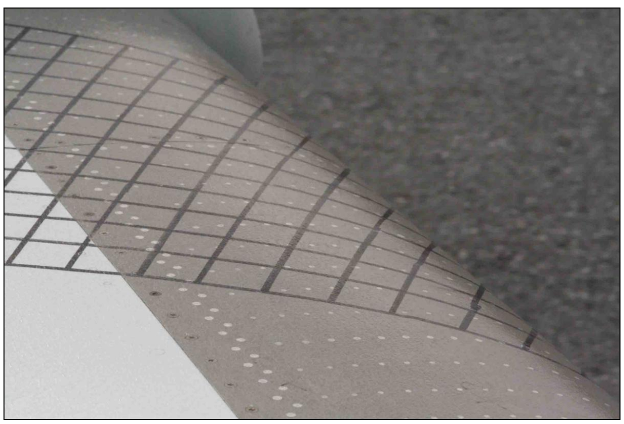


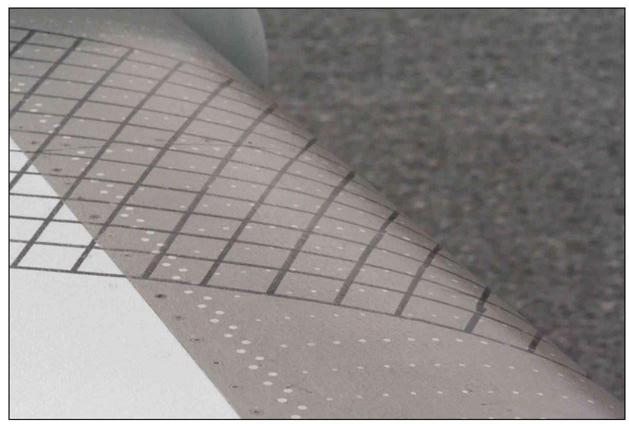


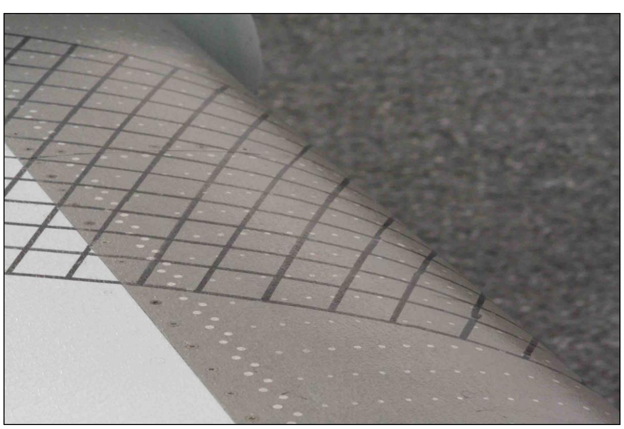


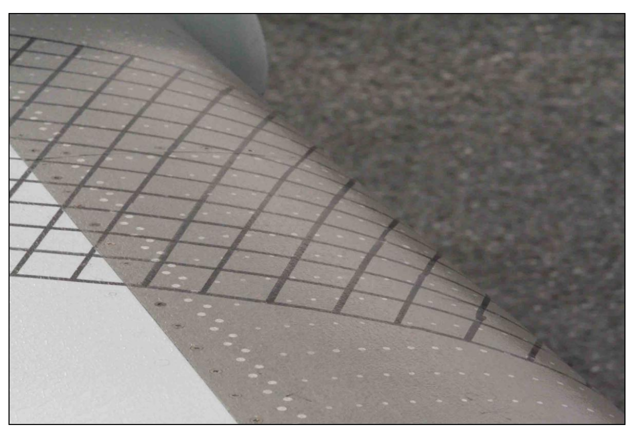


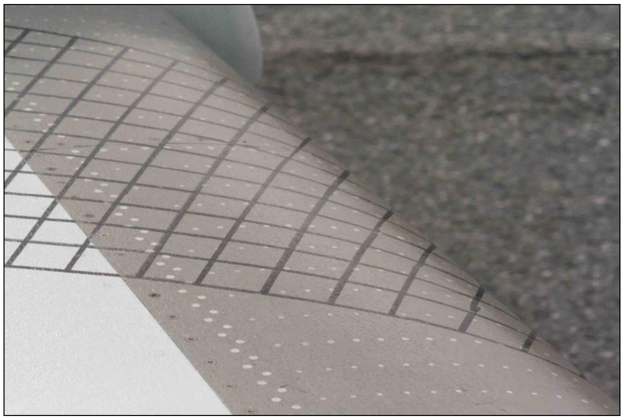

Δt: 50 Seconds

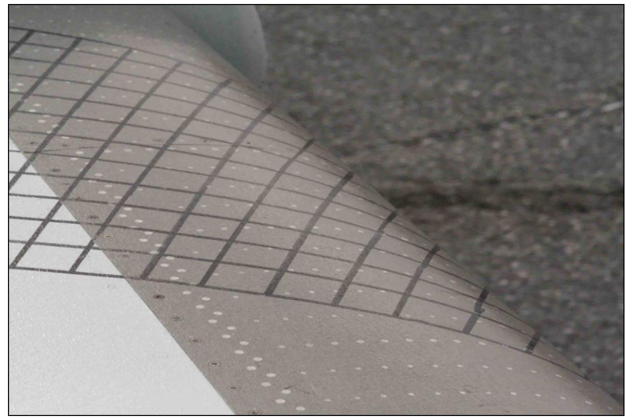


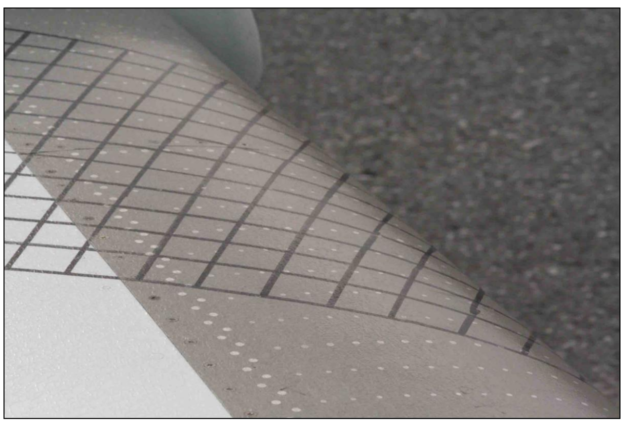


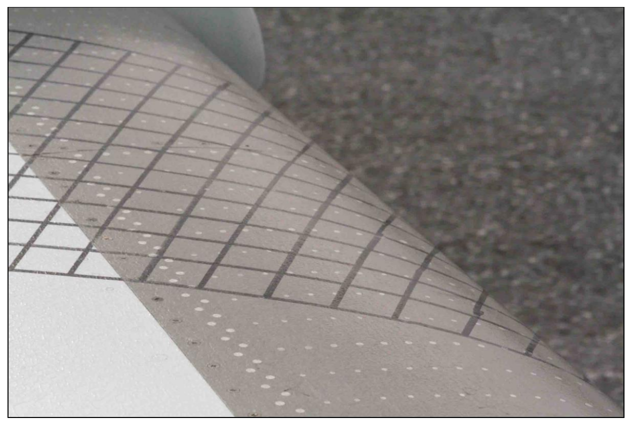


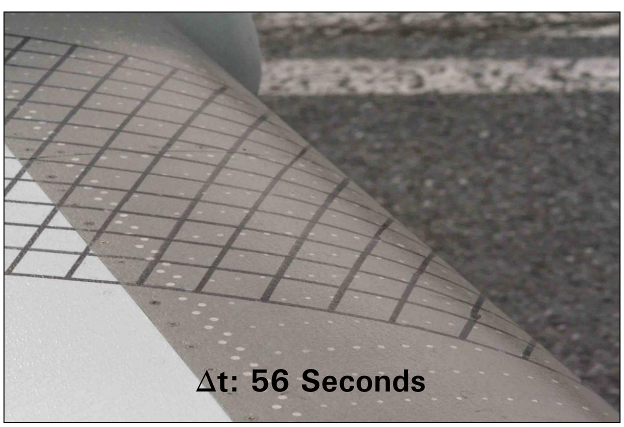






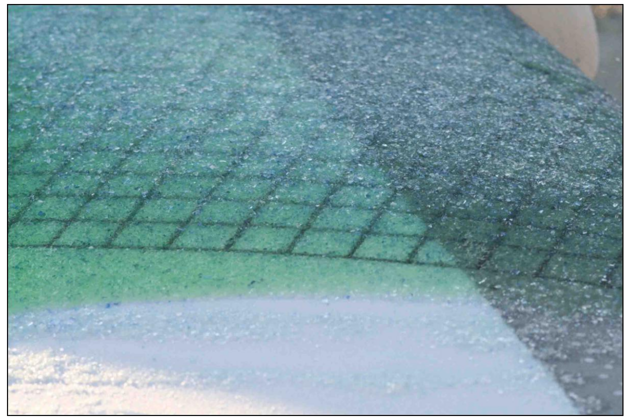


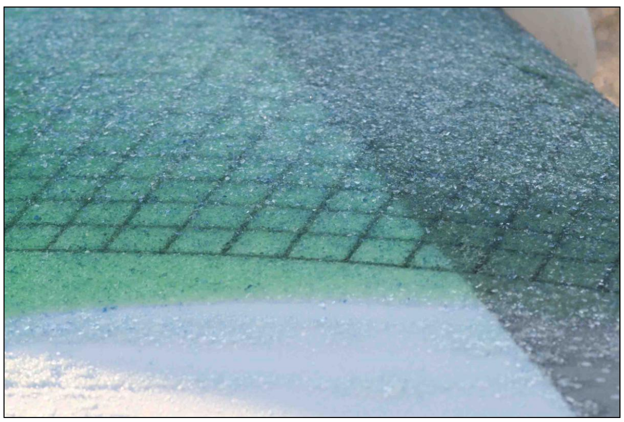


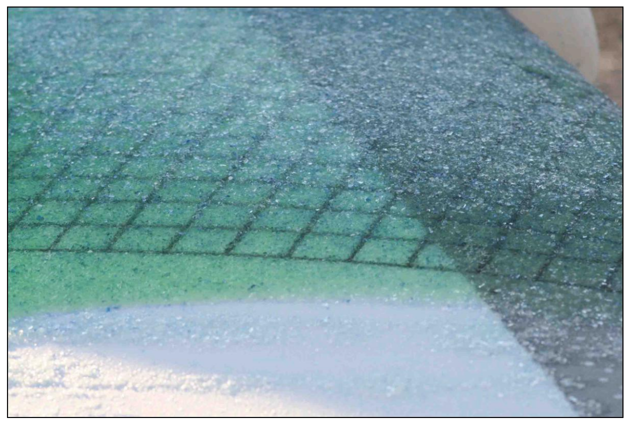

Δt: 56 Seconds

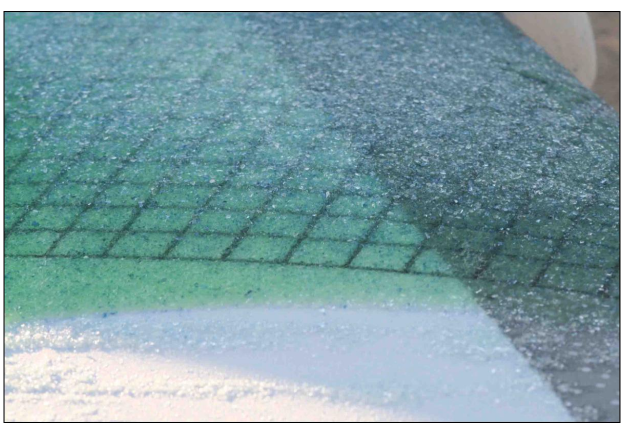
RUN 8

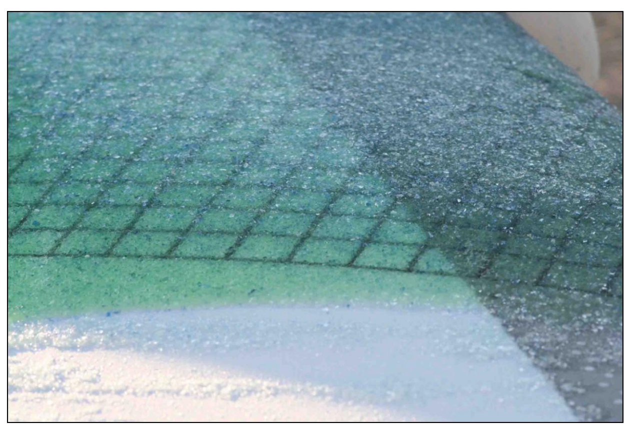

BREAK RELEASE – Δt: 0 Seconds

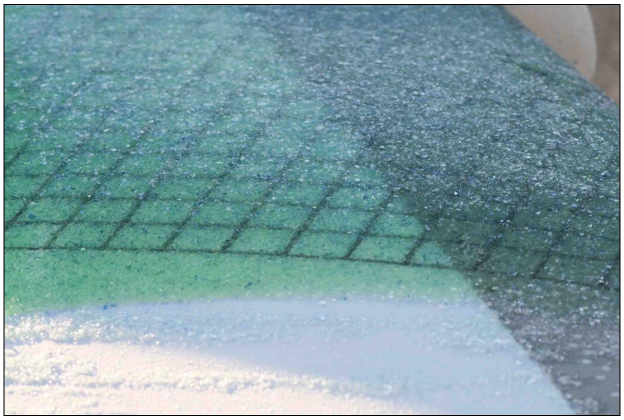


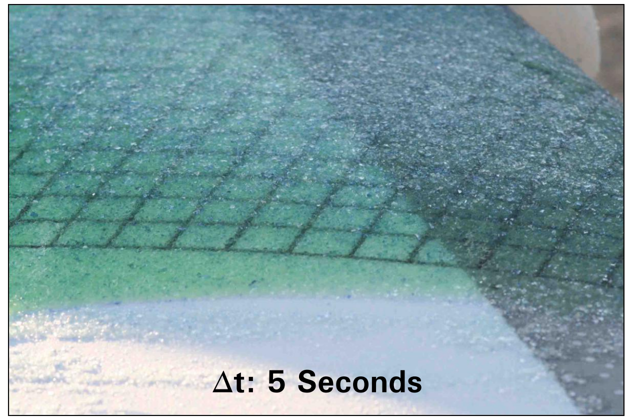


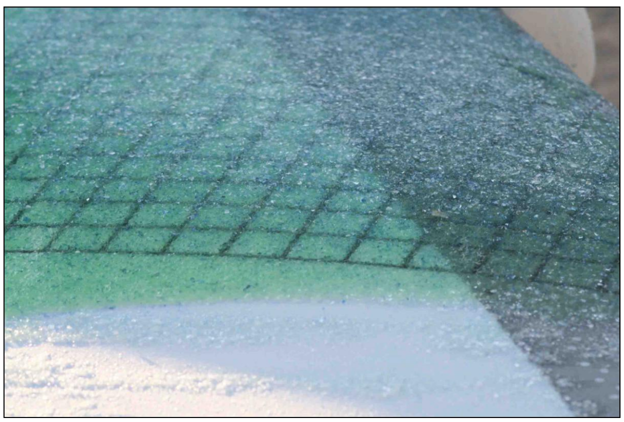


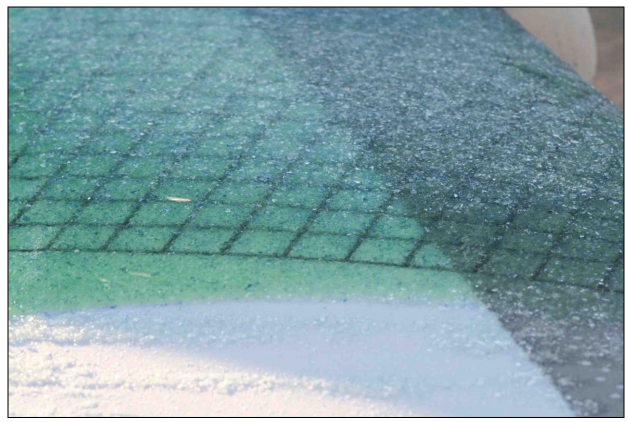


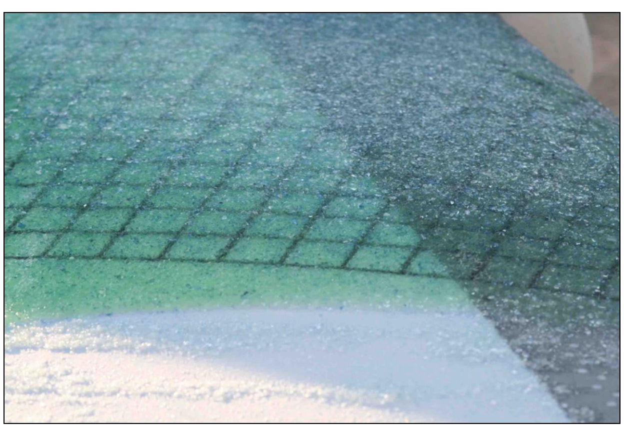


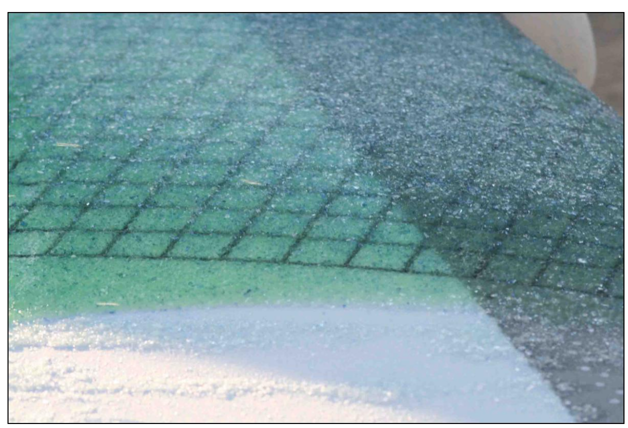


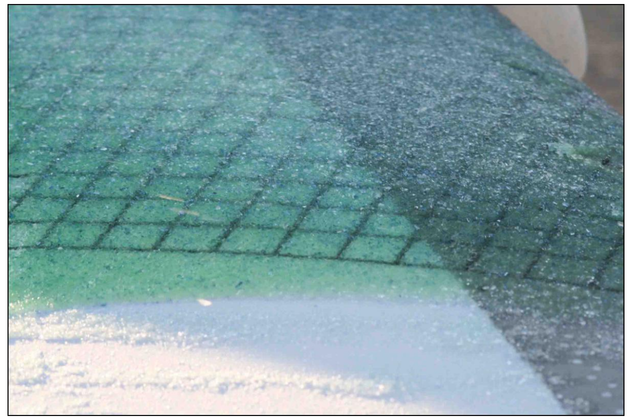

Δt: 5 Seconds

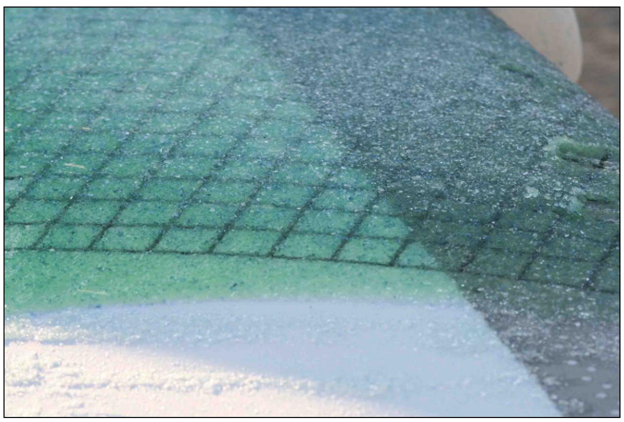


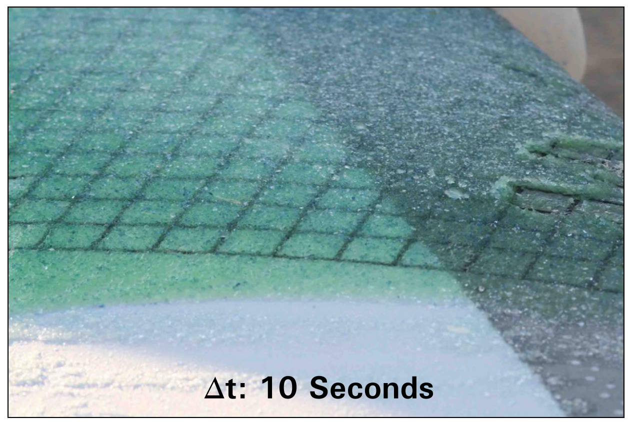








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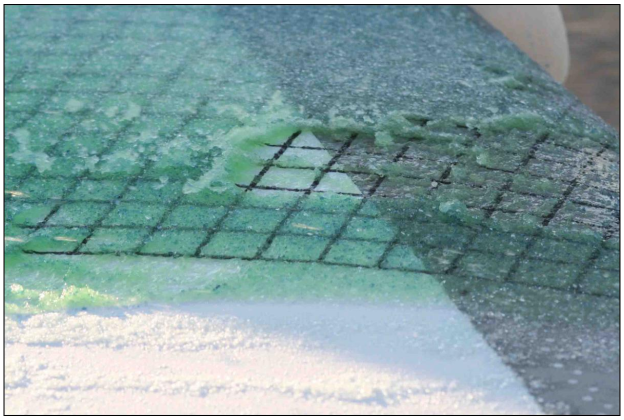

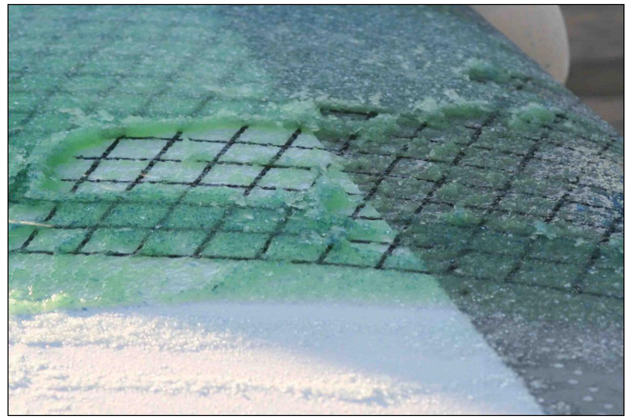

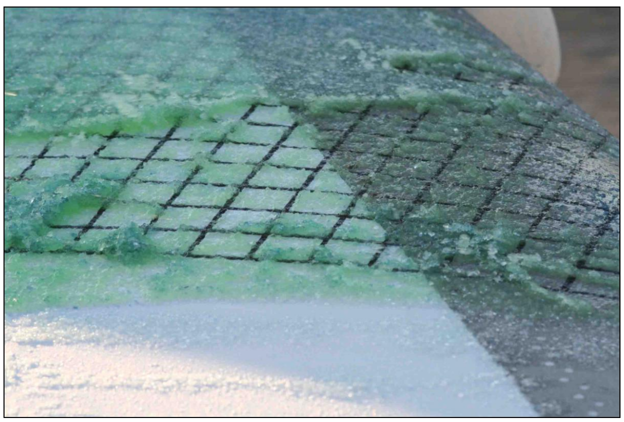

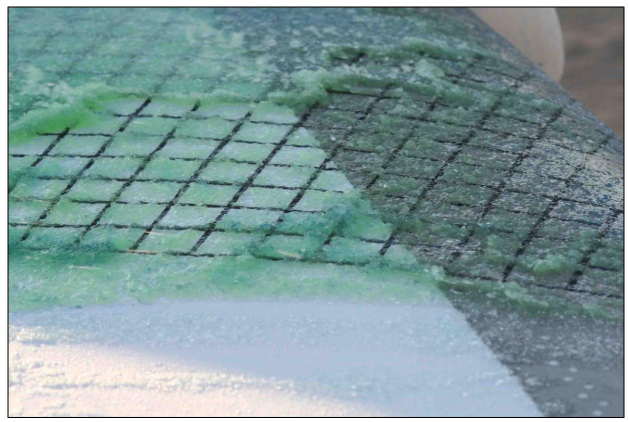

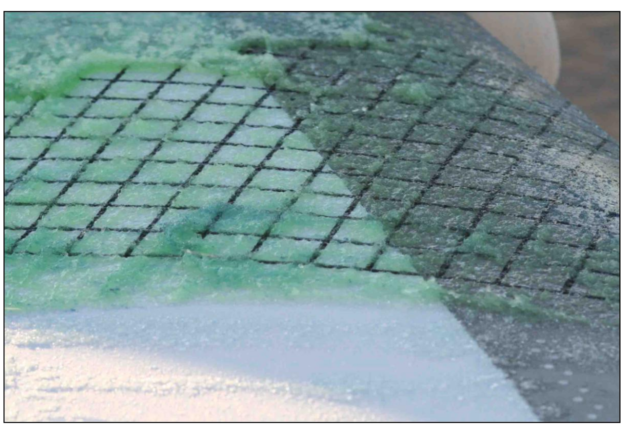

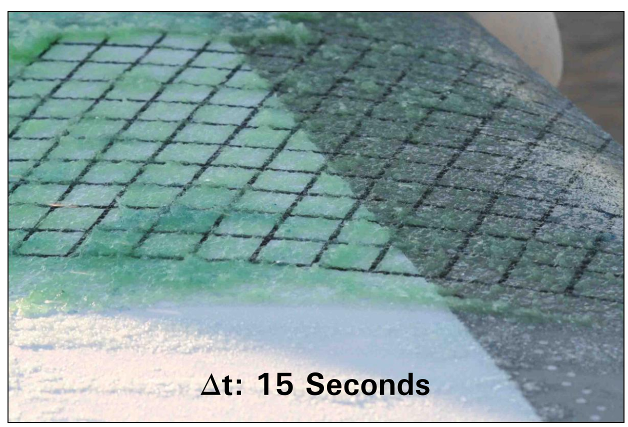
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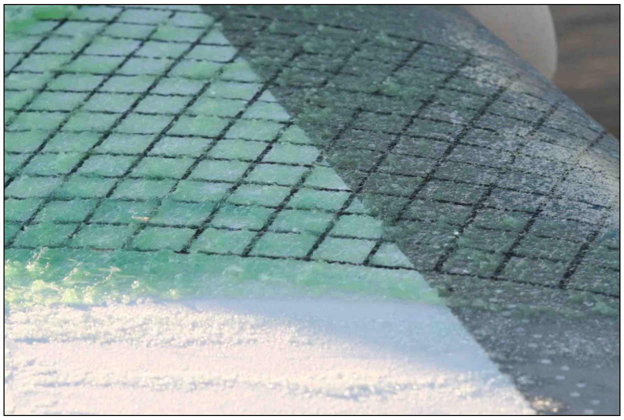
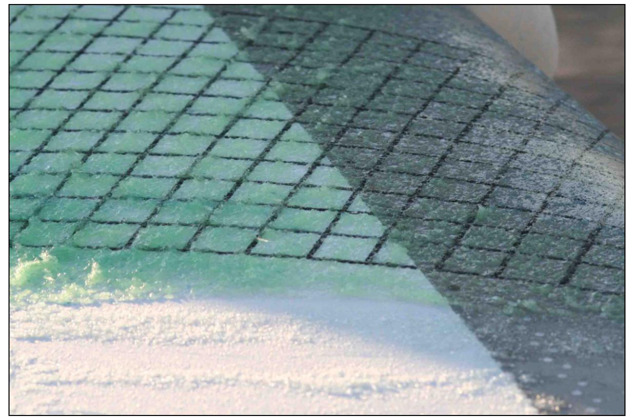
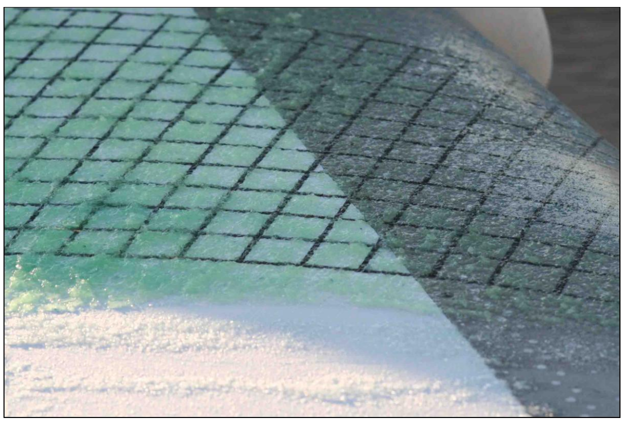
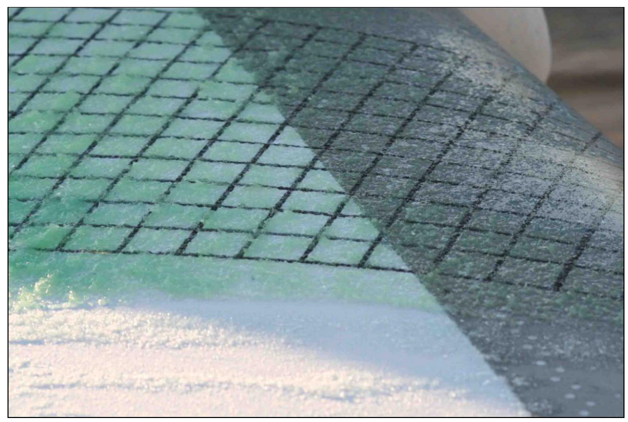
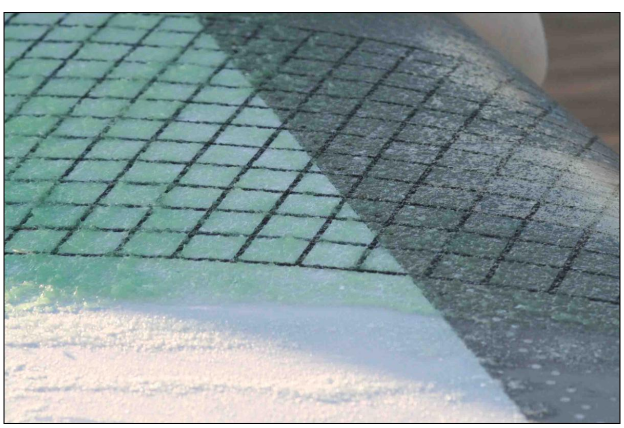
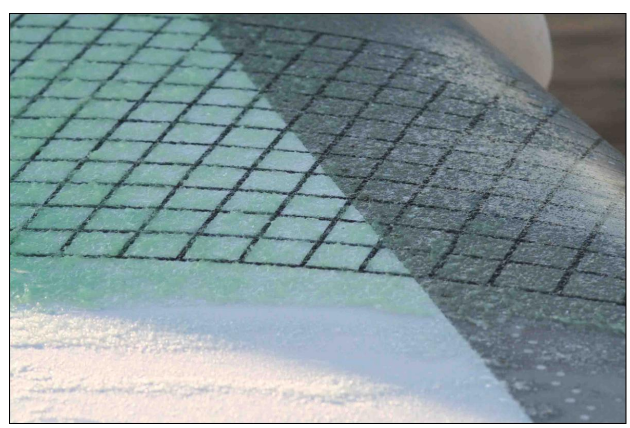

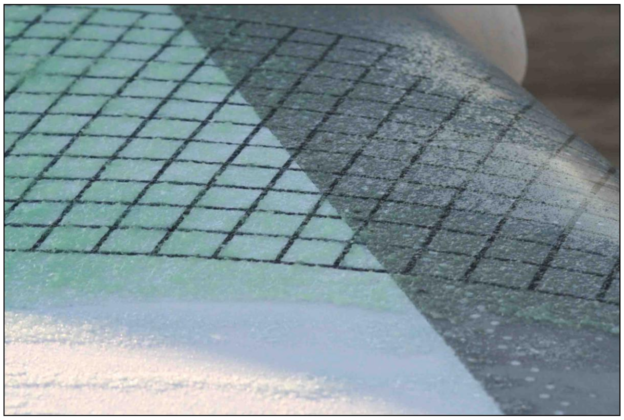

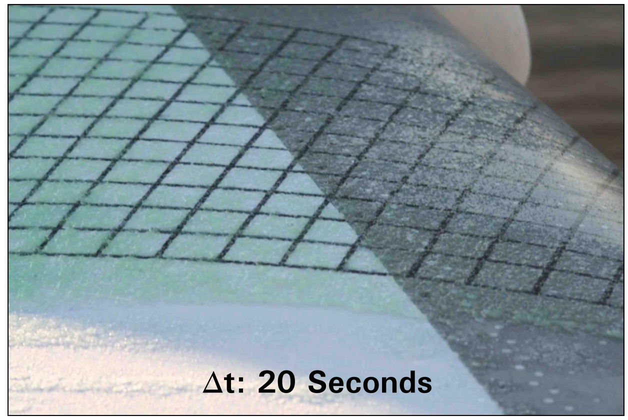
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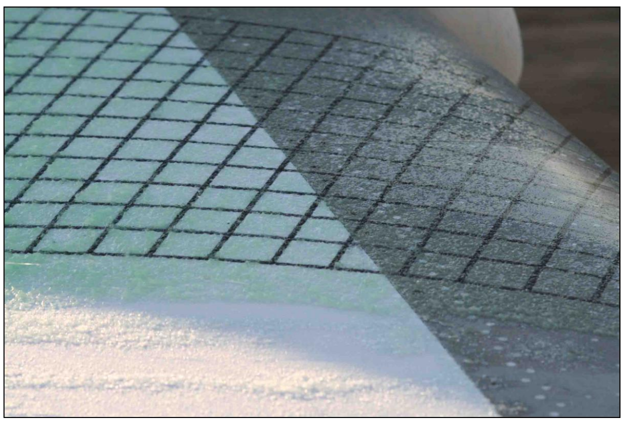

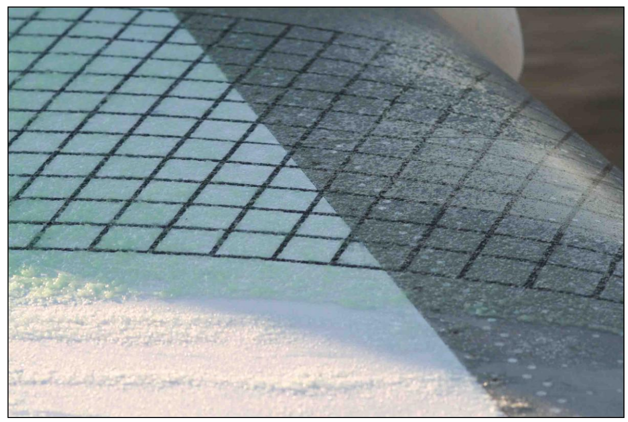

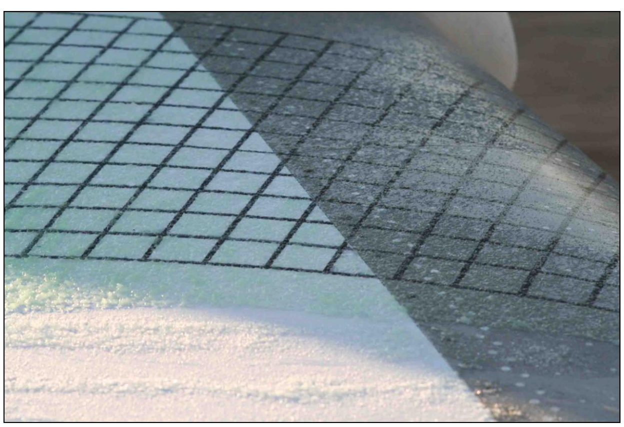

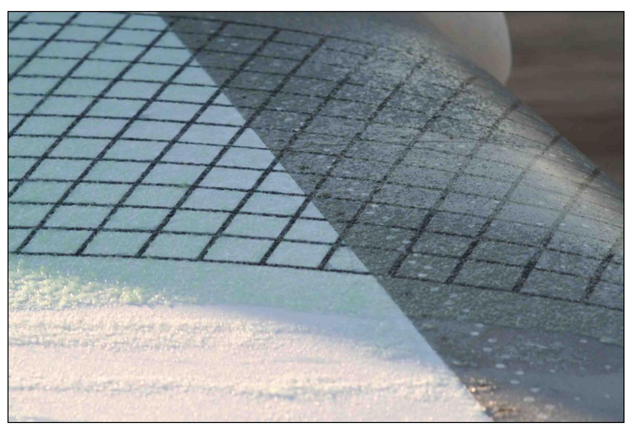

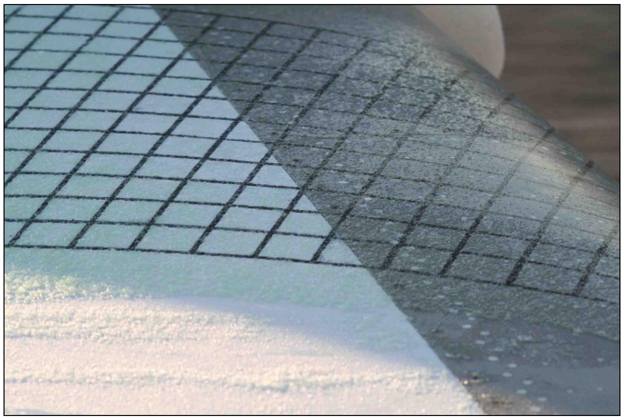

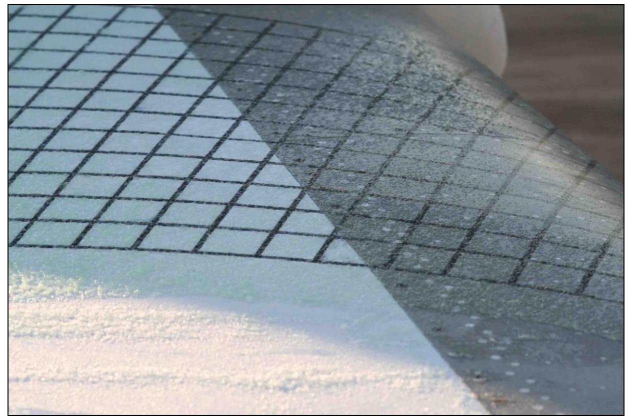

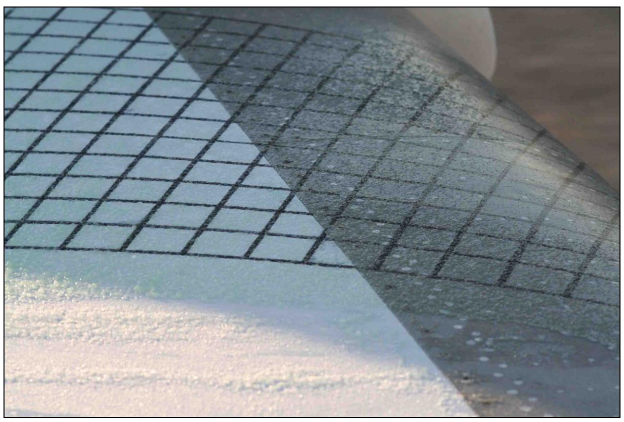

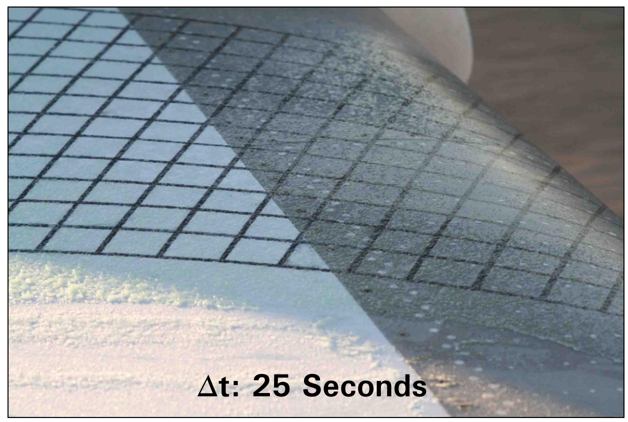
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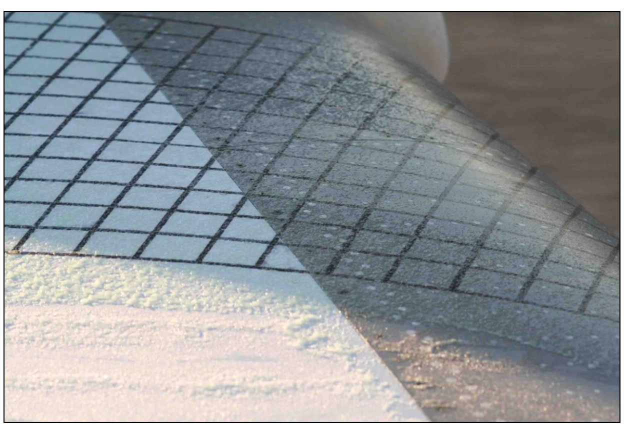

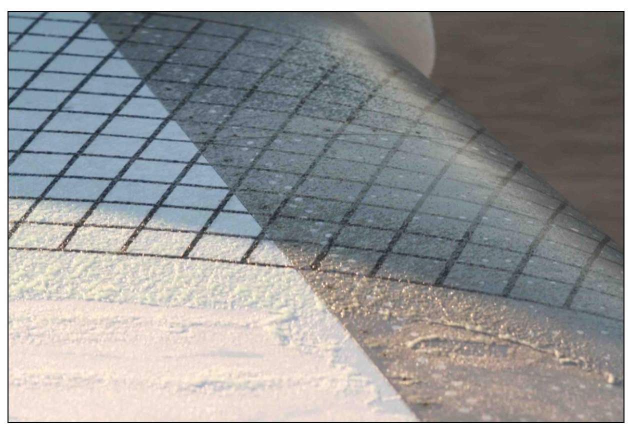

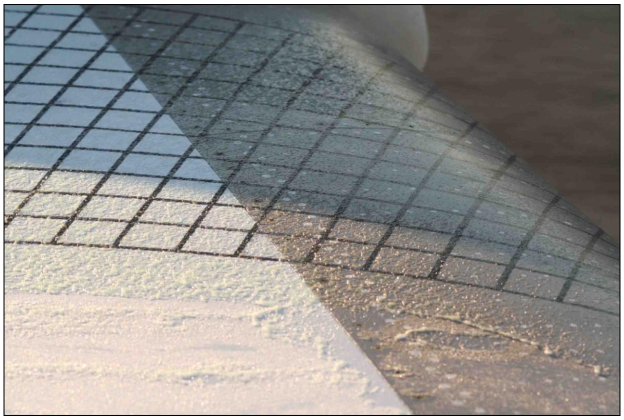

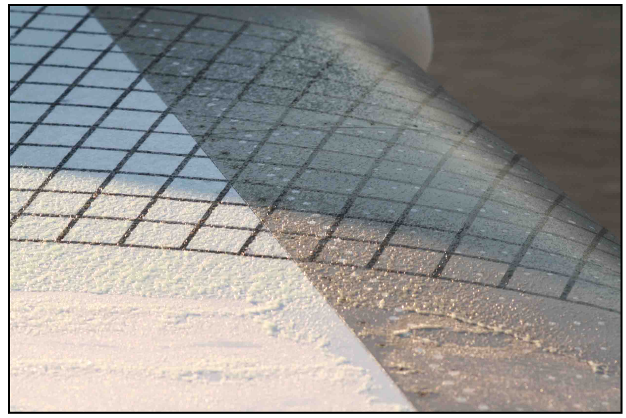

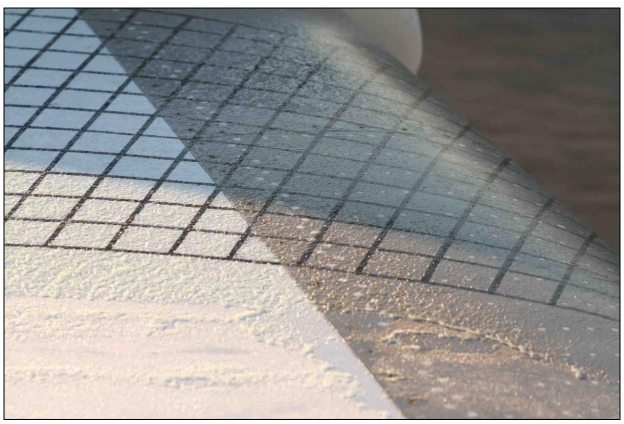

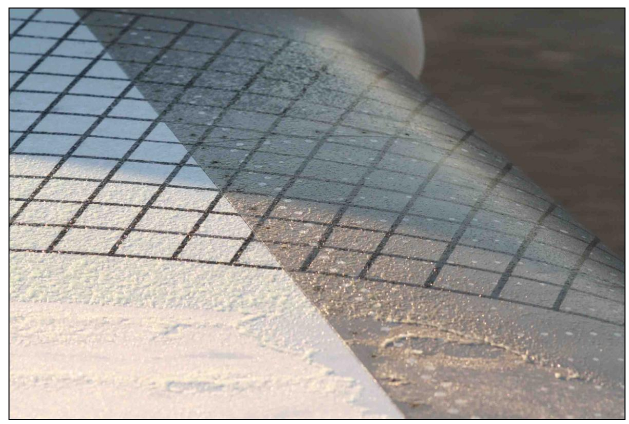

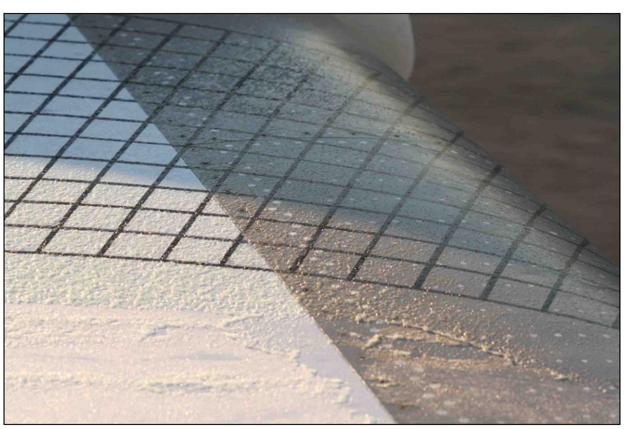

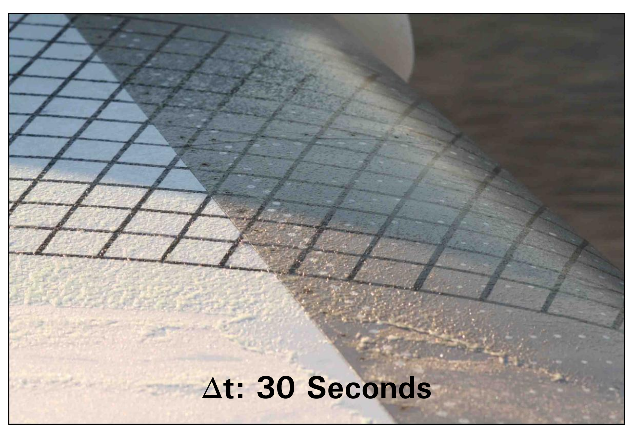
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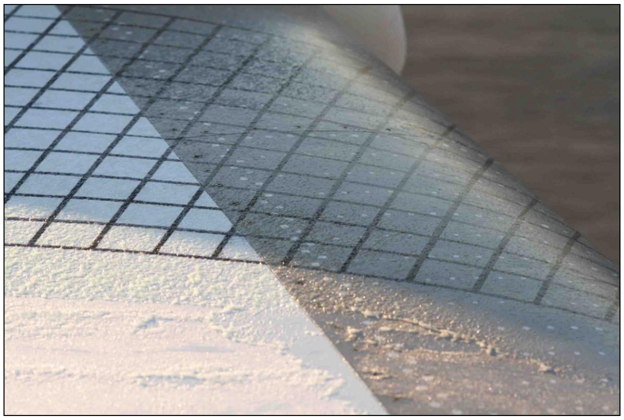

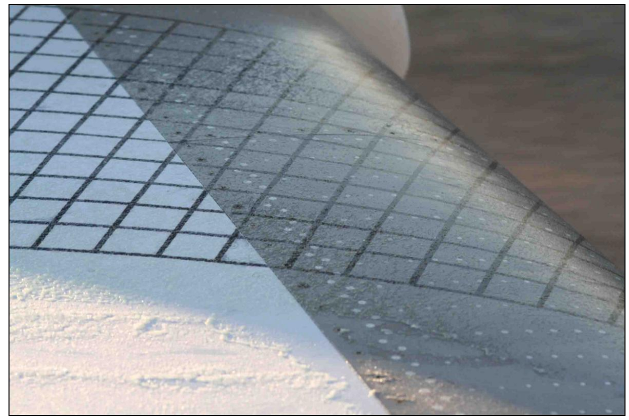

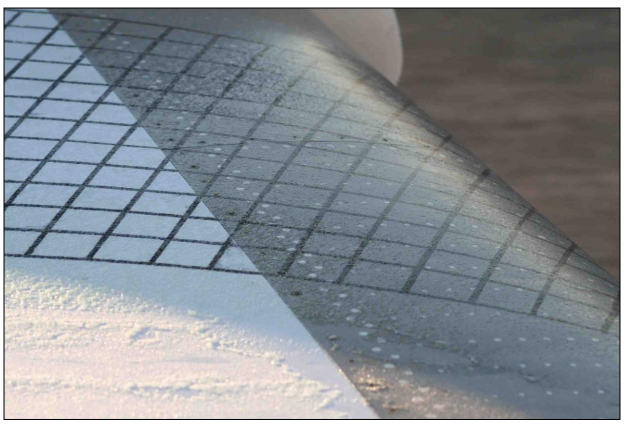

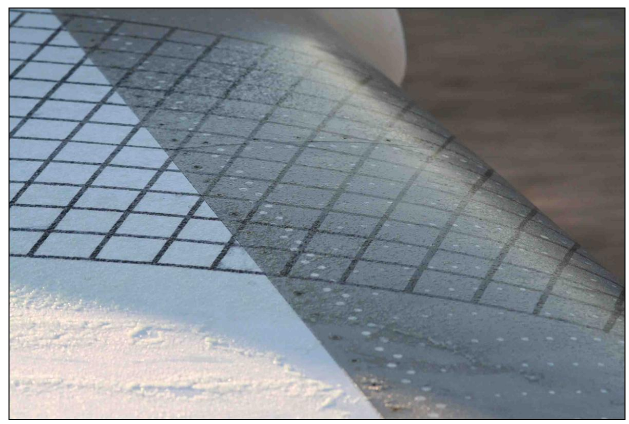

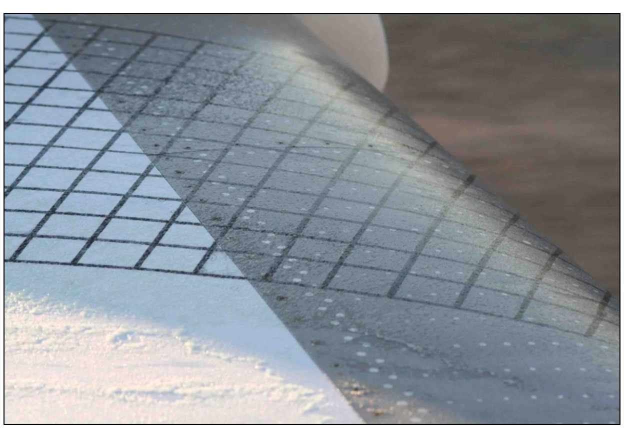

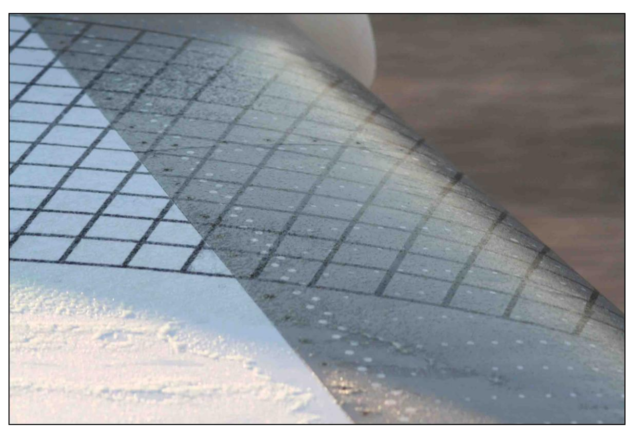

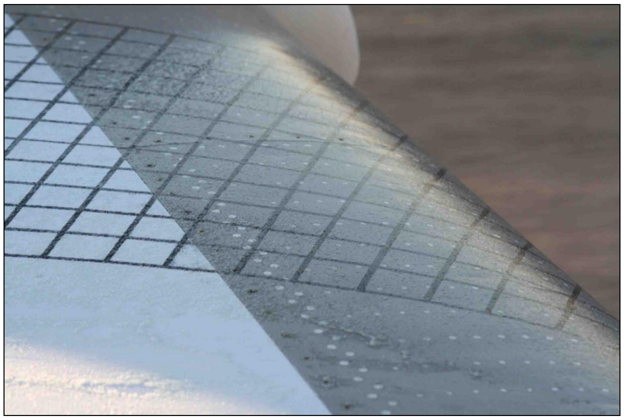

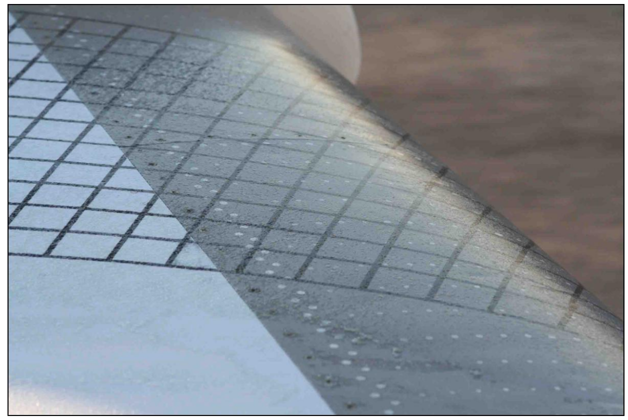

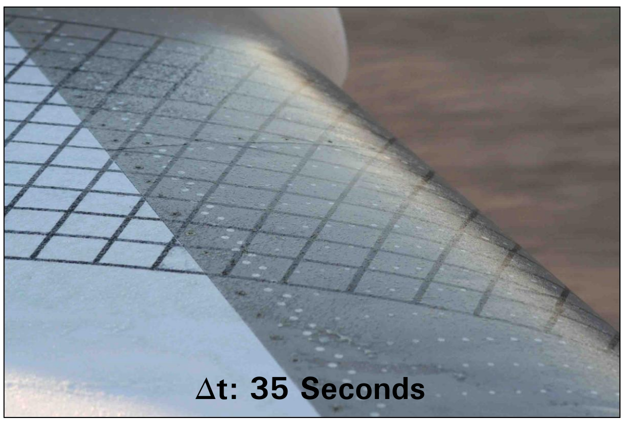
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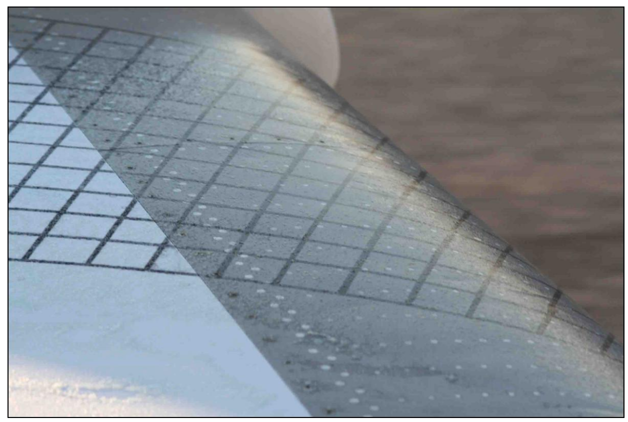

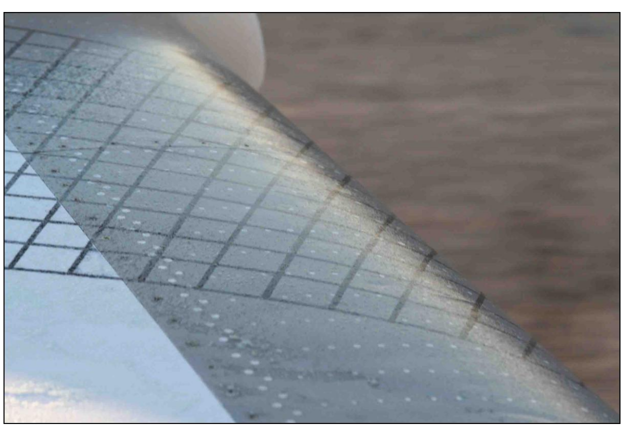

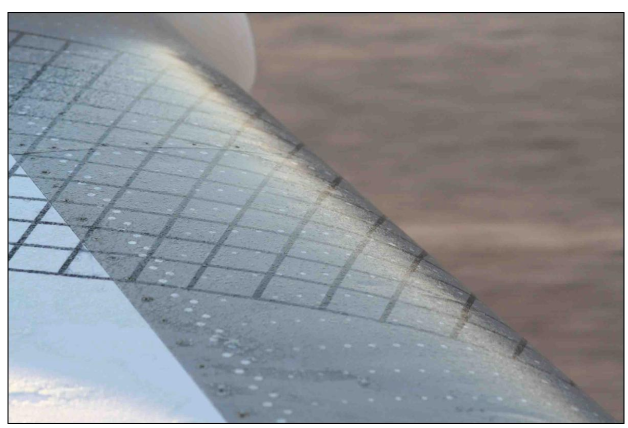

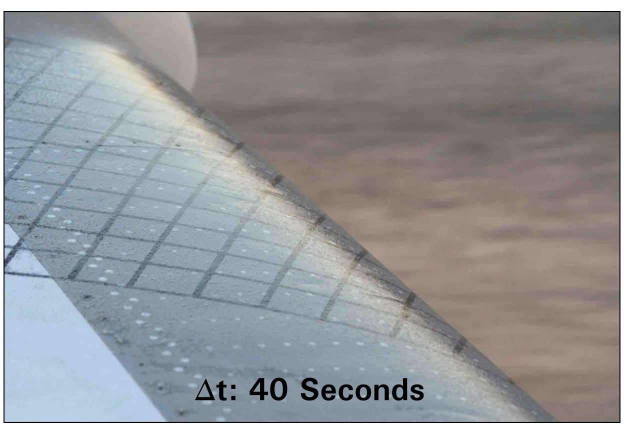
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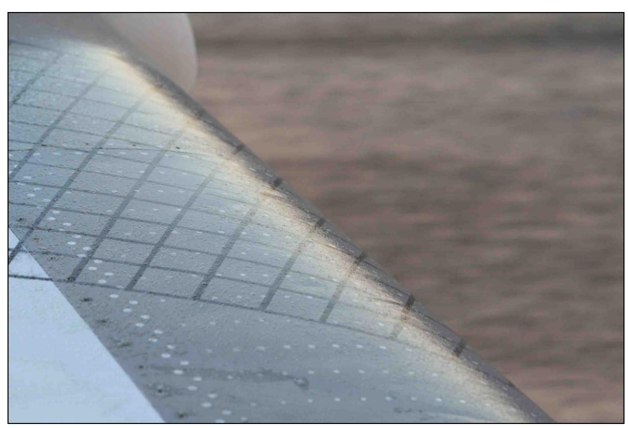

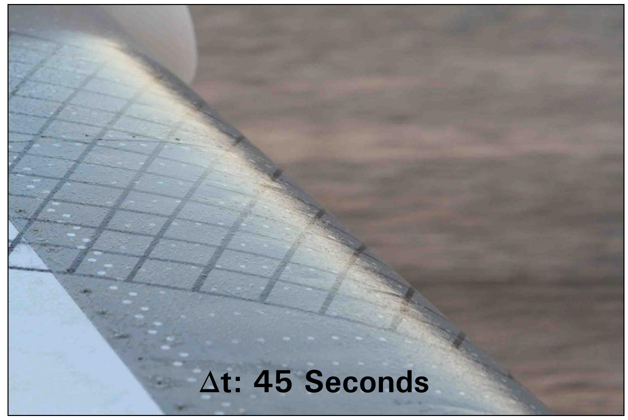
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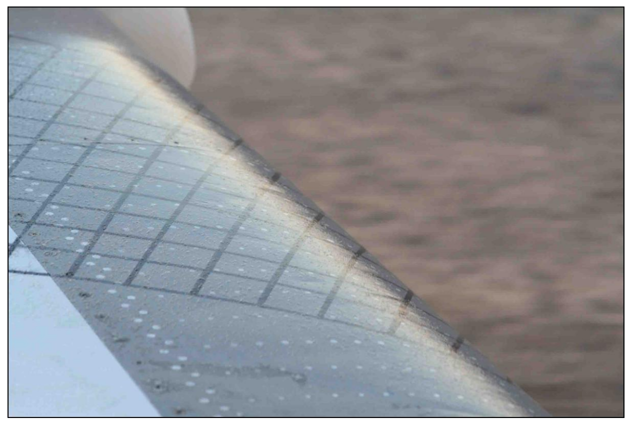

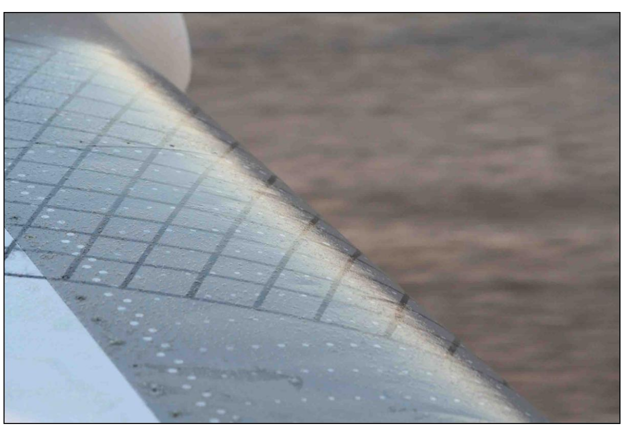

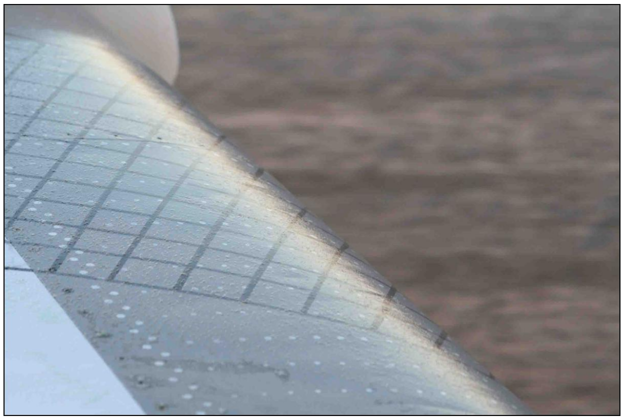


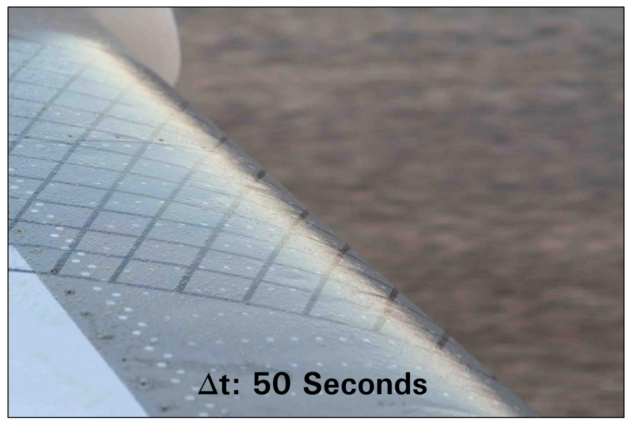
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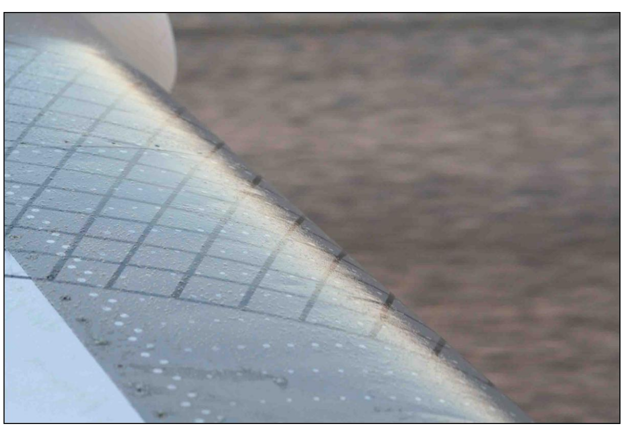


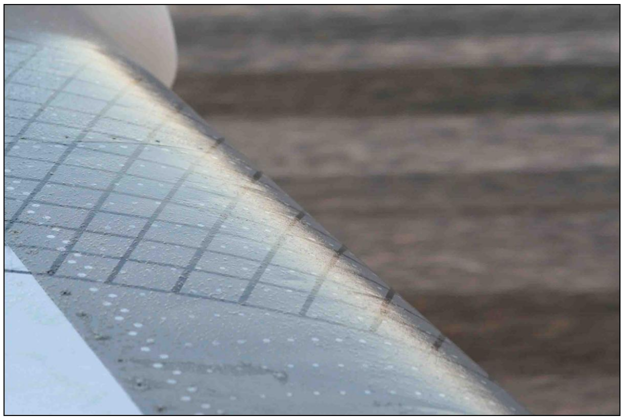

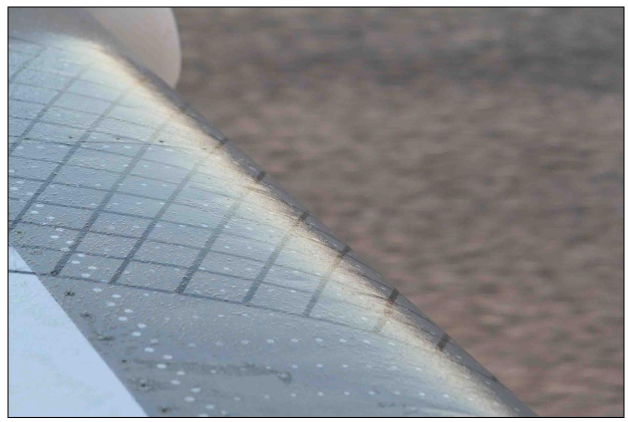

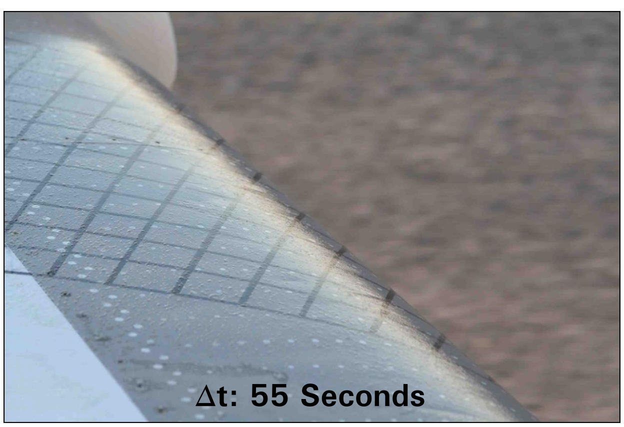
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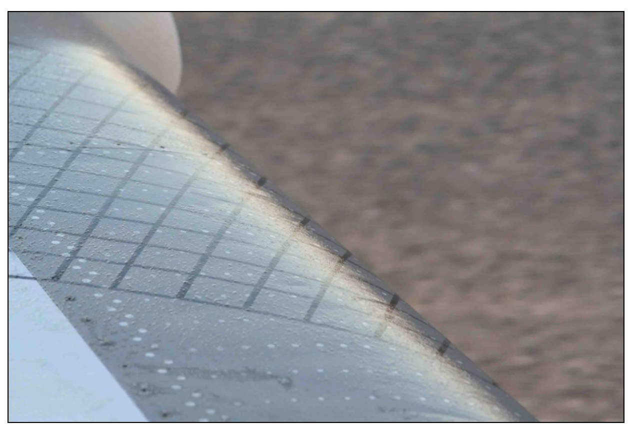

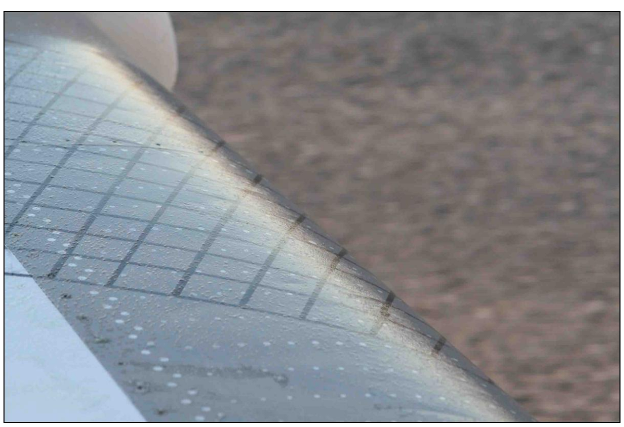

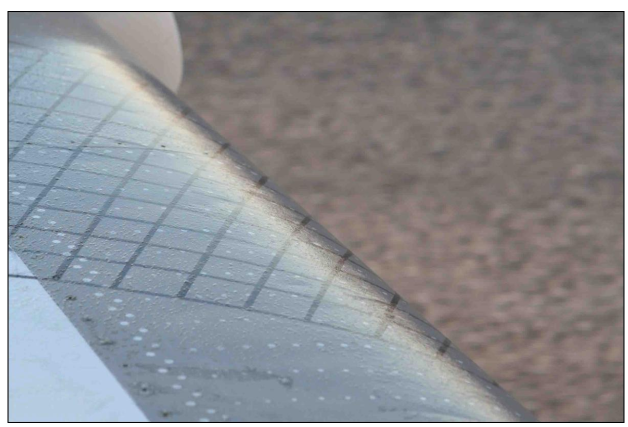

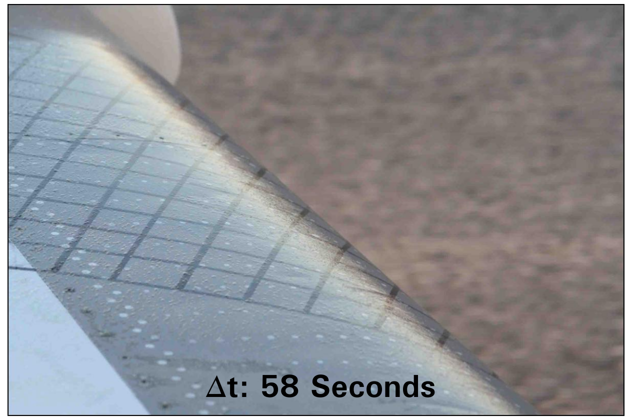
Δt: 58 Seconds

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