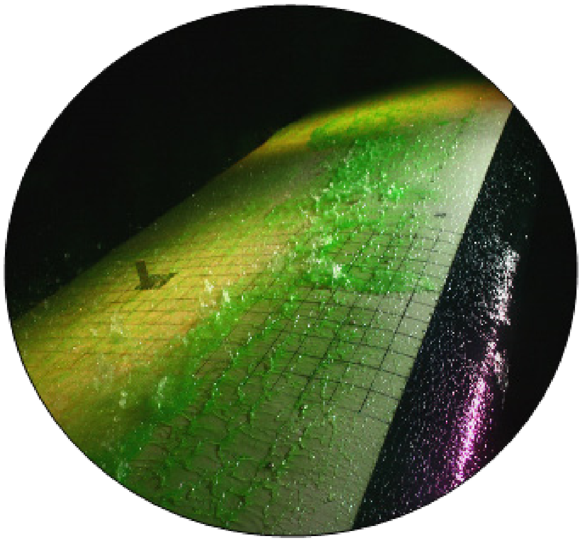
TP 14779E

Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets



Prepared for

Transportation Development Centre

In cooperation with

Civil Aviation
Transport Canada

and

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by

APS Aviation Inc.

January 2008
Final Version 1.0

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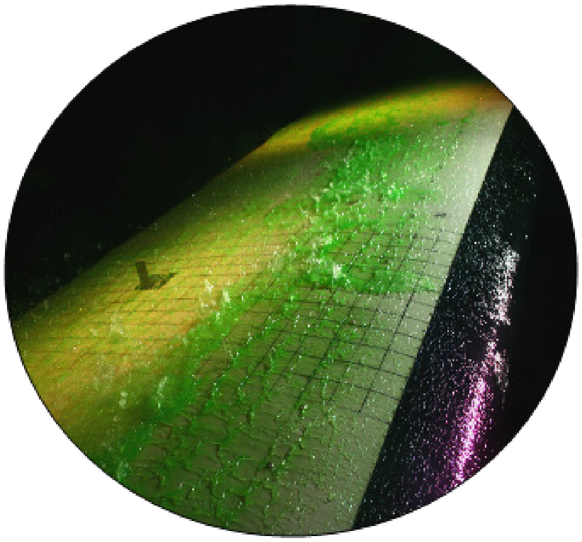

By:

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January 2008
Final Version 1.0

DOCUMENT ORIGIN AND APPROVAL RECORD

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Un sommaire français se trouve avant la table des matières.

This report was first provided to Transport Canada as Final Draft 1.0 in January 2008.
It has been published as Final Version 1.0 in October 2020.

***Final Draft 1.0 of this report was signed and provided to Transport Canada in January 2008. A Transport Canada technical and editorial review was subsequently completed and the report was finalized in October 2020; Jack Rigley was not available to participate in the final review or to sign the current version of the report.*

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 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 assist in the testing of flow of contaminated fluid from simulated 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;
- To conduct endurance time tests in frost on various test surfaces;
- To conduct preliminary wind tunnel endurance time tests in heavy snow;
- To compile historical data for calculation of holdover times based on a small number of inputs;
- To examine the use of non-glycol tempered steam technology to deice aircraft; and
- To assist Department of National Defence Canada in evaluating the effects of slipstream on anti-icing fluid.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2006-07 are documented in eight reports. The titles of the reports are as follows:

- TP 14452E Feasibility of ROGIDS Test Conditions Stipulated in SAE Draft Standard AS5681;
- TP 14776E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2006-07 Winter;
- TP 14777E Winter Weather Impact on Holdover Time Table Format (1995-2007);
- TP 14778E Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report;

• TP 14779E	Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets;
• TP 14780E	Evaluation of Tempered Steam Technology (TST) for Aircraft Deicing Applications;
• TP 14781E	Aircraft Ground Icing General Research Activities During the 2006-07 Winter; and
• TP 14782E	Regression Coefficients Used to Develop the Winter 2007-08 Type I Generic and Dow UCAR Endurance EG106 Holdover Time Tables.

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

- *Preliminary Aircraft Deicing Research in Heavy Snow Conditions;*
- *Endurance Time Testing in Snow: Comparison of Indoor and Outdoor Data for 2006-07;*
- *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions;*
- *Effect of Heat on Fluid Endurance Times Using Composite Surfaces;*
- *Effect of Heat on Endurance Times of Anti-Icing Fluids; and*
- *Regression Coefficients Used to Develop Aircraft Ground Deicing Holdover Time Tables: Winter 2007-08.*

In addition, the following report was written for Department of National Defence as part of this contract; this report does not have a TP number:

- Support for Testing to Ascertain the Effects of SAE Type IV De/Anti-Icing Fluids on CC-130 Hercules and CP-140 Aurora Aircraft Takeoff Handling.

This report, TP 14779E, has the following objective:

- To conduct flat plate and aerodynamic testing to provide a basis for guidance material for operations in mixed conditions with ice pellets.

This objective was met by conducting small scale testing on flat plates, followed by a series of tests using the National Research Council Canada open circuit wind tunnel and the National Research Council Canada Falcon 20 aircraft to examine the flow-off properties of anti-icing fluids contaminated with simulated mixed conditions including ice pellets.

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, Stephanie Bendickson, Ryan Brydges, Michael Chaput, John D'Avirro, Peter Dawson, Dany Posteraro, Marco Ruggi, Joey Tiano, 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.

PROJECT ACKNOWLEDGEMENTS

The author of this report would like to acknowledge and thank Barry Myers (Transport Canada) and Warren Underwood (Federal Aviation Administration) whose individual specializations played a critical role in directing the experiments. The author would also like to acknowledge and thank the staff of the National Research Council Canada Open-Circuit Propulsion and Icing Wind Tunnel, the National Research Council Canada Institute for Aerospace Research, and the National Research Council Canada Climatic Engineering Facility, for their diligence and commitment in providing support for the conduct of the experiments.

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Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 14779E

2. Project No.
5498-5501 (a-d)

3. Recipient's Catalogue No.

4. Title and Subtitle
Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets

5. Publication Date
January 2008

6. Performing Organization Document No.
CM2020.002

7. Author(s)
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8. Transport Canada File No.
2450-BP-14

9. Performing Organization Name and Address
APS Aviation Inc.
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Montreal, Quebec, H4T 2B5

10. PWGSC File No.
MTB-5-21166

11. PWGSC or Transport Canada Contract No.
T8200-055516/001/MTB

12. Sponsoring Agency Name and Address
Transportation Development Centre
Transport Canada
800 René-Lévesque Blvd. West, Suite 600
Montreal, Quebec, H3B 1X9

13. Type of Publication and Period Covered
Final

14. Project Officer
Antoine Lacroix for Barry Myers

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. Several reports 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 conduct flat plate and aerodynamic testing to provide a basis for guidance material for operations in mixed conditions with ice pellets. The research activities consisted of small scale testing conducted on flat plates, followed by full-scale testing conducted in the National Research Council Canada (NRC) open circuit wind tunnel and with the NRC Falcon 20 aircraft.

The lift coefficient data collected in the wind tunnel indicated that the application of anti-icing fluid caused a lift loss when compared to the baseline dry wing aerodynamic properties. In general, the application of contamination to the anti-icing fluid did not generate significant additional lift losses; the lift data collected during fluid and contamination tests and fluid only tests was comparable. Testing conducted with the Falcon 20 aircraft confirmed the results obtained in the wind tunnel and demonstrated that the wind tunnel test methodology provided a representative substitute for full-scale aircraft tests.

Allowance time guidelines for operations during mixed conditions with ice pellets were generated based on the results obtained in the wind tunnel and with the Falcon 20 aircraft. Restrictions for the guidelines were issued based on residual contamination observed on the airfoil, lift characteristics, and limitations of the data collected regarding rotation speeds, test temperatures, and other pertinent parameters. The ice pellet allowance times were issued in the Transport Canada Holdover Time Guidelines for the winter of 2007-08.

Further testing is recommended as a result of the observations made during the 2006-07 tests. It is recommended that additional testing be conducted at the NRC wind tunnel and with the NRC Falcon 20 aircraft to refine and possibly expand the current ice pellet allowance times. Testing should investigate conditions such as the effects of lower rotation speeds, improper or degraded fluid application, and flaps and leading edge devices on the fluid flow-off properties.

17. Key Words
Ice Pellet, Allowance Time, Mixed Conditions, Open Circuit Wind Tunnel, Falcon 20, Fluid Adherence

18. Distribution Statement
Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)
Unclassified

20. Security Classification (of this page)
Unclassified

21. Declassification (date)
—

22. No. of Pages
xxvi, 184 apps

23. Price
—

CDT/TDC 79-005
Rev. 96

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. Nº de la publication de Transports Canada
TP 14779E

2. Nº de l'étude
5498-5501 (a-d)

3. Nº de catalogue du destinataire

4. Titre et sous-titre
Development of Allowance Times for Aircraft Deicing Operations During Conditions with Ice Pellets

5. Date de la publication
Janvier 2008

6. Nº de document de l'organisme exécutant
CM2020.002

7. Auteur(s)
Marco Ruggi

8. Nº de dossier - Transports Canada
2450-BP-14

9. Nom et adresse de l'organisme exécutant

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10. Nº de dossier - TPSGC
MTB-5-21166

11. Nº de contrat - TPSGC ou Transports Canada
T8200-055516/001/MTB

12. Nom et adresse de l'organisme parrain

Centre de développement des transports
Transports Canada
800, Boul. René-Lévesque Ouest, Bureau 600
Montréal (Québec) H3B 1X9

13. Genre de publication et période visée
Final

14. Agent de projet
Antoine Lacroix pour Barry Myers

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. Plusieurs rapports 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

Cette étude avait pour objectif de mener des essais aérodynamiques et sur plaque plane pour appuyer l'élaboration de lignes directrices pour la navigation aérienne dans des conditions mixtes avec granules de glace. Les activités de recherche consistaient en des essais à petite échelle menés sur des plaques planes, suivis d'essais en grandeur réelle menés dans la soufflerie à circuit ouvert du Conseil national de recherches Canada (CNRC) et sur l'aéronef Falcon 20 du CNRC.

Les données sur le coefficient de portance recueillies dans la soufflerie ont démontré que l'application de liquide d'antigivrage entraînait une diminution de portance comparativement aux propriétés aérodynamiques de référence d'une aile sèche. En général, l'ajout de contaminants au liquide d'antigivrage n'a pas entraîné de grandes pertes de portance supplémentaires ; les données sur la portance recueillies durant les essais sur les liquides avec contamination étaient comparables à celles recueillies durant les essais sur les liquides non contaminés. Les essais menés sur l'aéronef Falcon 20 ont permis de valider les résultats obtenus dans la soufflerie. Ils ont démontré que la méthodologie d'essais en soufflerie fournit un substitut représentatif aux essais réalisés sur des aéronefs pleine grandeur.

Des lignes directrices sur les marges de tolérance pour la navigation aérienne dans des conditions mixtes avec granules de glace ont été élaborées à la lumière des résultats obtenus lors des essais réalisés dans la soufflerie et sur l'aéronef Falcon 20. Elles ont été soumises à des restrictions en raison de la contamination résiduelle observée sur la surface portante, des caractéristiques de portance et des limites des données recueillies sur les vitesses de rotation, les températures d'essai et d'autres paramètres pertinents. Les marges de tolérance dans des conditions de granules de glace ont été publiées dans les lignes directrices de Transport Canada sur les durées d'efficacité de l'hiver 2007-2008.

En raison des résultats observés durant les essais de 2006-2007, il est recommandé de procéder à des essais supplémentaires. D'autres essais devraient être menés dans la soufflerie du CNRC et sur l'aéronef Falcon 20 afin de préciser et, possiblement, d'augmenter les marges de tolérance actuelles dans des conditions de granules de glace. Les essais devraient étudier des conditions telles que l'effet de vitesses de rotation plus basses, de l'utilisation d'un liquide dégradé ou appliqué incorrectement et du recours à des volets et à des dispositifs de bord d'attaque sur les propriétés de ruissellement du liquide.

17. Mots clés
Granule de glace, marge de tolérance, conditions mixtes, soufflerie à circuit ouvert, Falcon 20, adhérence de liquide

18. Diffusion
Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)
Non classifiée

20. Classification de sécurité (de cette page)
Non classifiée

21. Déclassification (date)
—

22. Nombre de pages
xxvi, 184 ann.

23. Prix
—

CDT/TDC 79-005
Rev. 96

Canada

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 anti-icing fluid flow-off properties under mixed precipitation conditions including ice pellets during simulated takeoff tests.

Background and Objective

Prior to the winter of 2005/06, Holdover Time (HOT) guidance material did not exist for ice pellet conditions, however aircraft could still depart during ice pellet conditions following aircraft deicing and a pre-takeoff contamination check. This protocol was feasible for common air carrier aircraft that provided access to emergency exit windows overlooking the leading edge of the aircraft wings; however, it posed a significant problem for cargo aircraft that have limited visibility of the wings from the cabin.

During the winter of 2005/06, the FAA provided a 25-minute allowance as a preliminary guideline; TC remained status quo. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research; these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. The allowance was then followed by a list of conditions; one restriction was that operations would be limited to ice pellets alone (no mixed conditions).

Due to the high occurrence of ice pellets combined with freezing rain, rain, freezing drizzle, or snow, the industry requested additional guidance material for operations in mixed ice pellet conditions. Additional endurance time testing and aerodynamic research were conducted in simulated ice pellet conditions during the winter of 2006-07. The research activities consisted of small-scale testing conducted on flat plates, followed by full-scale testing conducted in the National Research Council Canada (NRC) open circuit wind tunnel and with the NRC Falcon 20 aircraft.

Data Collection and Testing

At the start of each aerodynamic test (both for the wind tunnel tests and the Falcon 20 tests), the test wing was treated with anti-icing fluid using a one-step operation. Simulated precipitation was then applied over the anti-iced test section until specified

levels of contamination were achieved. Data such as fluid thickness, wing temperatures, and fluid freeze points were recorded. The wind tunnel or Falcon 20 aircraft was then operated through a simulated takeoff test. The behaviour of the fluid during the simulated takeoff was documented with high-speed digital still cameras and video cameras.

Drag and lift data collected by the NRC from the NACA 23012 test wing section was used to generate lift coefficient curves for each test conducted in the wind tunnel. The lift data collected during contaminated fluid tests were compared to the data collected during the baseline fluid only and dry wing tests. The Falcon 20 tests were primarily conducted as a verification of the results obtained in the wind tunnel; lift data was not collected.

Conclusions

The lift coefficient data collected in the wind tunnel indicated that the application of anti-icing fluid caused a lift loss when compared to the baseline dry wing aerodynamic properties. In general, the application of the specified and limited amounts of contamination to the anti-icing fluid did not generate significant additional lift losses; the lift data collected during fluid with contamination tests and fluid only tests was comparable. Testing conducted with the Falcon 20 aircraft confirmed the results obtained in the wind tunnel and demonstrated that the wind tunnel test methodology provided a representative substitute for full-scale aircraft tests.

Ice pellet allowance times for operations during mixed conditions with ice pellets were generated based on the results obtained in the wind tunnel and with the Falcon 20 aircraft. The allowance times were developed based on the presence of residual contamination observed on the airfoil, lift characteristics, and the limited range of the data collected regarding rotation speeds, test temperatures and other pertinent parameters. The ice pellet allowance times were issued within the TC HOT Guidelines and the FAA Approved Deicing Program updated for the winter of 2007-08.

Recommendations

Further testing is recommended as a result of the observations made during the 2006-07 tests. It is recommended that additional testing be conducted at the NRC wind tunnel and with the NRC Falcon 20 aircraft to refine and possibly expand the current ice pellet allowance times. Testing should investigate the effect of parameters such as lower rotation speeds, improper or degraded fluid application, and flaps and leading edge devices on fluid flow-off.

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 documenté dans le présent rapport avait pour objectif d'examiner les propriétés de ruissellement du liquide d'antigivrage dans des conditions de précipitations mixtes comprenant des granules de glace durant des essais de décollage simulé.

Contexte et objectif

Avant l'hiver 2005-2006, il n'y avait pas de lignes directrices sur les durées d'efficacité (HOT) dans des conditions de granules de glace, mais les aéronefs pouvaient quand même partir dans des conditions de granules de glace, après un dégivrage et une vérification de contamination avant le décollage. Ce protocole était acceptable pour les aéronefs de transport équipés de fenêtres d'issues de secours au-dessus du bord d'attaque de l'aile de l'aéronef ; cependant, il causait un problème important dans le cas d'aéronefs de transport offrant une visibilité limitée des ailes à partir de la cabine.

Au cours de l'hiver 2005-2006, la FAA a donné une marge de tolérance de 25 minutes à titre de ligne directrice préliminaire ; Transports Canada a maintenu le statu quo. Cette marge se fondait sur des recherches antérieures menées au cours de l'hiver de 2005-2006, principalement suite à la recherche aérodynamique sur le Falcon 20 ; ces résultats ont été présentés à la réunion de la Society of Automotive Engineers (SAE), à Lisbonne en mai 2006. Cette marge était suivie d'une liste de conditions ; l'une des restrictions s'appliquait aux opérations dans des conditions de granules de glace seulement (pas aux conditions mixtes).

En raison des conditions fréquentes de granules de glace combinées à la pluie verglaçante, à la pluie, à la bruine verglaçante ou à la neige, l'industrie a demandé des lignes directrices additionnelles pour les opérations dans des conditions mixtes de granules de glace. Au cours de l'hiver 2006-2007, des recherches additionnelles aérodynamiques et sur les durées d'efficacité ont été menées dans des conditions simulées de granules de glace. Les activités de recherche consistaient en des essais à petite échelle menés sur des plaques planes, suivis d'essais en grandeur réelle menés dans la soufflerie à circuit ouvert du Conseil national de recherches Canada (CNRC) et sur l'aéronef Falcon 20 du CNRC.

Collecte de données et essais

Au début de chaque essai aérodynamique (tant dans la soufflerie que sur le Falcon 20), l'aile testée était traitée au moyen d'un liquide d'antigivrage à l'aide d'une méthode en une étape. Des précipitations artificielles étaient ensuite appliquées par-dessus la section traitée par le liquide d'antigivrage jusqu'à ce que le taux de contamination déterminé soit atteint. Des données telles que l'épaisseur et le point de congélation du liquide et la température des ailes ont été recueillies. Une simulation de décollage a ensuite été réalisée dans la soufflerie ou avec l'aéronef Falcon 20. Le comportement du liquide a été documenté durant la course au moyen d'appareils photographiques et de caméras vidéo numériques à grande vitesse.

Les données sur la traînée et la portance recueillies par le CNRC sur le profil d'aile NACA 23012 ont été utilisées pour générer des courbes de coefficient de portance pour chaque essai mené dans la soufflerie. Les données sur la portance recueillies lors des essais menés avec des liquides contaminés ont été comparées à celles recueillies durant les essais de référence sur les ailes sèches et les ailes traitées au moyen de liquides non contaminés. Les essais menés sur le Falcon 20 servaient principalement à valider les résultats obtenus dans la soufflerie ; aucune donnée de portance n'a été recueillie.

Conclusions

Les données sur le coefficient de portance recueillies dans la soufflerie ont démontré que l'application de liquide d'antigivrage entraînait une diminution de portance comparativement aux propriétés aérodynamiques de référence d'une aile sèche. En général, l'ajout de contaminants au liquide d'antigivrage n'a pas entraîné de grandes pertes de portance supplémentaires ; les données sur la portance recueillies durant les essais sur les liquides avec contamination étaient comparables à celles recueillies durant les essais sur les liquides non contaminés. Les essais menés sur l'aéronef Falcon 20 ont permis de valider les résultats obtenus dans la soufflerie. Ils ont démontré que la méthodologie d'essais en soufflerie fournit un substitut représentatif aux essais réalisés sur des aéronefs pleine grandeur.

Des marges de tolérance pour la navigation aérienne dans des conditions mixtes avec granules de glace ont été déterminées à la lumière des résultats des essais réalisés dans la soufflerie et sur l'aéronef Falcon 20. Elles ont été élaborées en tenant compte de la présence de contamination résiduelle sur la surface portante, des caractéristiques de portance et de la portée limitée des données recueillies sur les vitesses de rotation, les températures d'essai et d'autres paramètres pertinents. Les marges de tolérance dans des conditions de granules de glace ont été publiées dans les lignes directrices de TC sur les durées d'efficacité et dans le programme approuvé de dégivrage de la FAA révisé pour l'hiver 2007-2008.

Recommandations

En raison des résultats observés durant les essais de 2006-2007, il est recommandé de procéder à des essais supplémentaires. D’autres essais devraient être menés dans la soufflerie du CNRC et sur l’aéronef Falcon 20 afin de préciser et, possiblement, d’augmenter les marges de tolérance actuelles dans des conditions de granules de glace. Les essais devraient étudier l’effet de paramètres tels que des vitesses de rotation plus basses, l’utilisation d’un liquide dégradé ou appliqué incorrectement et le recours à des volets et à des dispositifs de bord d’attaque sur le ruissellement du liquide.

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GLOSSARY

APS	APS Aviation Inc.
CDU	Cockpit Display Unit
CSA	Canadian Space Agency
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
NCAR	National Center for Atmospheric Research
NRC	National Research Council Canada
NRCIAR	National Research Council Canada Institute for Aerospace Research
OAT	Outside Air Temperature
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 pellet conditions, APS conducted a series of small-scale plate tests and full-scale tests with the NRC open circuit wind tunnel and Falcon 20 aircraft to determine the maximum amount of ice pellet contamination that will flow-off an anti-iced aircraft at takeoff.

1.1 Background

Prior to the winter of 2006, HOT guidance material did not exist for ice pellet conditions; however, aircraft could still depart during ice pellet conditions following aircraft deicing and a pre-takeoff contamination check. This protocol was feasible for common air carrier aircraft that provided access to emergency exit windows overlooking the leading edge of the aircraft wings; however, it posed 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.

During the winter of 2006, the FAA provided a 25-minute allowance as a preliminary guideline; TC remained status quo. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research; these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. To address the option of a pre-takeoff contamination check, the 20-minute proposed allowance was extended to 25 minutes; pre-takeoff contamination checks would no longer apply. This allowance was followed by a list of conditions; one restriction was that operations would be limited to ice pellets alone (no mixed conditions).

Due to the high occurrence of ice pellets combined with freezing rain or snow, the industry requested additional guidance material for operations in mixed ice pellet conditions. Additional endurance time testing and aerodynamic research were conducted in simulated ice pellet conditions during the winter of 2006-07.

1.2 Program Objectives

A test program was developed for the winter of 2006-07 in an attempt to substantiate and possibly expand the current 25-minute ice pellets only allowance time. A series of tests were designed and carried out during the winter of 2006-07 to support the guidance material in ice pellet and mixed conditions. Research was conducted in the following simulated precipitation conditions:

- Light Freezing Rain and Light Ice Pellets (ZR-/IP-);
- Freezing Drizzle and Light Ice Pellets (ZR-/IP-);
- Light Rain and Light Ice Pellets (ZR-/IP-);
- Light Ice Pellets Only (IP-);
- Moderate Ice Pellets Only (IP mod); and
- Snow and Light Ice Pellets (SN/IP-).

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

1.3 Previous Falcon 20 Full-Scale Testing

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. These trials, based on simulated takeoff tests 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).

Research was conducted during the winter of 2005-06 using the Falcon 20 aircraft to determine the maximum amount of ice pellet contamination that will flow off an anti-iced aircraft at takeoff. This research is documented in detail in a report written by APS for TC:

1. TP 14716E, *Falcon 20 Trials to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets* (6).

1.4 Previous NRC Wind Tunnel Full-Scale Testing

Previous trials to examine the aerodynamic performance effects of de/anti-icing fluids that had been contaminated by varying quantities of freezing precipitation were conducted over three winter seasons at the NRC 3 m x 6 m open-circuit wind tunnel. The airfoil tested was a full-scale National Aeronautics and Space Administration (NASA) LS(1)-0417 section with a Fowler flap deployed at 15 degrees. A spray bar located in the wind tunnel settling chamber produced artificial snow. Takeoff was simulated by accelerating the wind speed over the test section, and aerodynamic data were obtained while pitching the airfoil to the stall. These trials, based on takeoff simulations, showed that the test approach was a viable one.

This research is documented in detail in a report written in May 1999 by the National Research Council Canada Institute for Aerospace Research (NRCIAR) for TC, TP 13426E, *Air-Flap Performance with De-Anti-Icing Fluids and Freezing Precipitation* (7).

1.5 Overview of 2006-07 Testing

Testing during the winter of 2006-07 comprised of small-scale testing conducted on flat plates followed by full-scale testing conducted in the NRC open-circuit wind tunnel and with the NRC Falcon 20 aircraft. The testing conducted is summarized below:

- Flat plate testing conducted to investigate fluid adherence in mixed ice pellet conditions (research geared to support aerodynamic research conducted):
    - Light freezing rain and light ice pellets adherence testing (September 2006 at the NRC);
    - Moderate snow and light ice pellets adherence testing (September 2006 at APS Facility);
    - Small vs. Large light ice pellets and light freezing rain adherence testing (April 2007 at the NRC); and
    - Ice pellet allowance time validation and mixed rain and ice pellets testing (July 2007 at the NRC).
- Aerodynamic research conducted to investigate fluid flow-off of contaminated fluid following simulated ice pellet and mixed conditions:
    - Aerodynamic research in ZR/IP, SN/IP, IP-, and IP conditions conducted at the NRC open-circuit wind tunnel; and
    - Aerodynamic research conducted using the NRC Falcon 20 aircraft as a spot check and validation of results obtained in the wind tunnel.

1.6 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 results from the flat plate tests conducted in simulated mixed ice pellet conditions;

c) Section 4 describes data collected during the full-scale testing conducted;

d) Section 5 describes the baseline data used as a comparative benchmark for aerodynamic research with contaminated fluids;

e) Section 6 describes the data, results, and conclusions supporting the allowance time recommendation for light ice pellets only conditions;

f) Section 7 describes the data, results, and conclusions supporting the allowance time recommendation for moderate ice pellets only conditions;

g) Section 8 describes the data, results, and conclusions supporting the allowance time recommendation for mixed light ice pellets and snow conditions;

h) Section 9 describes the data, results, and conclusions supporting the allowance time recommendation for mixed light ice pellets and light freezing rain conditions;

i) Section 10 presents a summary of the recommended allowance time for ice pellet conditions; and

j) Section 11 lists recommendations for future testing.

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2. METHODOLOGY

This section describes the test methodologies followed. The following list provides short descriptions of subsequent subsections:

- Subsection 2.1: Test methodologies and equipment specific to the Wind Tunnel Tests;
- Subsection 2.2: Test methodologies and equipment specific to the Falcon 20 aircraft tests; and
- Subsection 2.3: General testing methodologies and equipment.

2.1 Wind Tunnel Tests

2.1.1 Test Site

The 2006-07 Open-Circuit Wind Tunnel tests were performed at the NRC Aerospace Facilities, Building M-46, at the NRC Montreal Road Campus, located in Ottawa. Figure 2.1 provides a schematic of the NRC Montreal Road Campus showing the location of the NRC Open-Circuit Propulsion and Icing Wind Tunnel. Photo 2.1 shows an outside view of the wind tunnel test facility. Photo 2.2 shows an inside view of the wind tunnel test section. The open-circuit layout, with a fan at entry, permits contaminants associated with the test articles (such as heat or de/anti-icing fluid) to discharge directly, without recirculating or contacting the fan. The fan is normally driven electrically, but high-speed operation (as required for the 2006-07 tests) can be accommodated by a gas turbine drive system.

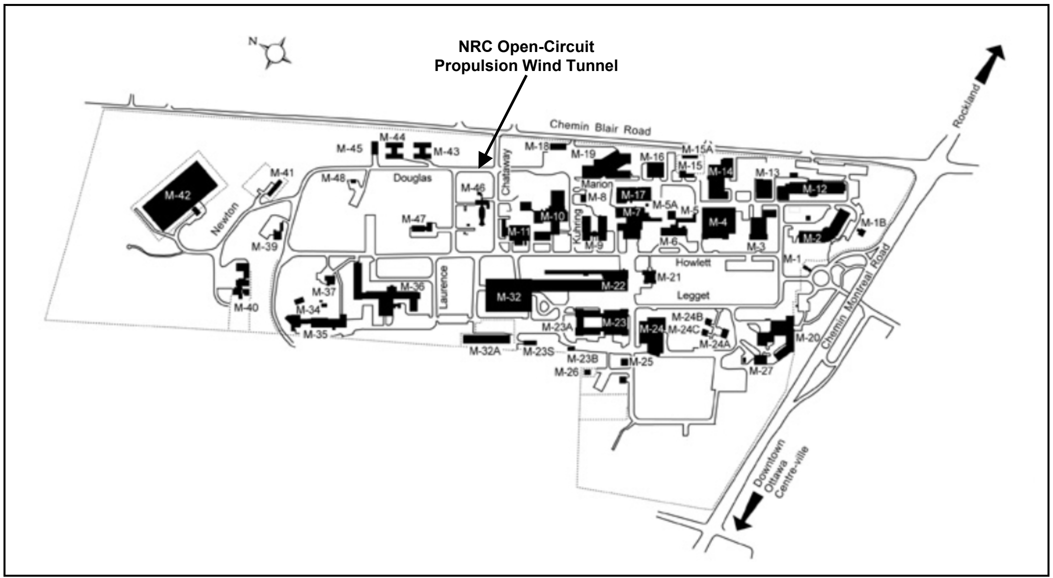


Figure 2.1: Schematic of NRC Montreal Road Campus

2.1.2 Test Schedule

Testing was scheduled for the period of February 12, 2007 to February 23, 2007. Due to the complexity of the aircraft ground icing simulation tests being performed in the NRC wind tunnel, a setup and calibration week was planned for the period of January 16, 2007 to January 19, 2007. Details of the setup and calibration work conducted are included in the TC report, TP 14778E, *Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report* (8).

A test plan was completed that allowed for modifications during the test period according to observations made during initial tests. During each test, fluid was applied to the wing section. Contamination was applied to the wing surface once the fluid had settled. Table 2.1 presents the calendar of wind tunnel tests performed in 2007.

Table 2.1: Calendar of Tests

Date	Number of Test Runs	Test Numbers
16-Jan-07	Setup	n/a
17-Jan-07	Setup/Precip Calib.	n/a
18-Jan-07	Setup/Precip Calib.	n/a
19-Jan-07	Setup/Dry Run	n/a
12-Feb-07	Set-up	n/a
13-Feb-07	Setup/Dry Run	n/a
14-Feb-07	4	1, 2, 3, 4
15-Feb-07	3	5, 6, 6a
16-Feb-07	3	1a, SS1, SS2
19-Feb-07	4	SS3, SS4, SS5, SS6
20-Feb-07	4	SP1, SP2, SP3, SS7
21-Feb-07	3	A1, A2, A3
22-Feb-07	4	7, 8, 9, SP4
23-Feb-07	4	10, 11, 12, 13

2.1.3 Procedure

To satisfy the program objective, simulated takeoff and climb-out tests were performed with the NRC NACA 23012 wing section. Different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests.

The procedure for each test was as follows:

a) The wing section was treated with Type IV fluid, poured in a one-step operation (no Type I fluid was used during the tests);

b) Contamination, in the form of simulated ice pellets, freezing rain, and snow, was applied to the wing section. Test parameters were measured at the beginning and end of the exposure to contamination; and

c) At the end of the contamination period, the tunnel was cleared of all equipment and scaffolding.

The wind tunnel was subsequently operated through a simulated takeoff and climb-out test. The behaviour of the fluid during takeoff and climb-out was recorded with digital video cameras and digital high-speed still cameras.

To validate the results, test results were compared to those obtained with the Falcon 20 aircraft.

2.1.4 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 B.

2.1.4.1 Wind Tunnel

The experiments were performed in the NRC Propulsion Wind Tunnel. This facility is an open-circuit wind tunnel with a fan at the entry, drawing air from and exhausting it to the outdoors; this design is ideal for de/anti-icing tests as it prevents contaminants from recirculating within the tunnel. This design also permits sub-freezing air to be drawn in during the Ottawa winter, thereby providing test section temperatures appropriate for these experiments. The test section is 3 m (10 ft.) wide by 6 m (20 ft.) high by 12 m (40 ft.) long, with a maximum wind speed of 78 knots when using the electrical turbine drive and with a maximum wind speed of 125 knots when using the gas turbine drive. Scaffolding was constructed to allow access to the wing section, which facilitated the application of fluids and the subsequent inspection and cleaning of the airfoil.

2.1.4.2 NACA 23012 Wing Section

The wing section used for testing was a NACA 23012, acquired by the NRC. Photo 2.3 shows the wing section used for testing; APS was in the process of marking a reference grid on the test surface. The wing section used was a hard wing similar to the airfoil of a Cessna Caravan. The NACA 23012 wing section had been used in recent years by the NRC for airborne icing experiments; this was the first time the wing section would be used for ground icing simulation tests.

2.1.4.3 NACA 23012 Design Characteristics

A cross sectional view of the NACA 23012 wing section used for testing has been included in Figure 2.2. Some of the pertinent dimensions of the wing section are:

a) Wing chord: 1.2 m (4 ft.);
b) Length: 3 m (10 ft.); and
c) Wing surface area: 3.6 m^2 (40 ft.^{2}).

The wing section used did not have slats or flaps. No moveable devices were available on the wing section.

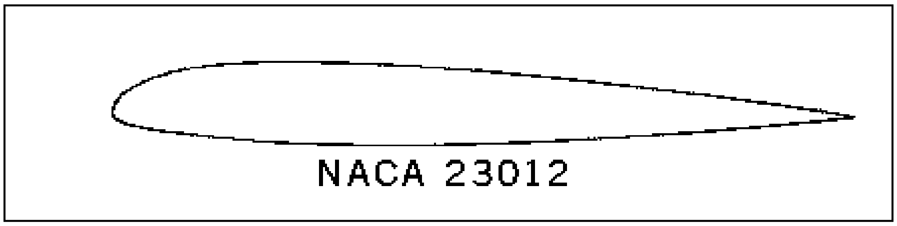


Figure 2.2: Cross Sectional View of NACA 23012 Wing Section

2.1.4.4 Wind Tunnel Measurement Capabilities

The NRC NACA 23012 wing section was supported on either side by 2-axis weigh scales capable of measuring drag and lift forces generated on the wing section. The wing section was attached to servo-systems capable of pitching the wing section to a static angle or generating dynamic movements. The servo-system was programmed to simulate pitch angles during takeoff and climb-out based on previous Falcon 20 data collected. The leading edge of the wing section was also equipped with thermistor sensors (installed by APS during the setup week) recording the skin temperature at various locations on the leading edge; however, the data collected was not monitored on a real-time basis. Data was backed up at the end of each day. The data collected from these sensors was not used in the analysis for this report, however it was analysed in TP 14778E (8).

The wind tunnel was equipped with sensors recording the following parameters:

- Air temperature inside the tunnel;
- Outside air temperature;
- Air pressure;
- Wind speed; and
- Relative humidity.

2.1.4.5 Test Area Grid

Prior to the testing, APS personnel used markers to draw a grid with dimensions of 0.61 m x 1.22 m (2 ft. x 4 ft.) along a chord approximately 0.65 m (2.1 ft.) from the tunnel wall. 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 leading edge (see Photo 2.4). The grid was used to facilitate observations of the fluid shearing off the wing and the movement of ice pellets during takeoff.

2.1.5 Simulated Precipitation Related Equipment

2.1.5.1 Ice Pellet Dispenser

Ice pellets were manufactured from ice cubes inside a 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 2.5.

2.1.5.2 Snow Dispenser

Snow was manufactured using a process similar to that used for the ice pellets. Once produced, the snow was stored in Styrofoam containers and applied over the test area using the ice pellet dispensers, modified to account for the finer snow particles.

2.1.5.3 Freezing Rain Sprayer

Simulated freezing rain was generated by the NRC freezing rain sprayer system. The same sprayer head and scanner used for HOT testing at the NRC Climatic Engineering Facility was employed for testing. The sprayer system uses compressed air and distilled water to produce the freezing rain. Four hypodermic needles are mounted onto a sprayer head whose movements are controlled by a 2-axis scanner. The freezing rain sprayer is shown in Photo 2.6.

2.1.5.4 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.

Digital still cameras were used to record visual observations of the testing. To create a consistent and stable setup for the cameras, APS mounted the cameras in the observation window overlooking the wing section. The flashes, operated through infrared sensors, were positioned in the opposing observation window; this created a shadow effect that could be used to measure and calculate the magnitude of the fluid waves and protruding contamination. Photos 2.7 and 2.8 demonstrate the camera setup used for the testing period. Video cameras, operated by NRC personnel, were positioned directly above the wing section. The cameras were zoomed in to observe the behaviour of the fluid and contamination on the wing.

In addition, a professional photographer used a digital still camera to take pictures of the test setup and all phases of the test.

2.1.6 Type IV Fluid Application Equipment

The Type IV fluids were stored outside the wind tunnel and were kept at outside air temperature (OAT). 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.

Type IV fluids were applied to the wing section by pouring directly from the 20 L fluid containers or from smaller 3 L containers (see Photo 2.9). A total of 20 L of fluid were applied to the wing section for each test.

2.1.7 Personnel

NRC personnel operated the wind tunnel. Five APS staff members were required to conduct the tests and three 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. Representatives from the TDC and the FAA provided direction in testing and participated as observers.

2.1.8 Measurement of Test Parameters

2.1.8.1 Fluid Thickness

For each test, the fluid thickness of the anti-icing fluid was measured at eight locations along the wing chord (and one location on the underside) just to the left of the test grid (closest to the centre of the wing section) using wet film thickness gauges (Photo 2.10). Measurements were taken during three stages in a typical test:

a) Before the ice pellet application;
b) After the ice pellet application; and
c) After the simulated takeoff test.

The locations designated for thickness measurement, identified in Figure 2.3, were the following:

- Wing Position 1: On the leading edge;
- Wing Position 2, 3, 4, 5: At equal distances (approximately 15 cm) between rivets along the wing chord;

- Wing Position 6: Approximately 30 cm from trailing edge;
- Wing Position 7: Approximately 15 cm from trailing edge;
- Wing Position 8: Approximately 2.5 cm from trailing edge; and
- Underside: The underside of wing section, as far as could be reached from the leading edge.

Measurements were taken along a chord approximately 1.3 m (4.3 ft.) from the tunnel wall (left-most section of the wing when facing the leading edge).

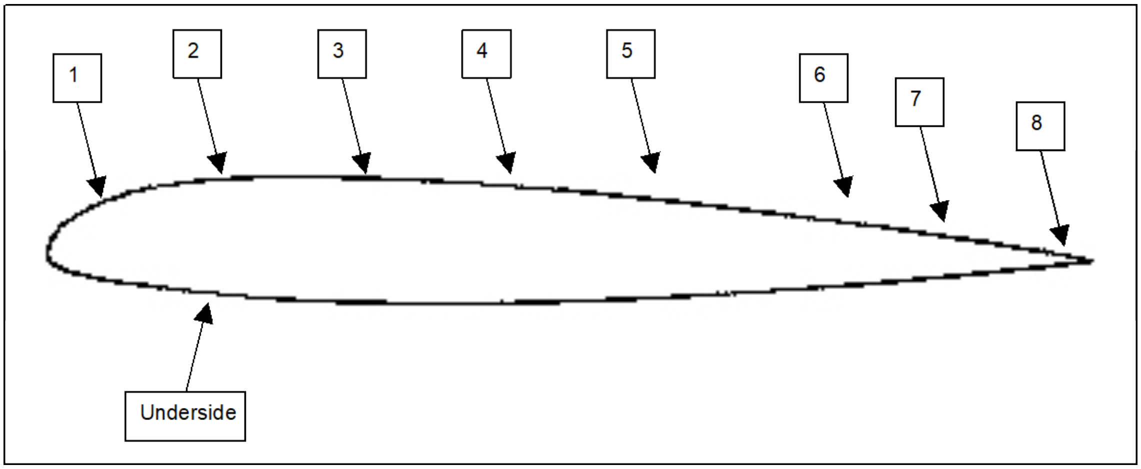


Figure 2.3: Measurement Locations Along Chord of NACA 23012 Wing Section

2.1.8.2 Fluid Brix

Fluid Brix was measured using hand-held refractometers (Photo 2.11) at three stages of the Type IV tests:

a) Before the ice pellet application;
b) After the ice pellet application; and
c) After the simulated takeoff test.

The locations designated for fluid Brix measurement, identified in Figure 2.3, were the following:

- Wing Position 2: On the leading edge; and
- Wing Position 5: As far as could be reached from the leading edge.

2.1.8.3 Wing Skin Temperature

Wing temperatures were measured using a hand-held temperature probe (Photo 2.12) at three stages of the Type IV tests:

a) Before the ice pellet application;

b) After the ice pellet application; and

c) After the simulated takeoff test.

The locations designated for skin temperature measurements, identified in Figure 2.3, were the following:

- Wing Position 2: On the leading edge;
- Wing Position 5: As far as could be reached from the leading edge; and
- Underside: The underside of wing section, as far as could be reached from the leading edge.

2.1.9 Data Forms

Several different forms were used to facilitate the documentation of the various data collected during the wind tunnel tests. These forms include:

a) Fluid Receipt Form;

b) General Form (every test);

c) Wing Temperature Form (every test);

d) Fluid Thickness and Brix Form (every test);

e) Condition of Wing and Plate Form (every test);

f) Camera Location Form (filled out only if changes were made);

g) Wind Tunnel General Setup Form (used only once); and

h) Log of Fluid Sample Bottles.

These forms are provided in the test procedure, which is included in Appendix B.

2.2 Falcon 20 Tests

2.2.1 Test Site

The 2006-07 Falcon 20 tests were performed at MacDonald-Cartier International Airport (YOW) in Ottawa. Figure 2.4 provides a schematic of the airport showing the runways and the location of the NRC hangar and apron. Photo 2.13 shows the NRC hangar.

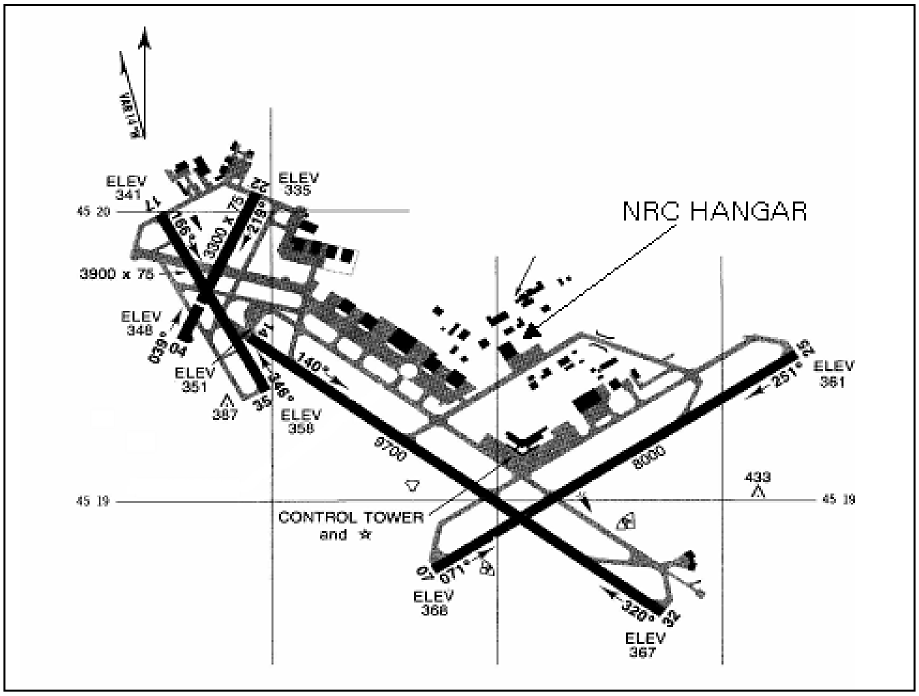


Figure 2.4: Schematic of Ottawa Airport

2.2.2 Test Schedule

Testing was scheduled for the period of February 26 to March 1, 2007. February 26 was scheduled as a setup day. A test plan was completed that allowed for modifications during the test period according to observations made during initial tests. During each test, fluid was applied to a pre-marked section on both port and starboard wings. Contamination was applied to only one wing section; the other wing section remained uncontaminated and was used as a baseline for the test. Table 2.2 presents the calendar of Falcon 20 tests performed in 2007. For example, on February 28, 2007, two tests were completed. Test 3 was done on both the port (Test 3P) and starboard (Test 3S) wings. Similarly, Test 4 was also done on the two wings (Tests 4P and 4S).

Table 2.2: Calendar of Tests

Date	Number of Test Runs	Test Numbers
26-Feb-07	Setup	n/a
27-Feb-07	2	1p, 1s, 2p, 2s
28-Feb-07	2	3p, 3s, 4p, 4s
1-Mar-07	2	5p, 5s, 6p, 6s

2.2.3 Procedure

To satisfy the program objective, simulated takeoff tests 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 test was as follows:

a) A designated test area on the port and starboard wings was treated with Type IV fluid, poured in a one-step operation outside the NRC hangar;

b) Contamination, in the form of simulated ice pellets, freezing rain, and snow, was applied to only one wing section; the other wing section was left uncontaminated and used as a baseline comparison test. Test parameters were measured at the beginning and end of the exposure to contamination;

c) At the end of the contamination period, the aircraft was taxied to the selected runway. Once at the button, APS personnel conducted an inspection of the contaminated wing section and measured selected test parameters; and

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

Test results were used to validate the results previously obtained in the NRC open-circuit wind tunnel.

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.

2.2.4.1 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 2.14). 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 Defence (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, 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.

2.2.4.2 Falcon 20 Design Characteristics

A three-view diagram of the Falcon 20 aircraft has been included in Figure 2.5. Some of the pertinent dimensions of the Falcon 20 are:

a) Wingspan: 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.

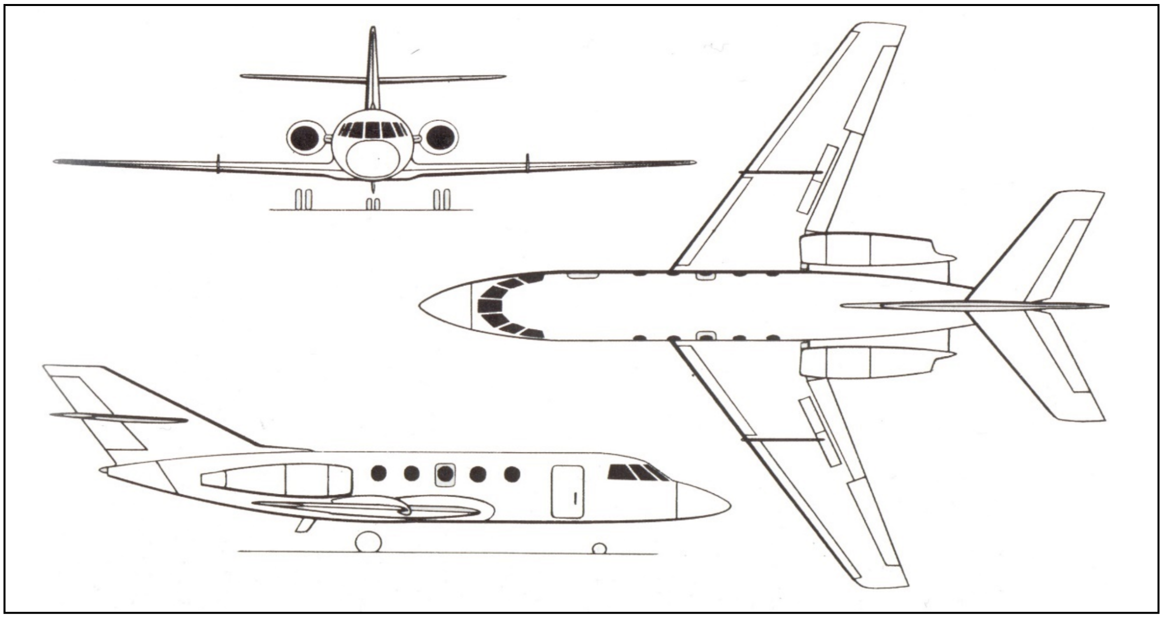


Figure 2.5: Schematic View of Dassault Falcon 20

2.2.4.3 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.

2.2.4.4 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.

2.2.4.5 Test Area

Areas on the port and starboard wings, just inboard of the fences, were selected to serve as the test surfaces 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.

The areas selected covered 1.1 m of the leading edge, inboard of the fence and the entire chord of the wing, as illustrated in Figure 2.6. The test surfaces had areas of 2.7 m^2 and were used for all tests.

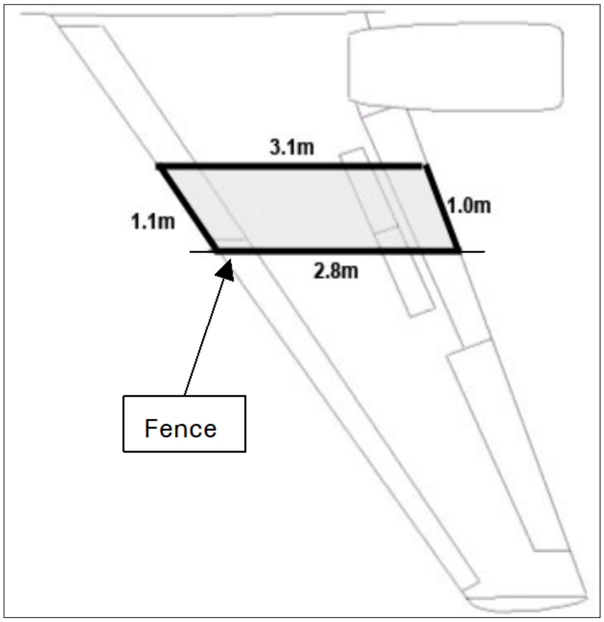


Figure 2.6: Test Area

2.2.4.6 Test Area Grid

Prior to the 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 and starboard wings 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 2.15) The grid was used to facilitate observations of the fluid shearing off the wing and the movement of ice pellets during takeoff.

2.2.5 Simulated Precipitation Related Equipment

2.2.5.1 Ice Pellet Dispenser

Ice pellets were manufactured from ice cubes inside a 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 2.16.

2.2.5.2 Snow Dispenser

Snow was manufactured using a process similar to that used for the ice pellets. Once produced, the snow was stored in Styrofoam containers until applied over the test area using the ice pellet dispensers, modified to account for the finer snow particles.

2.2.5.3 Freezing Rain Dispenser

Simulated freezing rain was produced by the APS mobile freezing rain sprayer system. The sprayer system uses compressed air and distilled water to produce the freezing rain. Three hypodermic needles (similar to those used by the NRC Climatic Engineering Facility for HOT testing) are mounted onto a hand-held sprayer head. The hand-held freezing rain dispenser is shown in Photo 2.17.

2.2.5.4 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 can take 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.

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 both emergency exit doors of the Falcon 20 with a temporary structure that had camera-mounting capability (see Photo 2.18). A video camera and a still camera were fitted to both port and starboard emergency exit doors. The cameras 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 tests.

2.2.6 Type IV Fluid Application Equipment

The Type IV fluids were kept at air 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.

Type IV fluids were applied to the Falcon 20 wing surfaces using several PVC pouring devices (Photo 2.19) manufactured for this purpose. Each 2.5 L device was fitted with pouring, refill, and breather holes, which permitted uniform fluid flow.

2.2.7 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.

2.2.8 Personnel

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

2.2.9 Measurement of Test Parameters

2.2.9.1 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 2.20). Measurements were taken at four stages in a typical test:

a) After fluid application;

b) After the ice pellet application;

c) Before the simulated takeoff test; and

d) After the simulated takeoff test.

The fluid thickness measurement locations on the port wing are shown in Figure 2.7; the same layout was used for the starboard wing. The locations designated for thickness measurement, identified in the data form, were the following:

- Wing Position 1: On the leading edge;
- Wing Position 2: On the leading edge, 2.5 cm (1 in.) from the joint;
- Wing Position 5: As far as could be reached from the leading edge;
- Wing Position 7: Just behind the spoiler; and
- Wing Position 8: Halfway between the trailing edge and the joint.

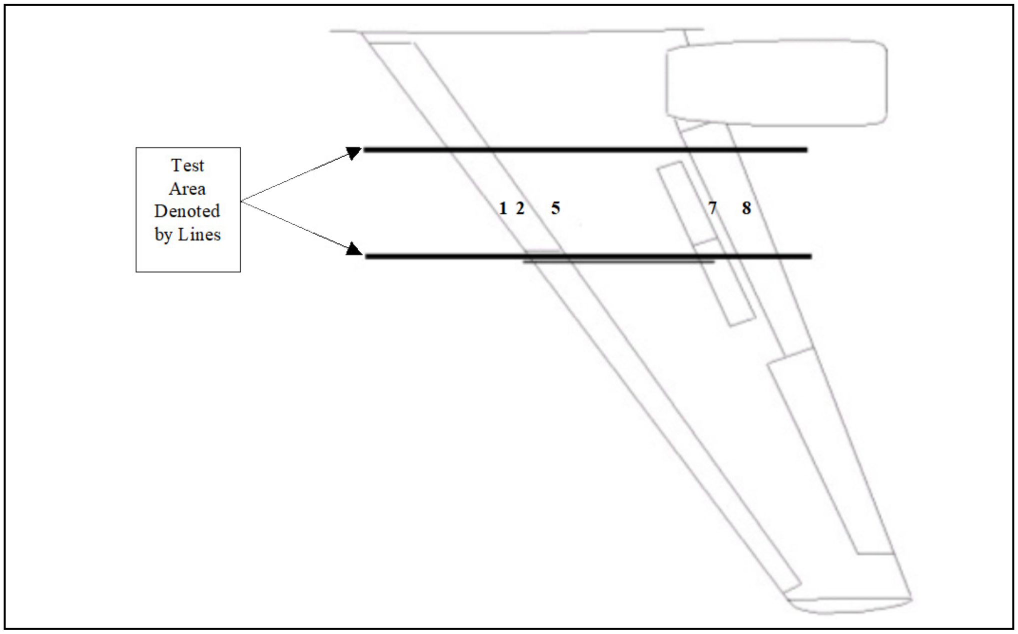


Figure 2.7: Fluid Thickness and Fluid Brix Measurement Locations

2.2.9.2 Fluid Brix

Fluid Brix was measured at the leading edge and the trailing edge using hand-held refractometers (Photo 2.21) at four stages of the Type IV tests:

a) After fluid application;

b) After the ice pellet application;

c) Before the simulated takeoff test; and

d) After the simulated takeoff test.

The locations designated for fluid Brix measurement, shown in Figure 2.7, were the following:

- Wing Position 2: On the leading edge, 2.5 cm (1 in.) from the joint;
- Wing Position 8: Halfway between the trailing edge and the joint.

2.2.9.3 Wing Skin Temperature

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

- 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: As far as could be reached from the leading edge; and
- Positions 7 and 8: Halfway between the trailing edge and the joint.

Wing temperatures were read directly off the temperature probe and recorded on the appropriate data form. Figure 2.8 shows the location of each measurement position.

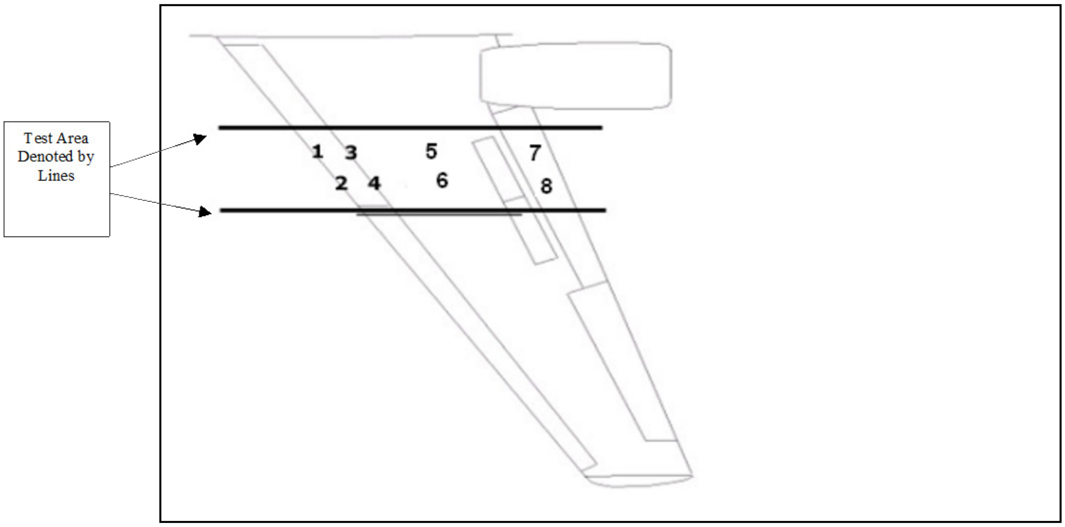


Figure 2.8: Wing Temperature Data Form

2.2.10 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) Fluid Receipt Form;

b) General Form (every test);

c) Wing Temperature Form (Port Wing);

d) Wing Temperature Form (Starboard Wing);

e) Fluid Thickness and Brix Form (Port Wing);

f) Fluid Thickness and Brix Form (Starboard Wing);

g) Freezing Rain/Snow Quantity Form;

h) Test Results Form (Port Wing);

i) Test Results Form (Starboard Wing);

j) Time Record of Operations; and

k) Nominal Test Conditions.

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

2.3 General

This section describes equipment and general information used for both the wind tunnel and Falcon 20 tests.

2.3.1 Viscometer

Viscosity measurements were carried out using a Brookfield viscometer (Model DV-1+, shown in Photo 2.23) fitted with a recirculating fluid bath and small sample adapter.

2.3.2 Fluid Freezing Point and Temperature Gauges

Fluid freezing points were measured using a hand-held Misco refractometer with a Brix scale. The freezing points of the various fluid samples were determined using the conversion curve or table provided to APS by the fluid manufacturer. The Kilfrost ABC-S table is shown in Table 2.3, and the Dow Ultra+ curve is shown in Figure 2.9.

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

2.3.3 Thickness Gauges

Wet film thickness gauges, shown in Figure 2.10, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thicknesses (0.1 mm to 10.2 mm) for Type IV fluids. The rectangular gauge shown in Figure 2.11 has a finer scale and was used in some cases when the fluid film was thinner (toward the end of a test). The observer recorded a thickness value (in mils), as read directly from the thickness gauge. The recorded value was the last wetted tooth of the thickness gauge; however, the true thickness lies between the last wetted tooth and the next un-wetted tooth. A thickness conversion table (shown in Table 2.4) was used to convert the recorded thickness values into the corrected thickness values.

Table 2.3: 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					

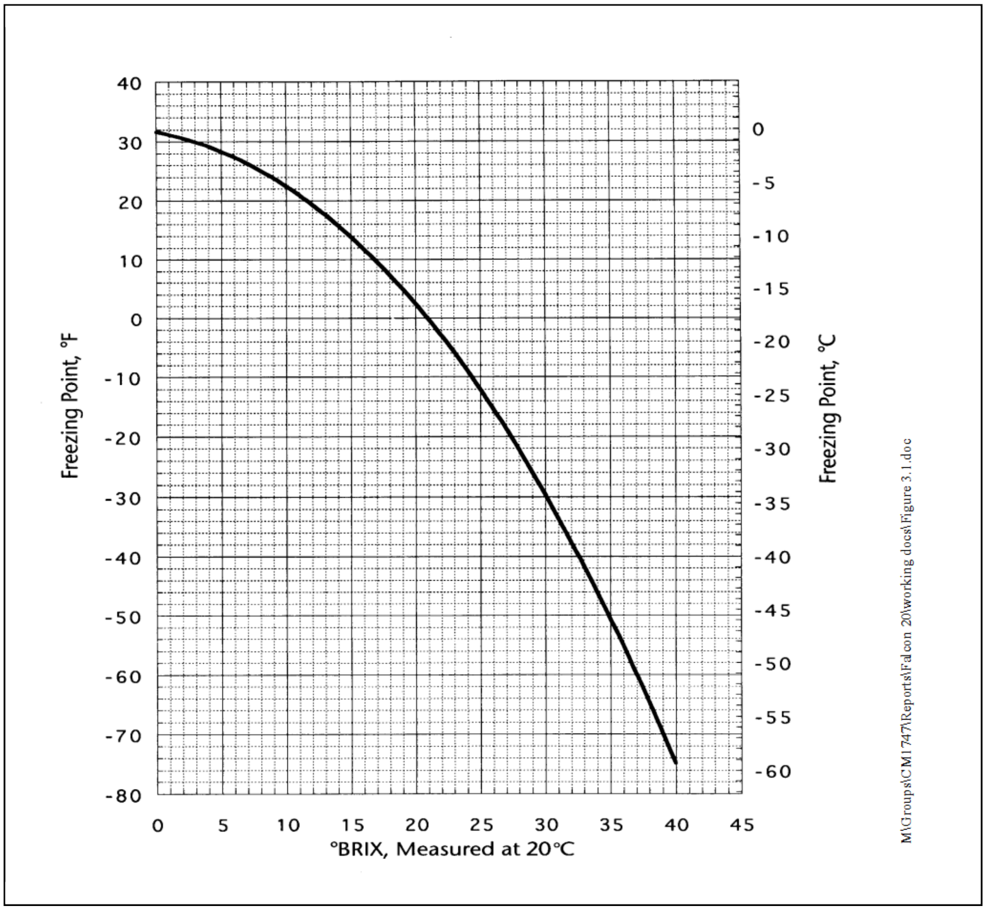
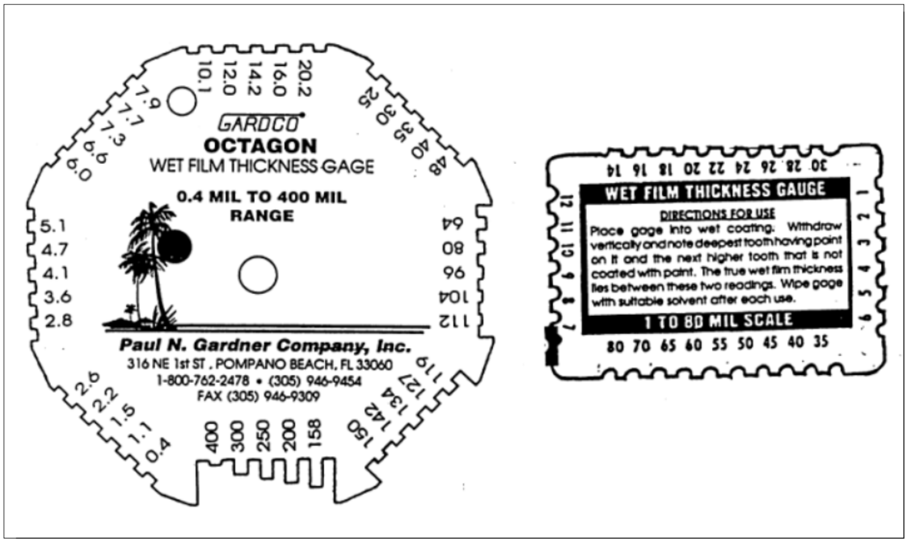


Figure 2.9: Freezing Point vs. Brix of Aqueous Solutions of Dow UCAR Ultra+



Place gage into wet coating. Withdraw vertically and note deepest tooth having point on it and the next higher tooth that is not coated with paint. The true wet film thickness lies between these two readings. Wipe gage with suitable solvent after each use.

M:\Groups\CM1747\Reports\Falcon 20\working docs\Figure 2.4.doc

Figure 2.10: Thickness Gauges

Table 2.4: 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.

2.3.4 Fluids

Two fluids were used in these tests: Dow Chemical UCAR Ultra+ and Kilfrost ABC-S. The pertinent characteristics of these fluids are given in Table 2.5. It should be noted that Dow Ultra+ fluid obtained the previous year was used for certain designated tests; the viscosity and condition of the fluid were found to be acceptable.

Table 2.5: Test Fluids

Fluid Name	Batch #	Quantity Received (L)	Date Received	Type	Formulation	Brix	Viscosity (mPa.s)
Dow Chemical UCAR Ultra+	UA255553D4	200*	Winter 2006	IV	EG	40.0º	48200**
Dow Chemical UCAR Ultra+	UK205553D2	200	Winter 2007	IV	EG	40.0º	45300**
Kilfrost ABC-S	10117	640	Winter 2007	IV	PG	36.0º	23400***

* Extra fluid from 2005-06 Falcon 20 tests

** Spindle SC4-31, 10 mL of fluid, 10 minutes, 0.3 rpm, 0°C

*** Equivalent to: Spindle LV-2, 150 mL of fluid, 10 minutes, 0.3 rpm, 20°C

2.3.5 Artificial Contamination

2.3.5.1 Ice Pellets

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, ice pellets were produced with diameters ranging from 1.0 mm to 4.0 mm to represent the most common ice pellet size observed during natural events.

The ice pellets were manufactured inside a refrigerated truck (see Photo 2.24). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.25) to obtain the required ice pellets size range. Hand-held motorized dispensers 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.

For observation purposes, colouring dye was used to produce coloured ice pellets. When applied to the wing surface, they represented 10 percent of the total ice pellet quantity applied. These served as tracers when observing the movement of the precipitation exposed to the airflow at takeoff.

2.3.5.2 Snow

Snow was produced using the same method for producing ice pellets. The snow used consisted of small ice crystals measuring less than 1.3 mm in diameter. Previous testing conducted by APS investigated the dissolving properties of the simulated snow versus natural snow. The simulated snow was selected as an appropriate substitute for natural snow.

The snow was manufactured inside a refrigerated truck. Cubes of ice were crushed and passed through calibrated sieves to obtain the required snow size range. Hand-held motorized dispensers (see Photo 2.16) were used to dispense the snow. The snow was applied to the leading and trailing edges of the wing at the same time.

2.3.5.3 Freezing Rain Dispenser

Simulated freezing rain was produced by the APS mobile freezing rain sprayer system. The sprayer system uses compressed air and distilled water to produce the freezing rain. Three hypodermic needles (similar to those used by the NRC Climatic Engineering Facility for HOT testing) are mounted onto a hand-held sprayer head.

The droplet diameters produced by the sprayer system were verified using the Whatman paper blue dye technique (developed by the NRC). The simulated freezing rain was selected as an appropriate substitute for natural freezing rain; simulated precipitation was freezing on the wing surfaces, and droplet diameters were representative of natural freezing rain.

Photo 2.1: Outside View of NRC Wind Tunnel Facility

Photo 2.2: Inside View of NRC Wind Tunnel Test Section

Photo 2.3: NACA 23012 Wing Section Used for Testing

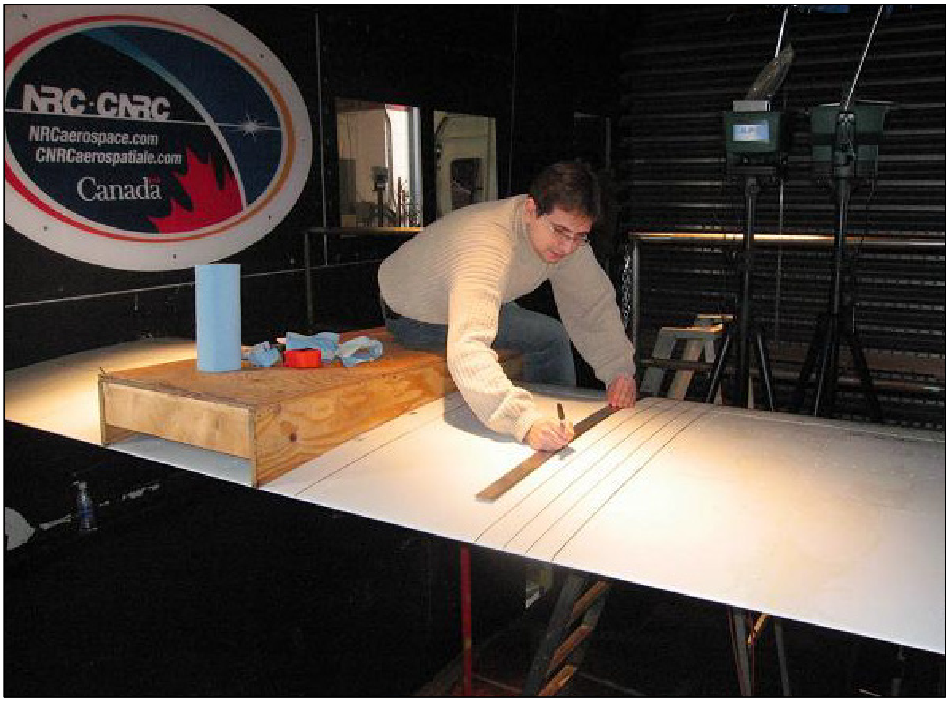


Photo 2.4: Grid Markings on NACA 23012 Wing Section

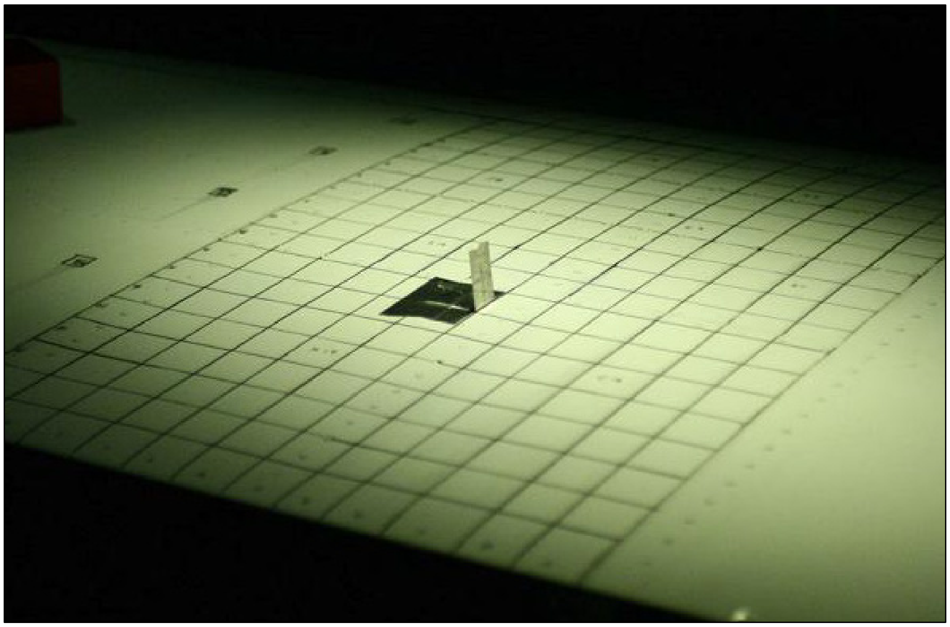


Photo 2.5: Ice Pellet Dispensers Operated by APS Personnel

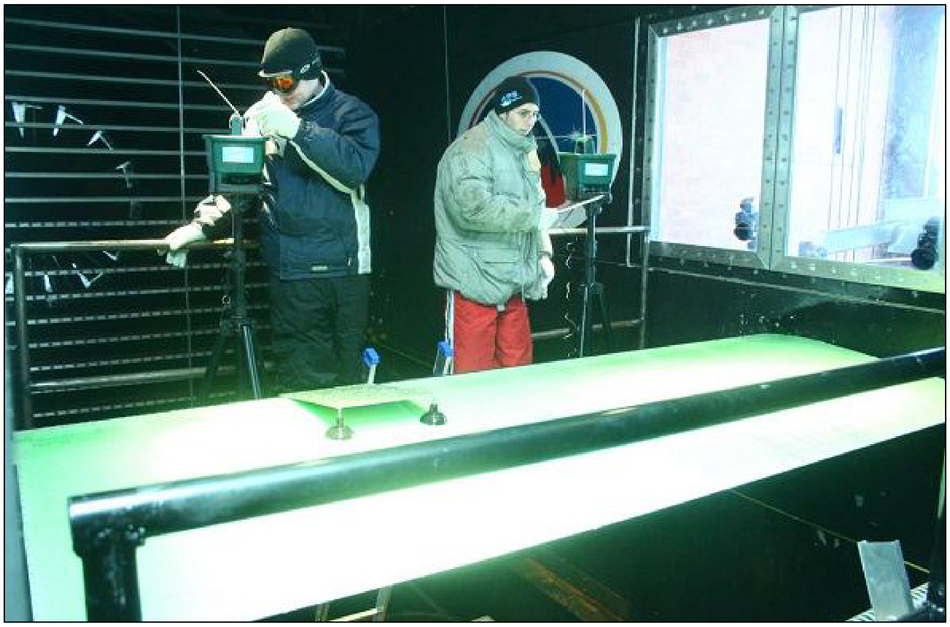


Photo 2.6: Ceiling-Mounted Freezing Rain Sprayer

Photo 2.7: Wind Tunnel Setup for Flashes

Photo 2.8: Wind Tunnel Setup for Digital Cameras

Photo 2.9: Fluid "Pour" Application

Photo 2.10: Wet Film Thickness Gauges

Photo 2.11: Hand-Held Brixometer

Photo 2.12: Hand-Held Temperature Probe

Photo 2.13: NRC YOW Institute for Aerospace Research Hangar

Photo 2.14: NRC Falcon 20 Aircraft

Photo 2.15: Reference Grid Drawn on Both Port and Starboard Wing Test Sections

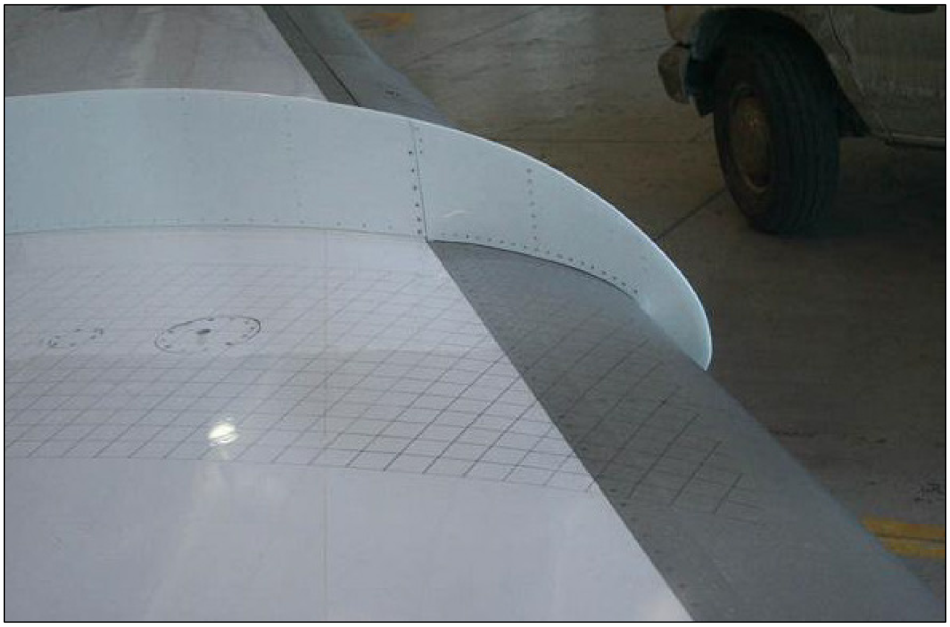


Photo 2.16: Ice Pellet Dispenser Setup for Falcon 20 Tests

Photo 2.17: Freezing Rain Sprayer Hand-Held Spray Bar

Photo 2.18: Camera Positioning Inside Emergency Exit Windows

Photo 2.19: PVC Fluid Pouring Devices

Photo 2.20: Fluid Thickness Measurement Using Wet Film Thickness Gauge

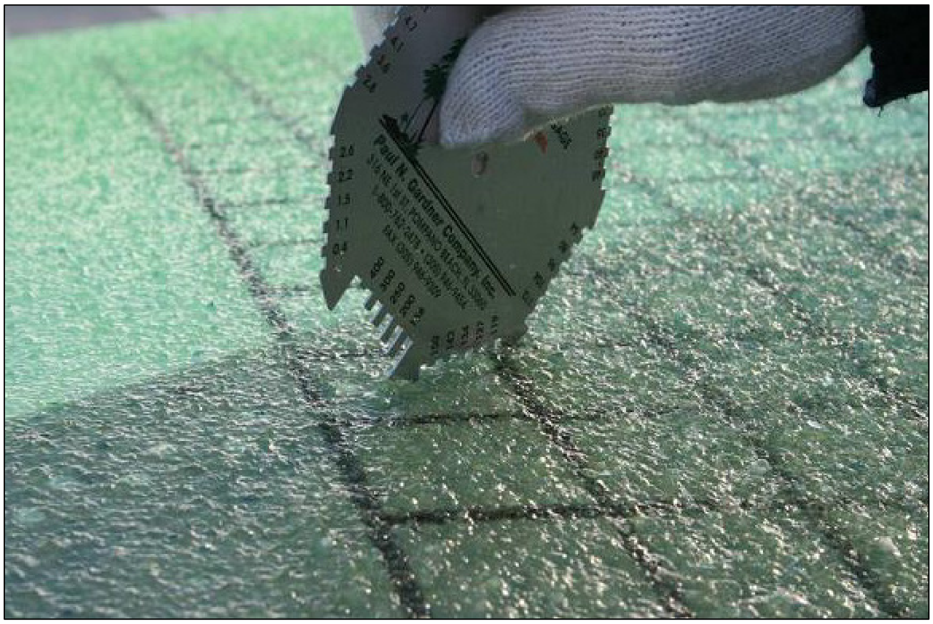


Photo 2.21: Fluid Freezing Point Measurement Using Hand-Held Brixometer

Photo 2.22: Wing Surface Temperature Measurement

Photo 2.23: Brookfield Digital Viscometer Model DV-1+

Photo 2.24: Refrigerated Truck Used for Manufacturing Ice Pellets

Photo 2.25: Calibrated Sieves Used to Obtain Desired Size Distribution

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3. FLAT PLATE TESTING

This section provides an overview of the flat plate testing conducted as part of the test program. Each series of tests was performed with the objective of exploring specific ice pellet conditions with the aim of minimizing full-scale testing required. The following list provides short descriptions of subsequent subsections:

- Subsection 3.1: Fluid Adherence in Mixed Ice Pellets and Freezing Rain Conditions;
- Subsection 3.2: Fluid Adherence in Mixed Ice Pellets and Snow Conditions and Simulated Cold Front Tests;
- Subsection 3.3: Fluid Adherence in Mixed Ice Pellets and Freezing Rain Conditions – Large vs. Small Ice Pellets and Intermittent Conditions; and
- Subsection 3.4: Ice Pellet Allowance Time Validation and Mixed Rain and Ice Pellets Testing.

3.1 Fluid Adherence in Mixed Ice Pellets and Freezing Rain Conditions

3.1.1 Objective

The objective of this project was to investigate the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface. Baseline testing was conducted in freezing rain conditions only. Testing was primarily conducted to validate the 25-minute allowance time that was recommended by the FAA for aircraft operations in ice pellets only conditions.

3.1.2 Methodology

Endurance time testing was conducted in September 2006 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. Test plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. The "Ice Pellet Dispenser" was positioned to dispense ice pellets on 6 of the 12 test plates.

3.1.3 Results

A detailed test report was compiled upon completion of testing. This report is included in Appendix E.

The results indicated that adherence is primarily caused by the freezing rain because the additional ice pellet precipitation did not significantly reduce the fluid protection time to adherence. Similar results were obtained using small and large diameter ice pellets for the mixed icing condition (see Subsection 3.3). At colder temperatures, the added ice pellet precipitation may be contributing to the fluid adherence. Additional testing was recommended to investigate the impact of ice pellets at the colder temperatures.

3.2 Fluid Adherence in Mixed Ice Pellets and Snow Conditions and Simulated Cold Front Tests

3.2.1 Objective

The objective of this project was to investigate the level of snow and ice pellet contamination required to cause fluid failure and adherence to the test surface.

As a secondary objective, this project investigated the effect of a simulated cold front on fluid adherence following the first visual failure.

3.2.2 Methodology

Endurance time testing was conducted in the APS refrigerated trailer using the standard flat plate HOT test procedure. The National Center for Atmospheric Research (NCAR) snow machine was used to produce the simulated snow. The NCAR bucket was placed inside the NCAR snow machine enclosure with the enclosure remaining open during the test. The “Ice Pellet Dispenser” was positioned above the NCAR bucket facing the open side of the NCAR enclosure. Both the NCAR snow machine and the ice pellet dispenser were run simultaneously to produce the desired mixed ice pellets and snow precipitation conditions.

To simulate a cold front during the mixed ice pellets and snow tests, the air temperature and the plate temperature were reduced by 3°C to 4°C at the time of first failure (failure to the 2.5 cm line). Fluid adherence was verified and documented during each test.

3.2.3 Results

A detailed test report was compiled upon completion of testing. This report is included in Appendix F.

Fluid adherence was not observed during the simulated mixed ice pellets and snow tests. The fluid failure mechanism during the mixed ice pellets and snow conditions was not conducive to fluid adherence. This was also the case during the simulated cold front tests. The decrease in plate temperature and air temperature was not sufficient to cause the diluted fluid to adhere to the test surface.

As a result of the added ice pellet conditions, contamination was present very early in the test; ice pellets were embedded in the fluid. During mixed conditions with snow as the dominant precipitation type, when bridging snow (snow sitting on the surface of the fluid diluted close to the freezing point which are not being absorbed by the fluid) became apparent on the surface of the fluid, the added ice pellet precipitation was difficult to see; ice pellets are translucent and are difficult to determine visually amidst bridging snow. During a tactile inspection, it was apparent that the ice pellets were dissolving slower in the areas where snow began bridging; the fluid in this area was likely nearing the fluid freezing point and was less effective at dissolving frozen precipitation. During mixed conditions with ice pellets as the dominant precipitation type, bridging snow was less apparent in the areas with failed fluid.

3.3 Fluid Adherence in Mixed Ice Pellets and Freezing Rain Conditions – Large vs. Small Ice Pellets and Intermittent Conditions

3.3.1 Objective

The objective of this project was to investigate the level of large or small ice pellets and freezing rain contamination required to cause fluid adherence to the test surface. Baseline testing was conducted in freezing rain conditions only. Large ice pellets used were 2.8 mm to 4.75 mm in diameter. Small ice pellets used were 1.0 mm to 2.8 mm in diameter.

As a secondary objective, this project investigated the effect of intermittent freezing rain and small ice pellet conditions on fluid adherence to the test surface. Baseline testing was conducted in freezing rain conditions only.

3.3.2 Methodology

Endurance time testing was conducted in April 2007 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. Two six-position test stands with plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. Two "Ice Pellet Dispensers" were positioned to dispense large ice pellets on the four left-most test plates (positions 1, 2, 7, and 8), and small ice pellets on the four right-most test plates (positions 5, 6, 11, and 12). Baseline tests were done in conjunction with the standard HOT testing.

In addition, a two-position test stand with plates was used and positioned directly underneath the simulated freezing precipitation sprayer assembly. To generate intermittent light freezing rain and ice pellet conditions, the test stand was physically moved outside of the light freezing rain spray area where an ice pellet dispenser was positioned to dispense small ice pellets on the test plates. The duration and sequence of precipitation types was determined at the beginning of each test. Baseline tests were done in conjunction with the standard HOT testing.

3.3.3 Results

A detailed test report was compiled upon completion of testing. This report is included in Appendix G.

The tests indicated that there was no significant difference in the fluid adherence results obtained using the large or small ice pellets combined with light freezing rain.

In general, the estimated visual fluid failure for large or small ice pellets combined with light freezing rain tests did not differ by more than two minutes. In comparison to the baseline light freezing rain only tests, the estimated visual failure time of the mixed icing tests (both for large and small ice pellets) was generally within five minutes of the baseline test failure call.

During the intermittent precipitation tests, the difference in time of first adherence for the intermittent light freezing rain and small ice pellet tests and the baseline (ZR only) tests did not exceed 4 minutes.

3.4 Ice Pellet Allowance Time Validation and Mixed Rain and Ice Pellets Testing

This testing was conducted following the completion of the wind tunnel and Falcon 20 tests conducted during the winter of 2006-07. The main purpose was to conduct indoor laboratory flat plate testing to validate the allowance time developed as a result of the aerodynamic testing conducted during the winter of 2006-07. This testing has been included in this section due to the link with flat plate testing and not due to the chronological order of events.

3.4.1 Objective

Testing was conducted to satisfy the following objectives:

- Validate the recently issued allowance times for ice pellets and mixed precipitation conditions with ice pellets by conducting flat plate testing to investigate the level of contamination observed at the end of the allowance period.
  - Investigate also the effects of fluid "aging" following the end of the allowance time.
- Provide a basis for an allowance time recommendation in mixed light rain and ice pellet conditions.

3.4.2 Methodology

Endurance time testing was conducted in July 2007 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. Test plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. The "Ice Pellet Dispensers" were positioned to dispense ice pellets on the four left-most test plates and on the four right-most test plates.

Validation of allowance time testing was conducted at the upper precipitation limits for each of the allowance time conditions. At the end of the allowance time, the fluid was inspected to verify for fluid adherence. To investigate the effects of fluid aging, the test plates were then removed from the test area and left in the cold chamber for an additional 30 minutes to observe any changes in the fluid condition.

During the light rain and ice pellets tests, the test plates were exposed to precipitation for 40 minutes, at which point the test was stopped.

3.4.3 Results

A detailed test report was compiled upon completion of testing. This report is included in Appendix H.

3.4.3.1 Mixed Light Freezing Rain and Light Ice Pellets

Testing conducted at -10ºC did not show signs of adherence at the end of the allowance time. A significant amount of fluid was still present on the test plate, and the fluid had not yet diluted to a critical freezing point. Testing conducted at -5ºC showed signs of adherence up to the 2.5 cm (1 in.) line of the test plate at the end of the allowance time. These results are typical with freezing rain at warmer temperatures.

3.4.3.2 Light Ice Pellets and Moderate Ice Pellet Conditions

Testing conducted in light and moderate ice pellet conditions generated similar results at the end of the allowance time; no adherence was documented, and bridging ice pellets were observed when the fluid diluted close to the fluid freezing point. Adherence was not observed during any of the tests conducted with light ice pellets or moderate ice pellets alone.

3.4.3.3 Mixed Snow and Light Ice Pellets

Testing conducted at -5ºC did not show any signs of fluid adherence at the end of the allowance time. It was observed that the snow dissolved quicker in comparison to the ice pellets. When the fluid was sufficiently contaminated and the fluid dilution would begin to near the freezing point, bridging snow could be observed.

3.4.3.4 Effects of Aging of Contaminated Fluid

When the test plate was removed from the test area (precipitation was stopped), the visual condition of the contaminated fluid would improve. Embedded or bridging frozen precipitate would further dissolve, resulting in the visual improvement. In all cases, with the exception of light freezing rain mixed with light ice pellets, the fluid had not neared the freezing point by the end of the allowance time; therefore, the contamination would be further dissolved.

In the case of light freezing rain mixed with light ice pellets, the fluid had diluted close to the freezing point by the end of the allowance time. It was believed that in the case of a drop in temperature, the adhered patches may be conducive to further freezing and adhering of the diluted fluid.

3.4.3.5 Mixed Light Rain and Ice Pellet Conditions

Testing was conducted at 0ºC, 1ºC, and 2ºC. At the end of the 40-minute precipitation period, adhered patches of ice were observed on the test plates for tests conducted at 0ºC and 1ºC. The latent heat of fusion associated with the melting of the ice pellets caused the plate temperature to drop below 0ºC and allowed the fluid to freeze once the corresponding fluid freezing point was reached. These results were similar to those observed during the light freezing rain and ice pellet tests conducted at -5ºC.

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4. FULL-SCALE DATA COLLECTED

4.1 Test Logs

4.1.1 Wind Tunnel Test Log

A detailed log of the tests conducted in the wind tunnel is shown in Table 4.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each column contains data specific to one test. The following is a brief description of the column headings for Table 4.1:

Test #:	Exclusive number identifying each test.
Test Objective:	Test objective describing simulated test condition.
Date:	Date when the test was conducted.
Type IV Fluid:	Type IV aircraft deicing fluid. EG specifies an Ethylene Glycol fluid, and PG specifies a Propylene Glycol fluid.
Test Area (m^2):	Wing section test area, measured in meters squared.
Ice Pellet Size (mm):	Size distribution of manufactured simulated ice pellets, measured in millimeters.
Duration of Precipitation (min):	Total duration of simulated precipitation condition, recorded in minutes.
Endurance Time on Plate (min):	Fluid endurance time recorded in minutes using reference test plate mounted on the wing section.
Ice Pellet Quantity (kg):	Total quantity of ice pellets applied to test section, measured in kilograms.
Effective Ice Pellet Rate ($g/dm^2/h$):	Simulated ice pellet precipitation rate, calculated in $g/dm^2/h$.

Freezing Precip. Type (ZD or ZR-):	Simulated freezing precipitation type (freezing drizzle or light freezing rain) generated from ceiling-mounted sprayer system.
Freezing Precip. Rate (g/dm^2/h):	Simulated freezing precipitation rate, calculated in g/dm^2/h.
Snow Size (mm):	Size distribution of manufactured simulated snow, measured in millimeters.
Snow Quantity (kg):	Total quantity of snow applied to test section, measured in kilograms.
Snow Rate (g/dm^2/h):	Simulated snow rate, calculated in g/dm^2/h.
Fluid Application Start Time:	Start of the fluid application, recorded in local time.
Precipitation End Time:	End of the simulated precipitation period, recorded in local time.
Tunnel Start Time:	Start of the simulated takeoff test, recorded in local time.
OAT (°C):	Outside air temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius.
Tunnel OAT (°C):	Static tunnel air temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius.
Average Tunnel OAT from fluid (°C):	Average tunnel air temperature recorded from the start of fluid application to the start of the takeoff test, measured in degrees Celsius.

Avg. OAT during last 10 min. of	Precipitation (°C): Average tunnel air temperature recorded during the last 10 minutes of precipitation application, measured in degrees Celsius.
Avg. Wing Temp. before Test (°C):	Average of the wing skin temperature measurements (excluding the under-wing measurement), recorded in degrees Celsius.
Angle of Attack (deg) and	Rate of Change (initial): Simulated takeoff angle of attack (recorded in degrees) and time rate of change (in seconds).
Ramp time (s) and VR speed (kts):	Ramp time (measured in seconds) required for the wind tunnel to accelerate up to the target rotation speed (measured in knots).
Visual Severity Rating (1-5)	*(WindTunnel tests)*:Rank based on contamination flow-off (photo analysis): 1-Trailing edge clean after 30 s (rotation); 2-Trailing edge clean after 45 s; 3-Trailing edge clean after 60 s; 4-Trailing edge clean after >60 s, contamination left after test; and 5-Same as 4, plus contamination on leading edge after 45 s.

Table 4.1: Wind Tunnel Test Log

Test #	1	2	3	4	5	6	6a	1a
Test Objective	Dry	Fluid only	Fluid only	ZR-	IP		ZR-/IP	Dry
Date	14-Feb-07	14-Feb-07	14-Feb-07	14-Feb-07	15-Feb-07	15-Feb-07	15-Feb-07	16-Feb-07
Type IV Fluid	none (dry)	PG	EG	PG	PG	PG	PG	none (dry)
Test Area [m2]	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Ice Pellet size [mm]	none (dry)	none(fluid only)	none(fluid only)	none	1.3 to 4	1.3 to 4	1.3 to 4	none (dry)
Duration of Precipitation (min)	none (dry)	none(fluid only)	none(fluid only)	60	60	40	20	none (dry)
Endurance Time on Plate (min)	N/A	N/A	N/A	22 (3xhairs adhered at 60min)	cannot call due to no definition	missed the failure call but estimate 10min	10 min	N/A
Ice Pellet Quantity (kg)	none (dry)	none(fluid only)	none(fluid only)	none	9.3	1.2	0.6	none (dry)
Effective Ice Pellet Rate (g/dm^2/h)	none (dry)	none(fluid only)	none(fluid only)	none	25	5	5	none (dry)
Freezing Precip. Type (ZD or ZR-)	none (dry)	none(fluid only)	none(fluid only)	ZR-	ZR-	ZR-	ZR-	none (dry)
Freezing Precip. Rate (g/dm^2/h)	none (dry)	none(fluid only)	none(fluid only)	28	0	20	20	none (dry)
Snow size [mm]	none (dry)	N/A	N/A	N/A	N/A	N/A	N/A	none (dry)
Snow Quantity (kg)	none (dry)	N/A	N/A	N/A	N/A	N/A	N/A	none (dry)
Snow rate (g/dm^2/h)	none (dry)	N/A	N/A	N/A	N/A	N/A	N/A	none (dry)
Fluid application start time	N/A	12:52	13:52	16:48	10:09	13:09	15:19	N/A
Precipitation end time	N/A	N/A	N/A	17:58	11:29	14:13	16:17	N/A
Tunnel start time	12:12	13:24	14:25	18:31	11:54	14:36	16:41	13:48
OAT [°C]	-14.6	-13	-13	-13	-16.9	-15	-14	-7
Tunnel OAT [°C]	-1.7	-10	-11	-2	-16.8	-8	-8	????
Average Tunnel OAT from fluid application to start of takeoff run	N/A	-10	-10.4	-1.8	-14.9	-8.6	-8.6	N/A
Average OAT during last 10 min of precip	N/A	N/A	N/A	-0.9	-12.1	-7.9	-8.6	N/A
AverageTunnel OAT from end of precip to start of takeoff run	N/A	N/A	N/A	-3.7	-13.4	-9.4	-10.1	N/A
Avg Wing Temp before Run [°C]	-2	-9	-8	-1	-13	-7	-7	N/A
Angle of Attack (deg) and Rate of Change (initial)	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s
Ramp time (s) and V_R speed (kts)	35 100	35 100	35 100	35 100	35 100	35 100	35 100	35/100
Rank based on contamination flow off (photo analysis) 1 - TE clean after 30s (rotation) 2 - TE clean after 45s 3 - TE clean after 60s 4 - TE clean after >60s, cont left after test 5 - same as 4, plus cont on LE after 45s	-	-	-	1	4.5	5	1	-

Table 4.1: Wind Tunnel Test Log (cont'd)

Test #	SP1	SP2	SP3	7	8	9	SP4	10	11	12	13
Test Objective	IP+S (was S2)	S+IP (was S1)	IP+S (was S4)	IP only	IP only	IP only	S+IP	IP+ZR-(20+5)	ZR+IP(20+5)	ZR+IP(20+5)	Fluid only
Date	20-Feb-07	20-Feb-07	20-Feb-07	22-Feb-07	22-Feb-07	22-Feb-07	22-Feb-07	23-Feb-07	23-Feb-07	23-Feb-07	23-Feb-07
Type IV Fluid	PG	PG	EG	PG	EG (06 batch)	PG	PG	PG	PG	EG (06 batch)	PG
Test Area [m2]	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7	3.7
Ice Pellet size [mm]	1.3 to 4	1.3 to 4	1.3 to 4	1.3 to 4	1.3 to 4	1.3 to 4	1.3 to 4	1.3 to 4	1.3 to 4	1.3 to 4	none
Duration of Precipitation (min)	40	40	40	60	60	30	30	40	40	40	none
Endurance Time on Plate (min)	cannot call failure due to definition	cannot call failure due to definition	cannot call failure due to definition	cannot call failure due to definition	cannot call failure due to definition	cannot call failure due to definition	cannot call failure due to definition	cannot call failure due to definition	19	40	N/A
Ice Pellet Quantity (kg)	1.2Kg/10min/dispenser*2	0.3Kg/10min/dispenser*	1.2Kg/10min/dispense	1.5 kg/disp/10 min wit	1.5 kg/disp/10 min wit	4.5 kg/disp/10min	1.5Kg/10min/dispenser*	1.2Kg/10min/dispenser*2	0.3Kg/10min/dispenser*2	0.3Kg/10min/dispenser*2	N/A
Effective Ice Pellet Rate (g/dm²/h)	19.5	4.9	19.5	24.3	24.3	73.0	24.3	19.5	4.9	4.9	N/A
Freezing Precip. Type (ZD or ZR-)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	ZR-	ZR-	ZR-	N/A
Freezing Precip. Rate (g/dm²/h)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	6.6	19.8	19.8	N/A
Snow size [mm]	<1.3	<1.3	<1.3	N/A	N/A	N/A	<1.3	N/A	N/A	N/A	N/A
Snow Quantity (kg)	100g/10min/dispenser*4	420g/10min/dispenser*4	100g/10min/dispenser	N/A	N/A	N/A	600g/10min/dispenser*4	N/A	N/A	N/A	N/A
Snow rate (g/dm²/h)	4.3	17.9	4.3	N/A	N/A	N/A	26.1	N/A	N/A	N/A	N/A
Fluid application start time	9:13	11:27	13:50	9:10	11:33	14:13	16:00	9:32	11:50	13:28	15:04
Precipitation end time	10:17	12:28	14:58	10:34	13:03	15:08	16:55	10:25	12:45	14:23	N/A
Tunnel start time	10:36	12:51	15:25	10:51	13:19	15:31	17:14	10:37	12:59	14:38	15:23:10
OAT [°C]	-11.3	-9	-7	-7.5	-6.8	-5.5	-4.7	-11.4	-8.6	-7.5	-7.5
Tunnel OAT [°C]	-2	-3	1.2	1	1	1.5	3.2	-7.2	-1.9	-5.9	-5.7
Average Tunnel OAT from fluid application to start of takeoff run	-2.7	-3.4	-0.3	0.7	-0.3	1.8	1.7	-4.6	-3.1	-3.4	-5.6
Average OAT during last 10 min of precip	-2.6	-5.3	-0.2	1	-0.3	2.5	2.1	-4	-2.7	-2.6	N/A
AverageTunnel OAT from end of precip to start of takeoff run	-2.1	-3.5	0.9	1	0.2	1.5	3.2	-5.5	-2.3	-3.7	N/A
Avg Wing Temp before Run [°C]	-7	-6	-8	-5.5	-9	-8	-7	-7	-4	-4	-5
Angle of Attack (deg) and Rate of Change (initial)	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s	8 in 3s
Ramp time (s) and V_R speed (kts)	35/100	35/100	35/100	35/100	35/100	35/100	35/100	35/100	35/100	35/100	35/100
Rank based on contamination flow off (photo analysis) 1 - TE clean after 30s (rotation) 2 - TE clean after 45s 3 - TE clean after 60s 4 - TE clean after >60s, cont left after test 5 - same as 4, plus cont on LE after 45s	2	1	1	1	1	2.5	2	3	2	1	-

4.1.2 Falcon 20 Test Log

A detailed log of the tests conducted with the Falcon 20 aircraft is shown in Table 4.2. It should be noted that tests #1S and #1P were conducted as part of the "heavy snow" research and therefore are not included in this test log. The "heavy snow" research was documented in an interim report, which was provided to TC and the FAA; a final report is expected to be published once the research is completed. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each column contains data specific to one test. The following is a brief description of the column headings for Table 4.2:

Test #:	Exclusive number identifying each test.
Test Objective:	Test objective describing simulated test condition.
Date:	Date when the test was conducted.
Type IV Fluid:	Type IV aircraft deicing fluid. EG specifies an Ethylene Glycol fluid, and PG specifies a Propylene Glycol fluid.
Test Area (m^2):	Wing section test area, measured in meters squared.
Ice Pellet Size (mm):	Size distribution of manufactured simulated ice pellets, measured in millimeters.
Duration of Precipitation (min.):	Total duration of simulated precipitation condition, recorded in minutes.
Ice Pellet Quantity (kg):	Total quantity of ice pellets applied to test section, measured in kilograms.
Effective Ice Pellet Rate (g/dm^2/h):	Simulated ice pellet precipitation rate, calculated in g/dm^2/h.
Freezing Precip. Type (ZD or ZR-):	Simulated freezing precipitation type (freezing drizzle or light freezing rain) generated from ceiling-mounted sprayer system.
Freezing Precip. Rate (g/dm^2/h):	Simulated freezing precipitation rate, calculated in g/dm^2/h.

Snow Size (mm):	Size distribution of manufactured simulated snow, measured in millimeters.
Snow Quantity (kg):	Total quantity of snow applied to test section, measured in kilograms.
Snow Rate (g/dm²/h):	Simulated snow rate, calculated in g/dm²/h.
Measured rate on LE (g/dm²/h):	Combined rate of precipitation on leading edge of wing test section, measured using a rate pan weighed at set intervals during the test and recorded in g/dm²/h.
Measured rate on TE (g/dm²/h):	Combined rate of precipitation on trailing edge of wing test section, measured using a rate pan weighed at set intervals during the test and recorded in g/dm²/h.
Fluid Application Start Time:	Start of the fluid application, recorded in local time.
Precipitation End Time:	End of the simulated precipitation period, recorded in local time.
Takeoff test start time:	Start of the Falcon 20 aircraft takeoff test, recorded in local time.
OAT at start of test (°C):	Outside air temperature recorded just before the start of the takeoff test, measured in degrees Celsius.
Wind Speed (kts):	Wind speed recorded just before the start of the takeoff test, measured in knots, provided by METAR.
Avg. Wing Temp. before Test (°C):	Average of the wing skin temperature measurements (excluding the under-wing measurement), recorded in degrees Celsius.
Ramp time (s) and VR speed (kts):	Ramp time (measured in seconds) required for the aircraft to accelerate up to the target rotation speed (measured in knots).

Table 4.2: Falcon 20 Test Log

Test #	2s	2p	3s	3p	4s
Test Objective	IP+S	Fluid only with ABC-S	IP+S	Fluid only with ABC-S	Fluid only with ABC-S
Date	27-Feb-07	27-Feb-07	28-Feb-07	28-Feb-07	28-Feb-07
Type IV Fluid	ABC-S	ABC-S	ABC-S	ABC-S	ABC-S
Test Area [m2]	2.7	2.7	2.7	2.7	2.7
Ice Pellet size [mm]	1.3 to 4	none	1.3 to 4	none	none
Duration of Precipitation (min)	30	none	30	none	none
Ice Pellet Quantity (kg)	0.7Kg/10min/dispenser*2 disp	N/A	0.7Kg/10min/dispenser*2 disp	N/A	N/A
Effective Ice Pellet Rate (g/dm²/h)	25.0	N/A	25.0	N/A	N/A
Freezing Precip. Type (ZD or ZR-)	N/A	N/A	N/A	N/A	N/A
Freezing Precip. Rate (g/dm²/h)	N/A	N/A	N/A	N/A	N/A
Snow size [mm]	<1.3	N/A	<1.3	N/A	N/A
Snow Quantity (kg)	0.7Kg/10min/dispenser*2 disp	N/A	0.7Kg/10min/dispenser*2 disp	N/A	N/A
Snow rate (g/dm^2/h)	25.0	N/A	25.0	N/A	N/A
Measured rate on LE (g/dm^2/h)	41	N/A	35	N/A	N/A
Measured rate on TE (g/dm^2/h)	44	N/A	21	N/A	N/A
Fluid application start time	9:01	9:07	5:18	5:08	7:43
Precipitation end time	9:54	N/A	6:25	N/A	N/A
Takeoff run start time	aborted	aborted	7:01	7:01	9:27
OAT at start of test [C]	-8	-8	-8	-8	-10
wind speed kts	calm	calm	9	9	13
Avg Wing Temp before Run [°C]	aborted	aborted	-11	-10.5	-6
Ramp time (s) and VR speed (kts)	25/120	25/120	25/120	25/120	25/120

Table 4.2: Falcon 20 Test Log (cont'd)

Test #	4p	5s	5p	6s	6p
Test Objective	ZR-/IP with ABC-S	Fluid only with Ultra+	S+IP	Fluid only with Ultra+	ZR-/IP with Ultra+
Date	28-Feb-07	1-Mar-07	1-Mar-07	1-Mar-07	1-Mar-07
Type IV Fluid	ABC-S	Ultra+ (last yrs batch)	ABC-S	Ultra+ (last yrs batch)	Ultra+ (new batch)
Test Area [m2]	2.7	2.7	2.7	2.7	2.7
Ice Pellet size [mm]	1.3 to 4	none	1.3 to 4	none	1.3 to 4
Duration of Precipitation (min)	40	none	30	none	30
Ice Pellet Quantity (kg)	0.15Kg/10min/dispenser*2 disp	N/A	0.15Kg/10min/dispenser*2 disp	N/A	0.15Kg/10min/dispenser*2 disp
Effective Ice Pellet Rate (g/dm²/h)	5.0	N/A	20.0	N/A	5.0
Freezing Precip. Type (ZD or ZR-)	ZR-	N/A	N/A	N/A	ZR-
Freezing Precip. Rate (g/dm²/h)	20.0	N/A	N/A	N/A	20.0
Snow size [mm]	N/A	N/A	<1.3	N/A	N/A
Snow Quantity (kg)	N/A	N/A	0.6Kg/10min/dispenser*2 disp	N/A	N/A
Snow rate (g/dm^2/h)	N/A	N/A	20.0	N/A	N/A
Measured rate on LE (g/dm^2/h)	19	N/A	24	N/A	45
Measured rate on TE (g/dm^2/h)	19.5	N/A	29	N/A	39
Fluid application start time	7:49	5:12	5:01	7:28	7:20
Precipitation end time	8:51	N/A	6:08	N/A	8:25
Takeoff run start time	9:27	6:52	6:52	8:59	8:59
OAT at start of test [C]	-10	-11	-11	-11	-11
wind speed kts	13	6	6	7	7
Avg Wing Temp before Run [°C]	-6	-14	-13	-3	-4
Ramp time (s) and VR speed (kts)	25/120	25/120	25/120	25/120	25/120

4.2 Precipitation Rate Measurement and Calibration

4.2.1 Ice Pellets and Snow

APS conducted testing to determine the efficiency of the ice pellet dispensers. Calibration work was conducted at the APS test site situated at the Pierre-Elliot Trudeau International Airport in Montreal using surfaces representative of the wind tunnel test wing, as well as the designated test section of the Falcon 20 aircraft wing.

It was found that the distribution efficiency of the dispensing system varied depending on the surface dimensions. As a result, a dispensing efficiency rate was calculated for the NACA 23012 wing section dimensions, as well as for the Falcon 20 test section dimensions. It was estimated that the dispensing efficiency on the NACA 23012 wing section was approximately 50 percent, whereas for the Falcon 20 test section, the dispensing efficiency was approximately 80 percent. The difference in efficiencies for the two test surfaces was largely due to the chord length of the NACA 23012 wing section versus the Falcon 20 test section. The NACA 23012 wing chord was less than half the length of the Falcon 20 chord; therefore, a significant amount of snow and ice pellets were lost as a result of overspray.

Dispensing was done by placing known quantities of simulated ice pellets or snow into the dispensing bucket, and allowing the dispenser to completely empty the contents over a set period of time (usually 10 minutes). The dispensers were re-filled every 10 minutes for the duration of the test. The calculated efficiencies were accounted for when weighing the required amounts of ice pellets and snow.

4.2.2 Freezing Rain Dispenser

The ceiling-mounted freezing rain sprayer used for the wind tunnel tests was equipped with a flow meter to monitor and control the volume of water being dispensed by the sprayer head. Calibration work was done by APS in conjunction with the NRC to correlate the flow meter readings to actual rates of precipitation measured using the standard rate pan method; pans were distributed evenly over the surface of the wing and weighed before and after exposure to precipitation. Consequently, the rate of precipitation on the wing section could be controlled by limiting or increasing the water supply to the sprayer head. The repeatability of the system was found to be acceptable; however, spot checks using one pan were done prior to running a test to ensure accurate precipitation rates.

For the Falcon 20 tests, a mobile sprayer unit was used to produce freezing rain. The equipment was similar, with the main difference being that the sprayer head was hand-held (rather than ceiling-mounted) and had to be directed and aimed manually (rather than controlled by a servo-motor). Calibration work was done using the actual Falcon 20 aircraft; collection pans were placed on the test surface, and the recorded rates of precipitation were calibrated against the system pressure readings. The repeatability of the system was found to be acceptable; however, spot checks using one pan were done prior to and during the tests.

4.2.3 Definition of Precipitation Rates

When simulating precipitation rates for full-scale and plate testing, the rate limits defined for standard HOT testing were referenced. Figure 4.1 demonstrates the HOT testing precipitation rate breakdown.

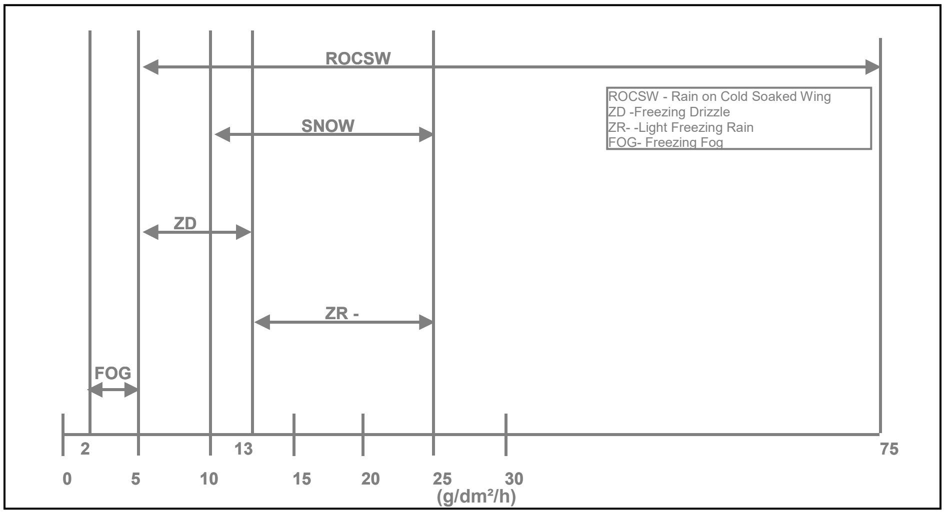

Figure 4.1: Precipitation Rate Breakdown

HOT testing protocol for ice pellets does not currently exist. As a result, ice pellet precipitation rate limits were based upon the freezing rain rate breakdown. The following precipitation rates were used for the full-scale and flat plate testing conducted during the winter of 2006-07:

Light Ice Pellets:	13-25 g/dm^2/h
Moderate Ice Pellets:	25-75 g/dm^2/h
Light Freezing Rain:	13-25 g/dm^2/h
Light Freezing Drizzle:	5-13 g/dm^2/h
Light Rain:	13-25 g/dm^2/h
Snow (Moderate):	10-25 g/dm^2/h

4.3 Wind Tunnel Temperature

4.3.1 Variation between OAT and Wind Tunnel Temperatures

The wind tunnel test area is enclosed in the wind tunnel building. The test temperature inside the wind tunnel is one of the critical parameters of the testing. The tunnel temperature is not a controlled variable because it depends on the OAT, outside sky conditions, and solar radiation, as well as the temperature inside the wind tunnel building. It is essential to maintain the air temperature inside the tunnel below freezing at all times during preparation and testing. The temperature inside the wind tunnel test area increases during the preparation of a typical wind tunnel test when workers are emanating heat in this area. The temperature inside the wind tunnel can be lowered by leaving the wind tunnel doors open and thus permitting the outside air to circulate through the tunnel. However, the outside airflow reduces the effectiveness of freezing precipitation dispersion over the test area.

In general, the wind tunnel test area was warmer than the OAT, on average, by 7°C. The average OAT during all 2006-07 wind tunnel tests was -9.5°C, while the average wind tunnel air temperature was -2.8°C.

It is recommended to forecast the weather and plan wind tunnel tests when the OAT is below -8°C. This parameter becomes even more critical if sunny weather is present. In 2006-07, extreme cases occurred when the tunnel air temperature was up to 13°C above the OAT.

4.3.2 Wind Tunnel Air Temperature Analysis

The air temperature inside the wind tunnel was monitored and logged by NRC personnel. The data was analysed in order to characterize the test temperature of each wind tunnel test. The data is presented in Figures 4.2 and 4.3.

Four temperature parameters were considered in the analysis:

- Instantaneous tunnel air temperature before test;
- Average tunnel air temperature during last 10 minutes of precipitation;
- Average tunnel air temperature from fluid application to start of takeoff test; and
- Average tunnel air temperature from end of precipitation to start of takeoff test.

The analysis showed that the instantaneous tunnel air temperature value might not be the correct temperature to be associated with the test. The temperature inside the wind tunnel varied considerably throughout the test. Also, the critical time of the precipitation phase takes place usually during the last minutes of precipitation when the fluid is failing. Therefore, a better and more conservative alternative is to consider the average air temperature in the wind tunnel during the last 10 minutes of precipitation as the reference temperature for a typical test. This temperature value is usually one of the highest and hence most conservative temperatures considered, as shown in Figures 4.2 and 4.3. This temperature measurement will be used for the analysis of the wind tunnel test for the remainder of this report.

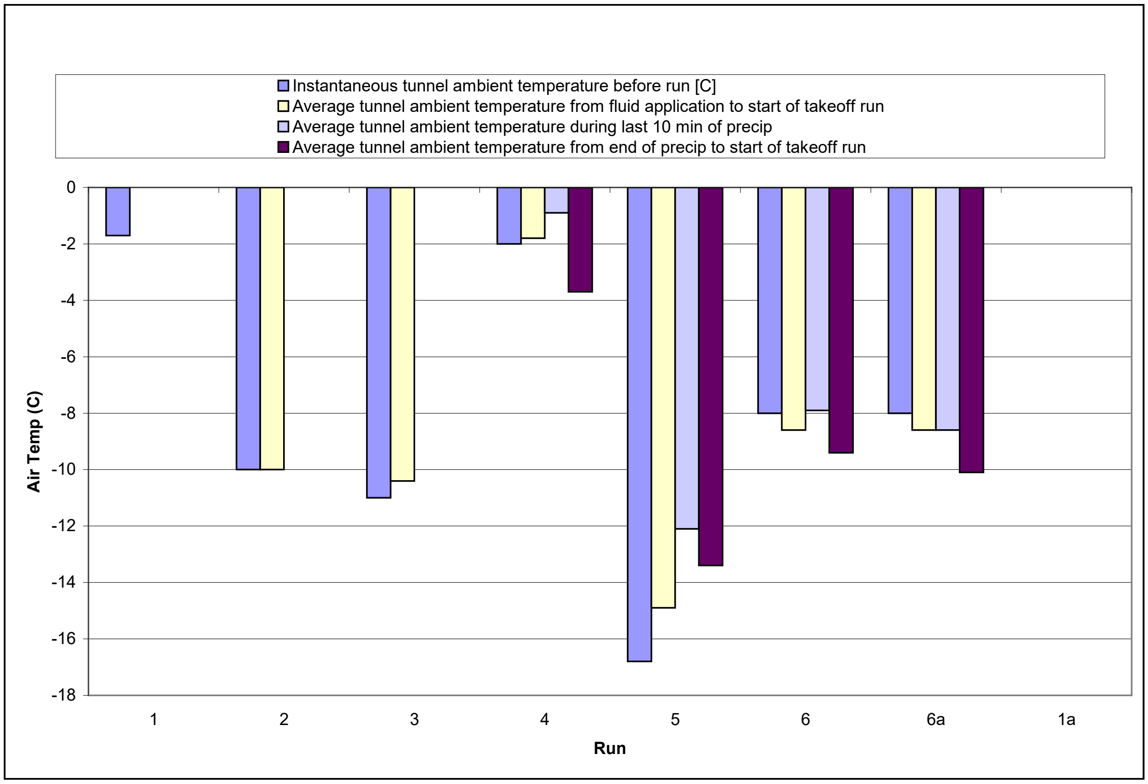

Figure 4.2: Wind Tunnel Temperature Analysis Chart for Test 1 to Test 1a

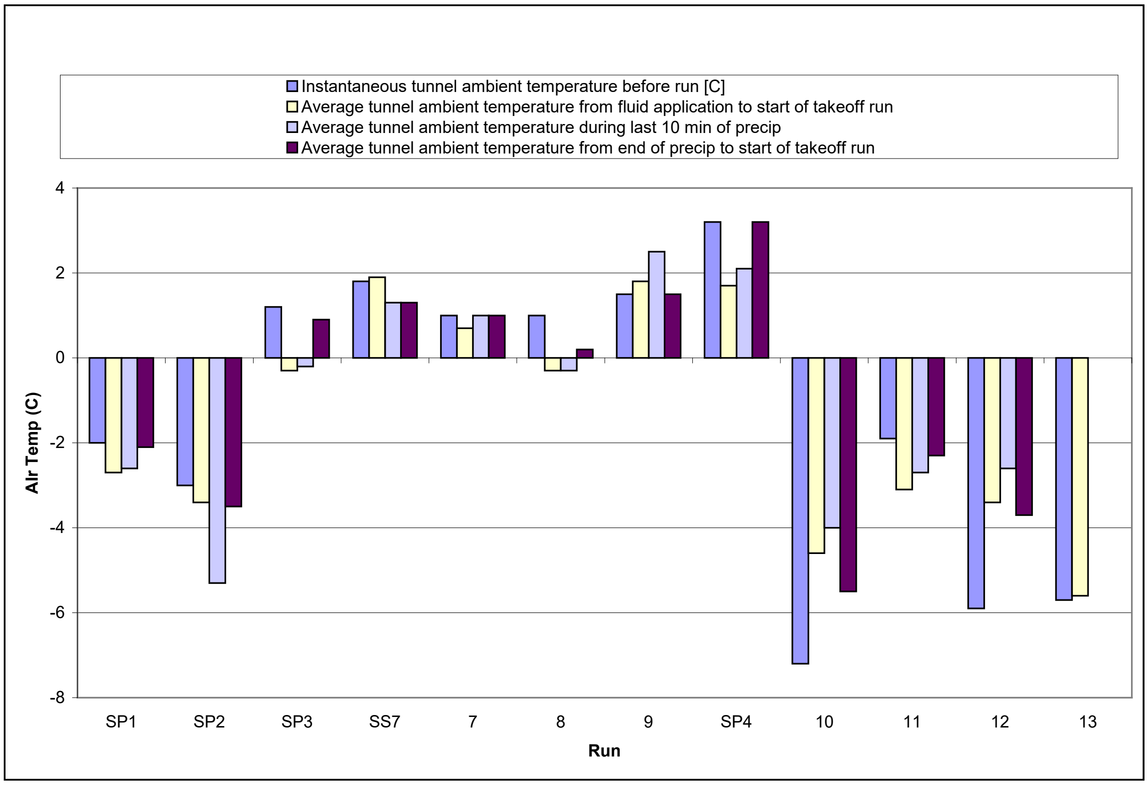

Figure 4.3: Wind Tunnel Temperature Analysis Chart for Test SP1 to Test 13

4.4 Wing Skin Temperature Analysis

The wing skin temperature was measured at three locations during the different phases of a typical wind tunnel test:

- On the leading edge;
- Mid-chord; and
- Under the wing.

A similar analysis to the air temperature study presented in Subsection 4.3.2 was conducted to select the proper wing skin temperature associated with each test. The results are shown in Figures 4.4 and 4.5. For this purpose, three parameters were compared:

- Approximate average wing temperature before test (average of the measurements recorded on the top surface of the wing);
- Approximate leading edge temperature before test; and
- Approximate under-wing temperature before test.

It was noted that the average wing skin and the leading edge temperatures were close for all tests. Therefore, the average wing skin temperature parameter can be associated with the reference wing skin temperature for each wind tunnel test.

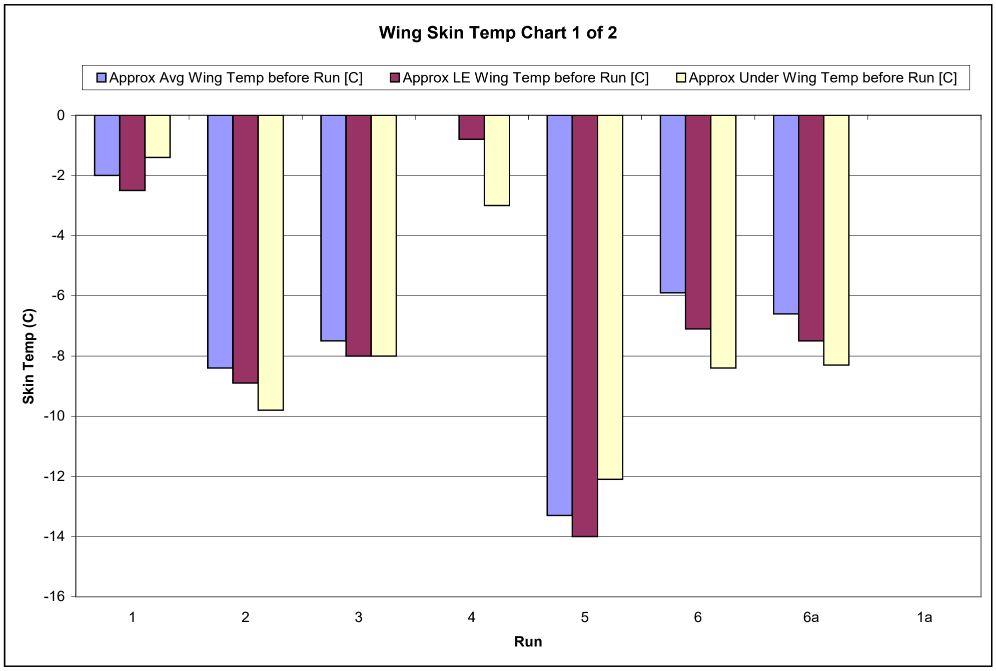

Figure 4.4: Wing Skin Temperature Analysis Chart for Test 1 to Test 1a

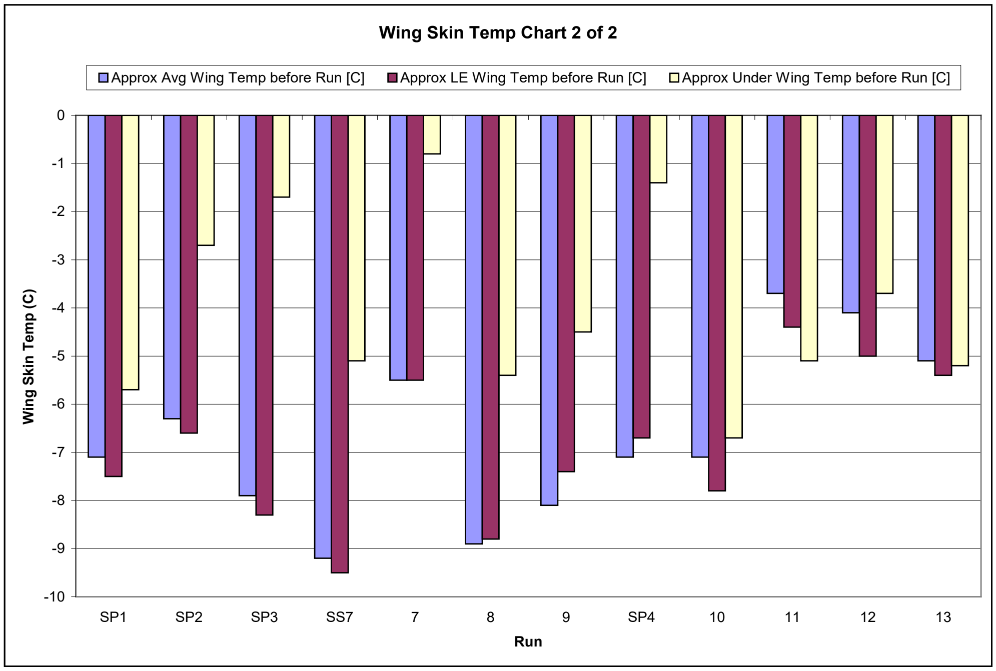

Figure 4.5: Wing Skin Temperature Analysis Chart for Test SP1 to Test 13

4.5 Photo and Video Recording

4.5.1 Wind Tunnel Photo and Video Recording

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 can take up to three pictures per second in continuous shooting mode. The cameras had two different lenses available:

a) 18-55 mm standard lens for wide angle pictures; and

b) 105 mm macro lens for close-ups (not used in 2006-07).

Digital still cameras were used to record visual observations of the testing. To create a consistent and stable setup for the cameras, APS mounted the cameras in the observation window overlooking the wing section. The flashes, operated through infrared sensors, were positioned in the opposing observation window (Figure 4.6); this created a shadow effect that could be used to measure and calculate the magnitude of the fluid waves and protruding contamination. Video cameras, operated by NRC personnel, were positioned directly above the wing section. The cameras were zoomed in to observe the behaviour of the fluid and contamination on the wing.

In addition, a professional photographer used a digital still camera to take pictures of the test setup and all phases of the tests.

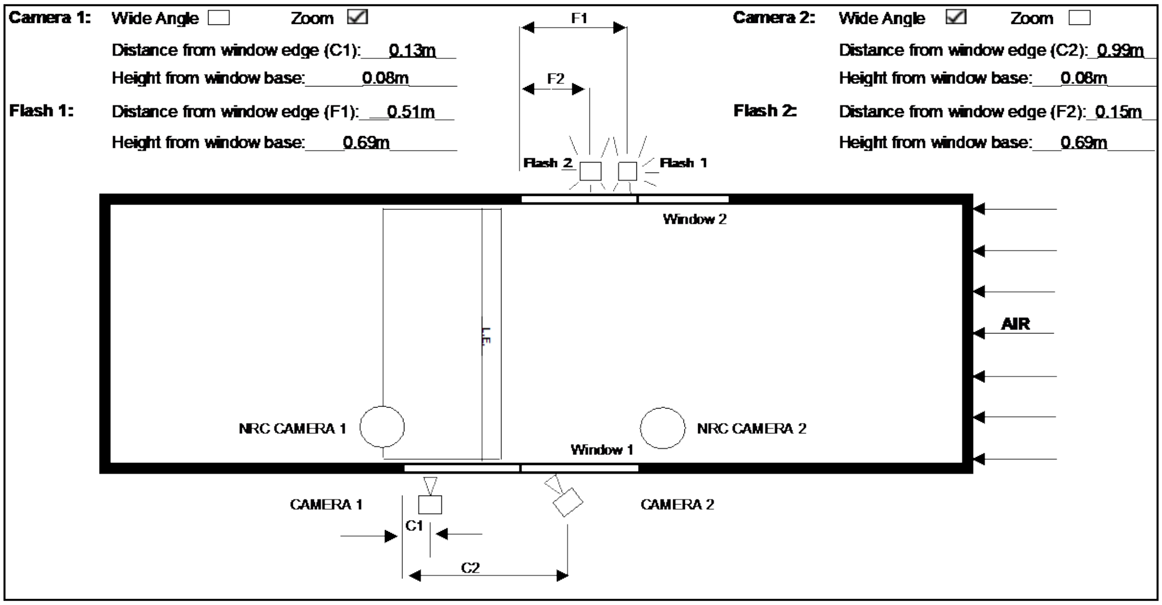

Figure 4.6: Wind Tunnel Camera and Flash Setup

4.5.2 Falcon 20 Camera Setup

Two Canon Digital Rebel XT SLR (single lens reflex) digital still cameras were used to obtain high-speed, high-resolution photographs of the testing. The cameras are described in Subsection 4.5.

Digital still cameras were used to record visual observations of the testing. To create a consistent and stable setup for the cameras, NRC personnel replaced the emergency doors overlooking the wing and the test area with removable hatches. Each hatch had two standard tripod mounts and a removable Plexiglas window. NRC personnel used one mount for a digital high-definition video camera, and APS personnel used the second mount for a digital still camera.

It must be noted that the camera-mounting space is limited and does not allow the mounting of two SLR still cameras. Also, the two hatches are not airworthy and cannot be used in testing involving actual aircraft takeoff.

In addition, a professional photographer used a digital still camera to take pictures of the test setup and all phases of the tests.

4.6 Wing to Plate Failure Correlation

In an effort to correlate the fluid failure (or condition) observed on a wing to that on a test plate, a setup was used during the wind tunnel tests to collect some preliminary data. A standard HOT test plate fitted with adjustable rubber feet was mounted onto the leading edge of the NACA 23012 wing section. The test plate was inclined at 10º and was anti-iced at the time of fluid application at the start of each wind tunnel test. The test plate was exposed to the same mixed conditions with ice pellets. The plate fluid condition was recorded at the end of each test. The completed data forms for each test are included in Appendix I.

In general, bridging precipitation and adherence was observed on the test plate prior to becoming visible on the wing section. This indicates that the test plate methodology allows for a conservative estimate of the wing condition under mixed conditions with ice pellets. It is recommended that wing to plate correlation work be continued in the 2007-08 test season.

Wing to plate failure correlation was not conducted for the Falcon 20 tests; however, the condition of the wing was documented at the end of each test. Completed data forms are included in Appendix J.

4.7 Test Sequence

For both the wind tunnel and the Falcon 20 tests, the test sequence followed the same critical path. The length of each test (from start of setup to end of last measurement) varied largely due to the length of exposure to precipitation. Time required for setup and teardown as well as preparing and configuring the wind tunnel and Falcon 20 aircraft stayed relatively the same from test to test. Figure 4.7 demonstrates a sample timeline for a typical wind tunnel test. Figure 4.8 demonstrates a sample timeline for a typical Falcon 20 test. It should be noted that in both figures, a precipitation exposure time of 60 minutes was used for demonstration purposes; this varied for each test depending on the objective. Completed data forms of the time record of operations during the Falcon 20 tests are included in Appendix K.

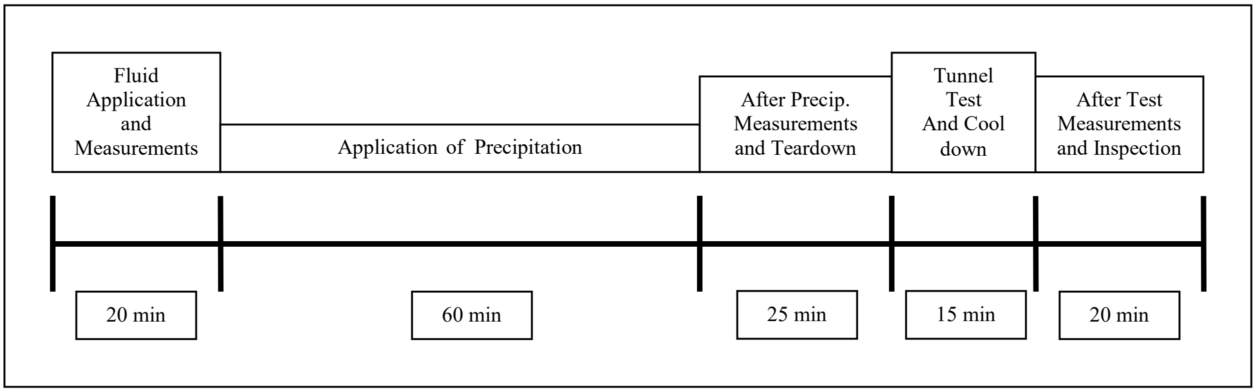

Figure 4.7: Typical Wind Tunnel Test Timeline

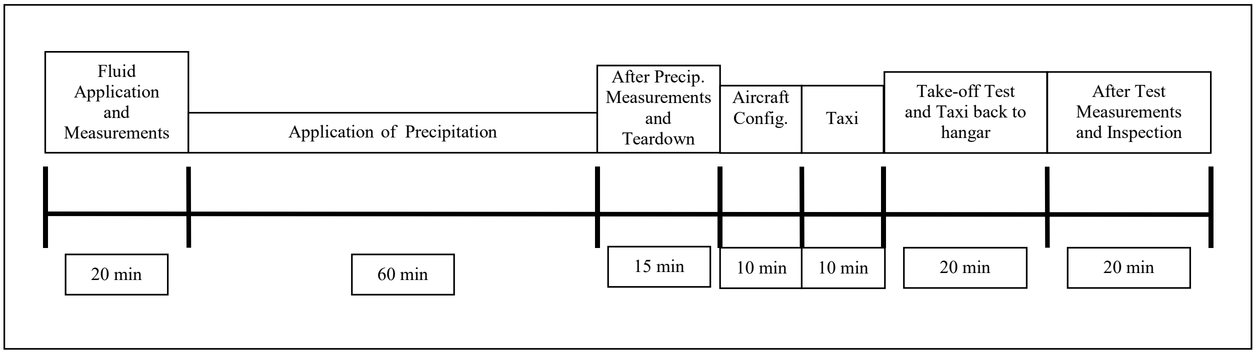

Figure 4.8: Typical Falcon 20 Test Timeline

4.8 Analysis

A working group meeting was held April 11-13, 2007. The attendees were representatives from TC, the FAA, and APS. The objective of the meeting was to review the current data collected and to recommend allowance times for mixed precipitation conditions with ice pellets. The data collected in the wind tunnel and with the Falcon 20 aircraft during the winters of 2005-06 and 2006-07 was analysed. Section 5 to Section 8 contain the data used for the analysis as well as a brief review of the methodology used. As data was limited, assumptions were made based on the information available.

The working group meeting prepared a series of conclusions and recommendations derived from the data collected during the winter of 2006-07. These recommendations have been included in the 2007-08 HOT Guidelines. Guidance material for operations in ice pellet conditions has been issued in the form of an "Ice Pellet Allowance Time Table" followed by a list of conditions restricting operations to specific meteorological and operational conditions. Section 10 documents the recommended guidance material.

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5. BASELINE TESTING

This section provides an overview of each test conducted to establish a baseline (for fluid only and dry wing) against which the effects of ice pellets on the flow-off properties of contaminated fluid can be objectively measured. The parameters for each test are detailed, and a description of the data collected during each test is provided.

5.1 Overview of Tests

A summary of the baseline tests conducted in the wind tunnel is shown in Table 5.1. A summary of the baseline tests conducted using the Falcon 20 aircraft is shown in Table 5.2. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. More detailed test logs of all conditions tested in the wind tunnel and using the Falcon 20 aircraft are provided in Subsections 4.1 and 4.2. The following is a brief description of the column headings for Table 5.1:

Test #:	Exclusive number identifying each test.
Date:	Date when the test was conducted.
Type IV Fluid:	Type IV aircraft deicing fluid. EG specifies an Ethylene Glycol fluid, and PG specifies a Propylene Glycol fluid.
Condition:	Simulated precipitation condition.
ZR Rate ($g/dm^2/h$):	Average simulated freezing rain precipitation rate, measured in $g/dm^2/h$.
IP Rate ($g/dm^2/h$):	Average simulated ice pellet precipitation rate, measured in $g/dm^2/h$.
SN Rate ($g/dm^2/h$):	Average simulated snow precipitation rate, measured in $g/dm^2/h$.
Precip. Time:	Total time of exposure to simulated precipitation.
Last 10 min. AVG OAT *(Wind Tunnel tests)*:	Average tunnel air temperature recorded during the last 10 minutes of precipitation application, measured in degrees Celsius.

OAT *(Falcon 20 tests)*:	The outside air temperature prior to the start of the simulated takeoff test, measured in degrees Celsius.
Wing Avg. Temp (ºC):	Average wing skin temperature, measured in degrees Celsius.
Visual Severity Rating (1-5) *(Wind Tunnel tests)*:	Rank based on contamination flow-off (photo analysis): 1-Trailing edge clean after 30 s (rotation); 2-Trailing edge clean after 45 s; 3-Trailing edge clean after 60 s; 4-Trailing edge clean after >60 s, contamination left after test; and 5-Same as 4, plus contamination on leading edge after 45 s.

Table 5.1: Summary of 2006-07 Baseline Testing in the NRC Wind Tunnel

Test #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precp. Time (min)	Last 10 min AVG OAT (ºC)	Wing Avg Temp (ºC)	Visual Severity Rating (1-5)
1	14-Feb-07	Dry	Dry	0	0	0	-	-1.7	-2	-
1A	16-Feb-07	Dry	Dry	0	0	0	-	-7	N/A	-
2	14-Feb-07	PG	Baseline	0	0	0	-	-10	-9	-
3	14-Feb-07	EG	Baseline	0	0	0	-	-11	-8	-
13	23-Feb-07	Dry	Baseline	0	0	0	-	-5.7	-5	-

Table 5.2: Summary of 2006-07 Baseline Testing with Falcon 20 Aircraft

Test #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precp. Time (min)	OAT (ºC)	Wing Avg Temp (ºC)
2P*	27-Feb-07	PG	Baseline	-	-	-	-	-8	-
3P	28-Feb-07	PG	Baseline	-	-	-	-	-8	-10.5
4S	28-Feb-07	PG	Baseline	-	-	-	-	-10	-6
5S	1-Mar-07	EG	Baseline	-	-	-	-	-11	-14
6S	1-Mar-01	EG	Baseline	-	-	-	-	-11	-3

*Test aborted

5.2 Data Collected

5.2.1 Coefficient of Lift Curves

Dry wing testing was conducted to determine the lift characteristics of the NACA 23012 wing section. The lift data collected would become the baseline test profile to be used as a comparative data point for all other fluid tests. In addition, fluid only testing was conducted.

Drag and lift data collected by the NRC in the wind tunnel was used to generate lift coefficient curves for each of the tests conducted in the wind tunnel. Figures 5.1 and 5.2 show the lift coefficient data for Test #1 and Test #1a conducted with a dry wing. Figures 5.3 to 5.5 show the lift coefficient data for Test #2, Test #3, and Test #13 conducted with fluid only. The x-axis indicates the time in seconds as of the start of rotation. The y-axis indicates the Cn (normal force coefficient) and Cl (lift coefficient) calculated from the data collected.

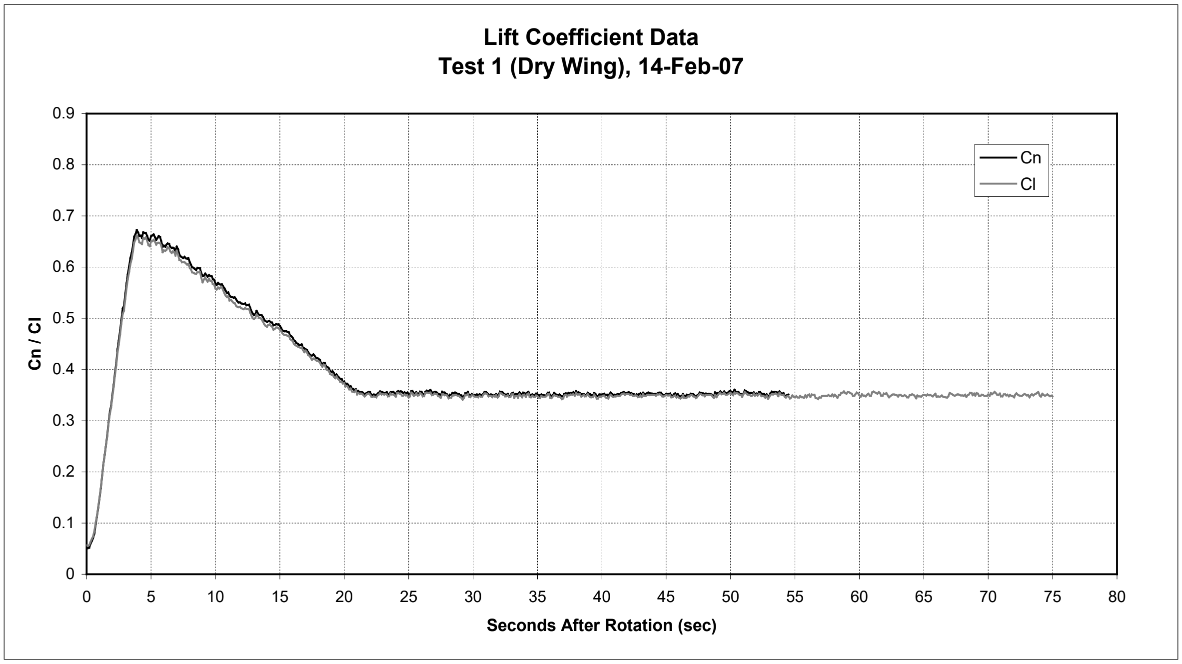

Figure 5.1: Test #1 Lift Coefficient Data

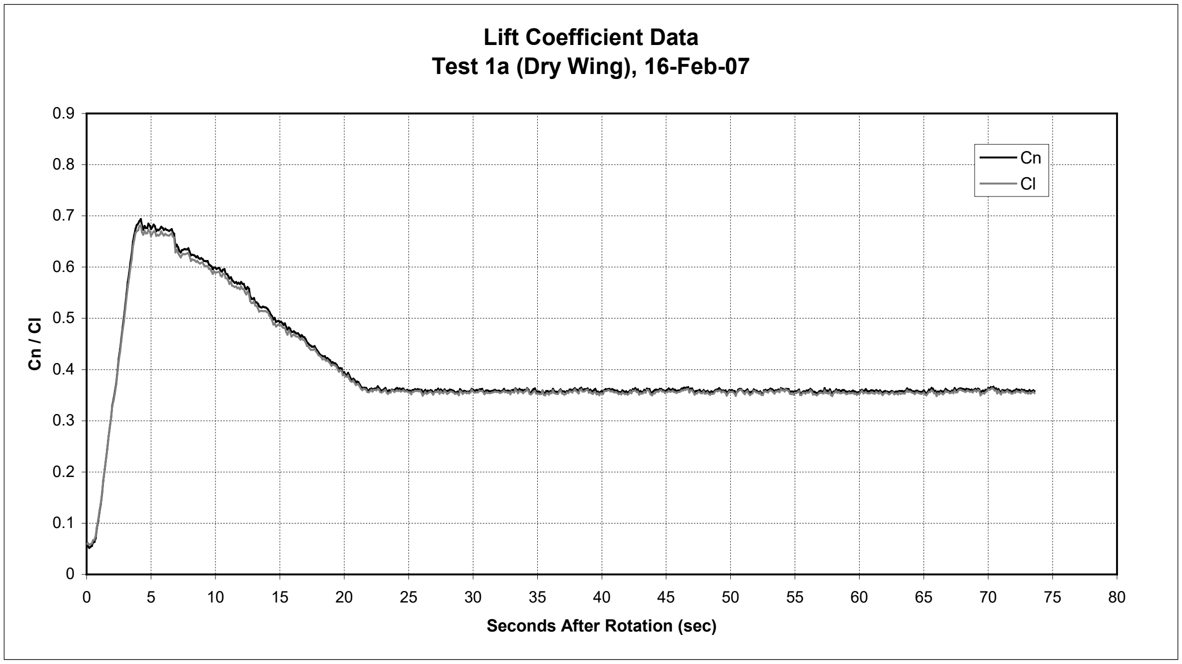

Figure 5.2: Test #1a Lift Coefficient Data

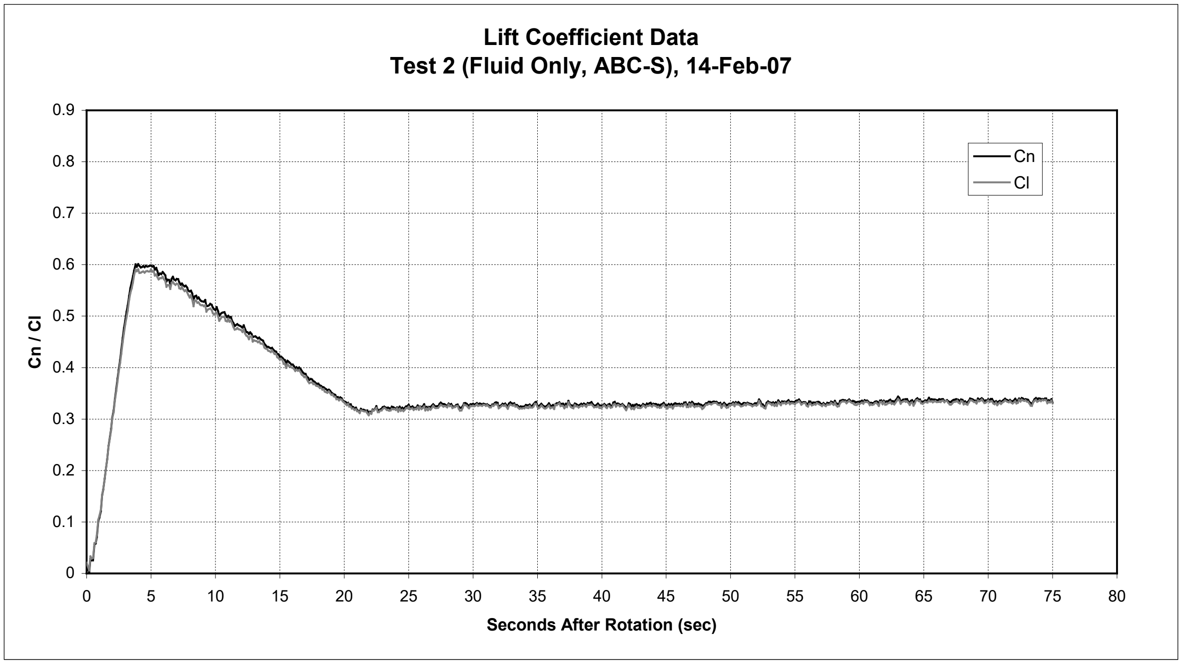

Figure 5.3: Test #2 Lift Coefficient Data

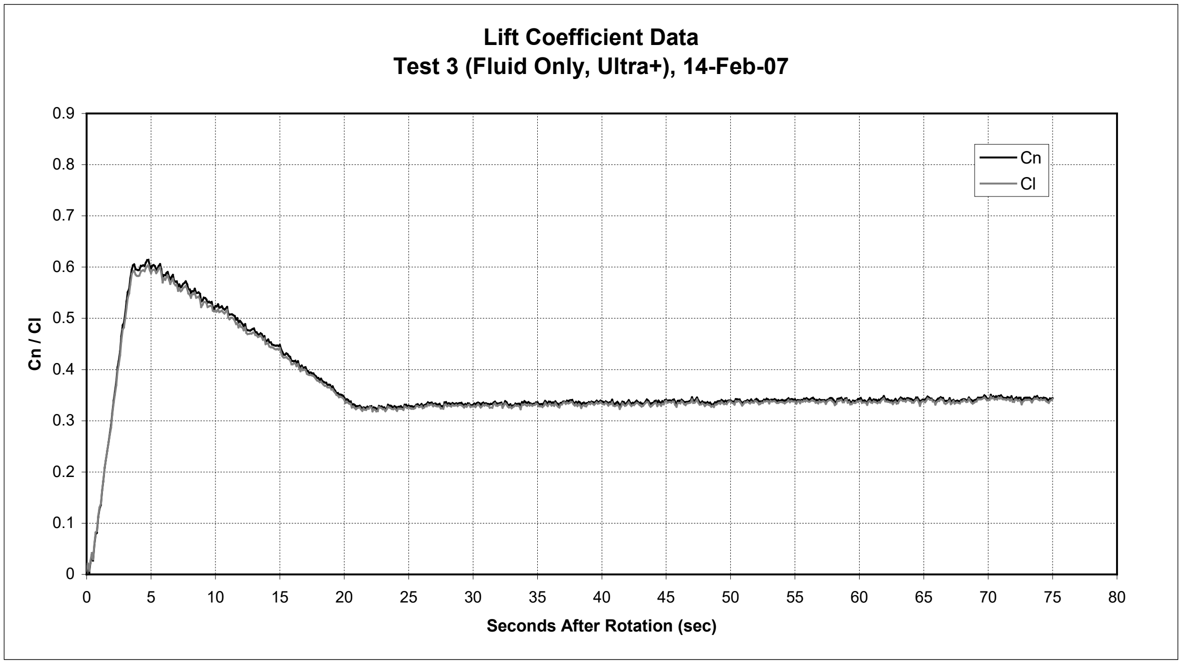

Figure 5.4: Test #3 Lift Coefficient Data

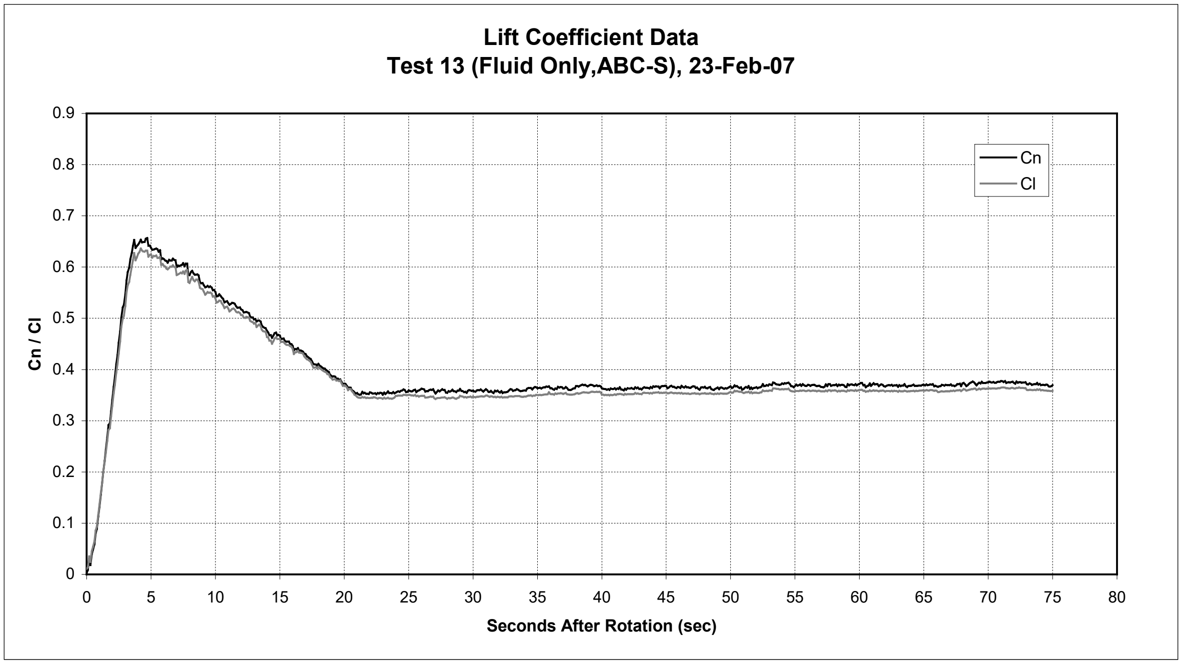

Figure 5.5: Test #13 Lift Coefficient Data

5.2.2 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.1 and 2.2.9.1. Fluid thickness measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 5.3 to 5.10 show the fluid thickness measurements collected during the tests. Tests #1 and #1a are not shown here as they were conducted on dry wings.

Table 5.3: Test #2 Fluid Thickness Data

TEST 2: ABC-S, fluid only			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.1	N/A	0.1
2	3.1	N/A	0.1
3	3.9	N/A	0.1
4	3.1	N/A	0.2
5	2.5	N/A	0.2
6	2.5	N/A	0.2
7	2.2	N/A	0.2
8	1.2	N/A	0.4

Table 5.4: Test #3 Fluid Thickness Data

TEST 3: Ultra+, fluid only			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.2	N/A	0.0
2	4.5	N/A	0.1
3	5.7	N/A	0.1
4	4.5	N/A	0.1
5	3.3	N/A	0.1
6	3.5	N/A	0.2
7	3.1	N/A	0.2
8	2.2	N/A	0.6

Table 5.5: Test #13 Fluid Thickness Data

TEST 13: ABC-S, fluid only			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.1	N/A	0.0
2	3.1	N/A	0.0
3	5.7	N/A	0.0
4	3.3	N/A	0.1
5	2.9	N/A	0.2
6	2.7	N/A	0.2
7	2.7	N/A	0.3
8	2.2	N/A	0.5

Table 5.6: Test #2P Fluid Thickness Data

TEST 2P: ABC-S, fluid only				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	0.8	0.7	N/A	N/A
2	1.6	1.3	N/A	N/A
5	3.5	3.1	N/A	N/A
7	1.1	1.5	N/A	N/A
8	1.8	0.7	N/A	N/A

Table 5.7: Test #3P Fluid Thickness Data

TEST 3P: ABC-S, fluid only				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	0.7	N/A	0.1
2	1.7	1.2	N/A	0.2
5	3.5	3.1	N/A	0.2
7	2.2	1.6	N/A	0.2
8	1.6	0.7	N/A	0.2

Table 5.8: Test #4S Fluid Thickness Data

TEST 4: ABC-S, fluid only				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	0.5	N/A	N/A	0.0
2	1.7	N/A	N/A	0.0
5	3.3	N/A	N/A	0.2
7	1.5	N/A	N/A	0.3
8	0.7	N/A	N/A	0.2

Table 5.9: Test #5S Fluid Thickness Data

TEST 5S: Ultra+, fluid only				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	0.8	N/A	0.1
2	2.2	1.8	N/A	0.2
5	4.5	4.5	N/A	0.2
7	2.2	2.2	N/A	0.2
8	2.2	2.2	N/A	0.2

Table 5.10: Test #6S Fluid Thickness Data

TEST 6S: Ultra+, fluid only				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	0.8	N/A	0.0
2	2.2	1.8	N/A	0.1
5	3.7	3.3	N/A	0.2
7	2.5	2.2	N/A	0.2
8	1.2	1.0	N/A	0.2

5.2.3 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.3 and 2.2.9.3. Skin temperature measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 5.11 to 5.19. Skin temperature measurements were not conducted during Test #1a.

Table 5.11: Test #1 Skin Temperature Data

TEST 1: Dry			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	3.1	N/A	0.1
5	2.5	N/A	0.2
Under-wing	1.2	N/A	0.4

Table 5.12: Test #2 Skin Temperature Data

TEST 2: ABC-S, fluid only			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-6.0	N/A	-7.5
5	-4.5	N/A	-6.2
Under-wing	-7.6	N/A	-8.8

Table 5.13: Test #3 Skin Temperature Data

TEST 3: Ultra+, fluid only			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-8.0	N/A	-6.9
5	-7.0	N/A	-5.8
Under-wing	-8.0	N/A	-8.3

Table 5.14: Test #13 Skin Temperature Data

TEST 13: ABC-S, fluid only			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-5.4	N/A	-4.3
5	-4.7	N/A	-3.9
Under-wing	-5.2	N/A	-4.7

Table 5.15: Test #2P Skin Temperature Data

TEST 2P: ABC-S, fluid only				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-5.2	10.2	N/A	N/A
2	-3.8	-9.3	N/A	N/A
3	-3.1	11.1	N/A	N/A
4	-1.6	8.3	N/A	N/A
5	-0.8	7.0	N/A	N/A
6	-3.0	2.0	N/A	N/A
7	1.4	3.5	N/A	N/A
8	0.5	4.0	N/A	N/A

Table 5.16: Test #3P Skin Temperature Data

TEST 3P: ABC-S, fluid only				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-9.6	-11.1	N/A	-9.8
2	-9.5	-11.1	N/A	-9.8
3	-8.6	-11.1	N/A	-10.1
4	-9.0	-11.1	N/A	-10.3
5	-7.8	-10.8	N/A	-9.6
6	-7.8	-10.3	N/A	-9.2
7	-9.0	-11.8	N/A	-8.7
8	-9.1	-11.7	N/A	-9.2

Table 5.17: Test #4S Skin Temperature Data

TEST 4S: ABC-S, fluid only				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-8.3	N/A	N/A	5.5
2	-8.3	N/A	N/A	4.8
3	-7.3	N/A	N/A	1.8
4	-7.0	N/A	N/A	0.5
5	-6.6	N/A	N/A	-4.0
6	-6.1	N/A	N/A	-3.8
7	-3.3	N/A	N/A	-5.9
8	-3.2	N/A	N/A	-5.7

Table 5.18: Test #5S Skin Temperature Data

TEST 5S: Ultra+, fluid only				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-12.0	-13.0	N/A	-8.7
2	-12.1	-13.1	N/A	-8.5
3	-11.7	-13.5	N/A	-11.0
4	-11.6	-13.6	N/A	-11.2
5	-10.2	-13.1	N/A	-12.5
6	-10.1	-13.0	N/A	-12.8
7	-12.7	-15.1	N/A	-12.7
8	-12.8	-14.9	N/A	-12.7

Table 5.19: Test #6S Skin Temperature Data

TEST 6S: Ultra+, fluid only				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-3.6	2.5	N/A	1.9
2	-3.7	0.2	N/A	0.7
3	-6.4	-0.4	N/A	0.9
4	-6.1	-0.5	N/A	-0.1
5	-6.6	-4.2	N/A	-4.9
6	-6.4	-3.7	N/A	-3.8
7	-7.9	-8.8	N/A	-6.4
8	-7.1	-8.5	N/A	-6.0

5.2.4 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.2 and 2.2.9.2. Fluid Brix measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Approximately 5 minutes after fluid application; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 5.20 to 5.27 show the fluid Brix measurements collected during the test. Tests #1 and #1a are not shown here as they were conducted on dry wings.

Table 5.20: Test #2 Fluid Brix Data

TEST 2: ABC-S, fluid only			
Wing Position	Fluid Brix (°)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.50	N/A	36.75
8	37.50	N/A	37.75

Table 5.21: Test #3 Fluid Brix Data

TEST 3: Ultra+, fluid only			
Wing Position	Fluid Brix (°)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	40.25	N/A	N/A
8	40.50	N/A	38.25

Table 5.22: Test #13 Fluid Brix Data

TEST 13: ABC-S, fluid only			
Wing Position	Fluid Brix (°)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.50	N/A	43.50
8	37.50	N/A	40.00

Table 5.23: Test #2P Fluid Brix Data

TEST 2P: ABC-S, fluid only				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	37.50	N/A	N/A
5	37.00	37.00	N/A	N/A

Table 5.24: Test #3P Fluid Brix Data

TEST 3P: ABC-S, fluid only				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	37.00	N/A	38.50
5	37.00	37.00	N/A	34.00

Table 5.25: Test #4S Fluid Brix Data

TEST 4S: ABC-S, fluid only				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	N/A	N/A	N/A
5	37.00	N/A	N/A	N/A

Table 5.26: Test #5S Fluid Brix Data

TEST 5S: Ultra+, fluid only				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	41.50	41.50	N/A	41.00
5	41.50	41.00	N/A	41.00

Table 5.27: Test #6S Fluid Brix Data

TEST 6S: Ultra+, fluid only				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	41.00	41.00	N/A	49.00
5	41.00	41.00	N/A	43.00

5.3 Photos

High-speed digital photography of each test was taken. Photos of both the leading edge and trailing edge are shown. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Time of rotation;
- 10 seconds after rotation; and
- End of test.

Photos 5.1 to 5.27 show the photo summaries for Tests #2, #3, and #13, as well as Falcon 20 Tests #3P, 4S, 5S, and 6S. Test #2P is not shown since the test was aborted. A compilation of selected high-speed photos taken during Test 2 are included Appendix L. A complete set of photos will be provided to the TDC.

5.4 Results

Baseline testing conducted in the wind tunnel demonstrated a lift loss when comparing the fluid only test to a dry wing test. The lift loss was a result of the anti-icing fluid applied to the wing section, which compromised the aerodynamic qualities of the wing section. Residual fluid was observed on the trailing edge of the wing section during the wind tunnel tests as well as during the Falcon 20 tests. The quantitative and qualitative aerodynamic data collected during the baseline fluid only testing was used for comparative analysis against the contaminated fluid tests in Sections 6 to 9.

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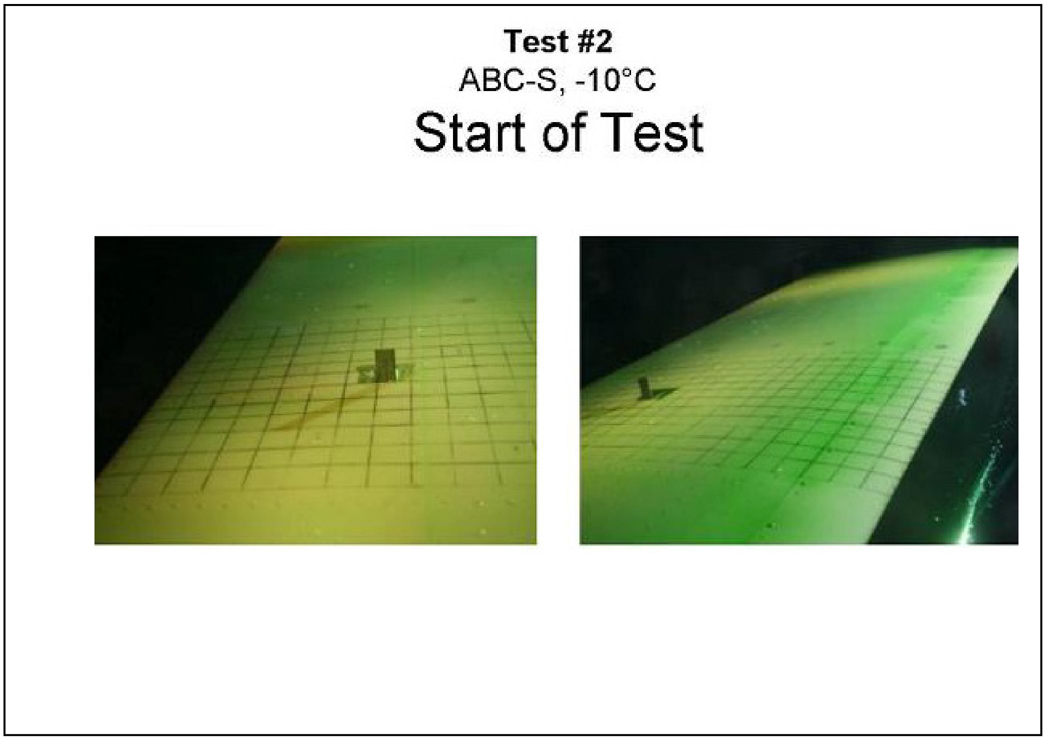
Photo 5.1: Test #2 – Start of Test

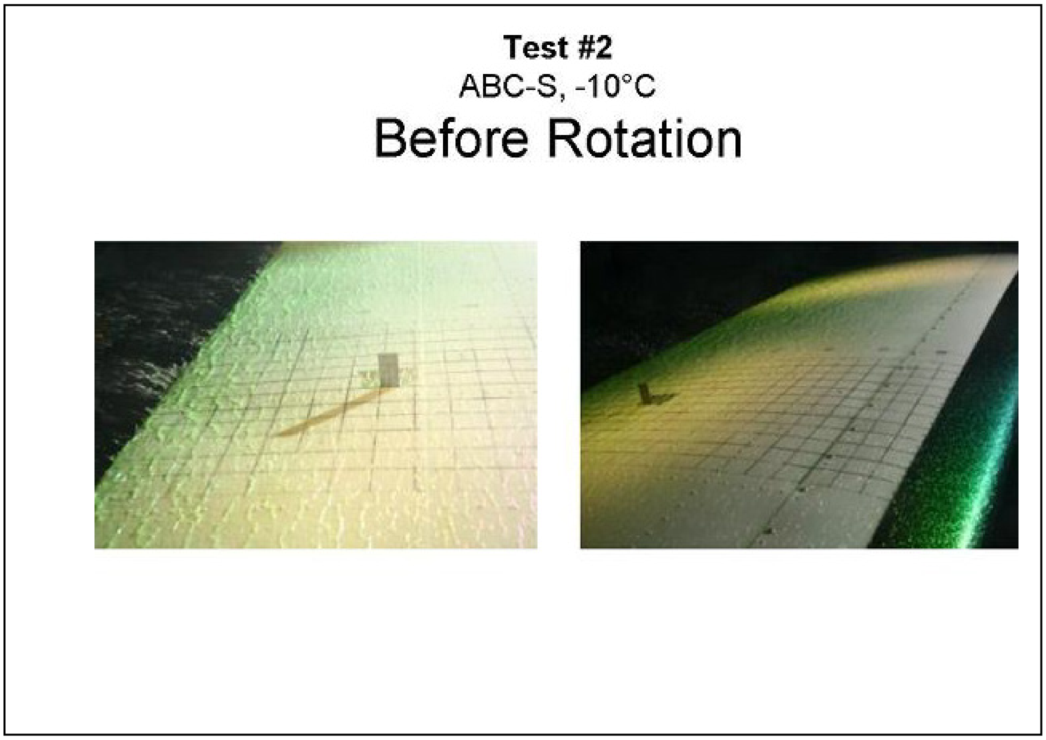


Test #2

ABC-S, -10°C

Start of Test

Photo 5.2: Test #2 – Before Rotation

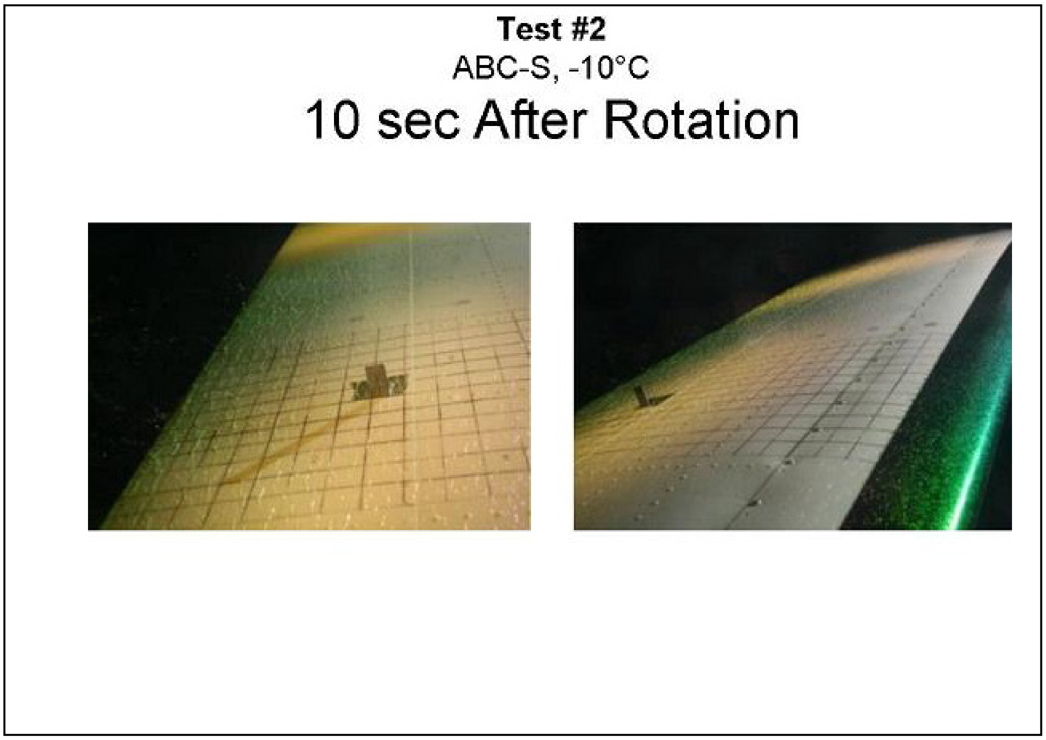


Test #2

ABC-S, -10°C

Before Rotation

Photo 5.3: Test #2 – 10 Seconds After Rotation

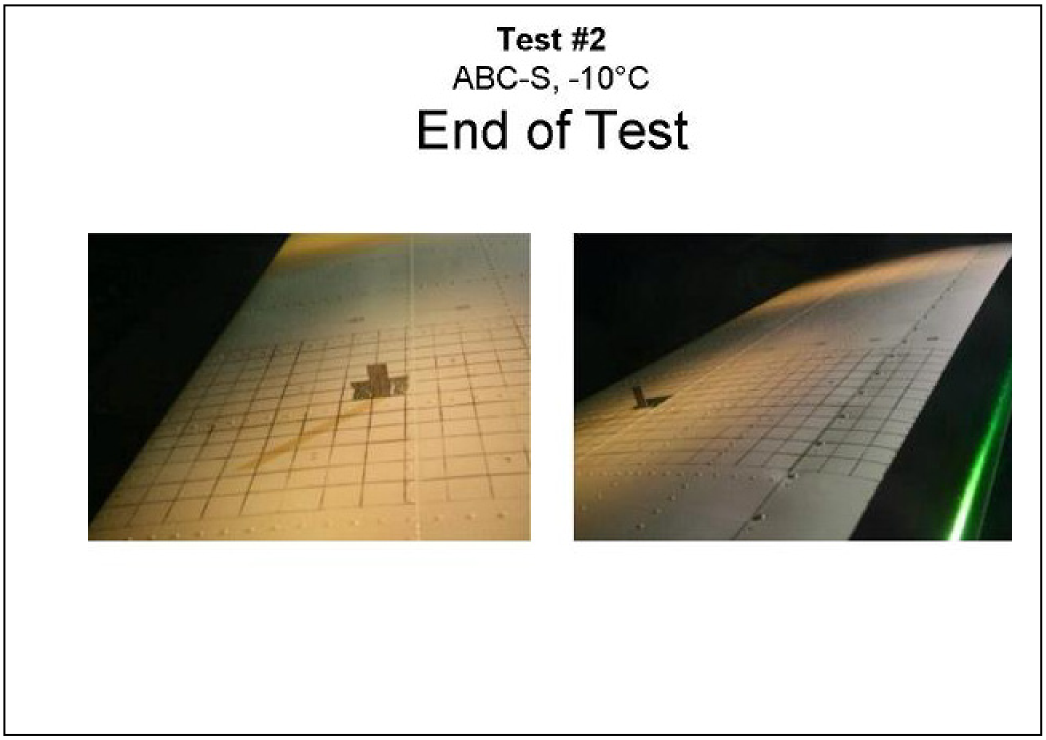


Test #2

ABC-S, -10°C

10 sec After Rotation

Photo 5.4: Test #2 – End of Test

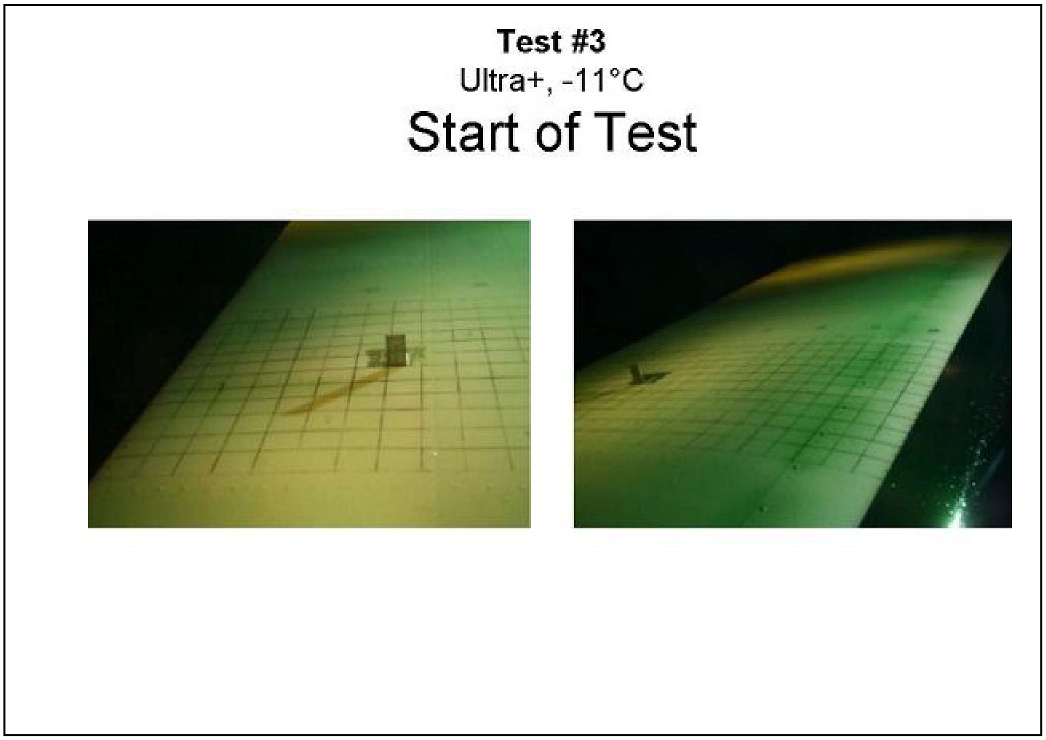


Test #2

ABC-S, -10°C

End of Test

Photo 5.5: Test #3 – Start of Test

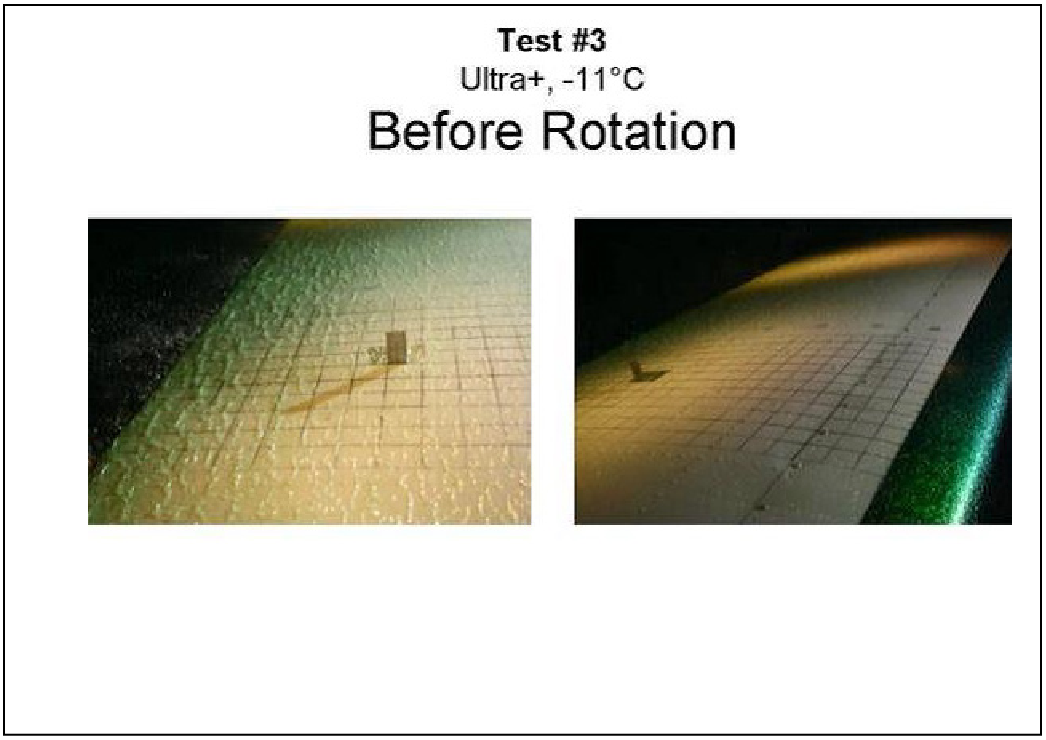


Test #3

Ultra+, -11°C

Start of Test

Photo 5.6: Test #3 – Before Rotation

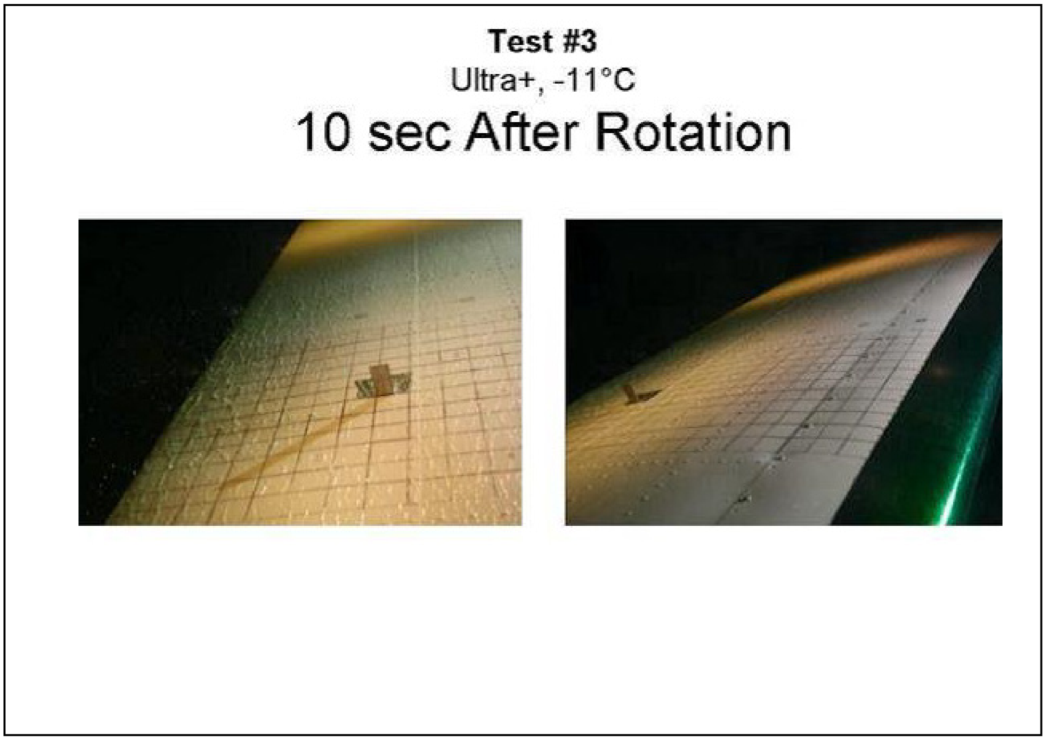


Test #3

Ultra+, -11°C

Before Rotation

Photo 5.7: Test #3 – 10 Seconds After Rotation

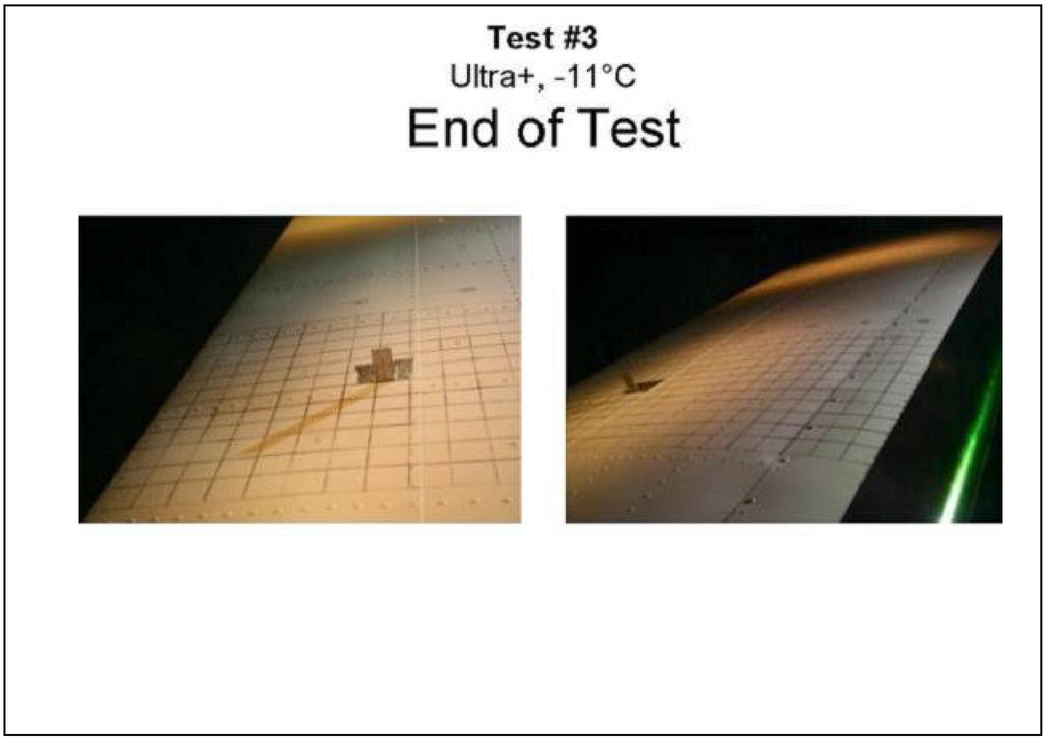


Test #3

Ultra+, -11°C

10 sec After Rotation

Photo 5.8: Test #3 – End of Test

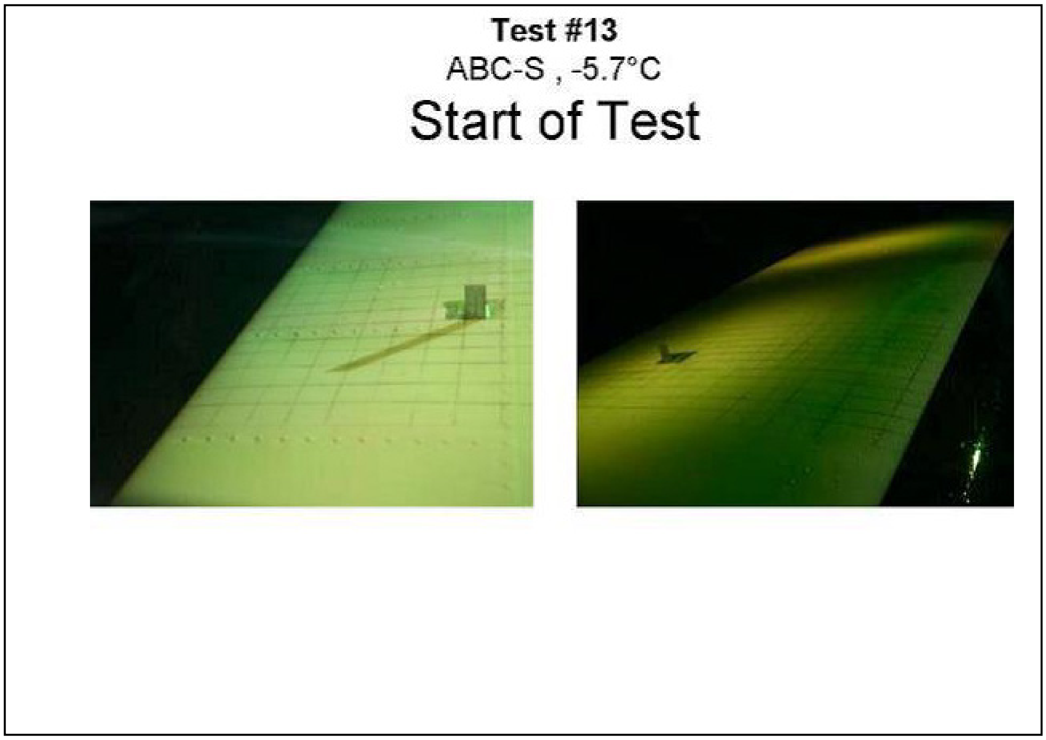


Test #3

Ultra+, -11°C

End of Test

Photo 5.9: Test #13 – Start of Test

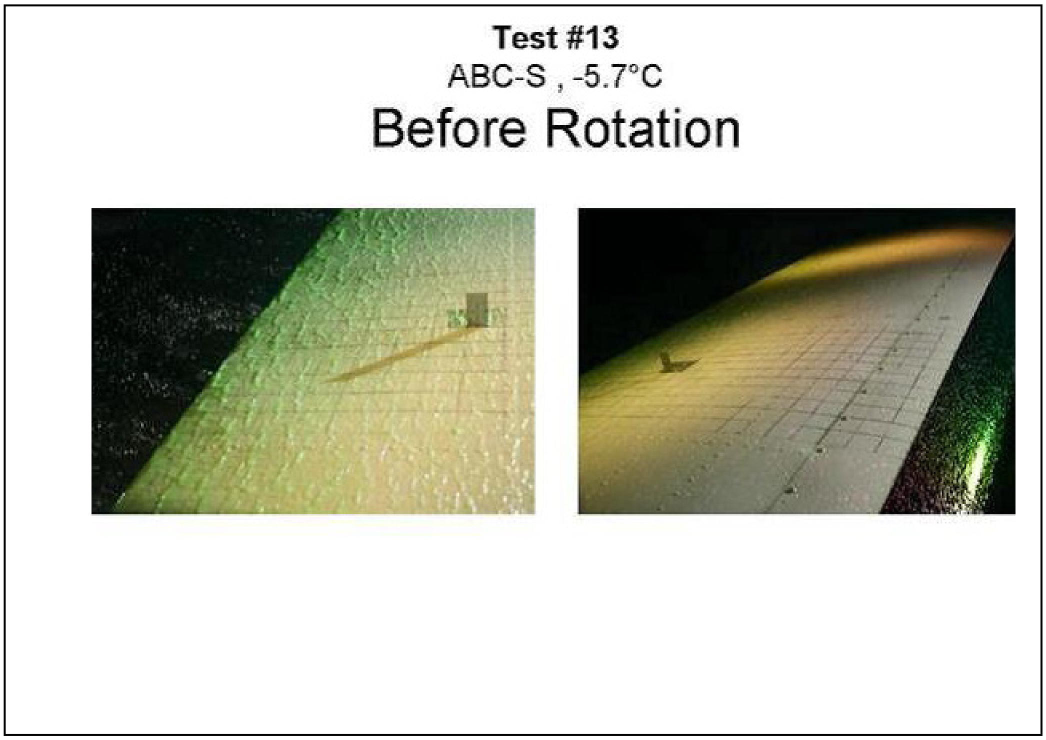


Test #13

ABC-S , -5.7°C

Start of Test

Photo 5.10: Test #13 – Before Rotation

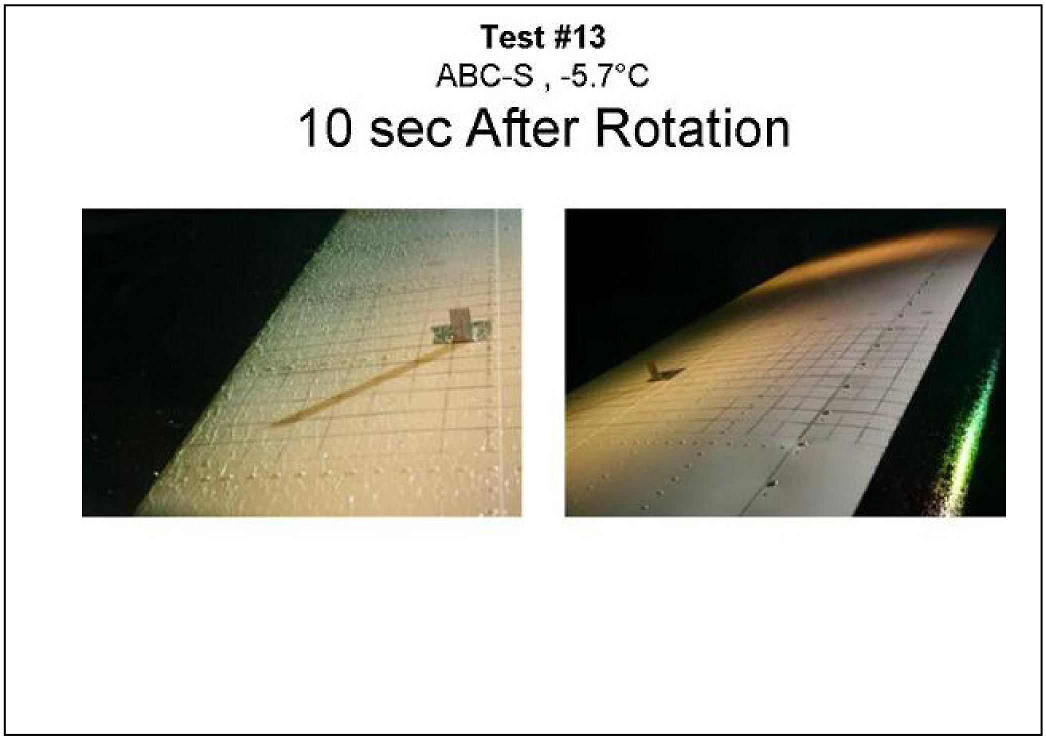


Test #13

ABC-S , -5.7°C

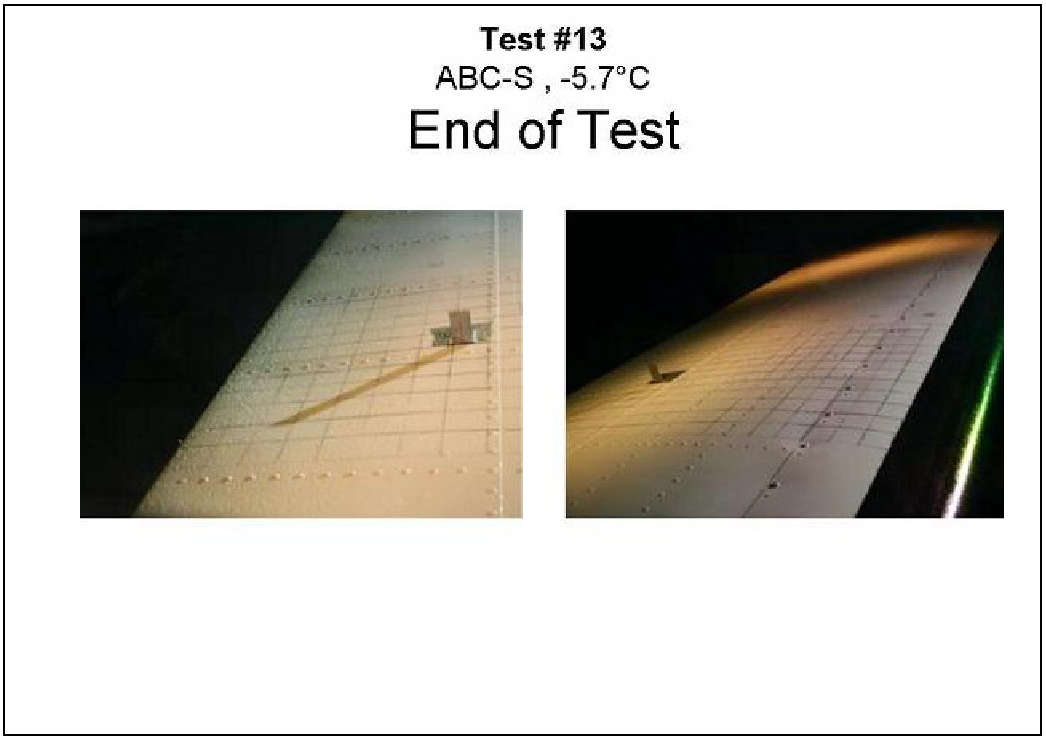
Before Rotation

Photo 5.11: Test #13 – 10 Seconds After Rotation



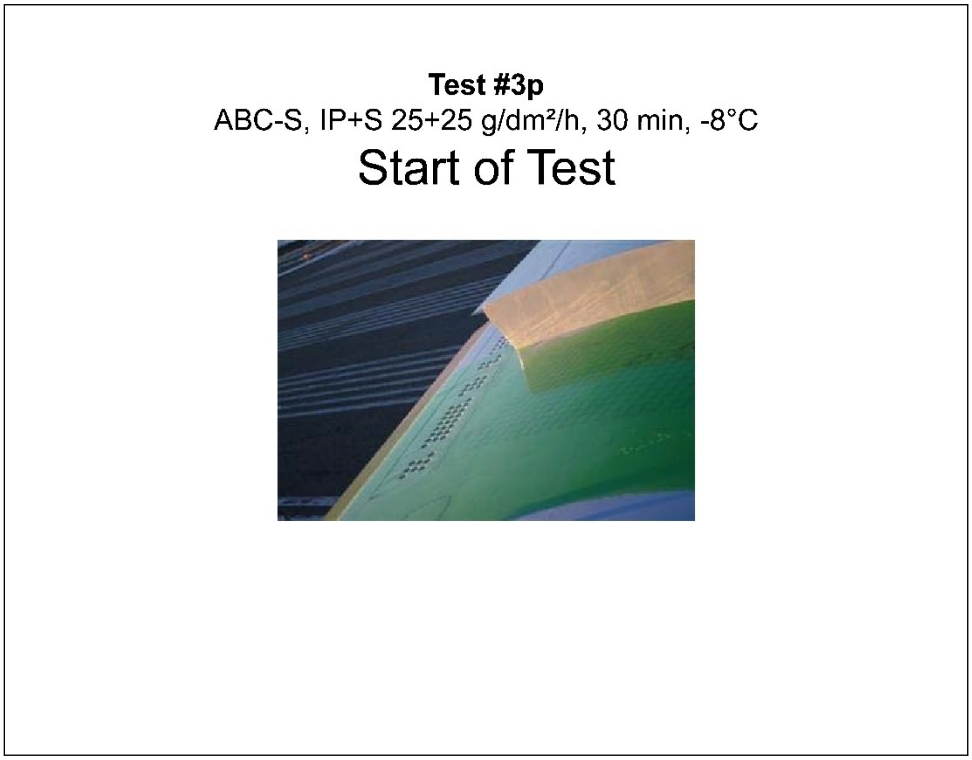
Test #13
ABC-S , -5.7°C
10 sec After Rotation

Photo 5.12: Test #13 – End of Test



Test #13
ABC-S , -5.7°C
End of Test

Photo 5.13: Test #3P – Start of Test

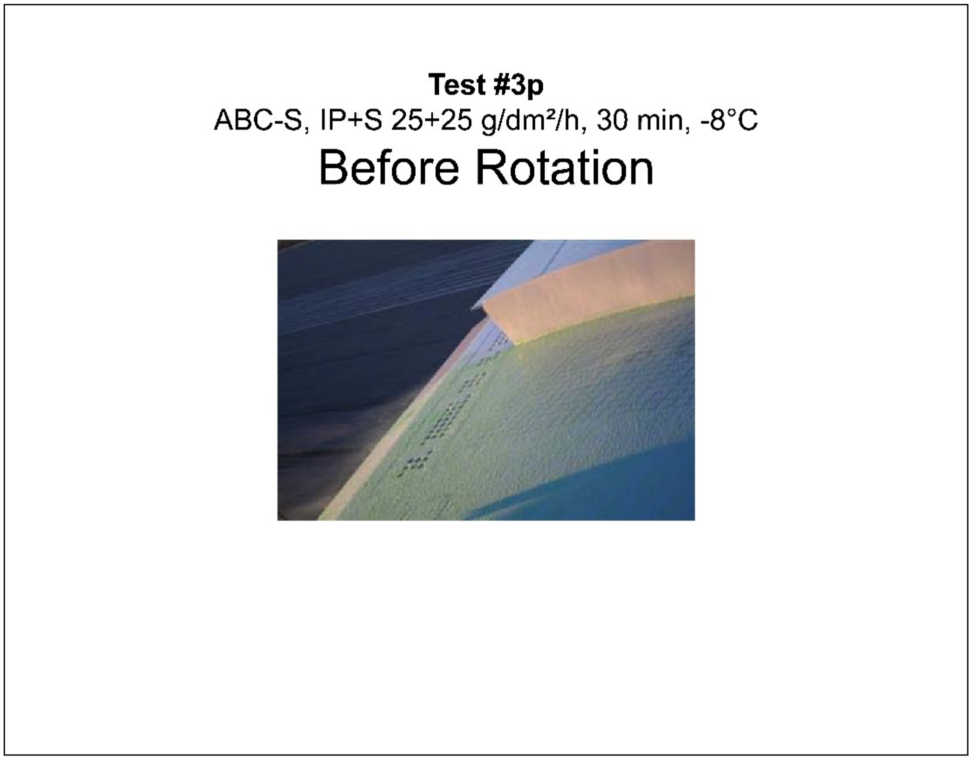


Test #3p

ABC-S, IP+S 25+25 g/dm²/h, 30 min, -8°C

Start of Test

Photo 5.14: Test #3P – Before Rotation

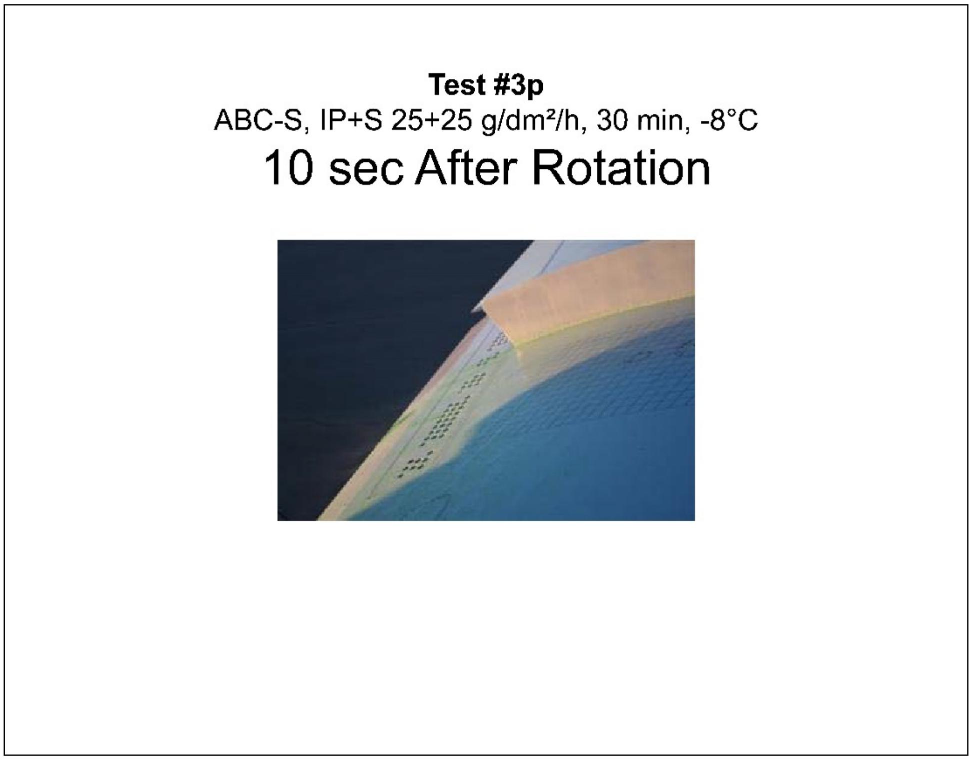


Test #3p

ABC-S, IP+S 25+25 g/dm²/h, 30 min, -8°C

Before Rotation

Photo 5.15: Test #3P – 10 Seconds After Rotation

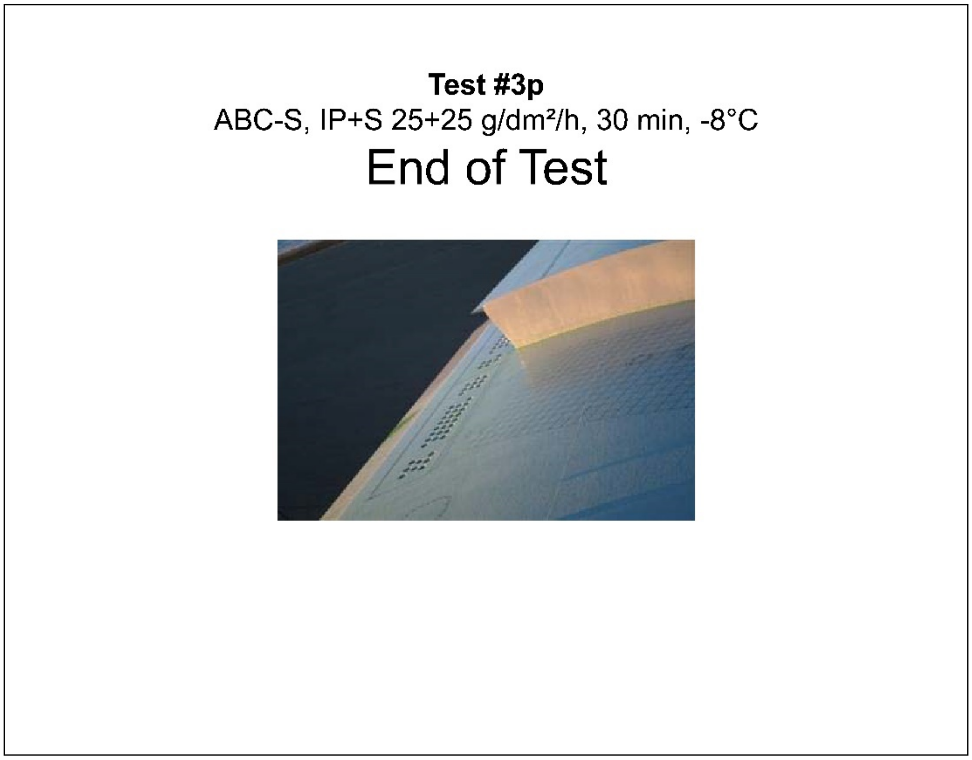


Test #3p

ABC-S, IP+S 25+25 g/dm²/h, 30 min, -8°C

10 sec After Rotation

Photo 5.16: Test #3P – End of Test

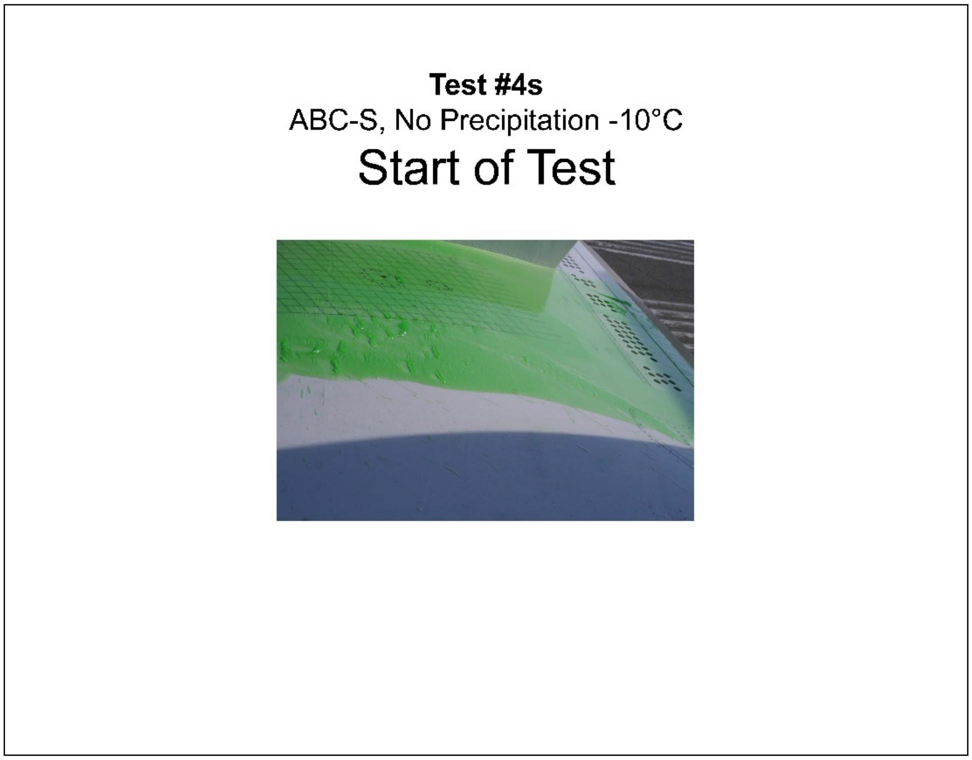


Test #3p

ABC-S, IP+S 25+25 g/dm²/h, 30 min, -8°C

End of Test

Photo 5.17: Test #4S – Start of Test

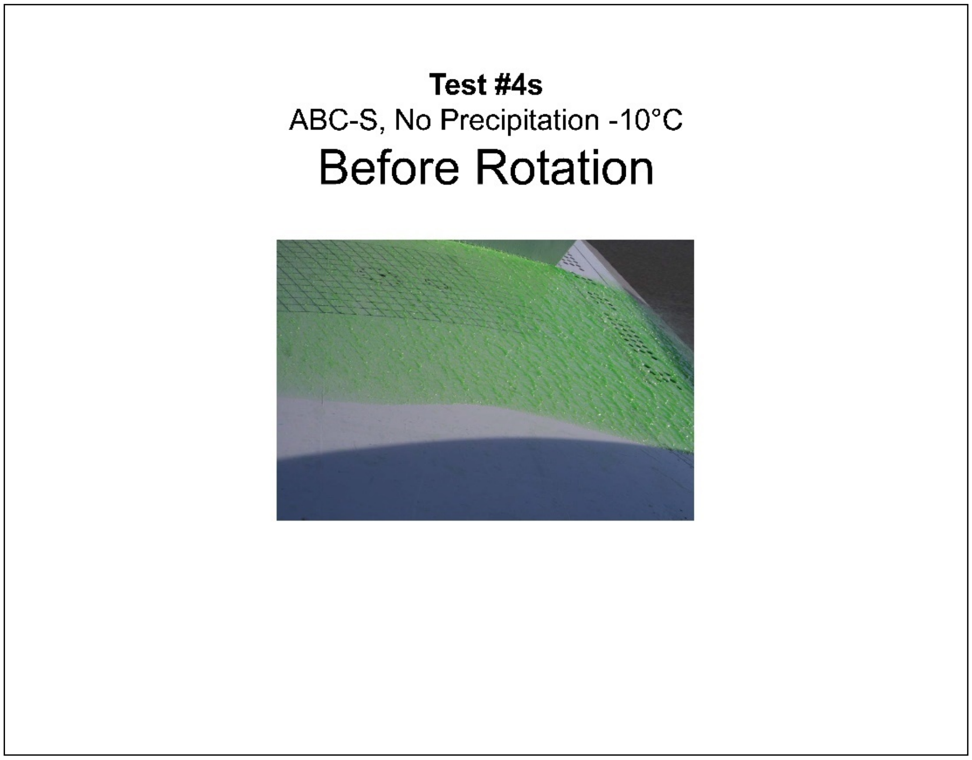


Test #4s

ABC-S, No Precipitation -10°C

Start of Test

Photo 5.18: Test #4S – Before Rotation

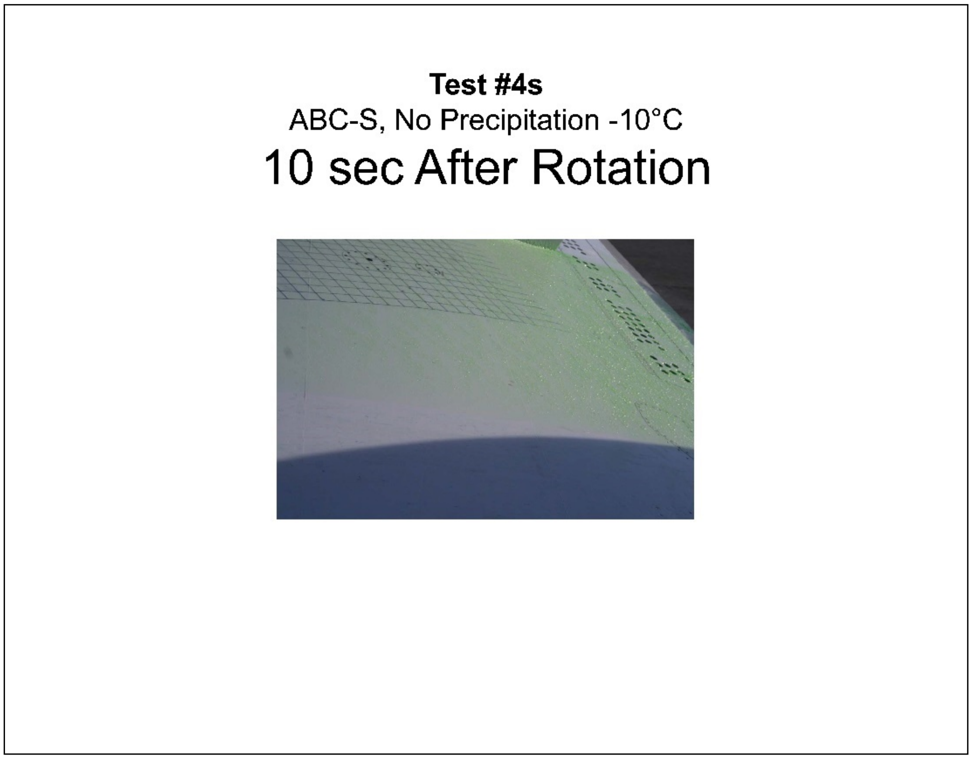


Test #4s

ABC-S, No Precipitation -10°C

Before Rotation

Photo 5.19: Test #4S – 10 Seconds After Rotation

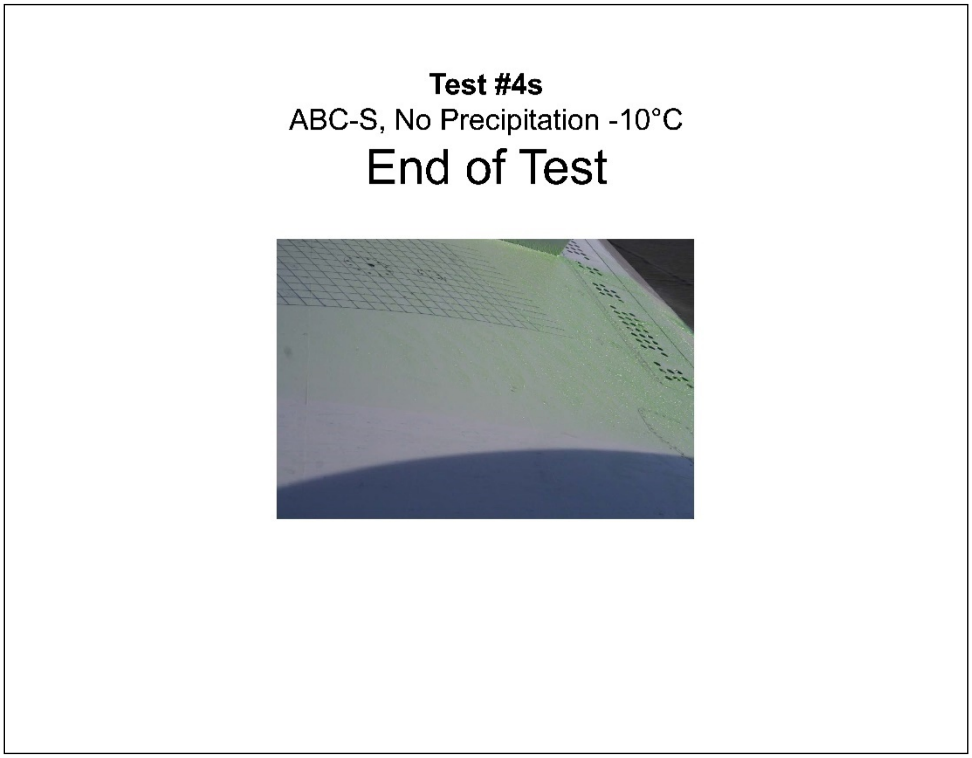


Test #4s

ABC-S, No Precipitation -10°C

10 sec After Rotation

Photo 5.20: Test #4S – End of Test

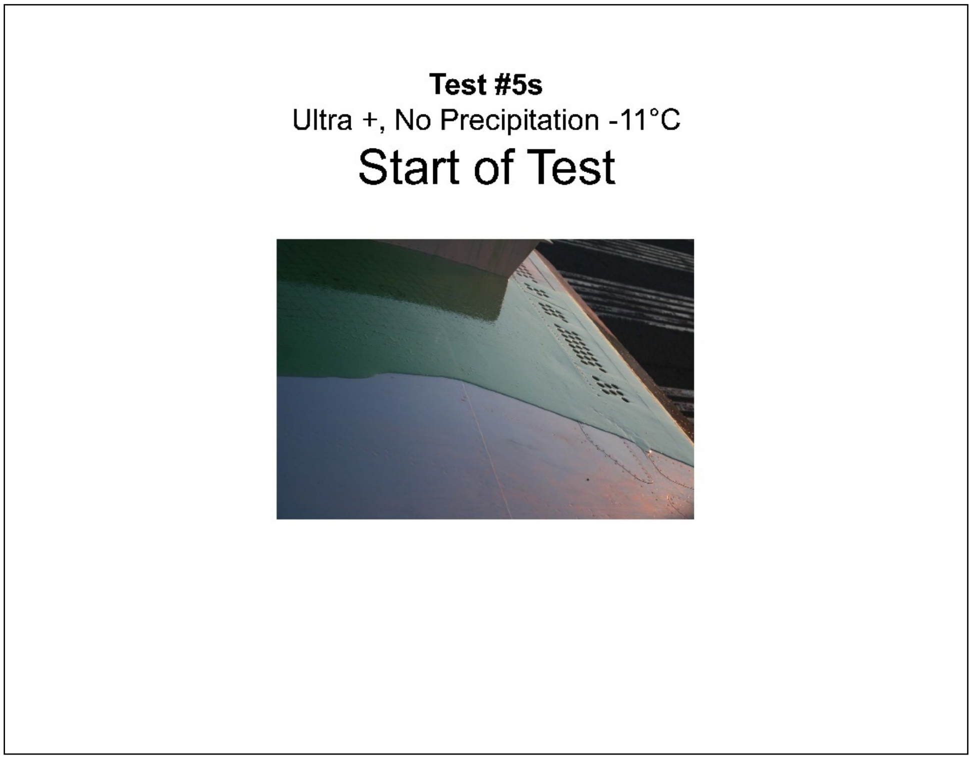


Test #4s

ABC-S, No Precipitation -10°C

End of Test

Photo 5.21: Test #5S – Start of Test

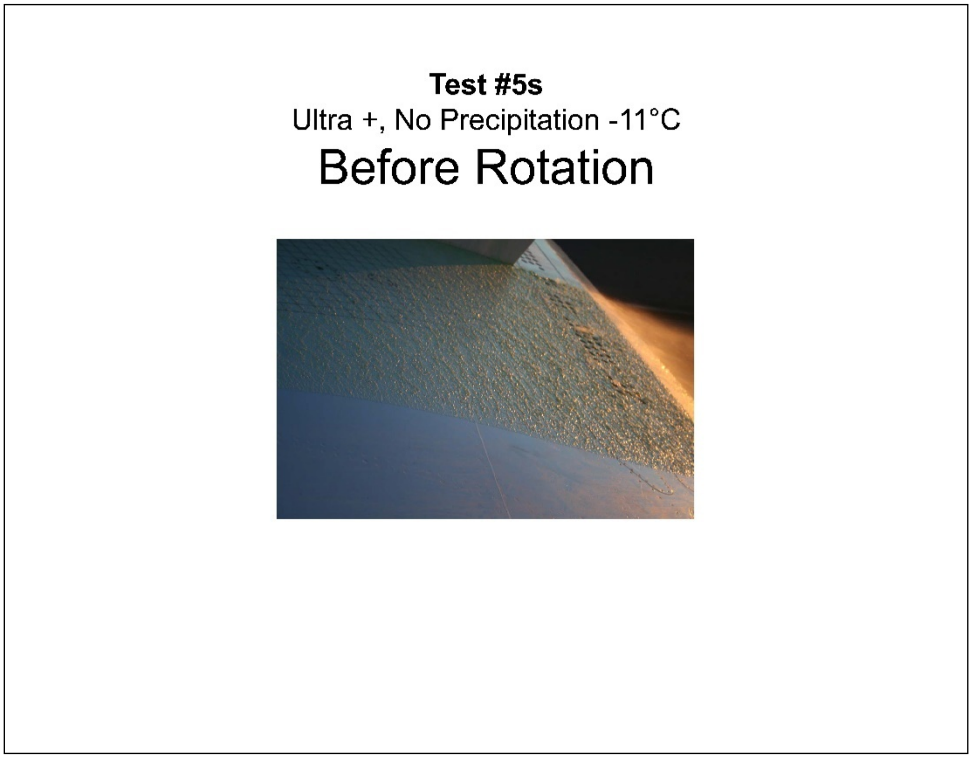


Test #5s

Ultra +, No Precipitation -11°C

Start of Test

Photo 5.22: Test #5S – Before Rotation

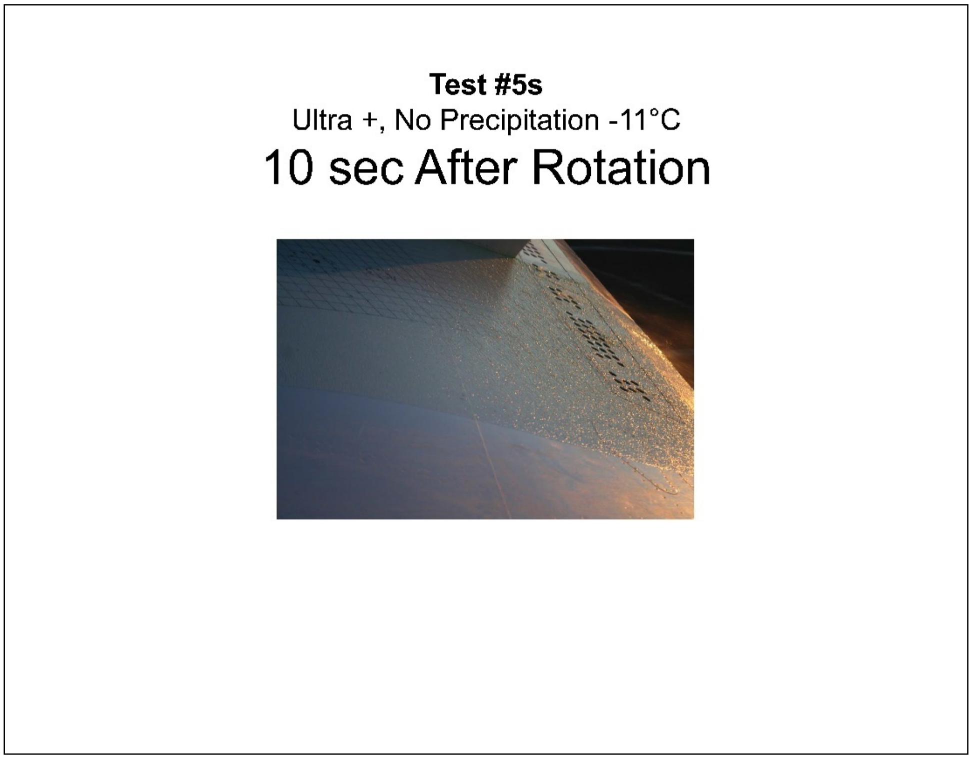


Test #5s

Ultra +, No Precipitation -11°C

Before Rotation

Photo 5.23: Test #5S – 10 Seconds After Rotation

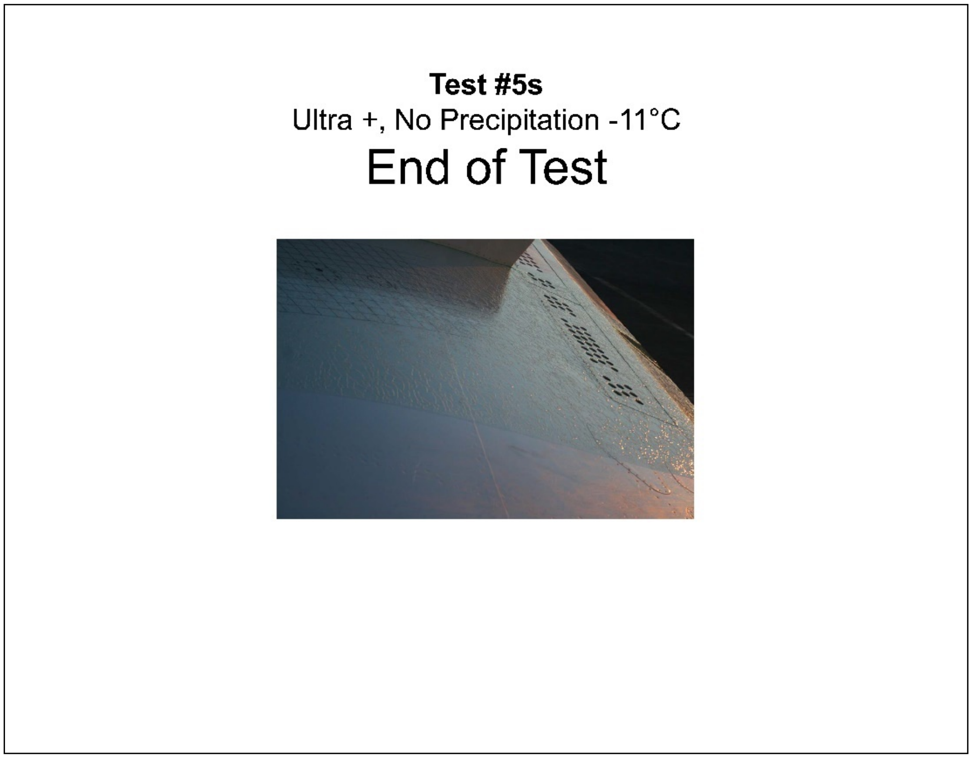


Test #5s

Ultra +, No Precipitation -11°C

10 sec After Rotation

Photo 5.24: Test #5S – End of Test

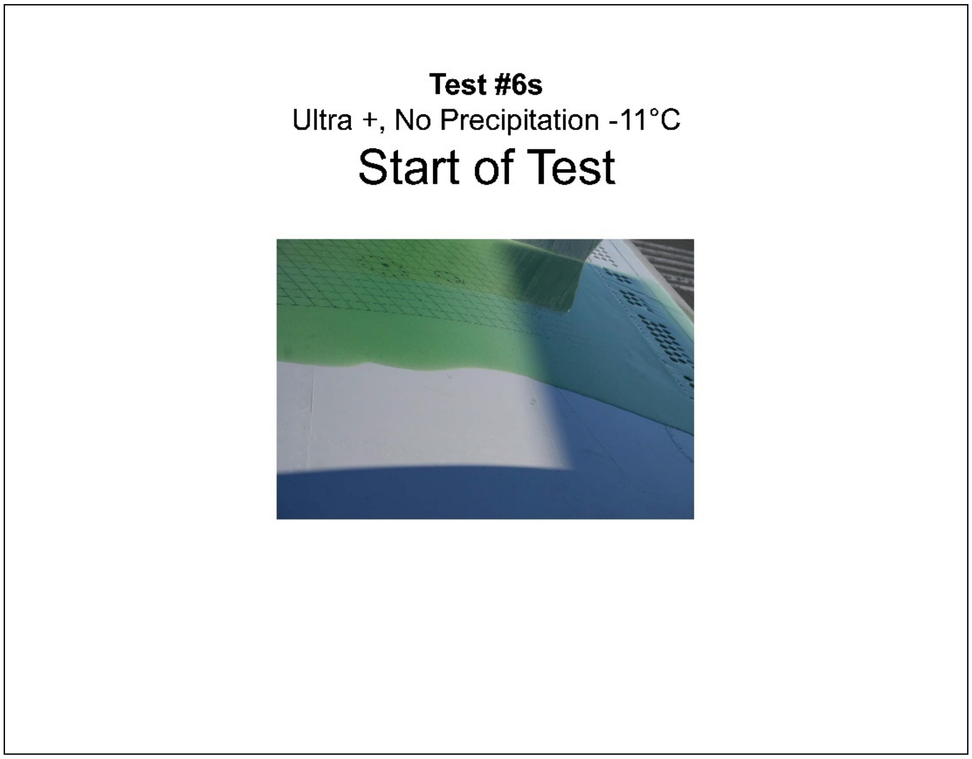


Test #5s

Ultra +, No Precipitation -11°C

End of Test

Photo 5.25: Test #6S – Start of Test

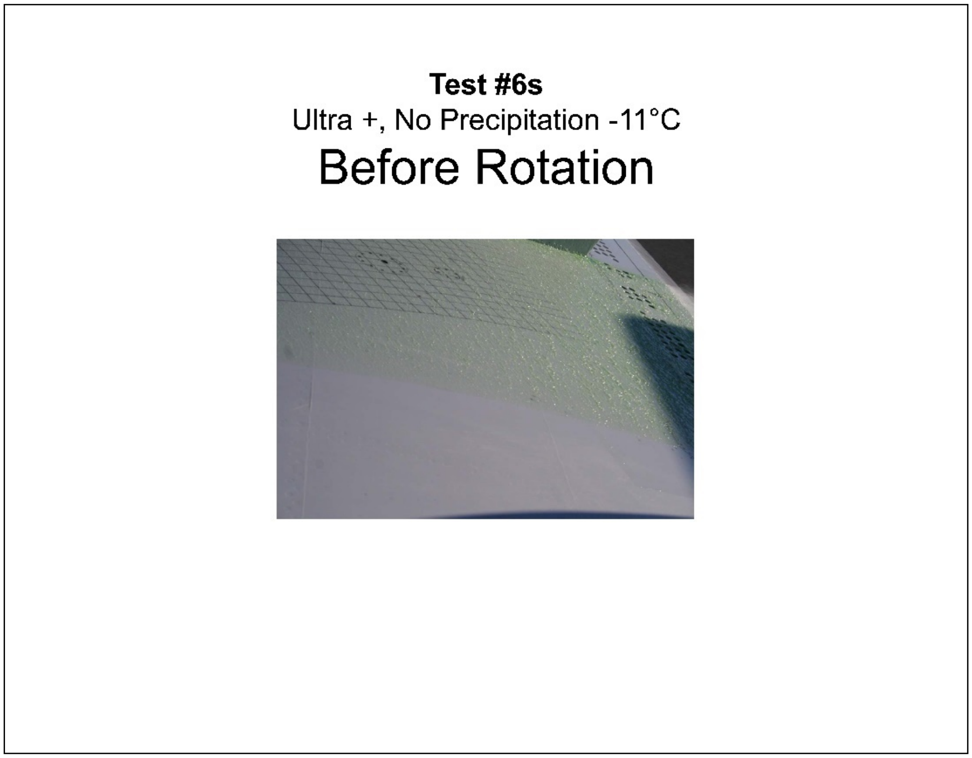


Test #6s

Ultra +, No Precipitation -11°C

Start of Test

Photo 5.26: Test #6S – Before Rotation

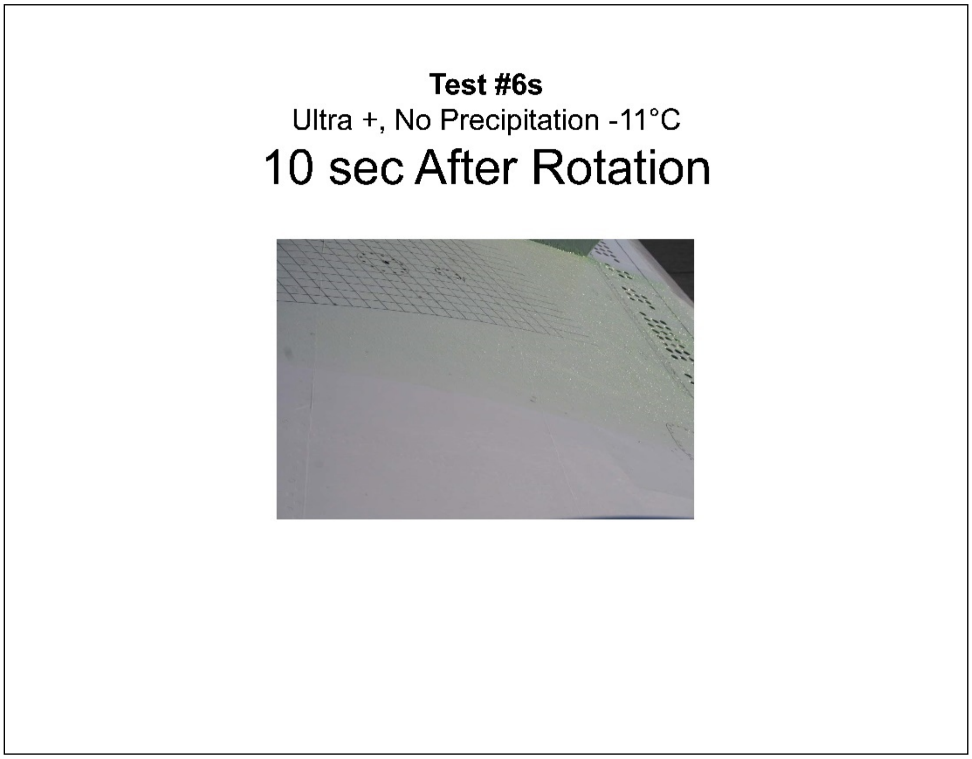


Test #6s

Ultra +, No Precipitation -11°C

Before Rotation

Photo 5.27: Test #6S – 10 Seconds After Rotation

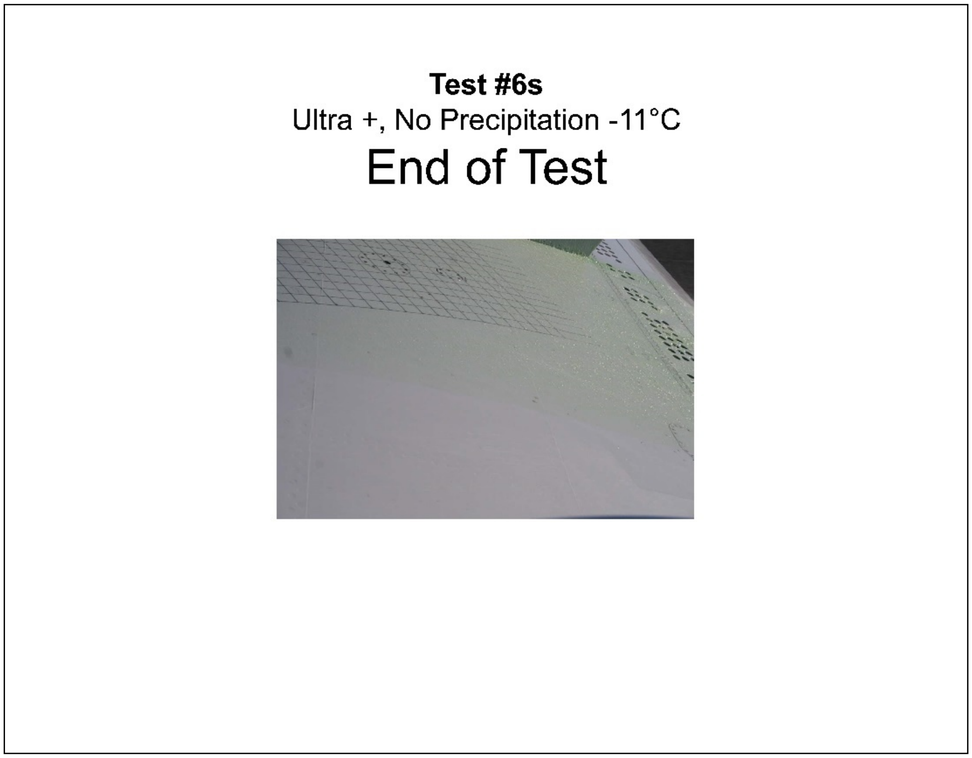


Test #6s

Ultra +, No Precipitation -11°C

10 sec After Rotation

Photo 5.28: Test #6S – End of Test



Test #6s

Ultra +, No Precipitation -11°C

End of Test

6. LIGHT ICE PELLETS ONLY TESTING

This section provides an overview of each test conducted as part of the test program to evaluate the behaviour of anti-icing fluid exposed to light ice pellets only conditions. The parameters for each test are detailed and a description of the data collected during each test is provided.

6.1 Overview of Tests

A summary of the tests conducted in the wind tunnel during light ice pellets only is shown in Table 6.1. The table provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. It should be noted that light ice pellets only testing was not conducted with the Falcon 20 aircraft during the winter of 2006-07; results from the 2005-06 testing were referenced and used during the analysis. More detailed test logs of all conditions tested in the wind tunnel and using the Falcon 20 aircraft are provided in Subsections 4.1 and 4.2. A brief description of the column headings can be found in Subsection 5.1.

Table 6.1: Summary of 2006-07 IP- Testing in the NRC Wind Tunnel

Test #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precp. Time (min)	Last 10 min AVG OAT (ºC)	Wing Avg Temp (ºC)	Visual Severity Rating (1-5)
5	15-Feb-07	PG	IP	0	25	0	60	-12.1	-13	4.5
7	22-Feb-07	PG	IP	0	24.3	0	60	1	-5.5	1
8	22-Feb-07	EG	IP	0	24.3	0	60	-0.3	-9	1

6.2 Data Collected

6.2.1 Coefficient of Lift Curves

Drag and lift data collected by the NRC was used to generate lift coefficient curves for each of the tests conducted in the wind tunnel. Figures 6.1 to 6.3 show the lift coefficient data for each of the tests conducted in ice pellets only conditions. The x-axis indicates the time in seconds as of the start of rotation. The y-axis indicates the Cn (normal force coefficient) and Cl (lift coefficient) calculated from the data collected; in some cases, only one curve was calculated due to a lack of data.

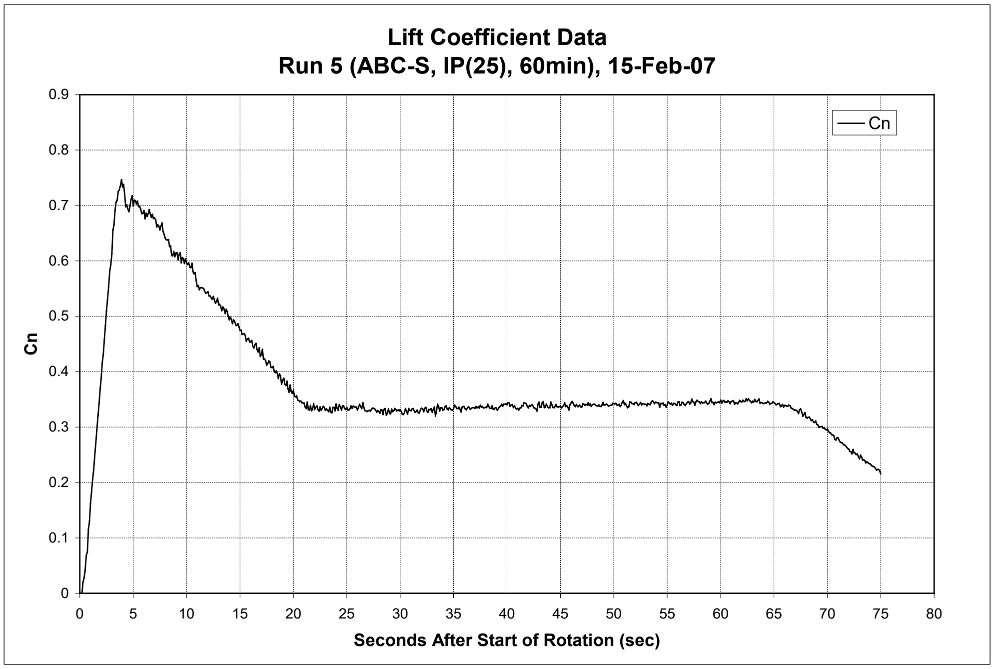


Figure 6.1: Test #5 Lift Coefficient Data

Figure 6.2: Test #7 Lift Coefficient Data

Figure 6.3: Test #8 Lift Coefficient Data

6.2.2 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.1 and 2.2.9.1. Fluid thickness measurements were recorded at the following intervals:

- Wind Tunnel Tests:
    - Approximately 5 minutes after fluid application;
    - After the application of contamination; and
    - After the wind tunnel test (end of test).

Tables 6.2 to 6.4 show the fluid thickness measurements collected during each test.

Table 6.2: Test #5 Fluid Thickness Data

TEST 5: ABC-S, IP(25)-60min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.0	2.2	0.1
2	1.5	5.7	0.0
3	3.3	8.9	0.1
4	1.8	8.9	0.1
5	1.8	8.9	0.1
6	1.8	7.0	0.1
7	1.8	5.7	1.5
8	1.4	5.7	1.8

Table 6.3: Test #7 Fluid Thickness Data

TEST 7: ABC-S, IP(25)-60min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.4	0.7	0.0
2	3.3	3.9	0.0
3	4.5	4.5	0.0
4	3.3	3.7	0.2
5	2.5	2.7	0.1
6	2.5	1.8	0.2
7	2.5	2.2	0.3
8	1.8	1.8	0.6

Table 6.4: Test #8 Fluid Thickness Data

TEST 8: Ultra+, IP(25)-60min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.1	1.0	0.0
2	3.1	3.1	0.0
3	4.5	7.0	0.0
4	3.1	2.2	0.0
5	2.7	1.4	0.0
6	3.1	1.4	0.1
7	2.7	1.1	0.1
8	2.2	0.8	0.2

6.2.3 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.3 and 2.2.9.3. Skin temperature measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 6.5 to 6.7.

Table 6.5: Test #5 Skin Temperature Data

TEST 5: ABC-S, IP(25)-60min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-14.6	-14.0	-11.6
5	-15.7	-12.5	-10.0
Under-wing	-14.4	-12.1	-13.0

Table 6.6: Test #7 Skin Temperature Data

TEST 7: ABC-S, IP(25)-60min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-0.8	-5.5	-0.4
5	0.7	-5.5	0.8
Under-wing	-0.2	-0.8	-0.4

Table 6.7: Test #8 Skin Temperature Data

TEST 8: Ultra+, IP(25)-60min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-0.1	-8.8	0.9
5	1.7	-8.9	2.6
Under-wing	0.0	-5.4	-0.2

6.2.4 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.2 and 2.2.9.2. Fluid Brix measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).

The fluid Brix measurements collected during each test are shown in Tables 6.8 to 6.10.

Table 6.8: Test #5 Fluid Brix Data

TEST 5: ABC-S, IP(25)-60min			
Wing Position	Fluid Brix (°)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.00	19.00	34.00
8	37.00	17.50	35.25

Table 6.9: Test #7 Fluid Brix Data

TEST 7: ABC-S, IP(25)-60min			
Wing	Fluid Brix (°)		
Position	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	36.75	22.50	33.00
8	36.75	17.00	34.50

Table 6.10: Test #8 Fluid Brix Data

TEST 8: Ultra+, IP(25)-60min			
Wing	Fluid Brix (°)		
Position	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	42.00	22.00	35.00
8	42.00	21.50	41.00

6.3 Photos

High-speed digital photography of each test was taken. Photos of both the leading edge and trailing edge are shown. For each of the tests, photo summaries have been compiled comprising four stages:

- Start of test;
- Time of rotation;
- 10 seconds after rotation; and
- End of test.

Photos 6.1 to 6.12 show the photo summaries for Tests #5, #7, and #8. A complete set of photos will be provided to the TDC.

6.4 Results

Wind tunnel Tests #7 and #8 were conducted at the high end of the precipitation rate for light ice pellets (with 60 minutes of exposure), with wing skin temperatures of -6°C and -9°C, respectively. The lift data collected did not demonstrate lift losses when compared to the baseline fluid only tests. Fluid and contamination were cleared from the trailing edge prior to the start of rotation.

Wind tunnel Test #5 was also conducted at the high end of the precipitation rate for light ice pellets (with 60 minutes of exposure), with a skin temperature of -13°C. Although the lift data did not demonstrate lift losses when compared to the fluid only tests, residual contamination was observed on the trailing edge of the wing section following the test.

6.5 Conclusion and Recommendations

Wind tunnel Tests #7 and #8, conducted at warmer temperatures, demonstrated positive results following 60 minutes of contamination. The working group considered the use of 60 minutes as an allowance time; however, an allowance time of 50 minutes for light ice pellets only conditions was agreed upon as a conservative alternative due to the lack of fluids tested as well as the possible variability in the rates produced.

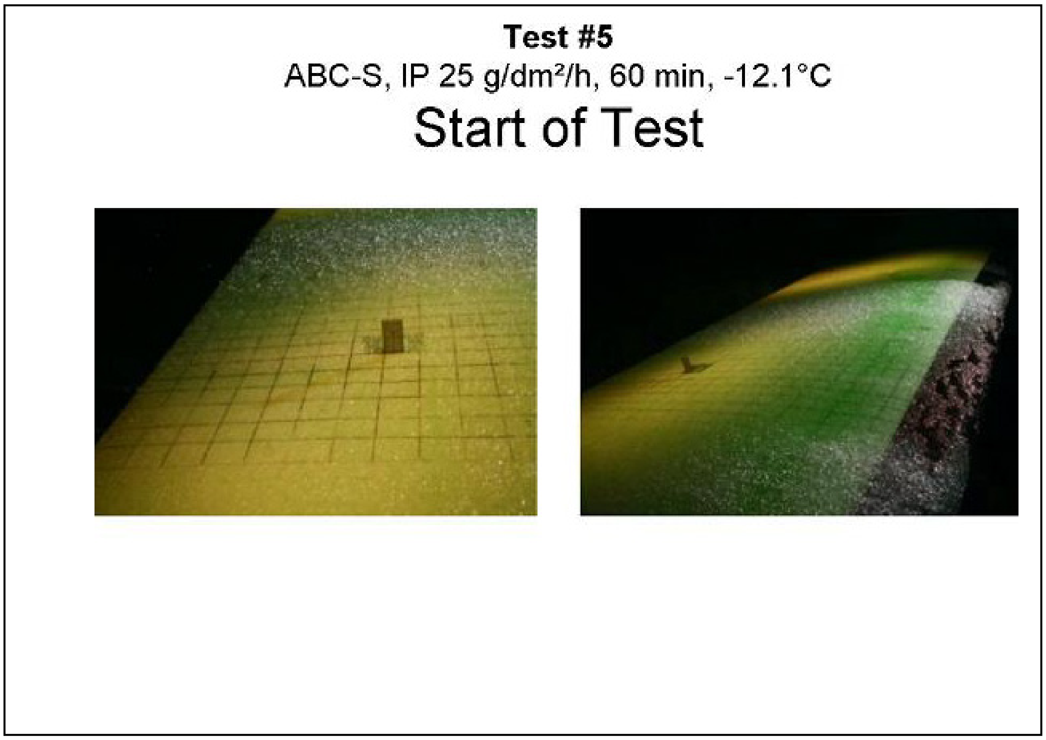
Historical occurrences suggested that operations may frequently occur in the -3°C to -5°C range. As a result of the test data showing good results (i.e., lift loss and residual contamination) at temperatures of -5°C and above, the recommendation to extend the -3°C temperature cut-off (adopted from the current HOT table format) to -5°C was supported. Table 6.11 demonstrates the recommended allowance times for light ice pellets only for -5°C and above conditions.

Wind tunnel Test #5, conducted at colder temperatures, showed signs of residual contamination at the end of the test. As a result, a reduced allowance time of 30 minutes was recommended for operations at -5°C and below. Table 6.11 demonstrates the recommended allowance times for light ice pellets only for -5°C and below conditions. A review of the Falcon 20 data collected during the winter of 2005-06 demonstrated results similar to the data collected during the winter of 2006-07 and supported the recommended allowance times.

Table 6.11: Recommended Allowance Times for Light Ice Pellets Only Conditions

	OAT -5° C and above	OAT Less than -5°C to -10°C	OAT Less than -10° C
Light Ice Pellets	50 Minutes	30 Minutes	30 Minutes

Photo 6.1: Test #5 – Start of Test

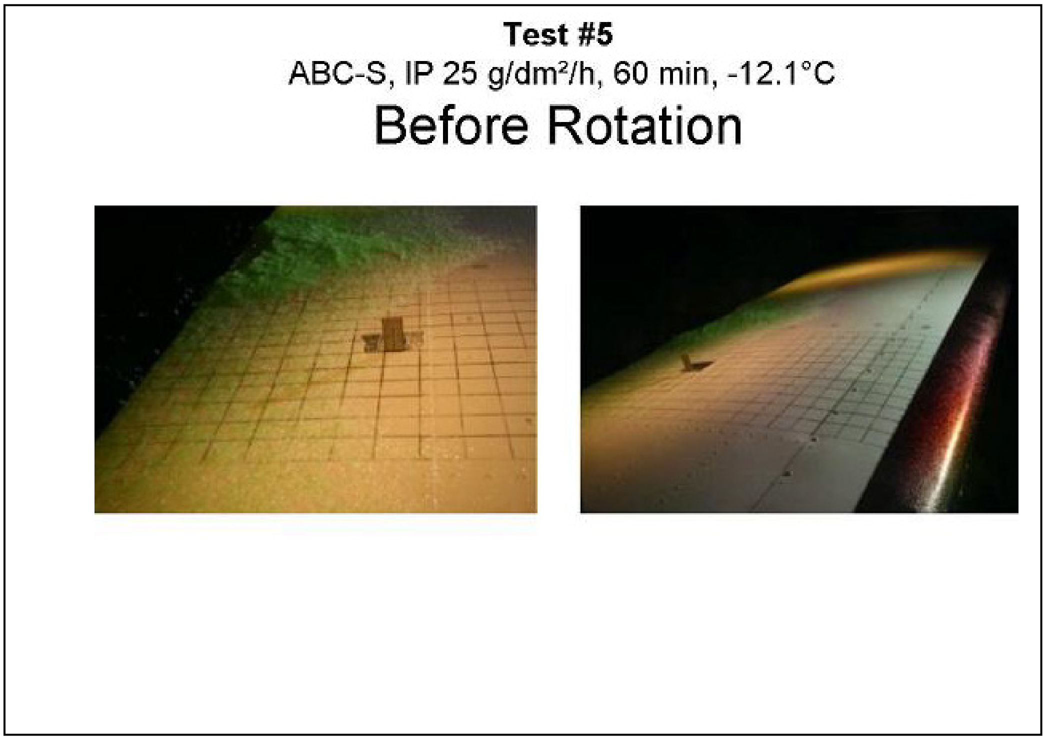


Test #5

ABC-S, IP 25 g/dm²/h, 60 min, -12.1°C

Start of Test

Photo 6.2: Test #5 – Before Rotation

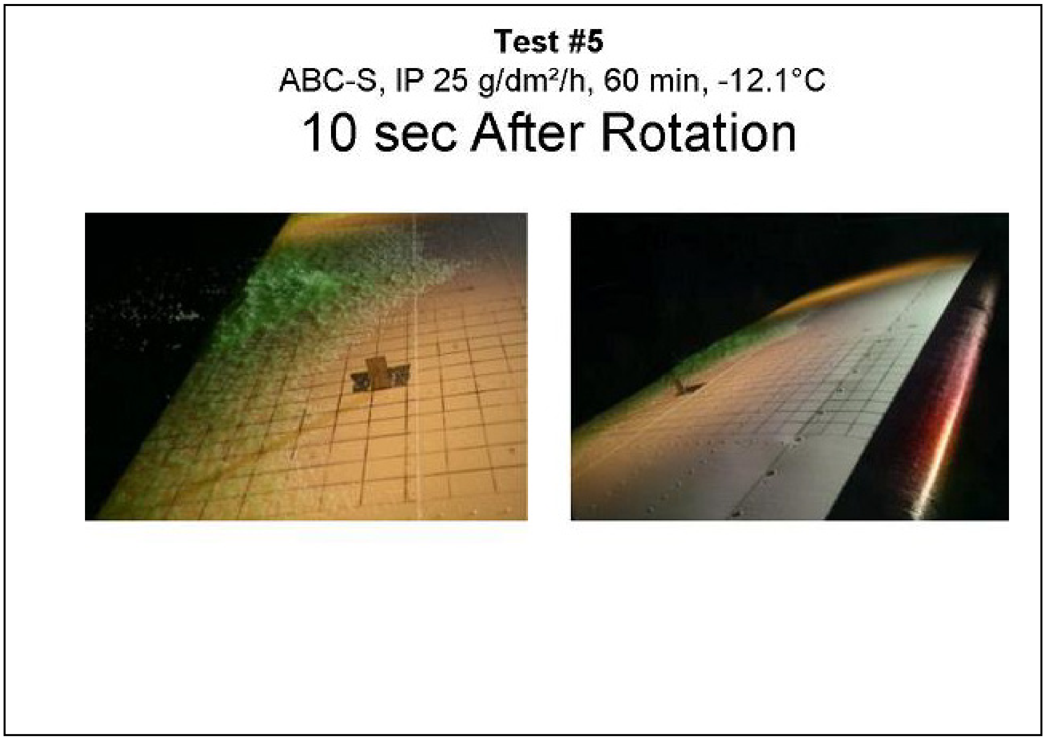


Test #5

ABC-S, IP 25 g/dm²/h, 60 min, -12.1°C

Before Rotation

Photo 6.3: Test #5 – 10 Seconds After Rotation

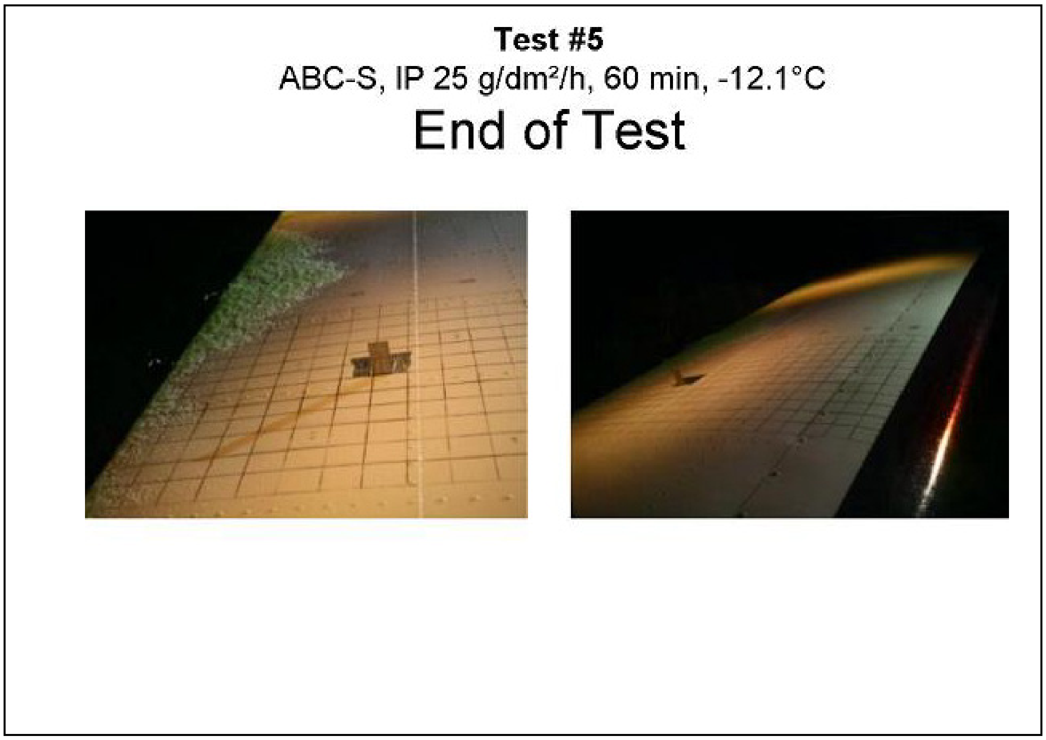


Test #5

ABC-S, IP 25 $g/dm^2/h$, 60 min, -12.1°C

10 sec After Rotation

Photo 6.4: Test #5 – End of Test

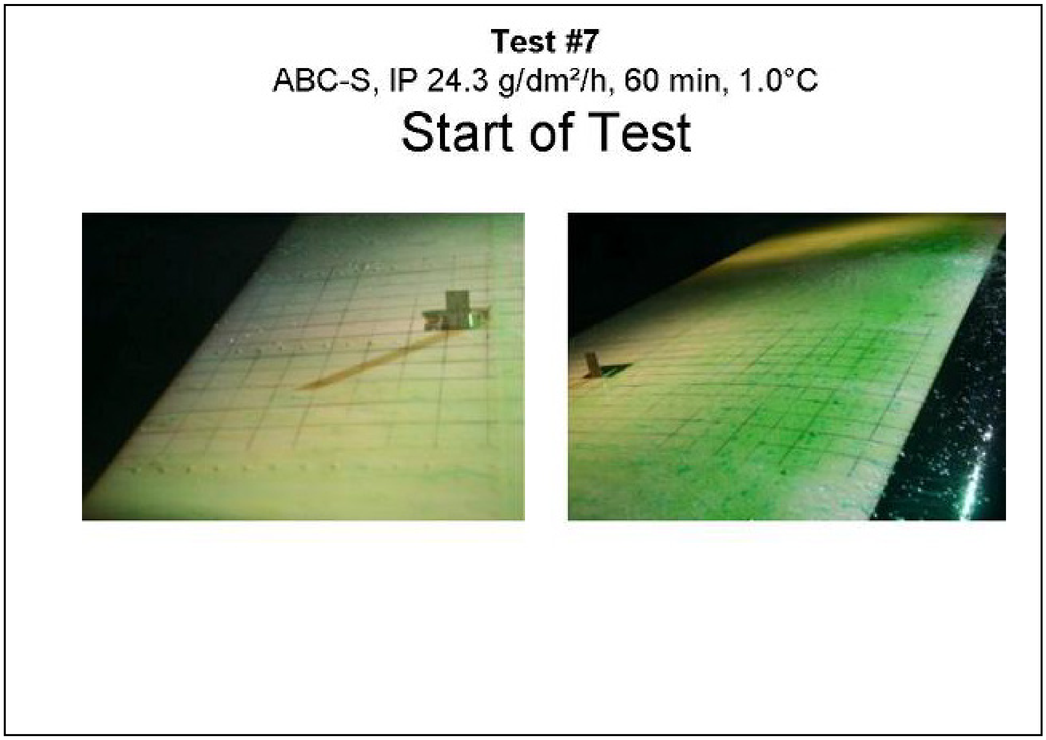


Test #5

ABC-S, IP 25 $g/dm^2/h$, 60 min, -12.1°C

End of Test

Photo 6.5: Test #7 – Start of Test

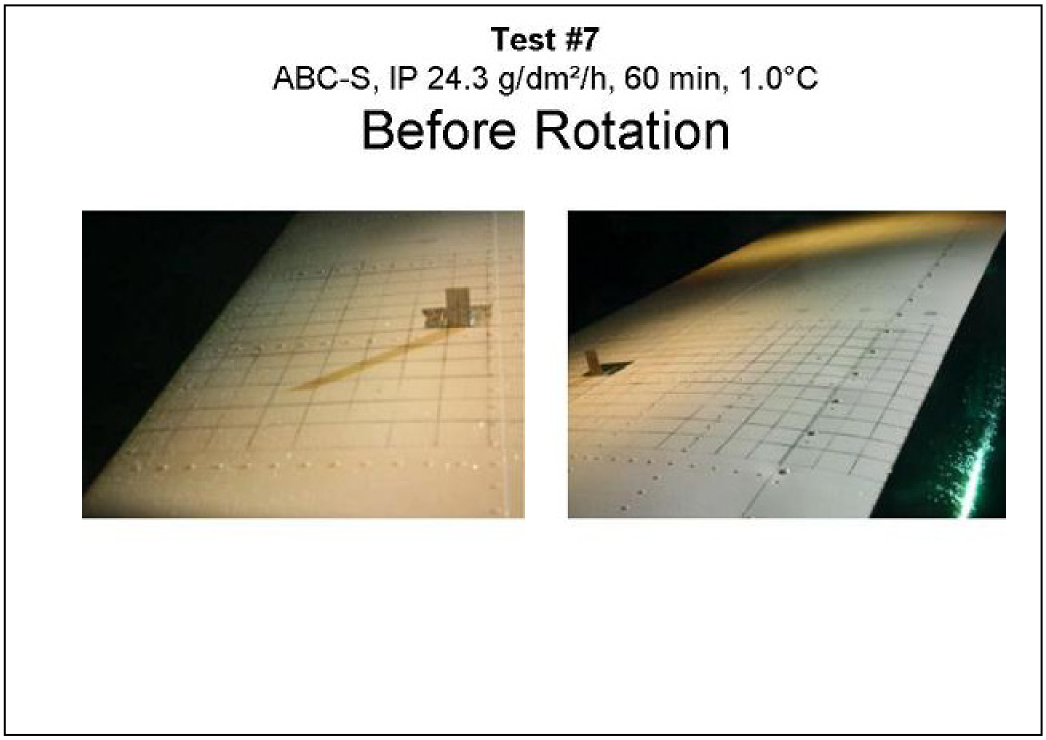


Test #7

ABC-S, IP 24.3 g/dm²/h, 60 min, 1.0°C

Start of Test

Photo 6.6: Test #7 – Before Rotation

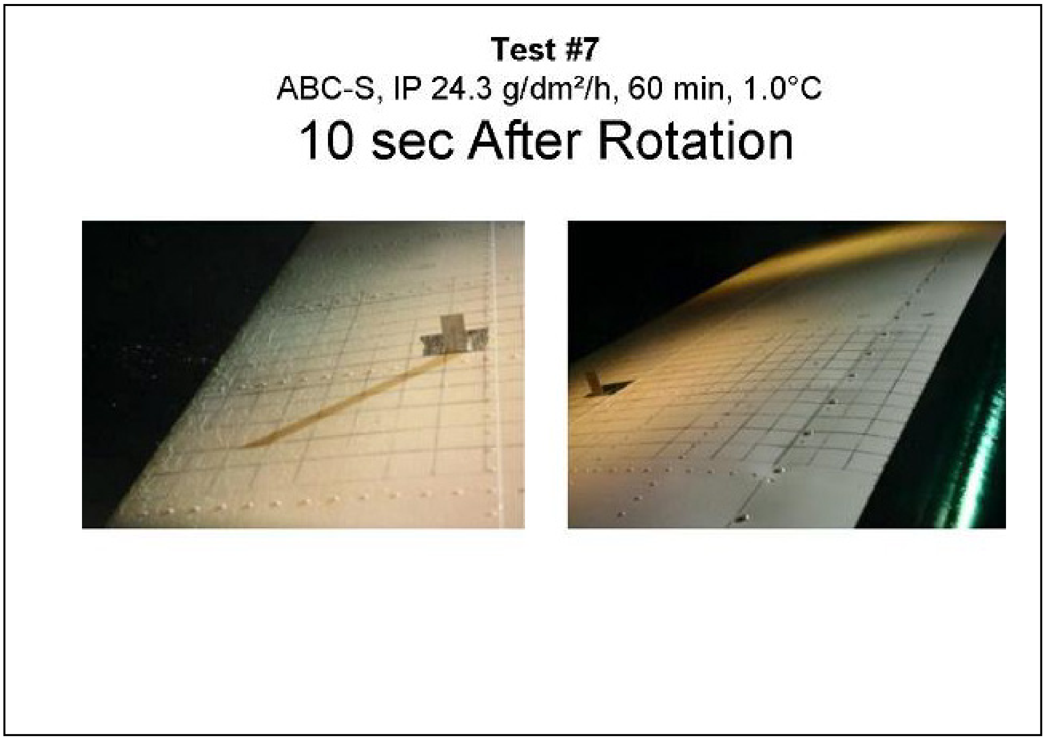


Test #7

ABC-S, IP 24.3 g/dm²/h, 60 min, 1.0°C

Before Rotation

Photo 6.7: Test #7 – 10 Seconds After Rotation

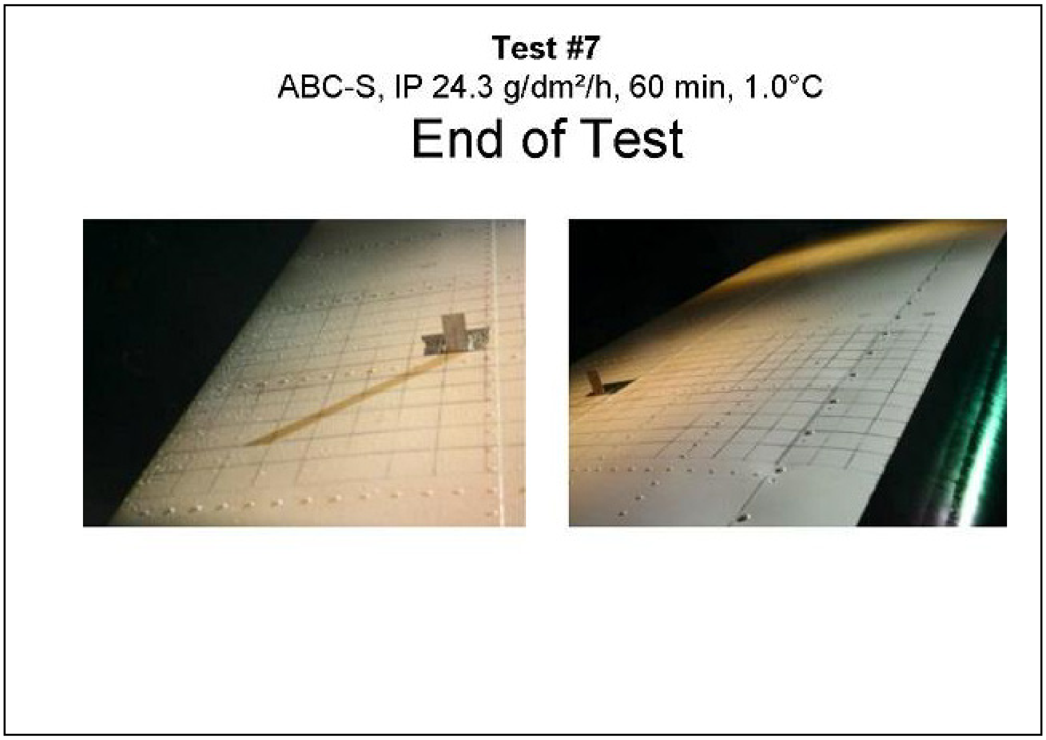


Test #7

ABC-S, IP 24.3 g/dm²/h, 60 min, 1.0°C

10 sec After Rotation

Photo 6.8: Test #7 – End of Test

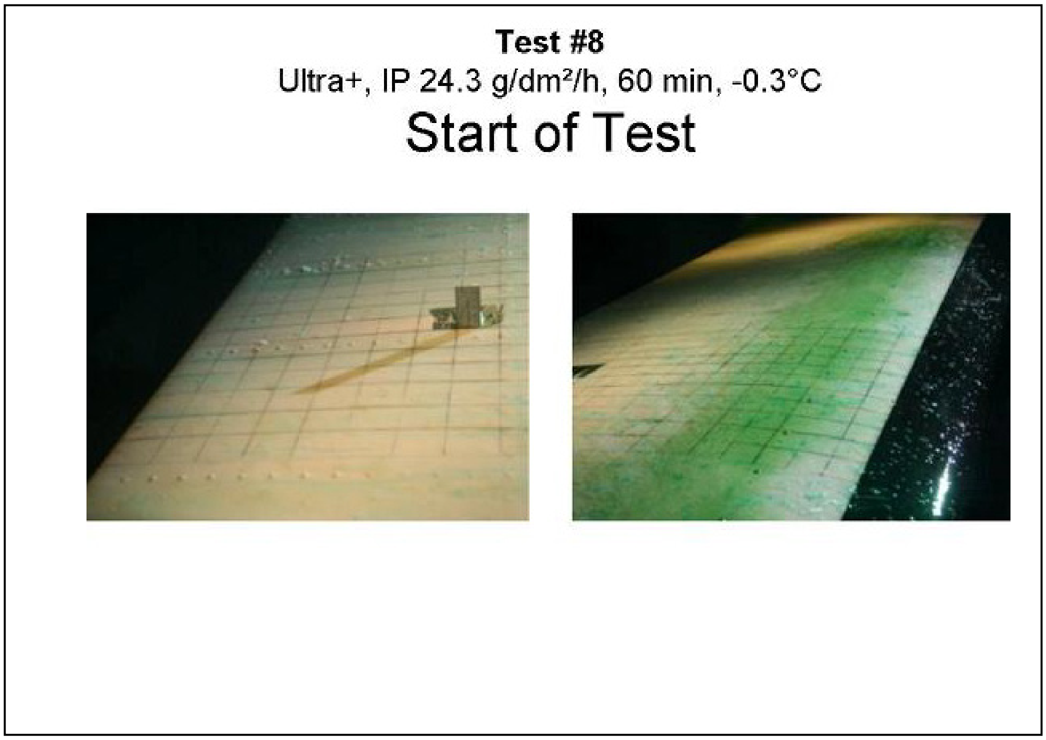


Test #7

ABC-S, IP 24.3 g/dm²/h, 60 min, 1.0°C

End of Test

Photo 6.9: Test #8 – Start of Test

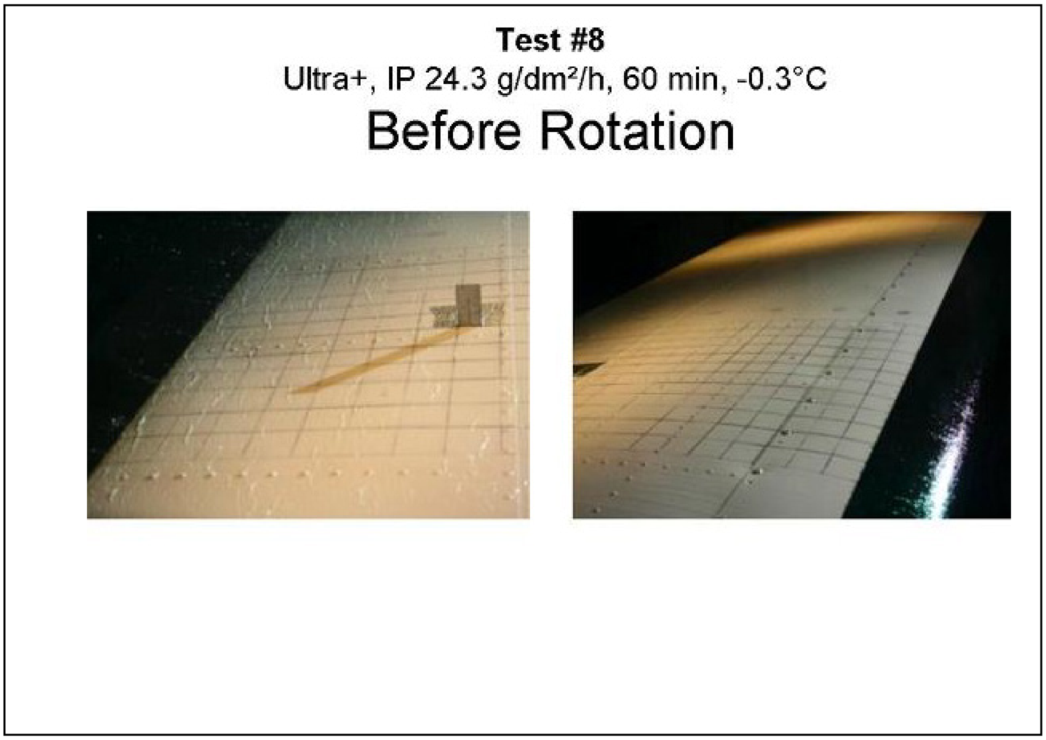


Test #8

Ultra+, IP 24.3 g/dm²/h, 60 min, -0.3°C

Start of Test

Photo 6.10: Test #8 – Before Rotation

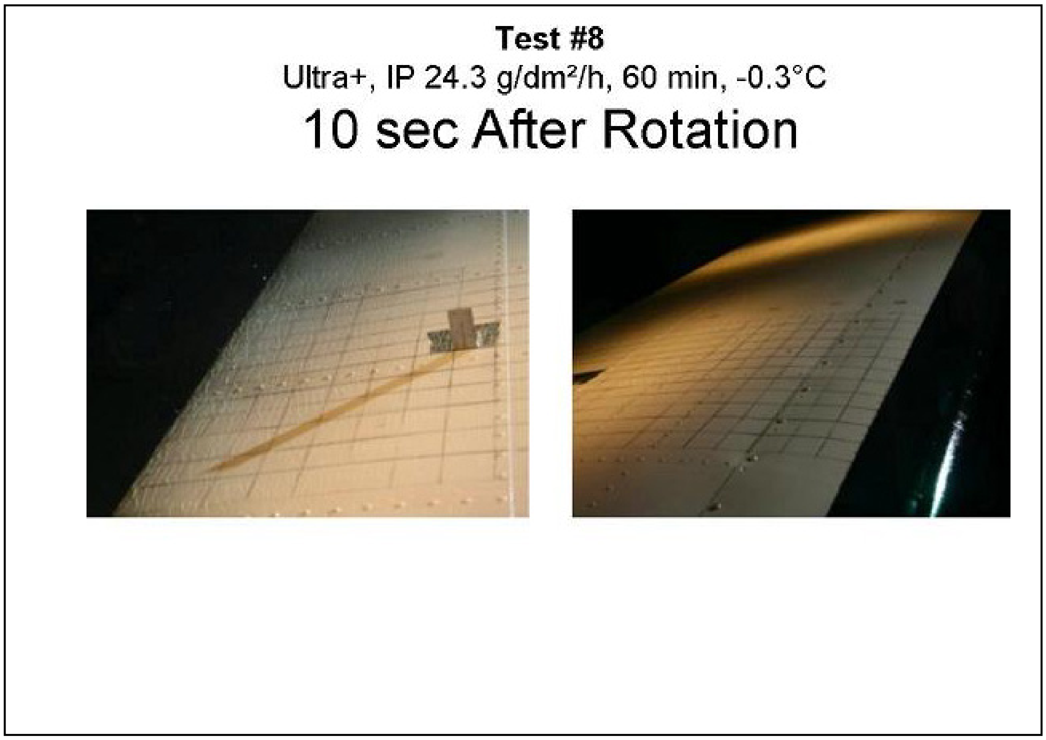


Test #8

Ultra+, IP 24.3 g/dm²/h, 60 min, -0.3°C

Before Rotation

Photo 6.11: Test #8 – 10 Seconds After Rotation

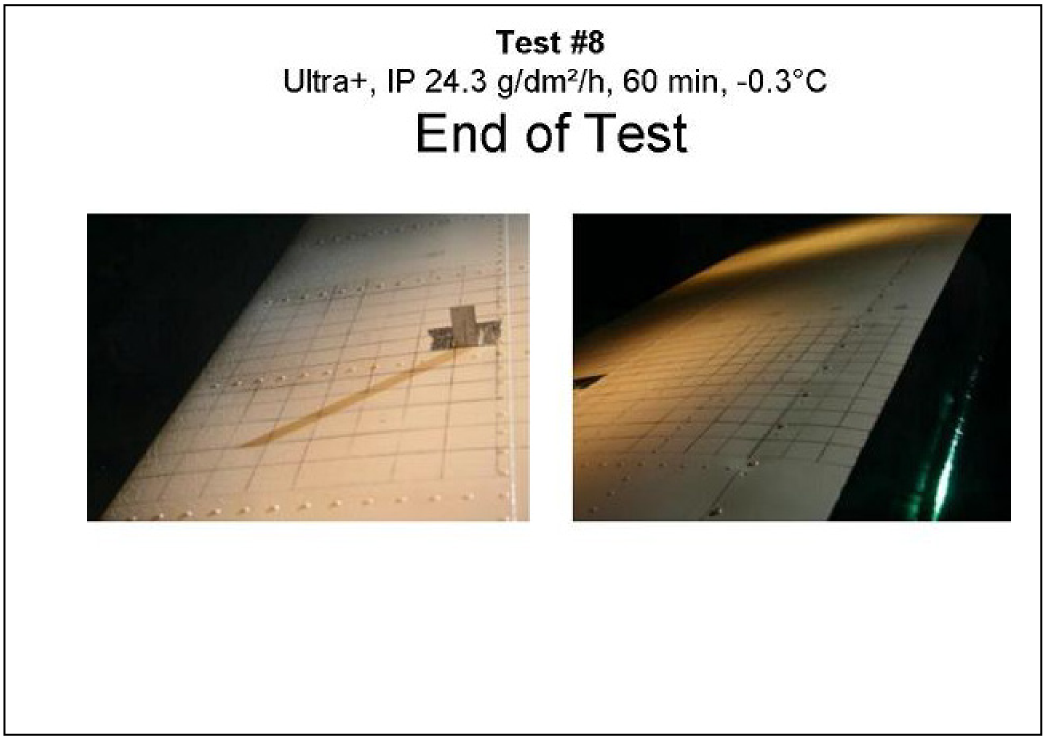


Test #8

Ultra+, IP 24.3 g/dm²/h, 60 min, -0.3°C

10 sec After Rotation

Photo 6.12: Test #8 – End of Test



Test #8

Ultra+, IP 24.3 g/dm²/h, 60 min, -0.3°C

End of Test

7. MODERATE ICE PELLETS ONLY TESTING

This section provides an overview of each test conducted as part of the test program to evaluate the behaviour of anti-icing fluid exposed to moderate ice pellets only conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

7.1 Overview of Tests

A summary of the test conducted in the wind tunnel during moderate ice pellets only is shown in Table 7.1. The table provides relevant information for the test, as well as final values used for the data analysis. The row contains data specific to the test. It should be noted that moderate ice pellets only testing was not conducted with the Falcon 20 aircraft during the winter of 2006-07; results from the 2005-06 testing were referenced and used during the analysis. More detailed test logs of all conditions tested in the wind tunnel and using the Falcon 20 aircraft are provided in Subsections 4.1 and 4.2. A brief description of the column headings can be found in Subsection 5.1.

Table 7.1: Summary of 2006-07 IP Moderate Testing in the NRC Wind Tunnel

Test #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precp. Time (min)	Last 10 min AVG OAT (ºC)	Wing Avg Temp (ºC)	Visual Severity Rating (1-5)
9	22-Feb-07	PG	IP (mod)	0	73	0	30	2.5	-7	2.5

7.2 Data Collected

7.2.1 Coefficient of Lift Curve

Drag and lift data collected by the NRC in the wind tunnel was used to generate a lift coefficient curve for the test.

Figure 7.1 shows the lift coefficient data for the test conducted in moderate ice pellets only conditions. The x-axis indicates the time in seconds as of the start of rotation. The y-axis indicates the Cn (normal coefficient) and Cl (lift coefficient) calculated from the data collected.

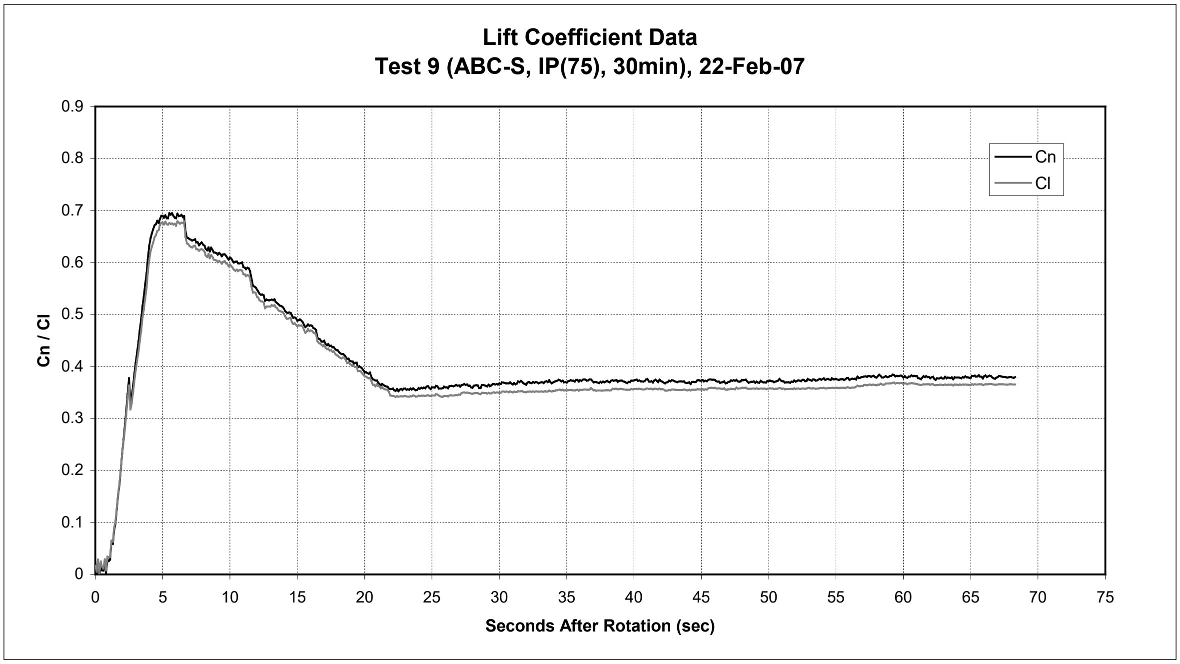


Figure 7.1: Test #9 Lift Coefficient Data

7.2.2 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.1 and 2.2.9.1. Fluid thickness measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).

Table 7.2 shows the fluid thickness measurements collected during the test.

Table 7.2: Test #9 Fluid Thickness Data

TEST 9: ABC-S, IP(75)-30min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.4	1.8	0.0
2	3.7	4.5	0.0
3	5.7	7.0	0.0
4	3.1	5.7	0.0
5	2.5	4.5	0.1
6	2.5	3.9	0.2
7	2.5	3.5	0.3
8	1.8	3.3	0.5

7.2.3 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.3 and 2.2.9.3. Skin temperature measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).

The wing temperature measurements recorded during the test are shown in Table 7.3.

Table 7.3: Test #9 Skin Temperature Data

TEST 9: ABC-S, IP(75)-30min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-1.3	-7.4	1.5
5	-1.3	-8.7	2.9
Under-wing	0.1	-4.5	1.2

7.2.4 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.2 and 2.2.9.2. Fluid Brix measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).

The fluid Brix measurements collected during the test are shown in Table 7.4.

Table 7.4: Test #9 Fluid Brix Data

TEST 9: ABC-S, IP(75)-30min			
Wing Position	Fluid Brix (°)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	36.75	24.50	25.00
8	36.75	19.50	29.50

7.3 Photos

For Test #9, photo summaries have been compiled comprising four stages:

- Start of test;
- Time of rotation;
- 10 seconds after rotation; and
- End of test.

Photos 7.1 to 7.4 show the photo summaries for Test #9. A complete set of photos will be provided to the TDC.

7.4 Results

Wind tunnel Test #9 was conducted at the high end of the precipitation rate for moderate ice pellets (with 30 minutes of exposure), with a wing skin temperature of -7°C. The lift data collected did not show significant signs of lift loss when compared to the baseline fluid only tests. However, some residual contamination was observed on the trailing edge of the wing section following the start of rotation; this contamination was cleared by the end of the test.

7.5 Conclusion and Recommendations

The wind tunnel Test #9 conducted at -7°C demonstrated positive results following 30 minutes of contamination. The working group considered the use of 30 minutes as an allowance time. However, an allowance time of 25 minutes for moderate ice pellets only conditions was agreed upon as a conservative alternative due to the lack of fluids tested as well as the possible variability in the rates produced.

Historical occurrences suggested that operations may frequently occur in the -3°C to -5°C range. As a result of the test data showing good results (i.e., lift loss and residual contamination) at temperatures of -5°C and above, the recommendation to extend the -3°C temperature cut-off (adopted from the current HOT table format) to -5°C was supported. Table 7.5 demonstrates the recommended allowance times for moderate ice pellets only for -5°C and above conditions.

A 10-minute allowance time for -5°C and below conditions was also recommended based on the results from wind tunnel Test #9. Falcon 20 testing conducted during the winter of 2005-06 supported the recommendation. Table 7.5 demonstrates the recommended allowance times for moderate ice pellets only for -5°C and below conditions.

Table 7.5: Recommended Allowance Times for Moderate Ice Pellets Only Conditions

	OAT -5° C and above	OAT Less than -5°C to -10°C	OAT Less than -10° C
Moderate Ice Pellets	25 Minutes	10 Minutes	10 Minutes

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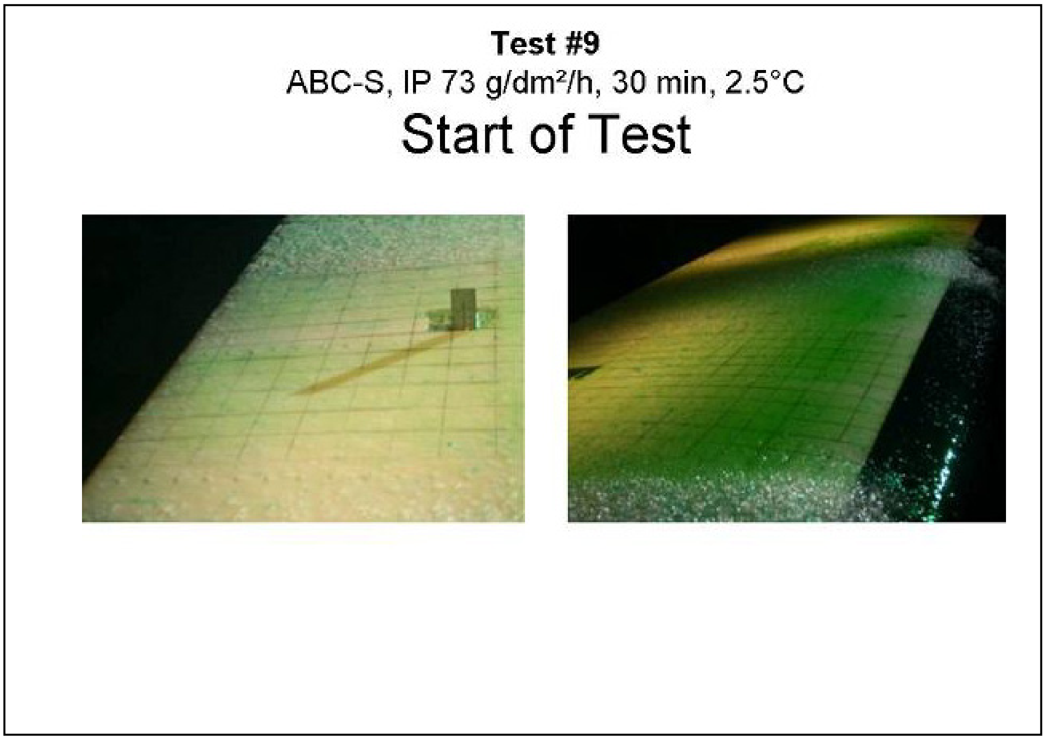
Photo 7.1: Test #9 – Start of Test

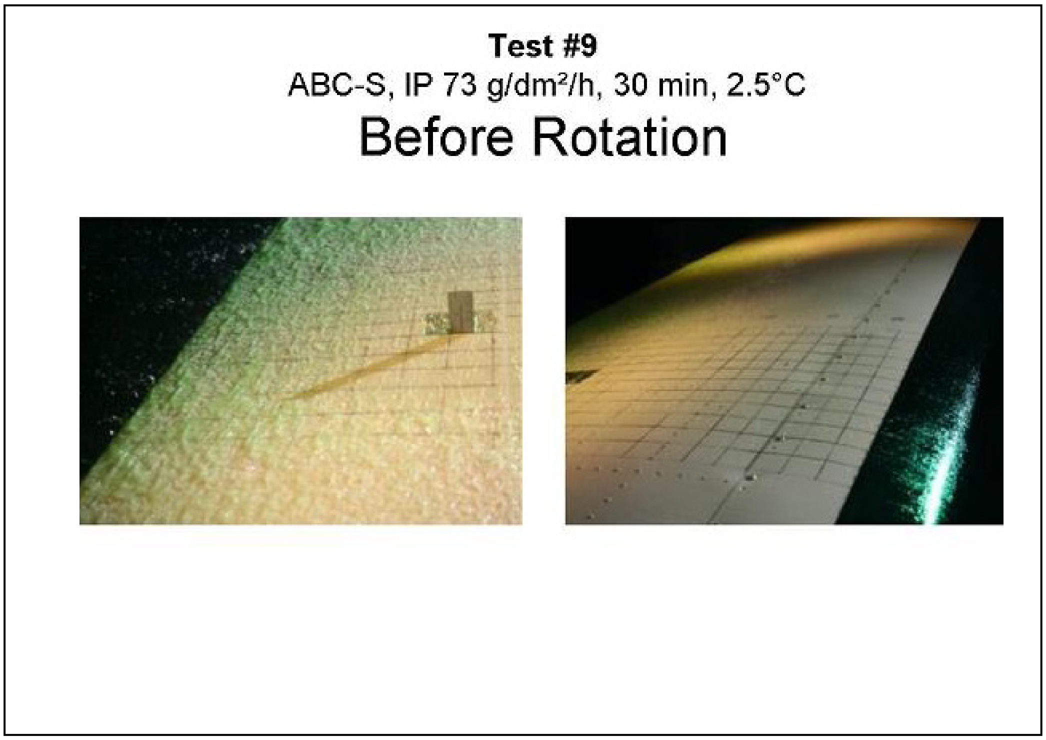


Test #9

ABC-S, IP 73 g/dm²/h, 30 min, 2.5°C

Start of Test

Photo 7.2: Test #9 – Before Rotation

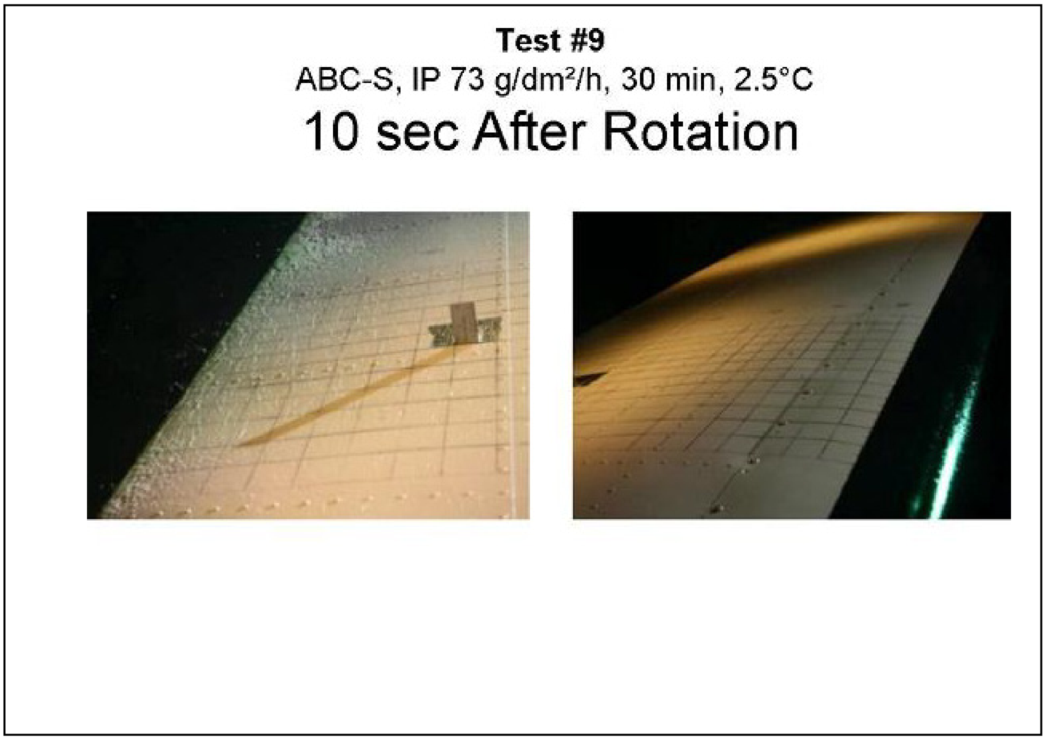


Test #9

ABC-S, IP 73 g/dm²/h, 30 min, 2.5°C

Before Rotation

Photo 7.3: Test #9 – 10 Seconds After Rotation

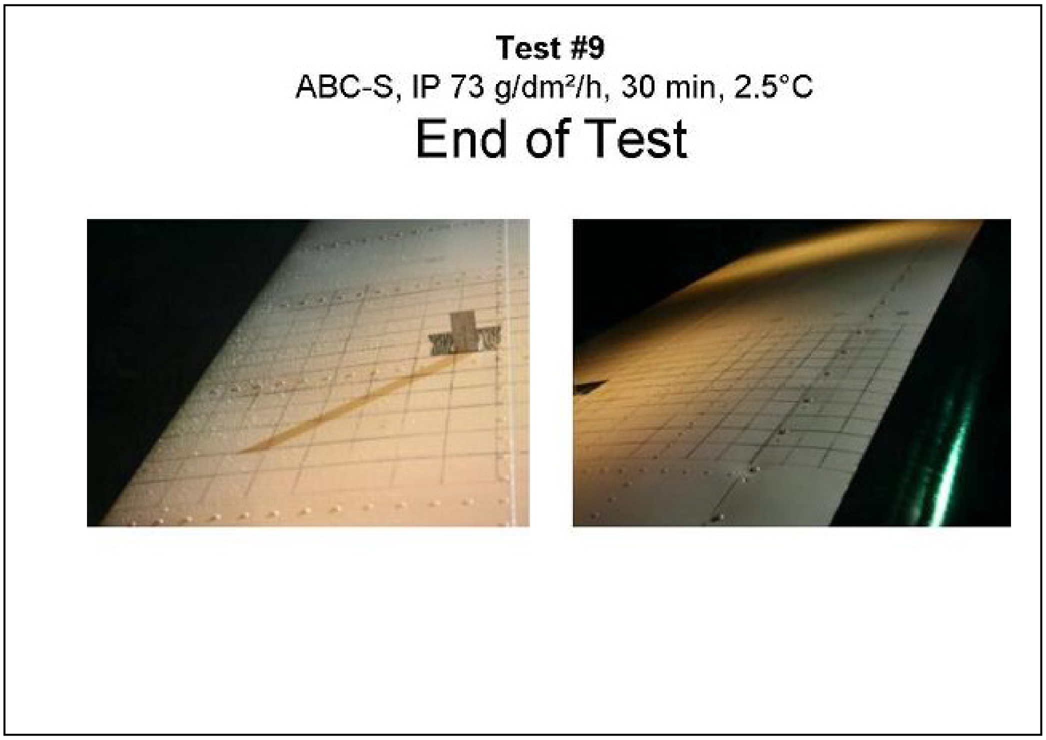


Test #9

ABC-S, IP 73 g/dm²/h, 30 min, 2.5°C

10 sec After Rotation

Photo 7.4: Test #9 – End of Test



Test #9

ABC-S, IP 73 g/dm²/h, 30 min, 2.5°C

End of Test

8. MIXED LIGHT ICE PELLETS AND SNOW

This section provides an overview of each test conducted as part of the test program to evaluate the behaviour of anti-icing fluid exposed to mixed ice pellets and snow conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

8.1 Overview of Tests

A summary of the tests conducted in the wind tunnel during mixed ice pellets and snow is shown in Table 8.1. A summary of the tests conducted using the Falcon 20 aircraft during mixed ice pellets and snow is shown in Table 8.2. The tables provide relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. More detailed test logs of all conditions tested in the wind tunnel and using the Falcon 20 aircraft are provided in Subsections 4.1 and 4.2. A brief description of the column headings can be found in Subsection 5.1.

Table 8.1: Summary of 2006-07 IP-/SN Testing in the NRC Wind Tunnel

Test #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precp. Time (min)	Last 10 min AVG OAT (ºC)	Wing Avg Temp (ºC)	Visual Severity Rating (1-5)
SP1	20-Feb-07	PG	IP/SN	0	19.5	4.3	40	-2.6	-7	2
SP2	20-Feb-07	PG	SN/IP	0	4.9	17.9	40	-5.3	-6	1
SP3	20-Feb-07	EG	IP/SN	0	19.5	4.3	40	-0.2	-8	1
SP4	23-Feb-07	PG	IP/SN	0	24.3	26.1	30	2.1	-7	2

Table 8.2: Summary of 2006-07 IP-/SN Testing with Falcon 20 Aircraft

Test #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precp. Time (min)	OAT (ºC)	Wing Avg Temp (ºC)
3S	**28-Feb-07**	**PG**	**IP/SN**	**-**	**25**	**25**	**30**	**-8**	**-11**
5P	**1-Mar-07**	**PG**	**IP/SN**	**-**	**20**	**20**	**30**	**-11**	**-13**

8.2 Data Collected

8.2.1 Coefficient of Lift Curves

Drag and lift data collected by the NRC was used to generate lift coefficient curves for each test conducted in the wind tunnel. Figures 8.1 to 8.4 show the lift coefficient data for the tests conducted in mixed ice pellets and snow conditions. The x-axis indicates the time in seconds as of the start of rotation. The y-axis indicates the Cn (normal force coefficient) and Cl (lift coefficient) calculated from the data collected.

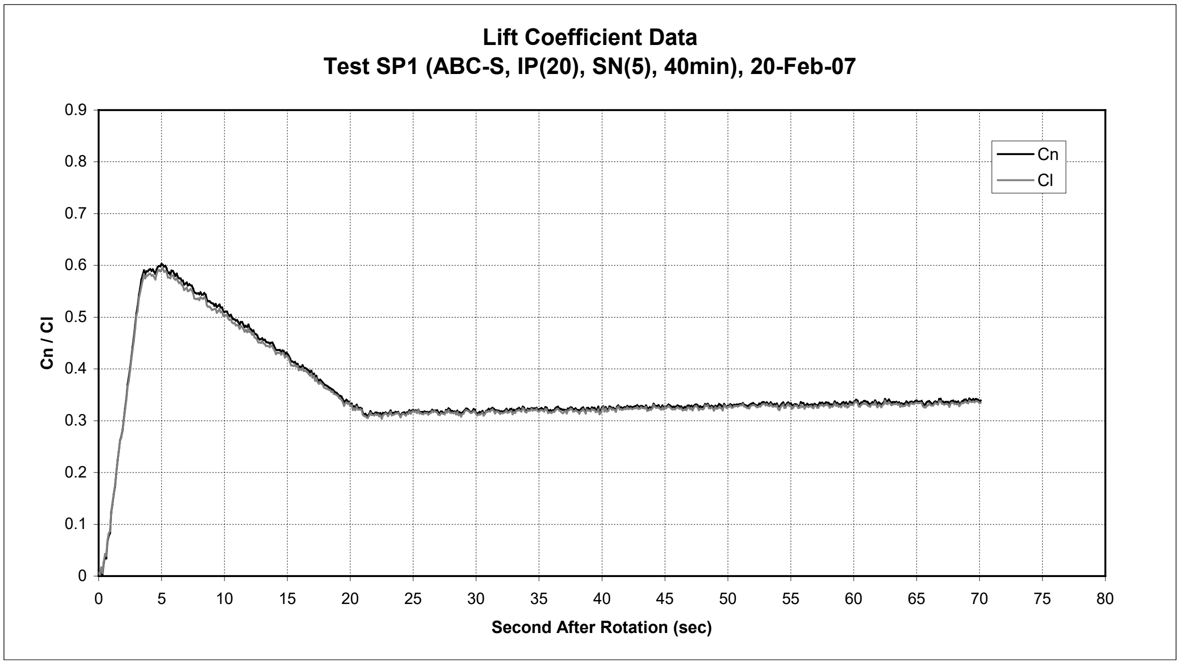


Figure 8.1: Test #SP1 Lift Coefficient Data

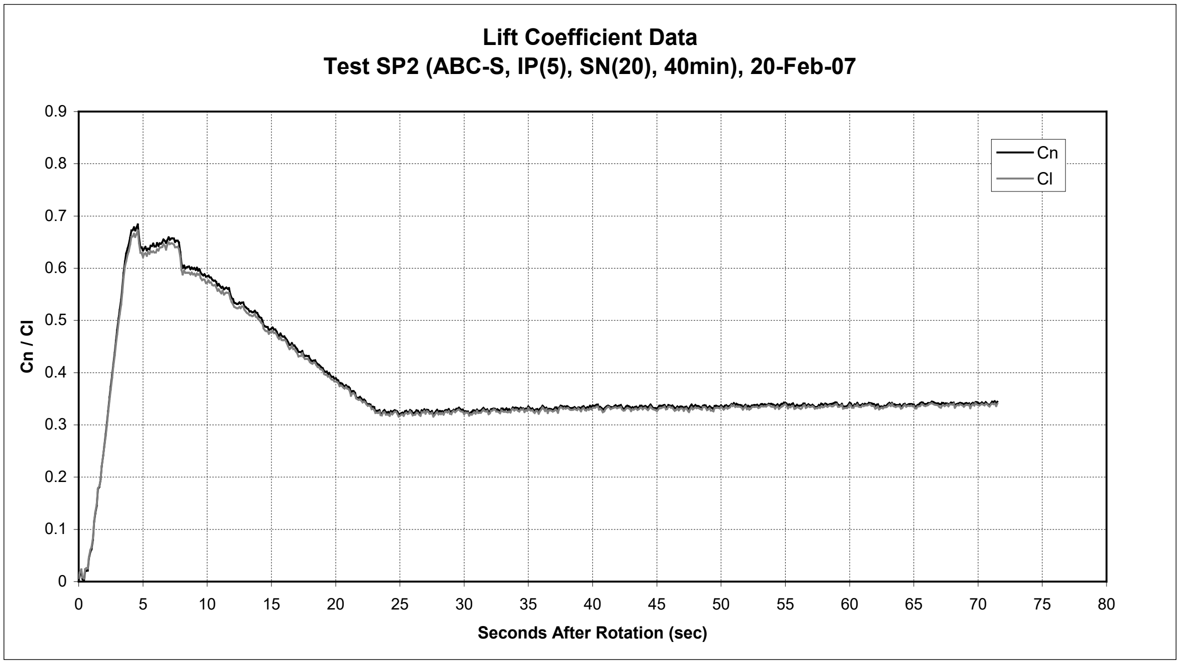


Figure 8.2: Test #SP2 Lift Coefficient Data

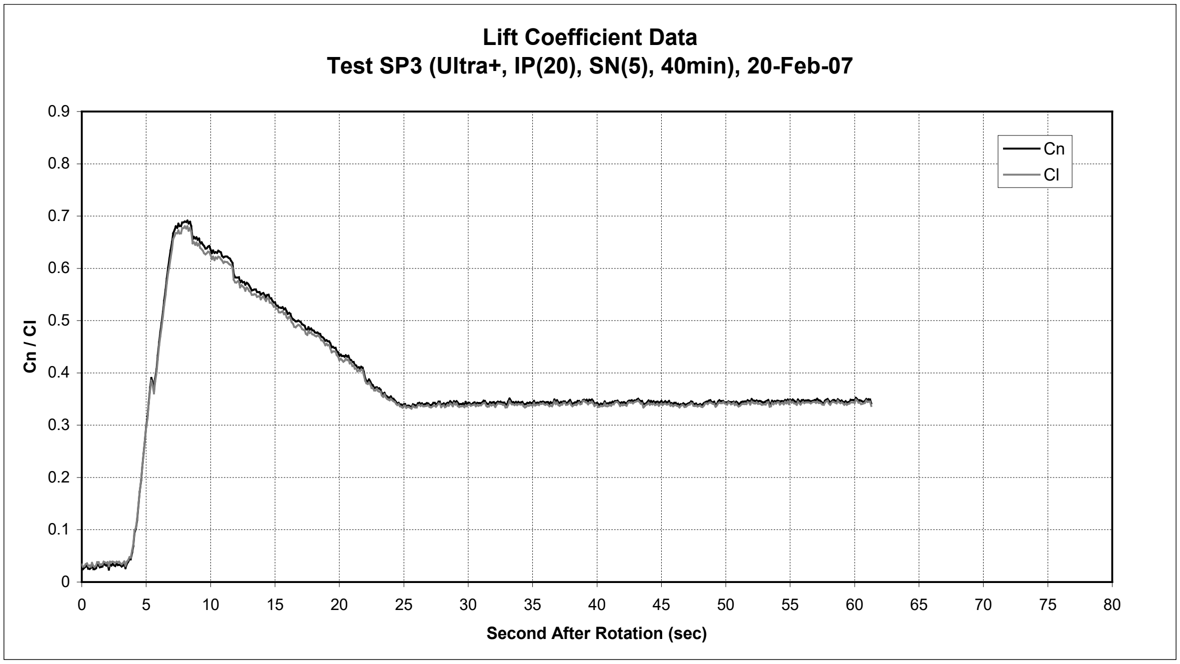


Figure 8.3: Test #SP3 Lift Coefficient Data

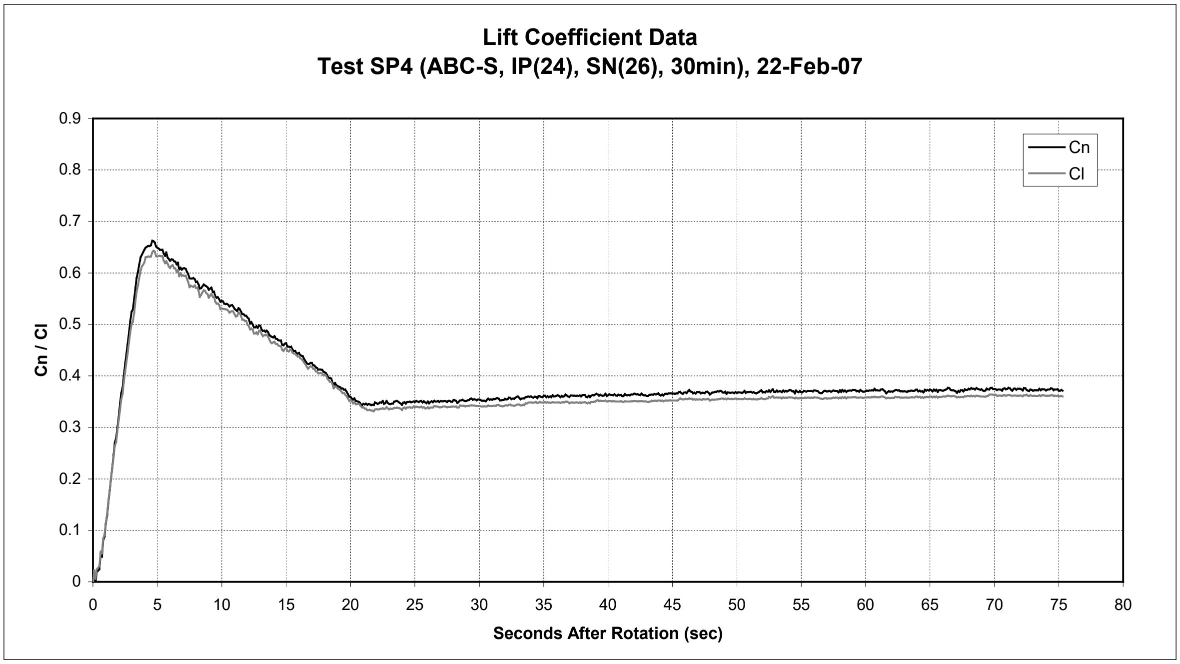


Figure 8.4: Test #SP4 Lift Coefficient Data

8.2.2 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.1 and 2.2.9.1. Fluid thickness measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 8.3 to 8.8 show the fluid thickness measurements collected during the test.

Table 8.3: Test #SP1 Fluid Thickness Data

TEST SP1: ABC-S, IP(20)/SN(5)-40min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.1	1.4	0.0
2	2.9	2.9	0.0
3	4.5	4.5	0.0
4	2.7	4.5	0.0
5	2.2	3.5	0.2
6	2.2	3.3	0.2
7	2.2	3.3	0.3
8	1.8	2.5	0.5

Table 8.4: Test #SP2 Fluid Thickness Data

TEST SP2: ABC-S, IP(5)/SN(20)-40min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	0.8	1.8	0.1
2	2.2	4.5	0.0
3	4.5	4.5	0.0
4	2.7	4.5	0.0
5	2.2	3.5	0.1
6	2.2	3.3	0.2
7	2.2	3.1	0.3
8	2.2	2.9	0.5

Table 8.5: Test #SP3 Fluid Thickness Data

TEST SP3: Ultra+, IP(5)/SN(20)-40min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.8	1.1	0.0
2	4.5	5.7	0.0
3	5.7	5.7	0.0
4	4.5	4.5	0.1
5	3.5	4.5	0.1
6	3.3	3.1	0.1
7	3.1	2.7	0.2
8	3.1	1.8	0.3

Table 8.6: Test #SP4 Fluid Thickness Data

TEST SP4: ABC-S, IP(25)/SN(25)-30min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.4	1.4	0.0
2	3.7	3.1	0.0
3	5.7	5.7	0.0
4	3.1	4.5	0.1
5	2.2	3.5	0.1
6	2.7	3.1	0.2
7	2.7	3.1	0.3
8	2.2	2.7	0.4

Table 8.7: Test #3S Fluid Thickness Data

TEST 3S: ABC-S, IP(25)/SN(25) - 30min				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	0.8	4.5	4.5	0.0
2	1.7	4.5	4.5	0.0
5	3.7	4.5	4.5	0.1
7	1.7	2.7	N/A	0.3
8	0.8	3.1	N/A	0.2

Table 8.8: Test #5P Fluid Thickness Data

TEST 5P: ABC-S, IP(20)/SN(20) - 30min				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	0.7	0.1	0.4	0.1
2	1.3	3.1	2.2	0.2
5	3.1	3.3	4.5	0.4
7	1.3	3.5	N/A	0.6
8	1.5	3.5	N/A	0.6

8.2.3 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.3 and 2.2.9.3. Skin temperature measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination;
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 8.9 to 8.14.

Table 8.9: Test #SP1 Skin Temperature Data

TEST SP1: ABC-S, IP(20)/SN(5)-40min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-6.0	-7.5	-5.0
5	-4.4	-6.7	-2.5
Under-wing	-5.0	-5.7	-6.0

Table 8.10: Test #SP2 Skin Temperature Data

TEST SP2: ABC-S, IP(5)/SN(20)-40min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-4.9	-6.6	-1.8
5	-4.4	-6.0	-0.3
Under-wing	-2.5	-2.7	-2.2

Table 8.11: Test #SP3 Skin Temperature Data

TEST SP3: Ultra+, IP(5)/SN(20)-40min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-3.0	-8.3	0.8
5	-1.4	-7.4	2.7
Under-wing	-1.1	-1.7	0.7

Table 8.12: Test #SP4 Skin Temperature Data

TEST SP4: ABC-S, IP(24)/SN(26)-30min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-0.9	-6.7	1.2
5	0.2	-7.4	3.2
Under-wing	0.0	-1.4	1.3

Table 8.13: Test #3S Skin Temperature Data

TEST 3S: ABC-S, IP(25)/SN(25) - 30min				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-9.0	-12.1	-10.1	-10.3
2	-9.1	-12.8	-10.2	-10.1
3	-8.9	-12.6	-11.0	-10.4
4	-8.7	-12.8	-11.2	-10.4
5	-7.8	-12.6	-10.8	-10.2
6	-7.8	-12.4	-10.8	-10.4
7	-10.4	-12.4	N/A	-10.1
8	-10.9	-13.0	N/A	-10.1

Table 8.14: Test #5P Skin Temperature Data

TEST 5P: ABC-S, IP(20)/SN(20) - 30min				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-12.5	-13.4	-11.7	-12.3
2	-12.6	-13.9	-12.3	-12.5
3	-12.3	-14.6	-12.7	-12.5
4	-12.9	-15.6	-13.1	-12.9
5	-10.8	-14.8	-13.3	-13.0
6	-10.7	-14.2	-13.9	-13.0
7	-13.5	-16.7	N/A	-13.6
8	-15.7	-16.7	N/A	-13.6

8.2.4 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.2 and 2.2.9.2. Fluid Brix measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination;
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The fluid Brix measurements collected during each test are shown in Tables 8.15 to 8.20.

Table 8.15: Test #SP1 Fluid Brix Data

TEST SP1: ABC-S, IP(20)/SN(5)-40min			
Wing	Fluid Brix (°)		
Position	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	36.75	28.00	27.00
8	37.00	17.50	31.00

Table 8.16: Test #SP2 Fluid Brix Data

TEST SP2: ABC-S, IP(5)/SN(20)-40min			
Wing	Fluid Brix (°)		
Position	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.00	25.50	30.00
8	37.00	21.50	34.50

Table 8.17: Test #SP3 Fluid Brix Data

TEST SP3: Ultra+, IP(5)/SN(20)-40min			
Wing	Fluid Brix (°)		
Position	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	40.25	18.00	37.50
8	40.25	23.50	39.25

Table 8.18: Test #SP4 Fluid Brix Data

TEST SP4: ABC-S, IP(24)/SN(26)-30min			
Wing	Fluid Brix (°)		
Position	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.00	22.00	22.00
8	37.00	17.00	27.50

Table 8.19: Test #3S Fluid Brix Data

TEST 3S: ABC-S, IP(25)/SN(25) - 30min				
Wing	Fluid Brix (°)			
Position	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	21.00	18.00	30.00
5	37.00	19.50	N/A	30.00

Table 8.20: Test #5P Fluid Brix Data

TEST 5P: ABC-S, IP(20)/SN(20) - 30min				
Wing	Fluid Brix (°)			
Position	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.50	26.50	24.50	26.25
5	37.25	23.25	N/A	23.25

8.3 Photos

For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- Time of rotation;
- 10 seconds after rotation; and
- End of test.

Photos 8.1 to 8.24 show the photo summaries for Tests #SP1, #SP2, #SP3, #SP4, #3S, and #5P. A complete set of photos will be provided to the TDC.

8.4 Results

Wind tunnel Test #SP1 was conducted at a combined precipitation rate of 25 g/dm²/h of mixed snow and ice pellets (with 40 minutes of exposure), with a wing skin temperature of -7°C. The contamination was completely cleared from the trailing edge shortly after the start of rotation. Some lift loss was also observed from the data collected; this may have been due to the “water deficient design” of the fluid, which allowed the fluid viscosity to increase as the fluid diluted from a neat concentration to approximately a 75/25 concentration, measured using the fluid Brixometer.

Wind tunnel Tests #SP2 and #SP3 were conducted at a combined precipitation rate of 25 g/dm²/h of mixed snow and ice pellets (with 40 minutes of exposure), with a wing skin temperature of -6°C and -8°C, respectively. The lift data collected did not show significant lift loss when compared to the fluid only tests. During both tests the contamination was cleared from the trailing edge before rotation.

Wind tunnel Test #SP4 was conducted at a combined precipitation rate of 50 g/dm²/h of mixed snow and ice pellets (with 30 minutes of exposure), with a wing skin temperature of -7°C. The lift data collected did not show significant lift loss when compared to the fluid only tests. Some contamination remained at the start of rotation, but was cleared shortly after; no contamination was left over at the end of the test.

Tests #3S and #5P were conducted using the Falcon 20 aircraft at a combined precipitation rate of 50 g/dm²/h of mixed snow and ice pellets (with 30 minutes of exposure) and demonstrated some residual contamination on the trailing edge of the wing test sections following the end of the tests. These tests were conducted with skin temperatures of -11°C and -13°C, respectively.

8.5 Conclusion and Recommendations

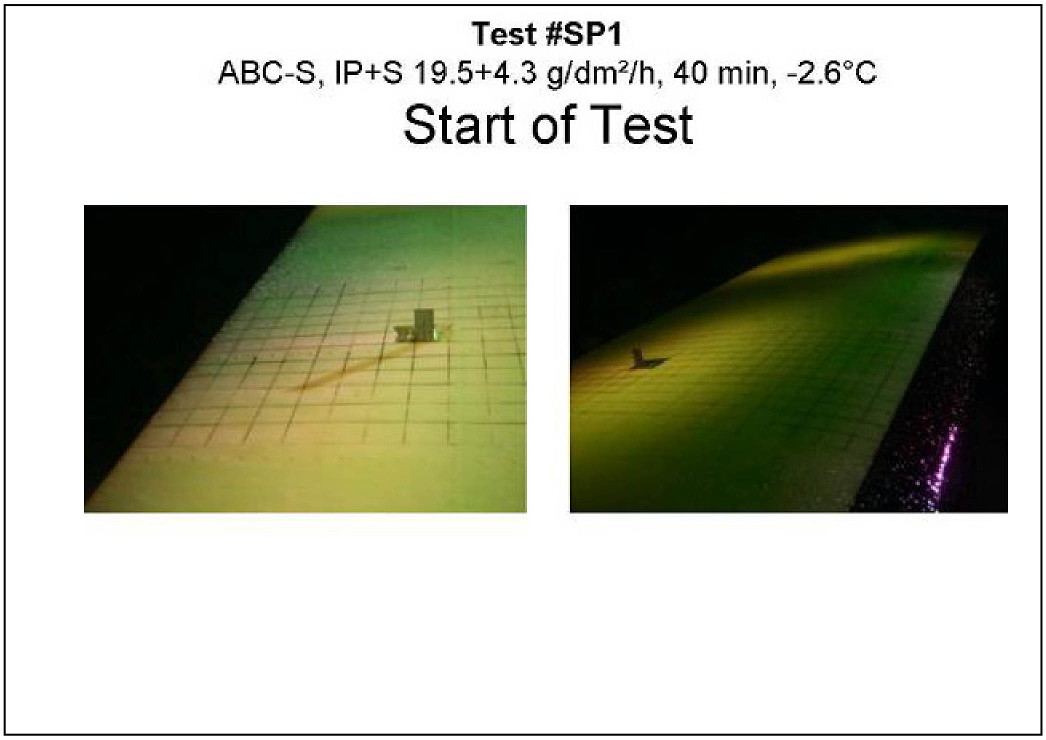
The generic snow HOTs were referenced during the working group meeting; the lower limit for above -3°C for a Type IV neat fluid in moderate snow conditions is 30 minutes. Based on the data collected and the possible lift losses observed in the wind tunnel during the mixed ice pellets and snow conditions, an allowance time of 25 minutes was recommended by the working group for light ice pellets mixed with snow conditions. This was deemed appropriate; the allowance time was shorter than the snow only HOT of 30 minutes for -3°C and above conditions and shorter than the light ice pellets only allowance time of 50 minutes for -5°C and above conditions.

Due to the residual contamination observed on the trailing edge during the Falcon 20 tests, operations in mixed ice pellets and snow conditions were restricted to above -5°C conditions. In addition, further work was recommended to investigate fluid flow-off properties in mixed ice pellets and snow conditions at temperatures below -5°C. Table 8.21 demonstrates the recommended allowance times for mixed ice pellets and snow conditions for -5°C and above conditions.

Table 8.21: Recommended Allowance Times for Ice Pellets and Snow Conditions

	OAT -5° C and above	**OAT Less than -5°C to -10°C**	**OAT Less than -10° C**
Light Ice Pellets Mixed with Light or Moderate Snow	25 Minutes	**Caution: No Allowance times currently exist**	

Photo 8.1: Test #SP1 – Start of Test

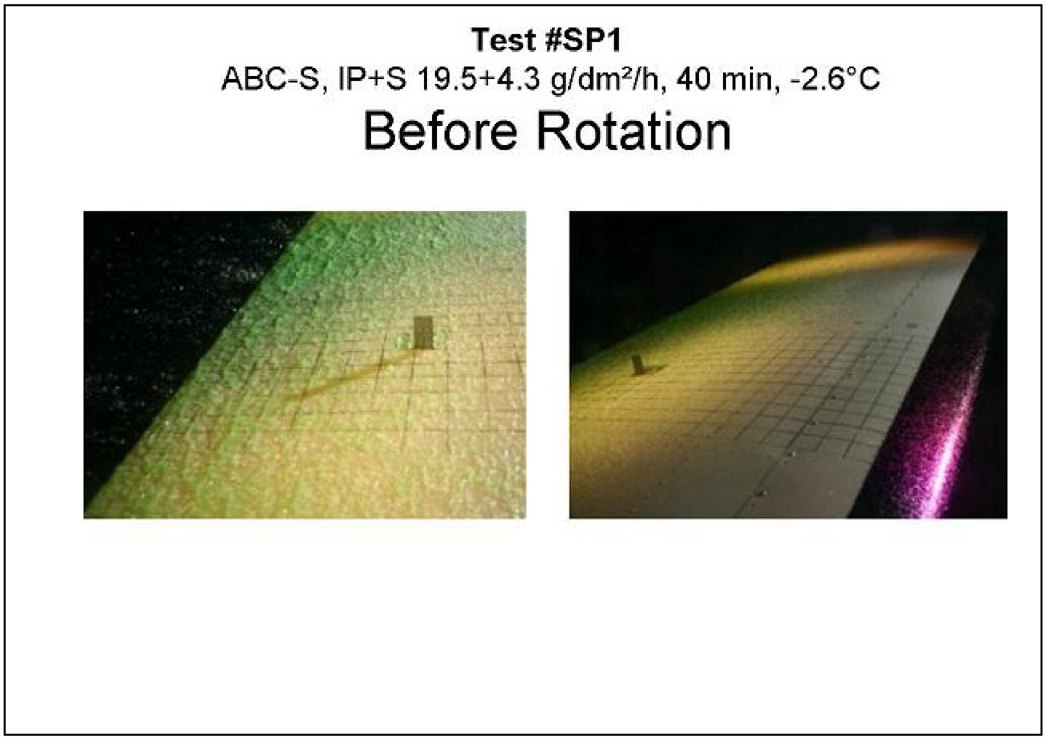


Test #SP1

ABC-S, IP+S 19.5+4.3 g/dm²/h, 40 min, -2.6°C

Start of Test

Photo 8.2: Test #SP1 – Before Rotation

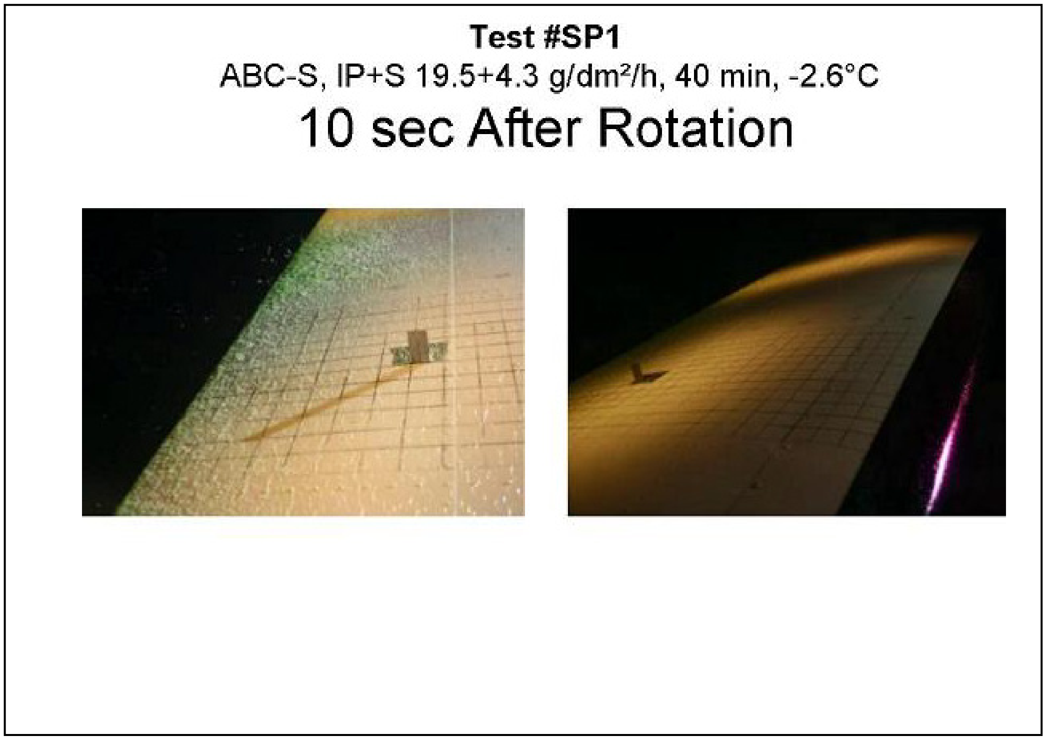


Test #SP1

ABC-S, IP+S 19.5+4.3 g/dm²/h, 40 min, -2.6°C

Before Rotation

Photo 8.3: Test #SP1– 10 Seconds After Rotation

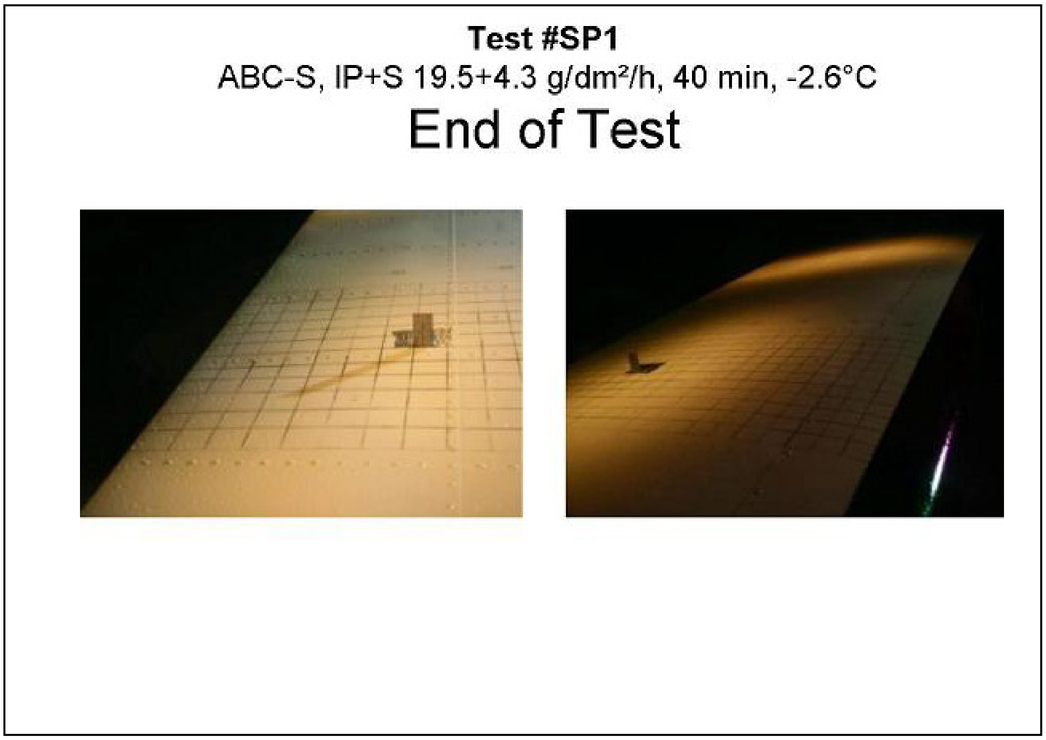


Test #SP1

ABC-S, IP+S 19.5+4.3 g/dm²/h, 40 min, -2.6°C

10 sec After Rotation

Photo 8.4: Test #SP1 – End of Test

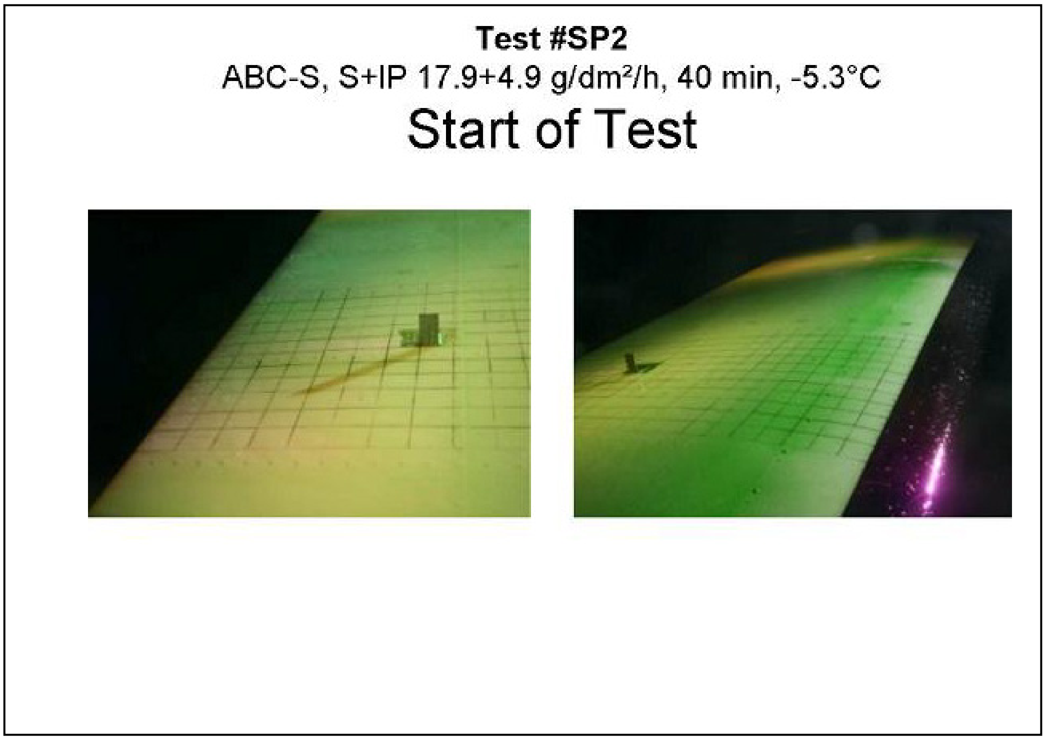


Test #SP1

ABC-S, IP+S 19.5+4.3 g/dm²/h, 40 min, -2.6°C

End of Test

Photo 8.5: Test #SP2 – Start of Test

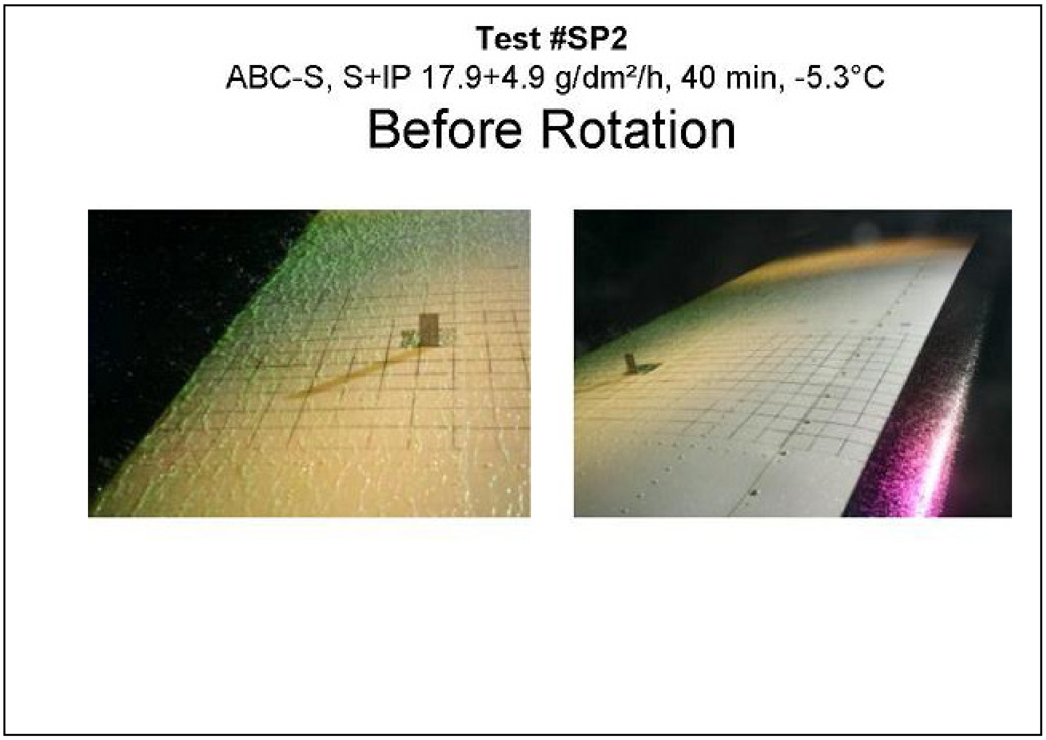


Test #SP2

ABC-S, S+IP 17.9+4.9 g/dm^2/h, 40 min, -5.3°C

Start of Test

Photo 8.6: Test #SP2 – Before Rotation

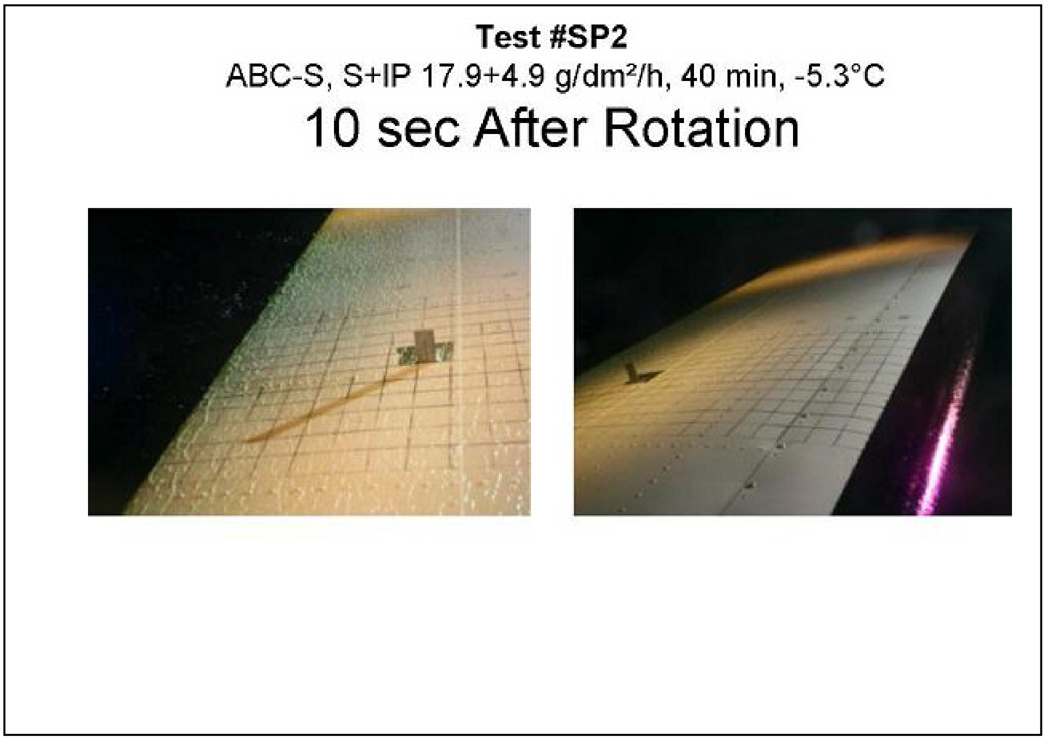


Test #SP2

ABC-S, S+IP 17.9+4.9 g/dm^2/h, 40 min, -5.3°C

Before Rotation

Photo 8.7: Test #SP2 – 10 Seconds After Rotation

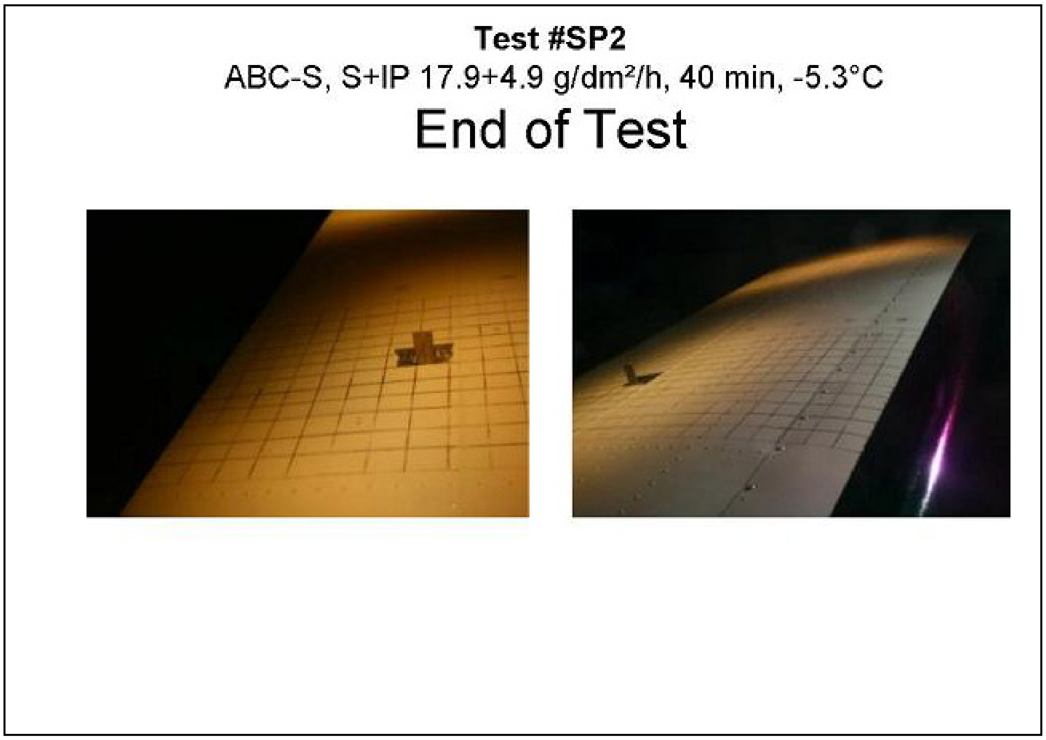


Test #SP2

ABC-S, S+IP 17.9+4.9 g/dm²/h, 40 min, -5.3°C

10 sec After Rotation

Photo 8.8: Test #SP2 – End of Test

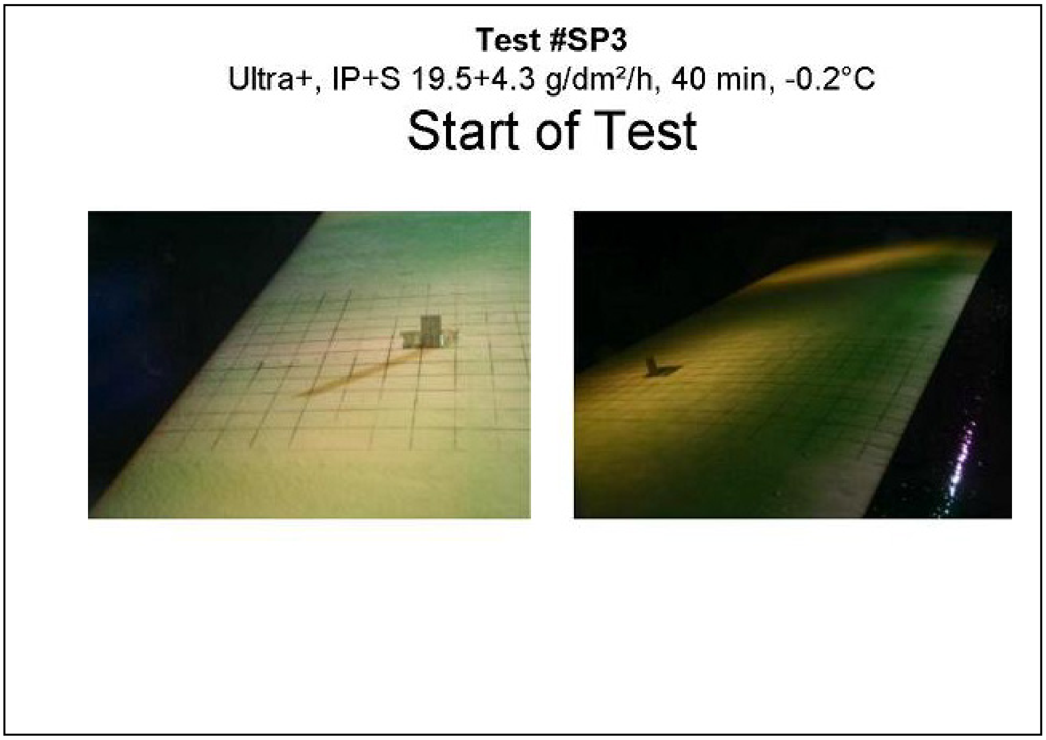


Test #SP2

ABC-S, S+IP 17.9+4.9 g/dm²/h, 40 min, -5.3°C

End of Test

Photo 8.9: Test #SP3 – Start of Test

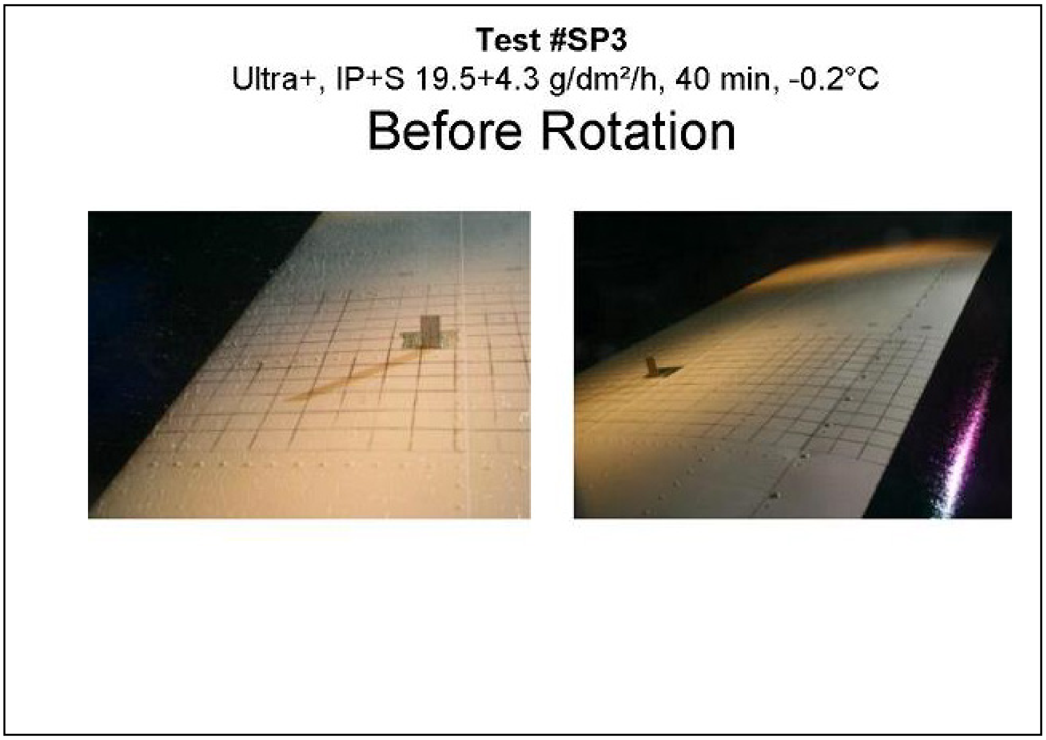


Test #SP3

Ultra+, IP+S 19.5+4.3 g/dm²/h, 40 min, -0.2°C

Start of Test

Photo 8.10: Test #SP3 – Before Rotation



Test #SP3

Ultra+, IP+S 19.5+4.3 g/dm²/h, 40 min, -0.2°C

Before Rotation

Photo 8.11: Test #SP3 – 10 Seconds After Rotation

Test #SP3

Ultra+, IP+S 19.5+4.3 g/dm²/h, 40 min, -0.2°C

10 sec After Rotation

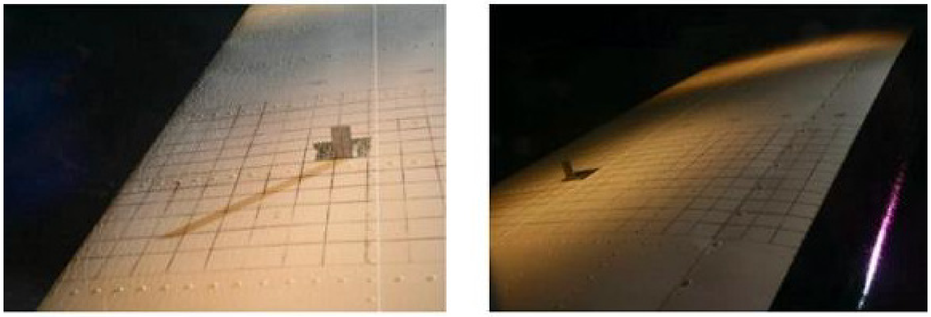


Photo 8.12: Test #SP3 – End of Test

Test #SP3

Ultra+, IP+S 19.5+4.3 g/dm²/h, 40 min, -0.2°C

End of Test

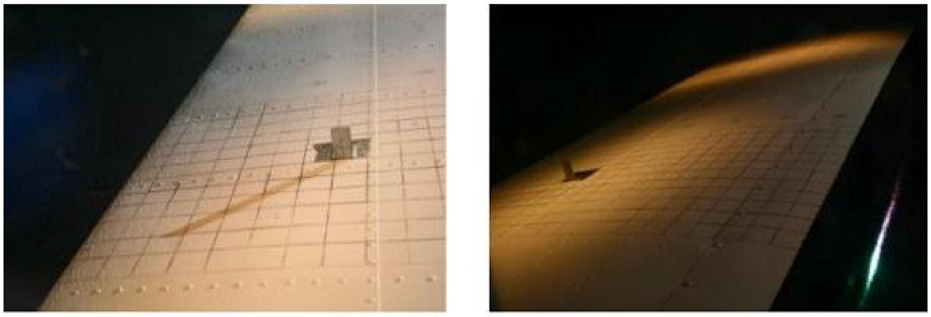
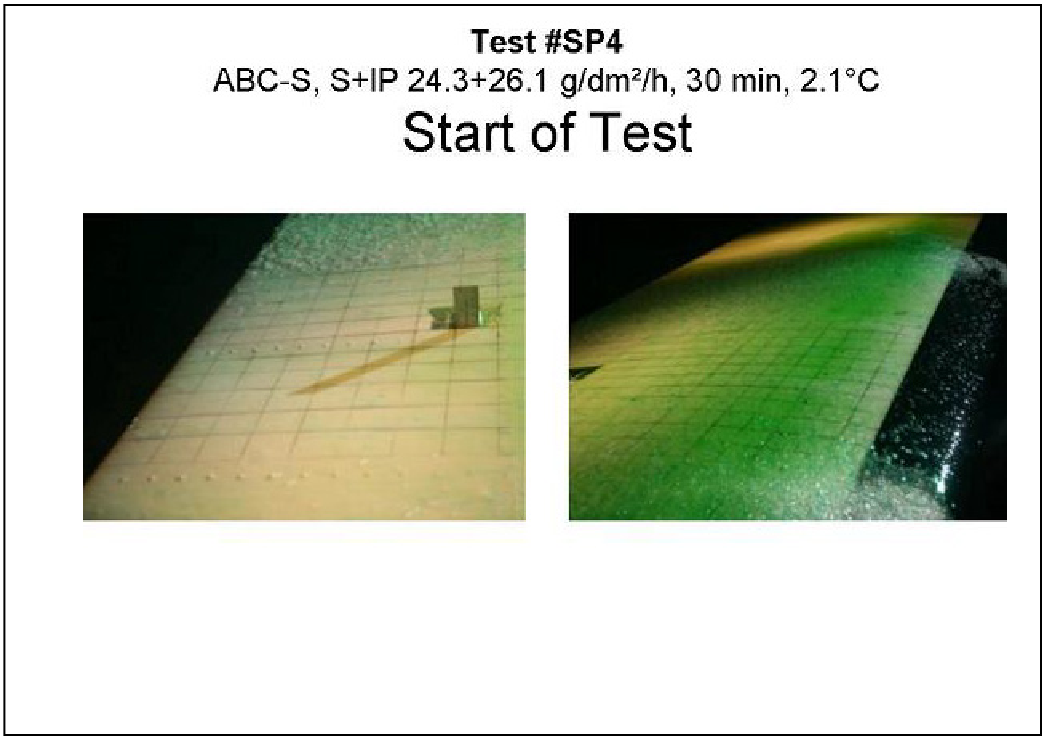


Photo 8.13: Test #SP4 – Start of Test

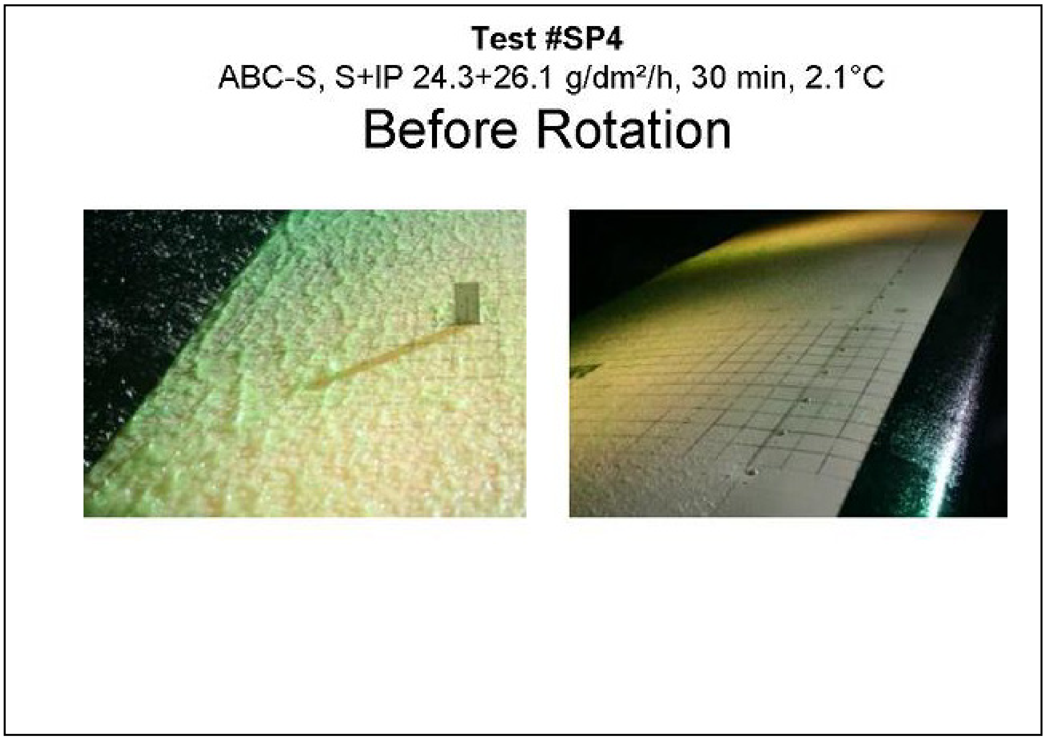


Test #SP4

ABC-S, S+IP 24.3+26.1 g/dm²/h, 30 min, 2.1°C

Start of Test

Photo 8.14: Test #SP4 – Before Rotation

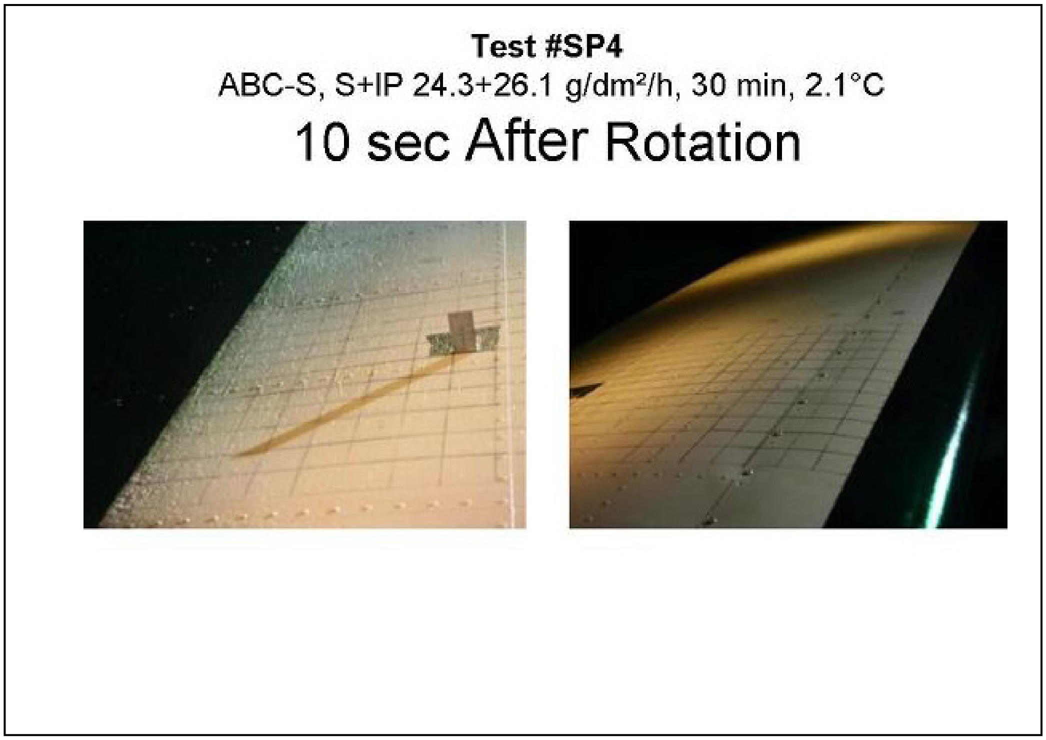


Test #SP4

ABC-S, S+IP 24.3+26.1 g/dm²/h, 30 min, 2.1°C

Before Rotation

Photo 8.15: Test #SP4 – 10 Seconds After Rotation

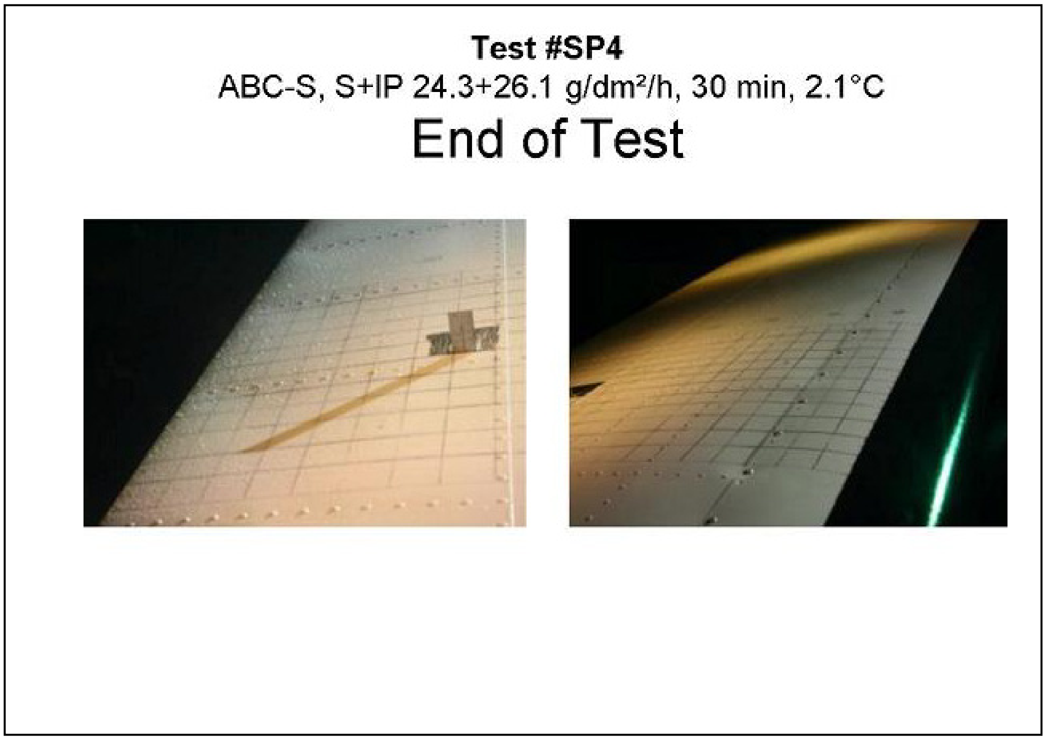


Test #SP4

ABC-S, S+IP 24.3+26.1 g/dm^2/h, 30 min, 2.1°C

10 sec After Rotation

Photo 8.16: Test #SP4 – End of Test

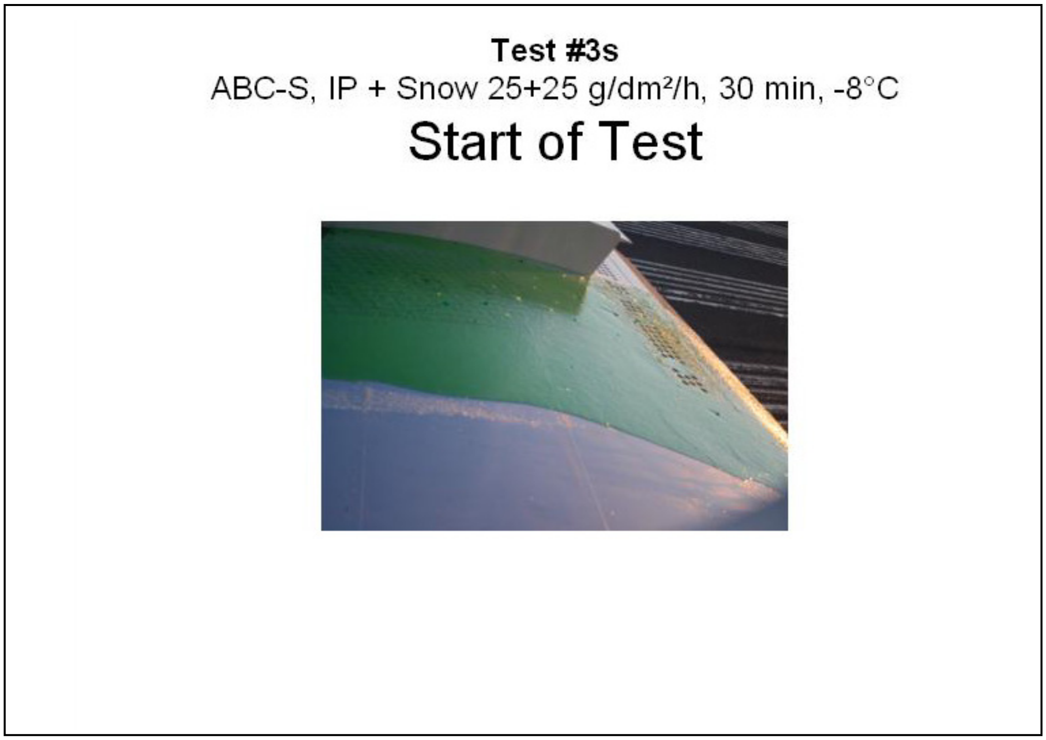


Test #SP4

ABC-S, S+IP 24.3+26.1 g/dm^2/h, 30 min, 2.1°C

End of Test

Photo 8.17: Test #3S – Start of Test

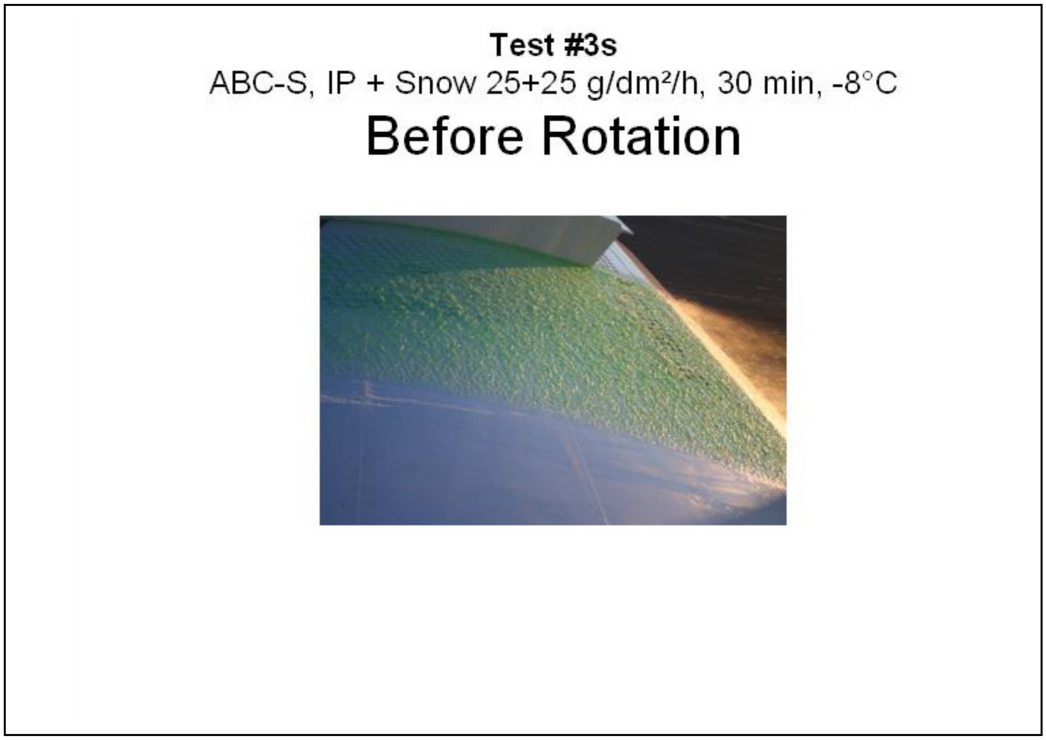


Test #3s

ABC-S, IP + Snow 25+25 g/dm²/h, 30 min, -8°C

Start of Test

Photo 8.18: Test #3S – Before Rotation

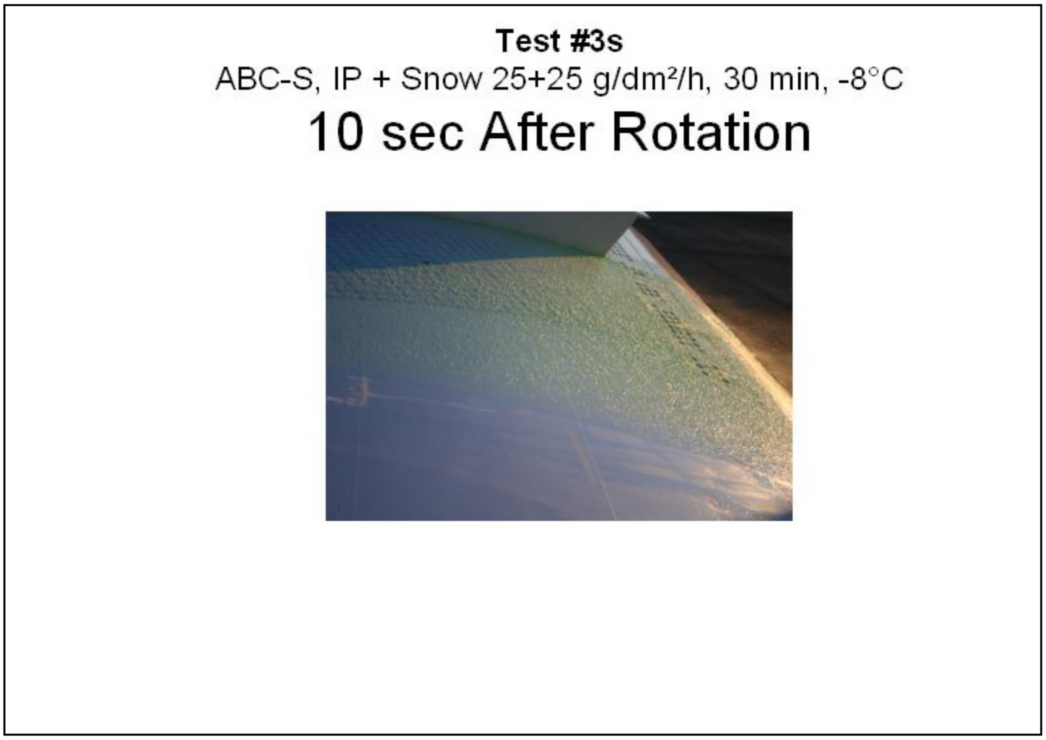


Test #3s

ABC-S, IP + Snow 25+25 g/dm²/h, 30 min, -8°C

Before Rotation

Photo 8.19: Test #3S – 10 Seconds After Rotation

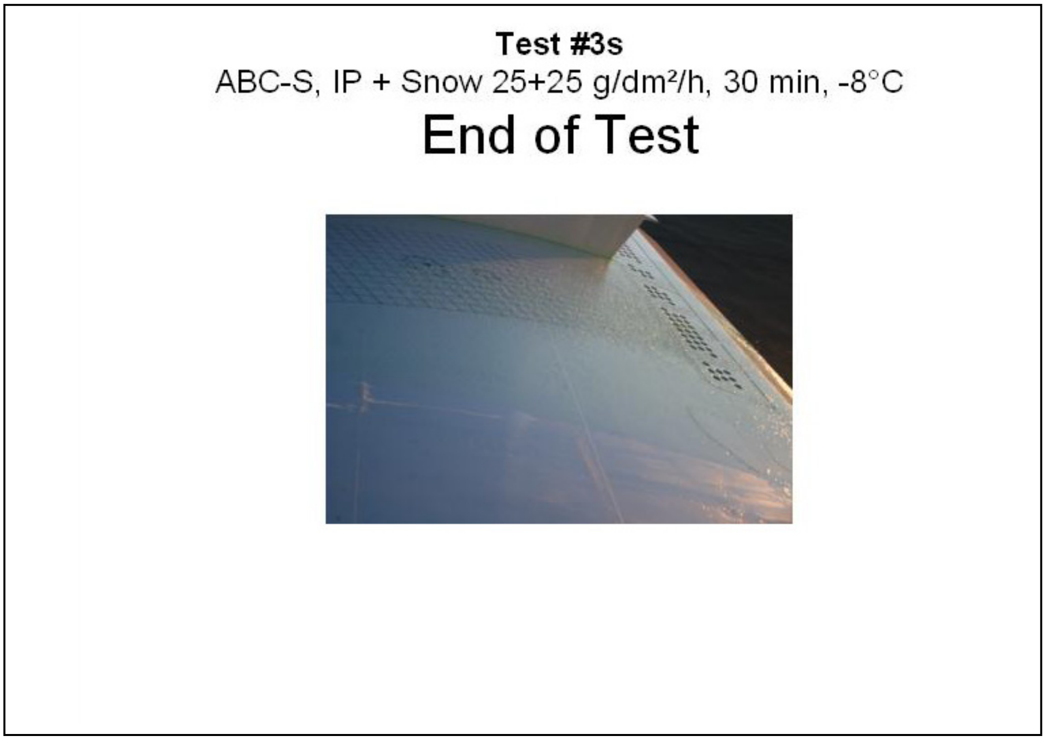


Test #3s

ABC-S, IP + Snow 25+25 g/dm²/h, 30 min, -8°C

10 sec After Rotation

Photo 8.20: Test #3S – End of Test

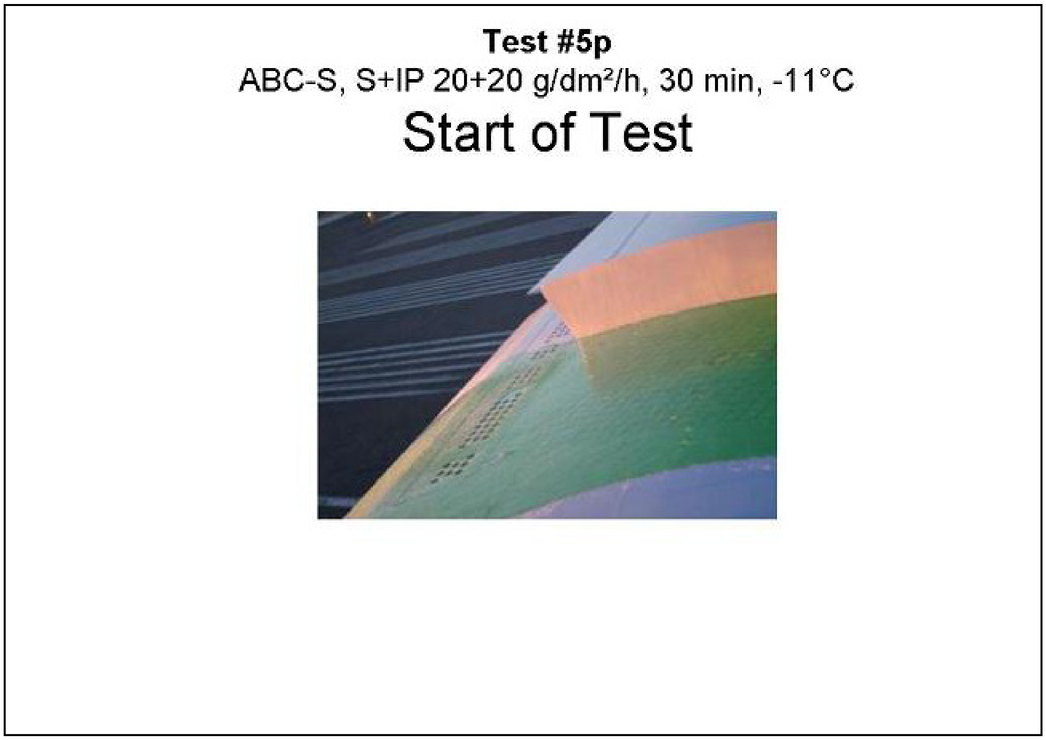


Test #3s

ABC-S, IP + Snow 25+25 g/dm²/h, 30 min, -8°C

End of Test

Photo 8.21: Test #5P – Start of Test

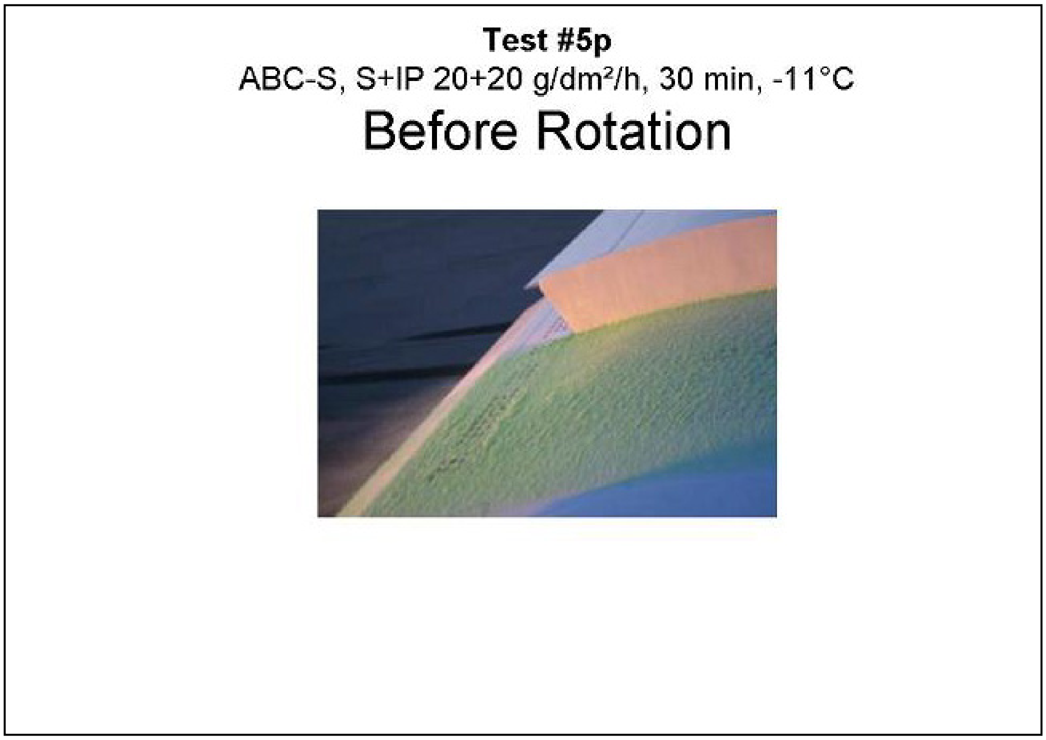


Test #5p

ABC-S, S+IP 20+20 g/dm^2/h, 30 min, -11°C

Start of Test

Photo 8.22: Test #5P – Before Rotation

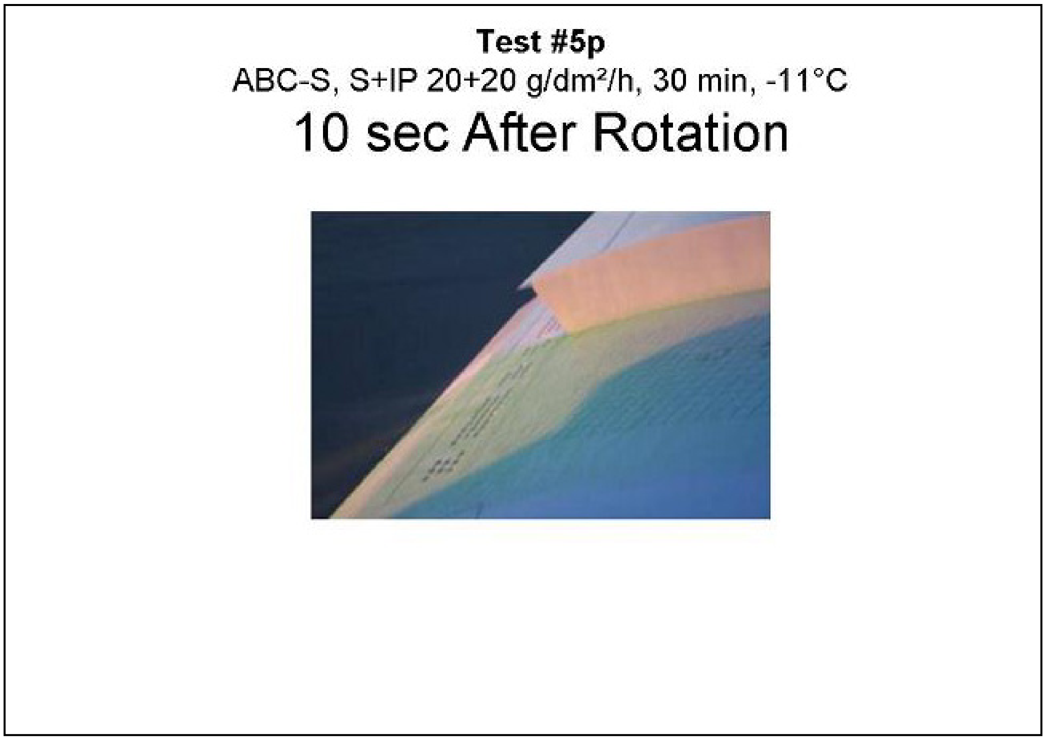


Test #5p

ABC-S, S+IP 20+20 g/dm^2/h, 30 min, -11°C

Before Rotation

Photo 8.23: Test #5P – 10 Seconds After Rotation

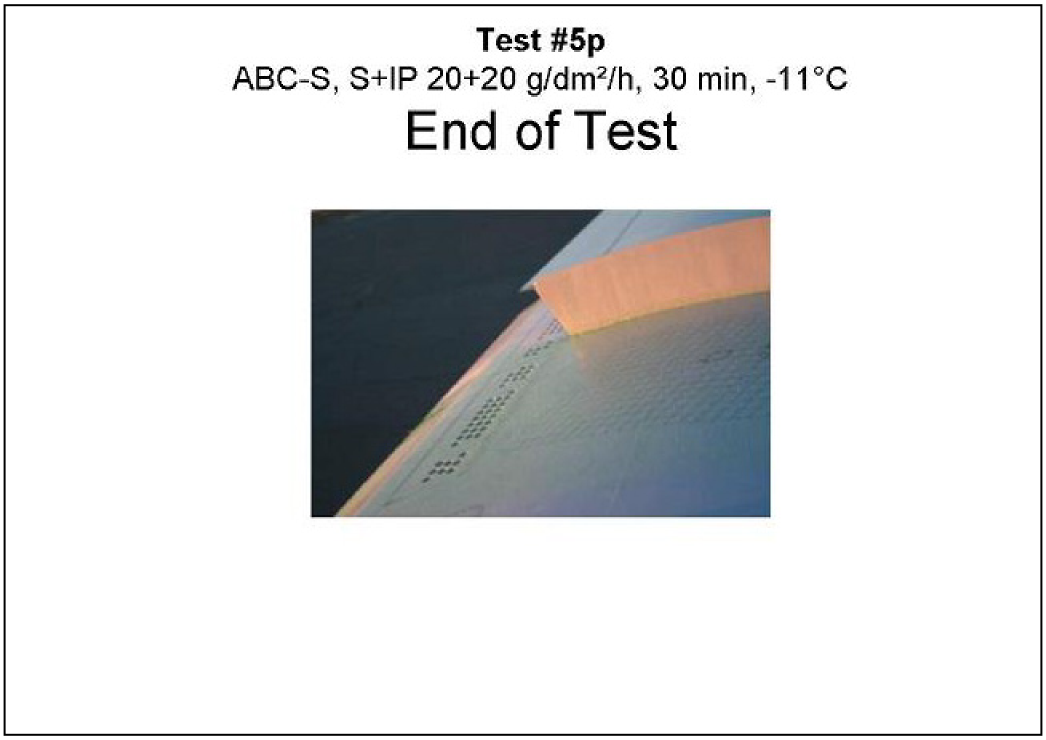


Test #5p

ABC-S, S+IP 20+20 g/dm²/h, 30 min, -11°C

10 sec After Rotation

Photo 8.24: Test #5P – End of Test



Test #5p

ABC-S, S+IP 20+20 g/dm²/h, 30 min, -11°C

End of Test

9. MIXED LIGHT ICE PELLETS AND LIGHT FREEZING RAIN

This section provides an overview of each test conducted as part of the test program to evaluate the behaviour of anti-icing fluid exposed to mixed light ice pellets and light freezing rain conditions. The parameters for each test are detailed, and a description of the data collected during each test is provided.

9.1 Overview of Tests

A summary of the tests conducted in the wind tunnel during mixed light ice pellets and light freezing rain conditions is shown in Table 9.1. A summary of the tests conducted using the Falcon 20 aircraft during mixed light ice pellets and light freezing rain conditions is shown in Table 9.2. The tables provide relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. More detailed test logs of all conditions tested in the wind tunnel and using the Falcon 20 aircraft are provided in Subsections 4.1 and 4.2. A brief description of the column headings can be found in Subsection 5.1.

Table 9.1: Summary of 2006-07 IP-/ZR- Testing in the NRC Wind Tunnel

Test #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Precp. Time (min)	Last 10 min AVG OAT (ºC)	Wing Avg Temp (ºC)	Visual Severity Rating (1-5)
6	15-Feb-07	PG	ZR/IP	20	5	0	40	-7.9	-7	5
6A	15-Feb-07	PG	ZR/IP	20	5	0	20	-8.6	-7	1
10	23-Feb-07	PG	IP/ZR	6.6	19.5	0	40	-4	-7	3
11	23-Feb-07	PG	ZR/IP	19.8	4.9	0	40	-2.7	-4	2
12	23-Feb-07	EG	ZR/IP	19.8	4.9	0	40	-2.6	-4	1

Table 9.2: Summary of 2006-07 IP-/ZR- Testing with Falcon 20 Aircraft

Run #	Date	Type IV Fluid	Condition	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	SN Rate g/dm²/h)	Precp. Time (min)	OAT (ºC)	Wing Avg Temp (ºC)
4P	28-Feb-07	PG	ZR/IP	20	5	-	40	-10	-6
6P	1-Mar-07	EG	ZR/IP	20	5	-	30	-11	-4

9.2 Data Collected

9.2.1 Coefficient of Lift Curves

Drag and lift data collected by the NRC in the wind tunnel was used to generate lift coefficient curves for each of the tests conducted in the wind tunnel. Figures 9.1 to 9.5 show the lift coefficient data for the tests conducted in mixed ice pellets and snow conditions. The x-axis indicates the time in seconds as of the start of rotation. The y-axis indicates the Cn (normal force coefficient) and Cl (lift coefficient) calculated from the data collected.

It should be noted that the Cn and Cl data collected during Test #6A did not match the usual lift profile. Technical difficulties were experienced during the tunnel ramp-up to 100 knots, and the engine was cut off prior to reaching the top speed. Although the appropriate rotation wind speed was not reached, the wing section still underwent rotation, and the fluid and contamination was completely eliminated.

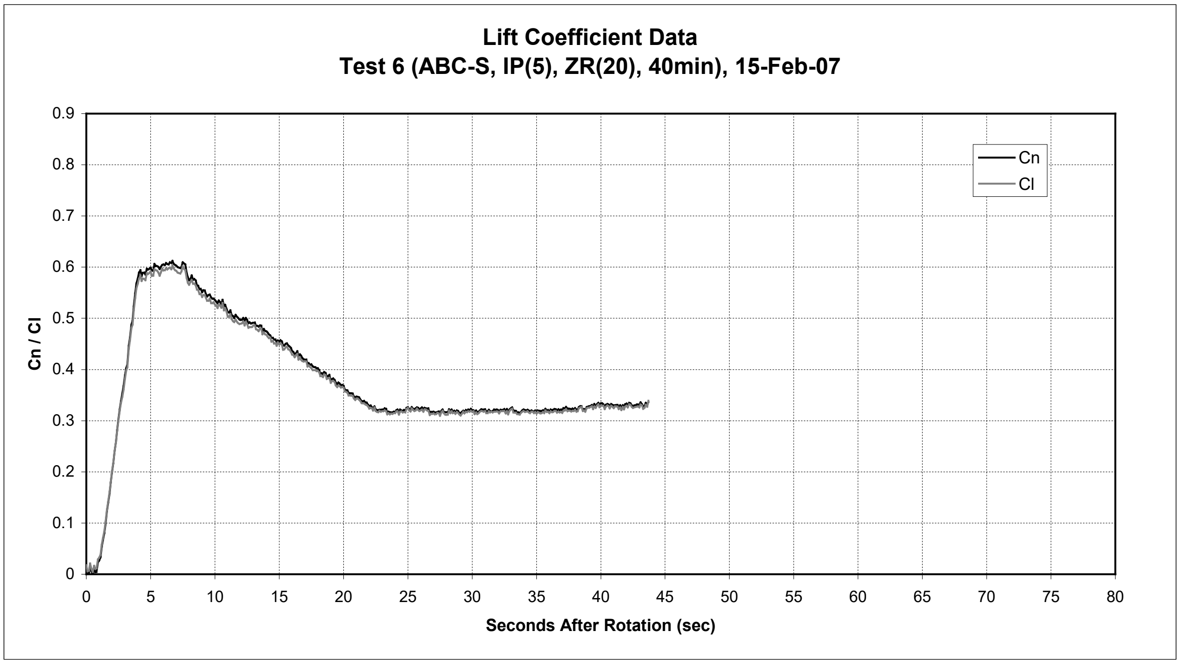


Figure 9.1: Test #6 Lift Coefficient Data

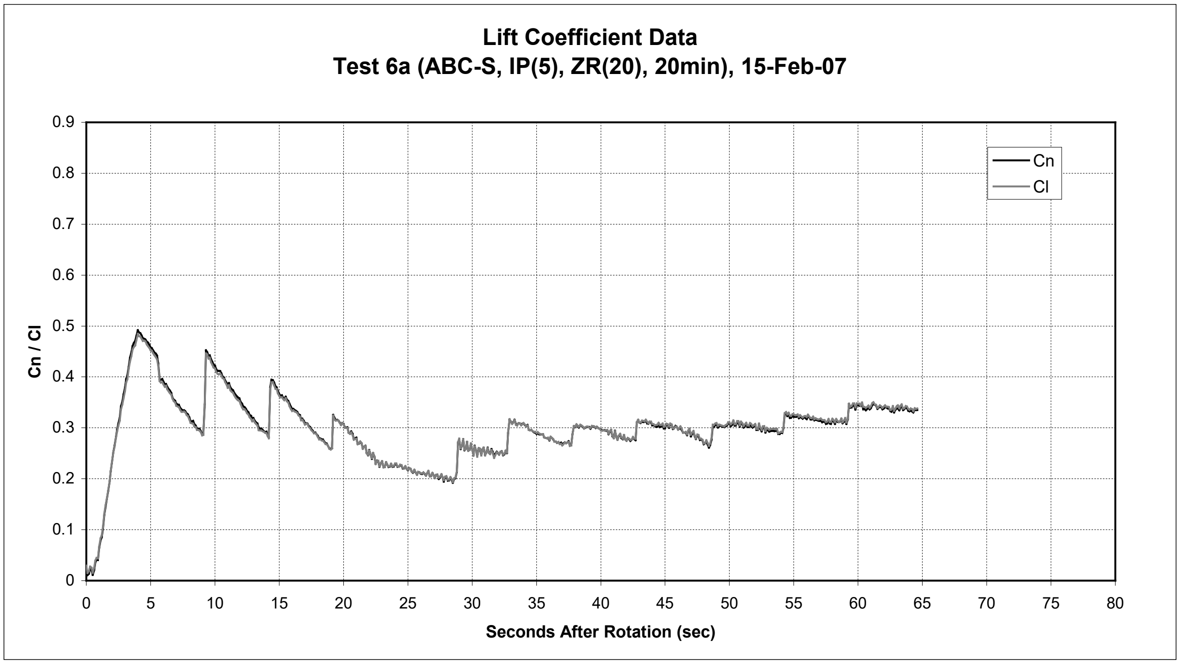


Figure 9.2: Test #6A Lift Coefficient Data

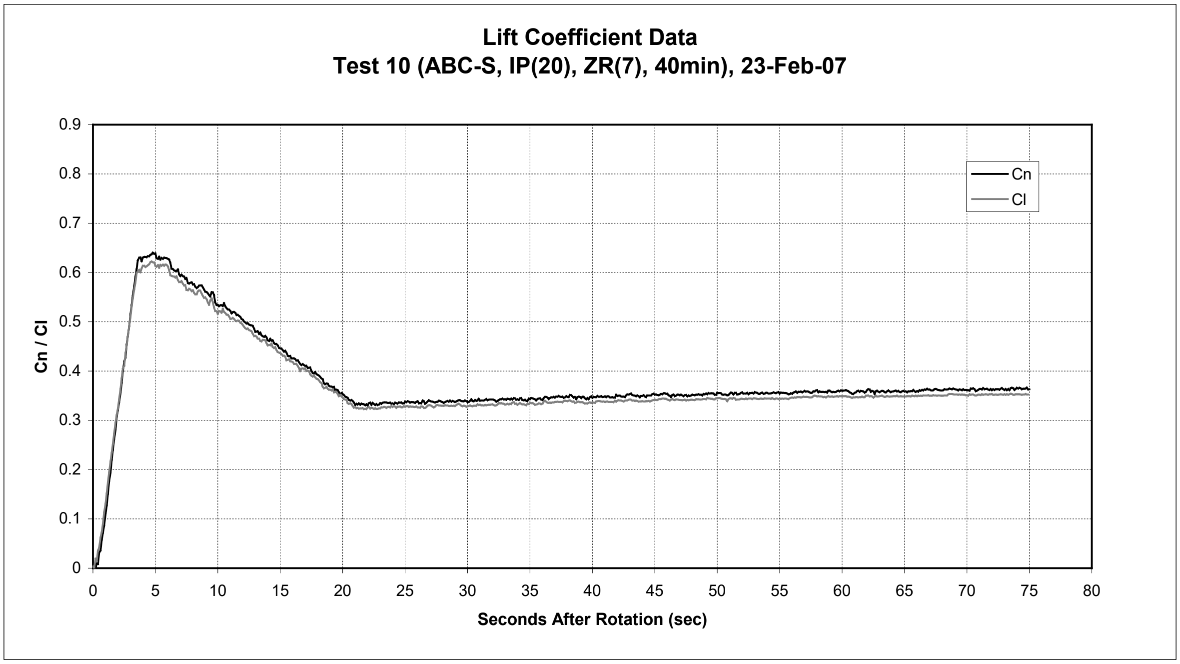


Figure 9.3: Test #10 Lift Coefficient Data

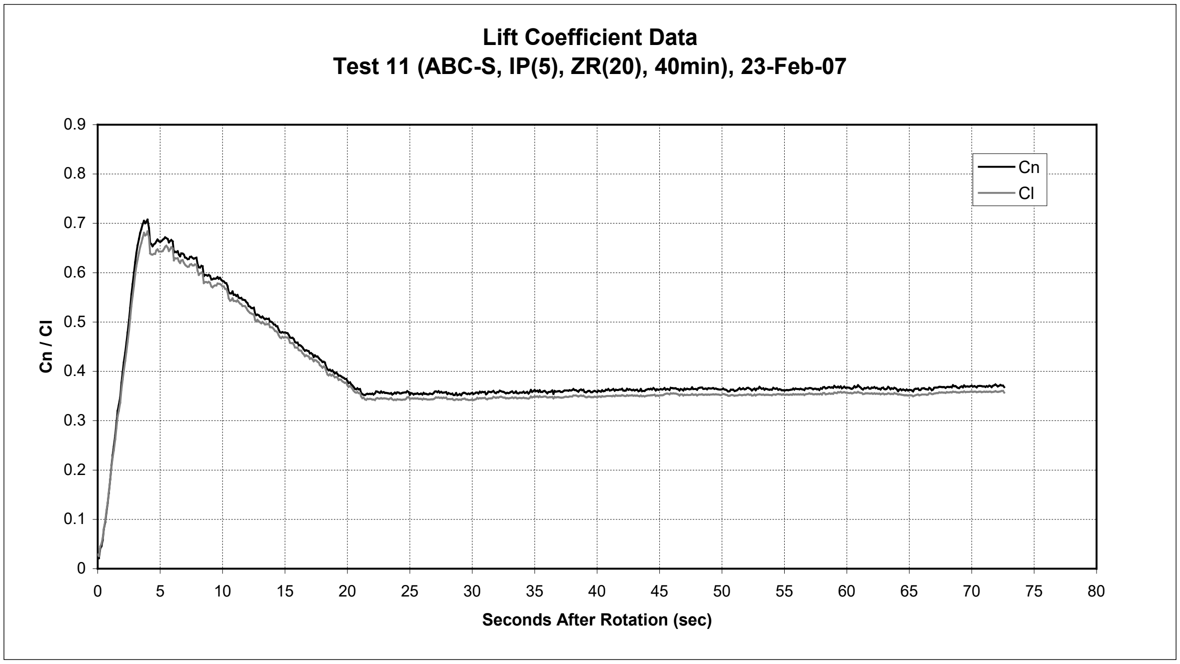


Figure 9.4: Test #11 Lift Coefficient Data

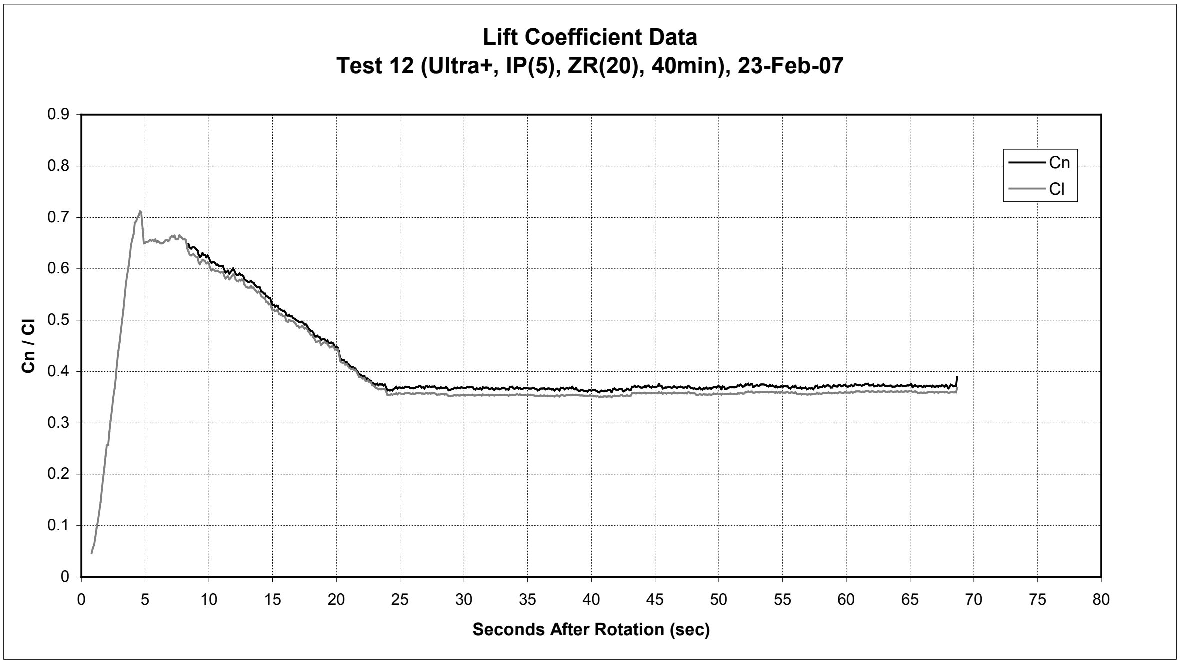


Figure 9.5: Test #12 Lift Coefficient Data

9.2.2 Fluid Thickness Data

Fluid thickness measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.1 and 2.2.9.1. Fluid thickness measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - Approximately 5 minutes after fluid application;
  - After the application of contamination (on the test wing, not the fluid only wing);
  - Before the takeoff test; and
  - After the takeoff test (end of test).

Tables 9.3 to 9.9 show the fluid thickness measurements collected during the test.

Table 9.3: Test #6 Fluid Thickness Data

TEST 6: ABC-S, ZR(20)/IP(5)-40min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.1	1.4	0.1
2	2.9	3.3	0.1
3	2.9	3.1	0.1
4	2.2	2.5	0.2
5	1.8	3.3	0.2
6	1.8	1.8	0.2
7	1.8	1.8	0.5
8	1.4	1.4	0.5

Table 9.4: Test #6A Fluid Thickness Data

TEST 6A: ABC-S, ZR(20)/IP(5)-20min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.2	0.7	0.2
2	2.9	2.7	0.2
3	4.5	4.5	0.1
4	2.2	3.3	0.2
5	2.2	2.2	0.3
6	2.2	3.1	0.4
7	2.2	2.9	0.5
8	1.8	2.2	0.7

Table 9.5: Test #10 Fluid Thickness Data

TEST 10: ABC-S, ZR(7)/IP(20)-30min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.1	1.2	0.1
2	3.1	3.3	0.1
3	5.7	5.7	0.1
4	3.5	3.7	0.1
5	2.9	3.5	0.1
6	2.7	3.7	0.2
7	2.7	3.7	0.2
8	2.2	3.1	0.8

Table 9.6: Test #11 Fluid Thickness Data

TEST 11: ABC-S, ZR(20)/IP(5)-40min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.1	0.8	0.0
2	2.9	3.1	0.0
3	5.7	5.7	0.1
4	3.5	4.5	0.1
5	3.1	3.1	0.1
6	2.7	2.5	0.2
7	2.7	2.2	0.3
8	1.8	1.4	0.5

Table 9.7: Test #12 Fluid Thickness Data

TEST 12: Ultra+, ZR(20)/IP(5)-40min			
Wing Position	Fluid Thickness (mm)		
	After Fluid Application	After Precip. Appl.	After Wind Tunnel Test
1	1.2	0.4	0.0
2	3.1	2.5	0.0
3	4.5	4.5	0.0
4	3.9	3.1	0.0
5	3.1	1.8	0.0
6	3.1	1.5	0.1
7	3.1	1.5	0.2
8	2.2	1.1	0.3

Table 9.8: Test #4P Fluid Thickness Data

TEST 4P: ABC-S, IP(5)/ZR(20) -40min				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	1.0	N/A	N/A	0.0
2	1.5	N/A	N/A	0.1
5	3.5	N/A	N/A	0.2
7	1.6	0.7	N/A	0.2
8	1.1	1.8	N/A	0.4

Table 9.9: Test #6P Fluid Thickness Data

TEST 6P: Ultra+, IP(5)/ZR(20) -30min				
Wing Position	Fluid Thickness (mm)			
	After Fluid Appl.	After Precip Appl.	Before Takeoff Test	After Takeoff Test
1	1.1	0.5	0.3	0.0
2	2.2	1.3	1.0	0.0
5	4.5	4.5	4.5	0.1
7	1.3	0.4	N/A	0.2
8	2.2	2.5	N/A	0.2

9.2.3 Skin Temperature Data

Skin temperature measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.3 and 2.2.9.3. Skin temperature measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination;
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The wing temperature measurements recorded during each test are shown in Tables 9.10 to 9.16.

Table 9.10: Test #6 Skin Temperature Data

TEST 6: ABC-S, ZR(20)/IP(5)-40min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-11.3	-7.1	-10.0
5	-10.6	-4.7	-7.9
Under-wing	-11.8	-8.4	-10.8

Table 9.11: Test #6A Skin Temperature Data

TEST 6A: ABC-S, ZR(20)/IP(5)-20min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-11.0	-7.5	-8.6
5	-10.0	-5.6	-6.2
Under-wing	-9.4	-8.3	-9.5

Table 9.12: Test #10 Skin Temperature Data

TEST 10: ABC-S, ZR(7)/IP(20)-30min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-6.7	-7.8	-7.7
5	-5.8	-6.3	-6.5
Under-wing	-7.0	-6.7	-8.6

Table 9.13: Test #11 Skin Temperature Data

TEST 11: ABC-S, ZR(20)/IP(5)-40min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-5.5	-4.4	-5.2
5	-4.5	-3.0	-3.8
Under-wing	-5.9	-5.1	-5.4

Table 9.14: Test #12 Skin Temperature Data

TEST 12: Ultra+, ZR(20)/IP(5)-40min			
Wing Position	Skin Temperature (°C)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	-5.4	-5.0	-4.2
5	-4.9	-3.2	-4.0
Under-wing	-5.4	-3.7	-4.7

Table 9.15: Test #4P Skin Temperature Data

TEST 4P: ABC-S, IP(5)/ZR(20) -40min				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-9.3	-9.0	-5.2	-3.2
2	-9.9	-8.5	-5.7	-7.2
3	-9.6	-8.4	-5.5	-3.6
4	-9.6	-7.7	-6.3	-6.7
5	-9.0	-8.0	-6.9	-5.8
6	-8.9	-7.9	-7.5	-6.8
7	-10.0	-5.9	N/A	-8.5
8	-5.5	-6.2	N/A	-8.4

Table 9.16: Test #6P Skin Temperature Data

TEST 6P: Ultra+, IP(5)/ZR(20) -30min				
Wing Position	Skin Temperature (°C)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
1	-10.1	-9.7	-1.7	-6.7
2	-10.6	-9.6	-3.7	-7.1
3	-10.1	-10.8	-4.5	-7.6
4	-10.6	-10.2	-4.6	-7.6
5	-9.1	-9.8	-7.4	-7.2
6	-9.6	-8.3	-7.6	-7.2
7	-10.4	-11.3	N/A	-8.8
8	-10.8	-11.1	N/A	-8.9

9.2.4 Fluid Brix Data

Fluid Brix measurements were collected by APS personnel. The wing positions used for the wind tunnel tests and Falcon 20 tests are described in Subsections 2.1.8.2 and 2.2.9.2. Fluid Brix measurements were recorded at the following intervals:

- Wind Tunnel Tests:
  - Before the application of contamination;
  - After the application of contamination; and
  - After the wind tunnel test (end of test).
- Falcon 20 Tests:
  - After fluid application;
  - After the application of contamination;
  - Before the takeoff test; and
  - After the takeoff test (end of test).

The fluid Brix measurements collected during each test are shown in Tables 9.17 to 9.23.

Table 9.17: Test #6 Fluid Brix Data

TEST 6: ABC-S, ZR(20)/IP(5)-40min			
Wing Position	Fluid Brix (°)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.00	25.25	35.00
8	37.00	21.25	37.00

Table 9.18: Test #6A Fluid Brix Data

TEST 6A: ABC-S, ZR(20)/IP(5)-20min			
Wing Position	Fluid Brix (º)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.25	30.00	30.50
8	37.25	24.50	36.50

Table 9.19: Test #10 Fluid Brix Data

TEST 10: ABC-S, ZR(7)/IP(20)-30min			
Wing Position	Fluid Brix (º)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.00	25.00	37.50
8	37.00	19.50	31.00

Table 9.20: Test #11 Fluid Brix Data

TEST 11: ABC-S, ZR(20)/IP(5)-40min			
Wing Position	Fluid Brix (º)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	37.00	20.00	33.50
8	37.00	17.00	35.50

Table 9.21: Test #12 Fluid Brix Data

TEST 12: Ultra+, ZR(20)/IP(5)-40min			
Wing Position	Fluid Brix (º)		
	Before Contamination	After Precip. Appl.	After Wind Tunnel Test
2	41.00	24.00	37.00
8	41.00	23.00	45.50

Table 9.22: Test #4P Fluid Brix Data

TEST 4P: ABC-S, IP(5)/ZR(20) -40min				
Wing Position	Fluid Brix (º)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	37.00	21.00	18.00	30.00
5	37.00	19.50	N/A	30.00

Table 9.23: Test #6P Fluid Brix Data

TEST 6P: Ultra+, IP(5)/ZR(20) -30min				
Wing Position	Fluid Brix (°)			
	After Fluid Appl.	After Precip. Appl.	Before Takeoff Test	After Takeoff Test
2	40.25	27.50	23.00	39.00
5	40.00	15.00	N/A	36.50

9.3 Photos

For each test, photo summaries have been compiled comprising four stages:

- Start of test;
- Time of rotation;
- 10 seconds after rotation; and
- End of test.

Photos 9.1 to 9.28 show the photo summaries for Tests #6, #6A, #10, #11, #12, #4P and #6P. A compilation of selected high-speed photos taken during Test #11 is included Appendix L. A complete set of photos will be provided to the TDC.

9.4 Results

Wind tunnel Test #6 was conducted at a combined precipitation rate of 25 g/dm²/h, the high end of the precipitation rate for mixed ice pellets and freezing rain (with 40 minutes of exposure) with freezing rain as the predominant condition, with a wing skin temperature of -7°C. Large adhered patches were documented prior to the test. The test demonstrated residual contamination at the end of the test on both the leading and trailing edge of the wing section, and several sections of the leading edge still had residual adhered contamination following the end of the test. Upon review of the lift data, no significant lift losses were observed from the data collected.

Wind tunnel Test #6A was a duplicate of Test #6; however, the exposure time to precipitation was reduced by half (20 minutes of exposure). The test showed significantly less residual contamination at the end of the test on both the leading and trailing edge of the wing section. No significant lift losses could be determined from the data collected.

Wind tunnel Test #10 was conducted at a combined precipitation rate of 27 g/dm²/h for mixed ice pellets and freezing rain (with 40 minutes of exposure) with ice pellets as the predominant condition, with a wing skin temperature of -7°C. Contamination on the trailing edge was present following the start of rotation; however, it was removed by the end of the test. Significant lift losses were not observed from the data collected.

Wind tunnel Tests #11 and #12 were conducted at a combined precipitation rate of 25 g/dm²/h of mixed ice pellets and freezing rain (with 40 minutes of exposure) with freezing rain as the predominant condition, with a wing skin temperatures of -4°C. During the tests, the contamination was cleared from the trailing edge at the time of rotation or shortly after. Significant lift losses were not observed from the data collected.

Tests #4P and #6P were conducted using the Falcon 20 aircraft at a combined precipitation rate of 25 g/dm²/h of mixed ice pellets and freezing rain (with 30 minutes of exposure) with freezing rain as the predominant condition and demonstrated some residual contamination on the trailing edge of the wing test sections following the end of the tests. All adhered patches of contamination on the leading edge were cleared by the end of the takeoff test. These tests were conducted with skin temperatures of -6°C and -4°C, respectively.

9.5 Conclusion and Recommendations

The generic freezing rain HOTs were referenced during the working group meeting; the lower limit for temperatures above -3°C for a Type IV neat fluid in light freezing rain conditions is 25 minutes, and the lower limit for temperatures below -3°C to -10°C for a Type IV neat fluid in light freezing rain conditions is 10 minutes. Based on the data collected, an allowance time of 25 minutes was recommended for light ice pellets mixed with freezing rain conditions. This time was deemed appropriate; the allowance time was equivalent to the freezing rain only HOT of 25 minutes for -3°C and above conditions and shorter than the light ice pellets only allowance time of 50 minutes for -5°C and above conditions.

Historical occurrences suggested that operations may frequently occur in the -3°C to -5°C range. As a result of the test data showing good results (i.e., lift loss and residual contamination) at temperatures of -5°C and above, the recommendation to extend the -3°C temperature cut-off (adopted from the current HOT table format) to -5°C was supported. Table 9.24 demonstrates the recommended allowance times for light ice pellets mixed with light freezing rain only for -5°C and above conditions.

A 10-minute allowance time was recommended for temperatures below -5°C to -10°C. This allowance time was supported by the data collected in the wind tunnel Tests #6, #6A, and #10 and the Falcon 20 Tests #4P and #6P.

Table 9.24: Recommended Allowance Times for Ice Pellets and Freezing Rain Conditions

	OAT -5° C and above	OAT Less than -5°C to -10°C	OAT Less than -10° C
Light Ice Pellets Mixed with Light Freezing Rain	25 Minutes	10 Minutes	**Caution: No Allowance times currently exist**

The recommended allowance times for light ice pellets mixed with light freezing rain were presented in May 2007 at the SAE meeting in San Diego. The industry requested additional guidance material for the following conditions:

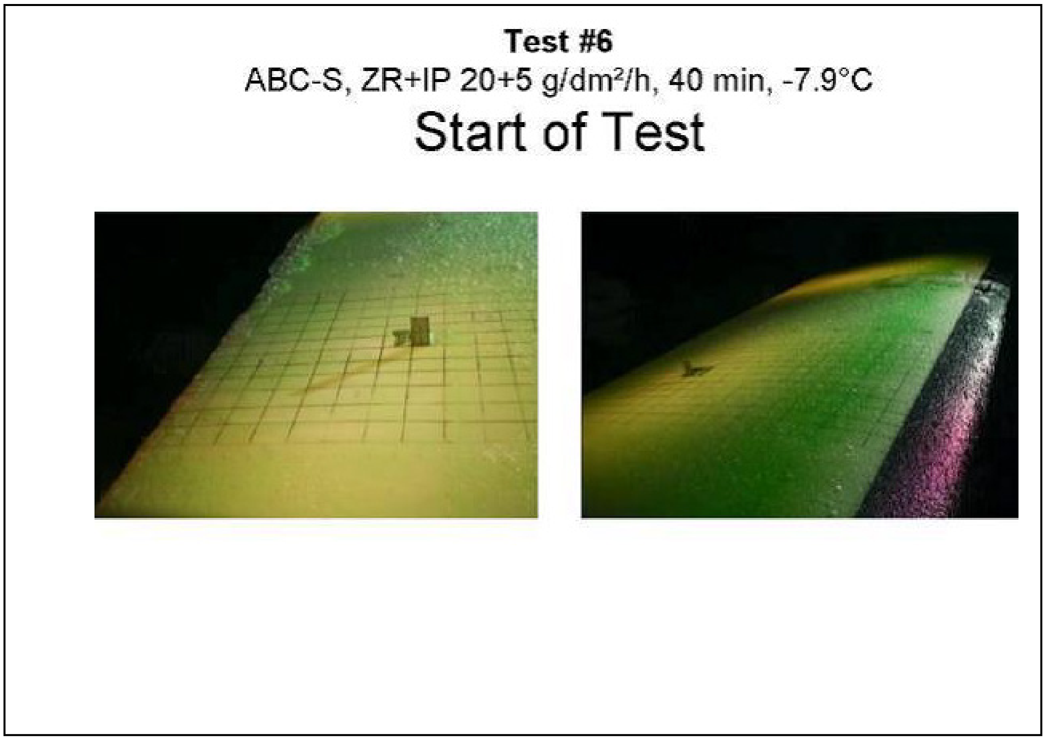
- Mixed Freezing Drizzle and Ice Pellets; and
- Mixed Light Rain and Ice Pellets.

Additional flat plate testing and analysis was conducted. Details of the flat plate testing conducted are included in Subsection 3.4. The recommended light ice pellets mixed with light freezing rain allowance times were applied for mixed freezing drizzle and ice pellets and mixed light rain and ice pellets, as both conditions are less severe as compared to light ice pellets mixed with light freezing rain. Table 9.25 demonstrates the recommended allowance times for mixed freezing drizzle and ice pellets and for mixed light rain and ice pellets.

Table 9.25: Recommended Allowance Times for Ice Pellets and Freezing Drizzle and Ice Pellets and for Light Rain and Ice Pellets

	OAT -5° C and above	OAT Less than -5°C to -10°C	OAT Less than -10° C
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 Minutes	10 Minutes	**Caution: No Allowance times currently exist**
Light Ice Pellets Mixed with Light Rain	25 Minutes		

Photo 9.1: Test #6 – Start of Test

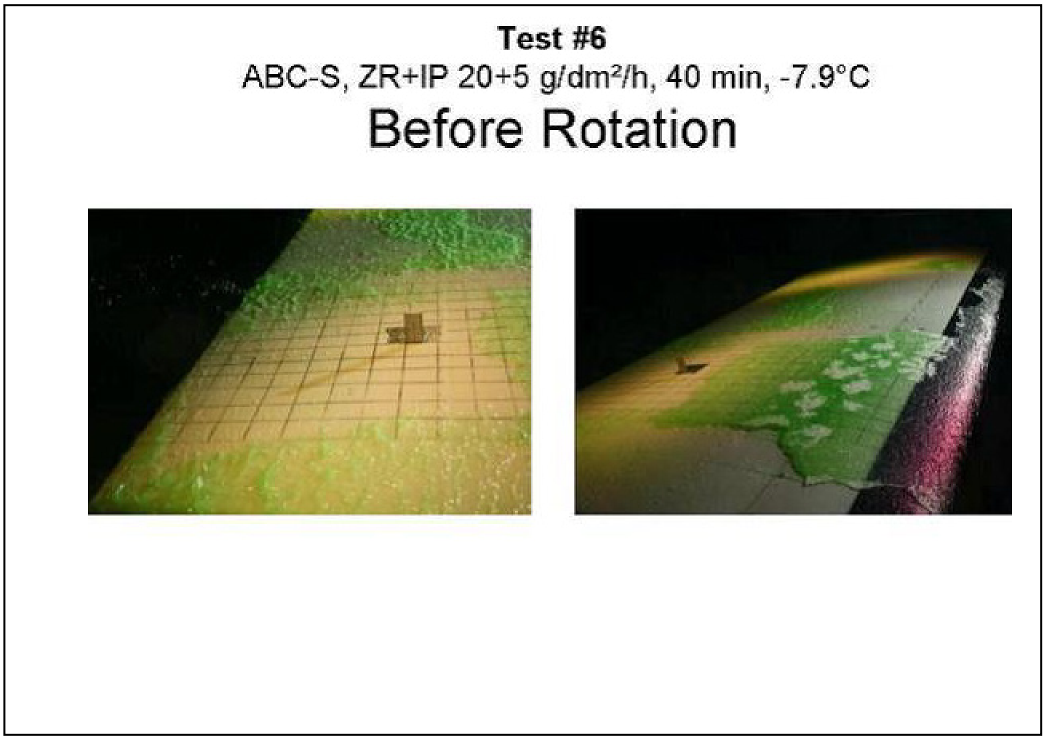


Test #6

ABC-S, ZR+IP 20+5 g/dm²/h, 40 min, -7.9°C

Start of Test

Photo 9.2: Test #6 – Before Rotation

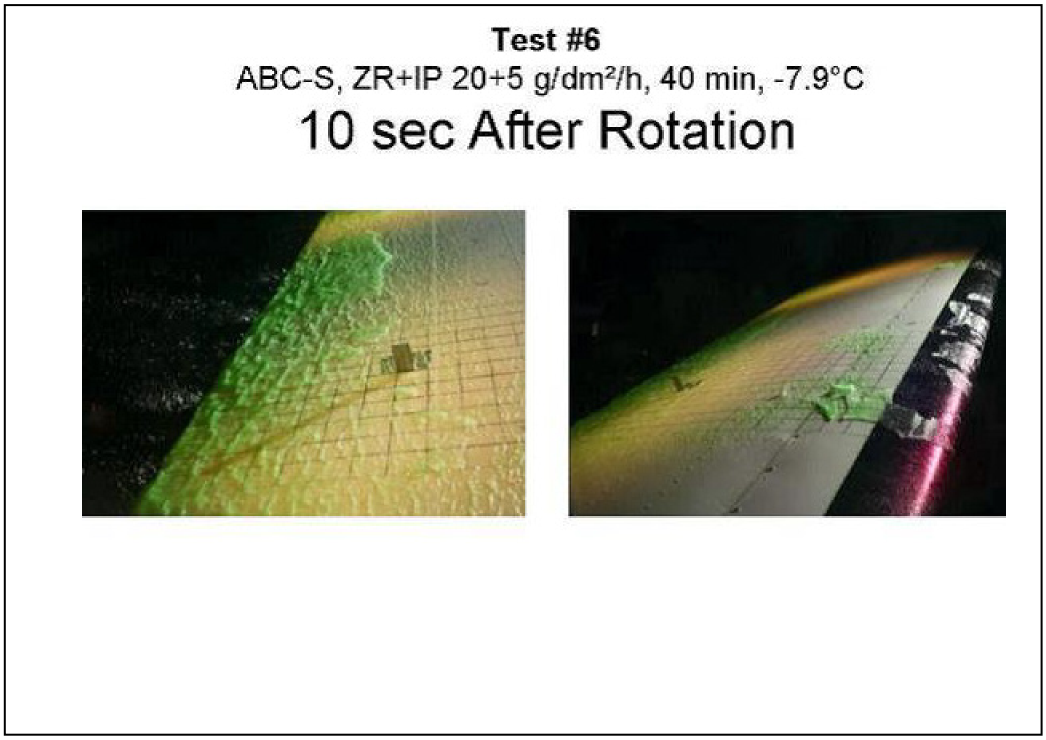


Test #6

ABC-S, ZR+IP 20+5 g/dm²/h, 40 min, -7.9°C

Before Rotation

Photo 9.3: Test #6 – 10 Seconds After Rotation

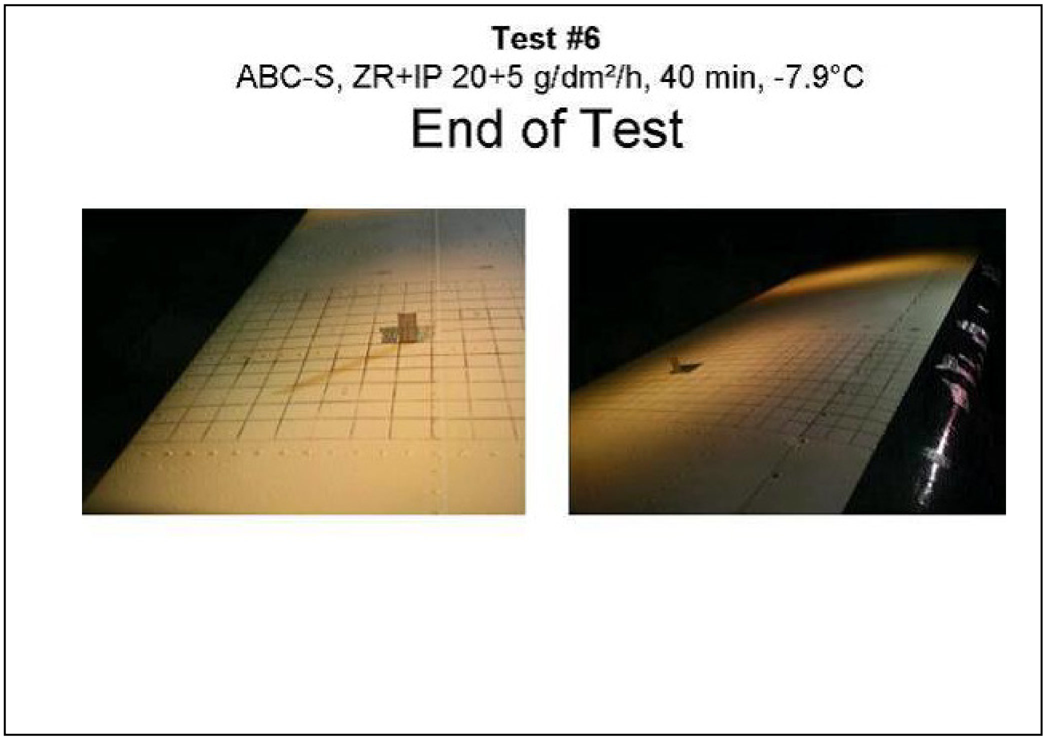


Test #6

ABC-S, ZR+IP 20+5 g/dm²/h, 40 min, -7.9°C

10 sec After Rotation

Photo 9.4: Test #6 – End of Test

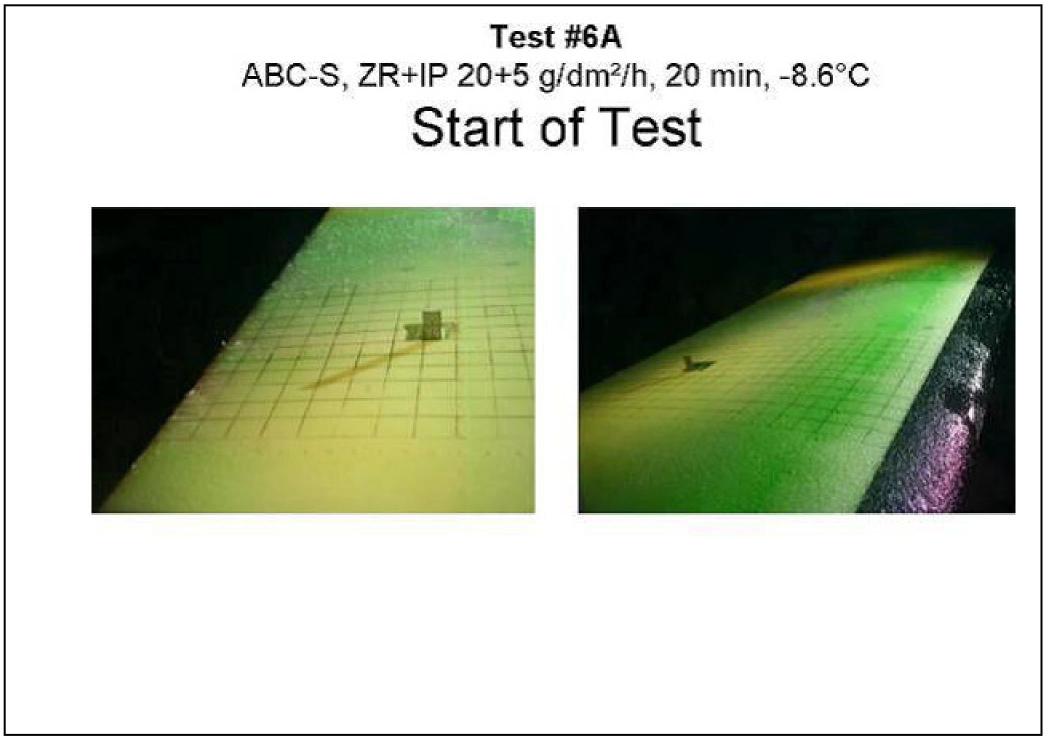


Test #6

ABC-S, ZR+IP 20+5 g/dm²/h, 40 min, -7.9°C

End of Test

Photo 9.5: Test #6A – Start of Test

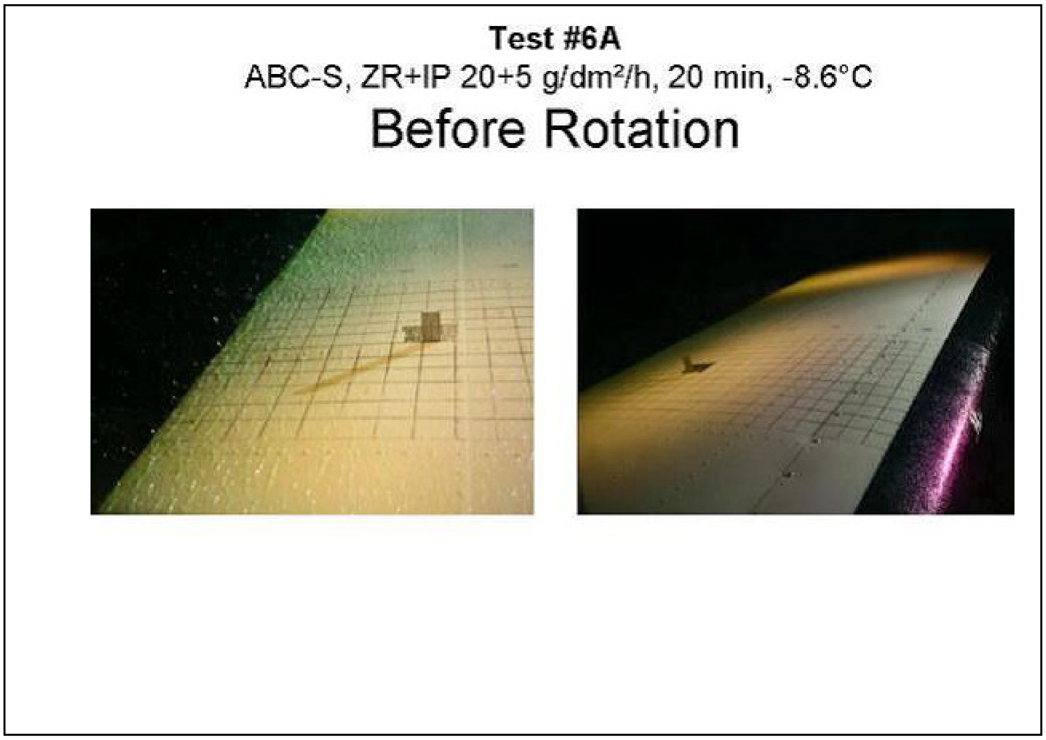


Test #6A

ABC-S, ZR+IP 20+5 g/dm^2/h, 20 min, -8.6°C

Start of Test

Photo 9.6: Test #6A – Before Rotation

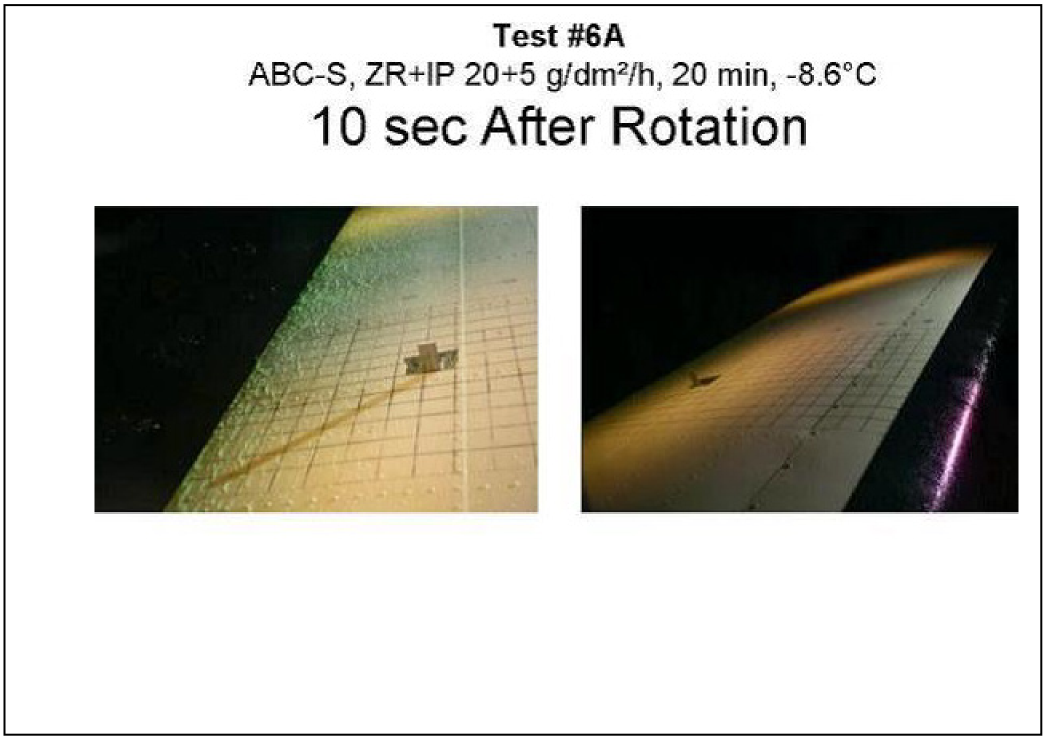


Test #6A

ABC-S, ZR+IP 20+5 g/dm^2/h, 20 min, -8.6°C

Before Rotation

Photo 9.7: Test #6A – 10 Seconds After Rotation

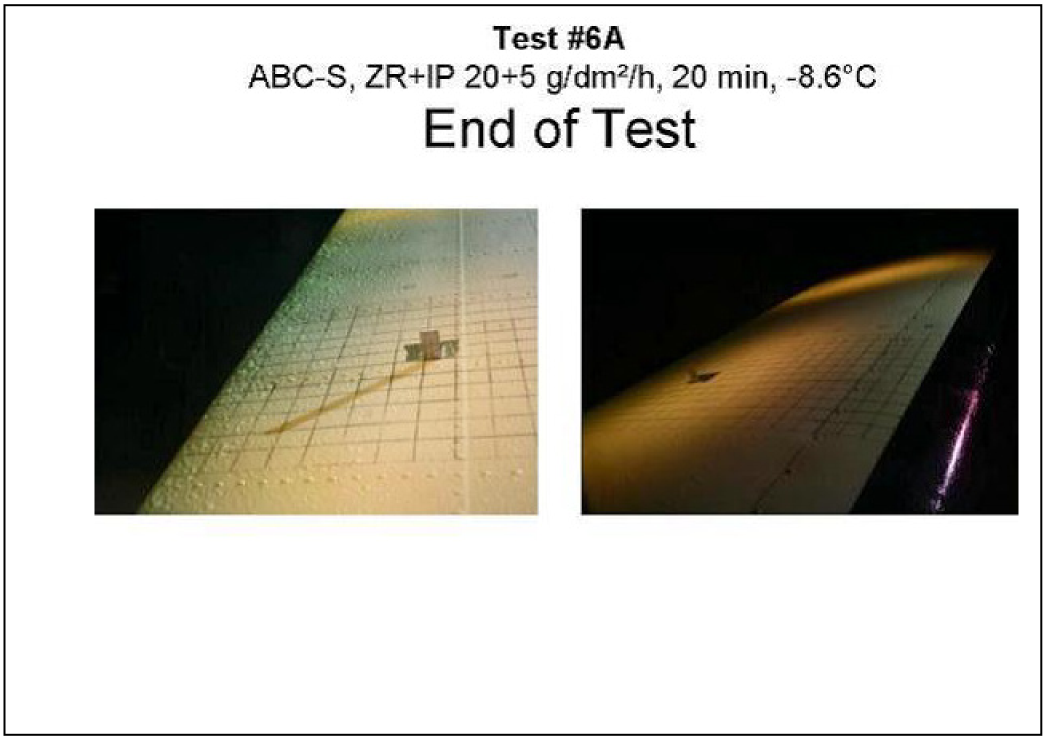


Test #6A

ABC-S, ZR+IP 20+5 g/dm^2/h, 20 min, -8.6°C

10 sec After Rotation

Photo 9.8: Test #6A – End of Test

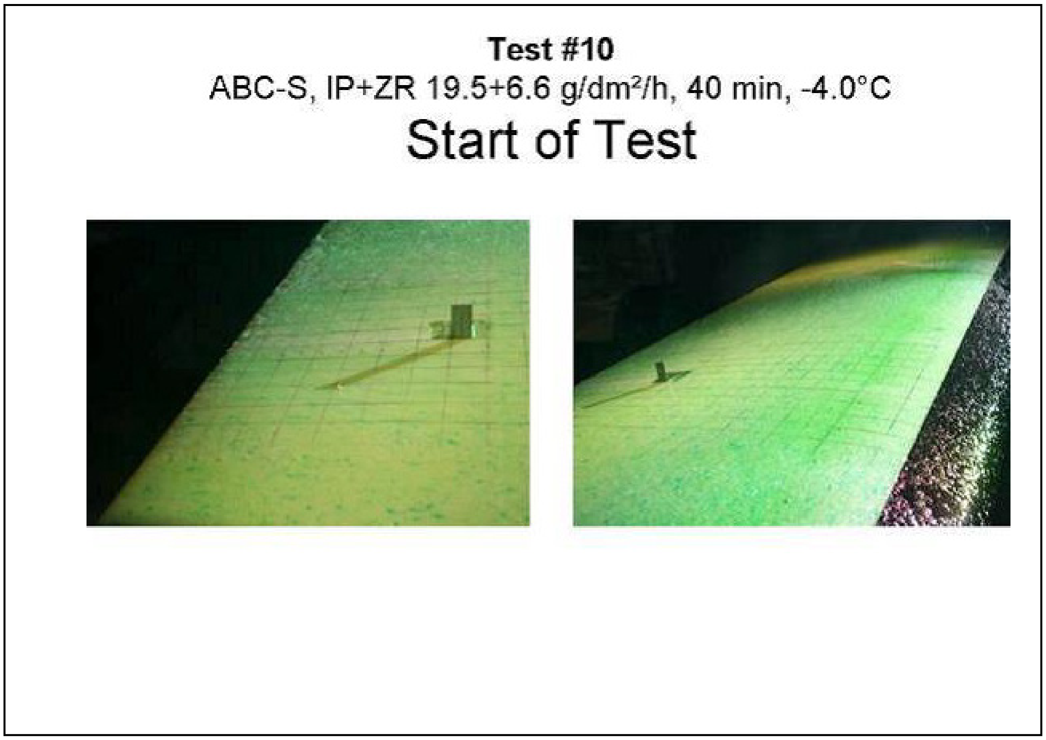


Test #6A

ABC-S, ZR+IP 20+5 g/dm^2/h, 20 min, -8.6°C

End of Test

Photo 9.9: Test #10 – Start of Test

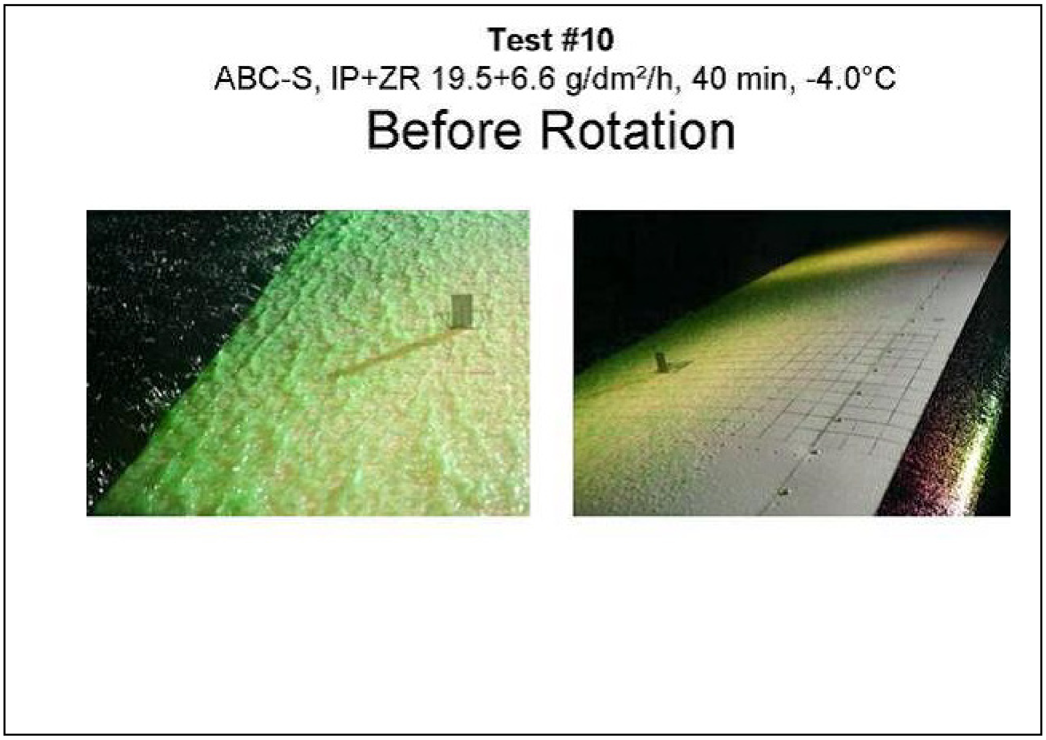


Test #10

ABC-S, IP+ZR 19.5+6.6 g/dm^2/h, 40 min, -4.0°C

Start of Test

Photo 9.10: Test #10 – Before Rotation

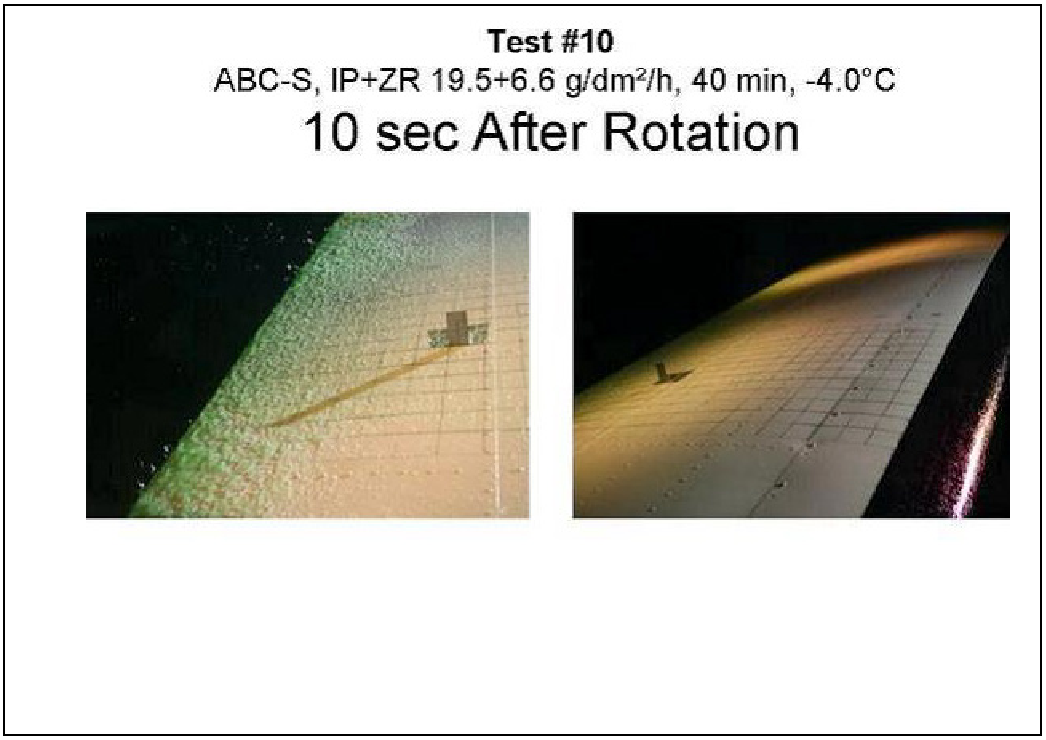


Test #10

ABC-S, IP+ZR 19.5+6.6 g/dm^2/h, 40 min, -4.0°C

Before Rotation

Photo 9.11: Test #10 – 10 Seconds After Rotation

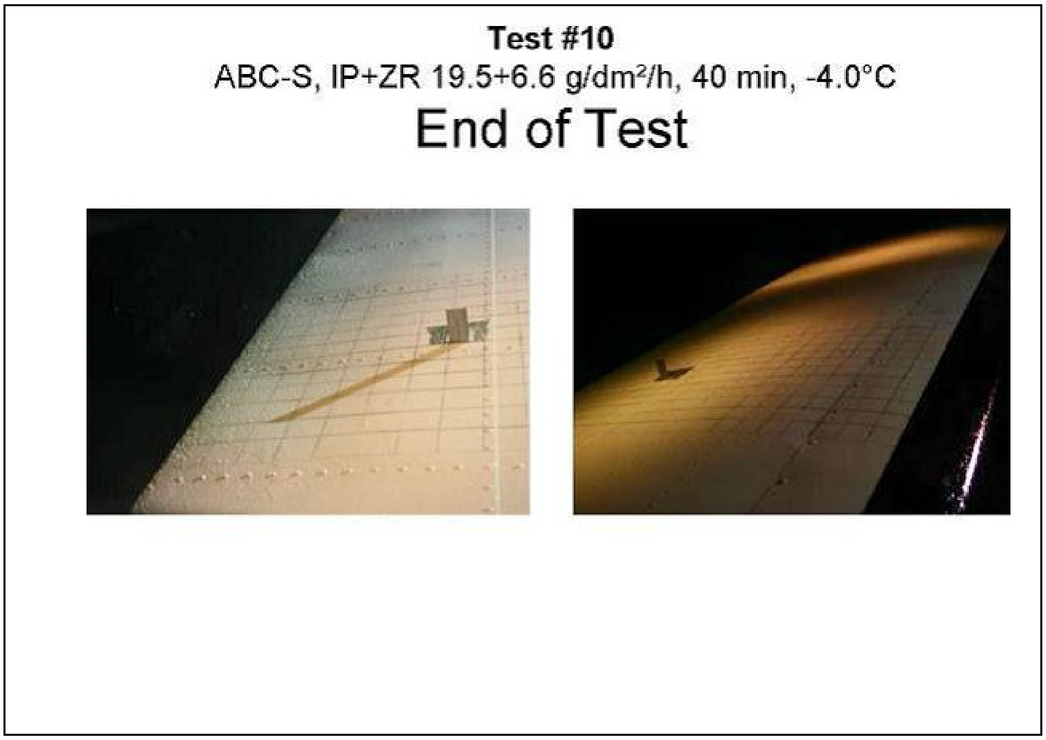


Test #10

ABC-S, IP+ZR 19.5+6.6 g/dm²/h, 40 min, -4.0°C

10 sec After Rotation

Photo 9.12: Test #10 – End of Test

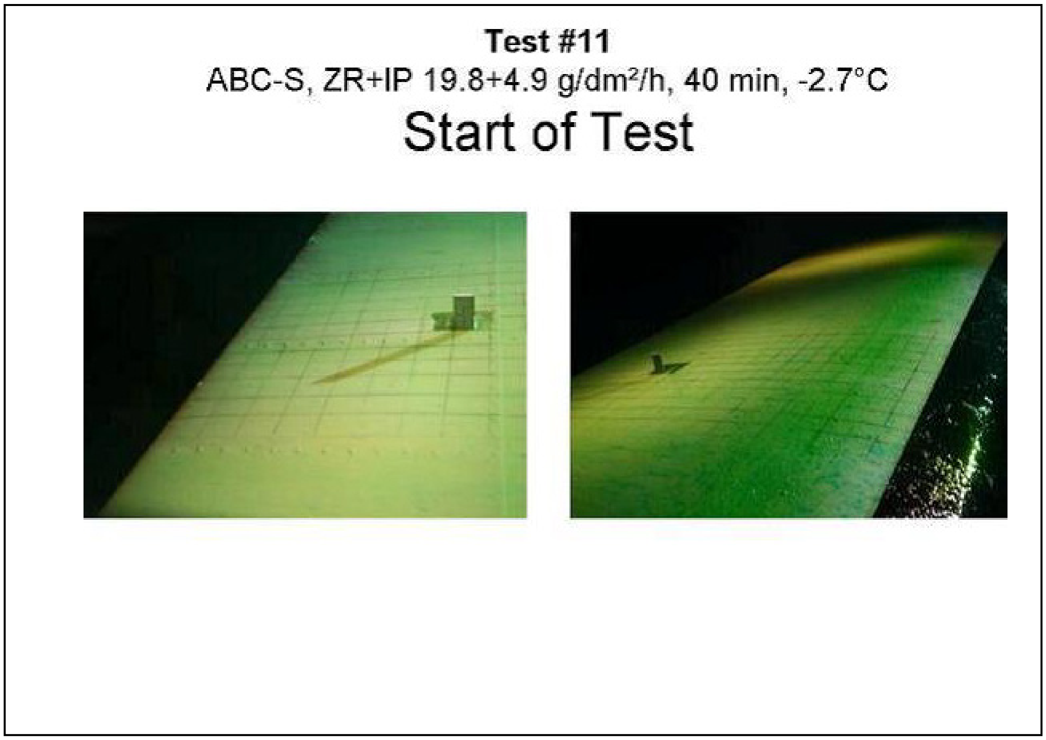


Test #10

ABC-S, IP+ZR 19.5+6.6 g/dm²/h, 40 min, -4.0°C

End of Test

Photo 9.13: Test #11 – Start of Test

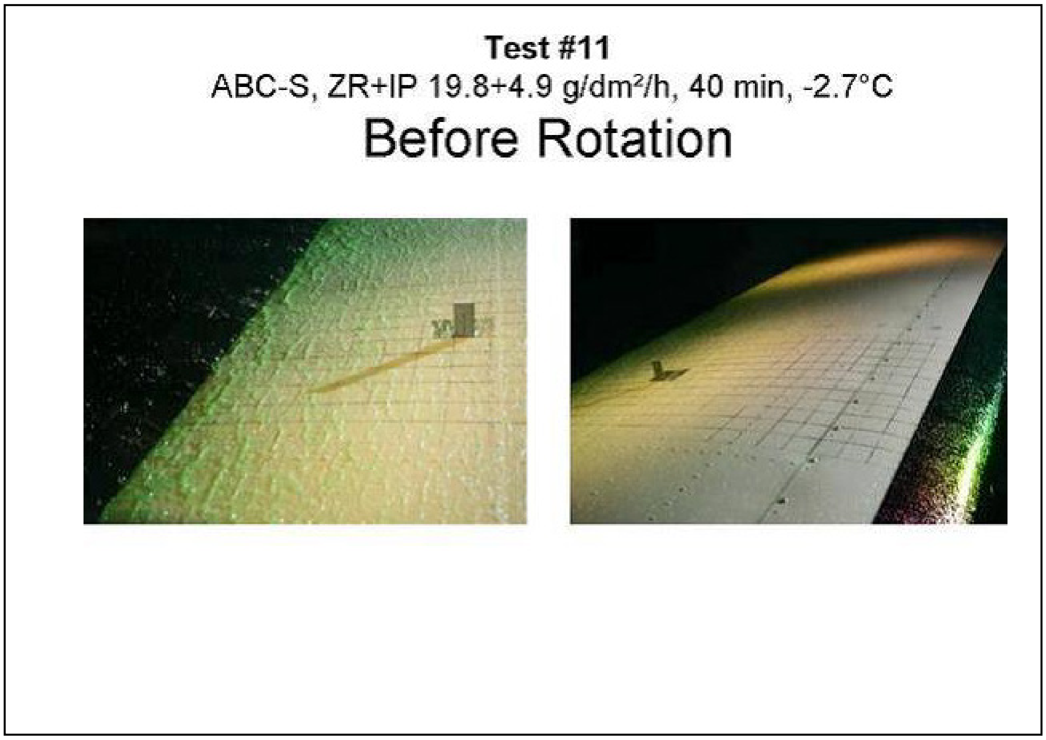


Test #11

ABC-S, ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.7°C

Start of Test

Photo 9.14: Test #11 – Before Rotation

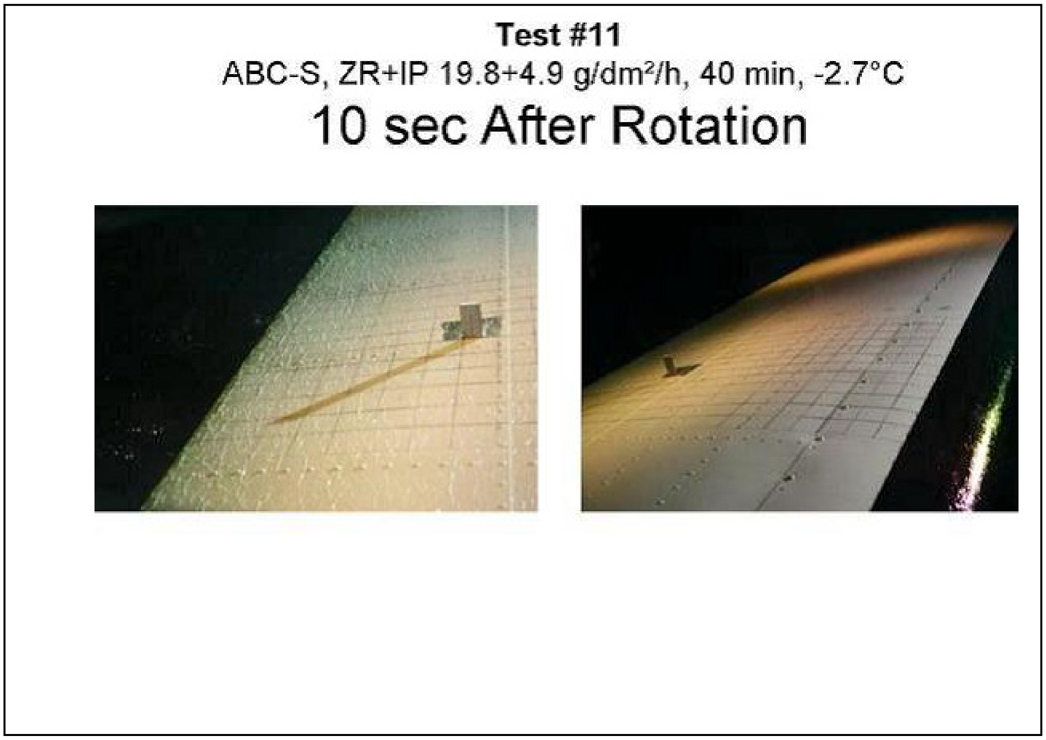


Test #11

ABC-S, ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.7°C

Before Rotation

Photo 9.15: Test #11 – 10 Seconds After Rotation

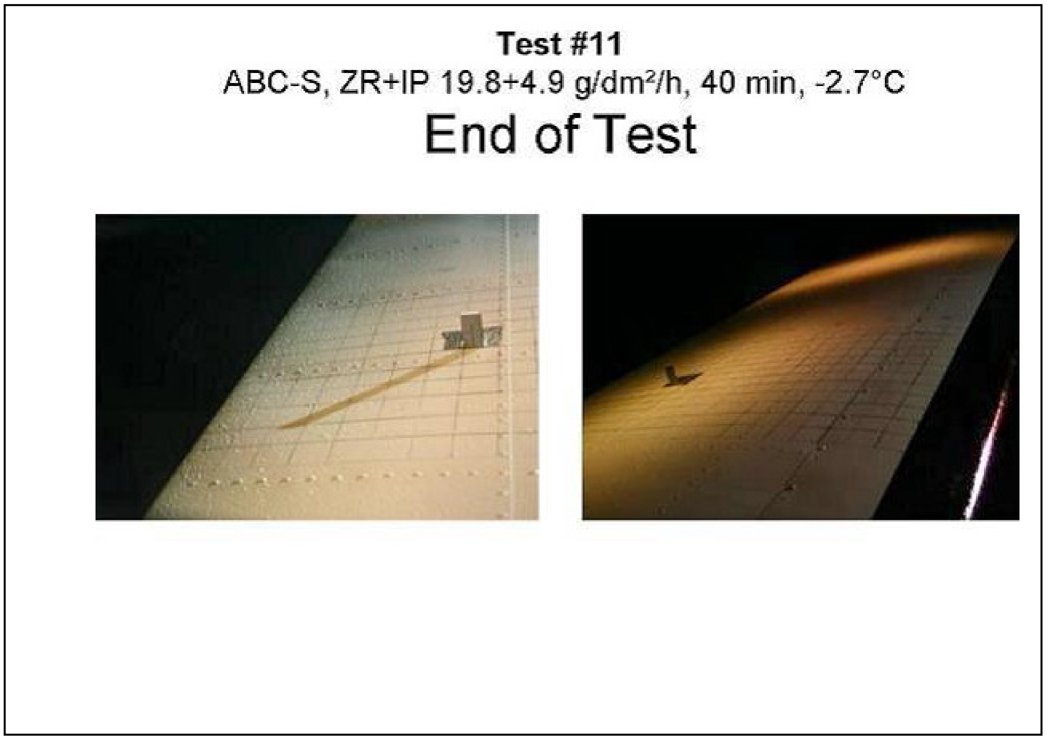


Test #11

ABC-S, ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.7°C

10 sec After Rotation

Photo 9.16: Test #11 – End of Test

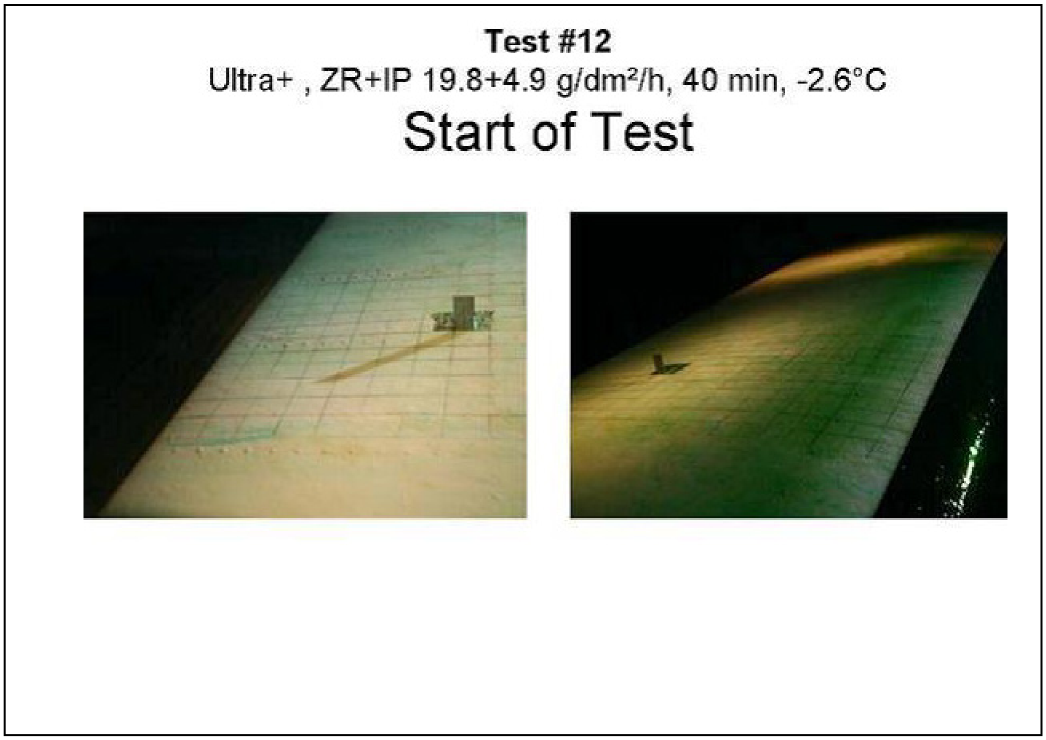


Test #11

ABC-S, ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.7°C

End of Test

Photo 9.17: Test #12 – Start of Test

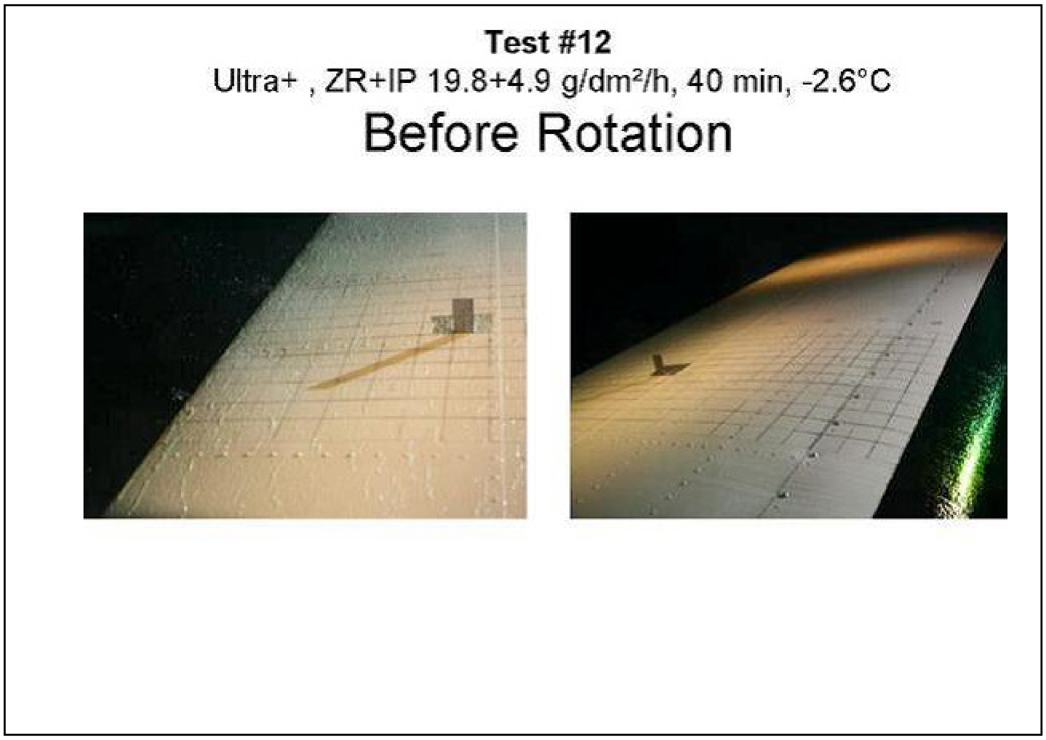


Test #12

Ultra+ , ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.6°C

Start of Test

Photo 9.18: Test #12 – Before Rotation

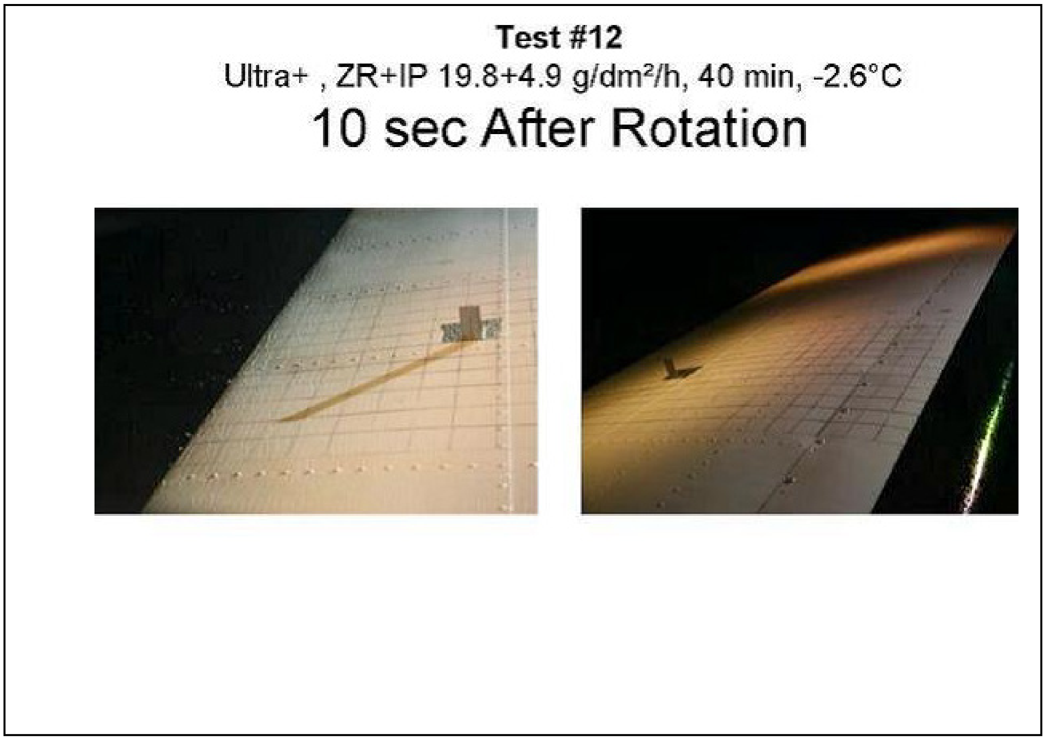


Test #12

Ultra+ , ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.6°C

Before Rotation

Photo 9.19: Test #12 – 10 Seconds After Rotation

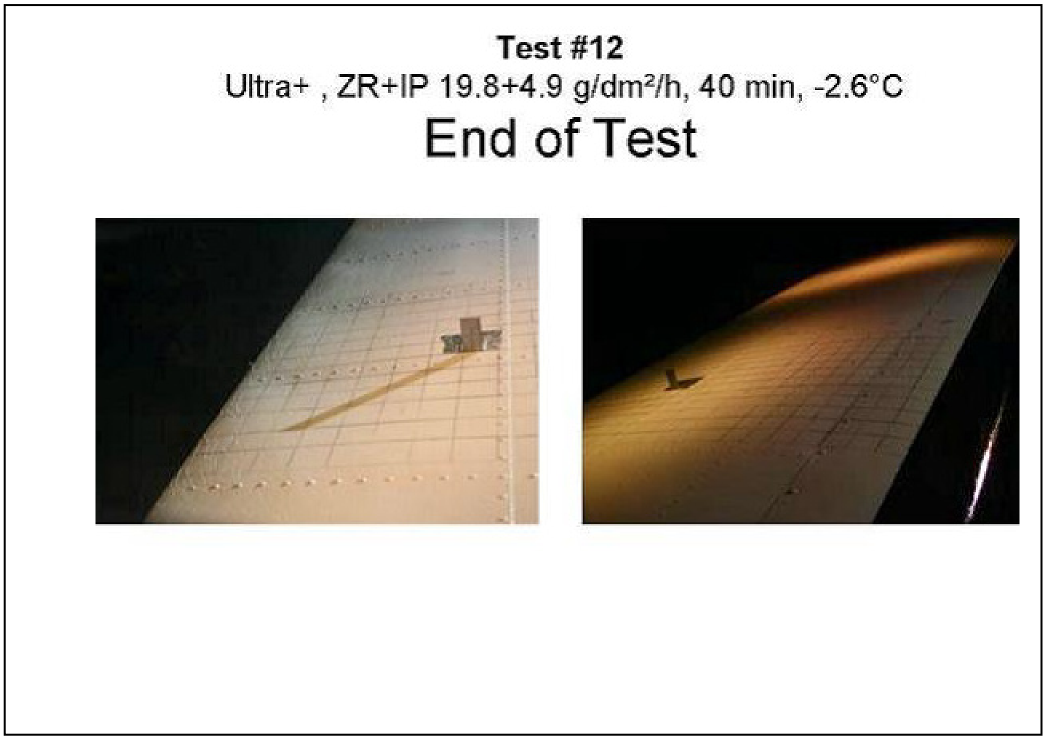


Test #12

Ultra+ , ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.6°C

10 sec After Rotation

Photo 9.20: Test #12 – End of Test

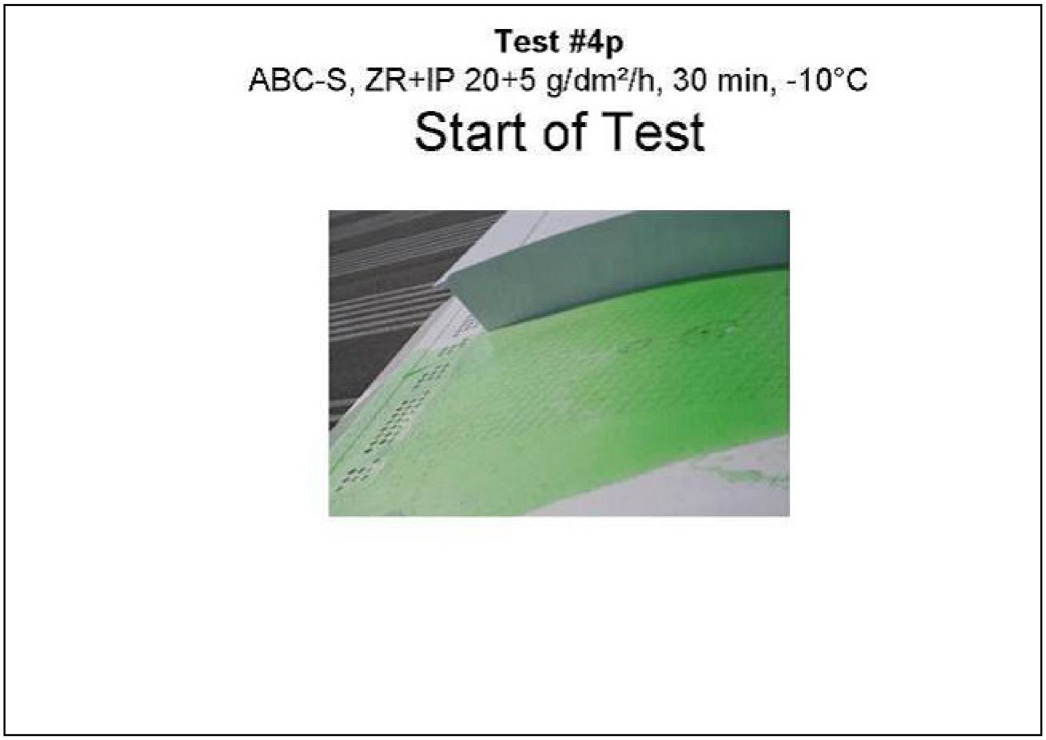


Test #12

Ultra+ , ZR+IP 19.8+4.9 g/dm²/h, 40 min, -2.6°C

End of Test

Photo 9.21: Test #4P – Start of Test

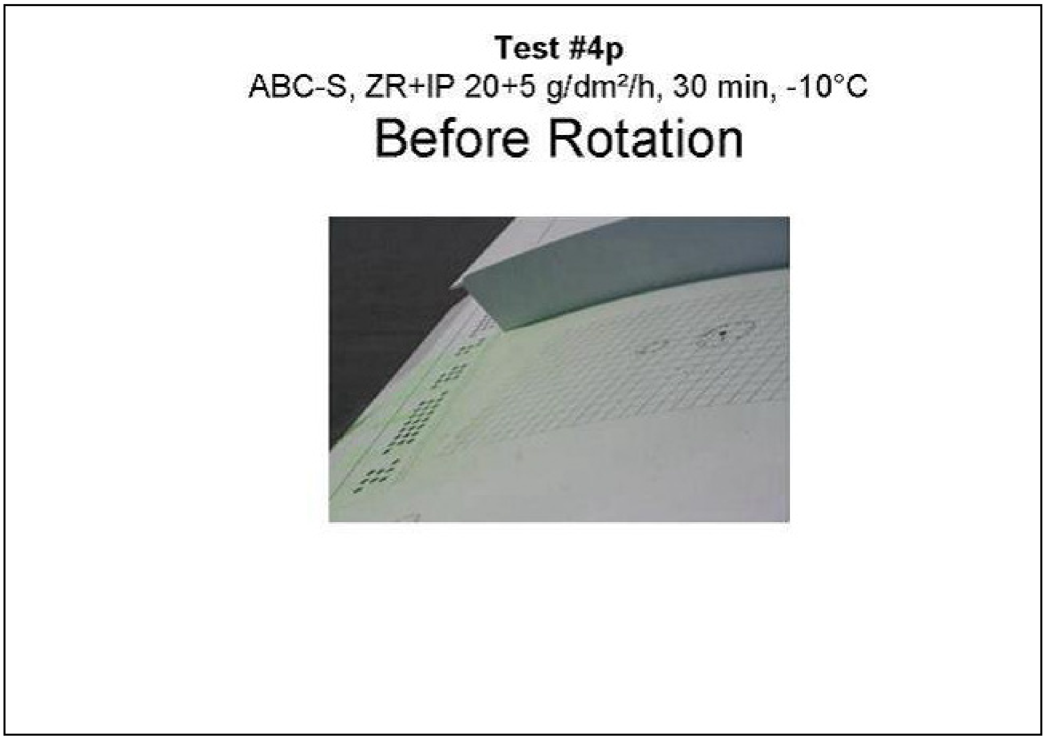


Test #4p

ABC-S, ZR+IP 20+5 g/dm²/h, 30 min, -10°C

Start of Test

Photo 9.22: Test #4P – Before Rotation

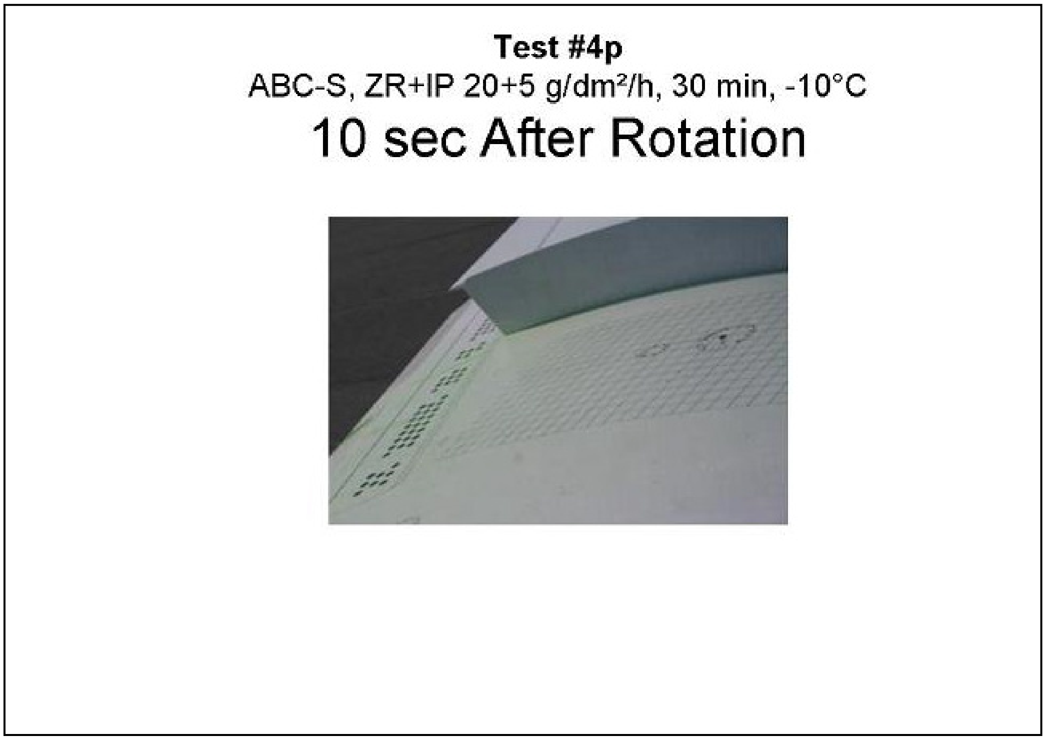


Test #4p

ABC-S, ZR+IP 20+5 g/dm²/h, 30 min, -10°C

Before Rotation

Photo 9.23: Test #4P – 10 Seconds After Rotation

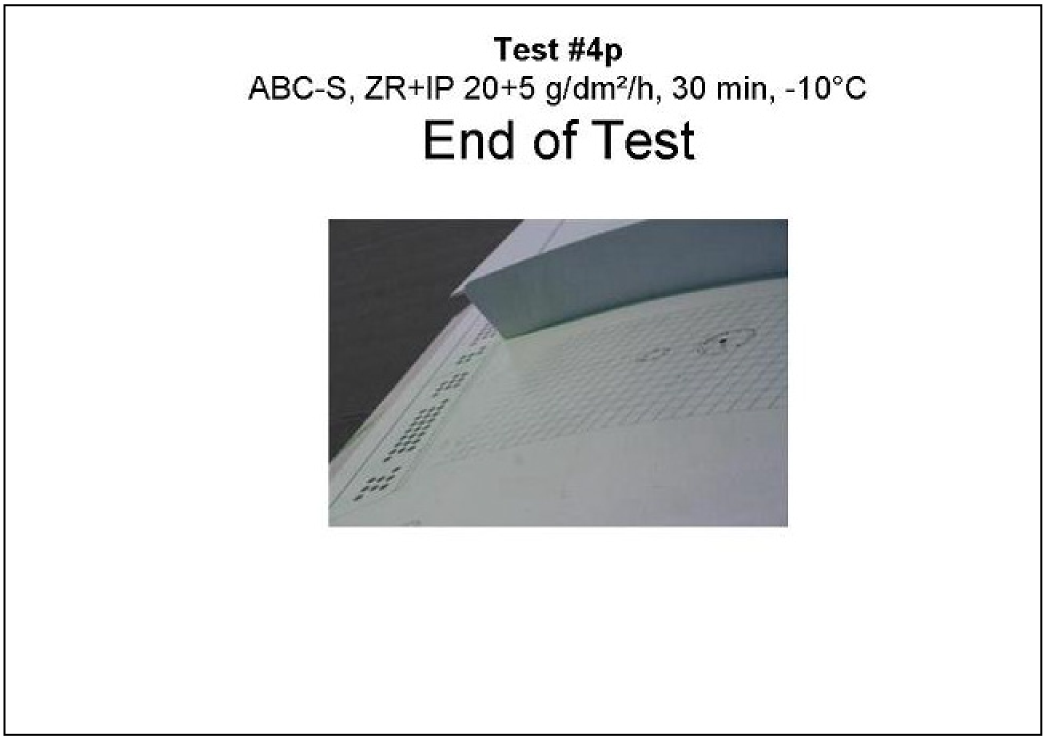


Test #4p

ABC-S, ZR+IP 20+5 g/dm²/h, 30 min, -10°C

10 sec After Rotation

Photo 9.24: Test #4P – End of Test

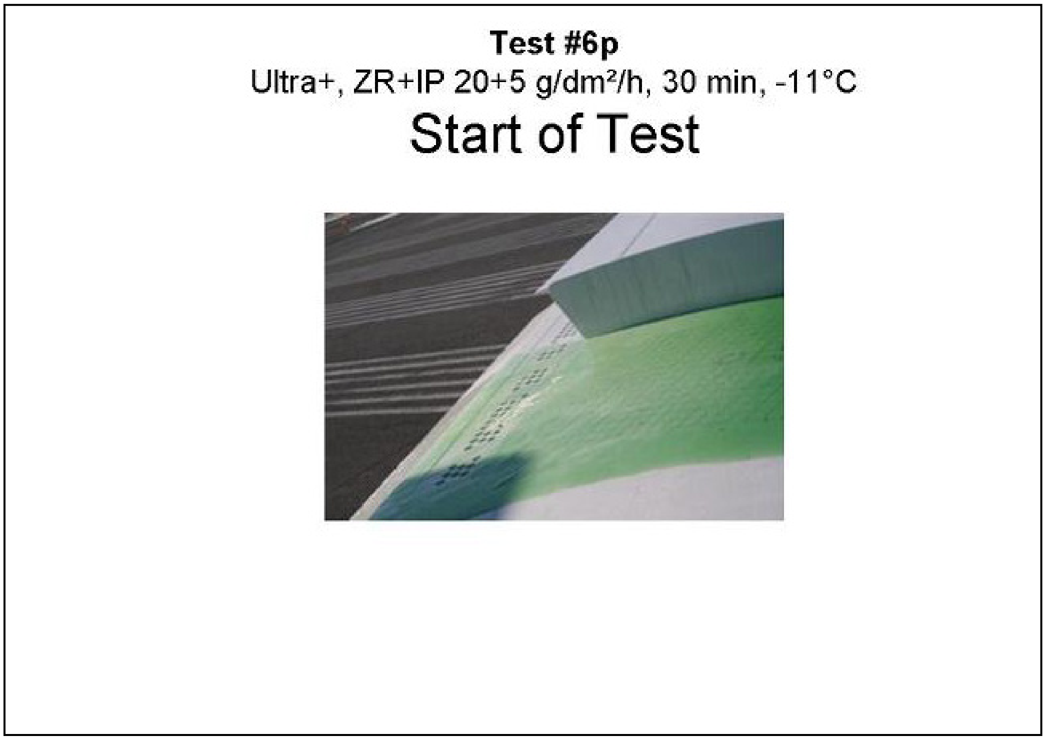


Test #4p

ABC-S, ZR+IP 20+5 g/dm²/h, 30 min, -10°C

End of Test

Photo 9.25: Test #6P – Start of Test

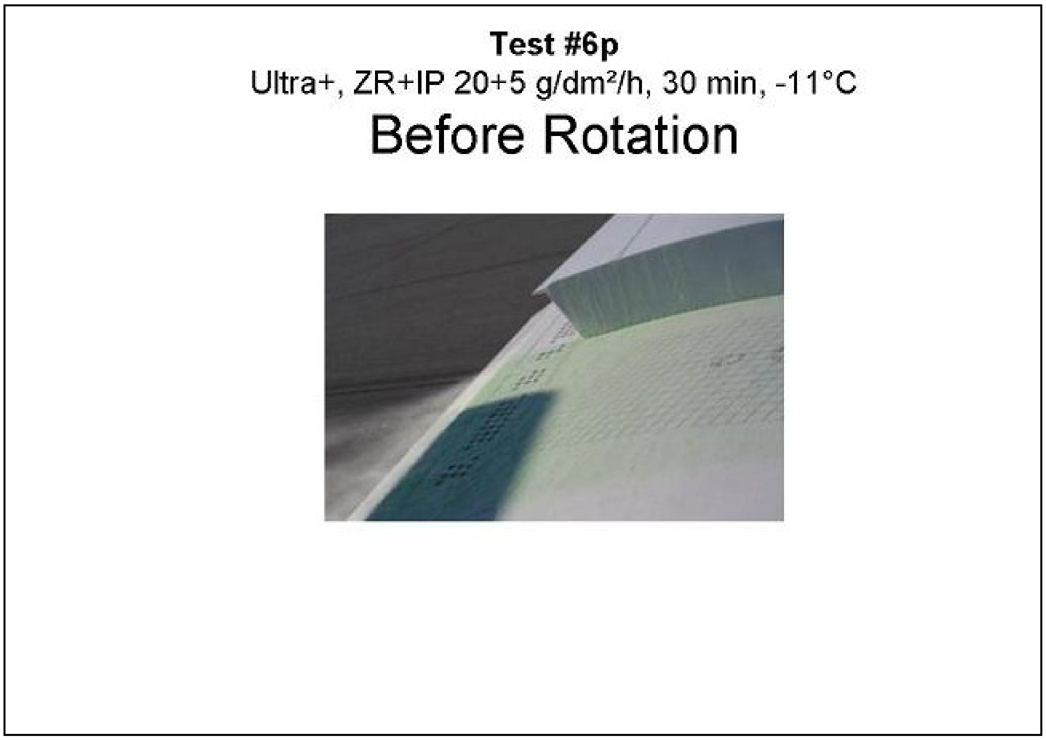


Test #6p

Ultra+, ZR+IP 20+5 g/dm²/h, 30 min, -11°C

Start of Test

Photo 9.26: Test #6P – Before Rotation

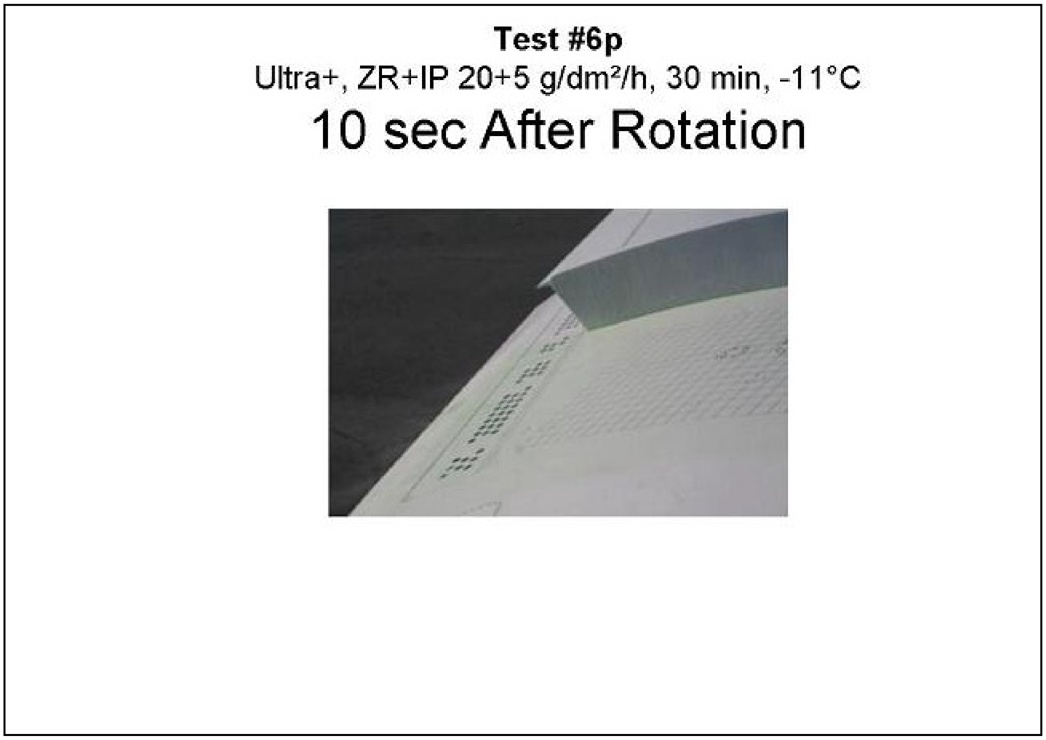


Test #6p

Ultra+, ZR+IP 20+5 g/dm²/h, 30 min, -11°C

Before Rotation

Photo 9.27: Test #6P – 10 Seconds After Rotation

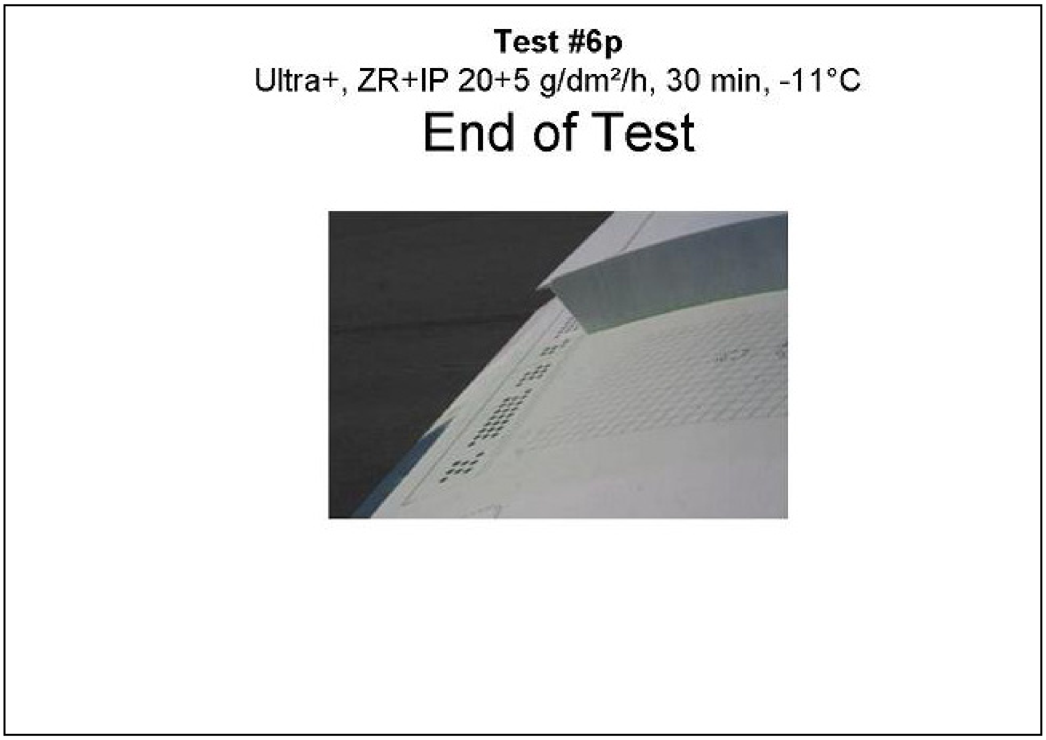


Test #6p

Ultra+, ZR+IP 20+5 g/dm²/h, 30 min, -11°C

10 sec After Rotation

Photo 9.28: Test #6P – End of Test



Test #6p

Ultra+, ZR+IP 20+5 g/dm²/h, 30 min, -11°C

End of Test

10. SUMMARY OF RECOMMENDED ALLOWANCE TIMES

A working group meeting was held April 11-13, 2007. The attendees were representatives from TC, the FAA, and APS. The objective of the meeting was to review the current data collected and to recommend allowance times for mixed precipitation conditions with ice pellets. The data collected in the wind tunnel and with the Falcon 20 aircraft during the winters of 2005-06 and 2006-07 was analysed. The following is a description of the operational guidelines and recommended allowance times included in the 2007-08 HOT Guidelines.

10.1 HOT Operational Guidelines for Ice Pellets

1) Tests have shown that ice pellets generally remain in the frozen state embedded in Type IV anti-icing fluid and are not dissolved by the fluid in the same manner as other forms of precipitation. Using current guidelines for determining anti-icing fluid failure, the presence of a contaminant not dissolved by the fluid (remaining embedded) would be an indication that the fluid has failed. These embedded ice pellets are generally not readily detectable by the human eye during pre-takeoff contamination inspection procedures.
2) The research data have also shown that after proper de/anti-icing, the accumulation of light ice pellets, moderate ice pellets, and light ice pellets mixed with other forms of precipitation in Type IV fluid will not prevent the fluid from flowing off the aerodynamic surfaces during takeoff.

   The allowance times were developed based on this aerodynamic testing and are shown in Table 10.1.
3) The ice pellet allowance times are contingent on the operator’s ground icing program being updated to incorporate the ice pellet information contained herein, including the following conditions and restrictions that must be satisfied:
   a) The aircraft critical surfaces must be properly deiced before the application of Type IV anti-icing fluid;
   b) The allowance time is valid only if the aircraft is anti-iced with undiluted Type IV fluid;
   c) These allowance times are from the start of the Type IV anti-icing fluid application;
   d) The allowance time is limited to aircraft with a rotation speed of 100 knots or greater;
   e) If the takeoff is not accomplished within the applicable allowance time shown in Table 10.1, the aircraft must be completely deiced, and if precipitation is still present, anti-iced again prior to a subsequent takeoff;

f) The allowance time cannot be extended by an inspection of the aircraft critical surfaces from either inside or outside the aircraft;

g) If the temperature decreases below the temperature on which the allowance time was based, where the new lower temperature has an associated allowance time for the precipitation condition and the present time is within the new allowance time, then that new time must be used as the allowance time limit;

h) If ice pellet precipitation becomes heavier than moderate or if the light ice pellets mixed with other forms of allowable precipitation exceeds the listed intensities or temperature range, the allowance time cannot be used; and

i) If the precipitation condition stops at or before the time limits of the applicable allowance time shown in Table 10.1 and does not restart, the aircraft may takeoff up to 90 minutes after the start of the application of the Type IV anti-icing fluid. However, under conditions of light ice pellets mixed with light freezing rain, the OAT must not decrease during the 90-minute period.

4) Examples:

a) Type IV anti-icing fluid is applied with a start of application time of 10:00, OAT is 0°C, and light ice pellets fall until 10:20 and stop and do not restart. The allowance time stops at 10:50; however, provided that no precipitation restarts after the allowance time of 10:50, the aircraft may takeoff without any further action up to 11:30.

b) Type IV anti-icing fluid is applied with a start of application time of 10:00, OAT is 0°C, and light ice pellets mixed with freezing drizzle falls until 10:10 and stops and restarts at 10:15 and stops at 10:20. The allowance time stops at 10:25; however, provided no precipitation restarts after the end of the allowance time at 10:25, the aircraft may takeoff without any further action up to 11:30.

c) Type IV anti-icing fluid is applied with a start of application time of 10:00, OAT is 0°C, and light ice pellets mixed with light freezing rain falls until 10:10 and stops and restarts at 10:15 and stops at 10:20. The allowance time stops at 10:25; however, provided that the OAT remains constant or increases and that no precipitation restarts after the end of the allowance time at 10:25, the aircraft may takeoff without any further action up to 11:30.

d) On the other hand, if Type IV anti-icing fluid is applied with a start of application time of 10:00, OAT is 0°C, and light ice pellets mixed with freezing drizzle falls until 10:10 and stops and restarts at 10:30 with the allowance time stopping at 10:25, the aircraft may not takeoff, no matter how short the time or type of precipitation after 10:25, without being de/anti-iced if precipitation is present.

Table 10.1: Ice Pellet Allowance Times Winter 2007-2008

	OAT -5° C and above	OAT Less than -5°C to -10°C	OAT Less than -10° C
Light Ice Pellets	50 Minutes	30 Minutes	30 Minutes
Moderate Ice Pellets	25 Minutes	10 Minutes	10 Minutes
Light Ice Pellets Mixed with Light or Moderate Freezing Drizzle	25 Minutes	10 Minutes	**Caution: No Allowance times currently exist**
Light Ice Pellets Mixed with Light Freezing Rain	25 Minutes	10 Minutes	
Light Ice Pellets Mixed with Light Rain	25 Minutes		
Light Ice Pellets Mixed with Light or Moderate Snow	25 Minutes		

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11. FUTURE WORK

The following future work is recommended for the winter of 2007-08.

11.1 Refine Current Ice Pellet Allowance Times

It is recommended that additional testing be conducted in the NRC wind tunnel during the winter of 2007-08 to expand the recommended allowance times issued during the winter of 2006-07. Testing should be geared towards different fluid types and formulations, air temperatures, and precipitation types.

11.2 Additional Testing in Mixed Ice Pellets and Snow Conditions

Testing in the wind tunnel and possibly with the Falcon 20 aircraft should be conducted in mixed snow and ice pellet conditions to provide guidance material for below -5°C conditions.

11.3 Operational Expansion of Allowance Times

In order to allow for greater latitude to aircraft operators, it is recommended that aerodynamic research be conducted using the NRC wind tunnel and the NRC Falcon 20 aircraft to investigate impacts on the current allowance times related to lower rotation speeds, fluid application, and perhaps the use of flaps.

11.3.1 Lower Rotation Speeds

The current allowance times were generated based on data collected with rotation speeds of approximately 100 knots. It is recommended that aerodynamic research be conducted to simulate aircraft takeoff with lower rotation speeds (i.e., 80 knots for operators at low rotation speed aircraft).

11.3.2 Improper Fluid Application

Testing should be conducted with fluid application at reduced thickness as well as with degraded fluid; this testing will investigate the effects of poor fluid application methods and poor fluid quality control on the use of the current allowance times.

11.3.3 Investigate Effect of Flaps on Fluid Flow-Off Properties

It is recommended that a wing section with a flap be acquired for testing in the wind tunnel. A flapped wing section will more accurately represent aircraft wing configurations with flaps during takeoff as well as possibly provide different aerodynamic forces resulting in different fluid flow-off properties.

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APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT – AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
2006-07

TRANSPORTATION DEVELOPMENT CENTRE
WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING
2006-07

6.2 Fluid Performance Research

6.2.1 Inclusion of Ice Pellets in Holdover Time Guidelines (Priority 1)

a) Adhesion of Ice Pellets: Investigate if endurance time testing during mixed precipitation conditions will demonstrate signs of fluid adhesion to aluminum test surfaces. Testing will be conducted in the following simulated conditions:

   i) Ice pellets and freezing rain; and

   ii) Ice pellets and snow.

   Results will be compared to baseline tests to determine impact of ice pellets on fluid endurance time.

b) Conduct additional tests at NRC chamber to validate wind tunnel and Falcon 20 tests and to investigate aging effects when precipitation stops.

c) Conduct tests at NRC to investigate "rain mixed with ice pellets" at 0ºC up to 2ºC.

6.3 Aircraft Performance Research

6.3.1 Flow of Contaminated Fluid from Aircraft Wings During Takeoff (Falcon 20 Tests)

a) Develop a test plan jointly with the NRC staff who operate the aircraft. Consideration will be given to using both slatted and non-slatted wing aircraft i.e. Bombardier Global Express and Dassault Falcon 20;

b) Plan and co-ordinate the application of SAE Type IV fluid (ethylene and propylene-based) at Ottawa airport over a period of four 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) 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 and following the takeoff run.

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

6.3.2 Flow of Contaminated Fluid from Simulated Aircraft Wings During Takeoff (Wind Tunnel Tests)

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

b) Plan and co-ordinate the application of SAE Type IV fluid (ethylene and propylene-based) at the Ottawa NRC open circuit Propulsion Wind Tunnel over a period of five days to establish feasibility;

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, during and following the wind tunnel run;

e) 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 wind tunnel run;
   - iv) Document the appearance of fluid on the wing during the simulated take off by analyzing the video records; and
   - v) Measurements of thickness, concentration, viscosity, and adherence of clean and contaminated fluid prior to and following the tunnel test.

f) Co-ordinate the fluid contamination of test activities and initiate tests in conjunction with NRC staff based on forecast weather, testing over a period of ten days.

APPENDIX B

PROCEDURE:
WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLET PRECIPITATION

CM2020.002 (06-07)

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLET PRECIPITATION

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi, George Balaban and Joey Tiano

Reviewed by: John D'Avirro

February 8, 2007
Final Version 2.0

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH MIXED ICE PELLET PRECIPITATION

1. BACKGROUND

1.1 Ice Pellet Endurance Time Research

Preliminary endurance time testing during simulated ice pellet conditions was conducted by APS at the NRC research facility during the spring of 2006 with the primary objective to investigate which conditions are most conducive to fluid adherence. A series of tests were conducted in simulated ice pellet conditions. Adherence occurred during tests conducted with Type I heated fluid in ice pellet conditions, and with Type IV fluid during mixed precipitation conditions. The preliminary testing also showed that adherence produced during ice pellet conditions in combination with freezing rain/drizzle was rough and "pimply". In comparison to adherence caused by freezing rain/drizzle alone, this may be an aerodynamically more severe condition.

1.2 Ice Pellet Falcon 20 Research

During the 2005-06 winter season, testing was conducted to address the effects of de/anti-icing fluid contaminated with ice pellets that the airflow at takeoff fails to remove. This objective was met by performing a series of takeoff tests using the NRC Falcon 20 aircraft in March 2006. A series of simulated takeoff runs were performed with the National Research Council Falcon 20 research aircraft at the Ottawa Airport. Nine runs were performed with simulated ice pellet precipitation rates ranging from 25 g/dm^2/h to 167 g/dm^2/h and two de/anti-icing fluids, DOW UCAR Ultra+ and Kilfrost ABC-S. One run was completed with Type I EG deicing fluid.

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 following the transfer of heat from the heated fluid to the cold wing surface. The fluid application method was not representative of actual operations. A normal deicing may generate more heat, which would likely generate more adhesion.

1.3 Regulatory Recommendation

As a result of the recent industry need to provide aircraft operators with holdover times for ice pellet conditions, the FAA provided a 25-minute allowance as a preliminary guideline. This allowance was followed by a list of conditions restricting operations, one condition being that the 25-minute allowance was acceptable in conditions with ice pellets alone. This recommendation was based on the previous endurance time research conducted during the winter of 2005-06, and as a result of Falcon 20 aerodynamic work. It was recommended to explore the worst-case mixed precipitation conditions in order to further evaluate or modify the current allowance time for ice pellet conditions.

2. OBJECTIVES

The objective of this project is to determine the level of contamination of anti-icing fluid at which the aerodynamic shear forces during take-off ground roll, rotation and lift off fails to remove the resultant slush. Contamination shall include simulated freezing drizzle or light freezing rain, both accompanied with ice pellets. As an additional objective, moderate and heavy snow contamination will be investigated.

To satisfy these objectives, a Cessna Caravan wing section will be subjected to a series of tests in the NRC wind tunnel. The tentative dates for testing will be February 12-23, 2007.

3. TEST PLAN

The NRC wind tunnel is an open circuit tunnel. The temperature inside the wind tunnel will be dependant on the outside ambient temperature. Prior to testing, the weather should be monitored to ensure proper temperatures for testing.

Representative Type IV propylene and ethylene fluids (ABC-S and ULTRA+) in neat form shall be evaluated against their uncontaminated performance; Attachment I and II presents the fluid specific Holdover Time guidelines of ABC-S and Ultra+ for reference purposes. A preliminary test plan summarizing the test objectives is shown in Table 3.1. Additional testing will be conducted depending on the results obtained during tests 1-7. A detailed preliminary test matrix is shown in Tables 3.2 and 3.3.

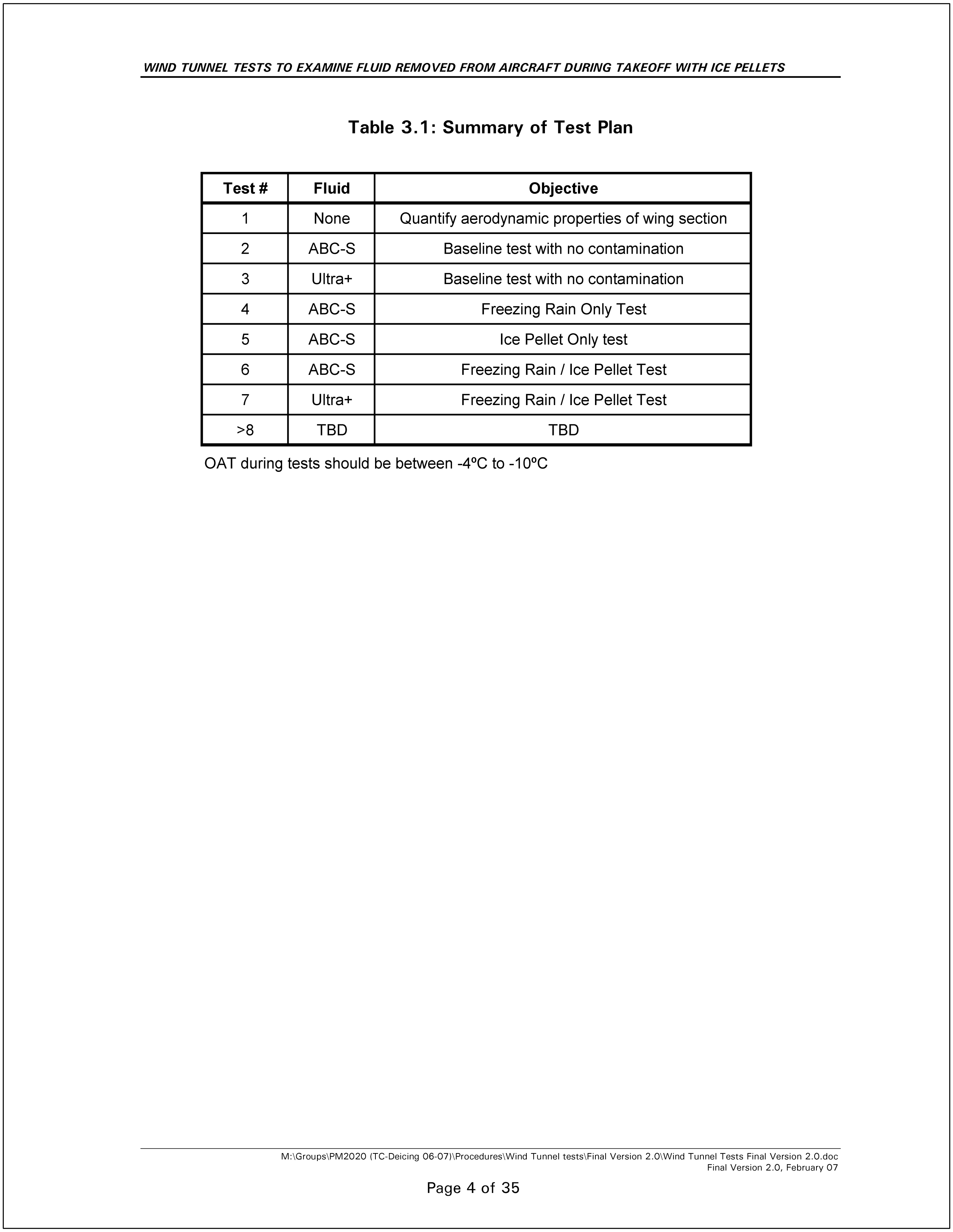


Table 3.1: Summary of Test Plan

Test #	Fluid	Objective
1	None	Quantify aerodynamic properties of wing section
2	ABC-S	Baseline test with no contamination
3	Ultra+	Baseline test with no contamination
4	ABC-S	Freezing Rain Only Test
5	ABC-S	Ice Pellet Only test
6	ABC-S	Freezing Rain / Ice Pellet Test
7	Ultra+	Freezing Rain / Ice Pellet Test
>8	TBD	TBD

OAT during tests should be between -4ºC to -10ºC

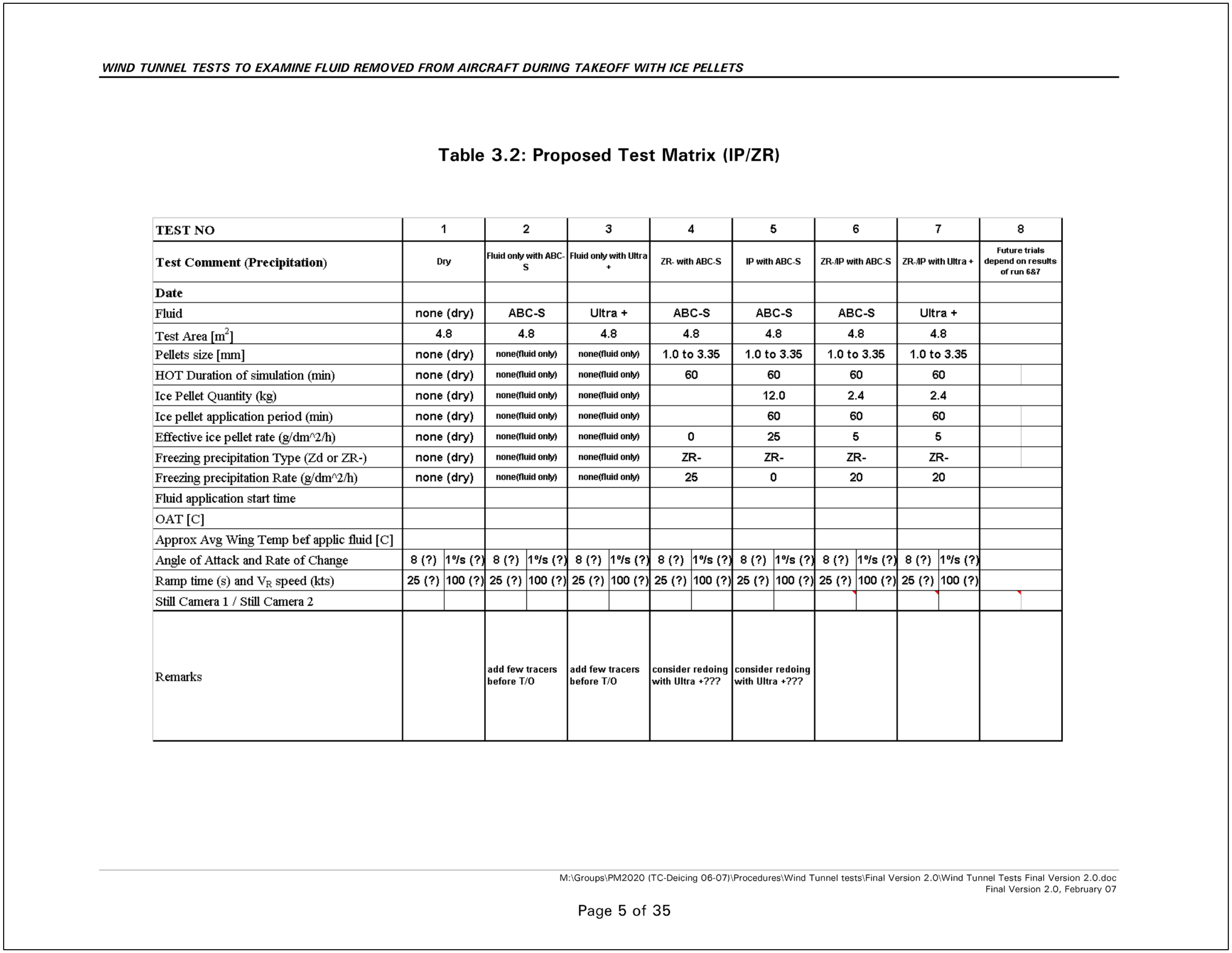


Table 3.2: Proposed Test Matrix (IP/ZR)

TEST NO	1	2	3	4	5	6	7	8
Test Comment (Precipitation)	Dry	Fluid only with ABC-S	Fluid only with Ultra +	ZR- with ABC-S	IP with ABC-S	ZR-/IP with ABC-S	ZR-/IP with Ultra +	Future trials depend on results of run 6&7
Date								
Fluid	none (dry)	ABC-S	Ultra +	ABC-S	ABC-S	ABC-S	Ultra +	
Test Area [m^2]	4.8	4.8	4.8	4.8	4.8	4.8	4.8	
Pellets size [mm]	none (dry)	none(fluid only)	none(fluid only)	1.0 to 3.35	1.0 to 3.35	1.0 to 3.35	1.0 to 3.35	
HOT Duration of simulation (min)	none (dry)	none(fluid only)	none(fluid only)	60	60	60	60	
Ice Pellet Quantity (kg)	none (dry)	none(fluid only)	none(fluid only)		12.0	2.4	2.4	
Ice pellet application period (min)	none (dry)	none(fluid only)	none(fluid only)		60	60	60	
Effective ice pellet rate (g/dm^2/h)	none (dry)	none(fluid only)	none(fluid only)	0	25	5	5	
Freezing precipitation Type (Zd or ZR-)	none (dry)	none(fluid only)	none(fluid only)	ZR-	ZR-	ZR-	ZR-	
Freezing precipitation Rate (g/dm^2/h)	none (dry)	none(fluid only)	none(fluid only)	25	0	20	20	
Fluid application start time								
OAT [C]								
Approx Avg Wing Temp bef applic fluid [C]								
Angle of Attack and Rate of Change	8 (?) 1°/s (?)	8 (?) 1°/s (?)	8 (?) 1°/s (?)	8 (?) 1°/s (?)	8 (?) 1°/s (?)	8 (?) 1°/s (?)	8 (?) 1°/s (?)	
Ramp time (s) and V_R speed (kts)	25 (?) 100 (?)	25 (?) 100 (?)	25 (?) 100 (?)	25 (?) 100 (?)	25 (?) 100 (?)	25 (?) 100 (?)	25 (?) 100 (?)	
Still Camera 1 / Still Camera 2								
Remarks		add few tracers before T/O	add few tracers before T/O	consider redoing with Ultra +???	consider redoing with Ultra +???			

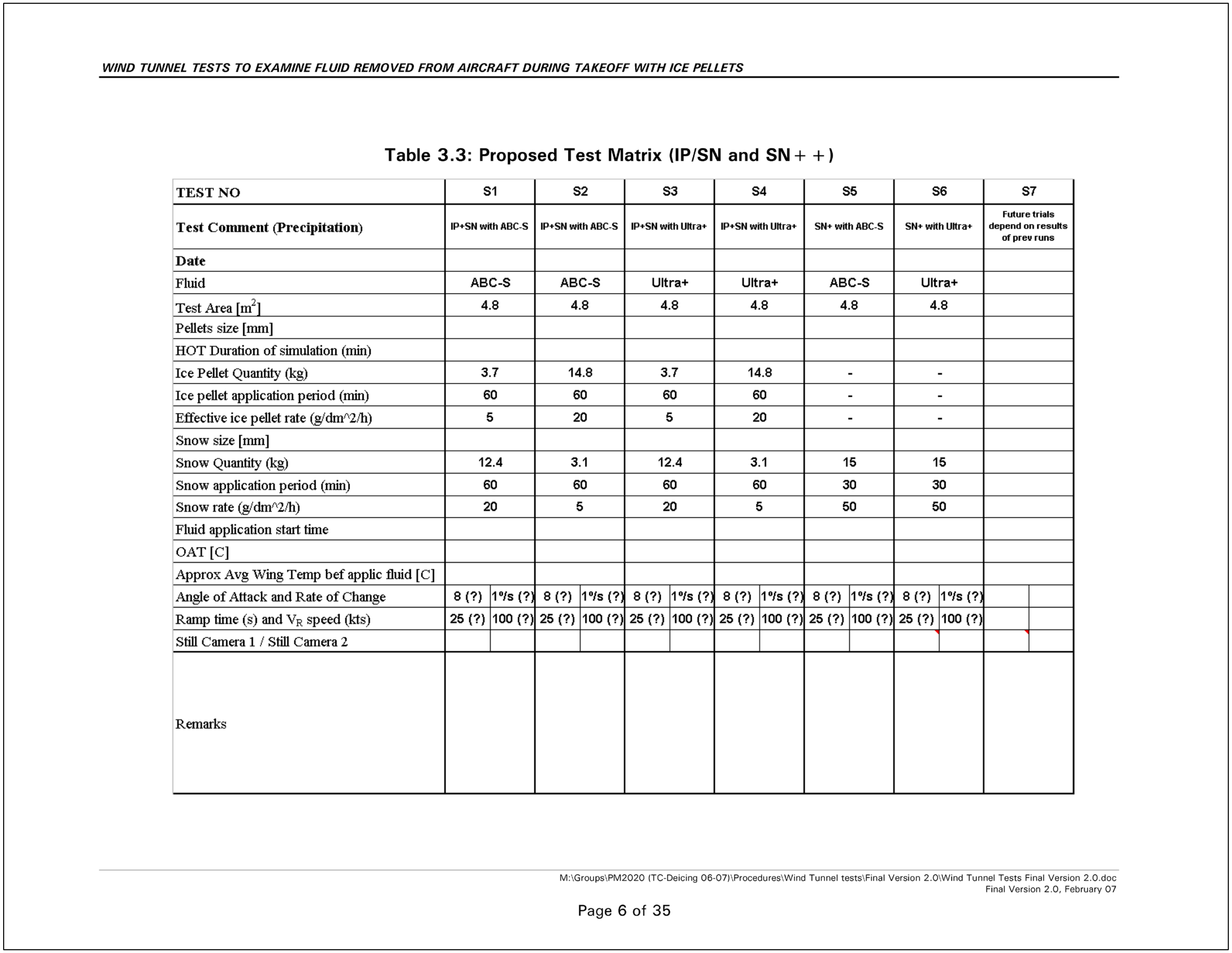


Table 3.3: Proposed Test Matrix (IP/SN and SN++)

TEST NO	S1		S2		S3		S4		S5		S6		S7	
Test Comment (Precipitation)	IP+SN with ABC-S		IP+SN with ABC-S		IP+SN with Ultra+		IP+SN with Ultra+		SN+ with ABC-S		SN+ with Ultra+		Future trials depend on results of prev runs	
Date														
Fluid	ABC-S		ABC-S		Ultra+		Ultra+		ABC-S		Ultra+			
Test Area [m^2]	4.8		4.8		4.8		4.8		4.8		4.8			
Pellets size [mm]														
HOT Duration of simulation (min)														
Ice Pellet Quantity (kg)	3.7		14.8		3.7		14.8		-		-			
Ice pellet application period (min)	60		60		60		60		-		-			
Effective ice pellet rate (g/dm^2/h)	5		20		5		20		-		-			
Snow size [mm]														
Snow Quantity (kg)	12.4		3.1		12.4		3.1		15		15			
Snow application period (min)	60		60		60		60		30		30			
Snow rate (g/dm^2/h)	20		5		20		5		50		50			
Fluid application start time														
OAT [C]														
Approx Avg Wing Temp bef applic fluid [C]														
Angle of Attack and Rate of Change	8 (?)	1°/s (?)	8 (?)	1°/s (?)	8 (?)	1°/s (?)	8 (?)	1°/s (?)	8 (?)	1°/s (?)	8 (?)	1°/s (?)		
Ramp time (s) and V_R speed (kts)	25 (?)	100 (?)	25 (?)	100 (?)	25 (?)	100 (?)	25 (?)	100 (?)	25 (?)	100 (?)	25 (?)	100 (?)		
Still Camera 1 / Still Camera 2														
Remarks														

Initially, contamination applied to the wing section will be equivalent to a 60-minute exposure at a rate of 25g/dm²/h applied in real time. Failure shall be determined by the on-site experts based on residual contamination.

Each test shall comprise of one fluid at one temperature and one contamination scenario. A test series will comprise of one fluid, at one temperature, using one form of contamination, with varying levels of exposure to the contamination. The first test in a series will closely emulate expected holdover time conditions the second test will effectively double or halve the first condition depending on whether failure to clear has occurred. The third test will double or halve the previous condition or halve the interval to the previous test depending on the failure history. This decision matrix is shown in Figure 3.1.

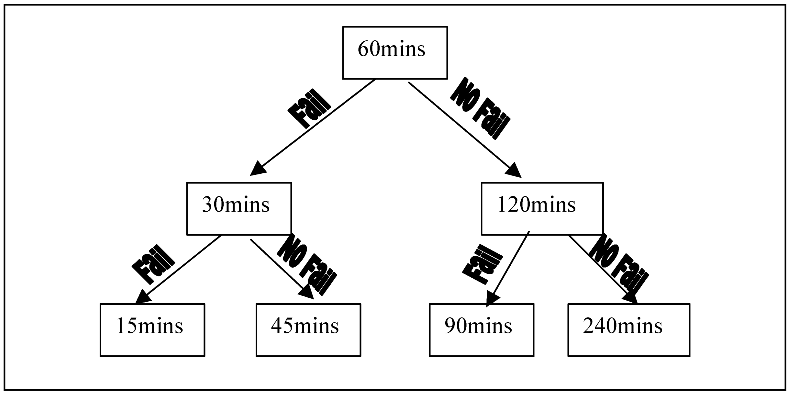


Figure 3.1: Decision Matrix for Each Test Series

4. PRE-TEST SETUP

The following describes the activities to be performed prior to the conduct of any tests:

- Co-ordinate with NRC wind tunnel personnel;
- Hotel accommodations for APS personnel;
- Arrange for vehicles to transport fluid and ice pellet material;
- Arrange personnel travel to Ottawa;
- Ensure proper functioning of ice pellets equipment;
- Mark wing data collection locations;
- Draw 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; and
- Arrange for storage and transportation of ice pellets.

5. PROCEDURE

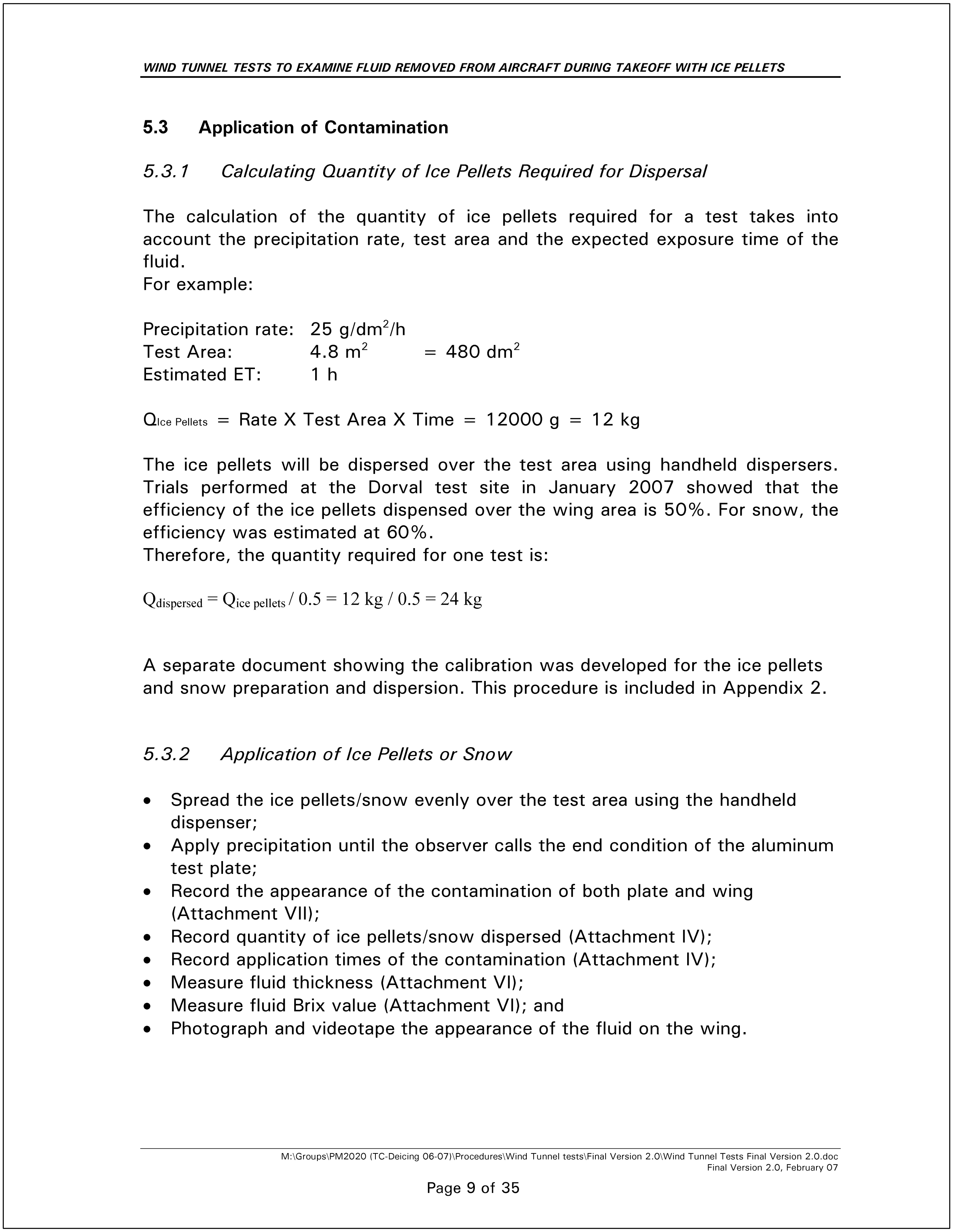
The following sections describe the tasks to be performed during each test conducted. It should be noted that some processes (i.e. fluid application and contamination application) will be omitted depending on the objective of the test.

5.1 Initial Test Conditions Survey

- Synchronize all clocks (NRC, APS clock, computer, cameras, etc);
- Record the wing section location with respect to the wind tunnel using the Wind Tunnel General Setup Form (Attachment IX). Fill this form only once;
- Establish camera locations and mark them on the Camera Locations Form (Attachment VIII). Fill this form only once unless camera positions are changed;
- Place a standard aluminum test plate on the wing using suction cups as supports;
- Ensure the plate is at a 10-degree angle (from the horizontal);
- Ensure fluid is at or close to OAT and record temperature;
- Record ambient conditions of the test (Attachment IV);
- Collect virgin samples of Type IV fluid for viscosity tests;
- Record wing temperature (Attachment V).

5.2 Fluid Application (Pour)

- First, pour fluid over the test plate;
- Pour fluid over the test area;
- Ensure the area under the test plate is covered by fluid;
- Record fluid application times (Attachment IV);
- Record fluid application quantities (Attachment IV);
- Let fluid settle for 5 minutes from start of Type IV application on wing;
- Measure fluid thickness at pre-determined locations on the wing (Attachment VI);
- Measure fluid Brix value (Attachment VI); and
- Photograph and videotape the appearance of the fluid on the wing.



5.3 Application of Contamination

5.3.1 Calculating Quantity of Ice Pellets Required for Dispersal

The calculation of the quantity of ice pellets required for a test takes into account the precipitation rate, test area and the expected exposure time of the fluid.
For example:

Precipitation rate: 25 $g/dm^2/h$
Test Area: 4.8 m^2 = 480 dm^2
Estimated ET: 1 h

$Q_{\text{Ice Pellets}}$ = Rate X Test Area X Time = 12000 g = 12 kg

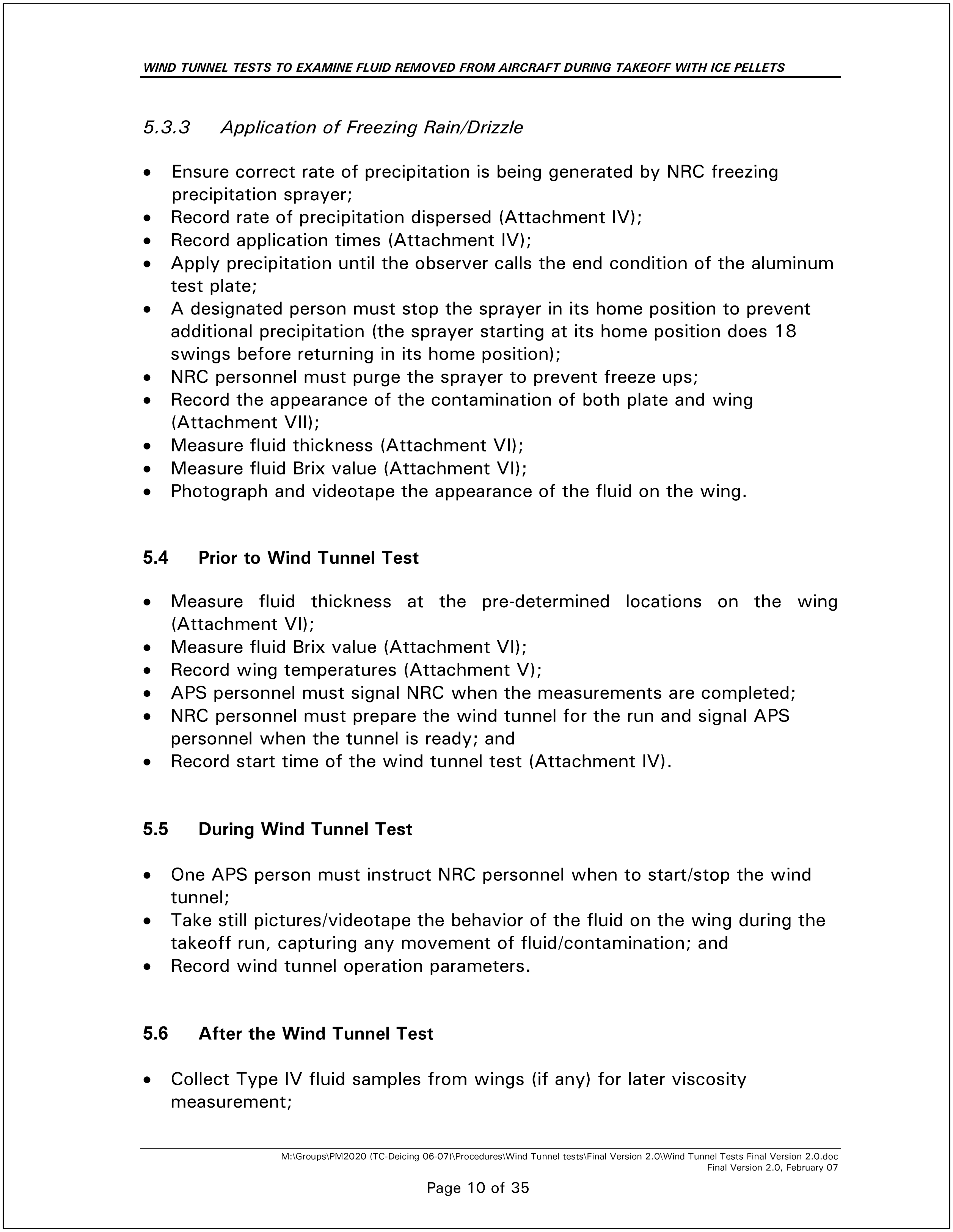
The ice pellets will be dispersed over the test area using handheld dispersers. Trials performed at the Dorval test site in January 2007 showed that the efficiency of the ice pellets dispensed over the wing area is 50%. For snow, the efficiency was estimated at 60%.
Therefore, the quantity required for one test is:

$Q_{\text{dispersed}} = Q_{\text{ice pellets}} / 0.5 = 12\text{ kg} / 0.5 = 24\text{ kg}$

A separate document showing the calibration was developed for the ice pellets and snow preparation and dispersion. This procedure is included in Appendix 2.

5.3.2 Application of Ice Pellets or Snow

- Spread the ice pellets/snow evenly over the test area using the handheld dispenser;
- Apply precipitation until the observer calls the end condition of the aluminum test plate;
- Record the appearance of the contamination of both plate and wing (Attachment VII);
- Record quantity of ice pellets/snow dispersed (Attachment IV);
- Record application times of the contamination (Attachment IV);
- Measure fluid thickness (Attachment VI);
- Measure fluid Brix value (Attachment VI); and
- Photograph and videotape the appearance of the fluid on the wing.



5.3.3 Application of Freezing Rain/Drizzle

- Ensure correct rate of precipitation is being generated by NRC freezing precipitation sprayer;
- Record rate of precipitation dispersed (Attachment IV);
- Record application times (Attachment IV);
- Apply precipitation until the observer calls the end condition of the aluminum test plate;
- A designated person must stop the sprayer in its home position to prevent additional precipitation (the sprayer starting at its home position does 18 swings before returning in its home position);
- NRC personnel must purge the sprayer to prevent freeze ups;
- Record the appearance of the contamination of both plate and wing (Attachment VII);
- Measure fluid thickness (Attachment VI);
- Measure fluid Brix value (Attachment VI);
- Photograph and videotape the appearance of the fluid on the wing.

5.4 Prior to Wind Tunnel Test

- Measure fluid thickness at the pre-determined locations on the wing (Attachment VI);
- Measure fluid Brix value (Attachment VI);
- Record wing temperatures (Attachment V);
- APS personnel must signal NRC when the measurements are completed;
- NRC personnel must prepare the wind tunnel for the run and signal APS personnel when the tunnel is ready; and
- Record start time of the wind tunnel test (Attachment IV).

5.5 During Wind Tunnel Test

- One APS person must instruct NRC personnel when to start/stop the wind tunnel;
- Take still pictures/videotape the behavior of the fluid on the wing during the takeoff run, capturing any movement of fluid/contamination; and
- Record wind tunnel operation parameters.

5.6 After the Wind Tunnel Test

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

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

5.7 At the End of Each Test Session

- All forms must be handed to the coordinator;
- The coordinator must check the forms for numbering and completeness;
- Decision will be taken for the next run; and
- Fill in the test matrix with the test data.

5.8 Timing and Process of a Typical Wind Tunnel Test

Table 5.1 demonstrates a typical Wind Tunnel test sequence of activities, assuming the test starts at 08:00:00.

Table 5.1: Typical Wind Tunnel Test

TIME	TASK
08:00:00	START OF THE TEST. ALL EQUIPMENT READY.
08:00:00	Record test conditions.
08:00:00	Deice floor and anti-ice wing with the same fluid planned for the test.
08:05:00	Calibrate ZR (if applicable)/ Calculate and calibrate SN and/or IP (see Appendix 2, Table A2-1)
08:15:00	Prepare wing for fluid application (clean wing, etc).
08:20:00	Measure wing temperature prior to fluid application.
08:25:00	Pour fluid at OAT over test area.
08:30:00	Measure Brix, thickness, temperature. Photograph test area.
08:35:00	Apply precipitation over test area.
09:05:00	Measure Brix, thickness, temperature. Photograph test area.
09:10:00	Clear area and start wind tunnel
09:15:00	Wind tunnel stopped
09:20:00	Measure Brix, thickness, temperature. Photograph test area. Record test observations
09:35:00	END OF TEST

6. EQUIPMENT

Equipment to be employed is shown in Table 6.1.

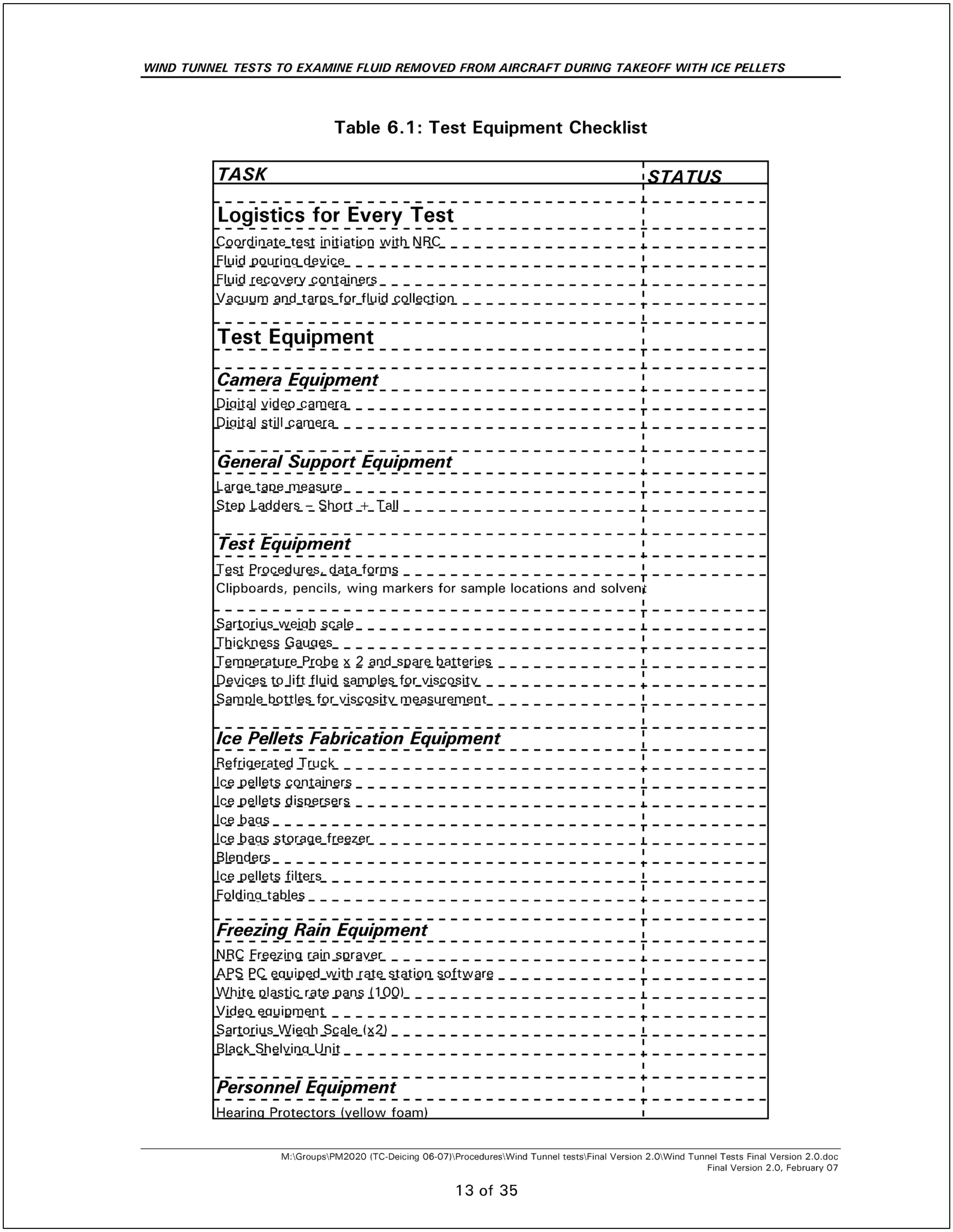


Table 6.1: Test Equipment Checklist

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 solven	
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	
Freezing Rain Equipment	
NRC Freezing rain sprayer	
APS PC equiped with rate station software	
White plastic rate pans (100)	
Video equipment	
Sartorius Wiegh Scale (x2)	
Black Shelving Unit	
Personnel Equipment	
Hearing Protectors (yellow foam)	

7. FLUIDS

Mid-viscosity samples of ethylene glycol-based UCAR Ultra+ Type IV and propylene glycol-based Kilfrost ABC-S Type IV will be used in the wind tunnel trials. Although the number off tests conducted will be determined based on the results obtained, the required fluid quantities were estimated and are shown in Table 7.1.

The fluid will be applied by pouring. It is estimated that approximately 20 liters of fluid are required for each test. The fluid must be pre-poured into small containers that will facilitate the application process. Samples of the on-wing fluid after the takeoff run will be collected for analysis.

Table 7.1: Fluid Requirements for Wind Tunnel Tests
(Fluid from two batches of Dow UCAR Ultra+ is available for the tests)

Fluid	Dilution	Viscosity	Quantity (L)
Kilfrost ABC-S	100/0	Mid	400
Dow UCAR Ultra+	100/0	Mid	200

8. PERSONNEL

Five APS staff members are required for tests at the NRC wind tunnel. Four additional persons will be required from Ottawa for making and dispersing the ice pellets. One additional person will be required from Ottawa to photograph 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 and operate the freezing rain/drizzle sprayer. The following are the specific task assignments for APS personnel for the wind tunnel tests.

Overall Co-ordinators (JD/MR)

- 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 data forms for every test;
- Ensure all data are collected and recorded, and that all test records submitted;
- Note the observed wing condition before and after each run (Attachment VII);
- Assist in setup of still cameras; and
- Communicate safety concerns.

Data Collection (NB/DY)

- Complete the Fluid Receipt Form (Attachment III) for each fluid (DY);
- Ensure the data forms are filed properly (DY);
- Ensure sample photos are taken to characterize the snow and ice pellets;
- Ensure Whatman paper samples are taken for freezing rain;
- Pour fluid over test area (including the test plate);
- Take temperature, thickness and Brix measurements;
- Assist in the collection of precipitation rates; and
- Assist with the snow/ice pellets dispersion.

Ice Pellets Coordinator (JT/DP)

- 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.

Ice Pellet/Snow Application (DP/DY)

- Apply ice pellets/snow to the test area;
- Prepare the ice pellets/snow for the test; and
- Ensure the quantity(s) of ice pellets/snow is/are sufficient for the test.

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 samples of ice pellets and snow on black felt with ruler in the background;
- Photograph all test set-up; and
- Photograph the condition of wing with contamination 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.

NRC Institute of Aerospace Research

Xing Zhong Huang:	(613) 990-6796
Myron Oleskiw:	(613) 993-5339

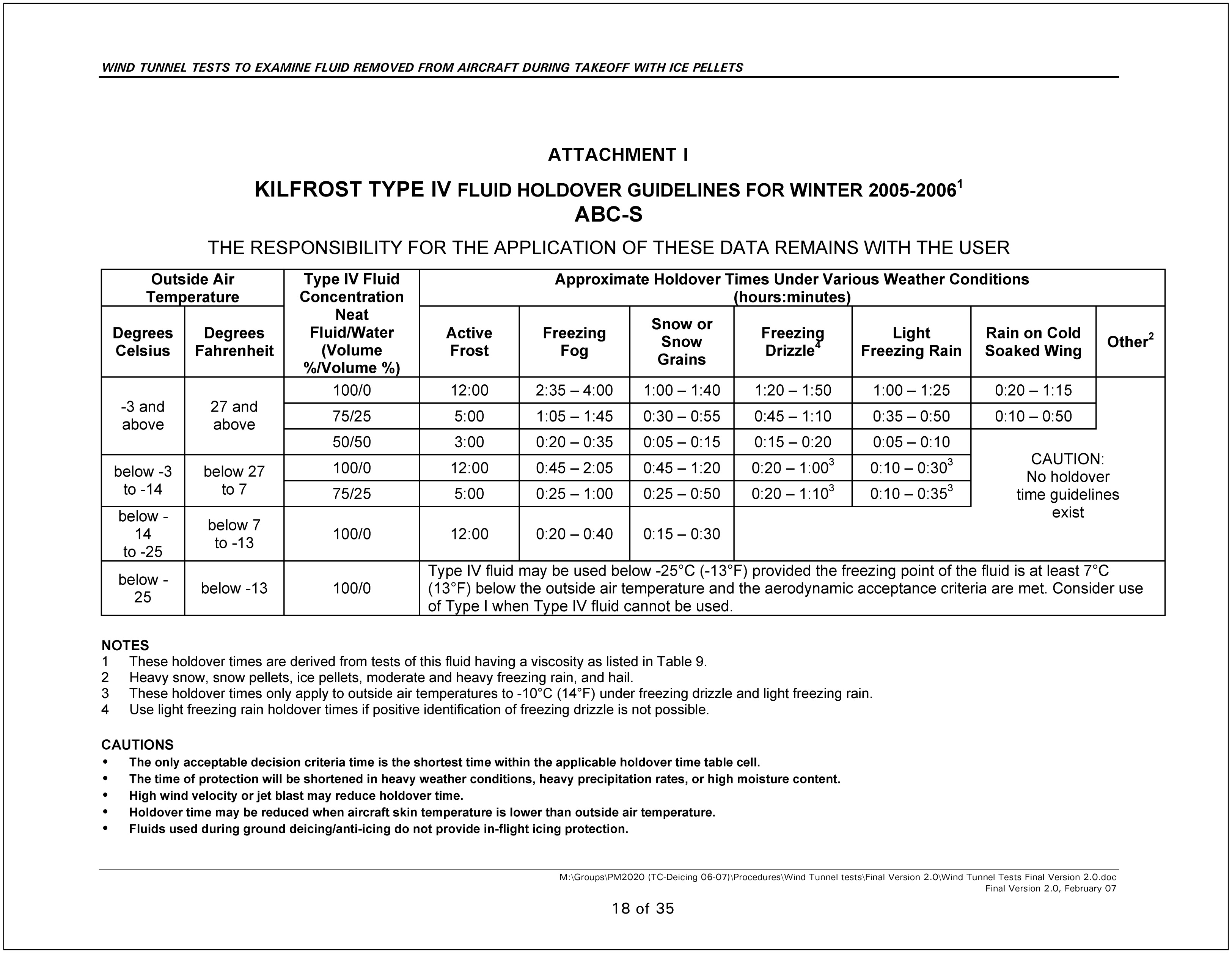
9. SAFETY

- All personnel must be familiar with Material Safety Data Sheets (MSDS) for fluids;
- Particular attention is required when working inside the tunnel as the floor and ladder are very slippery;
- Caution when walking under the wing as fluid from the wing will drip;
- Prior to operating the wind tunnel, loose objects should be removed from the vicinity;
- When wind tunnel is operating, ensure ear plugs are worn and personnel 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;
- Safety goggles must be used when working with or around fluids;
- 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.

10. DATA FORMS

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

- Attachment III – Fluid Receipt Form (Generic form used by APS; will be used for this project as appropriate);
- Attachment IV – General Form (Every Test);
- Attachment V – Wing Temperature Form;
- Attachment VI – Fluid Thickness and Brix;
- Attachment VII – Condition of Wing and Plate Form;
- Attachment VIII – Camera Locations Form (use only once unless camera locations are changed;
- Attachment IX – Wind Tunnel General Setup Form (use only once); and
- Attachment X – Log of Fluid Sample Bottles



ATTACHMENT I

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

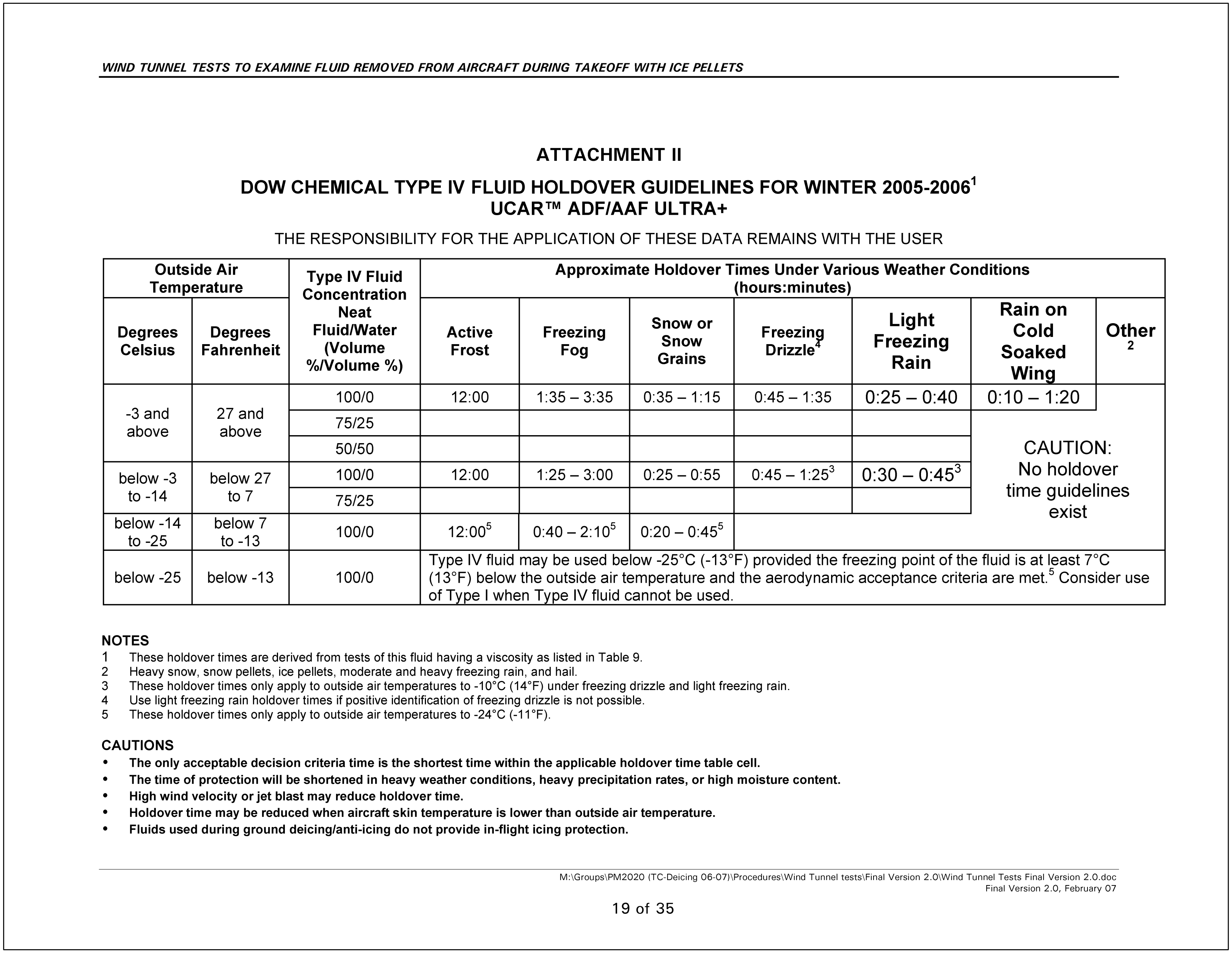
Outside Air Temperature		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
Degrees Celsius	**Degrees Fahrenheit**		**Active Frost**	**Freezing Fog**	**Snow or Snow Grains**	**Freezing Drizzle[4]**	**Light 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

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 III: Fluid Receipt Form

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

GENERAL

Fluid Name: ______________________

Manufacturer: ______________ **Fluid Type:** ____ **Batch #:** ____________________

APS Code: ______________________

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)

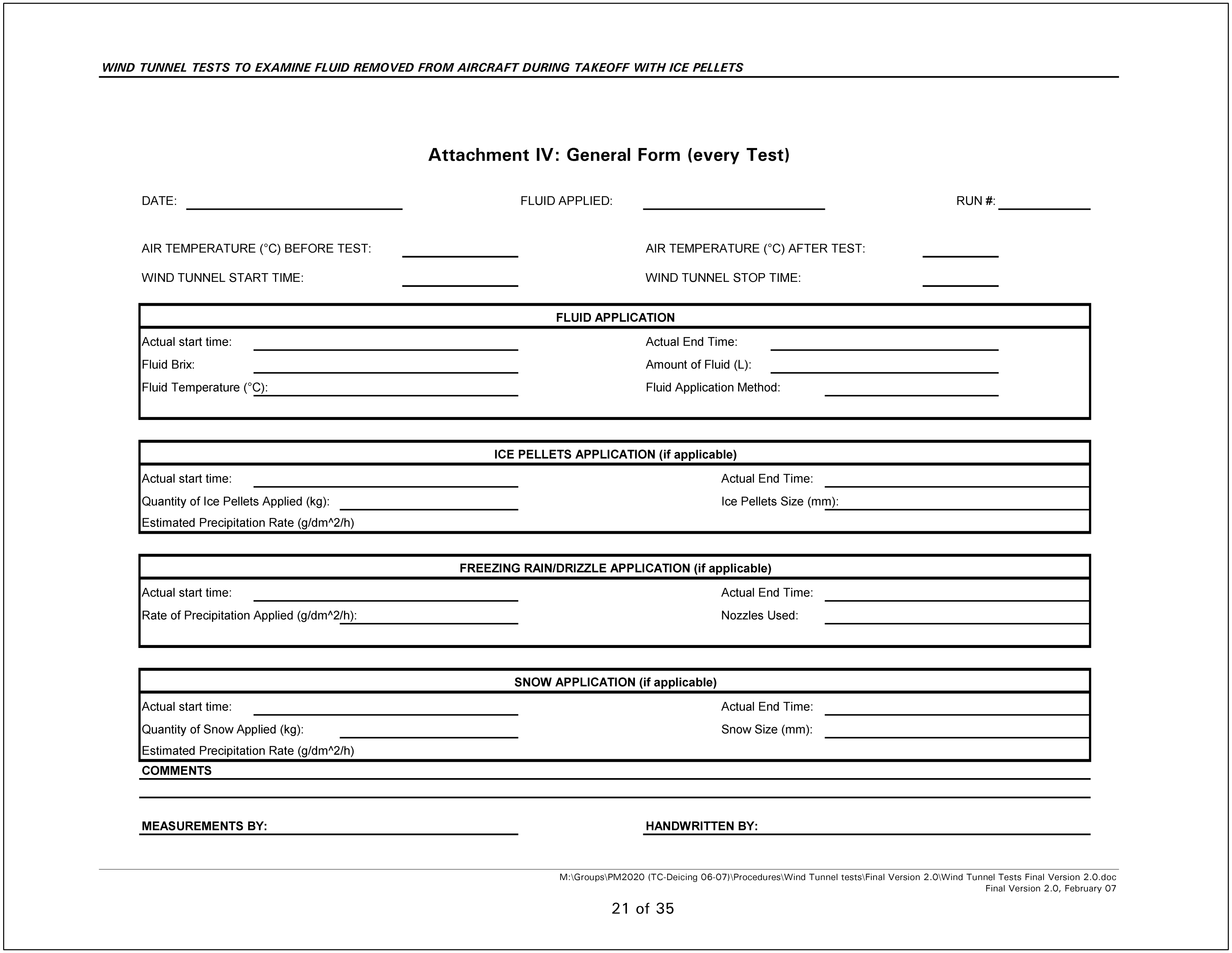
on: _______________________
(DATE)

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 IV: General Form (every Test)

DATE: ______________ FLUID APPLIED: ______________ RUN #: ________

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

WIND TUNNEL START TIME: ________ WIND TUNNEL STOP TIME: ________

FLUID APPLICATION

Actual start time: ______________ Actual End Time: ______________

Fluid Brix: ______________ Amount of Fluid (L): ______________

Fluid Temperature (°C): ______________ Fluid Application Method: ______________

ICE PELLETS APPLICATION (if applicable)

Actual start time: ______________ Actual End Time: ______________

Quantity of Ice Pellets Applied (kg): ______________ Ice Pellets Size (mm): ______________

Estimated Precipitation Rate (g/dm^2/h)

FREEZING RAIN/DRIZZLE APPLICATION (if applicable)

Actual start time: ______________ Actual End Time: ______________

Rate of Precipitation Applied (g/dm^2/h): ______________ Nozzles Used: ______________

SNOW APPLICATION (if applicable)

Actual start time: ______________ Actual End Time: ______________

Quantity of Snow Applied (kg): ______________ Snow Size (mm): ______________

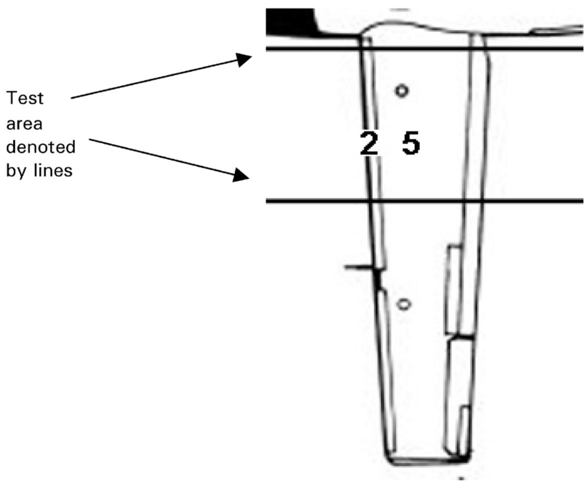
Estimated Precipitation Rate (g/dm^2/h)

COMMENTS

MEASUREMENTS BY: ______________ **HANDWRITTEN BY:** ______________

Attachment V: Wing Temperature Form

Date: ____________________ Run Number: _______



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

Test Phase	Position	Time	Temp (°C)
Before Contamination	2		
	5		
	Under wing		
Before Run	2		
	5		
	Under wing		
After Run	2		
	5		
	Under wing		

Comments: ____

____

____

OBSERVER: ______________________________

ASSISTED BY: ____________________________

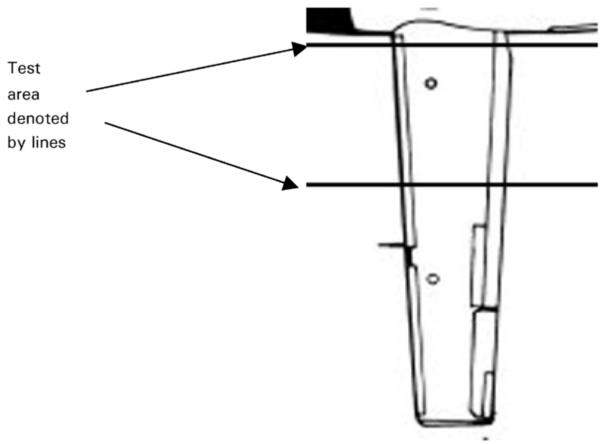
Attachment VI: Fluid Thickness and Brix

Date: ____________________

Run Number: _______

FLUID THICKNESS			
Wing Position	Before IP Application	After IP Application	After Wind Tunnel Run
1			
2			
3			
4			
5			
START TIME			
END TIME			

FLUID BRIX			
Wing Position	Before IP Application	After IP Application	After Wind Tunnel Run
2			
5			
TIME			



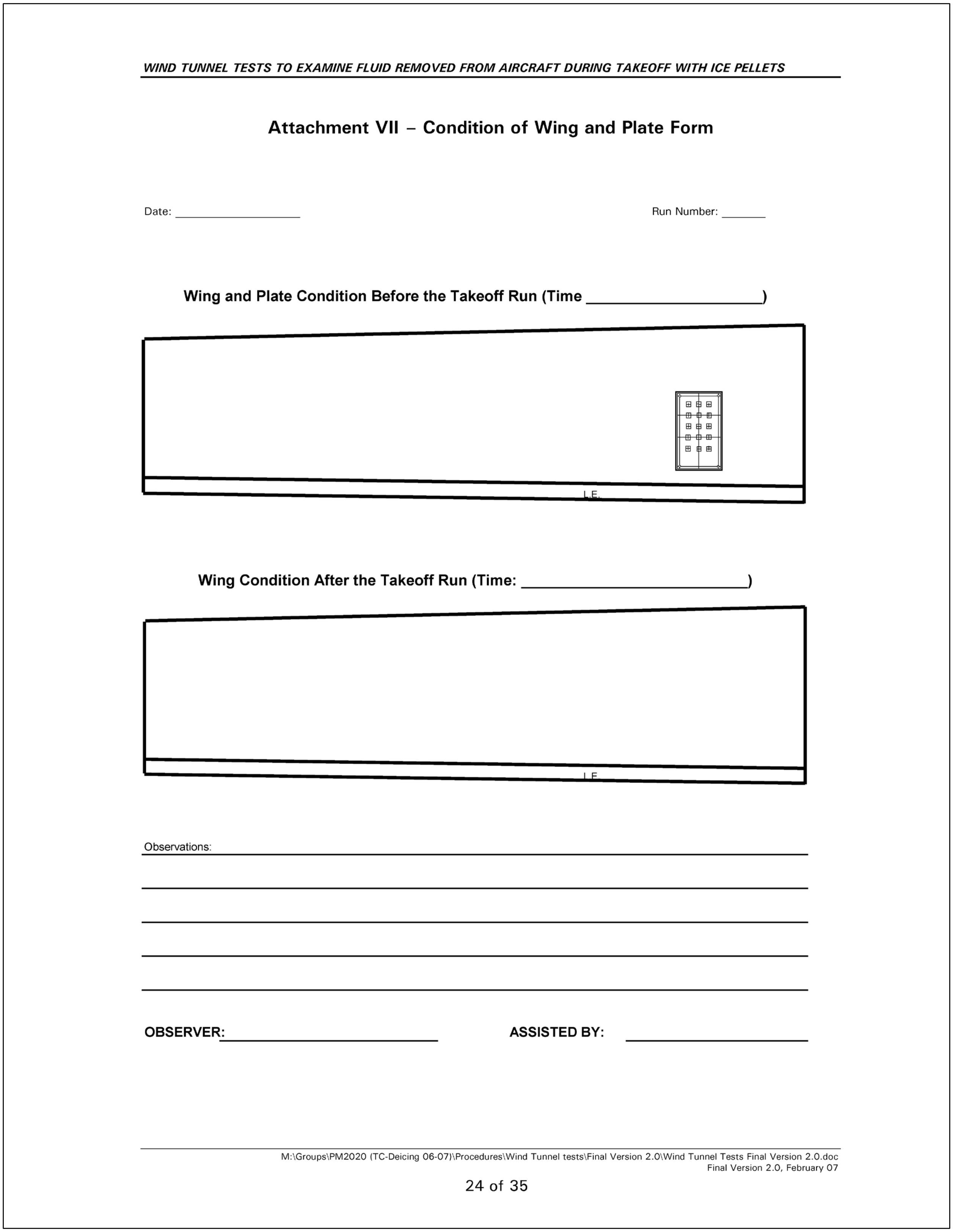
Location: 1 - Closest to the leading edge
2, 3, 4 - At equal distances between natural rivets, along the wing cord
5 - As far as one can reach

Note: - Measure thickness at locations
marked on wing (see Attachment IX - Form 6).

Comments: ______________________________
____
____

OBSERVER: ______________

ASSISTED BY: ______________



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

Attachment VII – Condition of Wing and Plate Form

Date: ____________________

Run Number: _______

Wing and Plate Condition Before the Takeoff Run (Time ______________________)

Wing Condition After the Takeoff Run (Time: ___________________________)

Observations: ____________________

OBSERVER: ____________________

ASSISTED BY: ____________________

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Final Version 2.0, February 07

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Attachment VIII – Camera Locations Form
(Fill in only once unless camera locations are changed)

Date: ____________________ Time: ____________________ Run Numbers: _______

Camera 1: Wide Angle ☐ Zoom ☐

Distance from window edge (C1):_________

Height from window base:_______________

Flash 1: Distance from window edge (F1):_________

Height from window base:_______________

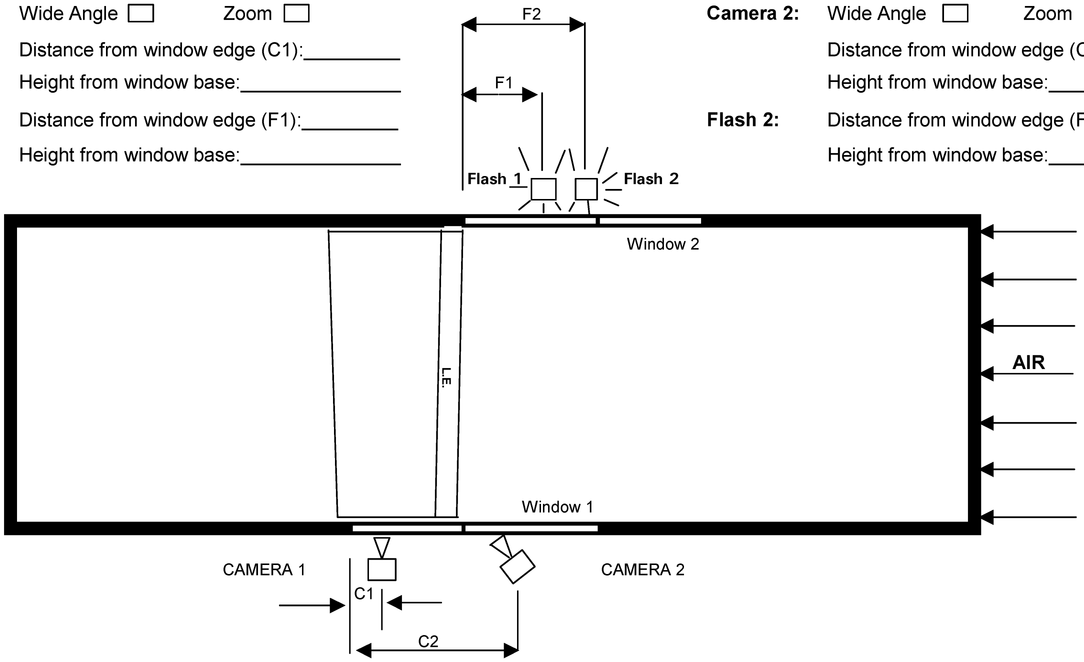
Camera 2: Wide Angle ☐ Zoom ☐

Distance from window edge (C2):_______

Height from window base:_____________

Flash 2: Distance from window edge (F2):_______

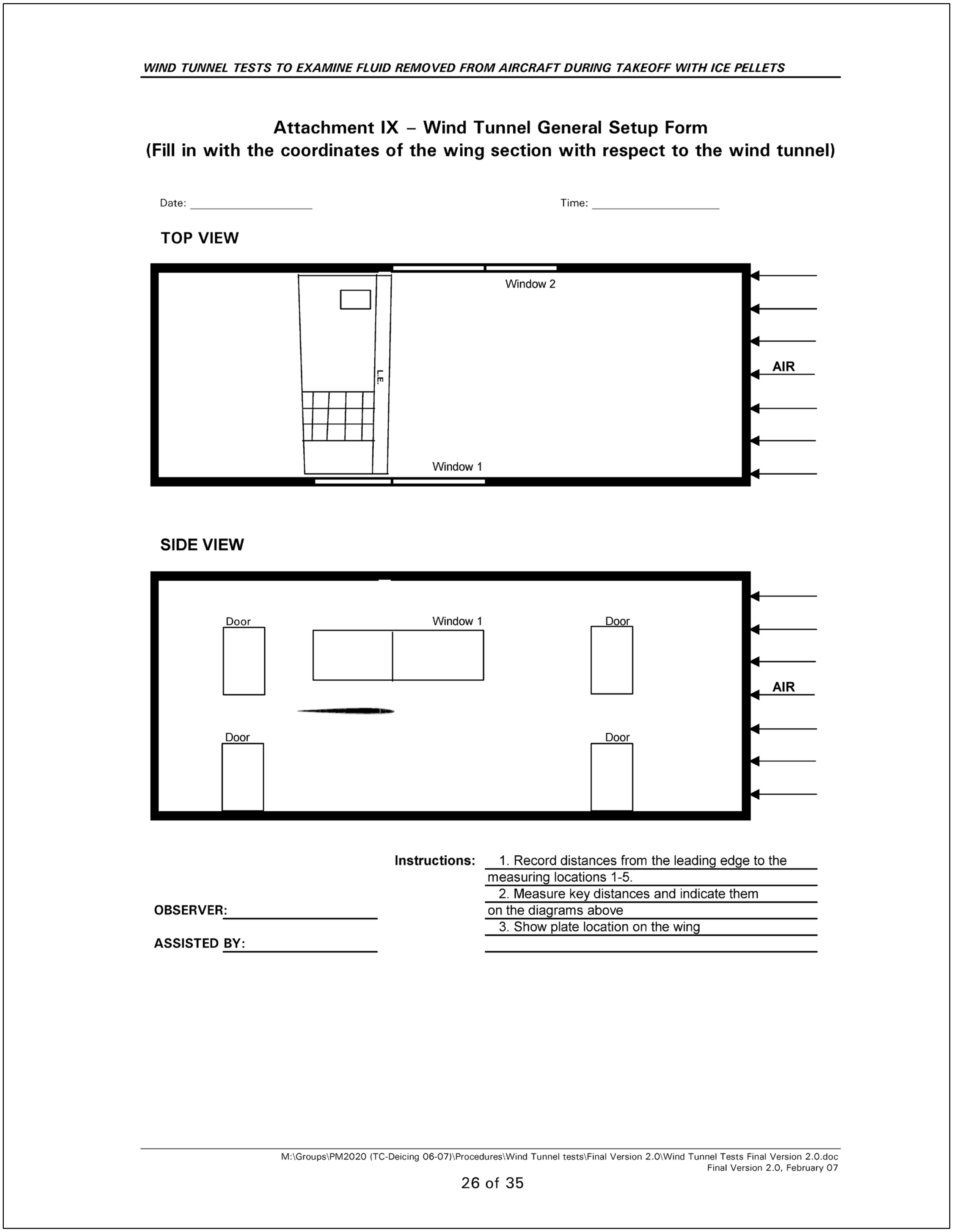
Height from window base:_____________



OBSERVER: ____________________________

ASSISTED BY: ____________________________

Observations: ____________________________



Attachment IX – Wind Tunnel General Setup Form
(Fill in with the coordinates of the wing section with respect to the wind tunnel)

Date: ____________________

Time: ____________________

TOP VIEW

SIDE VIEW

Instructions:

1. Record distances from the leading edge to the measuring locations 1-5.
2. Measure key distances and indicate them on the diagrams above
3. Show plate location on the wing

OBSERVER: ____________________

ASSISTED BY: ____________________

Attachment X – Log of Fluid Sample Bottles

Bottle Label #	Date of Extraction	Fluid and Dilution	Sample Source (on-wing/virgin)	Comments

APPENDIX 1 – Task List for Dry Run and Actual Tests

No.	Task	Status
	Planning and Preperation	
1	Establish quantities of fluid to be ordered	
2	Order fluid	
3	Investigate IP/ZR/SN dispersal techniques and location	
4	Arrange for Freezer in test area (for IP)	
5	Inquire about moving floor in tunnel	
6	Arrange for video/photo recording of the test	
7	Book Hotels for APS/TC/FAA personel	
8	Establish quantity of ice pellets required (and size)	
9	Estimate manufacturing time for ice pellets	
10	Pre-manufacture ice pellets	
11	Hire people in Ottawa to help with making of ice pellets	
12	Finalize list of materials required	
13	Prepare procedure	
14	Prepare data forms for the test	
	Perform Dry Run at NRC Test site	
15	Check with NRC the status of the testing site, tunnel etc	
16	Check weather prior to establishing test dates	
17	Arrange for hotel and transportation for personnel	
	Day 1	
18	Pack and leave YUL for YOW	
19	Setup rate station	
20	Setup IP manufacturing material	
21	Test and prepare IP dispensing equipment	
22	Verify ZR sprayer installation	
23	Verify Grid on Wing Section	
24	Ice and freezer delivery	
25	Train IP making personnel	
	Day 2	
26	ZR Calibration (run 12 rates)	
27	IP manufacturing	
28	Investigate fluid application (wand vs APS spreader)	

No.	Task	Status
	Day 3	
29	IP Dispenser Calibration (run 12 rates)	
30	Mixed IP Calibration	
31	Investigate SN (Myron bars vs. APS crushed ice)	
	Day 4	
32	Dry Run of tests (APS / NRC)	
33	Calibrate SN	
34	Pack up and leave for YUL	
	Day 5	
35	Spare Day...	
	Perform Tests at NRC Test site	
36	Check with NRC the status of the testing site, tunnel etc	
37	Check weather prior to establishing test dates	
38	Arrange for hotel and transportation for personnel	
39	Prepare equipment and fluid to be used for test	
40	Manufacture ice pellets	
41	Arrange for photo doc. of the test (if necessary)	
42	Prepare data forms for test	
43	Conduct tests based on test plan	
44	Modify test plan based on results obtained	

APPENDIX 2

Ice Pellet/Snow Dispenser Calibration and Set-Up for Wind Tunnel Testing

Calibration work was done on the modified dispensers prior to testing in the Wind Tunnel. Achieving rates of 5 and 25 (g/dm^2/h) for ice pellets, and 50 (g/dm^2/h) for snow, was successfully completed. The distribution and efficiencies of the dispensers were measured and are the prime factors in achieving the target rates for the specified precipitation type. The dispenser efficiencies are 50% for ice pellets and 60% for snow. The following will give a detailed description, and preparation for tests using the modified dispensers for tests in the Wind Tunnel.

Ice Pellet and Snow Preparation

A pre-measured amount of ice pellets and snow will be prepared prior to each test. The following steps will be repeated for the preparation of every test involving the use of ice pellets/snow:

1. Confirm the type and rate of the upcoming test.
2. Prepare the amount of ice pellets/snow needed, **by re-sieving the desired amount**. (Refer to Efficiency Table Below)
3. Pack desired amount of ice pellets/snow in a closed, labeled Styrofoam cooler, and transport it to the scaffold.
4. Repeat steps 1-3 for proceeding tests.

Dispenser Set-Up

Two dispensers will be set-up on top of the scaffold facing the leading edge of the wing. The following steps will be repeated for every test involving the use of the dispensers.

1. Make sure the dispensers are completely emptied. (No Residue Ice/Snow from previous tests).
2. Each dispenser stand will be placed on the floating scaffold, 2½ ft from their respective side of the wall of the Wind Tunnel.
3. The center of the each dispenser stand will be 1 ft, from the leading edge.
4. The dispenser height from scaffold to opening of the bucket is 4 ft.
5. Each dispenser should be rotated approximately 30° clockwise from its normal.

6. Fix dispenser settings, depending on type, rate, and time. (Refer to Table A2-1)
7. Run dispensers for a few minutes before testing. (Warm up)
8. Fill buckets with pre-measured amount of ice pellets/snow. (Using the 10 minute amount in Table Below)
9. Commence dispensing.
10. Use the wooden spoons to unblock the opening of the dispensers to have a constant flow.

    (Note: For Snow, constant unblocking of the opening is needed to achieve the desired rate.)
11. Refill the buckets every 10 minutes, making sure the dispenser bucket is fully emptied before adding any more ice pellets/snow.
12. Test completed.
13. Clear the scaffold area (Stands, spoons, Styrofoam coolers, measuring cups, etc).
14. Repeat Steps 1-13, for the next test.

Table A2-1 IP/Snow Calibration Table

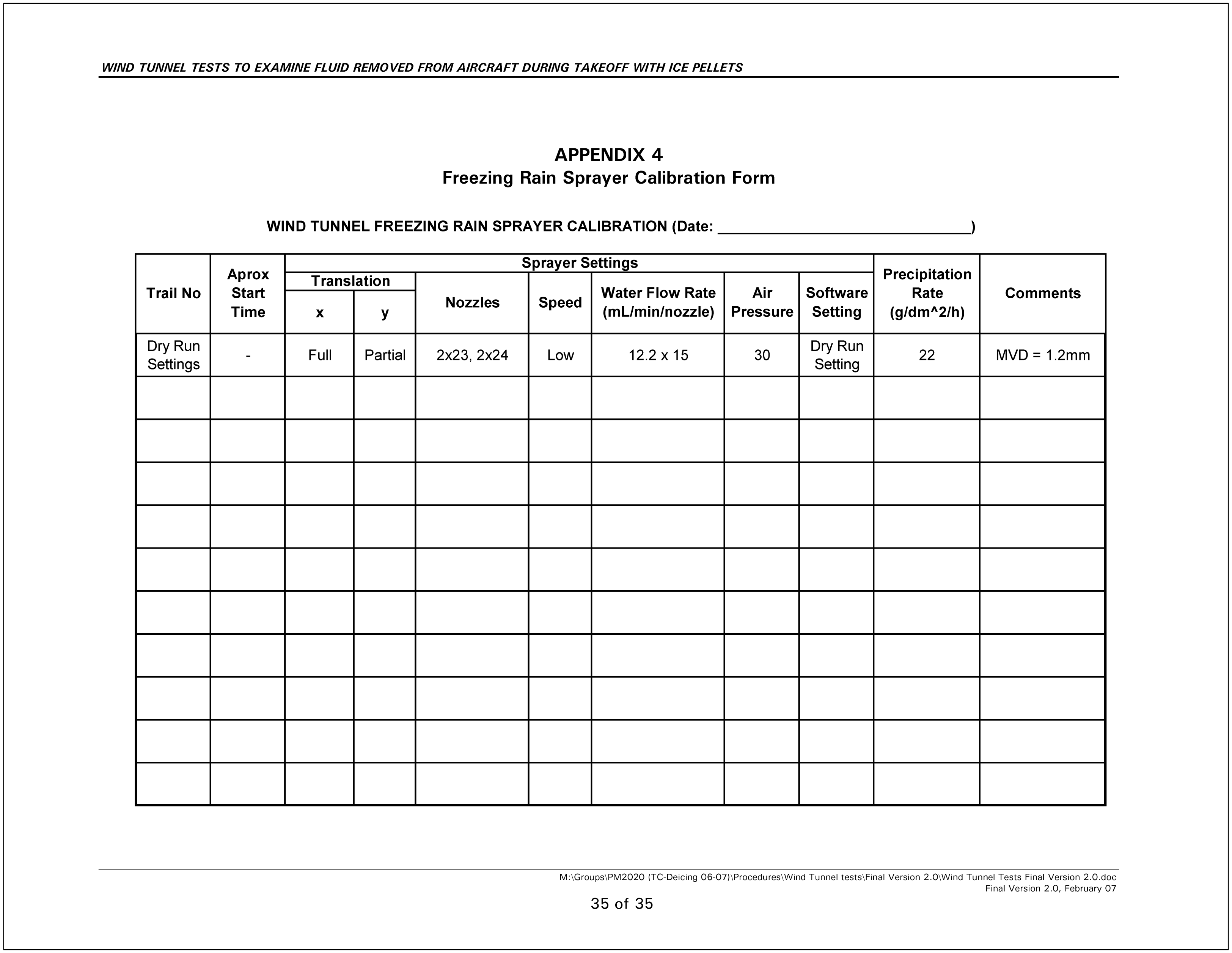
Ice Pellet/Snow Dispenser Calibration Table for Wind Tunnel Tests										
Type	Target Rate (g/dm2/h)	Dispensor Settings			Total Amount of Precipitation Needed On Wing (kg)	Efficiency (%)	Total Amount of Precipitation to be Dispersed (kg)			
							Total	Per Dispenser	Total	Per Dispenser
		Dial	Notch Openning	Speed			1 Hour	1 Hour	10 Minutes	10 Minutes
Ice Pellets	5	1	1.25	8	1.9	50%	3.7	1.9	0.6	0.3
Ice Pellets	25	2	2.25	8	9.3	50%	18.6	9.3	3.1	1.5
Snow	50	5	6	8	18.6	60%	31.0	15.5	5.2	2.6

APPENDIX 3
WIND TUNNEL NOMINAL TEST CONDITIONS (ZR/IP)

TEST NO										
Test Comment (Precipitation)										
Date										
Fluid										
Test Area [m^2]										
Pellets size [mm]										
HOT Duration of simulation (min)										
Ice Pellet Quantity (kg)										
Ice pellet application period (min)										
Effective ice pellet rate (g/dm^2/h)										
Freezing precipitation Type (Zd or ZR-)										
Freezing precipitation Rate (g/dm^2/h)										
Fluid application start time										
OAT [C]										
Approx Avg Wing Temp bef applic fluid [C]										
Angle of Attack and Rate of Change										
Ramp time (s) and V_R speed (kts)										
Still Camera 1 / Still Camera 2										
Remarks										

WIND TUNNEL NOMINAL TEST CONDITIONS (SN/IP and SN++)

TEST NO										
Test Comment (Precipitation)										
Date										
Fluid										
Test Area [m^2]										
Pellets size [mm]										
HOT Duration of simulation (min)										
Ice Pellet Quantity (kg)										
Ice pellet application period (min)										
Effective ice pellet rate (g/dm^2/h)										
Snow size [mm]										
Snow Quantity (kg)										
Snow application period (min)										
Snow rate (g/dm^2/h)										
Fluid application start time										
OAT [C]										
Approx Avg Wing Temp bef applic fluid [C]										
Angle of Attack and Rate of Change										
Ramp time (s) and V_R speed (kts)										
Still Camera 1 / Still Camera 2										
Remarks										



APPENDIX 4
Freezing Rain Sprayer Calibration Form

WIND TUNNEL FREEZING RAIN SPRAYER CALIBRATION (Date: ______________________________)

Trail No	Aprox Start Time	Sprayer Settings							Precipitation Rate (g/dm^2/h)	Comments
		Translation		Nozzles	Speed	Water Flow Rate (mL/min/nozzle)	Air Pressure	Software Setting		
		x	y							
Dry Run Settings	-	Full	Partial	2x23, 2x24	Low	12.2 x 15	30	Dry Run Setting	22	MVD = 1.2mm

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APPENDIX C

PROCEDURE:
FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS, SNOW AND/OR FREEZING RAIN

CM2020.002 (06-07)

PROCEDURE
FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS, SNOW AND/OR FREEZING RAIN

Winter 2006-07

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: For George Balaban

Reviewed by: John D'Avirro

January 5, 2006
Final Version 1.0

FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS, SNOW AND/OR FREEZING RAIN

Winter 2006-07

A series of wind tunnel tests will be conducted during the period February 12-23, 2007 at the NRC wind tunnel prior to the actual scheduled testing on February 26 – March 2, 2007. Details of the wind tunnel tests are outlined in the procedure "Wind Tunnel Tests to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets, Snow and/or Freezing Rain". Results from the wind tunnel tests may result in changes, or modifications to this procedure. An updated version of this procedure (Final Version 2.0) will be issued prior to conducting the actual testing and will include any changes.

1. BACKGROUND

1.1 Previous Falcon 20 Tests

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 2005-06 addressed the effects of deicing fluid contaminated with ice pellets that the airflow at takeoff fails to remove.

In March 2006, a series of simulated takeoff runs were performed with the National Research Council Falcon 20 research aircraft at the Ottawa Airport. Eight runs were performed with simulated ice pellet precipitation rates ranging from 25 $g/dm^2/h$ to 167 $g/dm^2/h$ and two Type IV de/anti-icing fluids, DOW UCAR Ultra+ and Kilfrost ABC-S. One run was completed with Type I EG deicing fluid.

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

1.2 Regulatory Recommendation

As a result of the recent industry need to provide aircraft operators with holdover times for ice pellet conditions, the FAA provided a 25-minute allowance as a preliminary guideline. This allowance was followed by a list of conditions restricting operations, one condition being that the 25-minute allowance was acceptable in conditions with ice pellets alone. This recommendation was based on the previous endurance time research conducted during the winter of 2005-06, and as a result of Falcon 20 aerodynamic work. It was recommended to explore the worst-case mixed precipitation conditions in order to further evaluate or modify the current allowance time for ice pellet conditions.

1.3 Mixed Precipitation Research

Preliminary endurance time testing in simulated freezing precipitation conditions was conducted by APS at the NRC research facility in 2006 to investigate which conditions are most conducive to fluid adherence. Adherence occurred during tests conducted with Type I heated fluid in ice pellet conditions, and with Type IV fluid during mixed precipitation conditions. The preliminary testing also showed that adherence produced during ice pellet conditions in combination with freezing rain/drizzle was rough in comparison to adherence caused by freezing rain/drizzle alone. This may be an aerodynamically more severe condition.

The 2007 Falcon 20 tests will be preceded by a series of tests studying ice pellets and mixed precipitation. These tests will be performed at the NRC Wind Tunnel in Ottawa. A separate procedure, *Wind Tunnel Tests to Examine Fluid Removed from Aircraft During Takeoff with Ice Pellets, Snow and/or Freezing Rain* was developed for this purpose.

During the course of the winter season, more procedures may be developed based upon results from initial testing and discussions with the industry.

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

2. OBJECTIVES

The objective of this procedure is to determine the level of contamination of anti-icing fluid caused by ice pellets mixed with freezing rain and/or snow at which the airflow at takeoff fails to remove the resultant contamination.

To satisfy this objective, 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 simulated takeoff run are required.

Desired weather conditions are dry, with subfreezing outside air temperatures. 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 February 26 – March 2 2007 will be based on the results of the wind tunnel tests performed in mixed precipitation conditions.

Attachment I presents the quantities of ice pellets required to achieve a target precipitation rate as well as the holdover time (HOT) tables for the fluids used in the tests. The ice pellet size is the same for both wind tunnel and Falcon 20 tests (1-3.35mm in diameter).

Attachment II contains a draft schedule that includes three types of tests. The test schedule may be revised based on the results of the wind tunnel tests.

- Tests with Type IV fluid exposed to ice pellets or freezing rain precipitation only.
- Tests with Type IV fluid exposed to ice pellets/freezing rain mixed precipitation.
- Tests with Type IV fluid exposed to ice pellets/snow mixed precipitation.

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

A glycol mitigation plan was prepared for the Ottawa Airport Authority prior to requesting the approval for the conduct of tests 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 DOW UCAR Ultra+ Type IV and propylene glycol-based Kilfrost ABC-S Type IV will be used in the February-March 2007 trials.

It is estimated that 200 L of Kilfrost ABC-S and 100 L of DOW UCAR Ultra+ will be used for the Falcon 20 tests.

5. PROCEDURE

The test procedures are shown in Attachment VI.

6. PERSONNEL

Six APS staff members are required for tests at the airport. Four 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 artificial precipitation application 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-March 2007:

- Attachment VIII – Fluid Receipt Form;
- Attachment IX – General Form (Every Test);
- Attachment X – Wing Temperature Form (Port Wing);
- Attachment XI – Wing Temperature Form (Starboard Wing);
- Attachment XII – Fluid Thickness and Brix (Port Wing);

- Attachment XIII – Fluid Thickness and Brix (Starboard Wing);
- Attachment XIV – Fluid Freeze Point Measurements (Port Wing);
- Attachment XV – Fluid Freeze Point Measurements (Starboard Wing);
- Attachment XVI – Freezing Rain/Snow Quantity Form;
- Attachment XVII – Test Results Form (Port Wing);
- Attachment XVIII – Test Results Form (Starboard Wing);
- Attachment XIX – Time Record of Operations;
- Attachment XX – Nominal Test Conditions.

ATTACHMENT I
Ice Pellets Requirements

1. DOW UCAR ADF/AAF ULTRA+

1.1 Rate of Precipitation

The baseline rate of precipitation for the 2007 Falcon 20 tests will be established following the wind tunnel tests. The rate of precipitation will be denoted “R” (in g/dm^2/h).

1.2 Holdover Time for Ultra+

From the HOT table attached, 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 FAA guidelines provide an allowance of 25 minutes, which is consistent with the HOT in *light freezing rain* conditions. An effective endurance time in mixed precipitation will be established following the wind tunnel tests. This reference time will be denoted “ET” (in hours).

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 endurance time of the fluid.

Precipitation rate: R (in g/dm^2/h)
Test Area: A (in dm^2)
Estimated HOT: ET (in h)

$Q_{\text{Ice Pellets}} = R \times A \times ET$

1.4 Quantity of Ice Pellets Dispersed

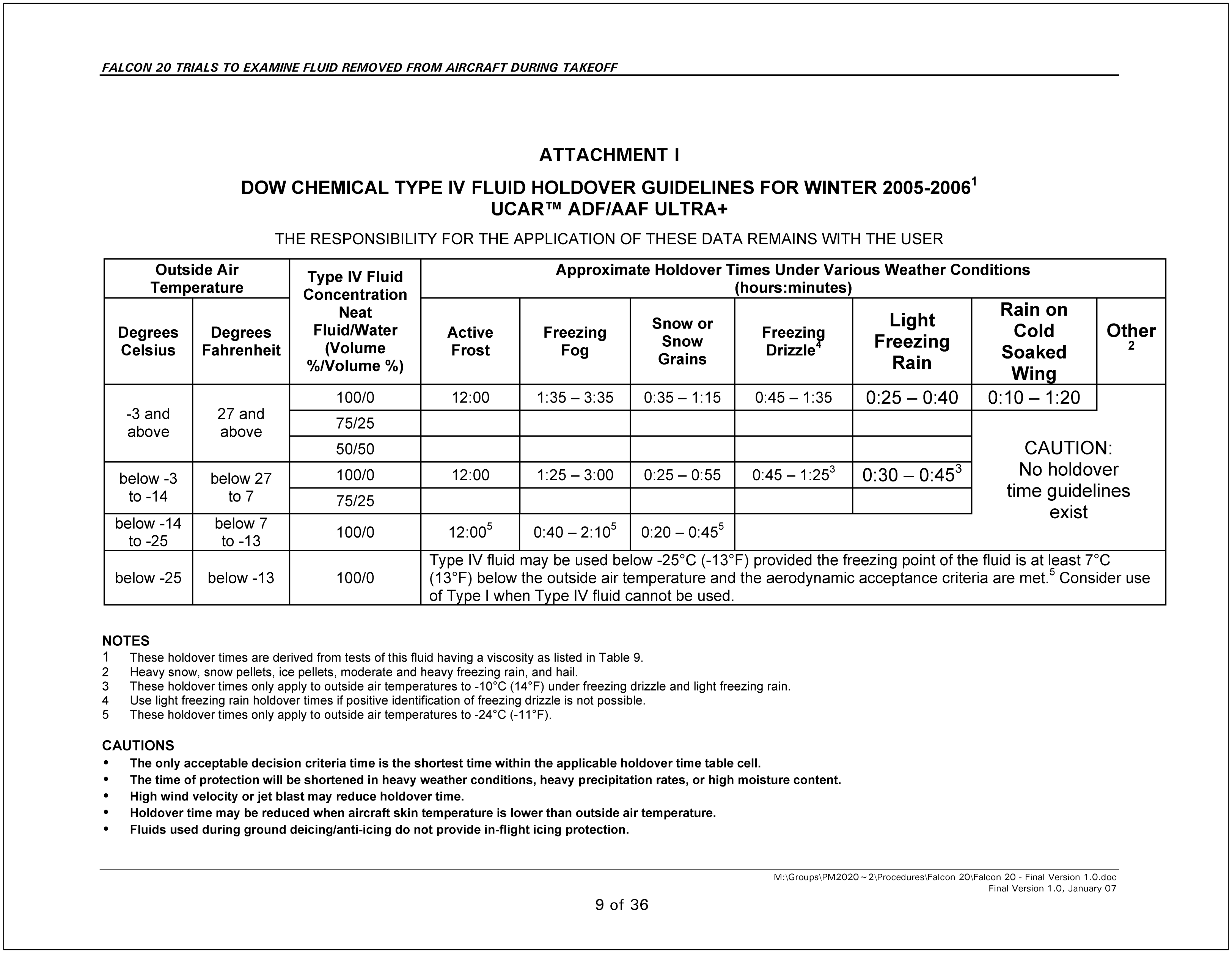
The ice pellets will be dispersed over the test area using handheld dispersers. Trials performed at the Dorval test site in February 2006 showed that the efficiency of the ice pellets disperser is 80%.

Therefore, the quantity required for one test is:

$Q_{\text{dispersed}} = Q_{\text{ice pellets}} / 0.8 = R \times A \times ET / 0.8$

2. KILFROST ABC-S

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



ATTACHMENT I

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 2006-07

Test #	Wing	Fluid	Precipitation	Precipitation Rate
1	Port	Kilfrost ABC-S	IP+ZR	TBD*
	Starboard	Kilfrost ABC-S	IP+Snow	TBD*
2	Port	UCAR Ultra+	IP+ZR	TBD*
	Starboard	UCAR Ultra+	IP+Snow	TBD*
3	Port	TBD	TBD	TBD**
	Starboard	TBD	TBD	TBD**
4	Port	TBD	TBD	TBD**
	Starboard	TBD	TBD	TBD**
5	Port	TBD	TBD	TBD**
	Starboard	TBD	TBD	TBD**
6	Port	TBD	TBD	TBD**
	Starboard	TBD	TBD	TBD**

* Precipitation rate will be based on NRC wind tunnel test results.
** Precipitation rate will be based on the results of the first Falcon 20 runs.

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)
FEBRUARY 26 – MARCH 2, 2007

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 mixed with freezing rain on the wing of Falcon 20 aircraft during takeoff are currently studied. Since the precipitation embedded in the fluid was 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 pellets/freezing rain mixed precipitation conditions.

The February-March 2007 tests at YOW will address the effects of deicing fluid contaminated with ice pellets and/or freezing rain 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 February-March 2007, 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 2.7 square-meter section of the aircraft wing by pouring, thus limiting the amount of fluid that falls on the ground after application.

In previous tests conducted at YOW in March 2006 ethylene and propylene fluids were applied over the same 2.7 square-meter section. In total, 60 liters of ethylene fluid and 100 liters of propylene fluid were used for the entire test session. All deicing fluid that fell to the ground within the application area was properly recovered.

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

Six tests are anticipated for February-March 2007 at YOW. Of this total, four will be performed with Dow Ultra+ (ethylene) and two 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 (160 of ethylene glycol and 80 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

Upon request, a 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 **Test Equipment**	***STATUS***
General Equipment	
Refrigerated truck	
Freezer for ice and ice pellets storage	
Portable radio	
Fluids (order and ship to Ottawa)	
Horse and tap for fluid barrel	
Vacuum and tarps for fluid collection	
Waste fluid containers	
Funnels	
Sample bottles for viscosity measurement	
Devices to lift fluid samples for viscosity	
Step Ladders – Short + Tall	
Squeegees	
Large tape measure	
Isopropyl	
Gloves, hearing protectors, paper towel	
Extension cords	
Security passes	
Camera Equipment	
Digital still cameras x3 (with lenses, chargers, batteries, etc)	
Video camera(s) provided by NRC	
Test Equipment	
Test Procedure, data forms	
Fluid pouring devices x6	
Ice pellets dispensing devices x6	
Desktop/Laptop computer with printer	
Portable hard drive and memory card reader	
Aluminum Rate pans	
Clipboards, pencils, wing markers for sample locations and solvent	
Temperature Probe x 2 and spare batteries	
Thickness Gauges (large and small)	
Brixometers X3	
Weigh scale	
Ice Pellets Fabrication Equipment	
Styrofoam containers x20	
Ice bags Blenders (x6) Ice pellets sieves	
Folding tables	
Scrapers	

ATTACHMENT V (cont.)
Test Equipment Checklist

TASK **Test Equipment (cont.)**	***STATUS***
Freezing Rain Sprayer Equipment	
Freezing Rain Sprayer pump	
Air Compressors X2	
Water container	
Water hoses	
Air hoses	
Freezing Rain Sprayer nozzles	
Needles for the nozzles	
Extension cords (heavy duty)	
Aluminum rate pans x2	

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;
- Ensure proper functioning of freezing rain sprayer;
- 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;
- Order fluids;
- Mark aircraft data collection locations; and
- Collect virgin samples of Type IV fluid for viscosity tests.

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 Prior to Fluid Application:

- Record OAT, wind speed, direction and sky condition (Attachment IX); and
- Measure wing temperature (Attachment X and XI).

3.2 Fluid Application (Pour):

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

3.3 Freezing Precipitation Application:

- Prepare and place rate pan on wing;
- Start the rate collection period;
- Record start of freezing precipitation application;
- Conduct freezing rain application;
- Spread the ice pellets evenly over the test area using the handheld dispenser;
- Measure the fluid freeze points at 2 numbered locations (see Attachments XIV and XV) at 5-minute intervals;
- When the desired level of precipitation has been applied to the wings, the wing observer will call for the end of the precipitation application process;
- Remove rate pans from the wing surface;
- Clean sprayer and prepare it for next run;
- Record quantity of ice pellets dispersed (Attachment IX);
- Record quantity of freezing rain applied (Attachments IX and XVI);
- Measure fluid thickness on the leading edge (Attachment XII and XIII);
- Measure fluid Brix value (Attachment XII and XIII); and
- Photograph and videotape the appearance of the fluid on the wing.

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

- Record wing temperatures at the numbered locations (Attachment X and XI);
- Measure fluid thickness (Attachment XII and XIII);
- Measure fluid Brix value (Attachment XII and XIII);
- Record departure runway, wind speed and direction (Attachment IX); and
- Record time of departure (Attachments IX and XIX).

3.5 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).

3.6 Upon Return to the De-icing Pad:

- Collect Type IV fluid samples from wings (if any) for later viscosity measurement; and
- Observe and record the status of the fluid/ice pellets (Attachment XVII and XVIII).

3.7 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.

3.8 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).
08:05:00	Prepare wings for fluid application (clean wing, etc).
08:15:00	Pour fluid over test area and let settle for 5 minutes
08:15:00	Start aircraft engines. Pilots follow standard pre-departure procedures
08:20:00	Measure fluid Brix, thickness. Photograph test area.
08:30:00	Disperse freezing precipitation over test area.
09:00:00	Measure Brix, thickness. Photograph test area.
09:20:00	Aircraft starts to taxi towards runway. Waste fluid collected and pad prepared for next test.
09:30:00	Aircraft is positioned for the simulated takeoff run. Measure Brix, thickness. Photograph test area.
09:40:00	Start of the simulated takeoff run.
09:50:00	Aircraft returns to the deicing pad.
09:50:00	Measure Brix, thickness. Photograph test area. Record test observations
10:00:00	END OF TEST

3.9 Typical Falcon 20 Test: Number of People Required

Below is a description of the major steps of a typical Falcon 20 test and the number of people required for each test.

STEP	TASKS	NO. OF PEOPLE REQUIRED
1	Complete general forms	1 (APS)
	Prepare fluid	2 (APS)
	Prepare IP for test	2 (IP makers)
	Prepare sprayer	2 (APS)
2	Pour fluid	4 (APS)
	Refill fluid pouring devices	2 (APS + IP makers)
3	Take measurements (temp, thickness, brix)	2 (APS)
	Ready IP dispensers	2 (APS + IP makers)
	Ready ZR sprayer	2 (APS)
4	Apply IP	4 (APS + IP makers)
	Apply ZR	2 (APS)
	Assist with ZR application and take measurements	1 (APS)
5	Take measurements at hangar	2 (APS)
	Clean sprayer and prepare for next test	2 (APS)
	Prepare fluid for next test	2 (APS + IP makers)
6	Take measurements at button and record test results	2 (APS)

ATTACHMENT VII
APS Staff Task Description

Overall Co-ordinator (JD)

- 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 XI) and Brix (Attachments XII, XIII, XIV and XV);
- 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 XIV);
- Communicate safety concerns.

Co-ordinator 2 (MR)

- 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 XIV);

Freezing Rain Sprayer Application (NB/DP/DY)

- Ensure the proper operation of the sprayer;
- Calibrate the sprayer prior to the test session;
- Apply freezing rain as required for each test; and
- Clean the sprayer and prepare it for the next test.

Data collection (DP/DY)

- Complete the Fluid Receipt Form (Attachment VIII) for each fluid;

- Record temperature measurements (Attachment X and XI);
- Record Brix and thickness measurements (Attachment XII and XIII);
- Record start and end of fluid application (Attachment IX);
- Record start and end of freezing precipitation application (Attachment IX);
- Record amount of ice pellets applied (Attachment IX);
- Record quantity of freezing rain applied (Attachment XVI);
- 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 (4 persons from Ottawa)

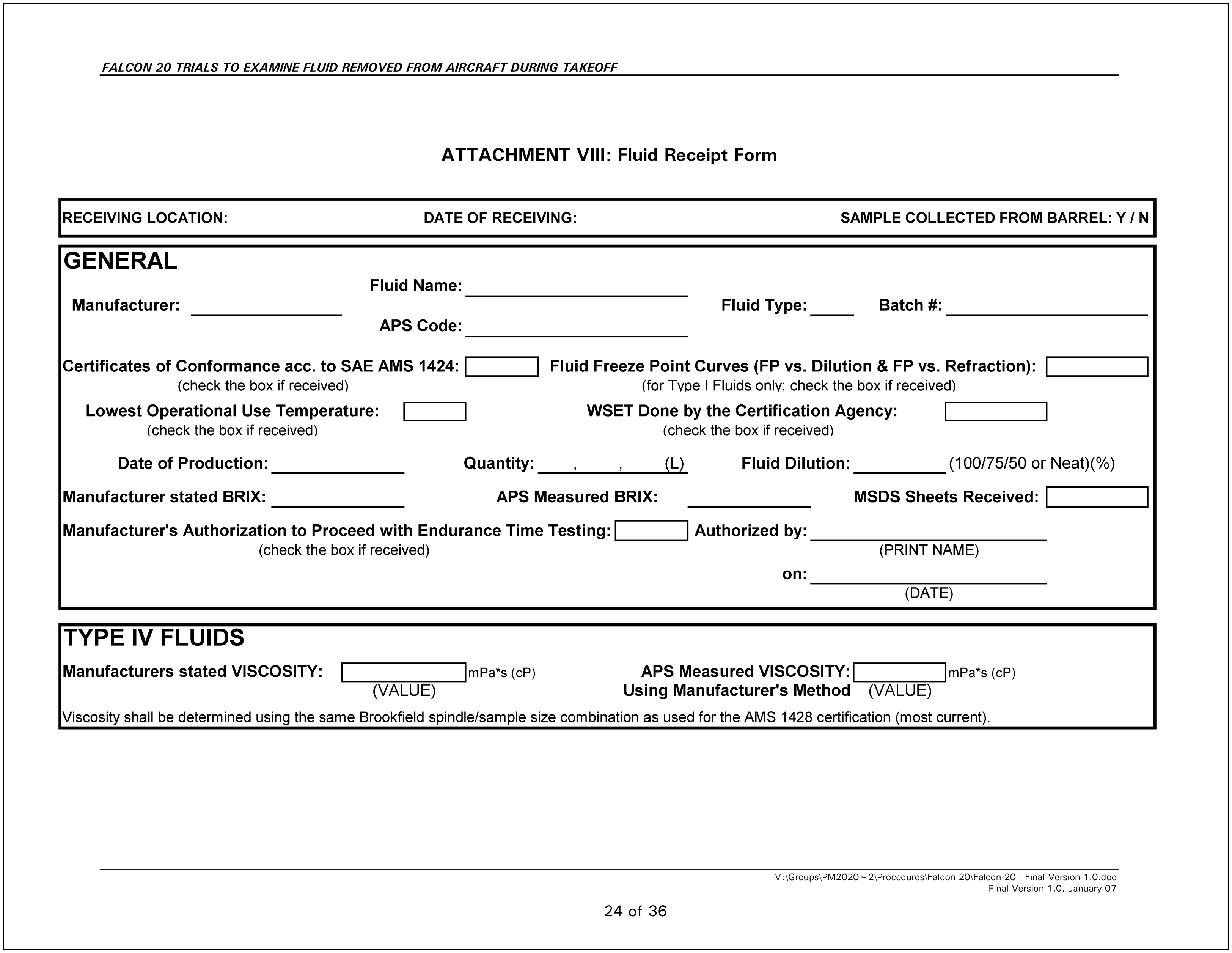
- Responsible for the fabrication of ice pellets;
- One ice pellet maker will operate the blender;
- One ice pellet maker will filter the crushed ice; and
- Assist with the ice pellet application.

Ice Pellets Co-ordinator (JT)

- 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 XV).



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)

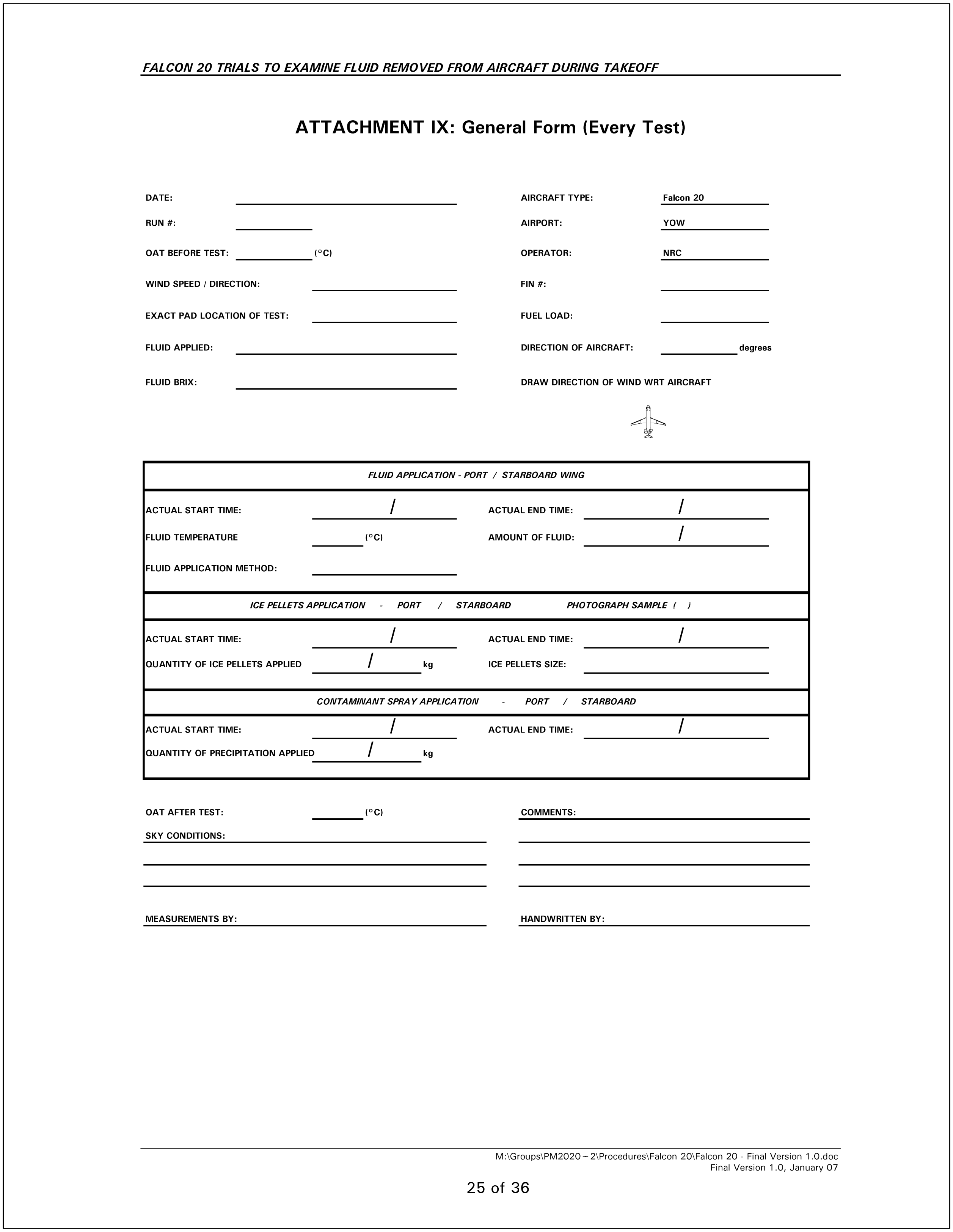
on: __________________________
(DATE)

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).



FALCON 20 TRIALS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF

ATTACHMENT IX: General Form (Every Test)

DATE:

RUN #:

OAT BEFORE TEST: (°C)

WIND SPEED / DIRECTION:

EXACT PAD LOCATION OF TEST:

FLUID APPLIED:

FLUID BRIX:

AIRCRAFT TYPE: Falcon 20

AIRPORT: YOW

OPERATOR: NRC

FIN #:

FUEL LOAD:

DIRECTION OF AIRCRAFT: degrees

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 - PORT / STARBOARD PHOTOGRAPH SAMPLE ( )

ACTUAL START TIME: /

ACTUAL END TIME: /

QUANTITY OF ICE PELLETS APPLIED / kg

ICE PELLETS SIZE:

CONTAMINANT SPRAY APPLICATION - PORT / STARBOARD

ACTUAL START TIME: /

ACTUAL END TIME: /

QUANTITY OF PRECIPITATION APPLIED / kg

OAT AFTER TEST: (°C)

SKY CONDITIONS:

COMMENTS:

MEASUREMENTS BY:

HANDWRITTEN BY:

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Final Version 1.0, January 07

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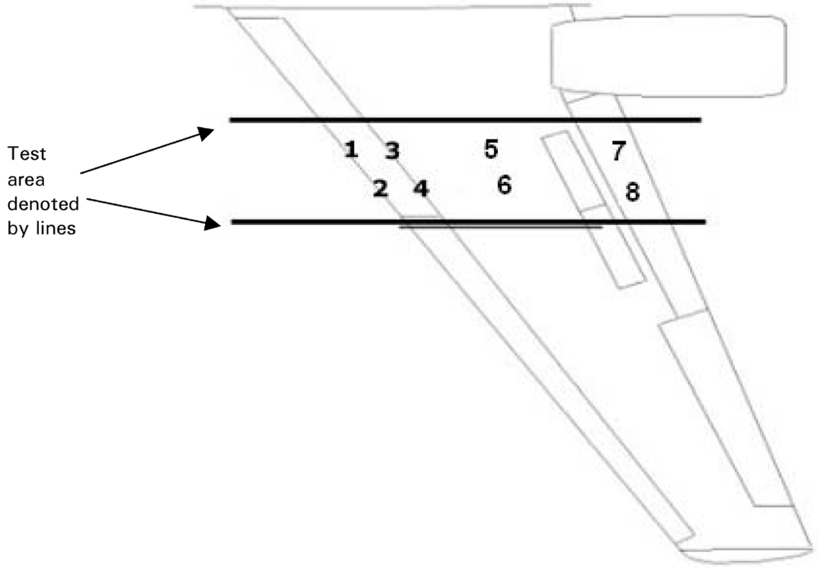
ATTACHMENT X: Wing Temperature Form (Port Wing)

Date: ____________________ Time: _____________________ Run Number: _______

Test Phase: A- Before Fluid Application ☐ B- After 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: ______________________________

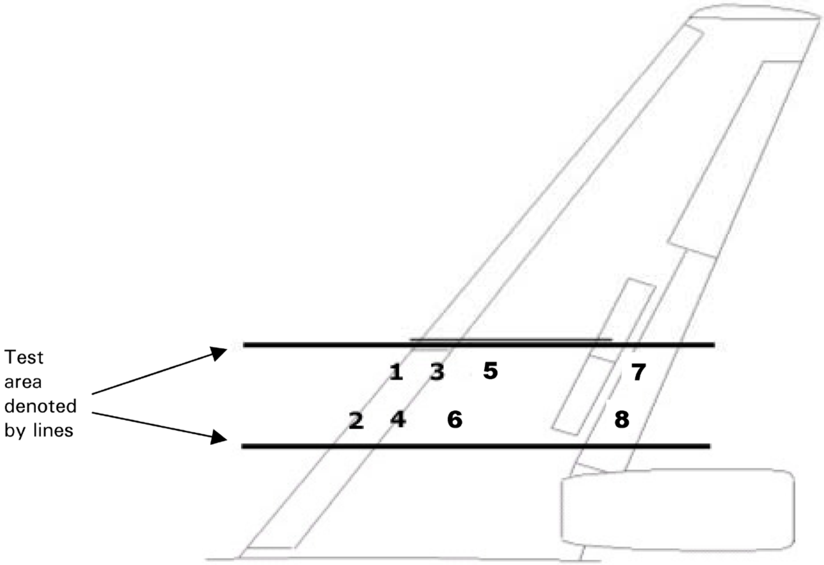
OBSERVER: ______________________________

ASSISTED BY: ______________________________

ATTACHMENT XI: Wing Temperature Form (Starboard Wing)

Date: ___________________ Time: ____________________ Run Number: _______

Test Phase: A- Before Fluid Application ☐ B- After 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: __________________________

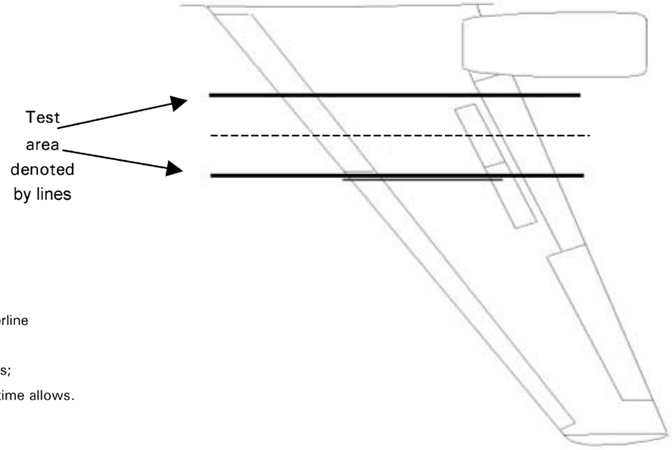
ATTACHMENT XII: Fluid Thickness and Brix (Port Wing)

Date: ____________________

Run Number: _______

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

FLUID BRIX							
After Fluid Application (lead./trail.)	Wing Position	After Precip App. (lead./trail.)	Wing Position	Before Takeoff Run (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: ____________________

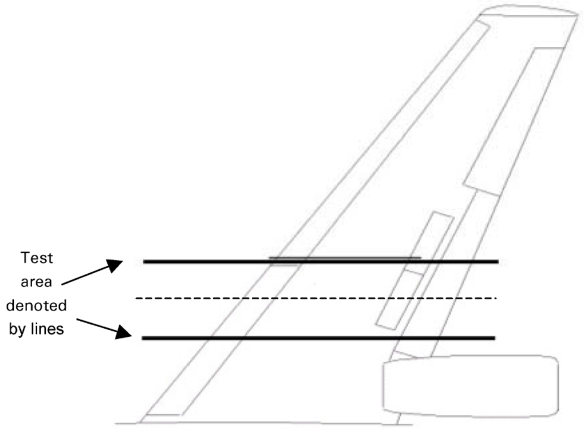
ATTACHMENT XIII: Fluid Thickness and Brix (Starboard Wing)

Date: ____________________

Run Number: _______

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

FLUID BRIX							
After Fluid Application (lead./trail.)	Wing Position	After Precip App. (lead./trail.)	Wing Position	Before Takeoff Run (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 XIV: Fluid Freeze Point Measurements on Wing (Port Wing)

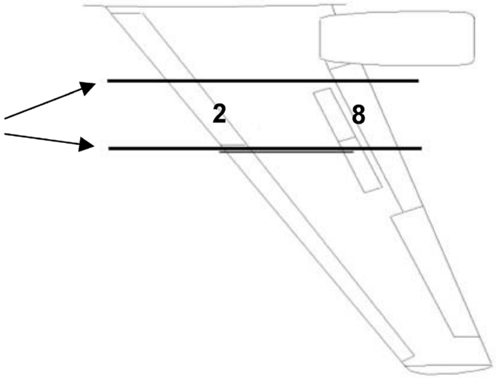
Date: ____________________ Run Number: _______ Fluid: _________________________

Location	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix
2																
8																

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

KILFROST ABC-S	
FFP (°C)	Brix
-2	5
-4	8
-6	12.5
-8	17
-10	19.3
-12	22
-14	23.5
-16	25.5

Test area denoted by lines



Comments: ____

____

____

OBSERVER: ____________________

ASSISTED BY: ____________________

ATTACHMENT XV: Fluid Freeze Point Measurements on Wing (Starboard Wing)

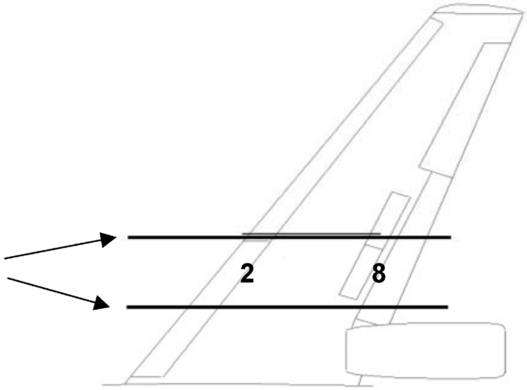
Date: ____________________ Run Number: _______ Fluid: _________________________

Location	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix	Time	Brix
2																
8																

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

KILFROST ABC-S	
FFP (°C)	Brix
-2	5
-4	8
-6	12.5
-8	17
-10	19.3
-12	22
-14	23.5
-16	25.5

Test area denoted by lines



Comments: ____

____

____

OBSERVER: ____________________

ASSISTED BY: ____________________

ATTACHMENT XVI: Freezing Rain/Snow Quantity Form

DATE:

RUN #:

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

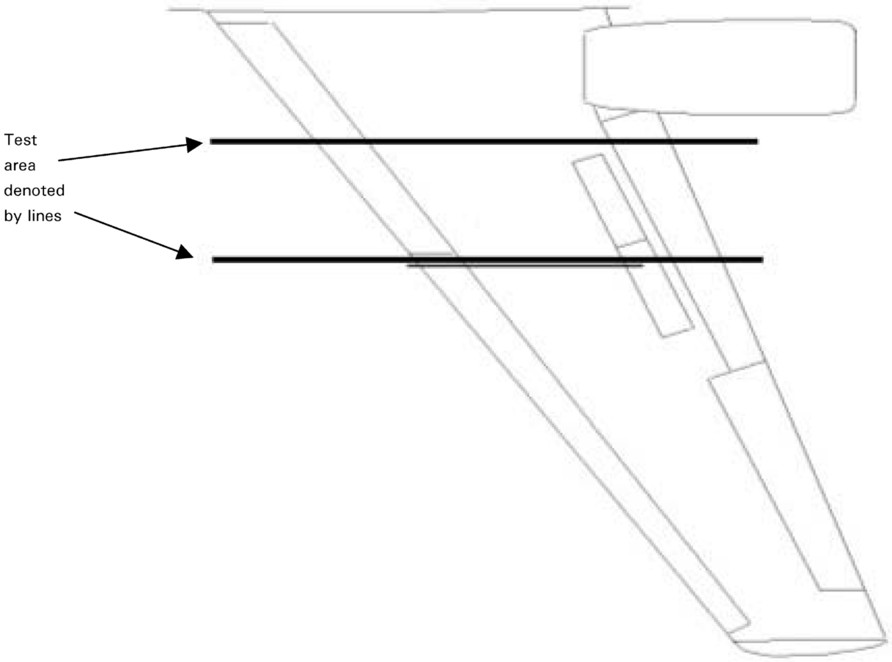
COMMENTS:

MEASUREMENTS BY:

HANDWRITTEN BY:

ATTACHMENT XVII: Test Results Form (Port Wing)

Date: ____________________ Time: ____________________ Run Number: _______



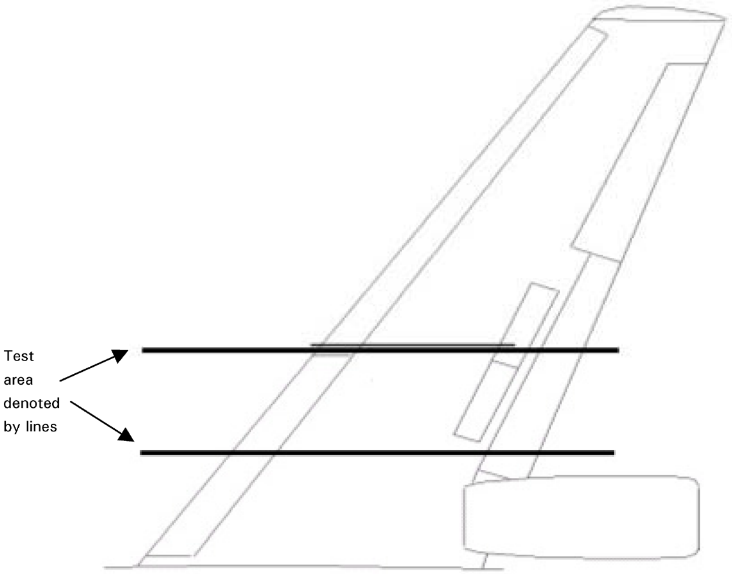
Observations: ____________________

OBSERVER: ____________________

ASSISTED BY: ____________________

ATTACHMENT XVIII: Test Results Form (Starboard Wing)

Date: ____________________ Time: ____________________ Run Number: _______



Observations: ______________________________

OBSERVER: ______________________

ASSISTED BY: ______________________

ATTACHMENT XX: Time Record of Operations

Run Number __________________ **Date** _______________ **OBSERVER**________________

OPERATION	TIME / OBSERVATION
Pilots Board	
Start Engines	
Systems Ready	
Measure Test Conditions (OAT, Sky Cond, etc)	
Fluid Application Start (Port / Starboard)	
Fluid Application Completed (Port / Starboard)	
Measure Fluid Thickness Brix and Temperature	
Start Pellet and ZR Application (Port/Starboard)	
Complete Pellet and ZR Application (Prt/Strbrd)	
Measure Fluid Thickness Brix and Temperature	
Close Door	
Ready to Roll	
Start Taxi	
Arrive Runway Hold	
Door Open	
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 Contamination and Record	
Arrive at Hanger	
Engine Shut Down	
Door Open	
Measure Fluid Thickness Brix and Temperature	

ATTACHMENT XX: Nominal Test Conditions

TEST NO	**1**	**2**	**3**	**4**	**5**
Date					
Fluid					
Precipitation (PORT / STARBOARD)	/	/	/	/	/
Pellets size [mm]					
Dyed Pellets					
PORT WING:	-	-	-	-	-
Effective IP Rate [g/dm^2/h]					
Total Pellet Weight Applied [kg]					
Effective ZR Rate [g/dm^2/h]					
Quantity of water applied [kg]					
Brix after precipitation application					
STARBOARD WING:	-	-	-	-	-
Effective IP Rate [g/dm^2/h]					
Total Pellet Weight Applied [kg]					
Effective ZR Rate [g/dm^2/h]					
Quantity of water applied [kg]					
Brix after precipitation application					
Remarks					

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)
FEBRUARY 26 – MARCH 2, 2007

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 mixed with freezing rain on the wing of Falcon 20 aircraft during takeoff are currently studied. Since the precipitation embedded in the fluid was 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 pellets/freezing rain mixed precipitation conditions.

The February-March 2007 tests at YOW will address the effects of deicing fluid contaminated with ice pellets and/or freezing rain 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 February-March 2007, 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 2.7 square-meter section of the aircraft wings by pouring, thus limiting the amount of fluid that falls on the ground after application.

In previous tests conducted at YOW in March 2006 ethylene and propylene fluids were applied over the same 2.7 square-meter section. In total, 60 liters of ethylene fluid and 100 liters of propylene fluid were used for the entire test session. All deicing fluid that fell to the ground within the application area was properly recovered.

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

Six tests are anticipated for February-March 2007 at YOW. Of this total, four will be performed with Dow Ultra+ (ethylene) and two 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 (160 of ethylene glycol and 80 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

Upon request, a 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

TEST REPORT:
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIPITATION CONDITIONS — ICE PELLETS / FREEZING RAIN

CM2020 (06-07)

TEST REPORT:
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIPITATION CONDITIONS – ICE PELLETS / FREEZING RAIN

Fall 06

Prepared for

Transportation Development Centre
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

November 3, 2006
Final Version 1.0

TEST REPORT:
ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIPITATION CONDITIONS – ICE PELLETS / FREEZING RAIN

November 3, 2006

1. BACKGROUND

1.1 Previous Research

Preliminary endurance time testing during simulated ice pellet conditions was conducted by APS at the NRC research facility in the spring of 2006 with the primary objective if investigating which conditions were most conducive to fluid adherence. A series of tests with the following objectives were conducted in simulated ice pellet conditions:

- Type I Heated Fluid Application Endurance Time Test;
- Type II/III/IV Fluid Application Endurance Time Test – Fluid at Room Temperature;
- Type II/III/IV Fluid Application Endurance Time Test – Fluid Heated to 60°C;
- Type II/III/IV Fluid Application Endurance Time Test – Exceeded HOT; and
- Type II/III/IV Fluid Application Endurance Time Test – Mixed Precipitation (Ice Pellets and Freezing Rain / Drizzle).

Adherence occurred during tests conducted with Type I heated fluid in ice pellet conditions, and with Type IV fluid during mixed precipitation conditions. The preliminary testing also showed that adherence produced during ice pellet conditions in combination with freezing rain/drizzle was rough and “pimply”. In comparison to adherence caused by freezing rain/drizzle alone, this can be an aerodynamically more severe condition. It was recommended to conduct further endurance time testing during mixed precipitation conditions (ice pellets and freezing rain) to investigate when fluid adherence occurs following exposure to precipitation with primarily Type IV EG and PG fluid.

1.2 Regulatory Recommendation

As a result of the recent industry need to provide aircraft operators with holdover times for ice pellet conditions, the FAA provided a 25-minute allowance as a preliminary guideline; TC remained status quo. This allowance was followed by a list of conditions restricting operations, one condition being that the 25-minute allowance was acceptable in conditions with ice pellets alone. This recommendation was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic work. Due to the high risk of occurrence of ice pellets combined with freezing rain, further work was recommended to explore the worst-case mixed precipitation conditions in order to further evaluate the current allowance time for ice pellet conditions.

2. OBJECTIVE

The objective of this project was to investigate the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface. Baseline testing was conducted in freezing rain conditions only. Testing was primarily conducted to validate the 25-minute allowance time that was recommended by the FAA for aircraft operations in ice pellet only conditions.

A full detailed report of the work described herein will be issued at a later date.

3. METHODOLOGY

Details of the methodology used for testing can be found in the procedure *"Experimental Program – Adhesion of Aircraft De/Anti-icing Fluids on Aluminum Surfaces During Mixed Precipitation Conditions – Ice Pellets / Freezing Rain".*

Endurance time testing was conducted in September 2006 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. Test plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. The "Ice Pellet Dispenser" was positioned so as to dispense ice pellets on 6 of the 12 test plates.

It should be noted that previous endurance time testing in simulated ice pellet conditions demonstrated that visual fluid failure was difficult to determine. For the purpose of this project, APS members approximated the fluid "failure time" based on the severity of the fluid condition. It should be noted that this is not the true fluid failure time as further work is ongoing in a separate project using wind tunnel simulations and full-scale aircraft to determine aerodynamic fluid failure.

3.1 Test Parameters Measured and Documented

1L of fluid at OAT was poured onto the test plate. Fluid dilution, fluid thickness, surface temperature, fluid failure, and adhesion were documented throughout the test. Photos of the test plate were taken every 5 minutes for the duration of the test. Rate of precipitation was measured just prior to the test and immediately following the end of the test.

4. TEST PLAN AND TEST LOG

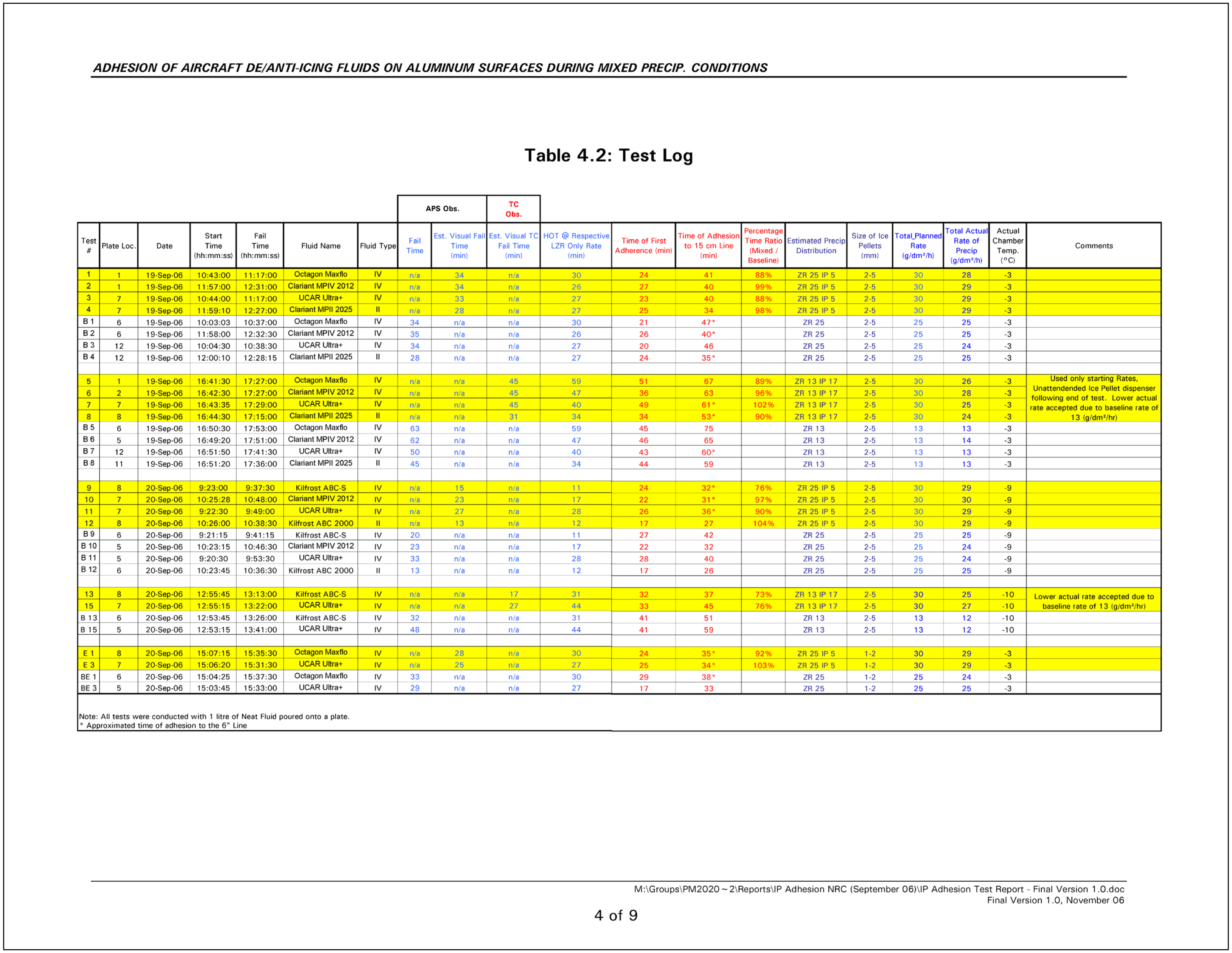
To investigate the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface, testing with Type II/IV fluid was conducted in simulated mixed icing conditions. In conjunction with every mixed precipitation test, a baseline endurance time test was conducted in freezing rain conditions alone; this allowed for a direct correlation of the baseline test data to the HOT Guidelines endurance time data. Table 4.1 describes the test conditions:

Table 4.1: Test Condition Parameters

Condtion	ZR Rate (g/dm²/h)	IP Rate (g/dm²/h)	OAT (ºC)	IP Size (mm)
High ZR / Low IP	25	5	-3	2-5
Approx. Equal IP and ZR	13	17	-3	2-5
High ZR / Low IP	25	5	-10	2-5
Approx. Equal IP and ZR	13	17	-10	2-5
High ZR / Low IP	25	5	-3	1-2

Note: Baseline tests conducted in ZR condition only

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS at the NRC research facility. The log presented in Table 4.2 provides relevant information for each of the endurance time tests conducted, as well as final values recorded. Each row contains data specific to one test.



ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIP. CONDITIONS

Table 4.2: Test Log

							APS Obs.		TC Obs.										
Test #	Plate Loc.	Date	Start Time (hh:mm:ss)	Fail Time (hh:mm:ss)	Fluid Name	Fluid Type	Fail Time	Est. Visual Fail Time (min)	Est. Visual TC Fail Time (min)	HOT @ Respective LZR Only Rate (min)	Time of First Adherence (min)	Time of Adhesion to 15 cm Line (min)	Percentage Time Ratio (Mixed / Baseline)	Estimated Precip Distribution	Size of Ice Pellets (mm)	Total_Planned Rate (g/dm²/h)	Total Actual Rate of Precip (g/dm²/h)	Actual Chamber Temp. (°C)	Comments
1	1	19-Sep-06	10:43:00	11:17:00	Octagon Maxflo	IV	n/a	34	n/a	30	24	41	88%	ZR 25 IP 5	2-5	30	28	-3	
2	1	19-Sep-06	11:57:00	12:31:00	Clariant MPIV 2012	IV	n/a	34	n/a	26	27	40	99%	ZR 25 IP 5	2-5	30	29	-3	
3	7	19-Sep-06	10:44:00	11:17:00	UCAR Ultra+	IV	n/a	33	n/a	27	23	40	88%	ZR 25 IP 5	2-5	30	29	-3	
4	7	19-Sep-06	11:59:10	12:27:00	Clariant MPII 2025	II	n/a	28	n/a	27	25	34	98%	ZR 25 IP 5	2-5	30	29	-3	
B 1	6	19-Sep-06	10:03:03	10:37:00	Octagon Maxflo	IV	34	n/a	n/a	30	21	47*		ZR 25	2-5	25	25	-3	
B 2	6	19-Sep-06	11:58:00	12:32:30	Clariant MPIV 2012	IV	35	n/a	n/a	26	26	40*		ZR 25	2-5	25	25	-3	
B 3	12	19-Sep-06	10:04:30	10:38:30	UCAR Ultra+	IV	34	n/a	n/a	27	20	46		ZR 25	2-5	25	24	-3	
B 4	12	19-Sep-06	12:00:10	12:28:15	Clariant MPII 2025	II	28	n/a	n/a	27	24	35*		ZR 25	2-5	25	25	-3	
5	1	19-Sep-06	16:41:30	17:27:00	Octagon Maxflo	IV	n/a	n/a	45	59	51	67	89%	ZR 13 IP 17	2-5	30	26	-3	Used only starting Rates, Unattendended Ice Pellet dispenser following end of test. Lower actual rate accepted due to baseline rate of 13 (g/dm²/hr)
6	2	19-Sep-06	16:42:30	17:27:00	Clariant MPIV 2012	IV	n/a	n/a	45	47	36	63	96%	ZR 13 IP 17	2-5	30	28	-3	
7	7	19-Sep-06	16:43:35	17:29:00	UCAR Ultra+	IV	n/a	n/a	45	40	49	61*	102%	ZR 13 IP 17	2-5	30	25	-3	
8	8	19-Sep-06	16:44:30	17:15:00	Clariant MPII 2025	II	n/a	n/a	31	34	34	53*	90%	ZR 13 IP 17	2-5	30	24	-3	
B 5	6	19-Sep-06	16:50:30	17:53:00	Octagon Maxflo	IV	63	n/a	n/a	59	45	75		ZR 13	2-5	13	13	-3	
B 6	5	19-Sep-06	16:49:20	17:51:00	Clariant MPIV 2012	IV	62	n/a	n/a	47	46	65		ZR 13	2-5	13	14	-3	
B 7	12	19-Sep-06	16:51:50	17:41:30	UCAR Ultra+	IV	50	n/a	n/a	40	43	60*		ZR 13	2-5	13	13	-3	
B 8	11	19-Sep-06	16:51:20	17:36:00	Clariant MPII 2025	II	45	n/a	n/a	34	44	59		ZR 13	2-5	13	13	-3	
9	8	20-Sep-06	9:23:00	9:37:30	Kilfrost ABC-S	IV	n/a	15	n/a	11	24	32*	76%	ZR 25 IP 5	2-5	30	29	-9	
10	7	20-Sep-06	10:25:28	10:48:00	Clariant MPIV 2012	IV	n/a	23	n/a	17	22	31*	97%	ZR 25 IP 5	2-5	30	30	-9	
11	7	20-Sep-06	9:22:30	9:49:00	UCAR Ultra+	IV	n/a	27	n/a	28	26	36*	90%	ZR 25 IP 5	2-5	30	29	-9	
12	8	20-Sep-06	10:26:00	10:38:30	Kilfrost ABC 2000	II	n/a	13	n/a	12	17	27	104%	ZR 25 IP 5	2-5	30	29	-9	
B 9	6	20-Sep-06	9:21:15	9:41:15	Kilfrost ABC-S	IV	20	n/a	n/a	11	27	42		ZR 25	2-5	25	25	-9	
B 10	5	20-Sep-06	10:23:15	10:46:30	Clariant MPIV 2012	IV	23	n/a	n/a	17	22	32		ZR 25	2-5	25	24	-9	
B 11	5	20-Sep-06	9:20:30	9:53:30	UCAR Ultra+	IV	33	n/a	n/a	28	28	40		ZR 25	2-5	25	24	-9	
B 12	6	20-Sep-06	10:23:45	10:36:30	Kilfrost ABC 2000	II	13	n/a	n/a	12	17	26		ZR 25	2-5	25	25	-9	
13	8	20-Sep-06	12:55:45	13:13:00	Kilfrost ABC-S	IV	n/a	n/a	17	31	32	37	73%	ZR 13 IP 17	2-5	30	25	-10	Lower actual rate accepted due to baseline rate of 13 (g/dm²/hr)
15	7	20-Sep-06	12:55:15	13:22:00	UCAR Ultra+	IV	n/a	n/a	27	44	33	45	76%	ZR 13 IP 17	2-5	30	27	-10	
B 13	6	20-Sep-06	12:53:45	13:26:00	Kilfrost ABC-S	IV	32	n/a	n/a	31	41	51		ZR 13	2-5	13	12	-10	
B 15	5	20-Sep-06	12:53:15	13:41:00	UCAR Ultra+	IV	48	n/a	n/a	44	41	59		ZR 13	2-5	13	12	-10	
E 1	8	20-Sep-06	15:07:15	15:35:30	Octagon Maxflo	IV	n/a	28	n/a	30	24	35*	92%	ZR 25 IP 5	1-2	30	29	-3	
E 3	7	20-Sep-06	15:06:20	15:31:30	UCAR Ultra+	IV	n/a	25	n/a	27	25	34*	103%	ZR 25 IP 5	1-2	30	29	-3	
BE 1	6	20-Sep-06	15:04:25	15:37:30	Octagon Maxflo	IV	33	n/a	n/a	30	29	38*		ZR 25	1-2	25	24	-3	
BE 3	5	20-Sep-06	15:03:45	15:33:00	UCAR Ultra+	IV	29	n/a	n/a	27	17	33		ZR 25	1-2	25	25	-3	

Note: All tests were conducted with 1 litre of Neat Fluid poured onto a plate.
* Approximated time of adhesion to the 6" Line

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5. GENERAL OBSERVATIONS

Table 5.1 summarizes the time of adherence to the 15 cm line for all respective mixed and baseline tests conducted. The following sections describe the observations and conclusions respective to each test condition.

5.1 High ZR / Low IP Tests (Large and Small Ice Pellets)

Consistent results were obtained at -3°C and at -10°C, as well as with large and small size ice pellets. The time of adherence to the 15 cm line for the mixed icing (ZR and IP) test was on average 7% shorter with respect to the baseline (ZR only) test. The estimated visual failure time of the mixed icing tests was generally equal to or slightly less than the baseline tests. It should be noted that the total mixed icing precipitation rate (30 $g/dm^2/h$) was greater than the baseline test rate of precipitation (25 $g/dm^2/h$). Similar results were also obtained using the smaller diameter ice pellets for the mixed icing conditions. The results indicated that adherence is primarily caused by the freezing rain considering the additional ice pellet precipitation did not significantly reduce the fluid protection time to adherence.

5.2 Approximately Equal ZR and IP Tests at -3°C (Large Ice Pellets)

The time of adherence to the 15 cm line for the mixed icing (ZR and IP) test was on average 6% shorter with respect to the baseline (ZR only) test. The estimated visual failure time of the mixed icing tests was considerably less than the baseline tests. It should be noted that the total mixed icing precipitation rate (30 $g/dm^2/h$) was significantly greater than the baseline test rate of precipitation (13 $g/dm^2/h$). The latter suggests that adherence is primarily a result of the freezing rain, and that the added ice pellet precipitation does not significantly contribute to the dilution and adhesion of the fluid to the test surface. In fact, previous research indicated that if the mixed precipitation condition is predominantly ice pellets, this resulted in a lesser degree of adhesion, and in some cases, bridging ice pellets actually helped prevent adherence.

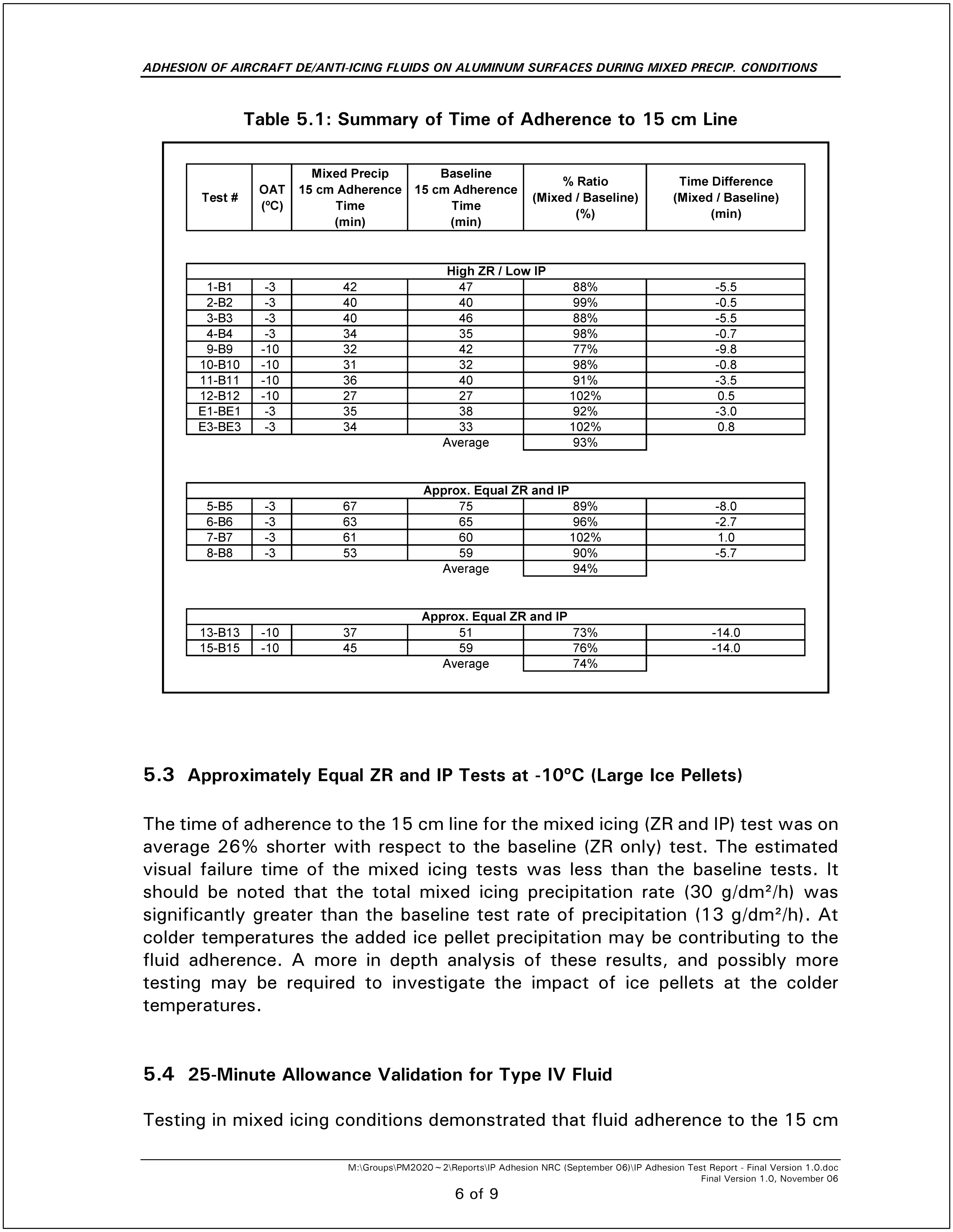


Table 5.1: Summary of Time of Adherence to 15 cm Line

Test #	OAT (ºC)	Mixed Precip 15 cm Adherence Time (min)	Baseline 15 cm Adherence Time (min)	% Ratio (Mixed / Baseline) (%)	Time Difference (Mixed / Baseline) (min)
High ZR / Low IP					
1-B1	-3	42	47	88%	-5.5
2-B2	-3	40	40	99%	-0.5
3-B3	-3	40	46	88%	-5.5
4-B4	-3	34	35	98%	-0.7
9-B9	-10	32	42	77%	-9.8
10-B10	-10	31	32	98%	-0.8
11-B11	-10	36	40	91%	-3.5
12-B12	-10	27	27	102%	0.5
E1-BE1	-3	35	38	92%	-3.0
E3-BE3	-3	34	33	102%	0.8
			Average	93%	
Approx. Equal ZR and IP					
5-B5	-3	67	75	89%	-8.0
6-B6	-3	63	65	96%	-2.7
7-B7	-3	61	60	102%	1.0
8-B8	-3	53	59	90%	-5.7
			Average	94%	
Approx. Equal ZR and IP					
13-B13	-10	37	51	73%	-14.0
15-B15	-10	45	59	76%	-14.0
			Average	74%	

5.3 Approximately Equal ZR and IP Tests at -10°C (Large Ice Pellets)

The time of adherence to the 15 cm line for the mixed icing (ZR and IP) test was on average 26% shorter with respect to the baseline (ZR only) test. The estimated visual failure time of the mixed icing tests was less than the baseline tests. It should be noted that the total mixed icing precipitation rate (30 g/dm²/h) was significantly greater than the baseline test rate of precipitation (13 g/dm²/h). At colder temperatures the added ice pellet precipitation may be contributing to the fluid adherence. A more in depth analysis of these results, and possibly more testing may be required to investigate the impact of ice pellets at the colder temperatures.

5.4 25-Minute Allowance Validation for Type IV Fluid

Testing in mixed icing conditions demonstrated that fluid adherence to the 15 cm line occurred at 34 minutes or later at -3°C, and at 31 minutes or later at -10°C. It should be noted that the first sign of adherence occurred as early as 23 minutes at -3°C, and at 22 minutes at -10°C.

The baseline HOT tests demonstrated endurance times that were on average 19% longer in comparison to the data used to compile the HOT Guidelines. This suggests that the fluid adherence with LOWV fluids may actually occur faster than what was documented during this testing.

Generally, HOT tests in freezing rain conditions alone demonstrate some level of adherence (usually to the 3 cm line) at the time of failure. Operationally, this may not be a great concern considering that the adherence created is smooth, and aerodynamically may not create a significant lift loss. During mixed icing conditions, the ice pellets will cause a rough “pimply” adherence to the test surface which may cause a more significant lift loss in comparison to freezing rain alone, therefore the first signs of adherence may cause potential safety concerns. Photos 5.1 and 5.2 show adherence to the 15 cm line during a baseline test (ZR alone) and a mixed icing test (ZR/IP); mixed icing adherence is rough compared to the smooth adherence from the freezing rain alone.

The results indicated that a 25-minute allowance time may cause potential safety hazards considering fluid adherence can occur prior to the 25 minutes. Aircraft may currently be departing in freezing rain conditions with partially adhered sections on their critical surfaces, however, these adhered sections are smooth and may not disturb the airflow. During mixed ice pellet conditions, a 25-minute allowance may allow aircraft to depart with partially adhered rough “pimply” sections on their critical surfaces, which may in turn effect the aerodynamic performance of the aircraft.

Aerodynamic research is required to quantify the lift loss caused by adhered ice pellet contamination. Based on the conclusions of this future work, it will be easier determine which of the following options is appropriate to enable safe aircraft operations:

- 25 minute allowance in light ice pellets and mixed light ZR/IP conditions;
- Operate using fluid specific light freezing rain HOT values in light ice pellets and mixed light ZR/IP conditions;
- Operate using reduced fluid specific light freezing rain HOT values in light ice pellets and mixed light ZR/IP conditions; and
- Operate using generic HOT values in light ice pellet and mixed light ZR/IP conditions based on the worst case light freezing rain values for each temperature range.

Photo 5.1: Adherence to 15 cm Line Caused by Light Freezing Rain Alone

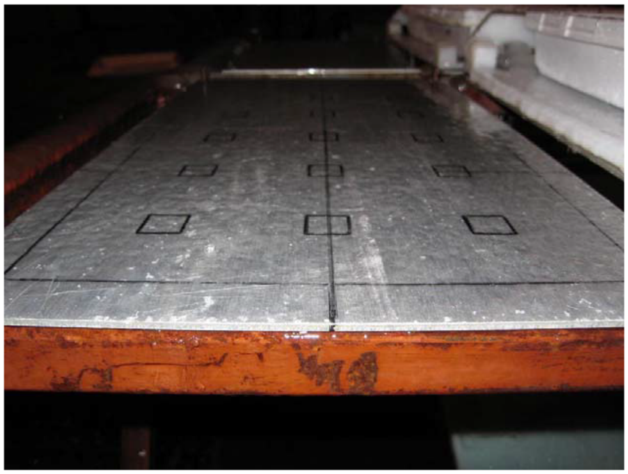


Photo 5.2: Adherence to 15 cm Line Caused by Light Mixed Icing (ZR / IP)

6. FUTURE WORK

6.1 Aerodynamic Research With Adhered Ice Pellet Contamination

Aerodynamic research is required to quantify the lift loss caused by adhered ice pellet contamination. Preliminary testing should be conducted in the NRC wind tunnel during mixed icing conditions. Following a review of the results obtained, full-scale testing should be conducted using aircraft possibly with slatted and non-slatted leading edge controls (i.e. NRC Falcon 20 aircraft, or the Tech Center Global Express).

6.2 Additional Mixed Precipitation (ZR/IP) Testing at Colder Temperatures

Testing conducted in approximately equal ZR and IP conditions at -10°C demonstrated that the additional ice pellet contamination accelerated the occurrence of fluid adhesion; this was not observed at -3°C. Further testing may be required in mixed precipitation (ZR/IP) conditions at temperatures below -3°C to quantify the effect of ice pellet contamination on fluid adherence.

6.3 Additional Mixed Precipitation (ZR/IP) Testing with Smaller Ice Pellets

It was observed that the smaller pellets dissolve more rapidly than the larger ones, however, create and rough adhered surface that is less severe when compared to the larger ice pellets. Further testing should be conducted in mixed precipitation (ZR/IP) conditions using smaller size ice pellets and larger ice pellets to try and quantify which of the two is the more aerodynamically, and operationally severe condition.

6.4 Documentation of Testing Conducted

A full detailed report of the work described herein will be issued at a later date.

APPENDIX F

TEST REPORT:
FLUID ADHERENCE IN MIXED ICE PELLETS AND SNOW AND SIMULATED COLD FRONT TESTS

CM2020 (06-07)

TEST REPORT:

FLUID ADHERENCE IN MIXED ICE PELLETS AND SNOW AND SIMULATED COLD FRONT TESTS

Winter 06

Prepared for

Transportation Development Centre
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

April 18, 2007
Final Version 1.0

TEST REPORT:

FLUID ADHERENCE IN MIXED ICE PELLETS AND SNOW AND SIMULATED COLD FRONT TESTS

April 18, 2007

1. BACKGROUND

1.1 Previous Research

Preliminary endurance time testing during simulated ice pellet conditions was conducted by APS at the NRC research facility in the spring of 2006 with the primary objective of investigating which conditions were most conducive to fluid adherence. It was found that adherence occurred during tests conducted with Type I heated fluid in ice pellet conditions, and with Type IV fluid during mixed precipitation conditions. The preliminary testing also showed that adherence produced during ice pellet conditions in combination with freezing rain/drizzle was rough and "pimply". In comparison to adherence caused by freezing rain/drizzle alone, this can be an aerodynamically more severe condition.

Additional testing was conducted by APS at the NRC research facility in the fall of 2006 with the primary objective of investigating the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface. The results indicated that the fluid adherence was primarily caused by the light freezing rain, and that in some instances the ice pellets may have helped to prevent the occurrence of fluid adhesion. Of the conditions tested, the high light freezing rain and low ice pellet condition (25 g/dm²/h and 5 g/dm²/h respectively) was deemed to be the more critical condition for fluid adherence.

It was recommended to conduct further endurance time testing during mixed precipitation conditions (snow and ice pellets) to investigate the effect of the ice pellets on fluid adherence, dilution, and failure.

1.2 Regulatory Recommendation

As a result of the recent industry need to provide aircraft operators with holdover times for ice pellet conditions, the FAA provided a 25-minute allowance as a preliminary guideline; TC remained status quo. This allowance was followed by a list of conditions restricting operations, one condition being that the 25-minute allowance was acceptable in conditions with ice pellets alone. This recommendation was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic work. Due to the high risk of occurrence of ice pellets combined with freezing rain, further work was recommended to explore the worst-case mixed precipitation conditions in order to further evaluate the current allowance time for mixed ice pellet conditions.

2. OBJECTIVE

The objective of this project was to investigate the level of snow and ice pellet contamination required to cause fluid failure and adherence to the test surface.

As a secondary objective, this project investigated the effect of a simulated cold front on fluid adhesion following the first visual failure.

3. METHODOLOGY

Testing was conducted during two sessions in September 2006 and January-February 2007. Details of the methodology used for the September 2006 testing can be found in the procedure *"Experimental Program – Adhesion of Aircraft De/Anti-icing Fluids on Aluminum Surfaces During Mixed Precipitation Conditions – Ice Pellets / Snow".* Details of the methodology used for the February 2007testing can be found in the procedure *"Experimental Program – Endurance Time Testing in Mixed Ice Pellets and Snow Conditions".*

Some changes were made to the procedure in order to satisfy the current test objectives. It should also be noted that during the February 2007 testing, the proposed "*Fluid Failure vs. Heater Power Analysis"* was not completed.

3.1 Mixed Ice Pellets and Snow Tests

Endurance time testing was conducted in the APS refrigerated trailer using the standard flat plate HOT test procedure. The NCAR snow machine was used to produce the simulated snow. The NCAR bucket was placed inside the NCAR snow machine enclosure with the enclosure remaining open during the test. The "Ice Pellet Dispenser" was positioned approximately 1.2 m (4 ft.) away from, and 1.2 m above the NCAR bucket facing the open side of the NCAR enclosure. Both the NCAR snow machine and the ice pellet dispenser were run simultaneously to produce the desired mixed ice pellet/snow precipitation conditions.

3.2 Simulated Cold Front

To simulate a cold front during the mixed ice pellet and snow tests, the ambient temperature and the plate temperature was reduced by 3-4°C at the time of first failure (failure to the 2.5 cm line). Fluid adhesion was verified and documented during each test.

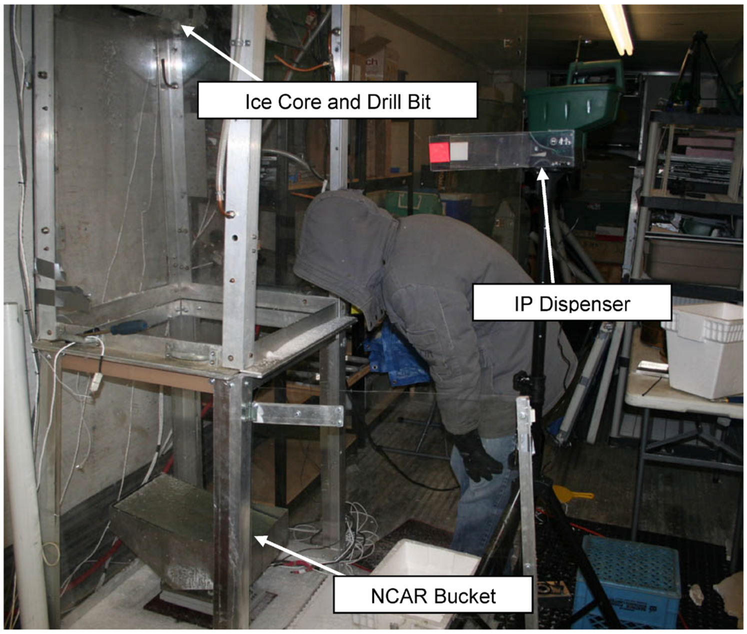
3.3 Visual Fluid Failure

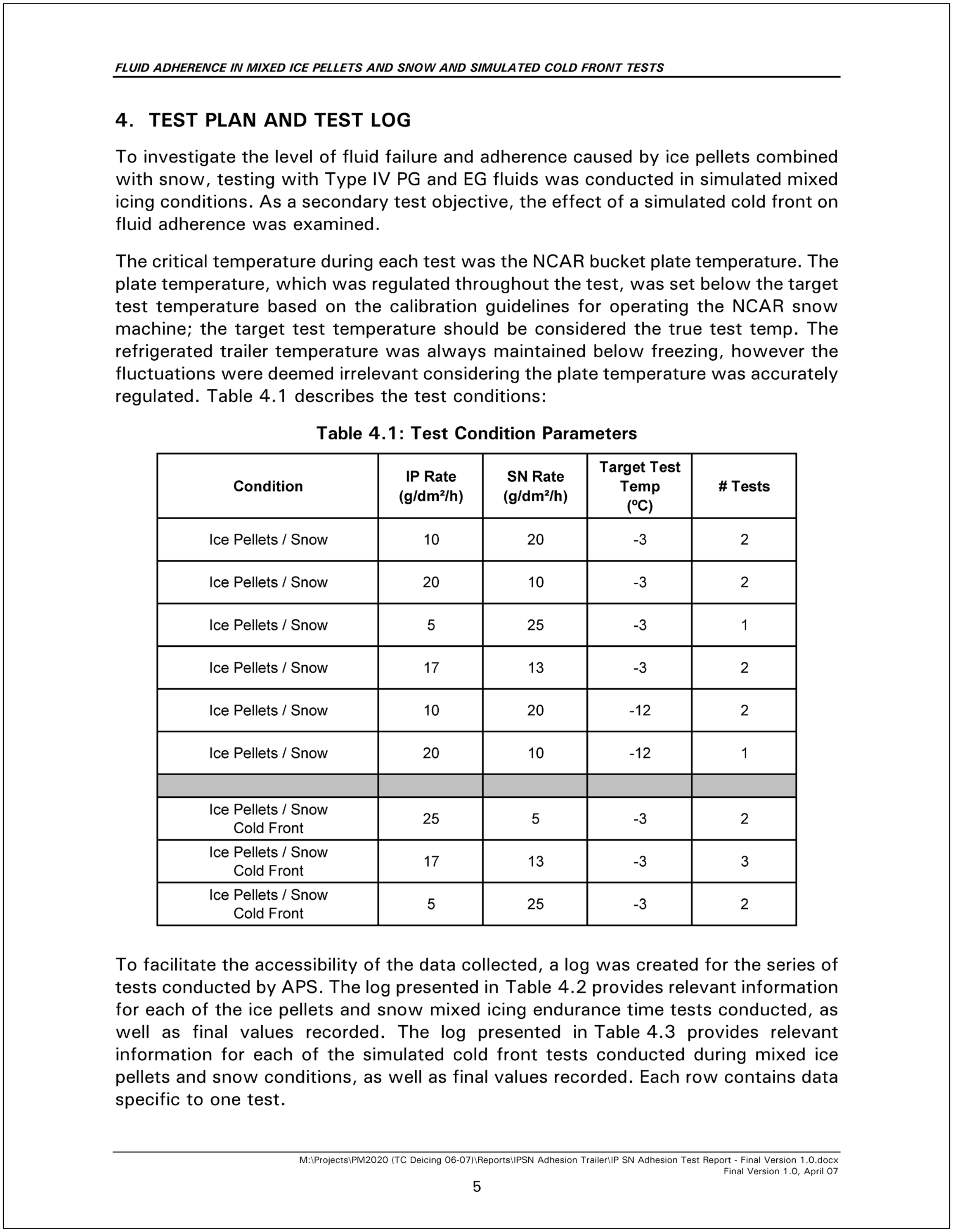
It should be noted that previous endurance time testing in simulated ice pellet conditions demonstrated that visual fluid failure was difficult to determine. For the purpose of this project, APS members approximated the fluid “failure time” based on the severity of the fluid condition. It should be noted that this is not the true fluid failure time as further work is ongoing in a separate project using wind tunnel simulations and full-scale aircraft to determine aerodynamic fluid failure.

3.4 Test Parameters Measured and Documented

1L of fluid at OAT was poured onto the test plate. Fluid dilution, surface temperature, fluid failure, and adhesion were documented throughout the test. Photos of the fluid condition were taken for most of the tests.

Photo 3.1: Setup for Mixed Ice Pellets and Snow Tests





4. TEST PLAN AND TEST LOG

To investigate the level of fluid failure and adherence caused by ice pellets combined with snow, testing with Type IV PG and EG fluids was conducted in simulated mixed icing conditions. As a secondary test objective, the effect of a simulated cold front on fluid adherence was examined.

The critical temperature during each test was the NCAR bucket plate temperature. The plate temperature, which was regulated throughout the test, was set below the target test temperature based on the calibration guidelines for operating the NCAR snow machine; the target test temperature should be considered the true test temp. The refrigerated trailer temperature was always maintained below freezing, however the fluctuations were deemed irrelevant considering the plate temperature was accurately regulated. Table 4.1 describes the test conditions:

Table 4.1: Test Condition Parameters

Condition	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	Target Test Temp (ºC)	# Tests
Ice Pellets / Snow	10	20	-3	2
Ice Pellets / Snow	20	10	-3	2
Ice Pellets / Snow	5	25	-3	1
Ice Pellets / Snow	17	13	-3	2
Ice Pellets / Snow	10	20	-12	2
Ice Pellets / Snow	20	10	-12	1
Ice Pellets / Snow Cold Front	25	5	-3	2
Ice Pellets / Snow Cold Front	17	13	-3	3
Ice Pellets / Snow Cold Front	5	25	-3	2

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS. The log presented in Table 4.2 provides relevant information for each of the ice pellets and snow mixed icing endurance time tests conducted, as well as final values recorded. The log presented in Table 4.3 provides relevant information for each of the simulated cold front tests conducted during mixed ice pellets and snow conditions, as well as final values recorded. Each row contains data specific to one test.

Table 4.2: Test Log – Mixed Icing Tests – Ice Pellets / Snow

Test No	Date	Fluid	Fluid Type	Condition			Test Parameters		Endurance Time (min)	Adhesion at the end of test
				Target Test Temp (ºC)	IP Rate (g/dm^2/h)	Snow Rate (g/dm^2/h)	Enclosure Temp (ºC)	Plate Temp (ºC)		
T1	12-Sep-06	Maxflo	IV PG	-3	10	20	-12	-5.1	34.8	No
T2b	12-Sep-06	Ultra+	IV EG	-3	10	20	-13	-5.1	28.3	No
T3	12-Sep-06	Maxflo	IV PG	-3	20	10	-13	-5.1	30.5	No
T4	12-Sep-06	Ultra+	IV EG	-3	20	10	-12	-5.1	28.7	No
T5	13-Sep-06	Maxflo	IV PG	-12	10	20	-13	-14.2	29.2	No
T6	13-Sep-06	Ultra+	IV EG	-12	10	20	-10	-14.2	39.7	No
T7	13-Sep-06	Maxflo	IV PG	-12	20	10	-13	-14.2	25.5	No
T9	22-Sep-06	Maxflo	IV PG	-3	5	25	-9.5	-5.1	35.0	No
T10	22-Sep-06	Maxflo	IV PG	-3	17	13	-9	-5.1	28.5	No
T11	22-Sep-06	Ultra+	IV EG	-3	17	13	-9	-5.1	33.3	No

Table 4.3: Test Log – Simulated Cold Front – Ice Pellets / Snow

Test No	Date	Fluid	Fluid Type	Condition			Test Parameters before 1st Failure		Time to 1st Failure (min)	Test Parameters after 1st Failure				Adhesion at the end of test
				Target Test Temp (ºC)	IP Rate (g/dm^2/h)	Snow Rate (g/dm^2/h)	Enclosure Temp (ºC)	Plate Temp (ºC)		Precipitation after 1st Failure	Plate End Condition (min)	Enclosure Temp (ºC) 25 min after End Condition	Plate Temp (ºC) 25 min after End Condition	
1	2-Feb-07	Maxflo	IV PG	-3	5	25	-7.5	-5.1	7.5	Yes	29	-11	-9	No
2	2-Feb-07	Ultra+	IV EG	-3	5	25	-7	-5.1	10	Yes	28	-10	-8.4	No
3	1-Feb-07	Maxflo	IV PG	-3	17	13	-6	-5.1	12	No	N/A	-11	-8.5	No
3b	2-Feb-07	Maxflo	IV PG	-3	17	13	-7	-5.1	11	Yes	29.5	-10	-9	No
4	1-Feb-07	Ultra+	IV EG	-3	17	13	-8	-5.1	13	No	N/A	-12	-9	No
5	31-Jan-07	Maxflo	IV PG	-3	25	5	-6	-5.1	19	No	N/A	-12	-9	No
6	1-Feb-07	Ultra+	IV EG	-3	25	5	-8	-5.1	21	No	N/A	-13	-9	No

5. GENERAL OBSERVATIONS

The following sections describe the observations and conclusions respective to each test condition.

5.1 Adherence - Mixed Ice Pellets and Snow Tests

Fluid adherence was not observed during the simulated mixed ice pellet and snow tests. The fluid failure mechanism during the mixed ice pellet and snow conditions was not conducive to fluid adherence.

5.2 Simulated Cold Front

Fluid adherence was not observed following the simulated cold front. The decrease in plate temperature and ambient temperature was not sufficient to cause the diluted fluid to adhere to the test surface.

5.3 Visual Fluid Failure

It should be noted that visual fluid failure call for each mixed icing test was estimated based on the standard snow precipitation failure call. As a result of the added ice pellet conditions, contamination was present very early in the test; ice pellets were imbedded in the fluid. During mixed conditions with snow as the dominant precipitation type, when bridging snow became apparent on the surface of the fluid, the added ice pellet precipitation was difficult to see; ice pellets are translucent and are difficult to determine visually amidst bridging snow. During a tactile inspection, it was apparent that the ice pellets were dissolving slower in the areas where snow began bridging; the fluid in this area was likely nearing the fluid freeze point and was less effective at dissolving frozen precipitation. During mixed conditions with ice pellets as the dominant precipitation type, bridging snow was less apparent in the areas with failed fluid.

Photo 5.1: Fluid Failure During Mixed IP/SN Conditions – IP as Dominant Condition

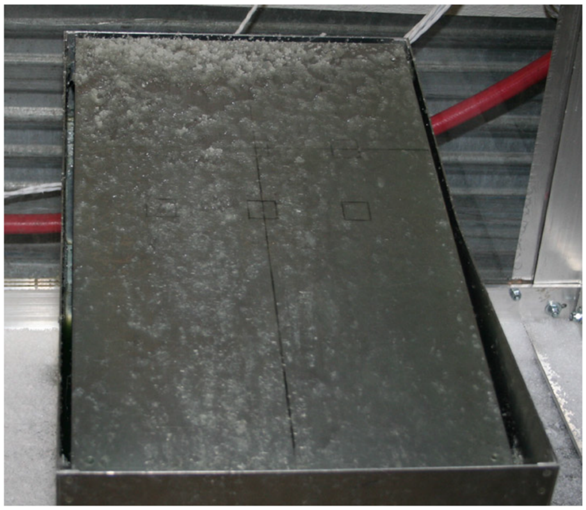
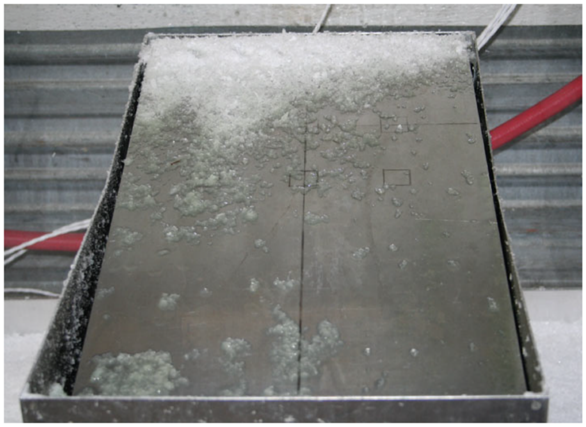


Photo 5.2: Fluid Failure During Mixed IP/SN Conditions – SN as Dominant Condition



6. FUTURE WORK

6.1 Aerodynamic Research with Mixed Ice Pellet Contamination

Aerodynamic research is required to quantify the lift loss caused by mixed ice pellet and snow contamination. Testing should be conducted in the NRC wind tunnel during mixed icing conditions.

6.2 Viscosity of Contaminated Fluid

Methods for quantifying contaminated fluid viscosity on a plate and on a wing should be investigated. The use of a field viscometer or a consistometer may provide quick comparative data for measuring differences in the viscosity of failed fluids at various temperatures.

APPENDIX G

TEST REPORT:
LARGE VS. SMALL ICE PELLETS WITH LIGHT FREEZING RAIN AND INTERMITTENT ICE PELLETS AND LIGHT FREEZING RAIN

CM2020 (06-07)

TEST REPORT:

LARGE vs. SMALL ICE PELLETS WITH LIGHT FREEZING RAIN AND INTERMITTENT ICE PELLETS AND LIGHT FREEZING RAIN

Winter 06

Prepared for

Transportation Development Centre
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

April 18, 2007
Final Version 1.0

TEST REPORT:

LARGE vs. SMALL ICE PELLETS WITH FREEZING RAIN AND INTERMITTENT ICE PELLETS AND FREEZING RAIN

April 18, 2007

1. BACKGROUND

1.1 Previous Research

Preliminary endurance time testing during simulated ice pellet conditions was conducted by APS at the NRC research facility in the spring of 2006 with the primary objective of investigating which conditions were most conducive to fluid adherence. It was found that adherence occurred during tests conducted with Type I heated fluid in ice pellet conditions, and with Type IV fluid during mixed precipitation conditions. The preliminary testing also showed that adherence produced during ice pellet conditions in combination with freezing rain/drizzle was rough and “pimply”. In comparison to adherence caused by freezing rain/drizzle alone, this can be an aerodynamically more severe condition.

Additional testing was conducted by APS at the NRC research facility in the fall of 2006 with the primary objective of investigating the level of ice pellet and freezing rain contamination required to cause fluid adherence to the test surface. The results indicated that the fluid adherence was primarily caused by the light freezing rain, and that in some instances the ice pellets may have helped to prevent the occurrence of fluid adhesion. Of the conditions tested, the high light freezing rain and low ice pellet condition (25 g/dm²/h and 5 g/dm²/h respectively) was deemed to be the more critical condition for fluid adherence.

It was recommended to conduct further endurance time testing during mixed precipitation conditions (light freezing rain and ice pellets) to investigate the effect of the size of the ice pellets on fluid adherence, dilution, and failure.

1.2 Regulatory Recommendation

As a result of the recent industry need to provide aircraft operators with holdover times for ice pellet conditions, the FAA provided a 25-minute allowance as a preliminary guideline; TC remained status quo. This allowance was followed by a list of conditions restricting operations, one condition being that the 25-minute allowance was acceptable in conditions with ice pellets alone. This recommendation was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic work. Due to the high risk of occurrence of ice pellets combined with freezing rain, further work was recommended to explore the worst-case mixed precipitation conditions in order to further evaluate the current allowance time for mixed ice pellet conditions.

2. OBJECTIVE

The objective of this project was to investigate the level of large or small ice pellets and freezing rain contamination required to cause fluid failure and adherence to the test surface.

As a secondary objective, this project investigated the effect of intermittent freezing rain and small ice pellet conditions on fluid failure and adherence to the test surface.

Baseline testing for both objectives was conducted in freezing rain conditions only.

3. METHODOLOGY

Details of the methodology used for testing can be found in the procedure *"Experimental Program – Adhesion of Aircraft De/Anti-icing Fluids on Aluminum Surfaces During Mixed Precipitation Conditions – Ice Pellets / Freezing Rain".* Some changes were made to the procedure in order to satisfy the current test objectives.

3.1 Mixed Light Freezing Rain and Large or Small Ice Pellet Tests

Endurance time testing was conducted in April 2007 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. Two six-position test stands with plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. Two "Ice Pellet Dispensers" were positioned so as to dispense large ice pellets on the four left most test plates (positions 1,2,7, and 8), and small ice pellets on the four right most test plates (positions 5,6,11, and 12). Large ice pellets used were 2.8mm to 4.75 mm in diameter. Small ice pellets used were 1.0mm to 2.8 mm in diameter. Baseline tests were done in conjunction with the standard HOT testing. Photo 3.1 demonstrates the setup used for testing.

3.2 Intermittent Light Freezing Rain and Ice Pellets

Endurance time testing was conducted in April 2007 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. A two-position test stand with plates was positioned directly underneath the simulated freezing precipitation sprayer assembly. To generate intermittent light freezing rain and ice pellet conditions, the test stand was physically moved outside of the light freezing rain spray area where an ice pellet dispenser was positioned so as to dispense small ice pellets on the test plates. The duration and sequence of precipitation types was determined at the beginning of each test. Baseline tests were done in conjunction with the standard HOT testing.

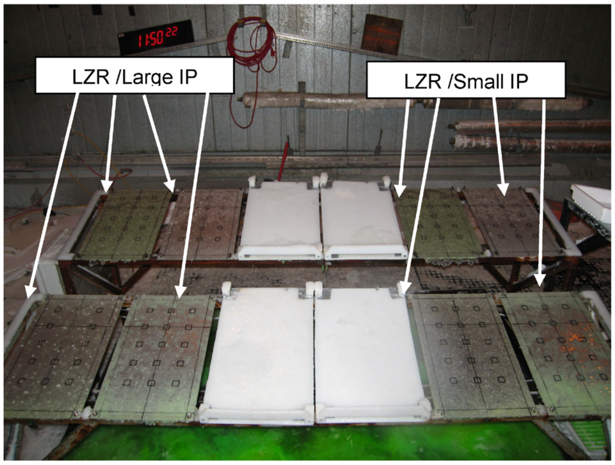
3.3 Visual Fluid Failure

It should be noted that previous endurance time testing in simulated ice pellet conditions demonstrated that visual fluid failure was difficult to determine. For the purpose of this project, APS members approximated the fluid “failure time” based on the severity of the fluid condition. It should be noted that this is not the true fluid failure time as further work is ongoing in a separate project using wind tunnel simulations and full-scale aircraft to determine aerodynamic fluid failure.

3.4 Test Parameters Measured and Documented

1L of fluid at OAT was poured onto the test plate. Fluid dilution, surface temperature, fluid failure, and adhesion were documented throughout the test. Photos of the fluid condition were taken for most of the tests.

Photo 3.1: Setup for Mixed Light Freezing Rain and Large or Small Ice Pellet Tests



4. TEST PLAN AND TEST LOG

To investigate the level of fluid adherence caused by large and small ice pellets combined with freezing rain, testing with Type II and Type IV fluid was conducted in simulated mixed icing conditions. As a secondary test objective, the effect of intermittent freezing rain and small ice pellet conditions on fluid adherence was examined. Baseline endurance time testing was conducted in freezing rain conditions alone; these tests were done in conjunction with the standard HOT tests. Table 4.1 describes the test conditions:

Table 4.1: Test Condition Parameters

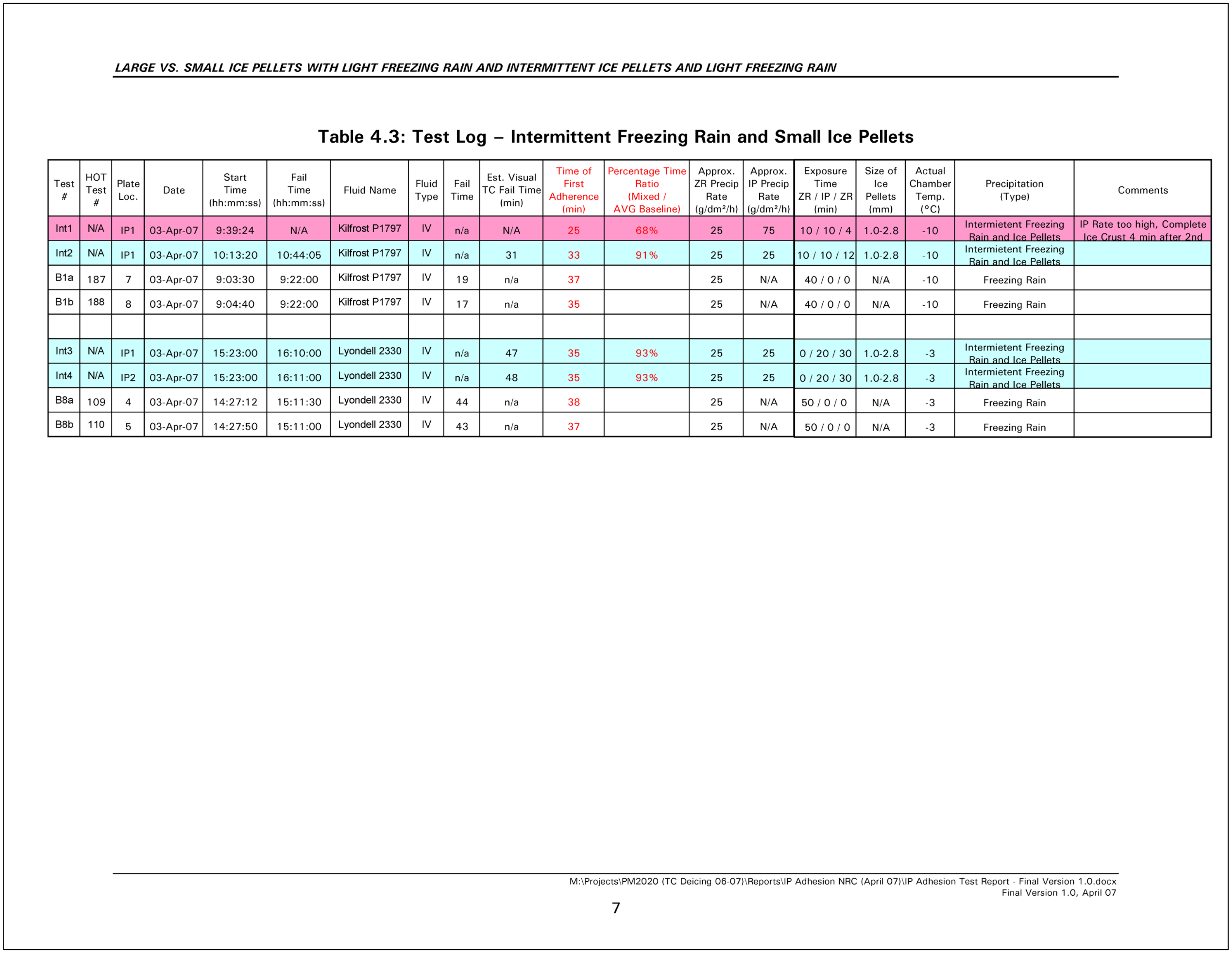
Condition	ZR- Rate (g/dm²/h)	IP Rate (g/dm²/h)	OAT (ºC)	IP Size (mm)
Small vs. Large IP / ZR	25	5	-3	1-3 and 3-5
Small vs. Large IP / ZR	25	5	-10	1-3 and 3-5
Intermittent ZR and IP	25	25	-3	1-3
Intermittent ZR and IP	25	25	-10	1-3

Note: Baseline tests conducted in ZR- condition only

To facilitate the accessibility of the data collected, a log was created for the series of tests conducted by APS at the NRC research facility. The log presented in Table 4.2 provides relevant information for each of the comparative large vs. small ice pellet and freezing rain endurance time tests conducted, as well as final values recorded. The log presented in Table 4.3 provides relevant information for each of the intermittent light freezing rain and small ice pellet endurance time tests conducted, as well as final values recorded. Each row contains data specific to one test.

Table 4.2: Test Log – Freezing Rain and Large vs. Small Ice Pellets

Test #	HOT Test #	Plate Loc.	Date	Start Time (hh:mm:ss)	Fail Time (hh:mm:ss)	Fluid Name	Fluid Type	Fail Time	Est. Visual TC Fail Time (min)	Time of First Adherence (min)	Percentage Time Ratio (Mixed / AVG Baseline)	Estimated Precip Distribution	Size of Ice Pellets (mm)	~~Total~~ Planned Rate (g/dm^2/hr)	Actual Chamber Temp. (°C)	Precipitation (Type)	Comments
L1	N/A	1	03-Apr-07	11:10:45	11:27:45	Kilfrost P1797	IV	n/a	17	34	94%	ZR 25 IP 5	2.8-4.75	30	-10	Mixed: Freezing Rain/Ice Pellets	
L2	N/A	2	03-Apr-07	11:11:15	11:26:20	Newave	II	n/a	15	17	100%	ZR 25 IP 5	2.8-4.75	30	-10	Mixed: Freezing Rain/Ice Pellets	Adh to 6" recorded, estimated 1" based on previous data
L3	N/A	7	03-Apr-07	11:11:45	11:41:15	XI'AN	II	n/a	30	24	N/A	ZR 25 IP 5	2.8-4.75	30	-10	Mixed: Freezing Rain/Ice Pellets	Adh 1-3"
L4	N/A	8	03-Apr-07	11:12:02	11:40:30	Lyondell 6166	IV	n/a	28	23	88%	ZR 25 IP 5	2.8-4.75	30	-10	Mixed: Freezing Rain/Ice Pellets	
S1	N/A	5	03-Apr-07	11:12:40	11:28:12	Kilfrost P1797	IV	n/a	16	34	94%	ZR 25 IP 5	1.0-2.8	30	-10	Mixed: Freezing Rain/Ice Pellets	
S2	N/A	6	03-Apr-07	11:13:20	11:27:50	Newave	II	n/a	15	17	100%	ZR 25 IP 5	1.0-2.8	30	-10	Mixed: Freezing Rain/Ice Pellets	Adh to 6" recorded, estimated 1" based on previous data
S3	N/A	11	03-Apr-07	11:14:45	11:43:10	XI'AN	II	n/a	28	21	N/A	ZR 25 IP 5	1.0-2.8	30	-10	Mixed: Freezing Rain/Ice Pellets	
S4	N/A	12	03-Apr-07	11:13:56	11:32:50	Lyondell 6166	IV	n/a	19	22	83%	ZR 25 IP 5	1.0-2.8	30	-10	Mixed: Freezing Rain/Ice Pellets	
B1a	187	7	03-Apr-07	9:03:30	9:22:00	Kilfrost P1797	IV	19	n/a	37		ZR 25	N/A	25	-10	Freezing Rain	
B2a	179	9	03-Apr-07	9:05:40	9:21:00	Newave	II	15	n/a	17		ZR 25	N/A	25	-10	Freezing Rain	
B3a	183	11	03-Apr-07	9:07:20	9:35:00	XI'AN	II	28	n/a	N/A		ZR 25	N/A	25	-10	Freezing Rain	HOT Test Stopped
B4a	175	4	03-Apr-07	9:01:30	9:25:00	Lyondell 6166	IV	24	n/a	27		ZR 25	N/A	25	-10	Freezing Rain	
B1b	188	8	03-Apr-07	9:04:40	9:22:00	Kilfrost P1797	IV	17	n/a	35		ZR 25	N/A	25	-10	Freezing Rain	
B2b	180	10	03-Apr-07	9:06:20	9:21:00	Newave	II	15	n/a	17		ZR 25	N/A	25	-10	Freezing Rain	
B3b	184	12	03-Apr-07	9:08:00	9:35:00	XI'AN	II	27	n/a	N/A		ZR 25	N/A	25	-10	Freezing Rain	HOT Test Stopped
B4b	176	5	03-Apr-07	9:02:10	9:24:00	Lyondell 6166	IV	22	n/a	26		ZR 25	N/A	25	-10	Freezing Rain	
L5	N/A	1	03-Apr-07	13:25:00	N/A	Kilfrost P1797	IV	n/a	N/A	55	103%	ZR 25 IP 5	2.8-4.75	30	-3	Mixed: Freezing Rain/Ice Pellets	HOT not called (rush)
L6	N/A	2	03-Apr-07	13:25:30	13:49:00	Newave	II	n/a	24	23	95%	ZR 25 IP 5	2.8-4.75	30	-3	Mixed: Freezing Rain/Ice Pellets	
L7	N/A	7	03-Apr-07	13:26:00	13:54:30	XI'AN	II	n/a	29	23	92%	ZR 25 IP 5	2.8-4.75	30	-3	Mixed: Freezing Rain/Ice Pellets	
L8	N/A	8	03-Apr-07	13:26:25	14:11:45	Lyondell 2330	IV	n/a	45	34	90%	ZR 25 IP 5	2.8-4.75	30	-3	Mixed: Freezing Rain/Ice Pellets	
S5	N/A	5	03-Apr-07	13:26:50	N/A	Kilfrost P1797	IV	n/a	N/A	52	97%	ZR 25 IP 5	1.0-2.8	30	-3	Mixed: Freezing Rain/Ice Pellets	HOT not called (rush)
S6	N/A	6	03-Apr-07	13:27:20	13:50:00	Newave	II	n/a	23	21	89%	ZR 25 IP 5	1.0-2.8	30	-3	Mixed: Freezing Rain/Ice Pellets	
S7	N/A	11	03-Apr-07	13:27:45	13:55:00	XI'AN	II	n/a	27	22	87%	ZR 25 IP 5	1.0-2.8	30	-3	Mixed: Freezing Rain/Ice Pellets	
S8	N/A	12	03-Apr-07	13:28:12	14:14:30	Lyondell 2330	IV	n/a	46	34	90%	ZR 25 IP 5	1.0-2.8	30	-3	Mixed: Freezing Rain/Ice Pellets	
B5a	133	2	03-Apr-07	14:25:47	15:29:00	Kilfrost P1797	IV	63	n/a	53		ZR 25	N/A	25	-3	Freezing Rain	
B6a	121	6	03-Apr-07	14:28:30	14:52:00	Newave	II	24	n/a	N/A		ZR 25	N/A	25	-3	Freezing Rain	HOT test stopped before adh tests
B7a	127	7	03-Apr-07	14:29:30	15:00:00	XI'AN	II	31	n/a	26		ZR 25	N/A	25	-3	Freezing Rain	
B8a	109	4	03-Apr-07	14:27:12	15:11:30	Lyondell 2330	IV	44	n/a	38		ZR 25	N/A	25	-3	Freezing Rain	
B5b	134	3	03-Apr-07	14:26:30	15:31:00	Kilfrost P1797	IV	65	n/a	54		ZR 25	N/A	25	-3	Freezing Rain	
B6b	122	12	03-Apr-07	14:32:00	14:56:30	Newave	II	25	n/a	24		ZR 25	N/A	25	-3	Freezing Rain	
B7b	128	8	03-Apr-07	14:30:04	15:01:00	XI'AN	II	31	n/a	25		ZR 25	N/A	25	-3	Freezing Rain	
B8b	110	5	03-Apr-07	14:27:50	15:11:00	Lyondell 2330	IV	43	n/a	37		ZR 25	N/A	25	-3	Freezing Rain	



LARGE VS. SMALL ICE PELLETS WITH LIGHT FREEZING RAIN AND INTERMITTENT ICE PELLETS AND LIGHT FREEZING RAIN

Table 4.3: Test Log – Intermittent Freezing Rain and Small Ice Pellets

Test #	HOT Test #	Plate Loc.	Date	Start Time (hh:mm:ss)	Fail Time (hh:mm:ss)	Fluid Name	Fluid Type	Fail Time	Est. Visual TC Fail Time (min)	Time of First Adherence (min)	Percentage Time Ratio (Mixed / AVG Baseline)	Approx. ZR Precip Rate (g/dm^2/h)	Approx. IP Precip Rate (g/dm^2/h)	Exposure Time ZR / IP / ZR (min)	Size of Ice Pellets (mm)	Actual Chamber Temp. (°C)	Precipitation (Type)	Comments
Int1	N/A	IP1	03-Apr-07	9:39:24	N/A	Kilfrost P1797	IV	n/a	N/A	25	68%	25	75	10 / 10 / 4	1.0-2.8	-10	Intermietent Freezing Rain and Ice Pellets	IP Rate too high, Complete Ice Crust 4 min after 2nd
Int2	N/A	IP1	03-Apr-07	10:13:20	10:44:05	Kilfrost P1797	IV	n/a	31	33	91%	25	25	10 / 10 / 12	1.0-2.8	-10	Intermietent Freezing Rain and Ice Pellets	
B1a	187	7	03-Apr-07	9:03:30	9:22:00	Kilfrost P1797	IV	19	n/a	37		25	N/A	40 / 0 / 0	N/A	-10	Freezing Rain	
B1b	188	8	03-Apr-07	9:04:40	9:22:00	Kilfrost P1797	IV	17	n/a	35		25	N/A	40 / 0 / 0	N/A	-10	Freezing Rain	
Int3	N/A	IP1	03-Apr-07	15:23:00	16:10:00	Lyondell 2330	IV	n/a	47	35	93%	25	25	0 / 20 / 30	1.0-2.8	-3	Intermietent Freezing Rain and Ice Pellets	
Int4	N/A	IP2	03-Apr-07	15:23:00	16:11:00	Lyondell 2330	IV	n/a	48	35	93%	25	25	0 / 20 / 30	1.0-2.8	-3	Intermietent Freezing Rain and Ice Pellets	
B8a	109	4	03-Apr-07	14:27:12	15:11:30	Lyondell 2330	IV	44	n/a	38		25	N/A	50 / 0 / 0	N/A	-3	Freezing Rain	
B8b	110	5	03-Apr-07	14:27:50	15:11:00	Lyondell 2330	IV	43	n/a	37		25	N/A	50 / 0 / 0	N/A	-3	Freezing Rain	

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Final Version 1.0, April 07

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5. GENERAL OBSERVATIONS

Table 5.1 summarizes the time to first adherence (adherence to the 3cm line) for all respective mixed and baseline tests conducted. The following sections describe the observations and conclusions respective to each test condition.

5.1 Time of First Adherence – Mixed Light Freezing Rain with Large and Small Ice Pellets

The time of first adherence for the light freezing rain and large ice pellet tests was on average 6% shorter with respect to the baseline (ZR only) tests. The time of first adherence for the light freezing rain and small ice pellet tests was on average 5% shorter with respect to the baseline (ZR only) tests. The total mixed icing precipitation rate (30 g/dm²/h) was greater than the baseline test rate of precipitation (25 g/dm²/h), likely causing the discrepancy. For all tests, the difference in time of adherence in comparison to the baseline test did not exceed 5 minutes.

The tests indicated that there was no significant difference in the fluid adherence results obtained using the large or small ice pellets combined with light freezing rain. Photo 5.1, 5.2, and 5.3 show the fluid condition at the time of first adherence for light freezing rain only, light freezing rain and large ice pellets, and light freezing rain and small ice pellets, respectively.

5.2 Time of Visual Fluid Failure – Mixed Light Freezing Rain with Large and Small Ice Pellets

It should be noted that visual fluid failure call for each mixed icing test was estimated based on the standard freezing rain precipitation failure call. Visual failure criteria for ice pellet conditions have not yet been determined.

5.2.1 Large vs. Small Ice Pellets

With the exception of tests L4 and S4, the estimated visual fluid failure for large or small ice pellets combined with light freezing rain tests did not differ by more than two minutes. The discrepancy in tests L4 and S4 was likely to an inaccuracy in calling the visual fluid failure.

The results indicated that the size of the ice pellets did not have a significant impact on the fluid failure call.

5.2.2 Mixed Icing vs. Baseline Tests

The estimated visual failure time of the mixed icing tests (both for large and small ice pellets) was generally within five minutes of the baseline test failure call.

As a result of the ice pellet conditions, contamination was present very early in the test; ice pellets were imbedded in the fluid. This early failure call based on imbedded ice pellet contamination was ignored.

5.3 Intermittent Light Freezing Rain and Small Ice Pellets

With the exception of test Int#1, which included a high rate of ice pellets (75 g/dm²/h for 10 minutes), the time of first adherence for the intermittent light freezing rain and small ice pellet tests was on average 7% shorter with respect to the baseline (ZR only) tests. The difference in time of adherence for all tests did not exceed 4 minutes.

The tests conducted at -3°C indicated that ice pellet conditions did not significantly reduce the fluid protection time to adherence or failure; results were similar to the baseline tests. The tests conducted at -10°C indicated that the fluid failure characteristics at lower temperature may have influenced the visual fluid failure call; baseline tests failed earlier in comparison to the intermittent light freezing rain and small ice pellet test. It should be noted that these results are based on a limited data set and that additional testing is required to validate the results obtained.

Table 5.1: Summary of Time to 1st Adherence for Mixed Light Freezing Rain and Large vs. Small Ice Pellets

Test #	OAT (ºC)	Mixed Precip 1st Adherence Time (min)	Baseline 1st Adherence Time (min)	% Ratio (Mixed / Baseline) (%)	Time Difference (Mixed / Baseline) (min)
Large Ice Pellets					
L1-B1	-10	34	36	93%	-2
L2-B2	-10	23	17	134%	6
L3-B3	-10	24	n/a	n/a	n/a
L4-B4	-10	23	27	87%	-4
L5-B5	-3	55	54	102%	1
L6-B6	-3	23	24	95%	-1
L7-B7	-3	23	25	93%	-2
L8-B8	-3	34	37	91%	-3
			Average	99%	
Small Ice Pellets					
S1-B1	-10	34	36	94%	-2
S2-B2	-10	21	17	122%	4
S3-B3	-10	21	n/a	n/a	n/a
S4-B4	-10	22	27	82%	-5
S5-B5	-3	52	54	97%	-2
S6-B6	-3	21	24	89%	-3
S7-B7	-3	22	25	88%	-3
S8-B8	-3	34	37	91%	-3
			Average	95%	

Photo 5.1: First Adherence Caused by Light Freezing Rain Alone

Photo 5.2: First Adherence Caused by Light Freezing Rain and Large Ice Pellets

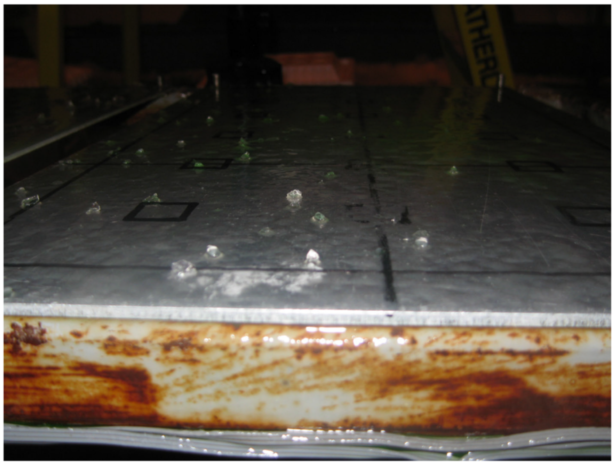
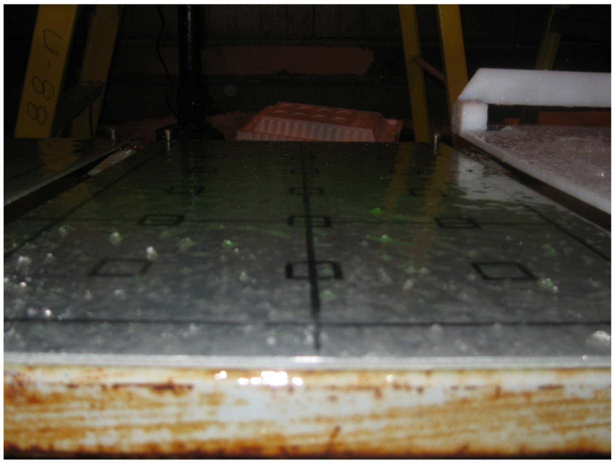


Photo 5.3Photo 5.3: First Adherence Caused by Light Freezing Rain and Small Ice Pellets



6. FUTURE WORK

6.1 Aerodynamic Research with Adhered Ice Pellet Contamination

Aerodynamic research is required to quantify the lift loss caused by adhered ice pellet contamination. Testing should be conducted in the NRC wind tunnel during mixed icing conditions.

Baseline testing should also be conducted with a bare wing exposed to mixed ice pellet and light freezing rain to evaluate the lift loss for the worst-case un-protected scenario.

6.2 Additional Mixed Precipitation (ZR/IP) Testing at Colder Temperatures

Testing conducted in light freezing rain and ice pellets conditions at -10°C demonstrated that the discrepancies in the results may be fluid specific. Further testing is recommended at -10°C. It is also recommended that testing be conducted to determine the effects of light freezing rain and ice pellets at -16°C, the lower temperature limit for natural occurrence of these conditions.

6.3 Effect of Aging on Fluid Adherence

Testing is recommended to investigate the effects of “aging” on fluid adherence. This testing will represent active mixed ice pellet conditions followed by periods of no precipitation. This testing should explore the effects of terminating precipitation on fluid adherence, dilution and failure.

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APPENDIX H

TEST REPORT:
ICE PELLET ALLOWANCE TIME VALIDATION AND MIXED RAIN AND ICE PELLETS TESTING

CM2020 (06-07)

TEST REPORT:
ICE PELLET ALLOWANCE TIME VALIDATION
AND
MIXED RAIN AND ICE PELLETS TESTING

Fall 2007

Prepared for

Transportation Development Centre
Transport Canada

And

The Federal Aviation Administration
William J. Hughes Technical Center

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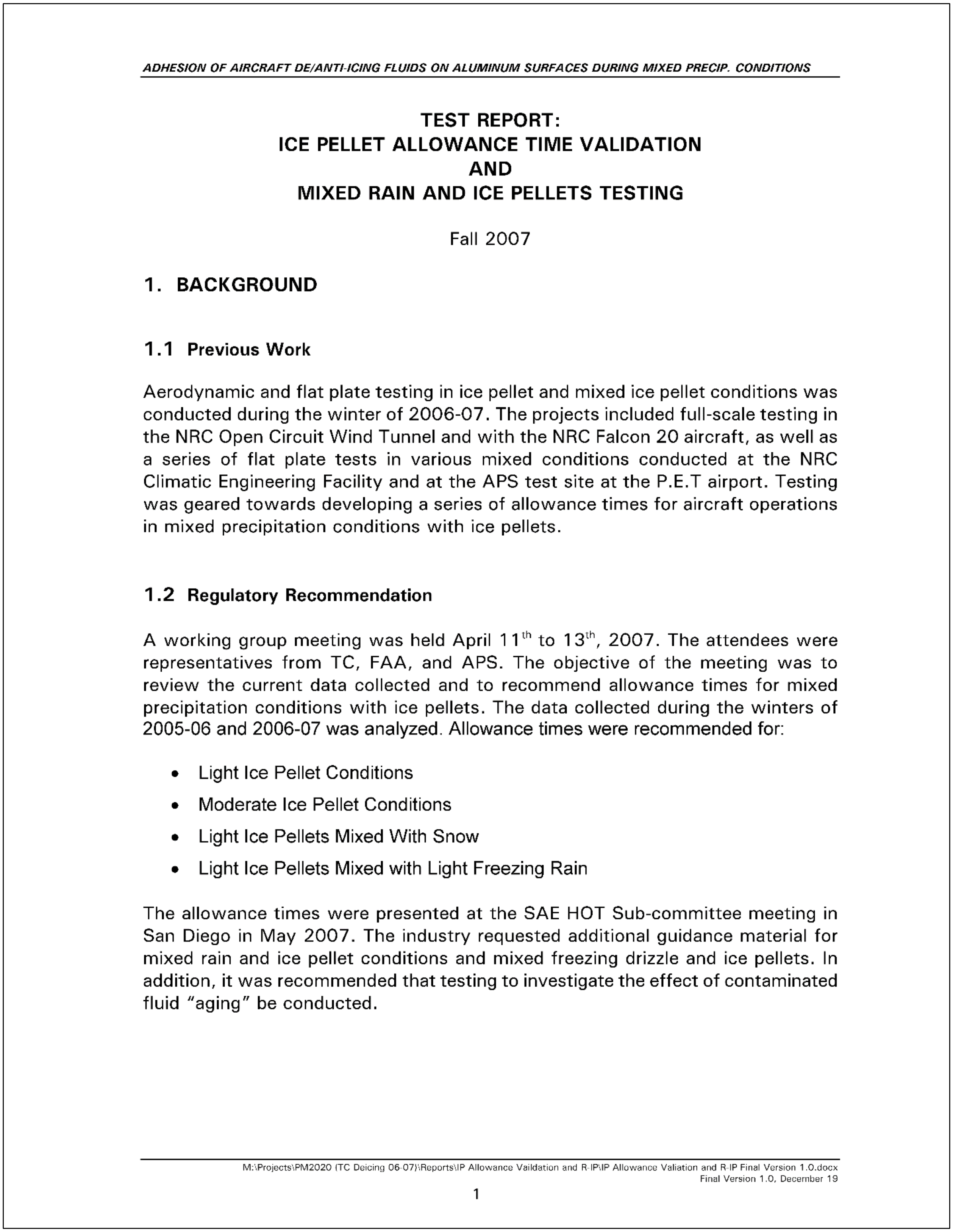
Reviewed by: John D'Avirro

December 18, 2019
Final Version 1.0



TEST REPORT:
ICE PELLET ALLOWANCE TIME VALIDATION
AND
MIXED RAIN AND ICE PELLETS TESTING

Fall 2007

1. BACKGROUND

1.1 Previous Work

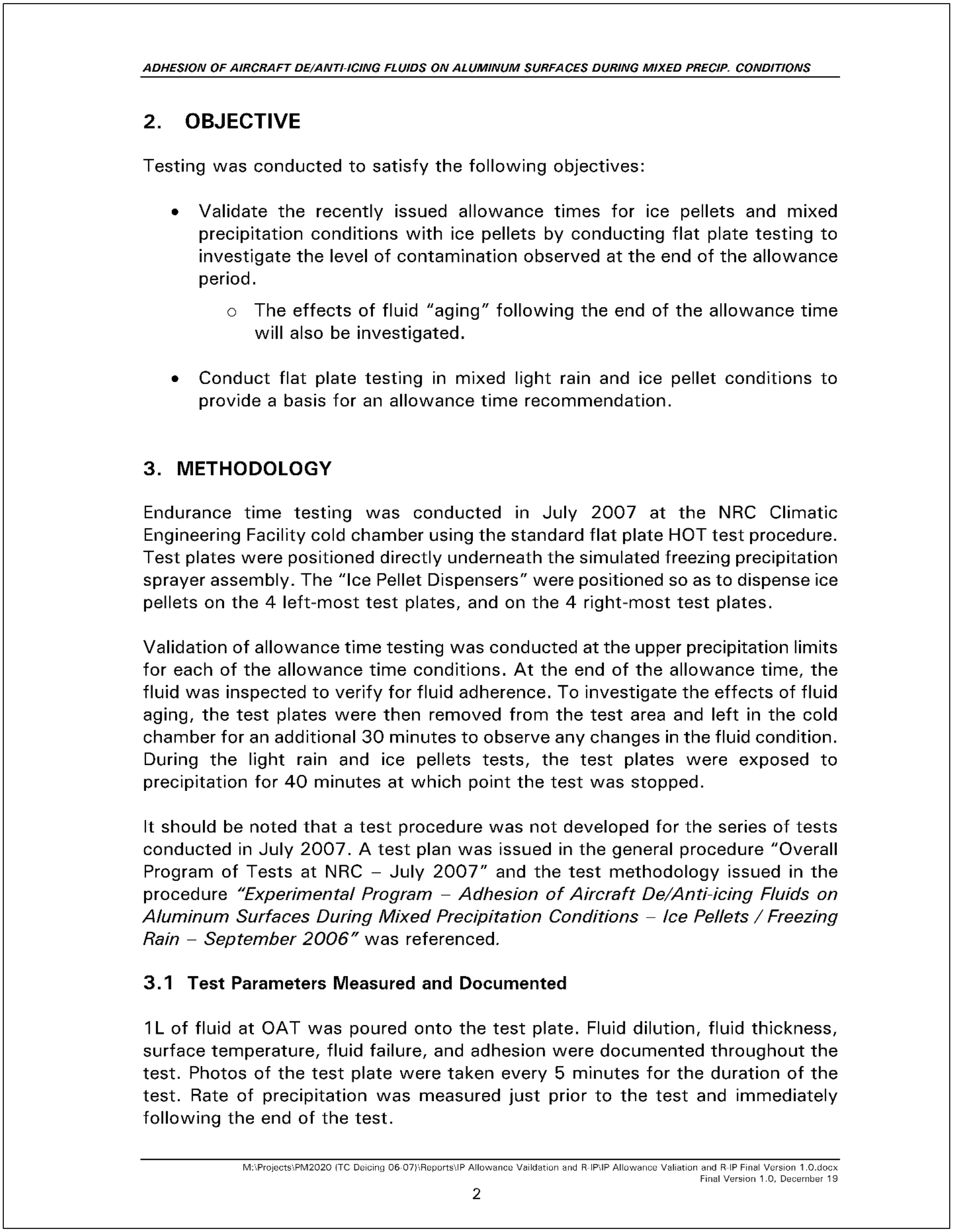
Aerodynamic and flat plate testing in ice pellet and mixed ice pellet conditions was conducted during the winter of 2006-07. The projects included full-scale testing in the NRC Open Circuit Wind Tunnel and with the NRC Falcon 20 aircraft, as well as a series of flat plate tests in various mixed conditions conducted at the NRC Climatic Engineering Facility and at the APS test site at the P.E.T airport. Testing was geared towards developing a series of allowance times for aircraft operations in mixed precipitation conditions with ice pellets.

1.2 Regulatory Recommendation

A working group meeting was held April 11th to 13th, 2007. The attendees were representatives from TC, FAA, and APS. The objective of the meeting was to review the current data collected and to recommend allowance times for mixed precipitation conditions with ice pellets. The data collected during the winters of 2005-06 and 2006-07 was analyzed. Allowance times were recommended for:

- Light Ice Pellet Conditions
- Moderate Ice Pellet Conditions
- Light Ice Pellets Mixed With Snow
- Light Ice Pellets Mixed with Light Freezing Rain

The allowance times were presented at the SAE HOT Sub-committee meeting in San Diego in May 2007. The industry requested additional guidance material for mixed rain and ice pellet conditions and mixed freezing drizzle and ice pellets. In addition, it was recommended that testing to investigate the effect of contaminated fluid “aging” be conducted.



2. OBJECTIVE

Testing was conducted to satisfy the following objectives:

- Validate the recently issued allowance times for ice pellets and mixed precipitation conditions with ice pellets by conducting flat plate testing to investigate the level of contamination observed at the end of the allowance period.
    - The effects of fluid "aging" following the end of the allowance time will also be investigated.
- Conduct flat plate testing in mixed light rain and ice pellet conditions to provide a basis for an allowance time recommendation.

3. METHODOLOGY

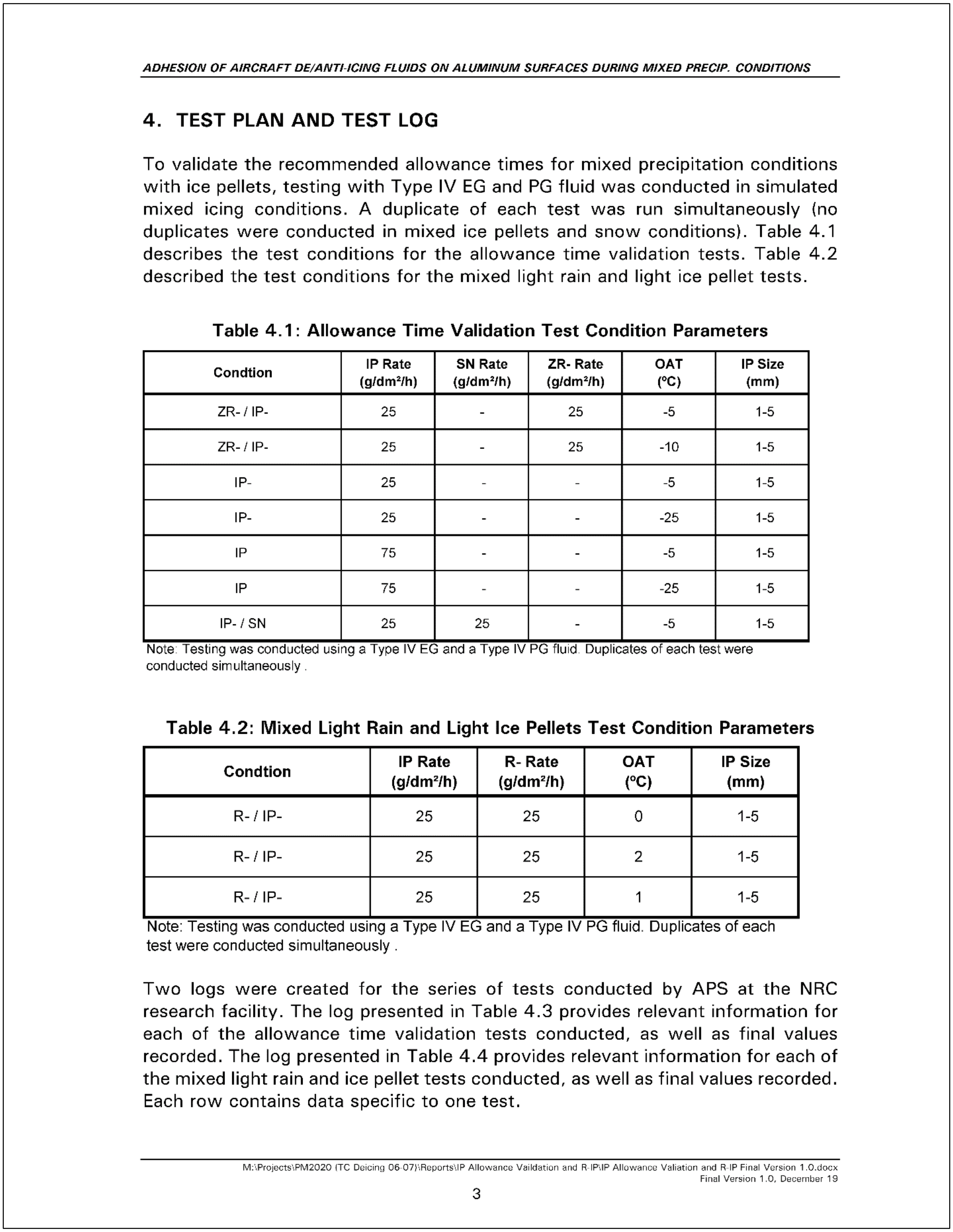
Endurance time testing was conducted in July 2007 at the NRC Climatic Engineering Facility cold chamber using the standard flat plate HOT test procedure. Test plates were positioned directly underneath the simulated freezing precipitation sprayer assembly. The "Ice Pellet Dispensers" were positioned so as to dispense ice pellets on the 4 left-most test plates, and on the 4 right-most test plates.

Validation of allowance time testing was conducted at the upper precipitation limits for each of the allowance time conditions. At the end of the allowance time, the fluid was inspected to verify for fluid adherence. To investigate the effects of fluid aging, the test plates were then removed from the test area and left in the cold chamber for an additional 30 minutes to observe any changes in the fluid condition. During the light rain and ice pellets tests, the test plates were exposed to precipitation for 40 minutes at which point the test was stopped.

It should be noted that a test procedure was not developed for the series of tests conducted in July 2007. A test plan was issued in the general procedure "Overall Program of Tests at NRC – July 2007" and the test methodology issued in the procedure *"Experimental Program – Adhesion of Aircraft De/Anti-icing Fluids on Aluminum Surfaces During Mixed Precipitation Conditions – Ice Pellets / Freezing Rain – September 2006"* was referenced.

3.1 Test Parameters Measured and Documented

1L of fluid at OAT was poured onto the test plate. Fluid dilution, fluid thickness, surface temperature, fluid failure, and adhesion were documented throughout the test. Photos of the test plate were taken every 5 minutes for the duration of the test. Rate of precipitation was measured just prior to the test and immediately following the end of the test.



4. TEST PLAN AND TEST LOG

To validate the recommended allowance times for mixed precipitation conditions with ice pellets, testing with Type IV EG and PG fluid was conducted in simulated mixed icing conditions. A duplicate of each test was run simultaneously (no duplicates were conducted in mixed ice pellets and snow conditions). Table 4.1 describes the test conditions for the allowance time validation tests. Table 4.2 described the test conditions for the mixed light rain and light ice pellet tests.

Table 4.1: Allowance Time Validation Test Condition Parameters

Condtion	IP Rate ($g/dm^2/h$)	SN Rate ($g/dm^2/h$)	ZR- Rate ($g/dm^2/h$)	OAT (°C)	IP Size (mm)
ZR- / IP-	25	-	25	-5	1-5
ZR- / IP-	25	-	25	-10	1-5
IP-	25	-	-	-5	1-5
IP-	25	-	-	-25	1-5
IP	75	-	-	-5	1-5
IP	75	-	-	-25	1-5
IP- / SN	25	25	-	-5	1-5

Note: Testing was conducted using a Type IV EG and a Type IV PG fluid. Duplicates of each test were conducted simultaneously .

Table 4.2: Mixed Light Rain and Light Ice Pellets Test Condition Parameters

Condtion	IP Rate ($g/dm^2/h$)	R- Rate ($g/dm^2/h$)	OAT (°C)	IP Size (mm)
R- / IP-	25	25	0	1-5
R- / IP-	25	25	2	1-5
R- / IP-	25	25	1	1-5

Note: Testing was conducted using a Type IV EG and a Type IV PG fluid. Duplicates of each test were conducted simultaneously .

Two logs were created for the series of tests conducted by APS at the NRC research facility. The log presented in Table 4.3 provides relevant information for each of the allowance time validation tests conducted, as well as final values recorded. The log presented in Table 4.4 provides relevant information for each of the mixed light rain and ice pellet tests conducted, as well as final values recorded. Each row contains data specific to one test.

Table 4.3: Allowance Time Validation Test Log

Test #	Plate Loc.	Date	Start Precip Time	End Precip Time	FAA/TC Allow. Time [min.]	Aging Time [min.]	Fluid Type	Fluid Brand	Dilution	Fluid Temp. [°C]	Chamber Temp. [°C]	Condition	Ice Pellet Diameter [mm]	Actual Freezing Rain Precip Rate [$\text{g/dm}^2\text{/h}$]	Actual Ice Pellet Precip Rate [$\text{g/dm}^2\text{/h}$]*	Actual Snow Precip Rate [$\text{g/dm}^2\text{/h}$]	Actual Combined Precip Rate [$\text{g/dm}^2\text{/h}$]	Fluid adherence at end of precip.	Comments
IP1	8	18-Jul-07	16:01:15	16:26:15	25	30	IV	Dow Ultra+	Neat	-5	-5	ZR- 25 / IP- 25	1-4.75	25	26	-	51	adh to <1" line	Following aging, adherence patches diminished in size. Adherence observed at end of allowance time was similar to adherence observed at fluid failure in ZR25/-3ºC conditions for Type IV fluids
IP1a	11	18-Jul-07	16:01:00	16:26:00	25	30	IV	Dow Ultra+	Neat	-5	-5	ZR- 25 / IP- 25	1-4.75	24	30	-	54	adh to <1" line	
IP2	7	18-Jul-07	16:01:15	16:26:15	25	30	IV	Kilfrost ABC-S	Neat	-5	-5	ZR- 25 / IP- 25	1-4.75	24	30	-	54	adh to 1" line	
IP2a	12	18-Jul-07	16:01:00	16:26:00	25	30	IV	Kilfrost ABC-S	Neat	-5	-5	ZR- 25 / IP- 25	1-4.75	24	26	-	51	adh to 1" line	
IP3	8	18-Jul-07	14:18:30	14:28:30	10	0	IV	Dow Ultra+	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	10	-	35	No adh.	IP Rate problem. Dispenser setting was not correct. IP precip rate was visually estimated to be approx 10 g/dm²/h. Test was still continued but no aging was done.
IP3a	11	18-Jul-07	14:18:00	14:28:00	10	0	IV	Dow Ultra+	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	10	-	35	No adh.	
IP4	7	18-Jul-07	14:18:30	14:28:30	10	0	IV	Kilfrost ABC-S	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	10	-	35	No adh.	
IP4a	12	18-Jul-07	14:18:00	14:28:00	10	0	IV	Kilfrost ABC-S	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	10	-	35	No adh.	
IP3-2	8	18-Jul-07	14:35:45	14:45:45	10	30	IV	Dow Ultra+	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	26	-	51	No adh.	No adherence was documented following 10 minutes of mixed precipitation. Plates were inspected following a 30 minute aging, and still no adherence.
IP3a-2	11	18-Jul-07	14:35:30	14:45:30	10	30	IV	Dow Ultra+	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	30	-	54	No adh.	
IP4-2	7	18-Jul-07	14:35:45	14:45:45	10	30	IV	Kilfrost ABC-S	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	30	-	55	No adh.	
IP4a-2	12	18-Jul-07	14:35:30	14:45:30	10	30	IV	Kilfrost ABC-S	Neat	-10	-10	ZR- 25 / IP- 25	1-4.75	25	26	-	51	No adh.	

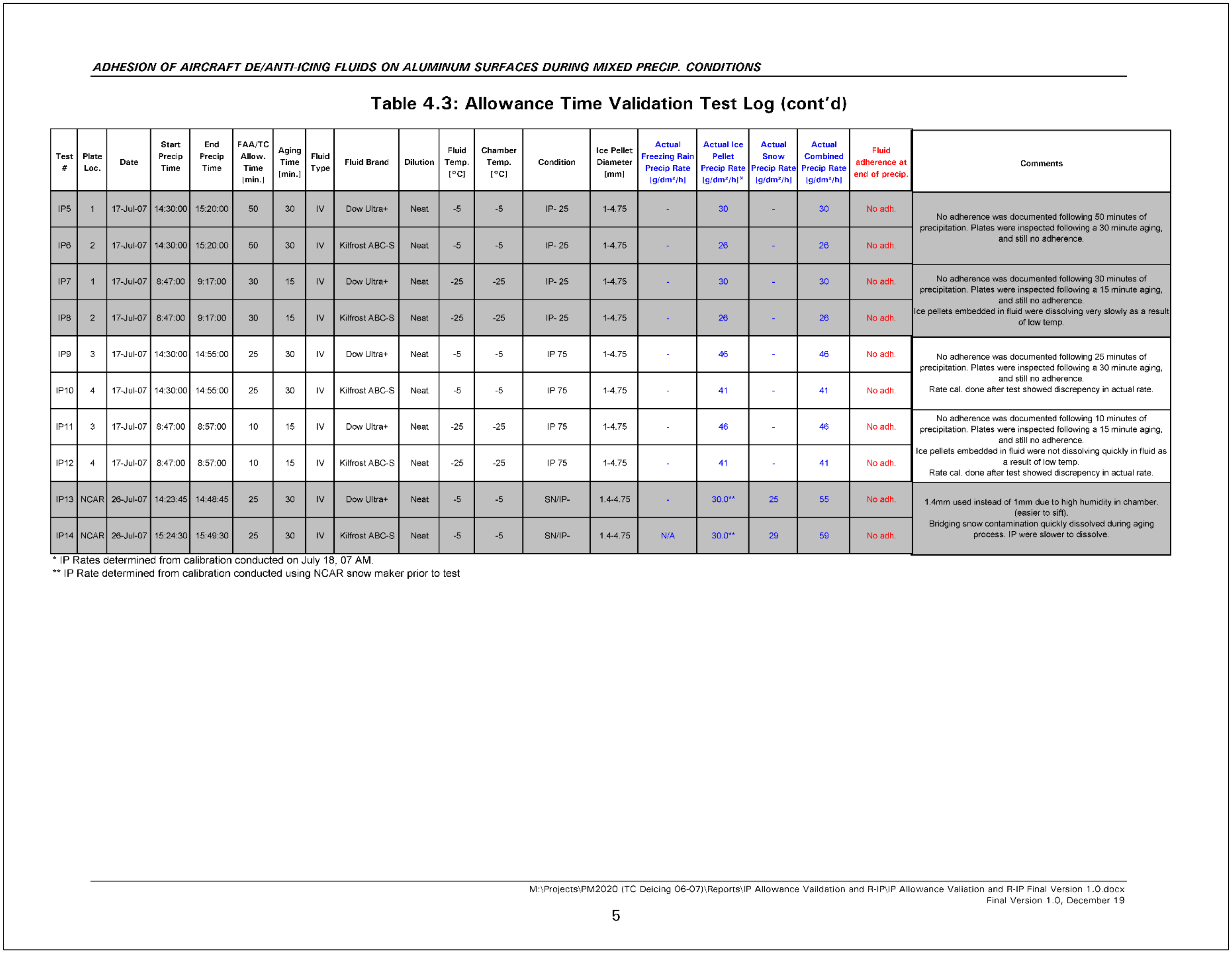
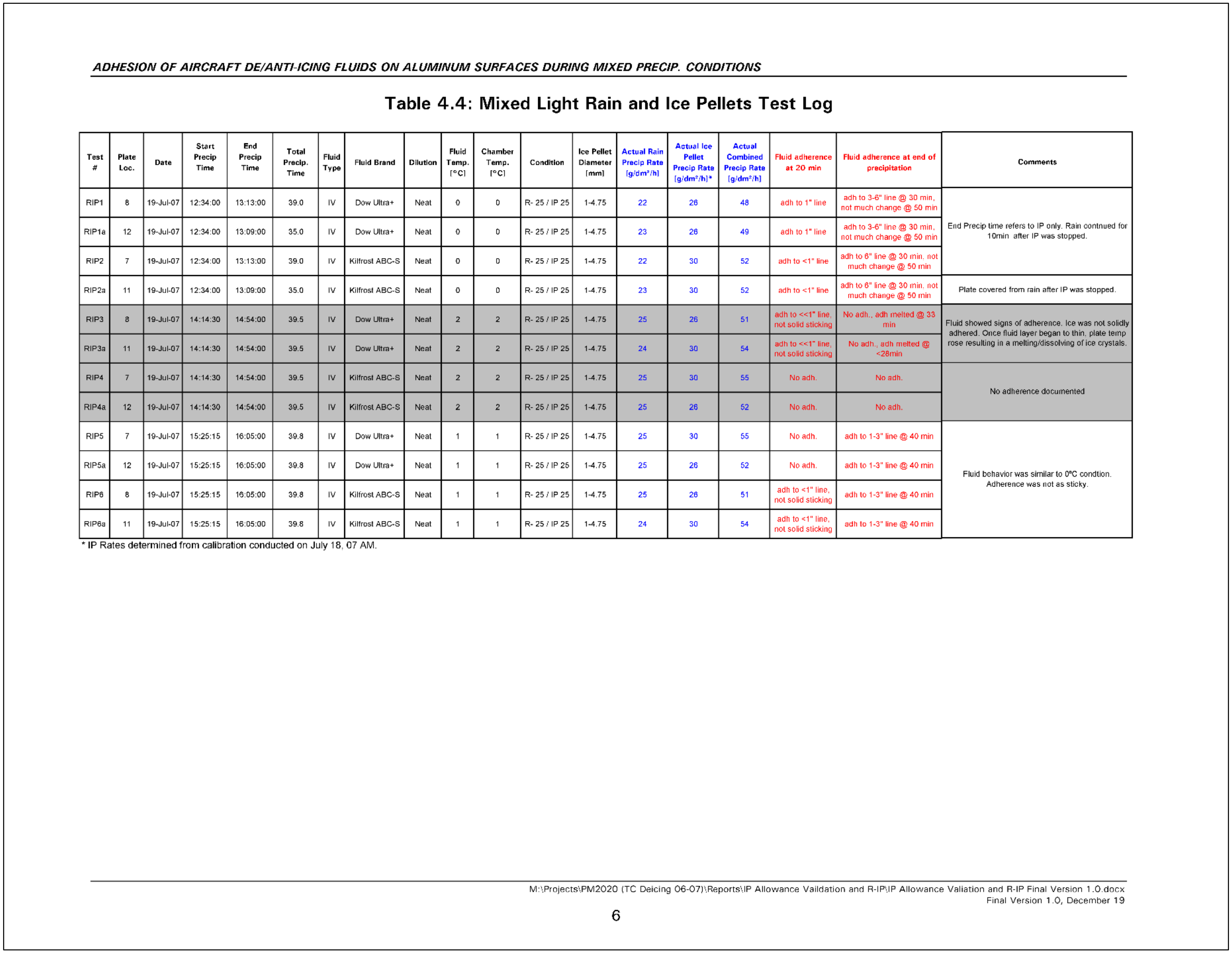


Table 4.3: Allowance Time Validation Test Log (cont'd)

Test #	Plate Loc.	Date	Start Precip Time	End Precip Time	FAA/TC Allow. Time [min.]	Aging Time [min.]	Fluid Type	Fluid Brand	Dilution	Fluid Temp. [°C]	Chamber Temp. [°C]	Condition	Ice Pellet Diameter [mm]	Actual Freezing Rain Precip Rate [g/dm^2/h]	Actual Ice Pellet Precip Rate [g/dm^2/h]*	Actual Snow Precip Rate [g/dm^2/h]	Actual Combined Precip Rate [g/dm^2/h]	Fluid adherence at end of precip.	Comments
IP5	1	17-Jul-07	14:30:00	15:20:00	50	30	IV	Dow Ultra+	Neat	-5	-5	IP- 25	1-4.75	-	30	-	30	No adh.	No adherence was documented following 50 minutes of precipitation. Plates were inspected following a 30 minute aging, and still no adherence.
IP6	2	17-Jul-07	14:30:00	15:20:00	50	30	IV	Kilfrost ABC-S	Neat	-5	-5	IP- 25	1-4.75	-	26	-	26	No adh.	
IP7	1	17-Jul-07	8:47:00	9:17:00	30	15	IV	Dow Ultra+	Neat	-25	-25	IP- 25	1-4.75	-	30	-	30	No adh.	No adherence was documented following 30 minutes of precipitation. Plates were inspected following a 15 minute aging, and still no adherence. Ice pellets embedded in fluid were dissolving very slowly as a result of low temp.
IP8	2	17-Jul-07	8:47:00	9:17:00	30	15	IV	Kilfrost ABC-S	Neat	-25	-25	IP- 25	1-4.75	-	26	-	26	No adh.	
IP9	3	17-Jul-07	14:30:00	14:55:00	25	30	IV	Dow Ultra+	Neat	-5	-5	IP 75	1-4.75	-	46	-	46	No adh.	No adherence was documented following 25 minutes of precipitation. Plates were inspected following a 30 minute aging, and still no adherence. Rate cal. done after test showed discrepency in actual rate.
IP10	4	17-Jul-07	14:30:00	14:55:00	25	30	IV	Kilfrost ABC-S	Neat	-5	-5	IP 75	1-4.75	-	41	-	41	No adh.	
IP11	3	17-Jul-07	8:47:00	8:57:00	10	15	IV	Dow Ultra+	Neat	-25	-25	IP 75	1-4.75	-	46	-	46	No adh.	No adherence was documented following 10 minutes of precipitation. Plates were inspected following a 15 minute aging, and still no adherence. Ice pellets embedded in fluid were not dissolving quickly in fluid as a result of low temp. Rate cal. done after test showed discrepency in actual rate.
IP12	4	17-Jul-07	8:47:00	8:57:00	10	15	IV	Kilfrost ABC-S	Neat	-25	-25	IP 75	1-4.75	-	41	-	41	No adh.	
IP13	NCAR	26-Jul-07	14:23:45	14:48:45	25	30	IV	Dow Ultra+	Neat	-5	-5	SN/IP-	1.4-4.75	-	30.0**	25	55	No adh.	1.4mm used instead of 1mm due to high humidity in chamber. (easier to sift). Bridging snow contamination quickly dissolved during aging process. IP were slower to dissolve.
IP14	NCAR	26-Jul-07	15:24:30	15:49:30	25	30	IV	Kilfrost ABC-S	Neat	-5	-5	SN/IP-	1.4-4.75	N/A	30.0**	29	59	No adh.	

* IP Rates determined from calibration conducted on July 18, 07 AM.

** IP Rate determined from calibration conducted using NCAR snow maker prior to test



ADHESION OF AIRCRAFT DE/ANTI-ICING FLUIDS ON ALUMINUM SURFACES DURING MIXED PRECIP. CONDITIONS

Table 4.4: Mixed Light Rain and Ice Pellets Test Log

Test #	Plate Loc.	Date	Start Precip Time	End Precip Time	Total Precip. Time	Fluid Type	Fluid Brand	Dilution	Fluid Temp. [°C]	Chamber Temp. [°C]	Condition	Ice Pellet Diameter [mm]	Actual Rain Precip Rate [g/dm²/h]	Actual Ice Pellet Precip Rate [g/dm²/h]*	Actual Combined Precip Rate [g/dm²/h]	Fluid adherence at 20 min	Fluid adherence at end of precipitation	Comments
RIP1	8	19-Jul-07	12:34:00	13:13:00	39.0	IV	Dow Ultra+	Neat	0	0	R- 25 / IP 25	1-4.75	22	26	48	adh to 1" line	adh to 3-6" line @ 30 min, not much change @ 50 min	End Precip time refers to IP only. Rain contnued for 10min after IP was stopped.
RIP1a	12	19-Jul-07	12:34:00	13:09:00	35.0	IV	Dow Ultra+	Neat	0	0	R- 25 / IP 25	1-4.75	23	26	49	adh to 1" line	adh to 3-6" line @ 30 min, not much change @ 50 min	
RIP2	7	19-Jul-07	12:34:00	13:13:00	39.0	IV	Kilfrost ABC-S	Neat	0	0	R- 25 / IP 25	1-4.75	22	30	52	adh to <1" line	adh to 6" line @ 30 min, not much change @ 50 min	
RIP2a	11	19-Jul-07	12:34:00	13:09:00	35.0	IV	Kilfrost ABC-S	Neat	0	0	R- 25 / IP 25	1-4.75	23	30	52	adh to <1" line	adh to 6" line @ 30 min, not much change @ 50 min	Plate covered from rain after IP was stopped.
RIP3	8	19-Jul-07	14:14:30	14:54:00	39.5	IV	Dow Ultra+	Neat	2	2	R- 25 / IP 25	1-4.75	25	26	51	adh to <<1" line, not solid sticking	No adh., adh melted @ 33 min	Fluid showed signs of adherence. Ice was not solidly adhered. Once fluid layer began to thin, plate temp rose resulting in a melting/dissolving of ice crystals.
RIP3a	11	19-Jul-07	14:14:30	14:54:00	39.5	IV	Dow Ultra+	Neat	2	2	R- 25 / IP 25	1-4.75	24	30	54	adh to <<1" line, not solid sticking	No adh., adh melted @ <28min	
RIP4	7	19-Jul-07	14:14:30	14:54:00	39.5	IV	Kilfrost ABC-S	Neat	2	2	R- 25 / IP 25	1-4.75	25	30	55	No adh.	No adh.	No adherence documented
RIP4a	12	19-Jul-07	14:14:30	14:54:00	39.5	IV	Kilfrost ABC-S	Neat	2	2	R- 25 / IP 25	1-4.75	25	26	52	No adh.	No adh.	
RIP5	7	19-Jul-07	15:25:15	16:05:00	39.8	IV	Dow Ultra+	Neat	1	1	R- 25 / IP 25	1-4.75	25	30	55	No adh.	adh to 1-3" line @ 40 min	Fluid behavior was similar to 0ºC condtion. Adherence was not as sticky.
RIP5a	12	19-Jul-07	15:25:15	16:05:00	39.8	IV	Dow Ultra+	Neat	1	1	R- 25 / IP 25	1-4.75	25	26	52	No adh.	adh to 1-3" line @ 40 min	
RIP6	8	19-Jul-07	15:25:15	16:05:00	39.8	IV	Kilfrost ABC-S	Neat	1	1	R- 25 / IP 25	1-4.75	25	26	51	adh to <1" line, not solid sticking	adh to 1-3" line @ 40 min	
RIP6a	11	19-Jul-07	15:25:15	16:05:00	39.8	IV	Kilfrost ABC-S	Neat	1	1	R- 25 / IP 25	1-4.75	24	30	54	adh to <1" line, not solid sticking	adh to 1-3" line @ 40 min	

* IP Rates determined from calibration conducted on July 18, 07 AM.

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5. GENERAL OBSERVATIONS

The following sections describe the observations and conclusions respective to each test condition.

5.1 Allowance Time Validation Tests

5.1.1 Mixed Light Freezing Rain and Light Ice Pellets

Testing conducted at -10°C did not show signs of adherence at the end of the allowance time. A significant amount of fluid was still present on the test plate, and the fluid had not yet diluted to a critical freeze point. Photo 5.1 shows the Type IV EG fluid condition at the end of the allowance time.

Testing conducted at -5°C showed signs of adherence up to the 1″ (2.5 cm) line at the end of the allowance time. These results are typical with freezing rain at warmer temperatures; during a standard Type IV HOT test at -3°C in light freezing rain, failure to the 6″ (15 cm) line will demonstrate signs of adherence between the 1″ (2.5 cm) and 3″ (7.6 cm) line. The ice pellets did not significantly contribute to the fluid dilution, but when combined with freezing rain, adhered ice pellets can generate a rough surface that may be aerodynamically hazardous. Photo 5.3 shows the Type IV EG fluid condition at the end of the allowance time.

5.1.2 Light Ice Pellets and Moderate Ice Pellet Conditions

Testing conducted in light and moderate ice pellet conditions generated similar results at the end of the allowance time; no adherence was documented, and bridging ice pellets were observed when the fluid diluted close to the fluid freeze point. The ice pellets were embedded in the fluid and were slow to dissolve; at the colder temperatures, the ice pellets embedded in the fluid took a significantly longer time to dissolve in comparison to tests conducted at warmer temperatures. Adherence was not observed during any of the tests conducted in light ice pellets or moderate ice pellets alone. Photos 5.5, 5.7, 5.9, and 5.11 show the Type IV EG fluid condition during 4 tests conducted in light and moderate ice pellets at -5°C and -25°C.

5.1.3 Mixed Snow and Light Ice Pellets

Testing conducted at -5°C did not show any signs of fluid adherence at the end of the allowance time. It was observed that the snow dissolved quicker in comparison to the ice pellets. When the fluid was sufficiently contaminated and the fluid dilution would begin to near the freeze point, bridging snow could be observed; the bridging snow could be used as a signal for fluid failure similar to endurance time testing in natural conditions. Photo 5.13 shows the Type IV EG fluid condition.

5.2 Effects of Aging of Contaminated Fluid

When the test plate was removed from the test area (precipitation was stopped), the visual condition of the contaminated fluid would improve. Imbedded or bridging frozen precipitate would further dissolve resulting in the visual improvement. In all cases, with the exception of light freezing rain mixed with light ice pellets, the fluid had not neared the freeze point by the end of the allowance time, therefore the contamination would be further dissolved. Photos 5.2, 5.6, 5.8, 5.10, 5.12, and 5.14 show the Type IV EG fluid condition following the aging period.

In the case of light freezing rain mixed with light ice pellets, the fluid had diluted close to the freeze point by the end of the allowance time (adhered patches were seen up to the 1" line). The fluid condition improved slightly during the aging period; adhered patched diminished in size. It was believed that in the case of a drop in temperature, the adhered patches may be conducive to further freezing and adhering of the diluted fluid. Photo 5.4 shows the Type IV EG fluid condition following the aging period.

5.3 Mixed Light Rain and Ice Pellet Conditions

Testing was conducted at 0°C, 1°C, and 2°C. At the end of the 40-minute precipitation period, adhered patches of ice were observed on the test plates for tests conducted at 0°C and 1°C. The latent heat of cooling generated by the melting ice pellets caused the plate temperature to drop below zero and allowed for the fluid to freeze once the required fluid freeze point was reached. These results were similar to those observed during the light freezing rain and ice pellet tests conducted at -5°C. Photos 5.15 and 5.16 show the Type IV EG fluid condition during the test.

In the case of the 2°C tests, the plate temperature did not sufficiently drop below 0°C to allow for solid adherence. Although some ice patches were present, these patches were not solidly adhered and could be easily pushed around the fluid with a pencil; the ice patches were dissolved by the end of the 40-minute test.

Photo 5.1: Test #IP3-2 – End of Allowance Time

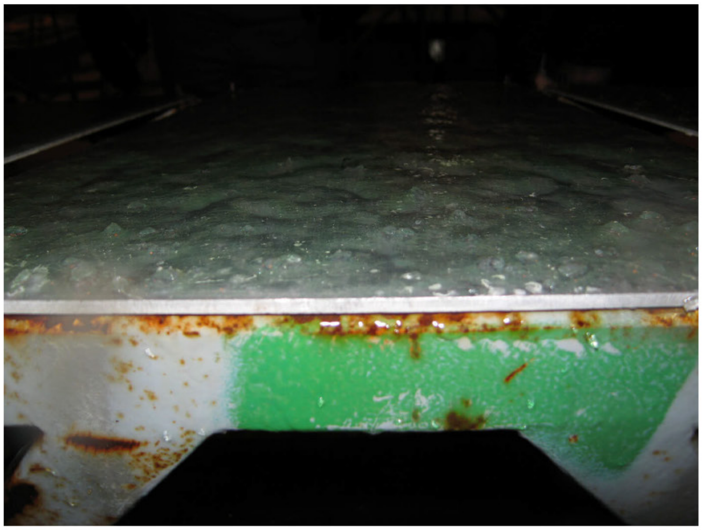

Photo 5.2: Test #IP3-2 – End of Aging Period

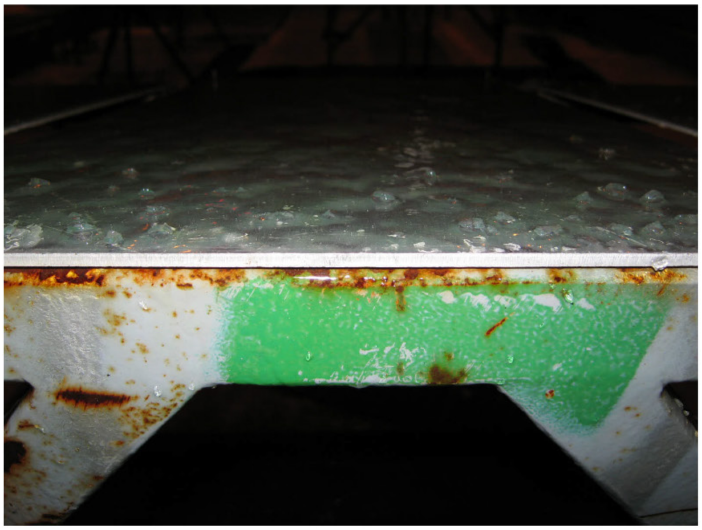

Photo 5.3: Test #IP1 – End of Allowance Time

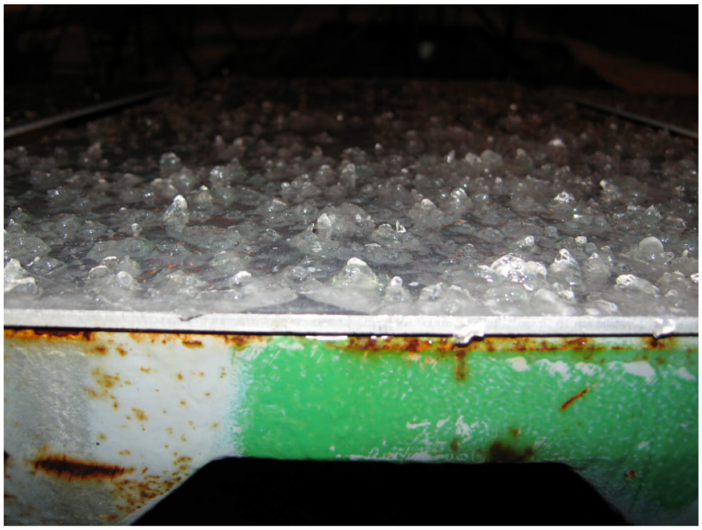

Photo 5.4: Test #IP1 – End of Aging Period

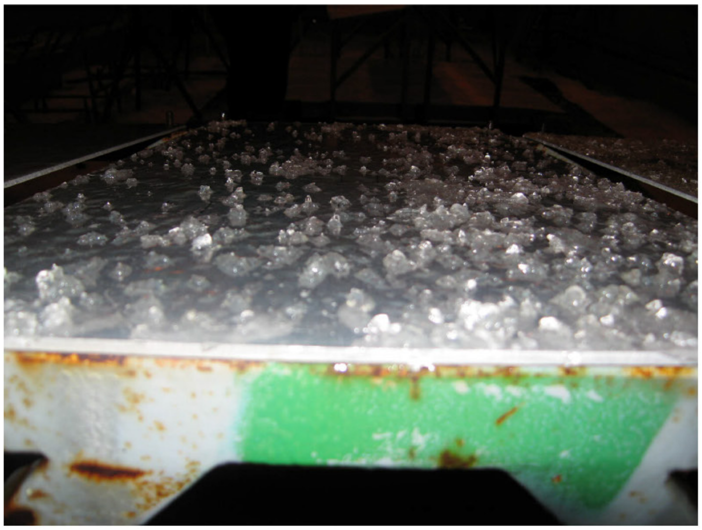

Photo 5.5: Test #IP5– End of Allowance Time

Photo 5.6: Test #IP5– End of Aging Period

Photo 5.7: Test #IP7– End of Allowance Time

Photo 5.8: Test #IP7– End of Aging Period

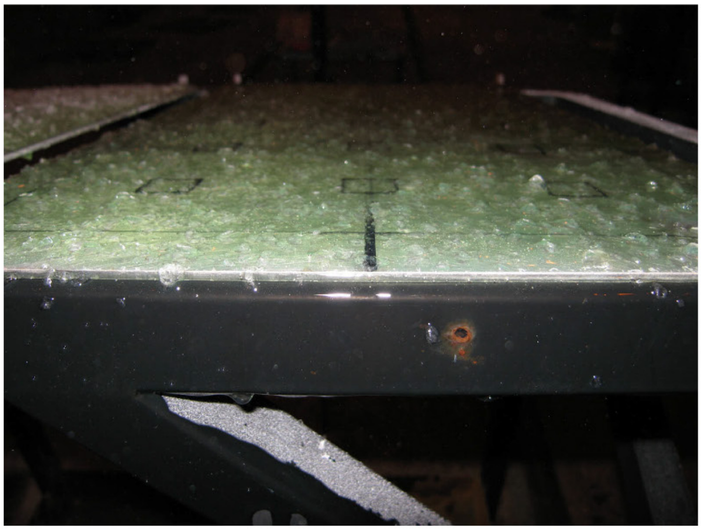

Photo 5.9: Test #IP9– End of Allowance Time

Photo 5.10: Test #IP9– End of Aging Period

Photo 5.11: Test #IP11– End of Allowance Time

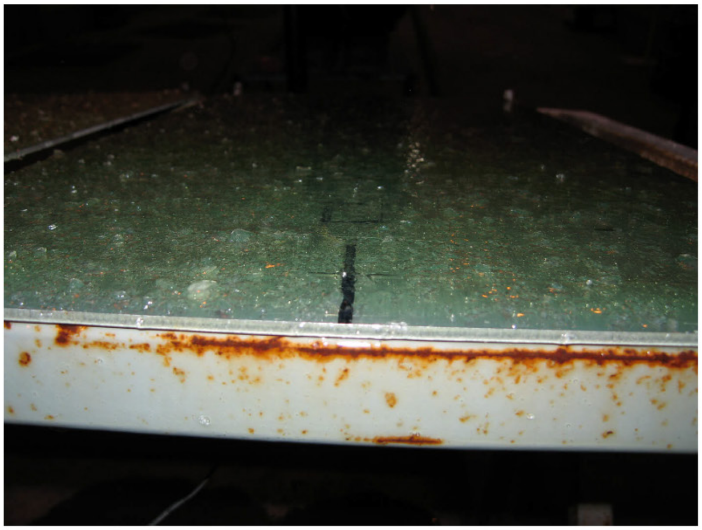

Photo 5.12: Test #IP11– End of Aging Period

Photo 5.13: Test #IP13– End of Allowance Time

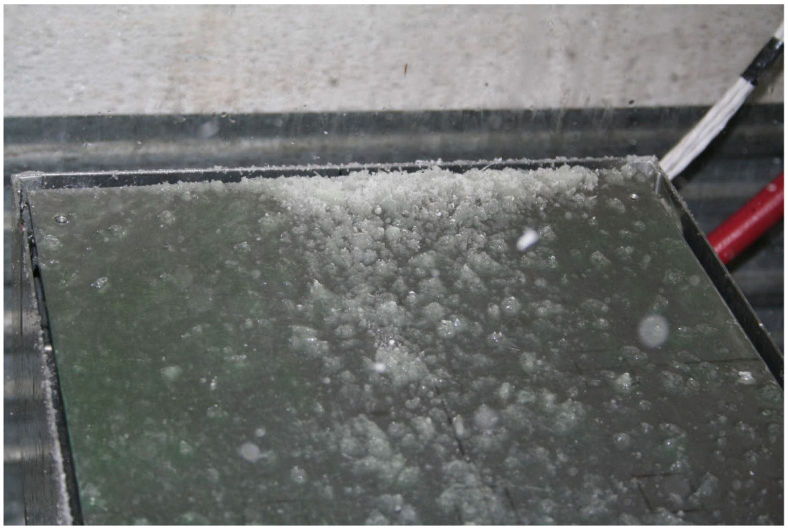

Photo 5.14: Test #IP13– End of Aging Period

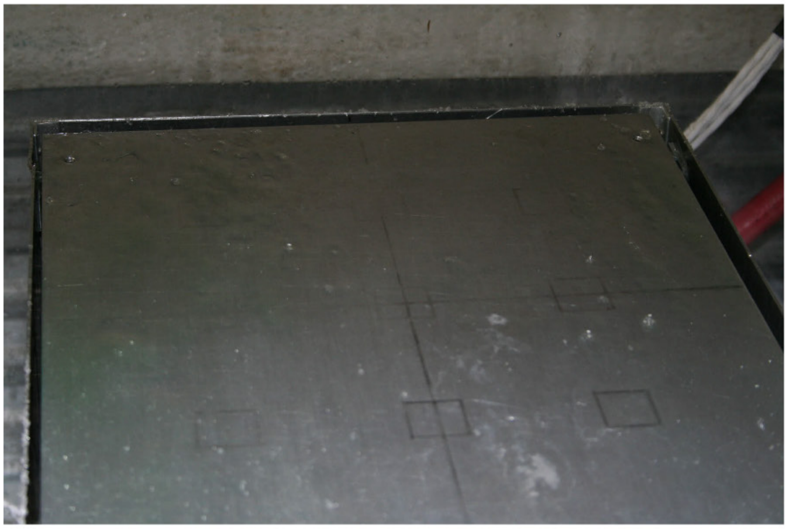

Photo 5.15: Test #RIP 5 – Condition at 20 Minutes

Photo 5.16: Test #RIP 5 – Condition at 40 Minutes

6. FUTURE WORK

6.1 Aerodynamic Research

Aerodynamic research is required to validate the allowance times generated for light rain and ice pellets; these allowance times were based on plate data. Testing should initially be conducted in the NRC wind tunnel. Following a review of the results obtained, full-scale testing should be considered using the Falcon 20 aircraft.

6.2 Documentation of Testing Conducted

A full detailed report of the work described herein will be issued at a later date.

APPENDIX I

END CONDITION OF WING AND PLATE DATA FORMS

APPENDIX I

END CONDITION OF WING AND PLATE DATA FORMS

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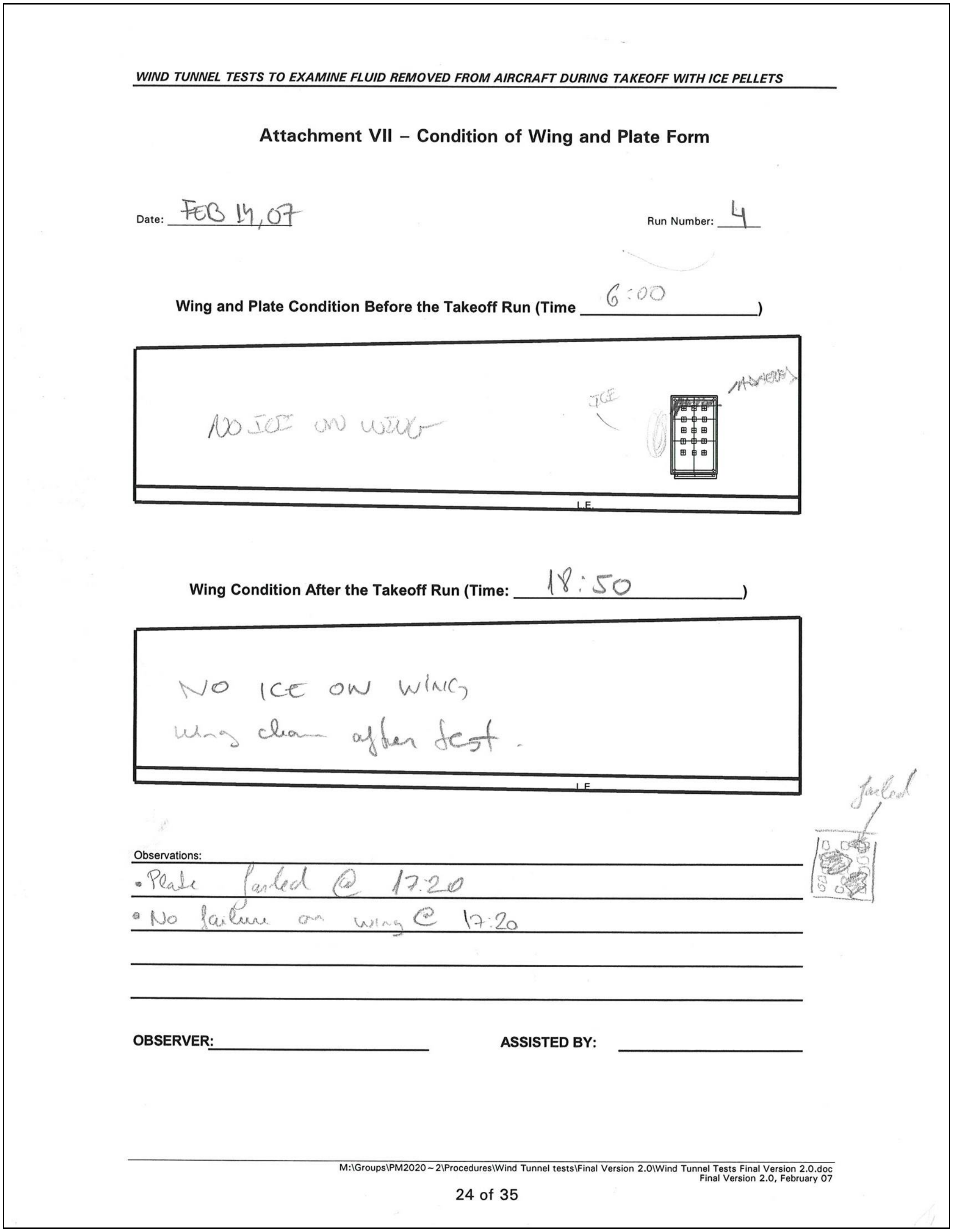

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: FEB 14, 07

Run Number: 4

Wing and Plate Condition Before the Takeoff Run (Time 6:00)

NO ICE ON WING

L.E.

Wing Condition After the Takeoff Run (Time: 18:50)

NO ICE ON WING

wing clean after test.

L.E.

Observations:

- Plate failed @ 17:20
- No failure on wing @ 17:20

OBSERVER: ____________________ **ASSISTED BY:** ____________________

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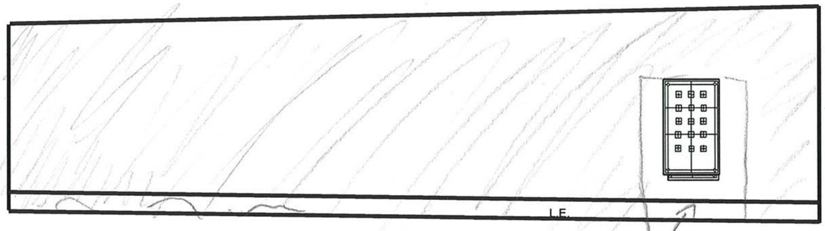
WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: FEB 15, 07

Run Number: ~~4~~ 5

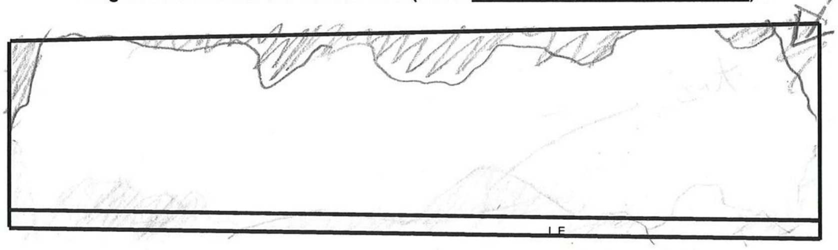
Wing and Plate Condition Before the Takeoff Run (Time ____________________)



clean

Wing Condition After the Takeoff Run (Time: 12:17)

cont after test



Observations: ____________________

OBSERVER: ____________________ ASSISTED BY: ____________________

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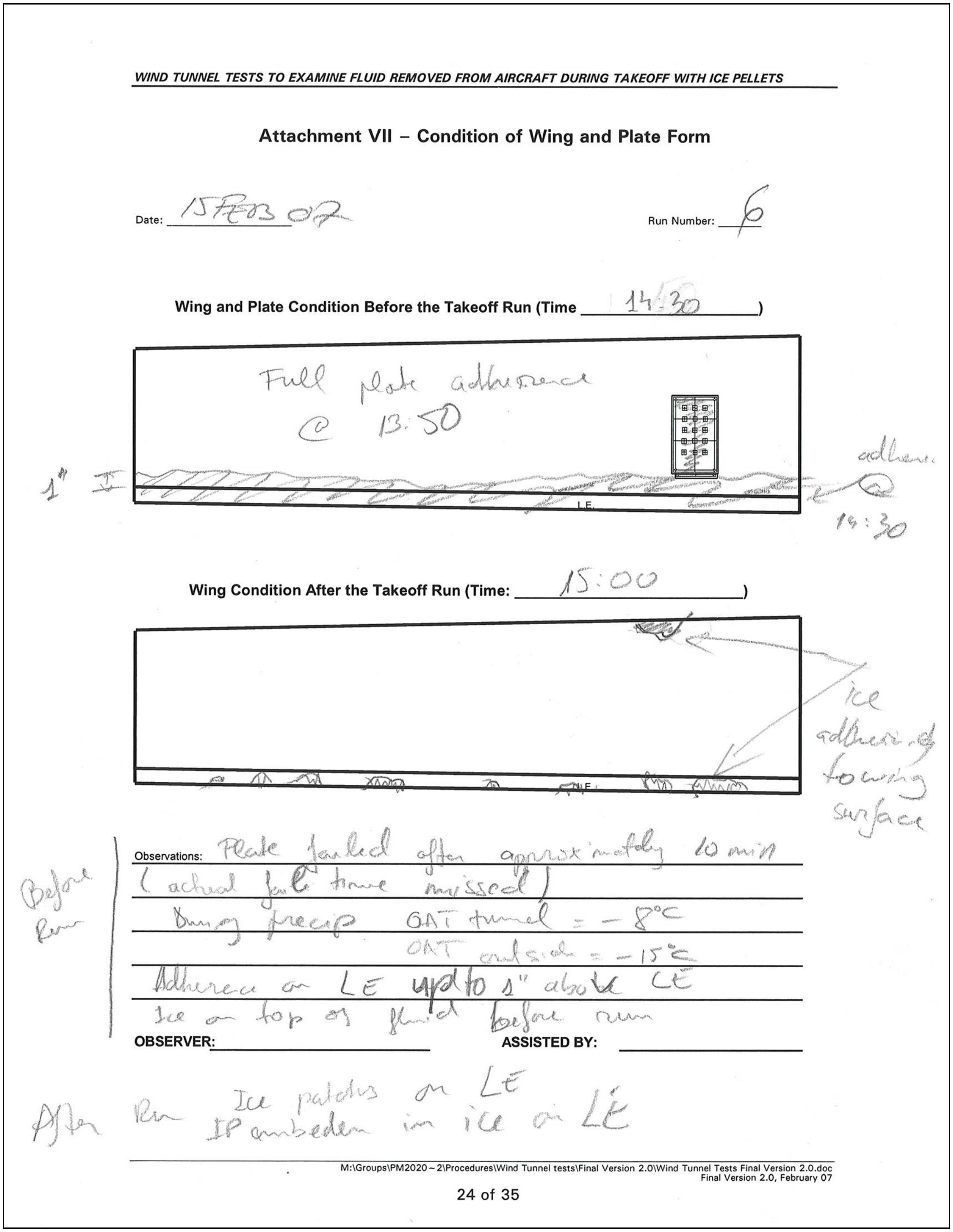

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 15 FEB 07

Run Number: 6

Wing and Plate Condition Before the Takeoff Run (Time 14:30)

Wing Condition After the Takeoff Run (Time: 15:00)

Observations: Plate failed after approximately 10 min
(actual fail time missed)
During precip GAT tunnel = −8°C
OAT outside = −15°C
Adherence on LE up to 1" above LE
Ice on top of fluid before run

Before Run

OBSERVER: __________ **ASSISTED BY:** __________

After Run Ice patches on LE
IP embeded in ice on LE

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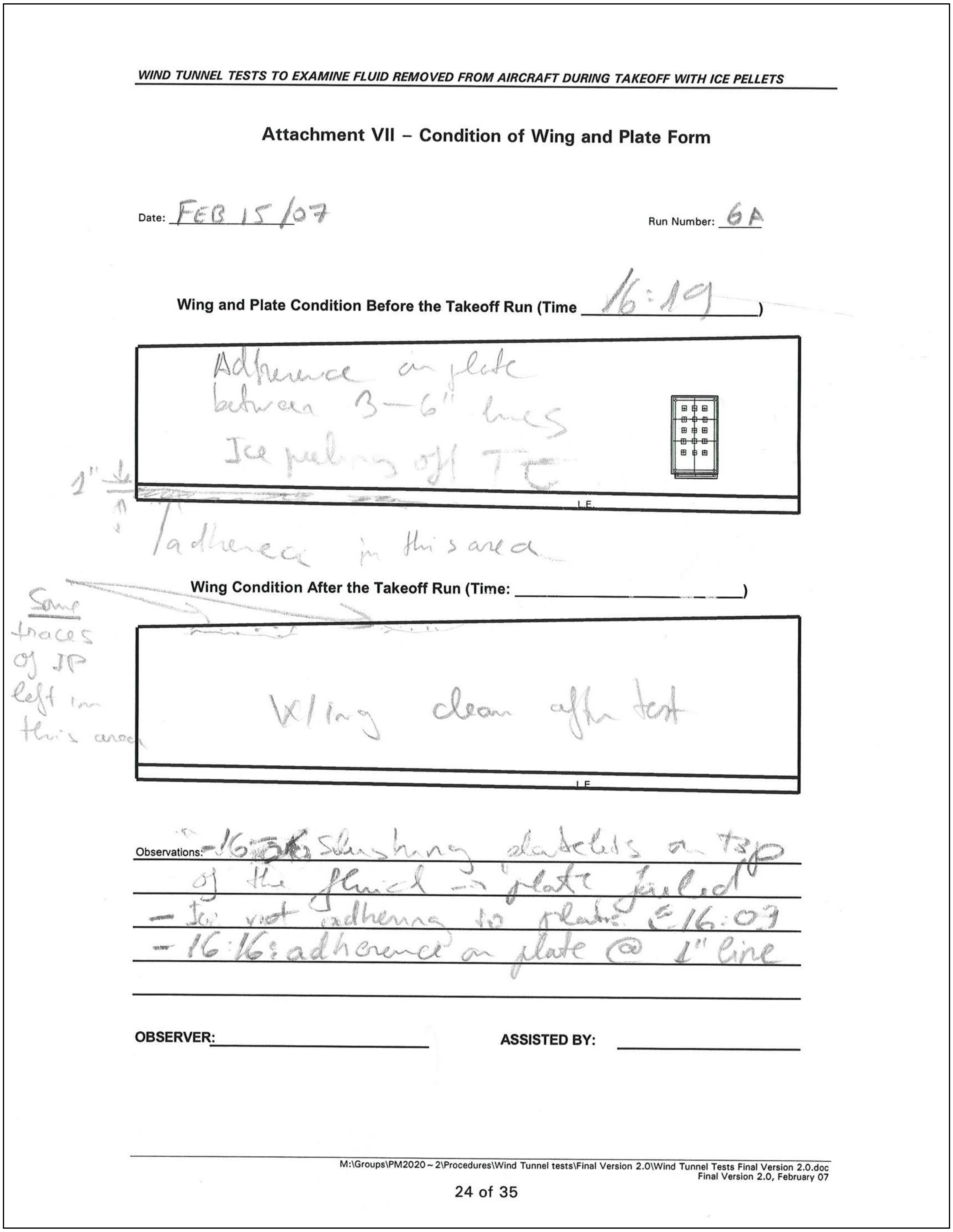

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: FEB 15/07

Run Number: 6A

Wing and Plate Condition Before the Takeoff Run (Time 16:19)

Adherence on plate
between 3–6" lines
Ice peeling off TE

1"

adherence in this area

Wing Condition After the Takeoff Run (Time:)

Some
traces
of IP
left in
this area

Wing clean after test

Observations: -16:[illegible] Slushing platelets on top of the fluid → plate failed
- Ice not adhering to plate @16:09
- 16:16: adherence on plate @ 1" line

OBSERVER:

ASSISTED BY:

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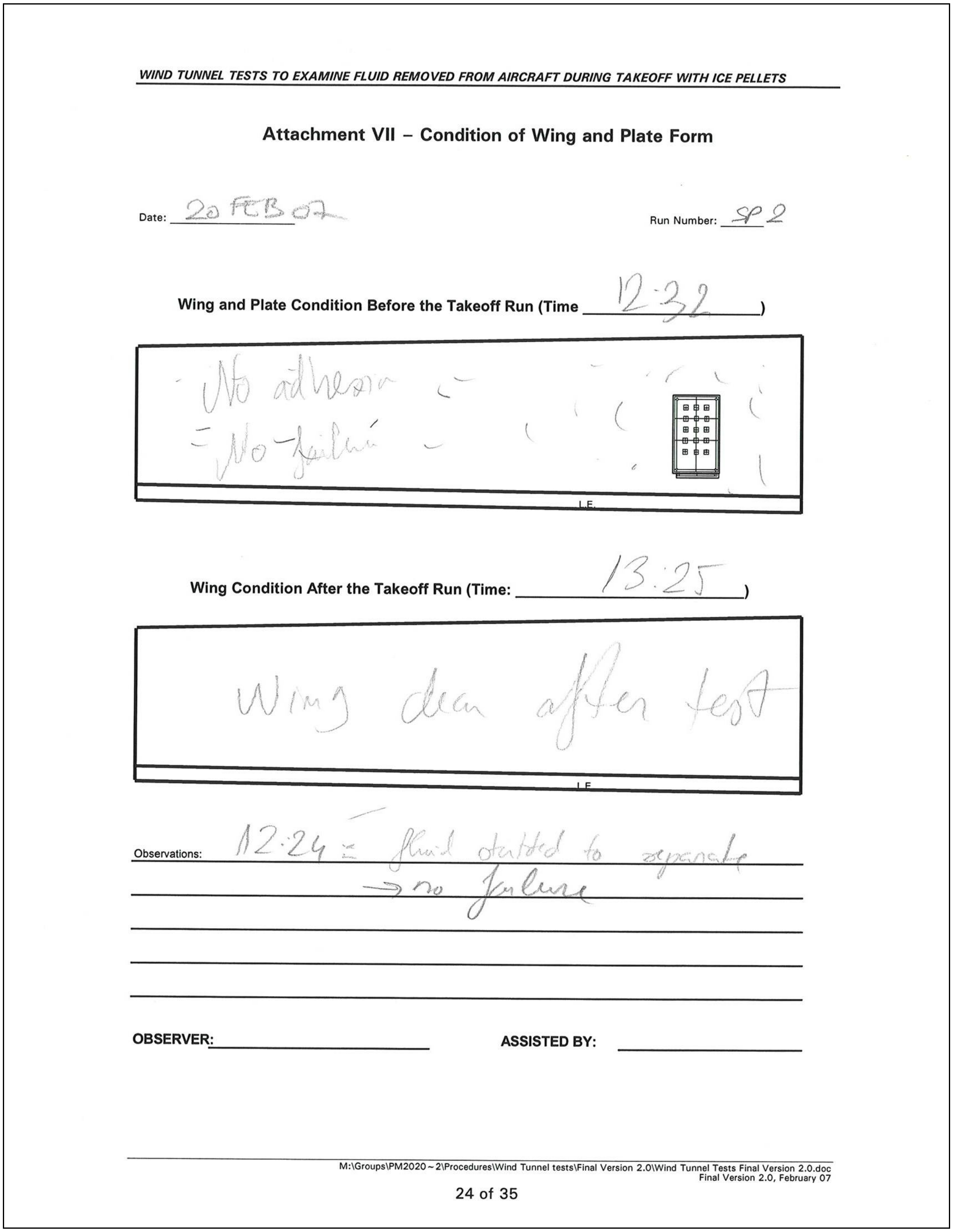

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 20 FEB 07

Run Number: SP2

Wing and Plate Condition Before the Takeoff Run (Time 12:32)

No adhesion

No failure

Wing Condition After the Takeoff Run (Time: 13:25)

Wing clean after test

Observations: 12:24 = fluid started to separate

→ no failure

OBSERVER:

ASSISTED BY:

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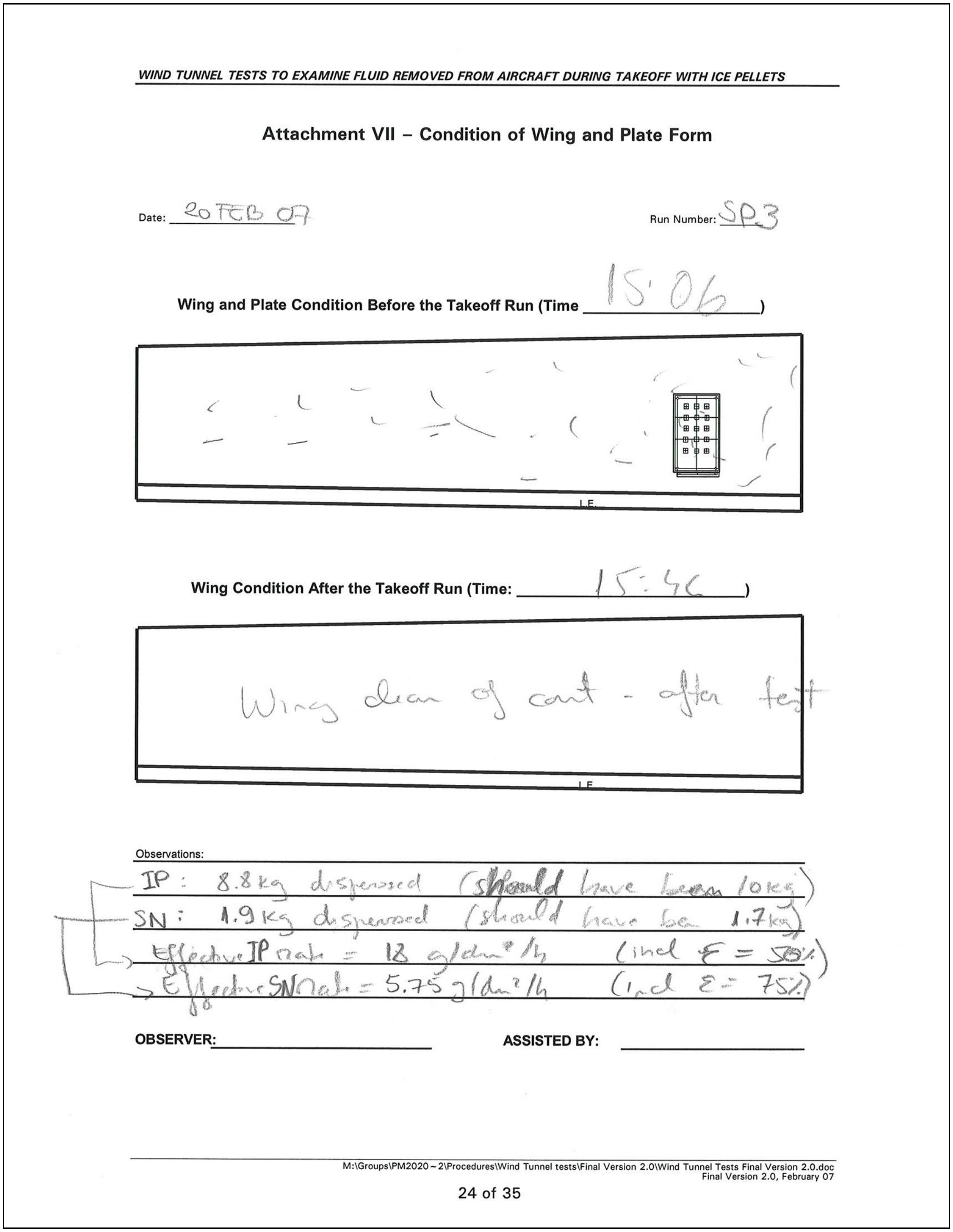

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 20 FEB 07

Run Number: SP3

Wing and Plate Condition Before the Takeoff Run (Time 15:06)

Wing Condition After the Takeoff Run (Time: 15:46)

Wing clean of cont - after test

Observations:

IP : 8.8 kg dispersed (should have been 10 kg)

SN : 1.9 kg dispersed (should have be 1.7 kg)

Effective IP rate = 18 $g/dm^2/h$ (incl ε = 50%)

Effective SN rate = 5.75 $g/dm^2/h$ (incl ε = 75%)

OBSERVER: __________ **ASSISTED BY:** __________

M:\Groups\PM2020~2\Procedures\Wind Tunnel tests\Final Version 2.0\Wind Tunnel Tests Final Version 2.0.doc
Final Version 2.0, February 07

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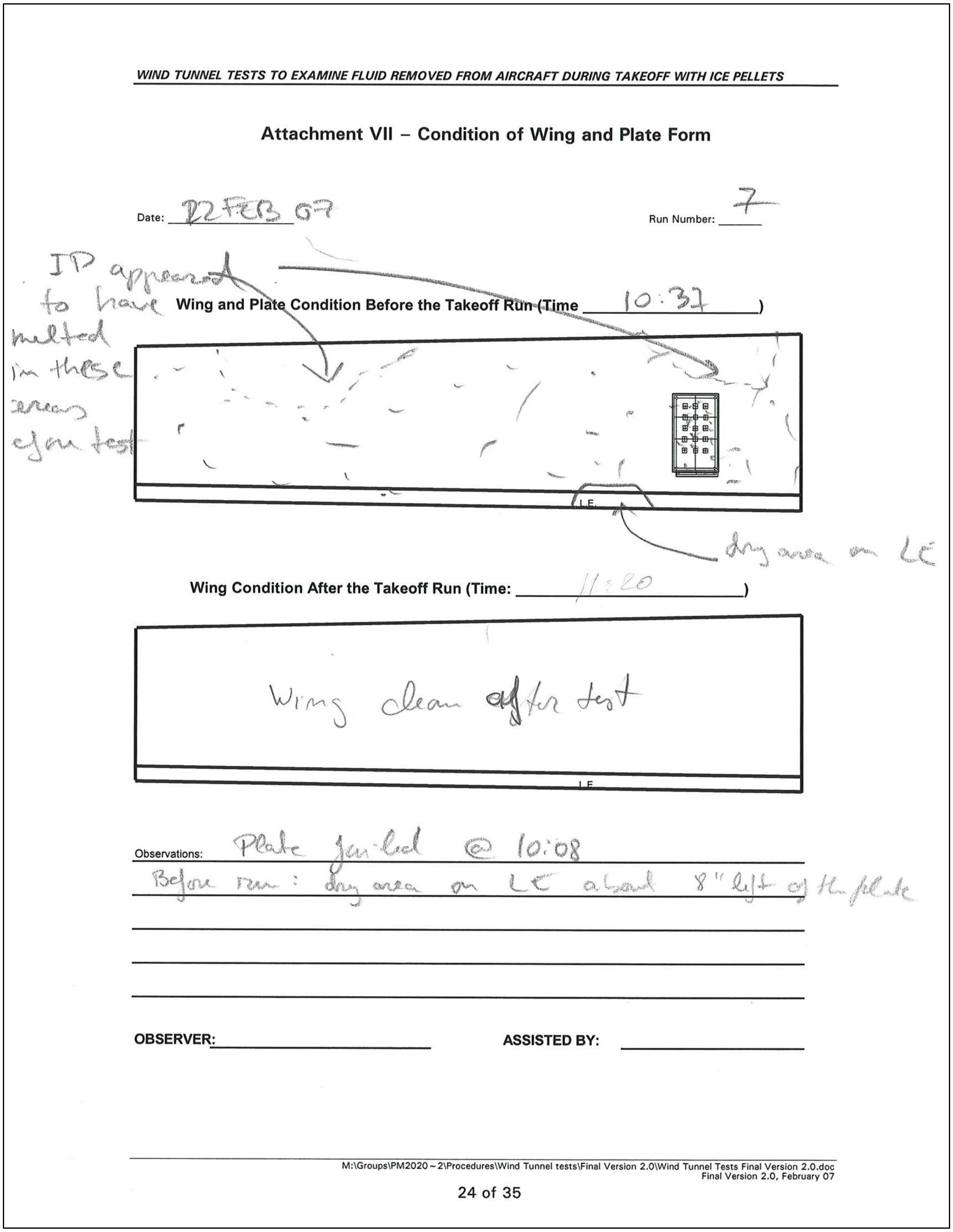

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 22 FEB 07

Run Number: 7

Wing and Plate Condition Before the Takeoff Run (Time 10:37)

IP appeared to have melted in these areas efore test

dry area on LE

Wing Condition After the Takeoff Run (Time: 11:20)

Wing clean after test

Observations: Plate failed @ 10:08

Before run: dry area on LE about 8" left of the plate

OBSERVER: ____________

ASSISTED BY: ____________

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Final Version 2.0, February 07

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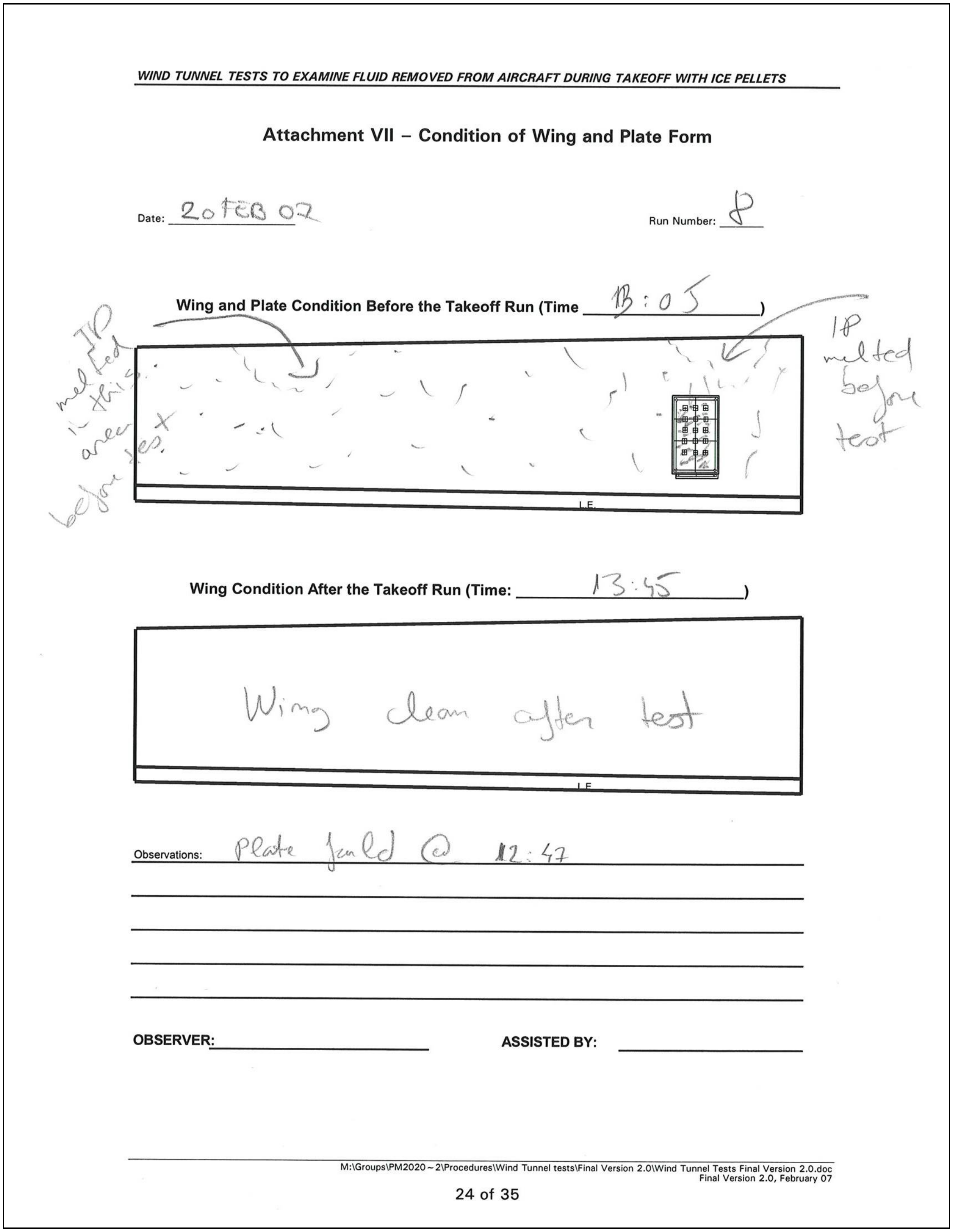

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 20 FEB 07

Run Number: 8

Wing and Plate Condition Before the Takeoff Run (Time 13:05)

IP melted in this area before test

IP melted before test

Wing Condition After the Takeoff Run (Time: 13:45)

Wing clean after test

Observations: Plate failed @ 12:47

OBSERVER:

ASSISTED BY:

M:\Groups\PM2020~2\Procedures\Wind Tunnel tests\Final Version 2.0\Wind Tunnel Tests Final Version 2.0.doc
Final Version 2.0, February 07

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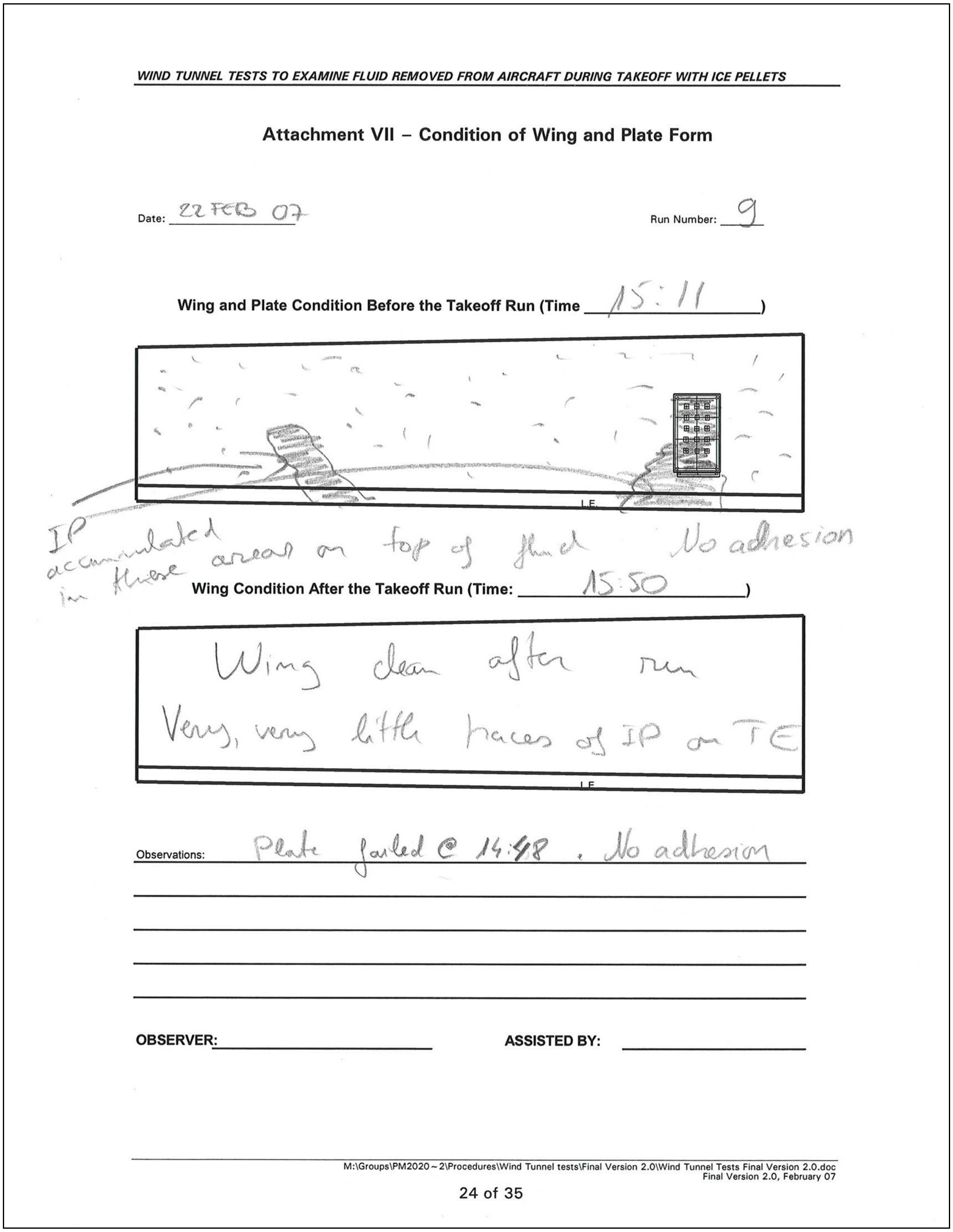

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 22 FEB 07

Run Number: 9

Wing and Plate Condition Before the Takeoff Run (Time 15:11)

IP accumulated in these areas on top of fluid

No adhesion

Wing Condition After the Takeoff Run (Time: 15:50)

Wing clean after run

Very, very little traces of IP on TE

Observations: Plate failed @ 14:48 . No adhesion

OBSERVER:

ASSISTED BY:

M:\Groups\PM2020~2\Procedures\Wind Tunnel tests\Final Version 2.0\Wind Tunnel Tests Final Version 2.0.doc
Final Version 2.0, February 07

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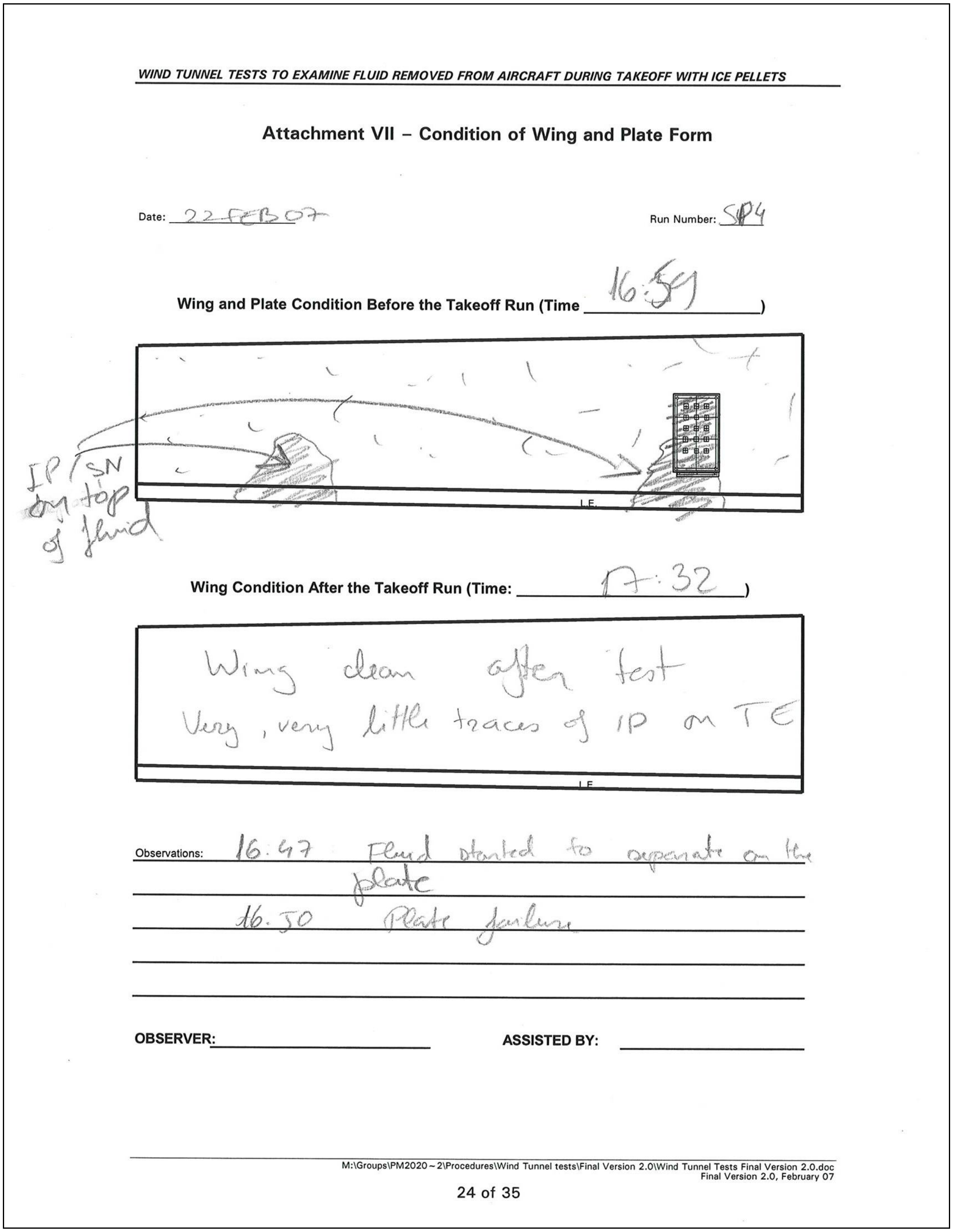


WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 22 FEB 07

Run Number: SP4

Wing and Plate Condition Before the Takeoff Run (Time 16:59)

IP / SN on top of fluid

Wing Condition After the Takeoff Run (Time: 17:32)

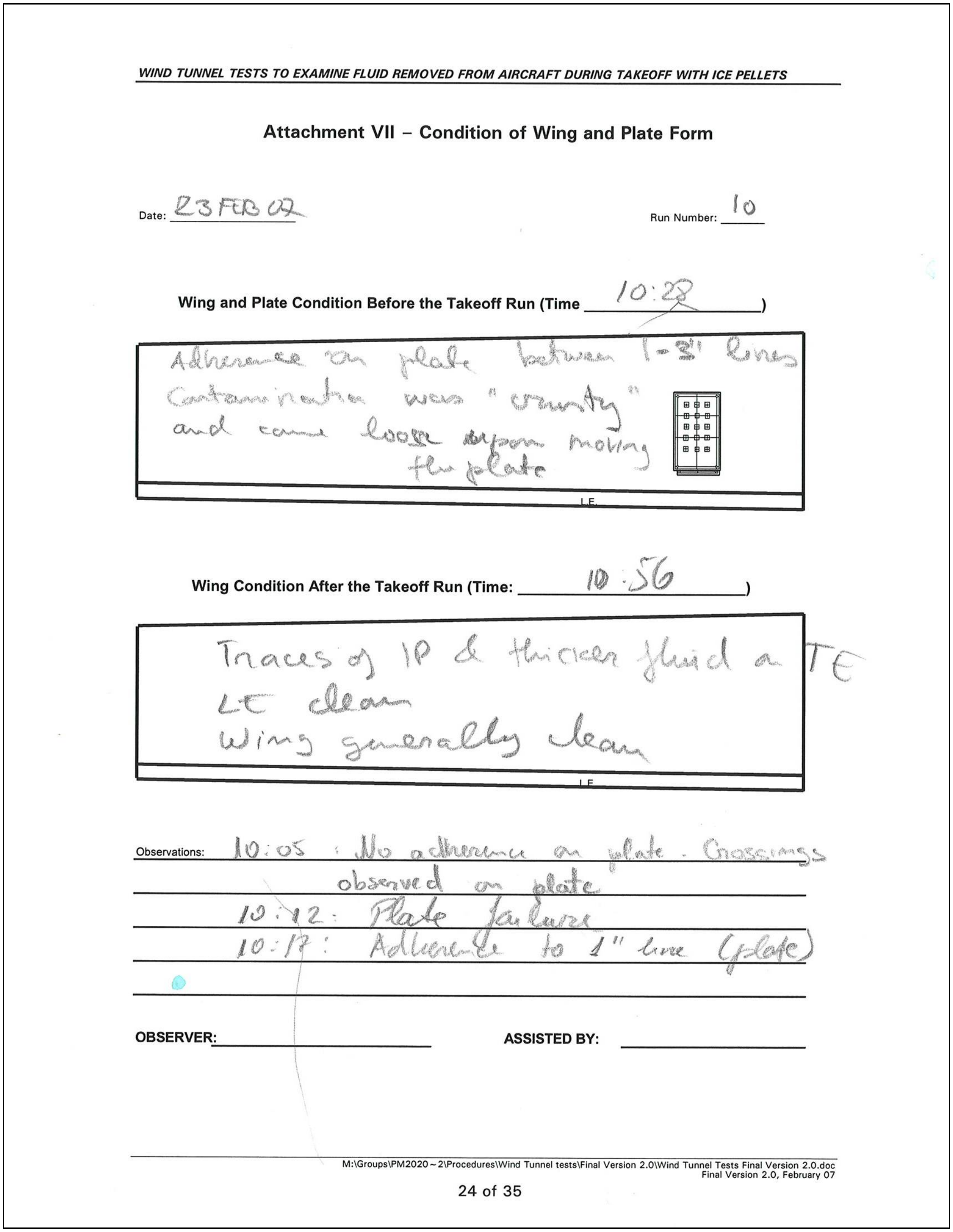
Wing clean after test
Very, very little traces of IP on TE

Observations: 16.47 Fluid started to separate on the plate

16.50 Plate failure

OBSERVER: ____________

ASSISTED BY: ____________



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

Attachment VII – Condition of Wing and Plate Form

Date: 23 FEB 07

Run Number: 10

Wing and Plate Condition Before the Takeoff Run (Time 10:28)

Adherence on plate between 1-3" lines
Contamination was "crunchy"
and came loose upon moving
the plate

Wing Condition After the Takeoff Run (Time: 10:56)

Traces of IP & thicker fluid a TE
LE clean
Wing generally clean

Observations: 10:05 : No adherence on plate. Crossings
observed on plate
10:12: Plate failure
10:17: Adherence to 1" line (plate)

OBSERVER: __________ **ASSISTED BY:** __________

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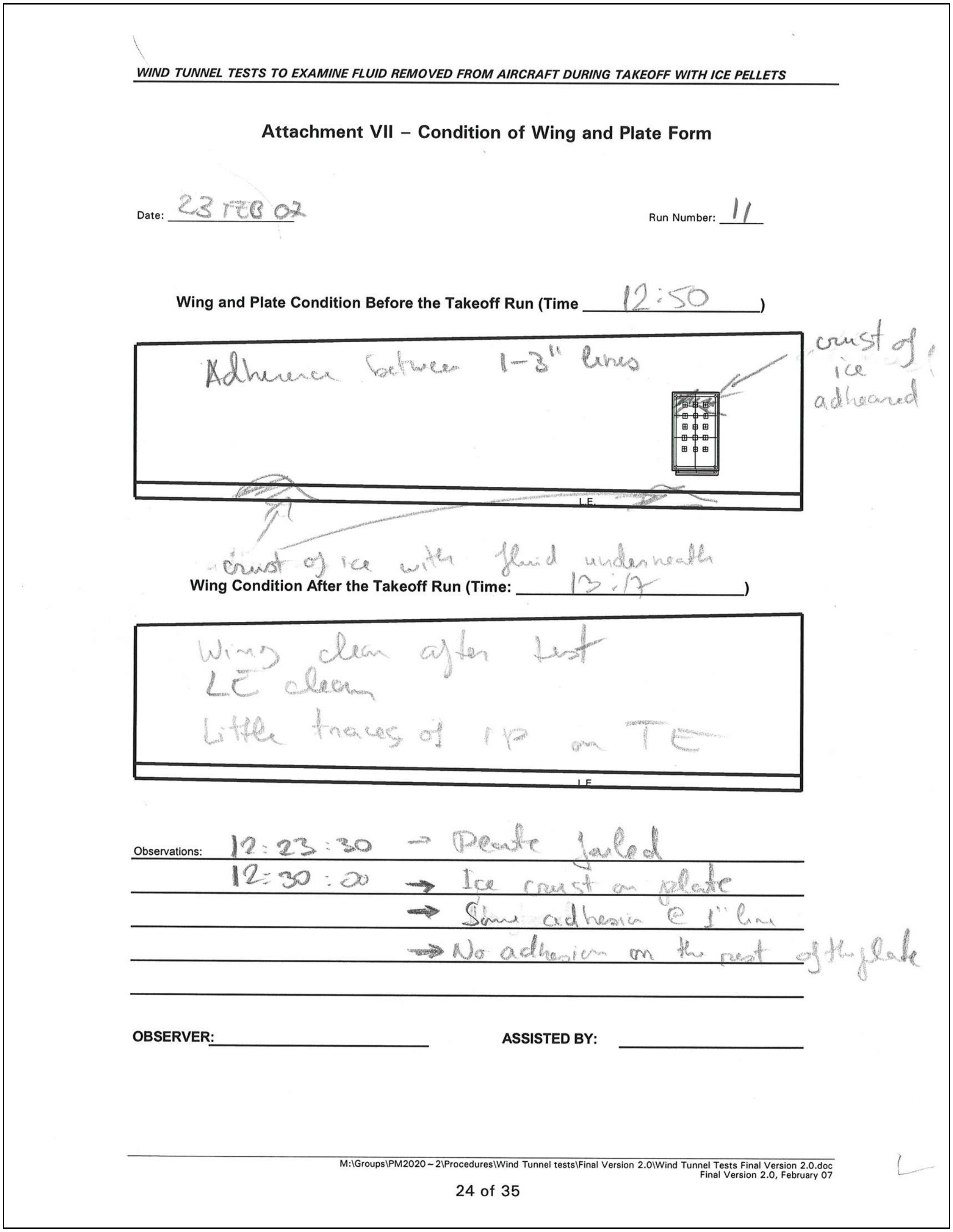

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 23 FEB 07

Run Number: 11

Wing and Plate Condition Before the Takeoff Run (Time 12:50)

Adherence between 1-3" lines

crust of ice adheared

crust of ice with fluid underneath

Wing Condition After the Takeoff Run (Time: 13:17)

Wing clean after test
LE clean
Little traces of IP on TE

Observations: 12:23:30 → Plate failed
12:30:00 → Ice crust on plate
→ Some adhesion @ 1" line
→ No adhesion on the rest of the plate

OBSERVER:

ASSISTED BY:

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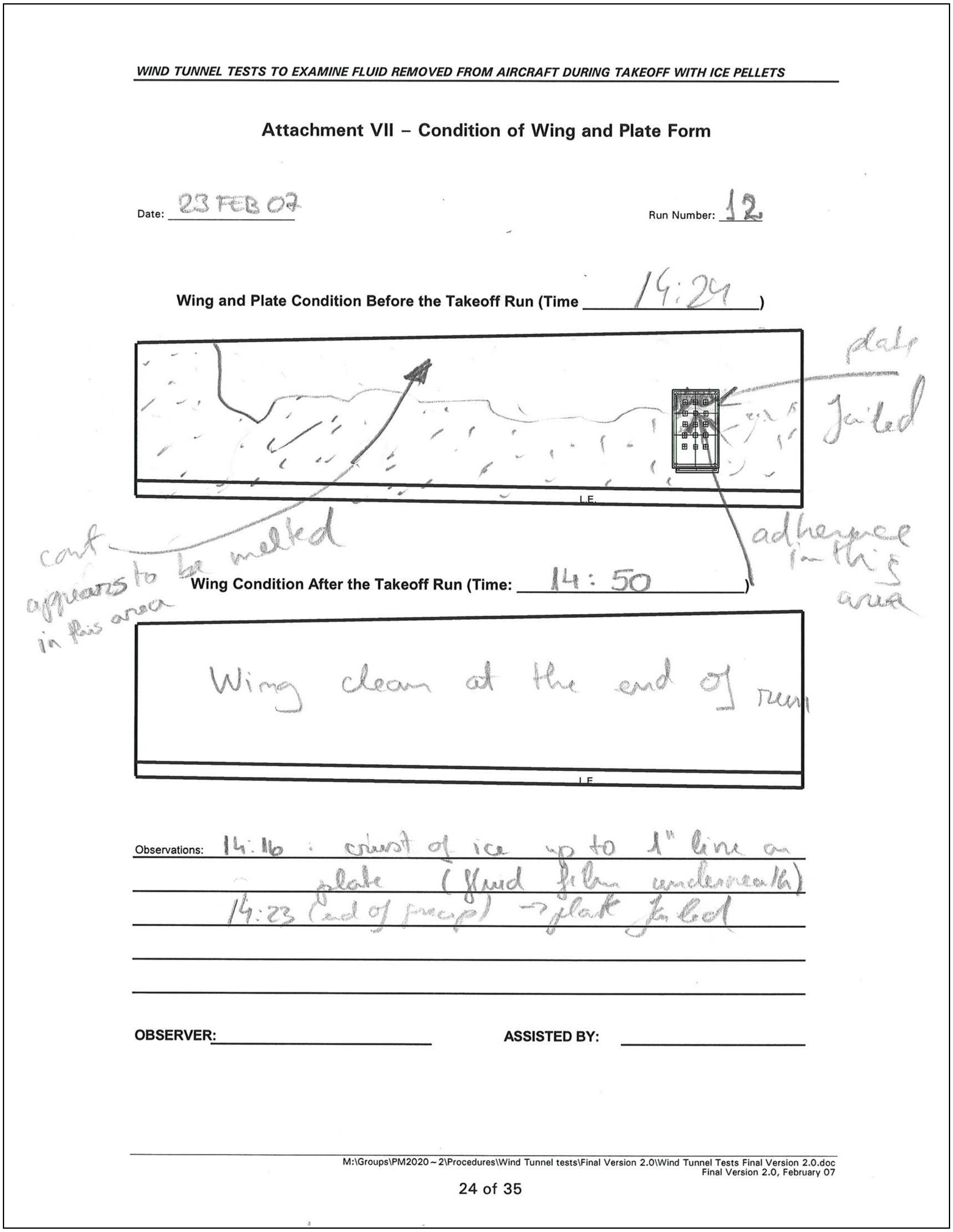

WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT DURING TAKEOFF WITH ICE PELLETS

Attachment VII – Condition of Wing and Plate Form

Date: 23 FEB 07

Run Number: 12

Wing and Plate Condition Before the Takeoff Run (Time 14:24)

plate failed

cont appears to be melted in this area

adherence in this area

Wing Condition After the Takeoff Run (Time: 14:50)

Wing clean at the end of run

Observations: 14:16 : crust of ice up to 1" line on plate (fluid film underneath)
14:23 (end of precip) → plate failed

OBSERVER: ____________

ASSISTED BY: ____________

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APPENDIX J

FALCON 20 TEST RESULTS DATA FORMS

FALCON 20 TEST RESULTS DATA FORMS

INDEX

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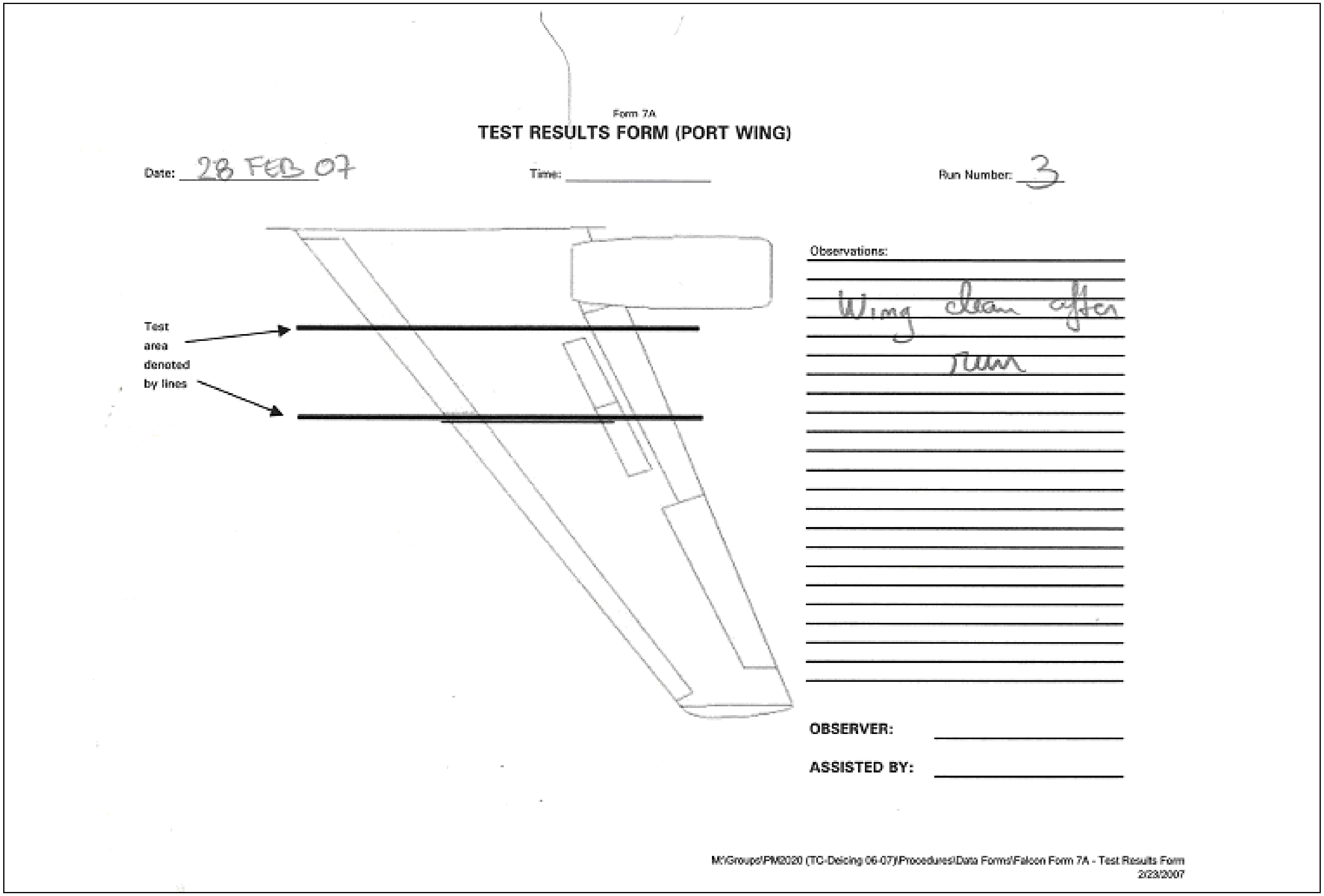


Form 7A

TEST RESULTS FORM (PORT WING)

Date: 28 FEB 07

Time: ______________

Run Number: 3

Test area denoted by lines

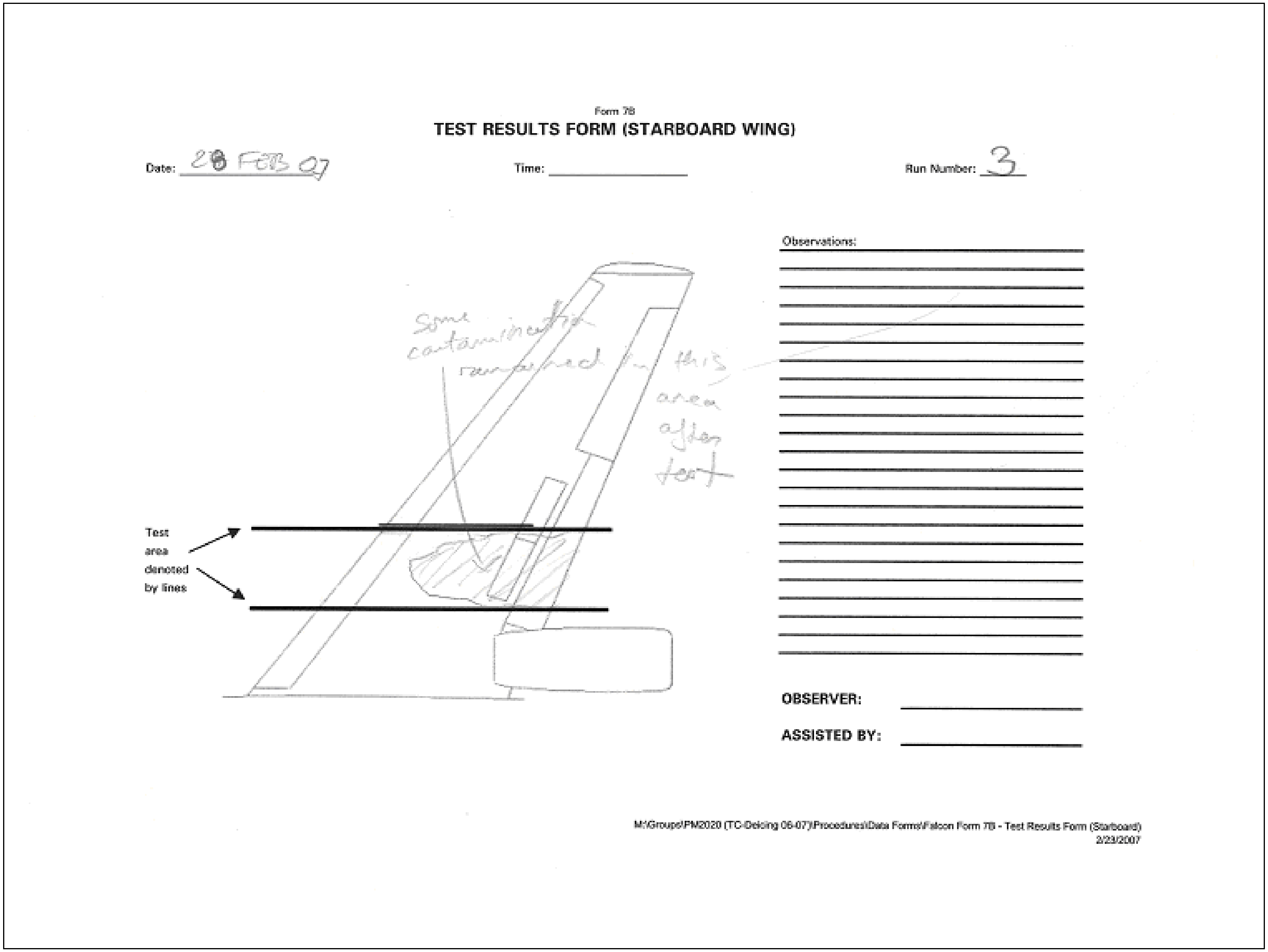
Observations:

Wing clean after run

OBSERVER: ______________

ASSISTED BY: ______________

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data Forms\Falcon Form 7A - Test Results Form
2/23/2007



Form 7B

TEST RESULTS FORM (STARBOARD WING)

Date: 28 FEB 07

Time: ________________

Run Number: 3

Some contamination remained in this area after test

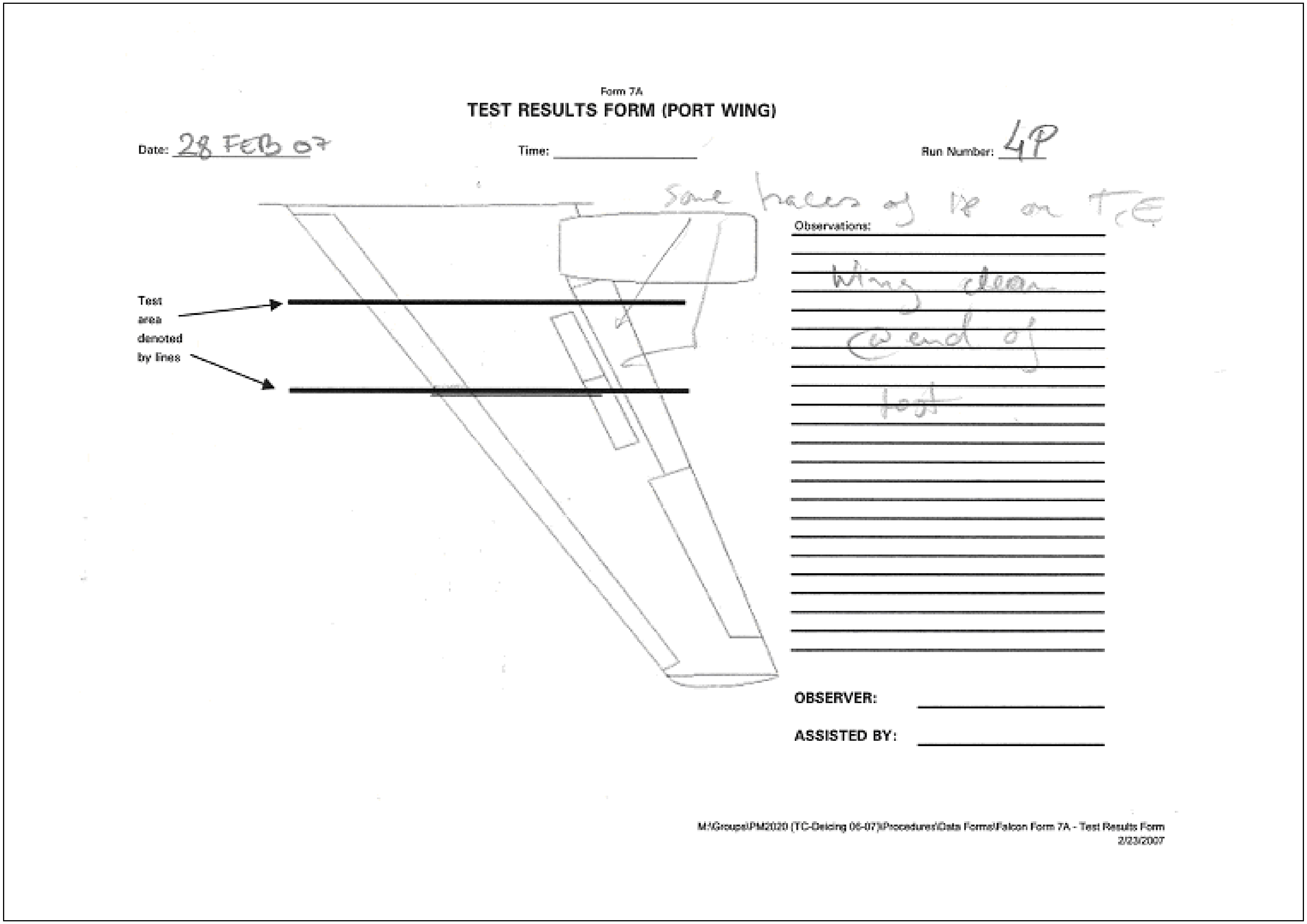
Test area denoted by lines

Observations:

OBSERVER: ________________

ASSISTED BY: ________________

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data Forms\Falcon Form 7B - Test Results Form (Starboard)
2/23/2007



Form 7A

TEST RESULTS FORM (PORT WING)

Date: 28 FEB 07

Time: ____________

Run Number: 4P

Some traces of IP on T.E.

Test area denoted by lines

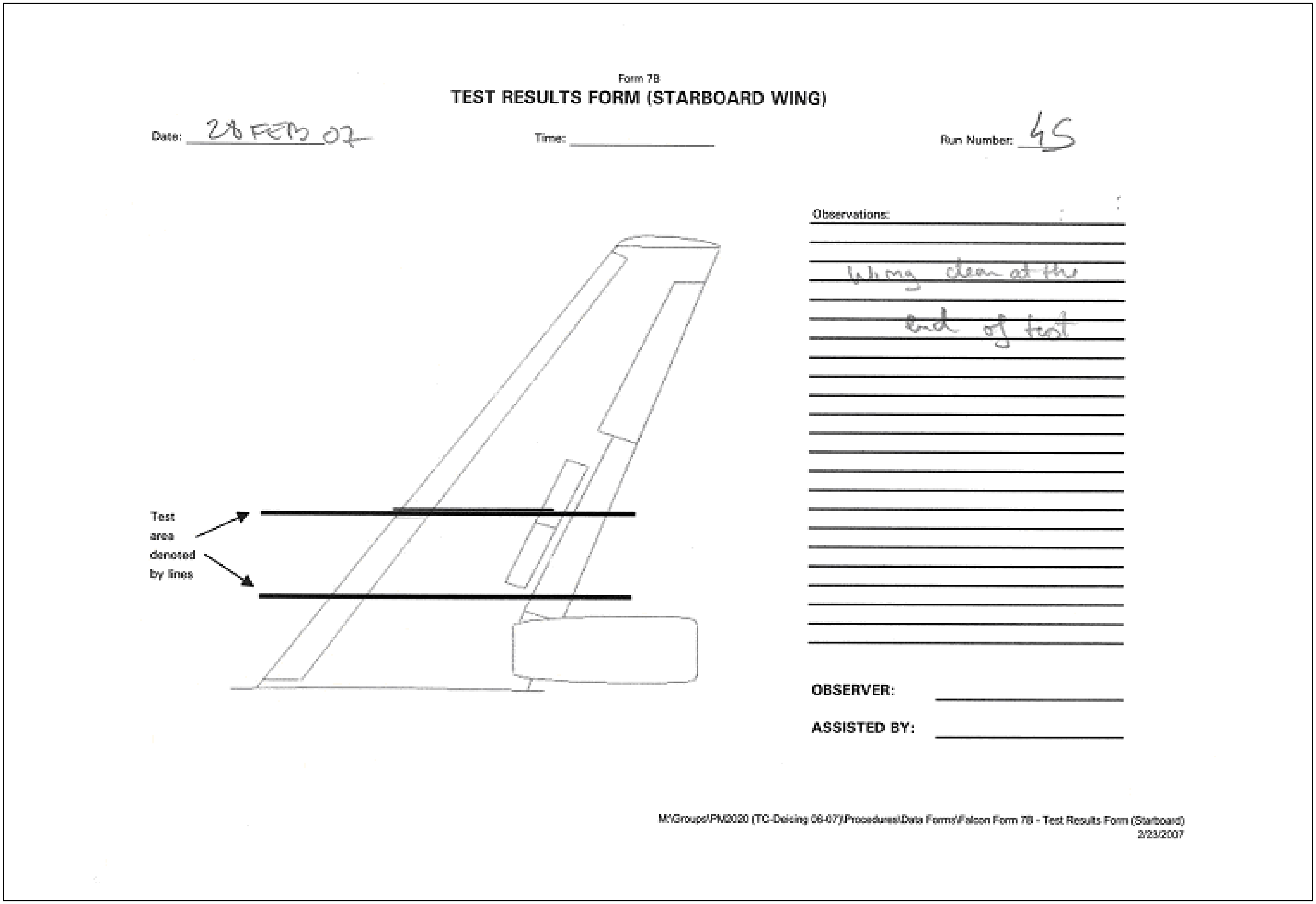
Observations:

Wing clean @ end of test

OBSERVER: ____________

ASSISTED BY: ____________

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data Forms\Falcon Form 7A - Test Results Form
2/23/2007



Form 7B

TEST RESULTS FORM (STARBOARD WING)

Date: 28 FEB 07

Time: ____________

Run Number: 45

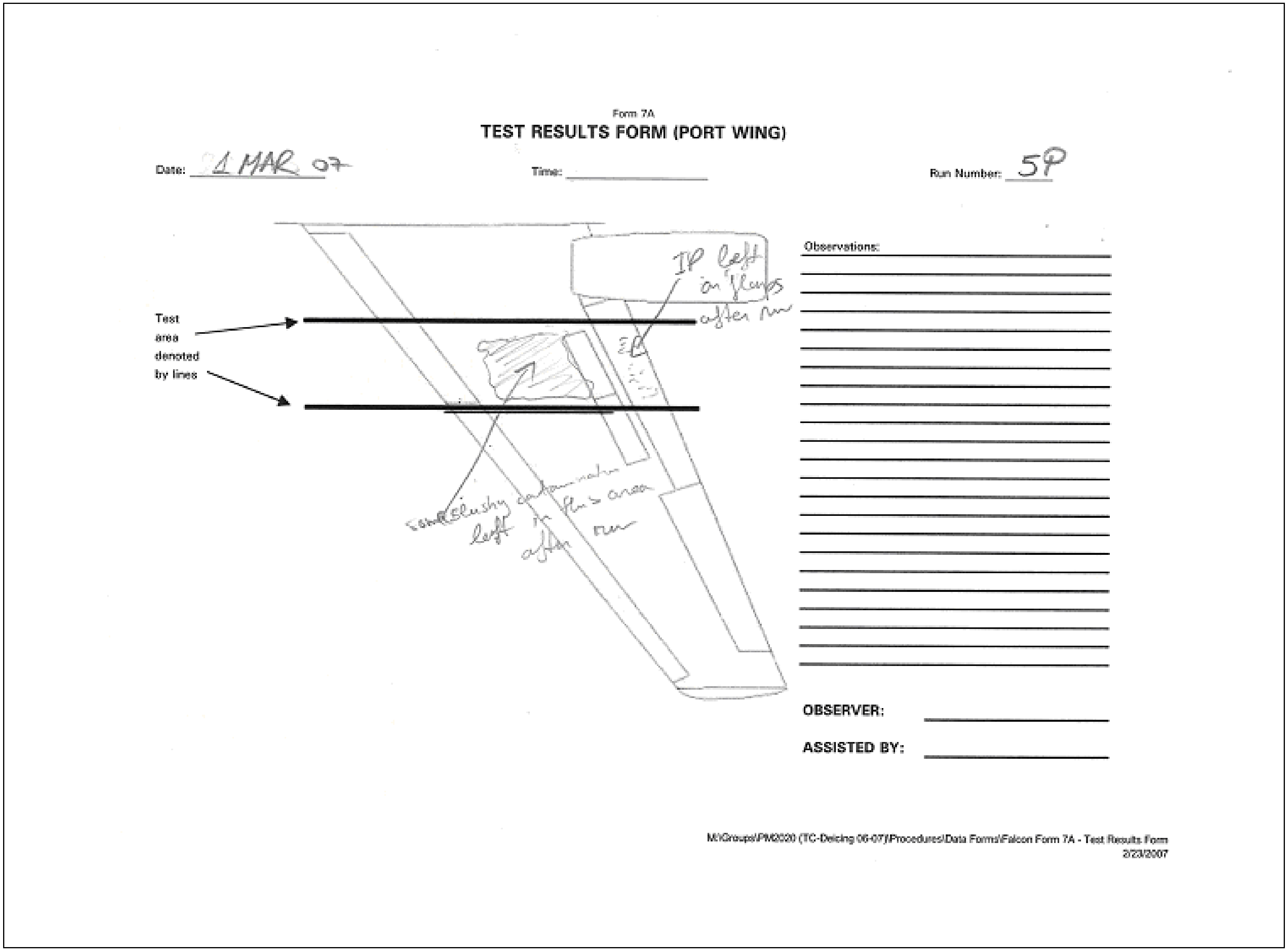
Observations:

Wing clean at the end of test

OBSERVER: ____________

ASSISTED BY: ____________

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data Forms\Falcon Form 7B - Test Results Form (Starboard)
2/23/2007



Form 7A

TEST RESULTS FORM (PORT WING)

Date: 21 MAR 07

Time: ______

Run Number: 5P

IP left on flaps after run

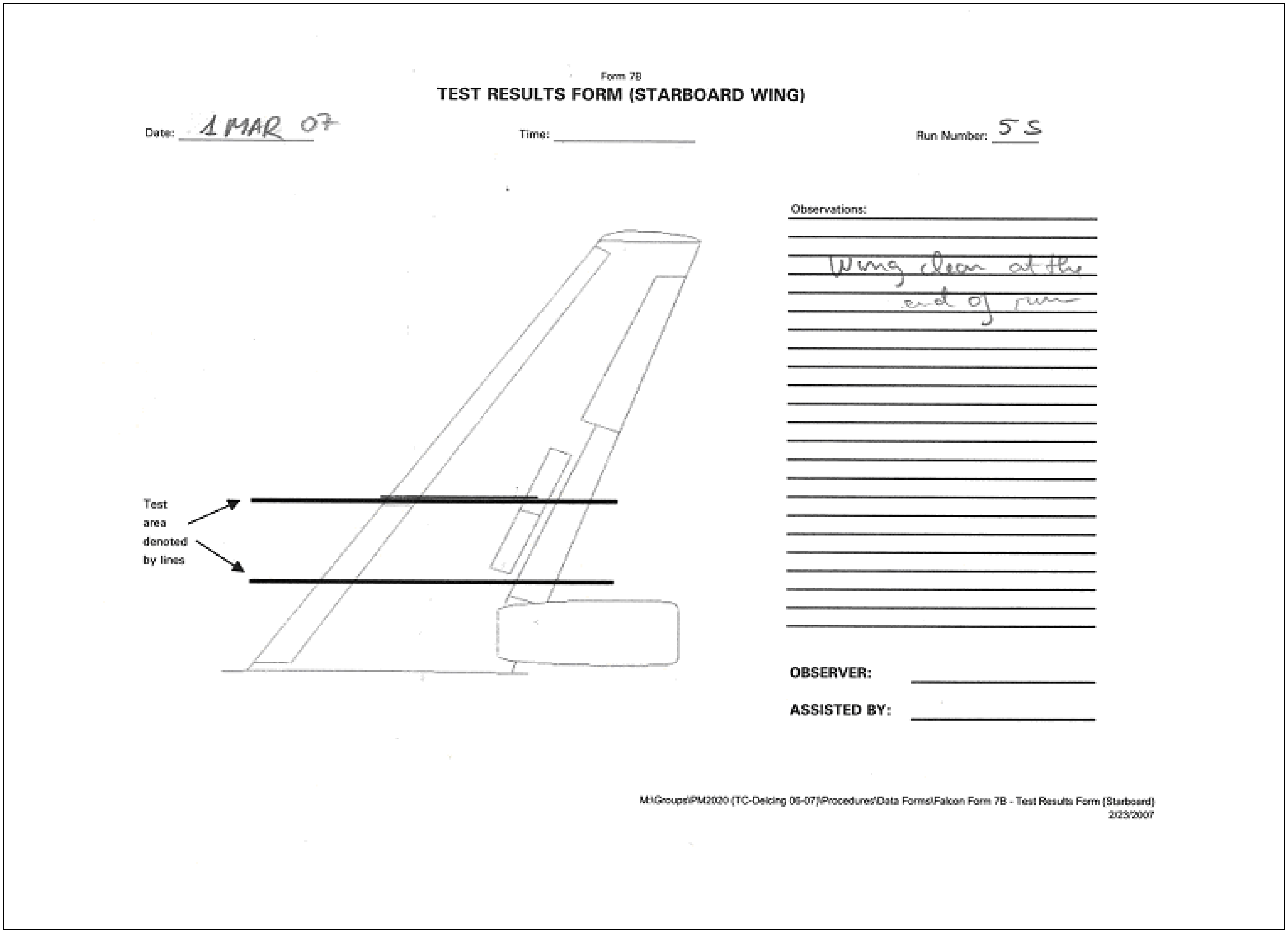
some slushy contamination left in this area after run

Observations:

OBSERVER: ______

ASSISTED BY: ______

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data Forms\Falcon Form 7A - Test Results Form
2/23/2007



Form 7B

TEST RESULTS FORM (STARBOARD WING)

Date: 1 MAR 07

Time: ______

Run Number: 5 S

Test area denoted by lines

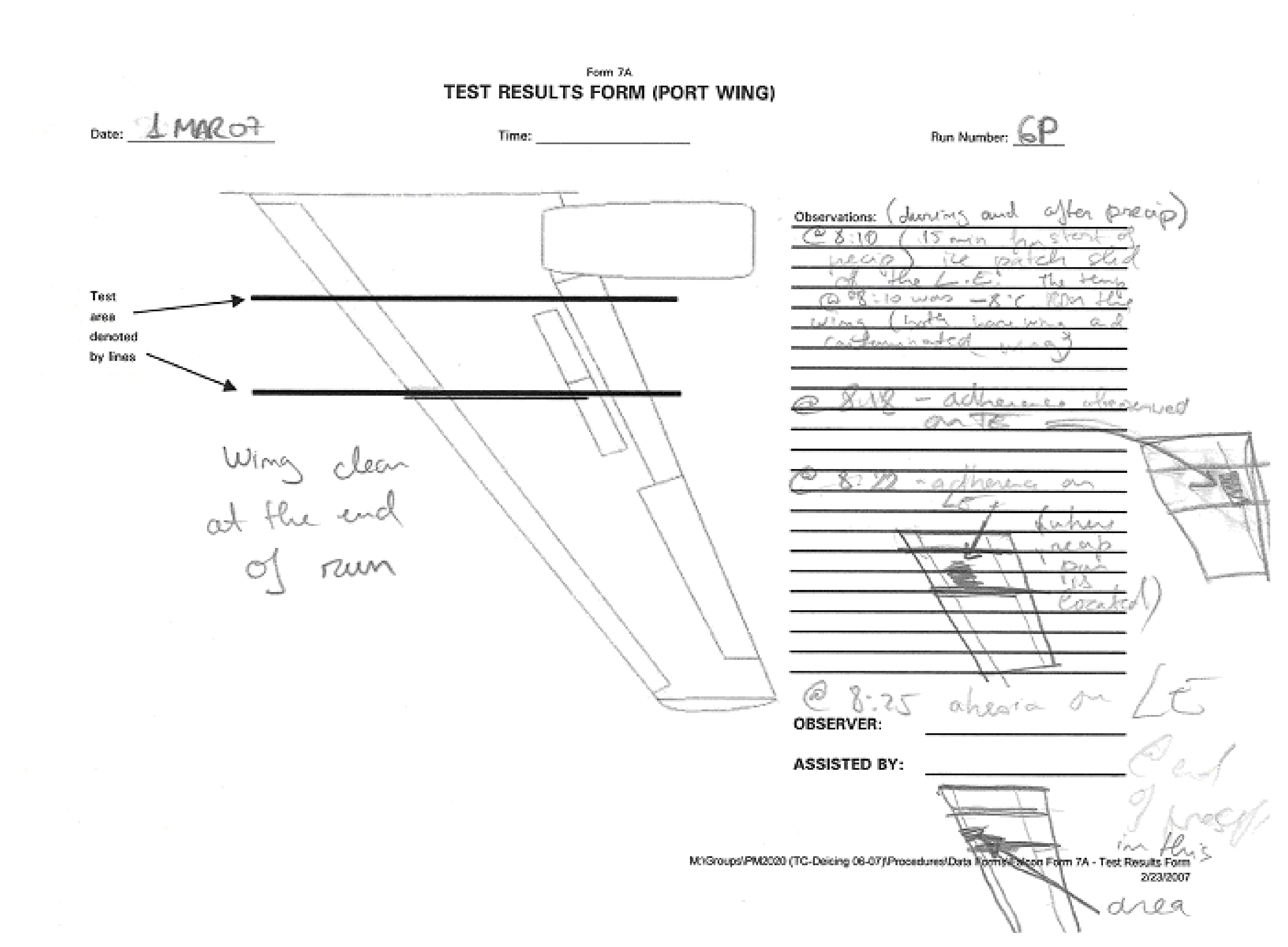
Observations:

Wing clean at the end of run

OBSERVER: ______

ASSISTED BY: ______

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data Forms\Falcon Form 7B - Test Results Form (Starboard)
2/23/2007



Form 7A

TEST RESULTS FORM (PORT WING)

Date: 1 MAR 07

Time: __________

Run Number: 6P

Test area denoted by lines

Wing clean at the end of run

Observations: (during and after precip)
@ 8:10 (15 min from start of precip) ice patch slid off the L.E. The temp @ 8:10 was −8°C from the wing (both bare wing and contaminated wing)

@ 8:18 – adherence observed on TE

@ 8:22 – adherence on LE (where precip pan is located)

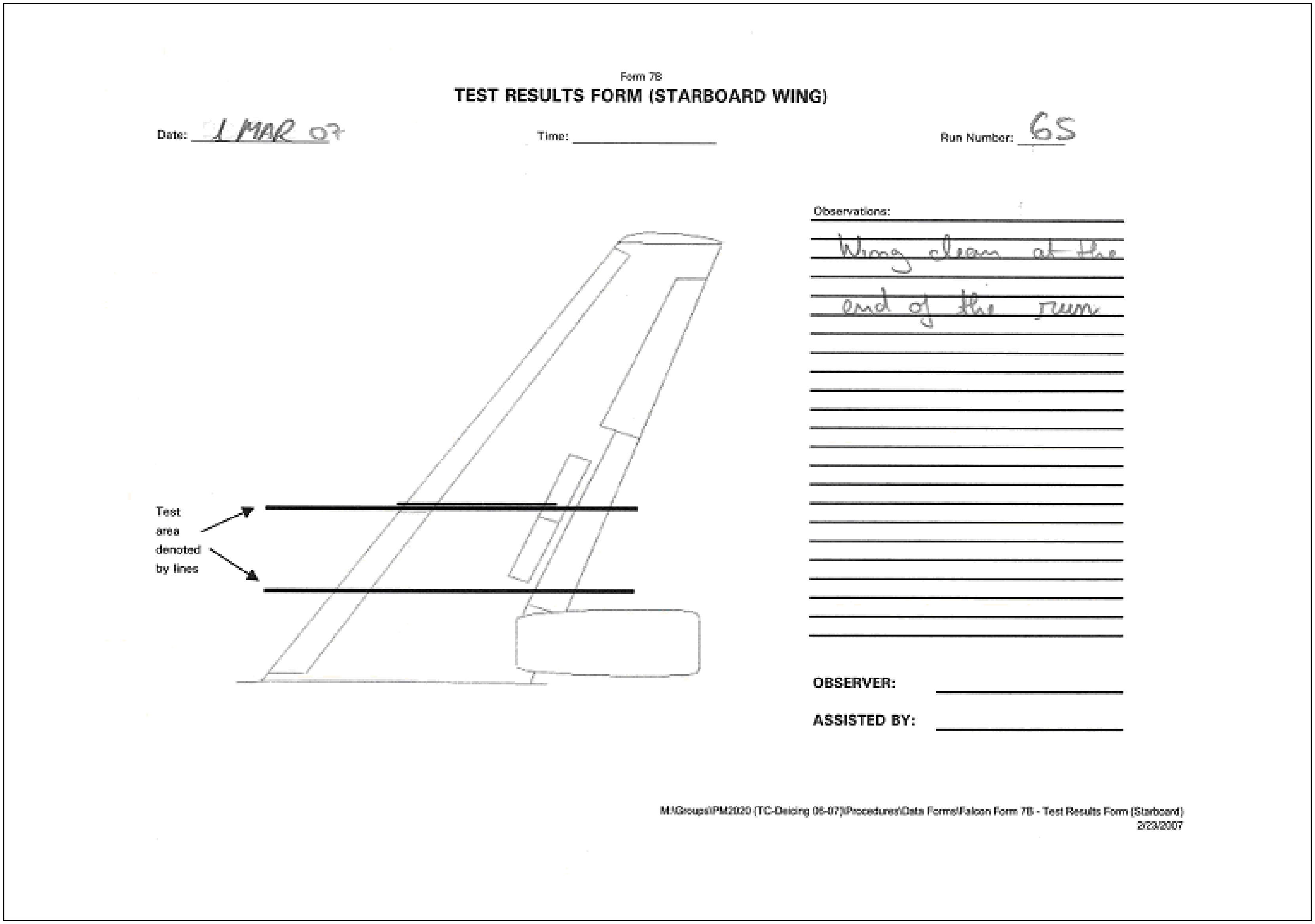
@ 8:25 adhesion on LE

@ end of precip in this area

OBSERVER: __________

ASSISTED BY: __________

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data forms\Falcon Form 7A - Test Results Form
2/23/2007



Form 7B

TEST RESULTS FORM (STARBOARD WING)

Date: 1 MAR 07

Time: ____________

Run Number: 65

Test area denoted by lines

Observations:

Wing clean at the end of the run

OBSERVER: ____________

ASSISTED BY: ____________

M:\Groups\PM2020 (TC-Deicing 06-07)\Procedures\Data Forms\Falcon Form 7B - Test Results Form (Starboard)
2/23/2007

APPENDIX K

FALCON 20 2007
TIME RECORD OF OPERATIONS DATA FORMS

FALCON 20 2007
TIME RECORD OF OPERATIONS DATA FORMS

INDEX

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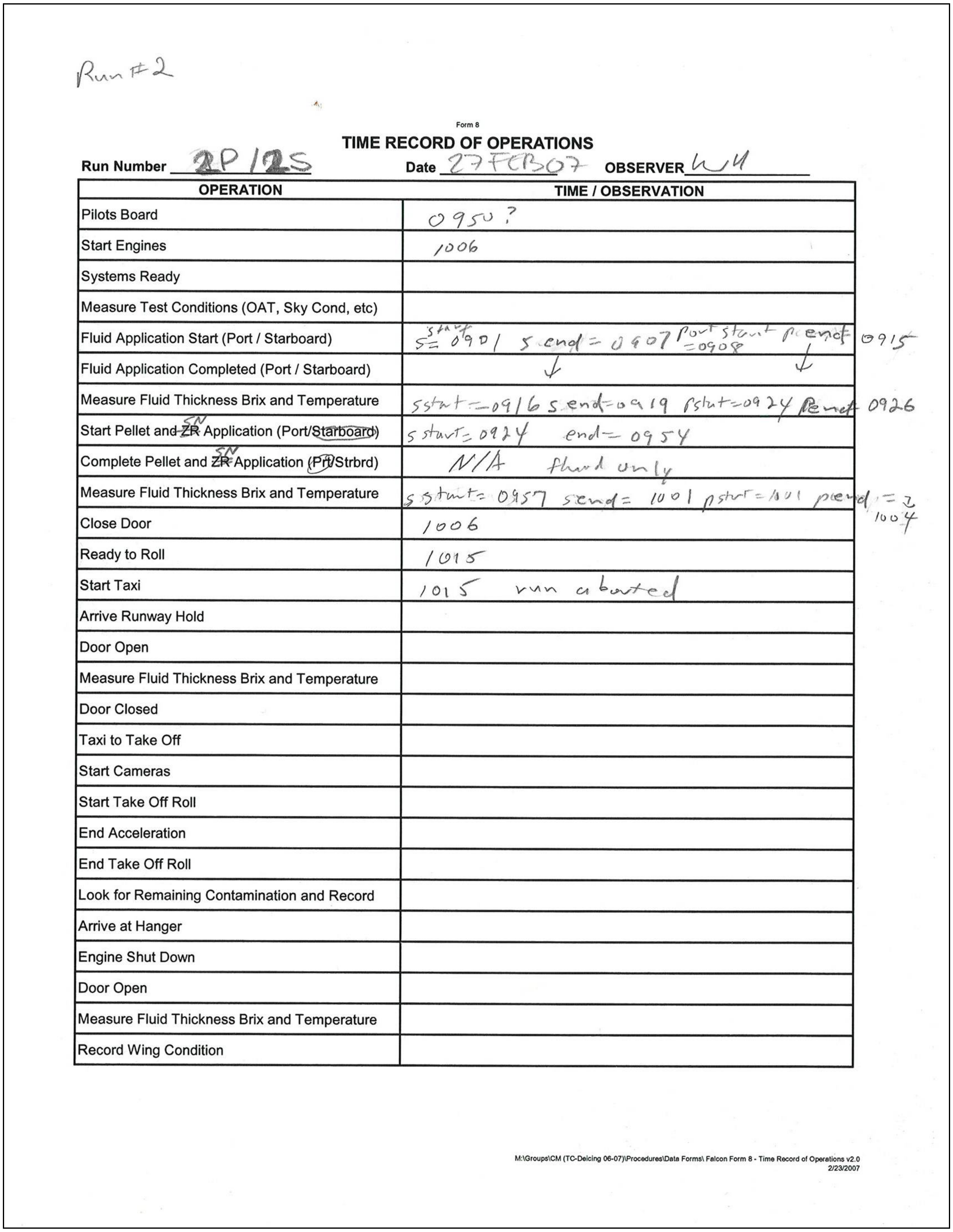


Run #2

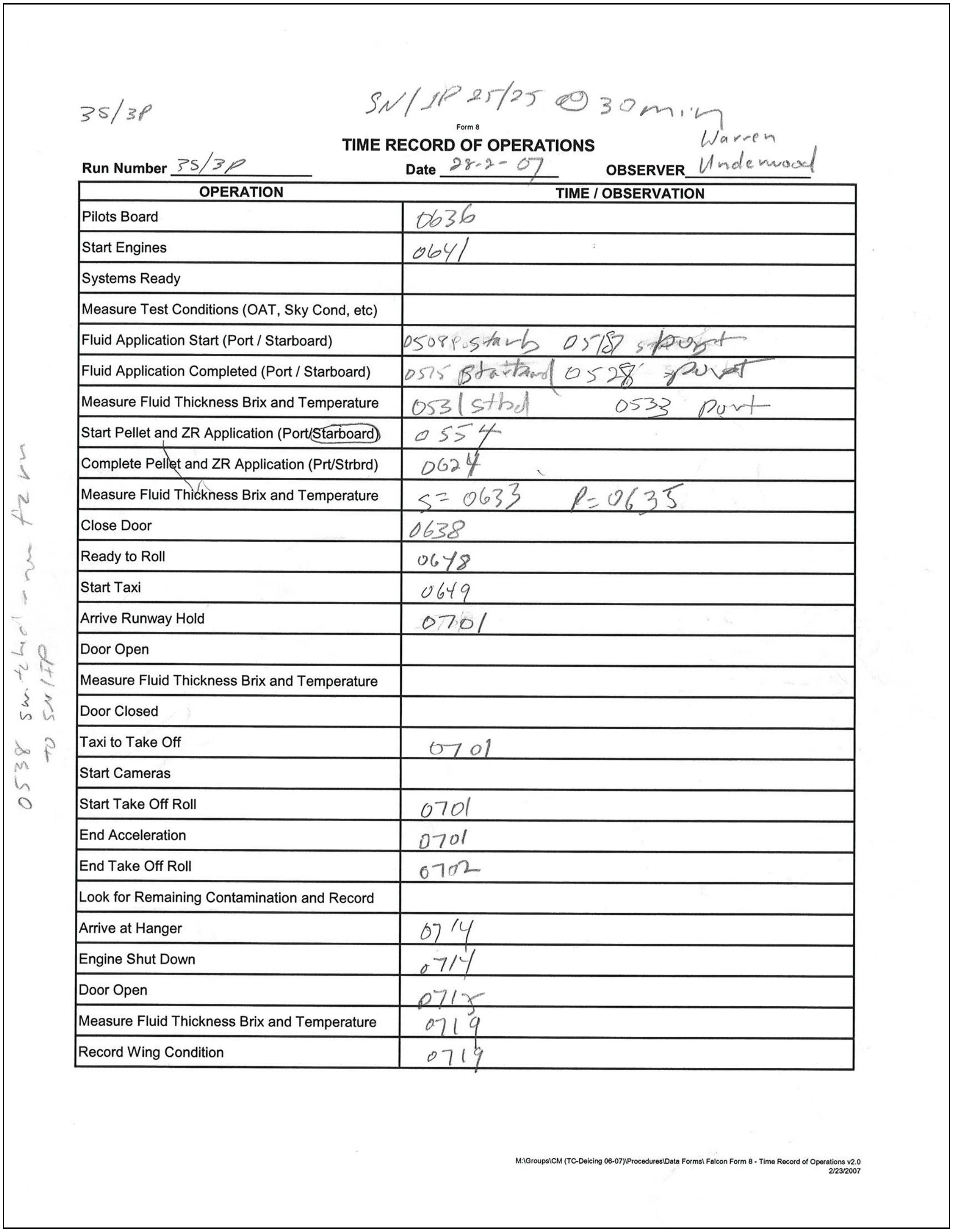
Form 8

TIME RECORD OF OPERATIONS

Run Number 2P/2S **Date** 27FEB07 **OBSERVER** WU

OPERATION	TIME / OBSERVATION
Pilots Board	0950 ?
Start Engines	1006
Systems Ready	
Measure Test Conditions (OAT, Sky Cond, etc)	
Fluid Application Start (Port / Starboard)	start s = 0901 s end = 0907 Port start = 0908 p end = 0915
Fluid Application Completed (Port / Starboard)	↓ ↓
Measure Fluid Thickness Brix and Temperature	sstart = 0916 s end = 0919 pstart = 0924 P end 0926
Start Pellet and ~~ZR~~ SN Application (Port/[✓ Starboard])	s start = 0924 end = 0954
Complete Pellet and ~~ZR~~ SN Application ([✓ Prt]/Strbrd)	N/A fluid only
Measure Fluid Thickness Brix and Temperature	s start = 0957 s end = 1001 pstart = 1001 p end = ? 1004
Close Door	1006
Ready to Roll	1015
Start Taxi	1015 run aborted
Arrive Runway Hold	
Door Open	
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 Contamination and Record	
Arrive at Hanger	
Engine Shut Down	
Door Open	
Measure Fluid Thickness Brix and Temperature	
Record Wing Condition	

M:\Groups\CM (TC-Deicing 06-07)\Procedures\Data Forms\ Falcon Form 8 - Time Record of Operations v2.0
2/23/2007



35/3P

SN/IP 25/25 @ 30 min

Form 8

TIME RECORD OF OPERATIONS

Run Number 35/3P

Date 28-2-07

OBSERVER Warren Underwood

0538 switched - run fzrn to SN/IP

OPERATION	TIME / OBSERVATION
Pilots Board	0636
Start Engines	0641
Systems Ready	
Measure Test Conditions (OAT, Sky Cond, etc)	
Fluid Application Start (Port / Starboard)	0508 Po starb 0518 ~~s~~ port
Fluid Application Completed (Port / Starboard)	0515 Bstarbard 0528 ~~s~~ port
Measure Fluid Thickness Brix and Temperature	0531 stbd 0533 port
Start Pellet and ZR Application (Port/[✓ Starboard])	0554
Complete Pellet and ZR Application (Prt/Strbrd)	0624
Measure Fluid Thickness Brix and Temperature	S= 0633 P= 0635
Close Door	0638
Ready to Roll	0648
Start Taxi	0649
Arrive Runway Hold	0701
Door Open	
Measure Fluid Thickness Brix and Temperature	
Door Closed	
Taxi to Take Off	0701
Start Cameras	
Start Take Off Roll	0701
End Acceleration	0701
End Take Off Roll	0702
Look for Remaining Contamination and Record	
Arrive at Hanger	0714
Engine Shut Down	0714
Door Open	0715
Measure Fluid Thickness Brix and Temperature	0719
Record Wing Condition	0719

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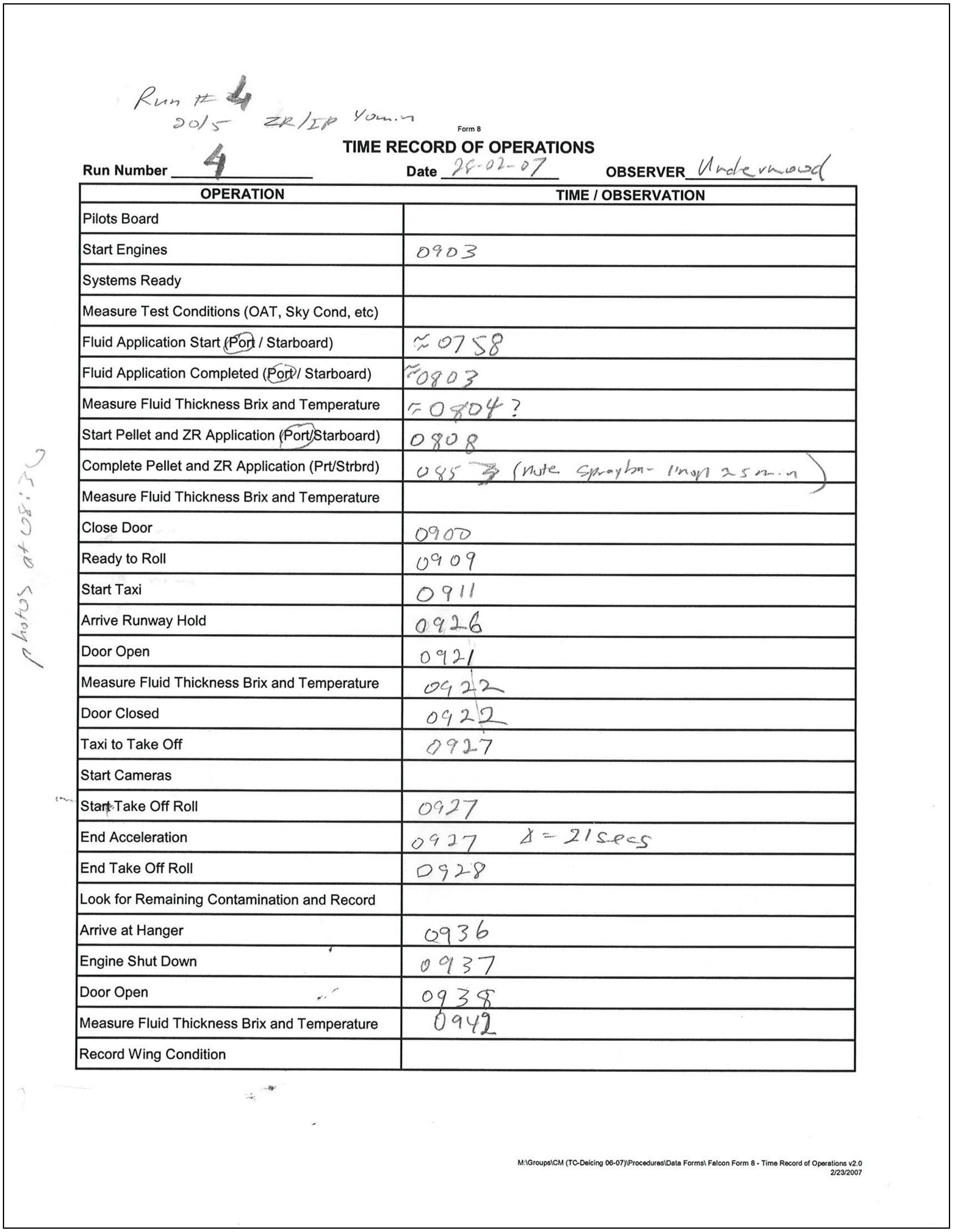
2/23/2007



Run # 4
20/5 ZR/IP 40min

Form 8

TIME RECORD OF OPERATIONS

Run Number 4 **Date** 28-02-07 **OBSERVER** Underwood

OPERATION	TIME / OBSERVATION
Pilots Board	
Start Engines	0903
Systems Ready	
Measure Test Conditions (OAT, Sky Cond, etc)	
Fluid Application Start ([✓ Port] / Starboard)	≈ 0758
Fluid Application Completed ([✓ Port] / Starboard)	≈0803
Measure Fluid Thickness Brix and Temperature	≈ 0804 ?
Start Pellet and ZR Application ([✓ Port]/Starboard)	0808
Complete Pellet and ZR Application (Prt/Strbrd)	0853 (note spraybar inop 25 min)
Measure Fluid Thickness Brix and Temperature	
Close Door	0900
Ready to Roll	0909
Start Taxi	0911
Arrive Runway Hold	0926
Door Open	0921
Measure Fluid Thickness Brix and Temperature	0922
Door Closed	0922
Taxi to Take Off	0927
Start Cameras	
Start Take Off Roll	0927
End Acceleration	0927 Δ = 21 secs
End Take Off Roll	0928
Look for Remaining Contamination and Record	
Arrive at Hanger	0936
Engine Shut Down	0937
Door Open	0938
Measure Fluid Thickness Brix and Temperature	0942
Record Wing Condition	

photos at 08:30

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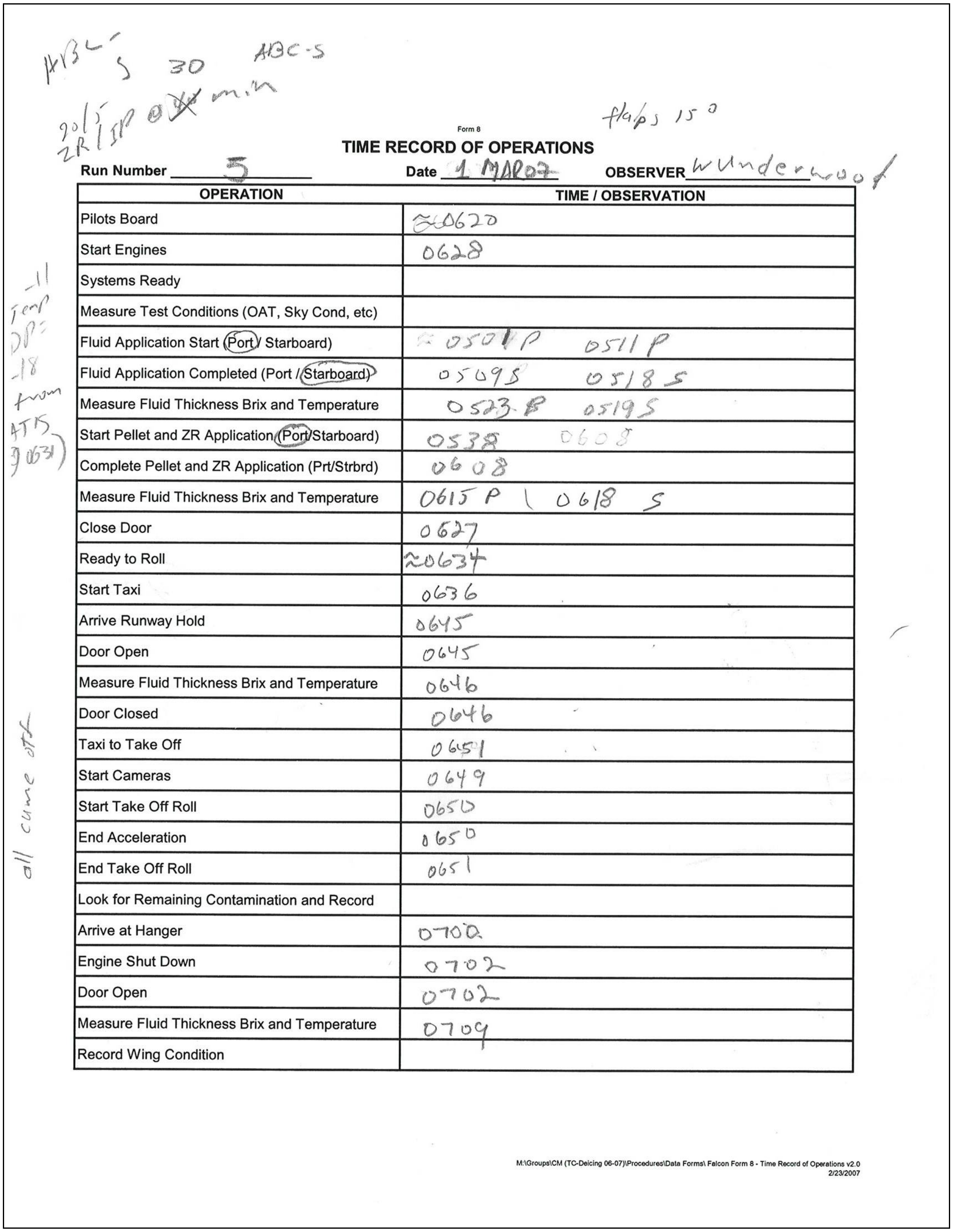
2/23/2007



ABC-S 30 ABC-S

90/5 ZR/IP @ ~~4~~ min

flaps 15°

Form 8

TIME RECORD OF OPERATIONS

Run Number 5 Date 1 MAR07 OBSERVER W Underwood

OPERATION	TIME / OBSERVATION
Pilots Board	≈0620
Start Engines	0628
Systems Ready	
Measure Test Conditions (OAT, Sky Cond, etc)	
Fluid Application Start ([✓ Port] / Starboard)	≈ 0501 P 0511 P
Fluid Application Completed (Port / [✓ Starboard])	0509 S 0518 S
Measure Fluid Thickness Brix and Temperature	0523 P 0519 S
Start Pellet and ZR Application ([✓ Port]/Starboard)	0538 0608
Complete Pellet and ZR Application (Prt/Strbrd)	0608
Measure Fluid Thickness Brix and Temperature	0615 P | 0618 S
Close Door	0627
Ready to Roll	≈0634
Start Taxi	0636
Arrive Runway Hold	0645
Door Open	0645
Measure Fluid Thickness Brix and Temperature	0646
Door Closed	0646
Taxi to Take Off	0651
Start Cameras	0649
Start Take Off Roll	0650
End Acceleration	0650
End Take Off Roll	0651
Look for Remaining Contamination and Record	
Arrive at Hanger	0702
Engine Shut Down	0702
Door Open	0702
Measure Fluid Thickness Brix and Temperature	0709
Record Wing Condition	

-11 Temp
DP= -18
from ATIS @ 0631)

all came off

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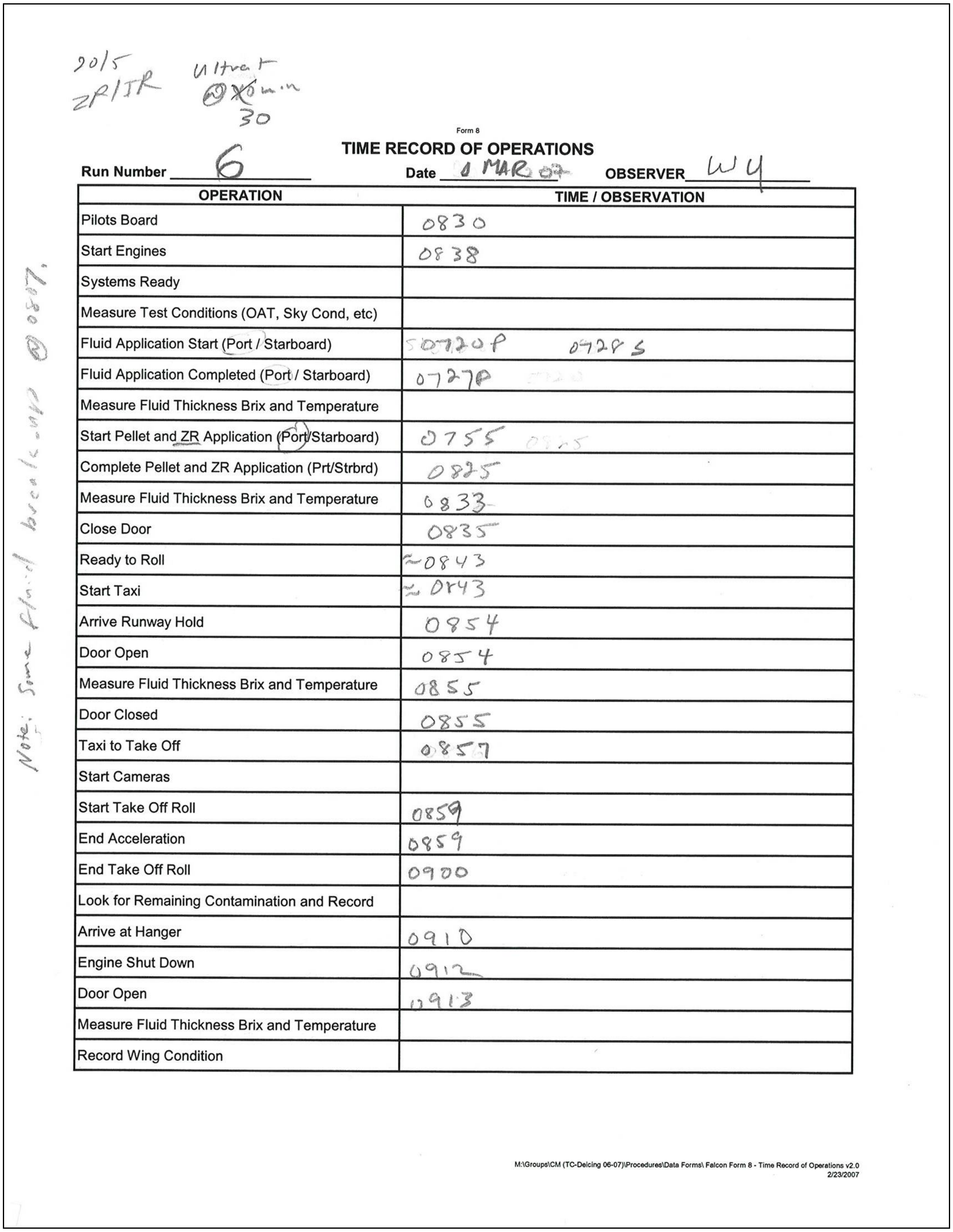
2/23/2007



2015
ZR/IR

Ultrat
@ ~~X~~0 min
30

Form 8

TIME RECORD OF OPERATIONS

Run Number 6　Date 1 MAR 07　OBSERVER WY

OPERATION	TIME / OBSERVATION
Pilots Board	0830
Start Engines	0838
Systems Ready	
Measure Test Conditions (OAT, Sky Cond, etc)	
Fluid Application Start (Port / Starboard)	0720 P　0728 S
Fluid Application Completed (Port / Starboard)	0727P
Measure Fluid Thickness Brix and Temperature	
Start Pellet and ZR Application (Port/Starboard)	0755　0825
Complete Pellet and ZR Application (Prt/Strbrd)	0825
Measure Fluid Thickness Brix and Temperature	0833
Close Door	0835
Ready to Roll	~0843
Start Taxi	≈ 0843
Arrive Runway Hold	0854
Door Open	0854
Measure Fluid Thickness Brix and Temperature	0855
Door Closed	0855
Taxi to Take Off	0857
Start Cameras	
Start Take Off Roll	0859
End Acceleration	0859
End Take Off Roll	0900
Look for Remaining Contamination and Record	
Arrive at Hanger	0910
Engine Shut Down	0912
Door Open	0913
Measure Fluid Thickness Brix and Temperature	
Record Wing Condition	

Note: Some fluid breakup @ 0807.

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2/23/2007

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APPENDIX L

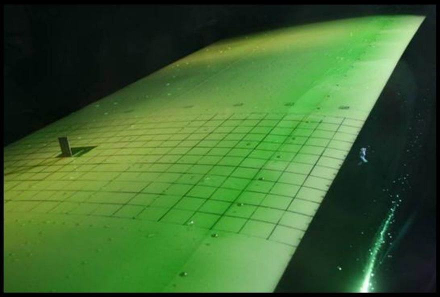
PHOTO DOCUMENTATION OF TESTS 2 AND 11 OF WIND TUNNEL TESTS

PHOTO DOCUMENTATION OF TEST 2

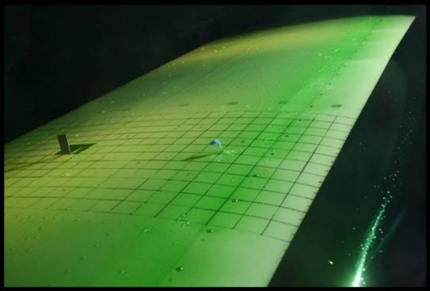
TEST #2

Type IV PG
No Contamination

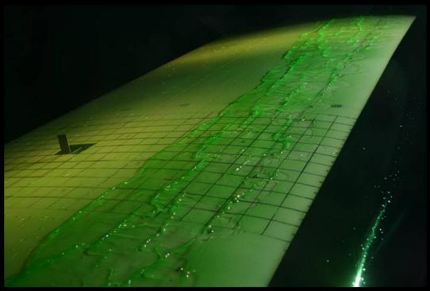
$\Delta t_{\text{Rotation}} = - 24 \text{ sec}$



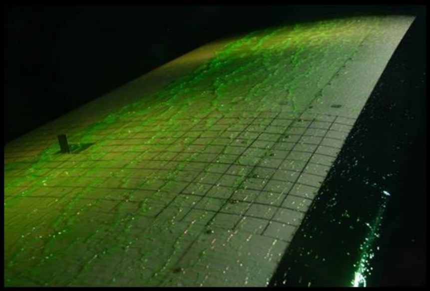
$\Delta t_{\text{Rotation}} = - 22 \text{ sec}$



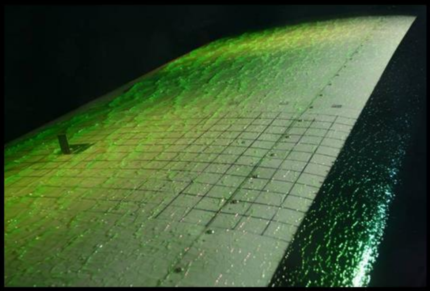
$\Delta t_{\text{Rotation}} = - 20 \text{ sec}$

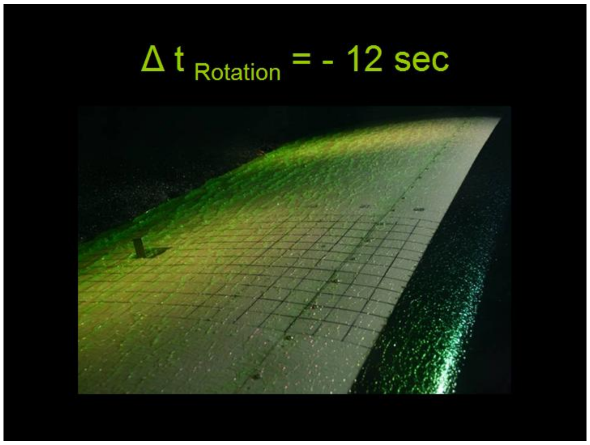


$\Delta t_{\text{Rotation}} = - 16 \text{ sec}$

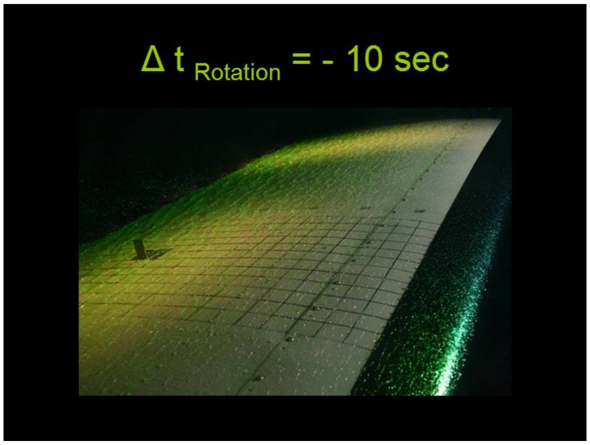


$\Delta t_{\text{Rotation}} = - 14 \text{ sec}$

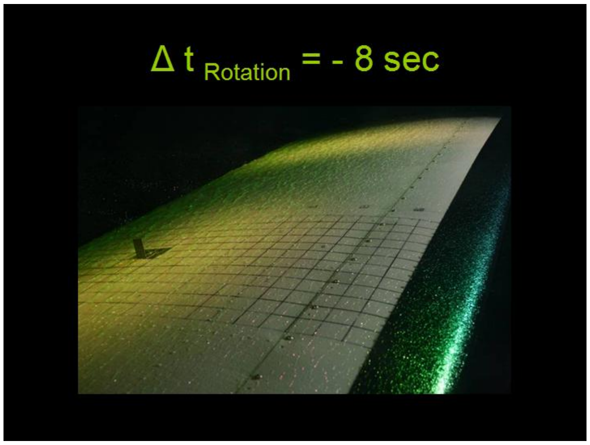




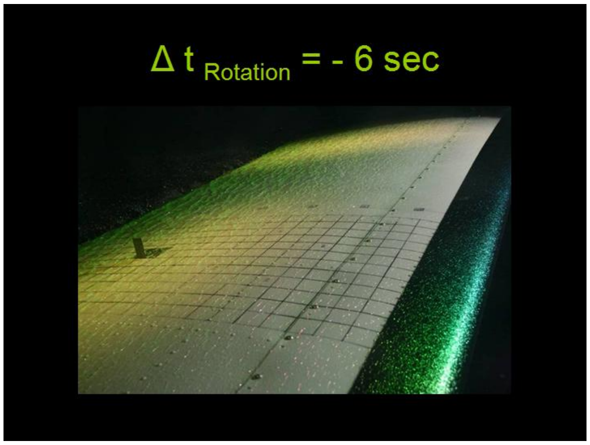
$\Delta t_{Rotation}$ = - 12 sec



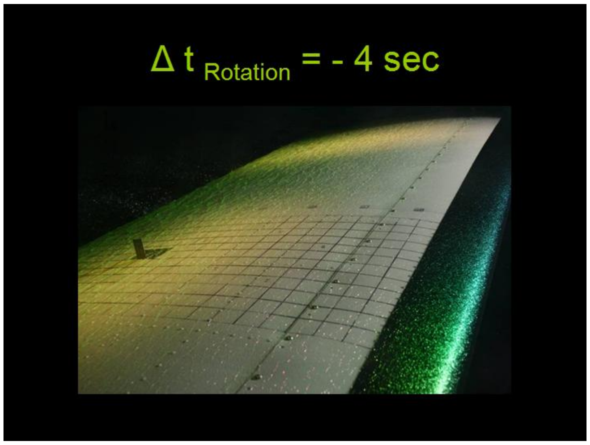
$\Delta t_{Rotation}$ = - 10 sec



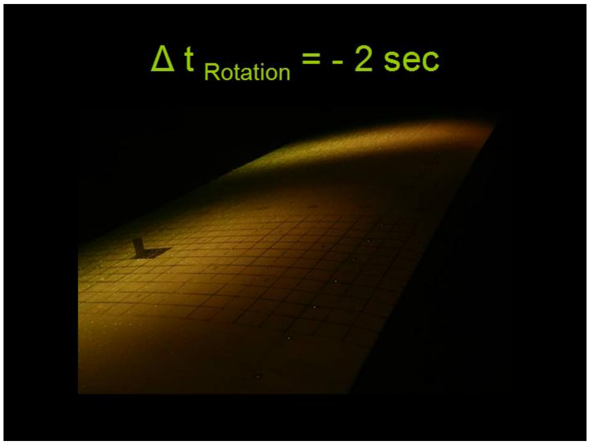
$\Delta t_{Rotation}$ = - 8 sec



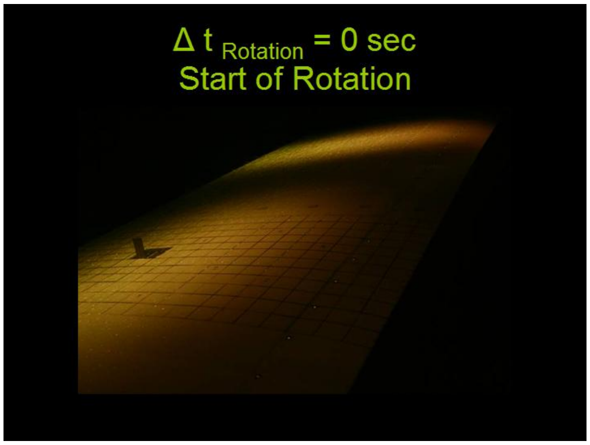
$\Delta t_{Rotation}$ = - 6 sec



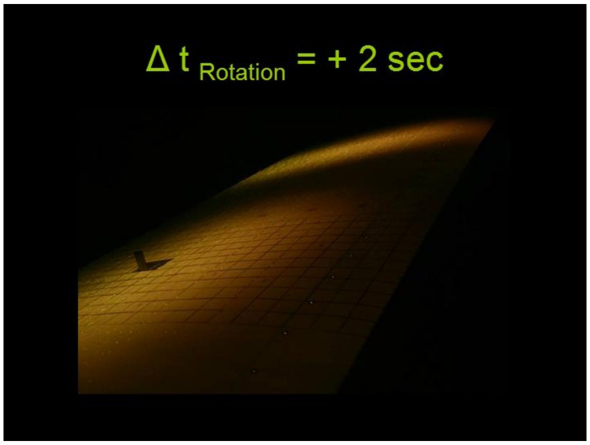
$\Delta t_{Rotation}$ = - 4 sec



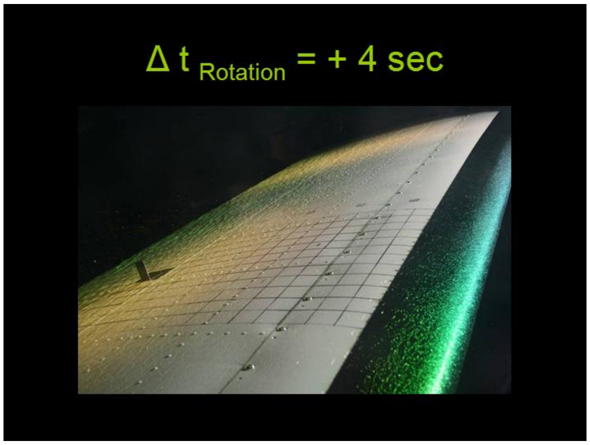
$\Delta t_{Rotation}$ = - 2 sec



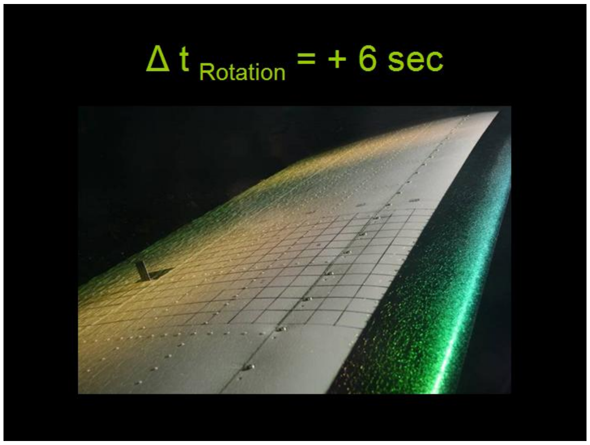
$\Delta t_{\text{Rotation}} = 0$ sec
Start of Rotation



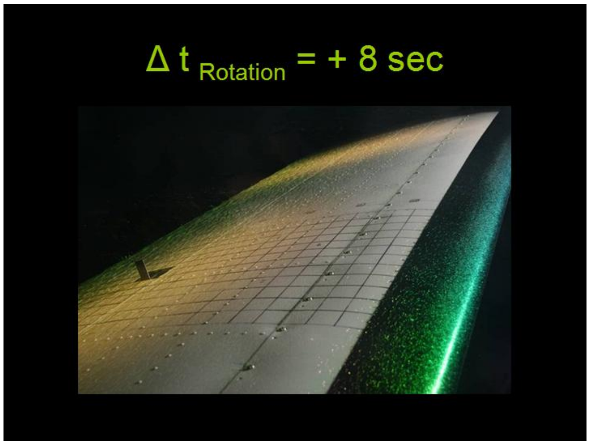
$\Delta t_{\text{Rotation}} = + 2$ sec



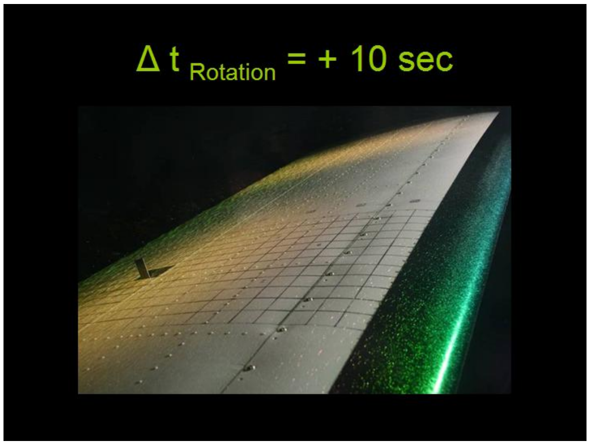
$\Delta t_{\text{Rotation}} = + 4$ sec



$\Delta t_{\text{Rotation}} = + 6$ sec

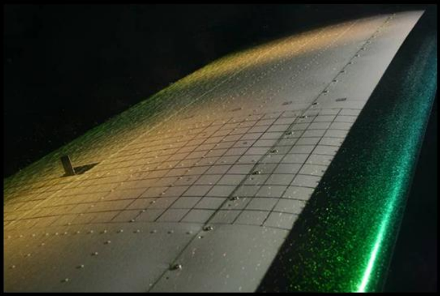


$\Delta t_{\text{Rotation}} = + 8$ sec

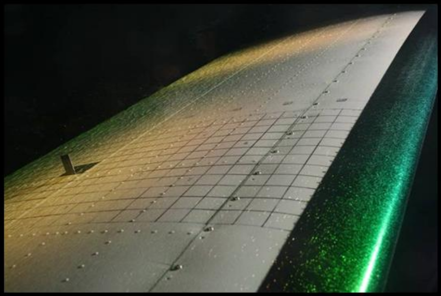


$\Delta t_{\text{Rotation}} = + 10$ sec

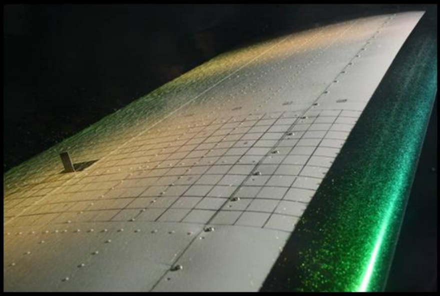
$\Delta t_{Rotation} = + 12$ sec



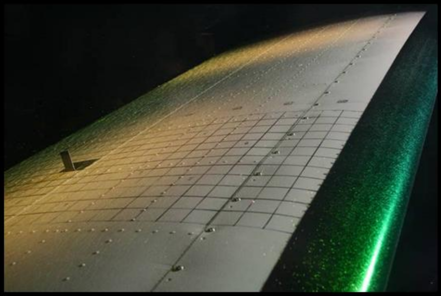
$\Delta t_{Rotation} = + 14$ sec



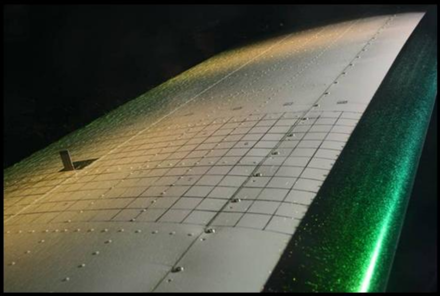
$\Delta t_{Rotation} = + 16$ sec



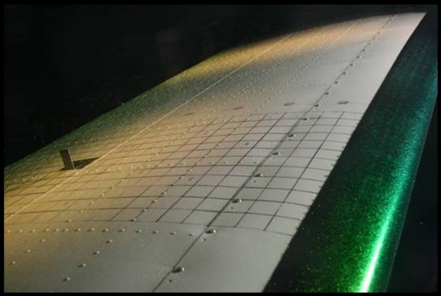
$\Delta t_{Rotation} = + 18$ sec

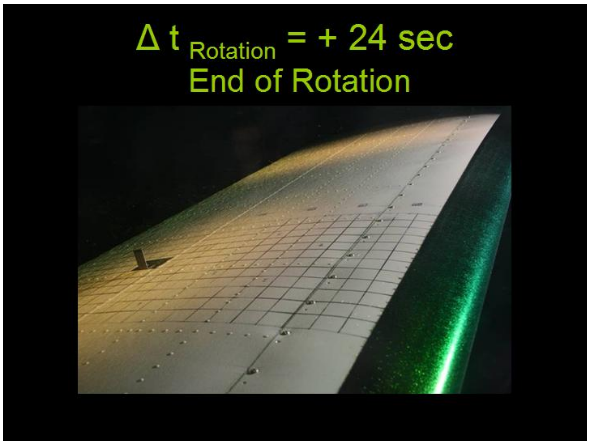
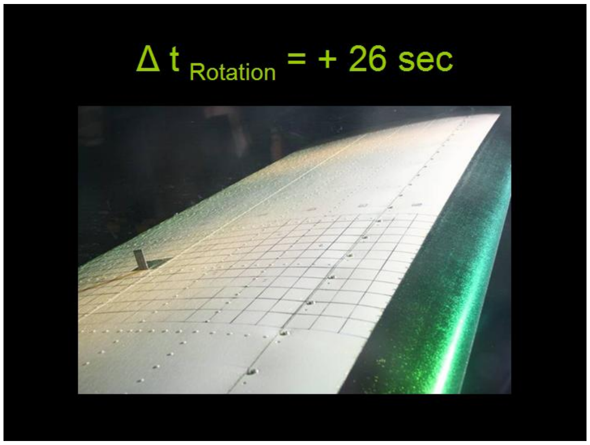
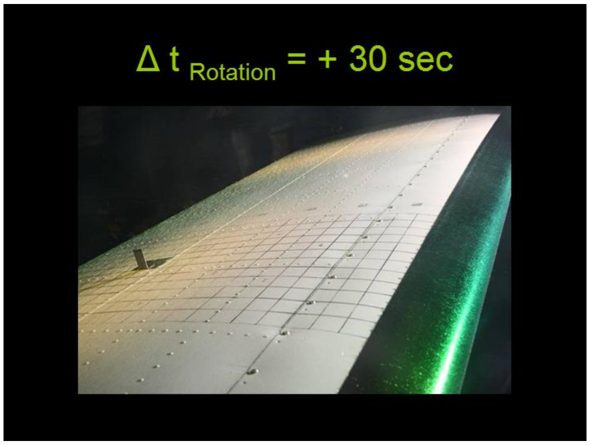
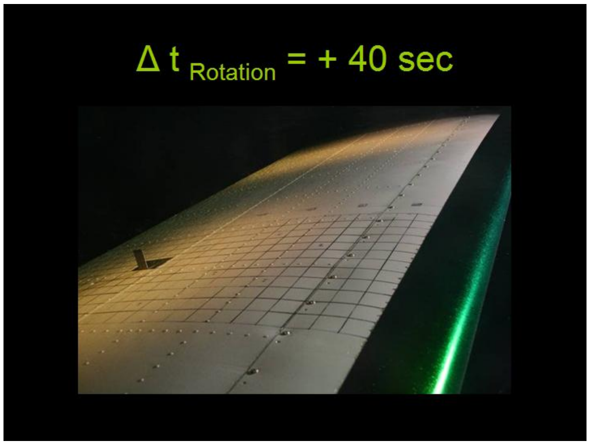
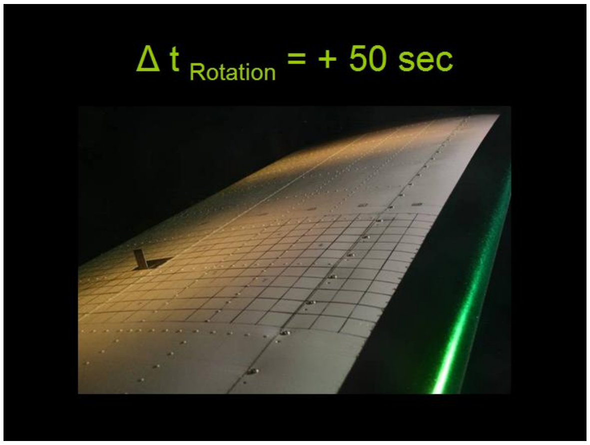
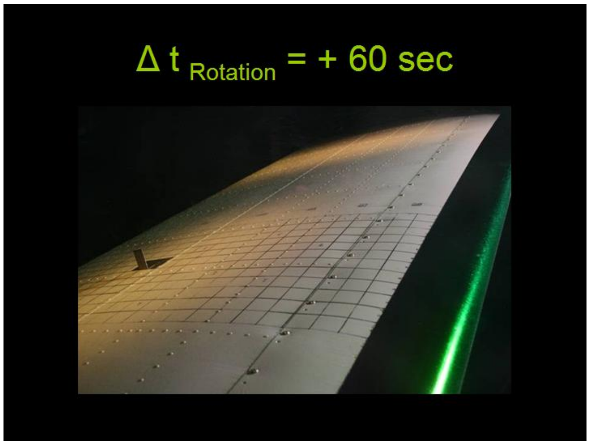


$\Delta t_{Rotation} = + 20$ sec



$\Delta t_{Rotation} = + 22$ sec



 $\Delta t_{Rotation} = + 24$ sec End of Rotation	 $\Delta t_{Rotation} = + 26$ sec
 $\Delta t_{Rotation} = + 30$ sec	 $\Delta t_{Rotation} = + 40$ sec
 $\Delta t_{Rotation} = + 50$ sec	 $\Delta t_{Rotation} = + 60$ sec

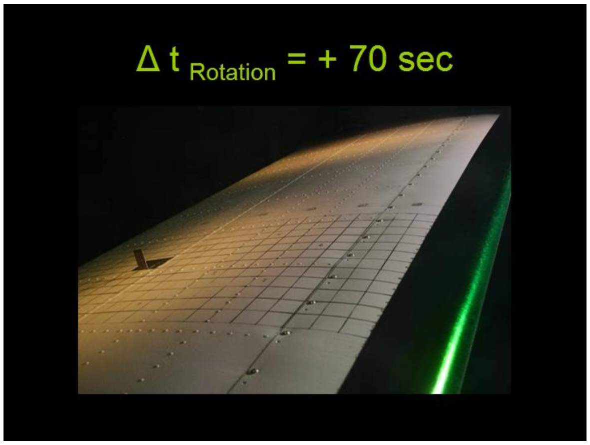
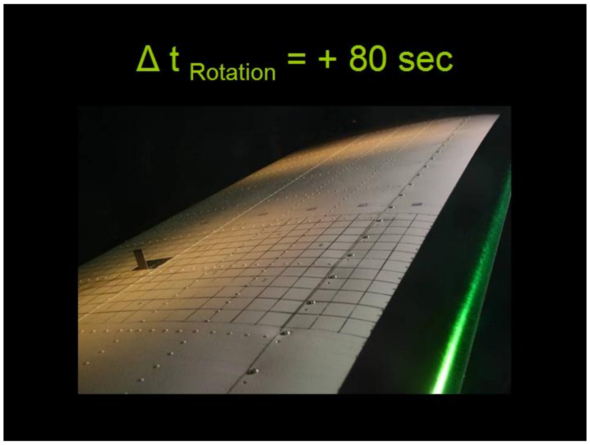
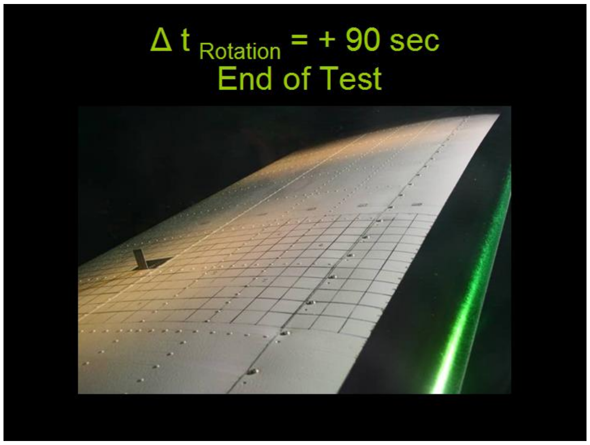
	
	***This cell intentionally left blank.***
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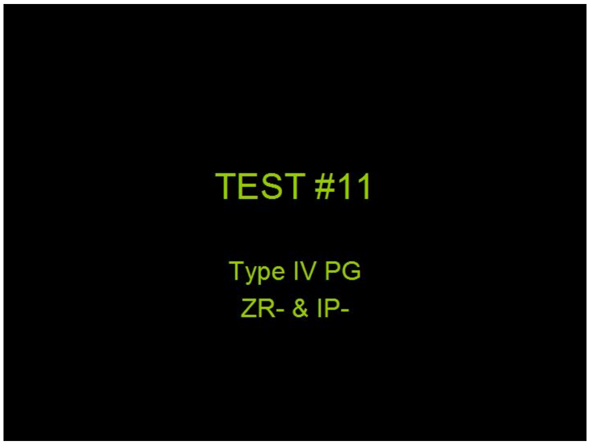
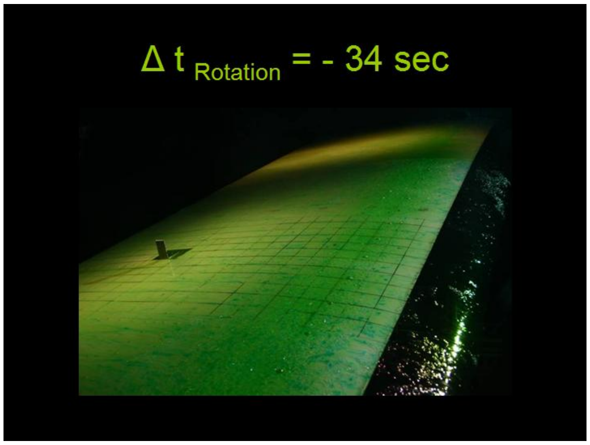
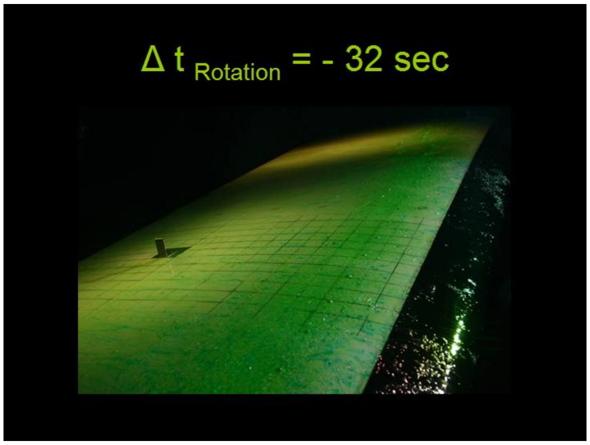
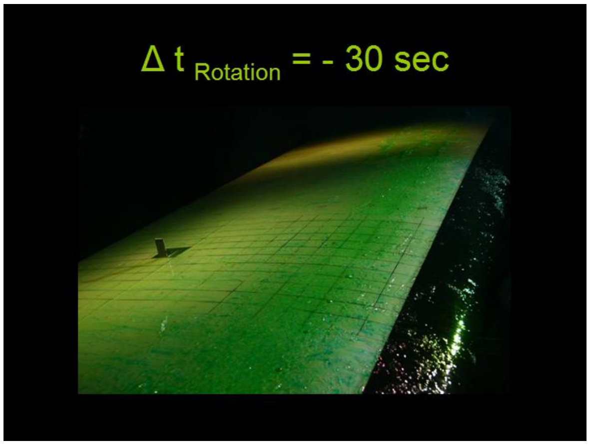
PHOTO DOCUMENTATION OF TEST 11

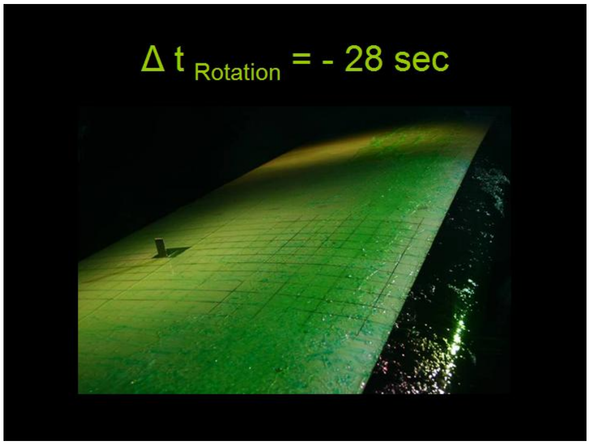

TEST #11

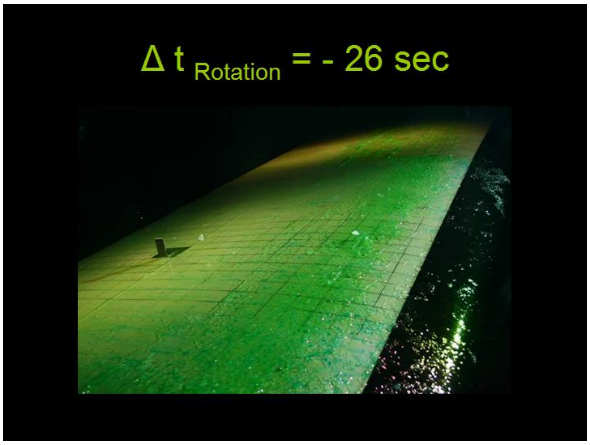
Type IV PG
ZR- & IP-

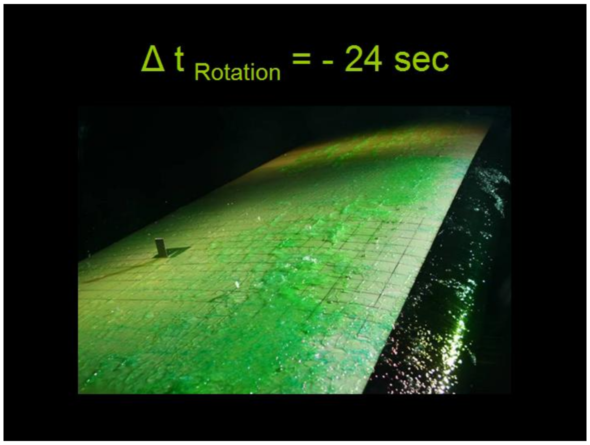

$\Delta t_{Rotation}$ = - 34 sec

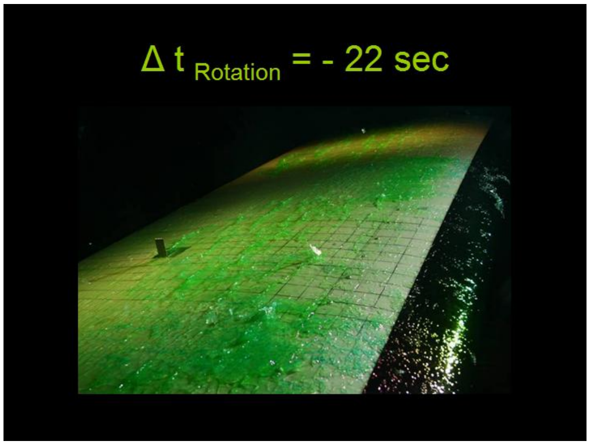

$\Delta t_{Rotation}$ = - 32 sec

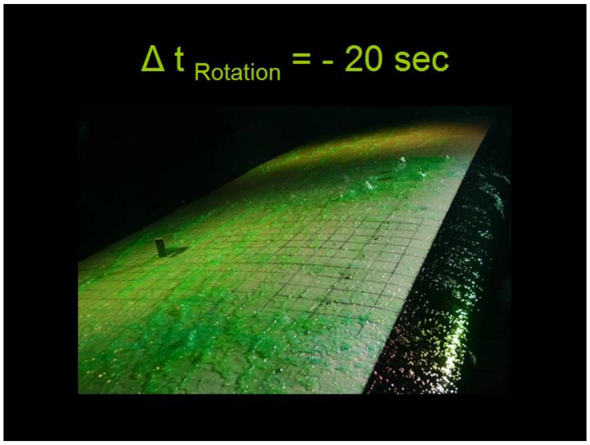

$\Delta t_{Rotation}$ = - 30 sec

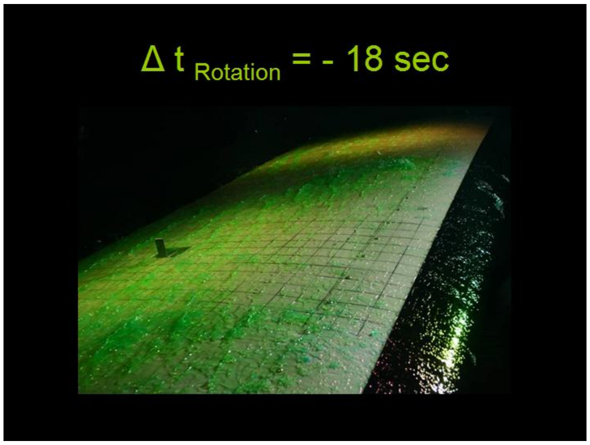

$\Delta t_{Rotation}$ = - 28 sec

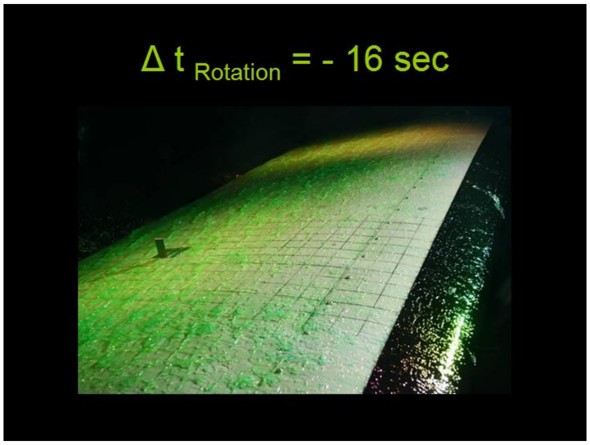

$\Delta t_{Rotation}$ = - 26 sec

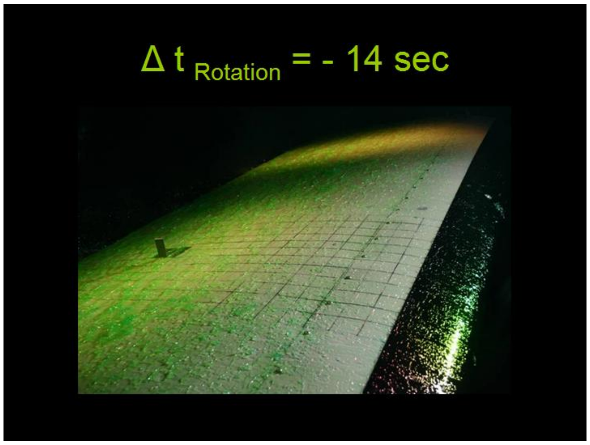

Δ t Rotation = - 24 sec

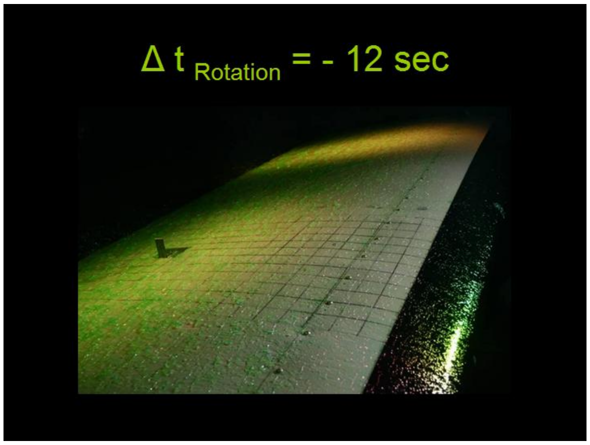
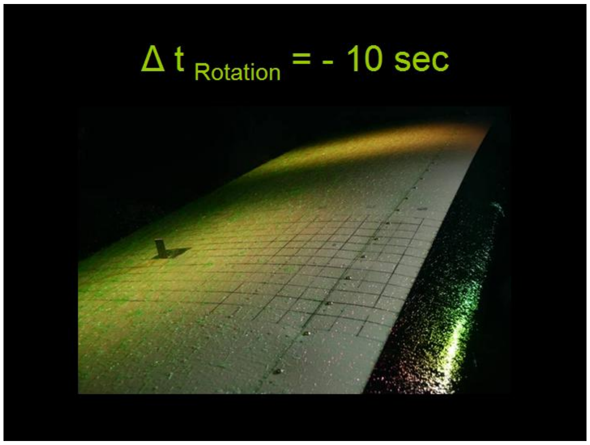
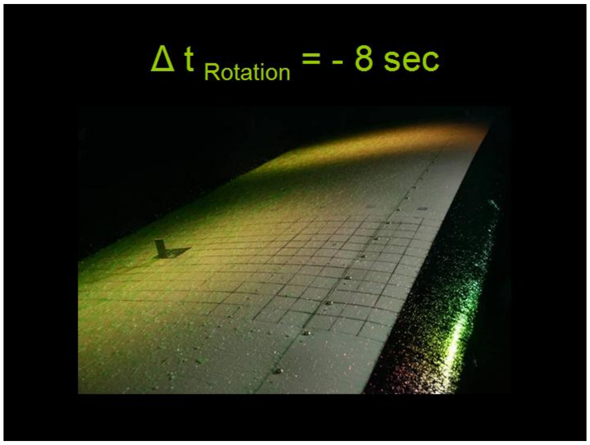
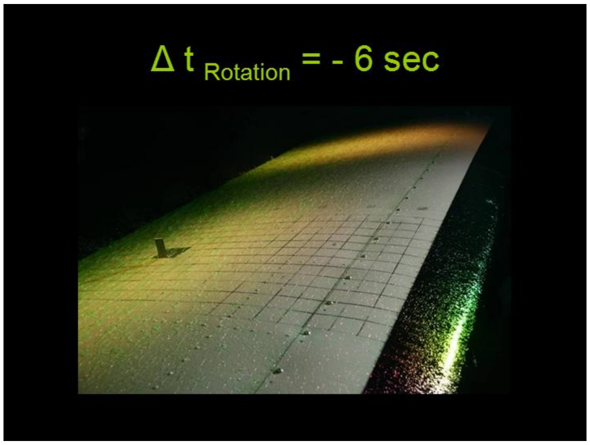
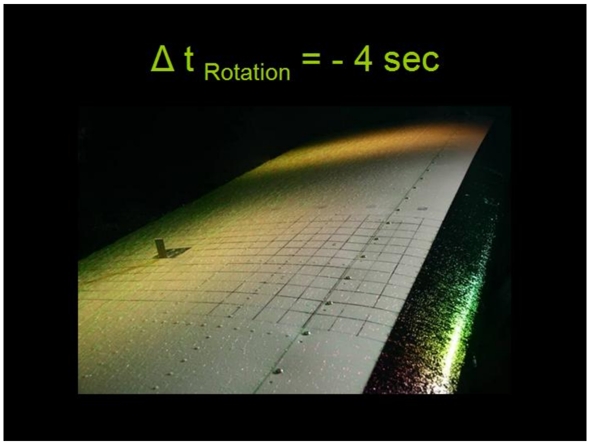
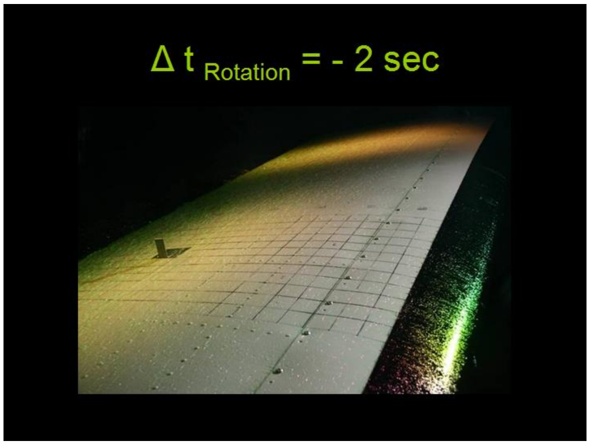

Δ t Rotation = - 22 sec

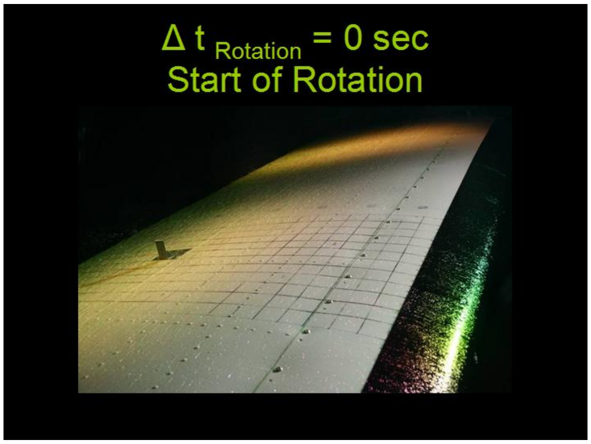

Δ t Rotation = - 20 sec


Δ t Rotation = - 18 sec


Δ t Rotation = - 16 sec

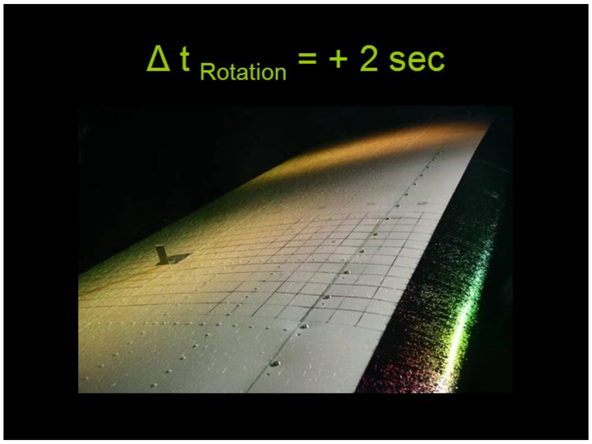

Δ t Rotation = - 14 sec

 $\Delta t_{\text{Rotation}} = -12$ sec	 $\Delta t_{\text{Rotation}} = -10$ sec
 $\Delta t_{\text{Rotation}} = -8$ sec	 $\Delta t_{\text{Rotation}} = -6$ sec
 $\Delta t_{\text{Rotation}} = -4$ sec	 $\Delta t_{\text{Rotation}} = -2$ sec

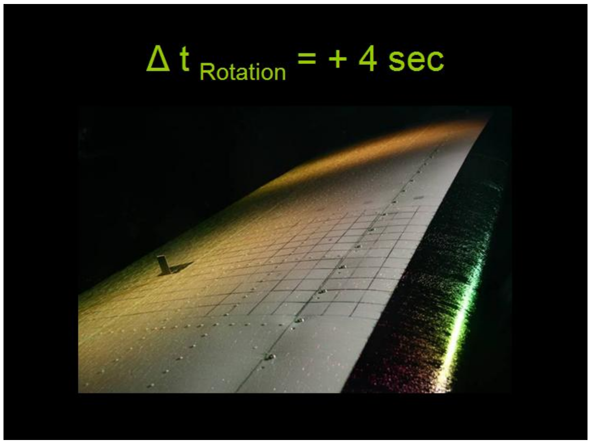


$\Delta t_{\text{Rotation}}$ = 0 sec

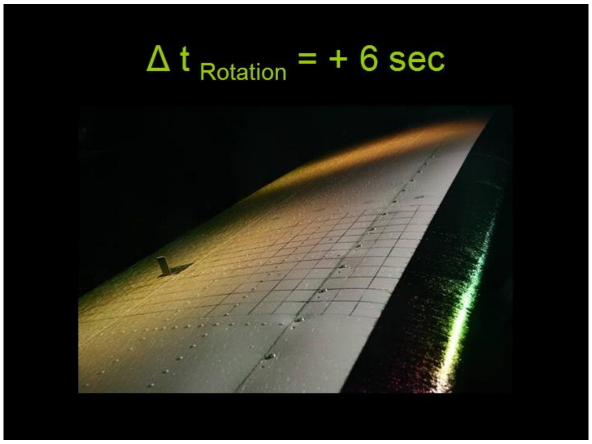
Start of Rotation



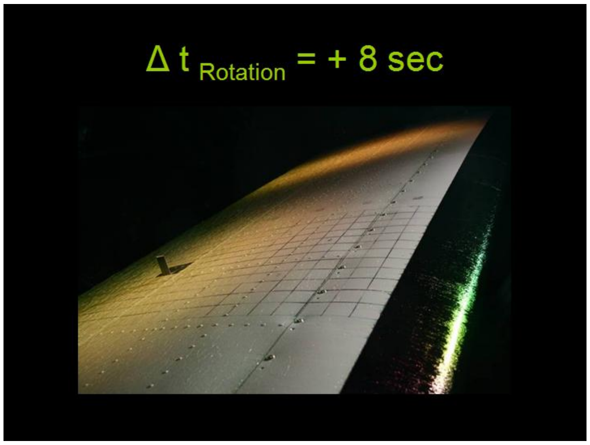
$\Delta t_{\text{Rotation}}$ = + 2 sec



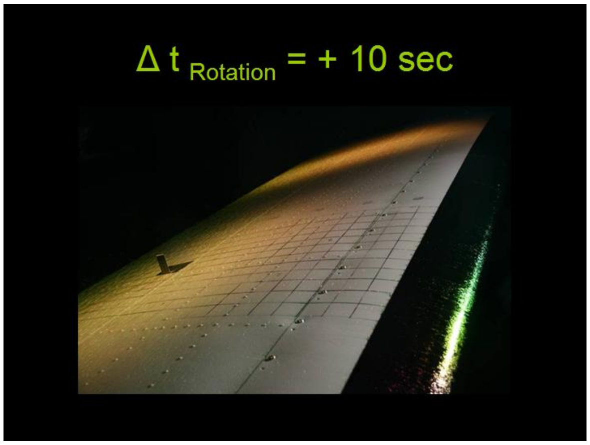
$\Delta t_{\text{Rotation}}$ = + 4 sec



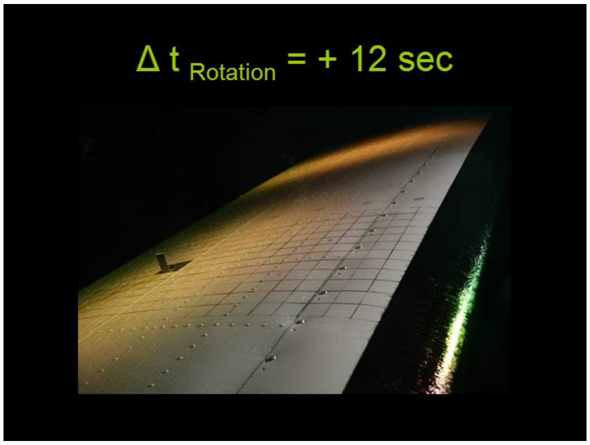
$\Delta t_{\text{Rotation}}$ = + 6 sec



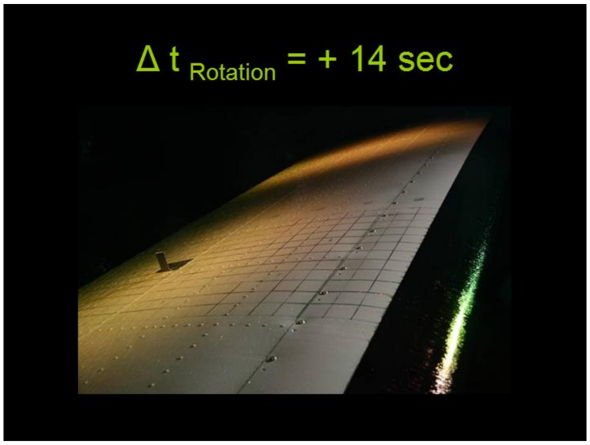
$\Delta t_{\text{Rotation}}$ = + 8 sec



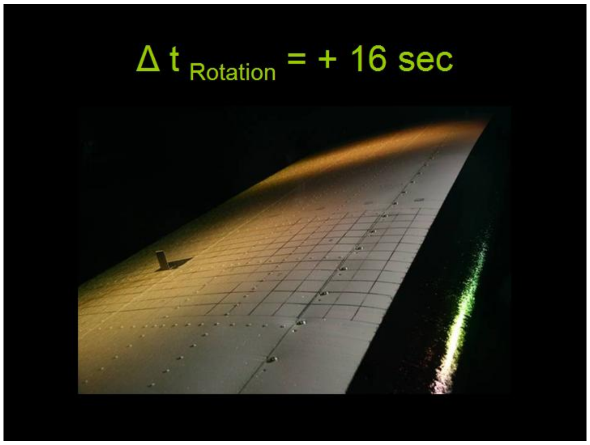
$\Delta t_{\text{Rotation}}$ = + 10 sec



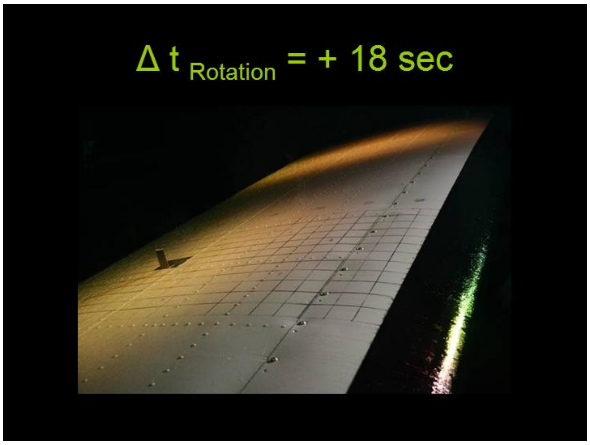
$\Delta t_{\text{Rotation}} = + 12 \text{ sec}$



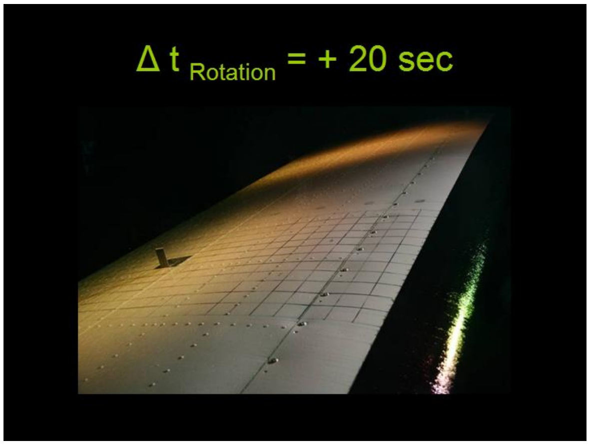
$\Delta t_{\text{Rotation}} = + 14 \text{ sec}$



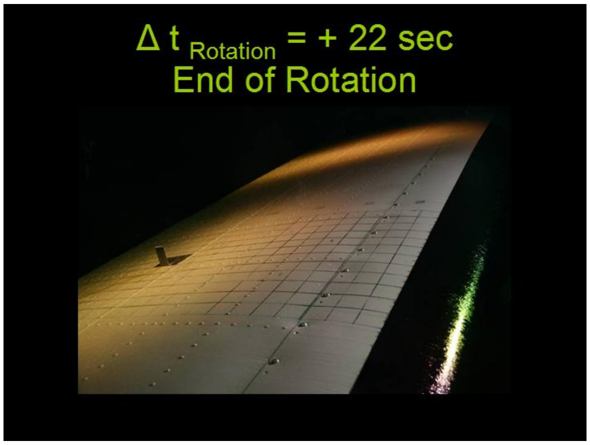
$\Delta t_{\text{Rotation}} = + 16 \text{ sec}$



$\Delta t_{\text{Rotation}} = + 18 \text{ sec}$

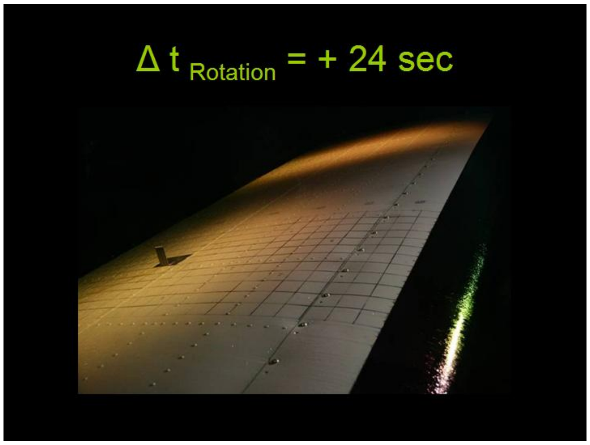
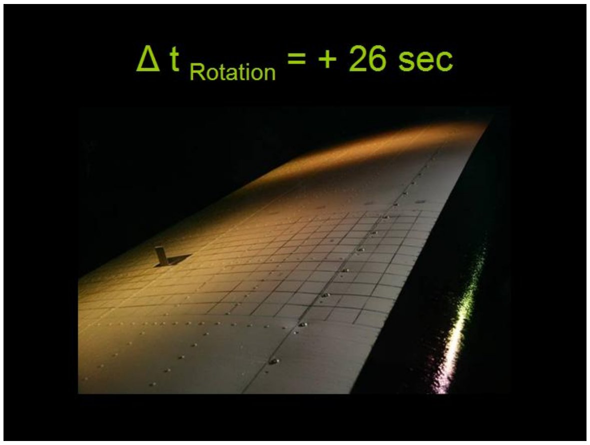
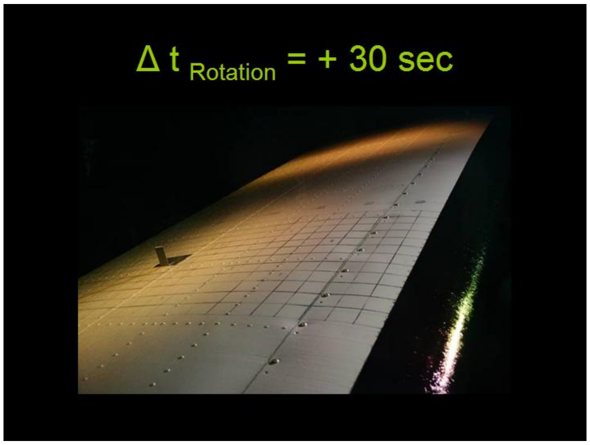
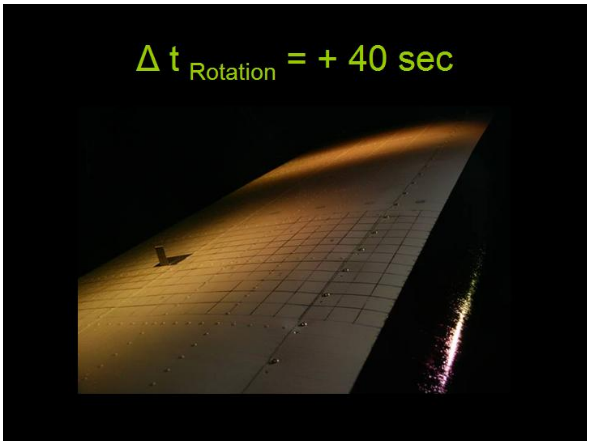
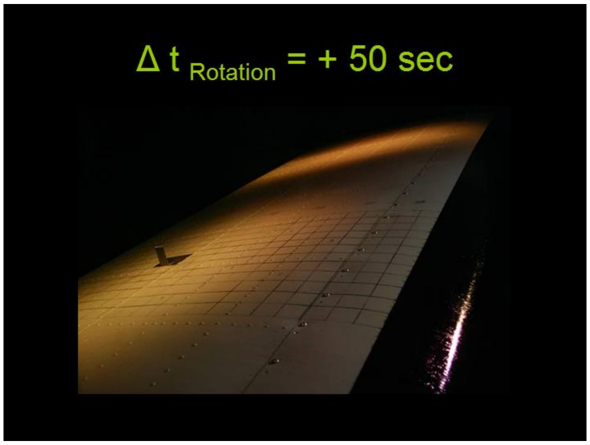
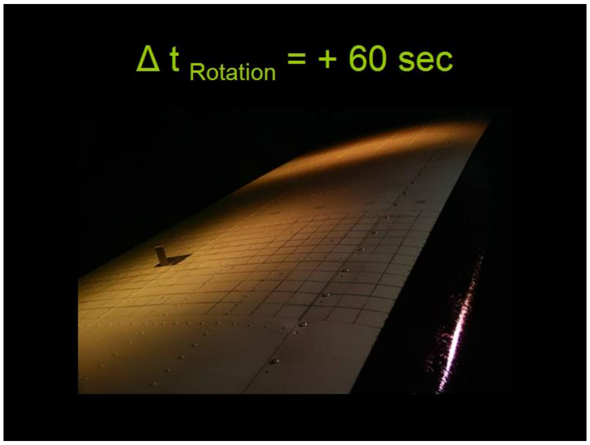


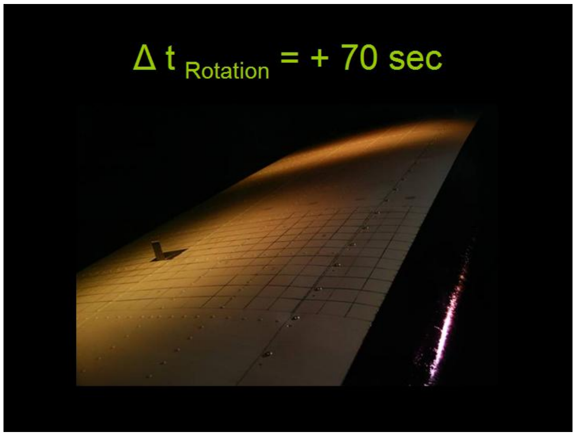
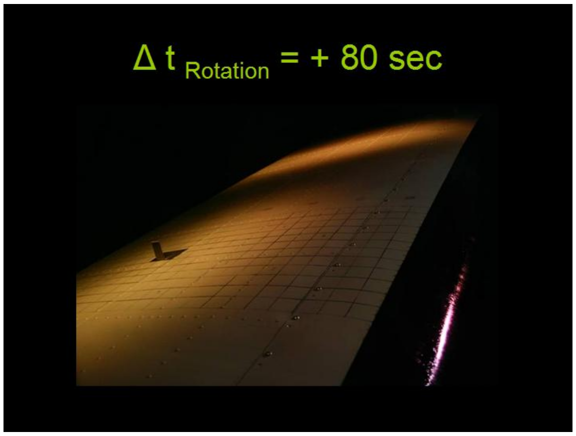
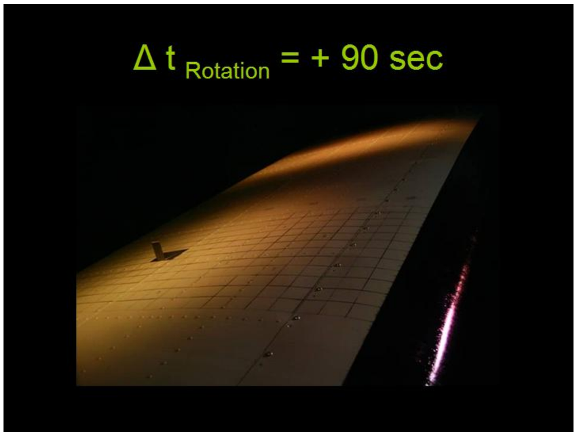
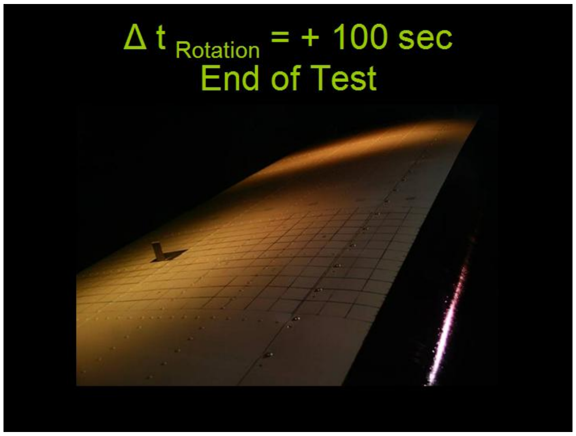
$\Delta t_{\text{Rotation}} = + 20 \text{ sec}$



$\Delta t_{\text{Rotation}} = + 22 \text{ sec}$

End of Rotation

 $\Delta t_{\text{Rotation}} = + 24$ sec	 $\Delta t_{\text{Rotation}} = + 26$ sec
 $\Delta t_{\text{Rotation}} = + 30$ sec	 $\Delta t_{\text{Rotation}} = + 40$ sec
 $\Delta t_{\text{Rotation}} = + 50$ sec	 $\Delta t_{\text{Rotation}} = + 60$ sec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