TP 15160E

Exploratory Wind Tunnel Aerodynamic Research

Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics

Winter 2010-11

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.

March 2012
Final Version 1.0

TP 15160E

Exploratory Wind Tunnel Aerodynamic Research

Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics

Winter 2010-11

by

Marco Ruggi

Prepared by:

APS Aviation Inc.

March 2012
Final Version 1.0

DOCUMENT ORIGIN AND APPROVAL RECORD

Prepared by:

Aug 24, 2021

Marco Ruggi, Eng., M.B.A. Date
Project Leader

Reviewed by:

Aug 24, 2021

John D'Avirro, Eng., PBDM Date
Program Manager

Approved by: **

John Detombe Date
Chief Engineer
ADGA Group Consultant Inc.

Un sommaire français se trouve avant la table des matières.

This report was first provided to Transport Canada as Final Draft 1.0 in March 2012.
It has been published as Final Version 1.0 in August 2021.

***Final Draft 1.0 of this report was signed and provided to Transport Canada in March 2012. A Transport Canada technical and editorial review was subsequently completed and the report was finalized in August 2021; John Detombe 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 with support from the Federal Aviation Administration, 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 and update and maintain the website for the holdover time guidelines;
- To evaluate weather data from previous winters that can have an impact on the format of the holdover time guidelines;
- To conduct general and exploratory de/anti-icing research;
- To conduct endurance time tests simulating vertical stabilizer anti-icing;
- To conduct endurance time tests simulating deployed flaps;
- To conduct endurance time tests with a snow machine in an attempt to refine the current test protocol;
- To conduct full-scale tests on aircraft in order to validate the composite holdover times;
- To conduct endurance time tests in heavy snow conditions;
- To support Federal Aviation Administration and Transport Canada in the development of an advisory circular for the implementation of a holdover time determination system;
- To evaluate the use of sensors in determining active frost conditions;
- To initiate research for development of ice detection capabilities for pre-deicing, engine deicing and departing aircraft at the runway threshold;
- To evaluate frost holdover times for use during cold-soaked wing frost conditions;
- To evaluate degraded fluid performance following contamination with runway deicer fluid;
- To update the regression coefficient report with the newly-qualified de/anti-icing fluids;
- To conduct endurance time tests on surfaces treated with ice phobic products;
- To evaluate holdover times for anti-icing in a hangar;
- To conduct research at the National Research Council Canada wind tunnel to further develop and expand ice pellet allowance times;
- To compile a list of lowest operational use temperatures for all de/anti-icing fluids in the holdover guidelines; and
- To conduct various aerodynamic research activities at the National Research Council Canada wind tunnel.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2010-11 are documented in five reports. The titles of the reports are as follows:

TP 15156E	Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2010-11 Winter;
TP 15157E	Winter Weather Impact on Holdover Time Table Format (1995-2011);
TP 15158E	Aircraft Ground Icing General Research Activities During the 2010-11 Winter;
TP 15159E	Regression Coefficients and Equations Used to Develop the Winter 2011-12 Aircraft Ground Deicing Holdover Time Tables; and
TP 15160E	Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2010-11.

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

- *Further Development of Ice Pellet Allowance Times: Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics Winter 2010-11; and*
- *Evaluation of De/Anti-Icing Fluid Endurance Times on Extended Flaps and Slats.*

This report, TP 15160E, has the following objective:

- To conduct various aerodynamic research activities at the National Research Council Canada wind tunnel.

This objective was met by conducting a series of full-scale tests using a supercritical wing section mounted in the National Research Council Canada open circuit wind tunnel to examine the flow-off properties of anti-icing fluids contaminated with various forms of simulated freezing precipitation to investigate several recent industry operational concerns. This work was completed in conjunction with the ice pellet research being conducted at the National Research Council Canada Propulsion Icing Wind Tunnel.

PROGRAM ACKNOWLEDGEMENTS

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

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Stephanie Bendickson, Michael Black, Geoffrey Clarke, John D'Avirro, Jesse Dybka, Benjamin Guthrie, Michael Hawdur, Arthur Hughes, Michael Jones, Michelle Pineau, Marco Ruggi, James Smyth, Michal Warchol, David Youssef, and Victoria Zoitakis.

Special thanks are extended to Howard Posluns, Yvan Chabot, Yagusha Bodnar, Doug Ingold and Warren Underwood, who on behalf of the Transportation Development Centre and the Federal Aviation Administration, 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 Yvan Chabot (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 Icing Wind for their diligence and commitment in providing support for the conduct of the experiments, as well as ABAX, Clariant, Dow, Kilfrost, and Octagon for their support in providing fluid samples required for this project, and Bombardier Aerospace for providing guidance in the design of the wing model.

REPORT ACKNOWLEDGEMENTS

The author would like to recognize the significant contributions of John D'Avirro, Priscilla Gravito, Michelle Pineau, David Youssef, and Victoria Zoitakis at APS Aviation Inc. for their support in preparing this report.

This page intentionally left blank.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 15160E

2. Project No.
B14W

3. Recipient's Catalogue No.

4. Title and Subtitle
Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2010-11

5. Publication Date
March 2012

6. Performing Organization Document No.
CM2169.003

7. Author(s)
Marco Ruggi

8. Transport Canada File No.
2450-BP-14

9. Performing Organization Name and Address
APS Aviation Inc.
6700 Cote-de-Liesse Rd., Suite 105
Montreal, Quebec, H4T 2B5

10. PWGSC File No.
MTB-8-25519

11. PWGSC or Transport Canada Contract No.
T8200-088510/001/MTB

12. Sponsoring Agency Name and Address
Transportation Development Centre
Transport Canada
330 Sparks St., 26th Floor
Ottawa, Ontario, K1A 0N5

13. Type of Publication and Period Covered
Final

14. Project Officer
Antoine Lacroix for Howard Posluns

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. The work described in this report was, in part, co-sponsored by the Federal Aviation Administration.

16. Abstract

This objective was met by conducting a series of full-scale tests using the National Research Council Canada (NRC) open-circuit wind tunnel to examine the flow-off properties of anti-icing fluids contaminated with various forms of simulated freezing precipitation to investigate several recent industry operational concerns; this work was completed in conjunction with the ice pellet research being conducted at the NRC Propulsion Icing Wind Tunnel.

- SURFACE ROUGHNESS AND HEAVY CONTAMINATION: For dry wing cases, the smooth light freezing rain adhered contamination did not have a significant impact on aerodynamic performance; however, the addition of ice pellets generated a much rougher surface which translated to larger lift losses. In the case of testing done with fluid, the results indicated that when severe levels of contamination are present, this can result in significant aerodynamic penalties.
- CLEAN LEADING EDGE: The test results demonstrated that the lift loss improved slightly as a result of the fluid being removed from the leading edge. However, it should be noted that in an operational scenario, the leading edge heater may result in "cooking" the fluid on the leading edge, and may cause residues to form. This potential residue may have a measurable thickness and roughness, and a resulting effect on lift loss.
- APPLYING INADEQUATE AMOUNTS OF FLUID: The visual observations supported the lift loss data which did not indicate significant differences in aerodynamic performance whether 2 L or 16-20 L were used. The results indicate that the improvement in aerodynamic performance when applying less fluid is not significant enough to offset the potential lift losses incurred from contamination due to early fluid failure.
- EFFECTS OF RAMP-UP TIME: For fluid only cases, PG fluids demonstrated approximately 0.08 percent decrease in lift loss per extra second in ramp-up time. For EG fluid, this was approximately half (0.03 percent). For the contamination cases, the PG fluids demonstrated a 0.22 percent and 0.64 percent decrease in lift loss per extra second in ramp-up time. This result indicated that in the case of contamination runs, the extra ramp-up time could have a more significant impact on resulting lift loss.
- MIXED PRECIPITATION CONDITIONS: The tests indicated a potential for an allowance times for Mixed Light Ice Pellets, Light Rain, and Snow, for Mixed Light Ice Pellets, Light Freezing Rain, and Snow, and for Mixed Light Freezing Rain, and Snow, however further testing would be required. The flap positioning during the test may play an important role on the development of the guidance, as a requirement to maintain flaps in a stowed position for as long as practical may be necessary.
- SNOW OR RAIN ON AN UN-PROTECTED WING: The dry snow test demonstrated that even with the cold wing skin temperature, the snow would not easily be blown off the wing during the ramp up. The majority of the snow was removed; however, a thin layer was still present at the time of rotation. During the test, it seemed difficult to ascertain the level of adhesion of the snow and difficult to predict whether it would be removed at rotation. The rain test however demonstrated an excellent flow-off of the rain present on the wing during the ramp-up.
- HEAVY SNOW: In general, the heavy snow testing results demonstrated similar visual and aerodynamic results (when compared to the moderate snow tests) for equivalent amounts of contamination, regardless of exposure time. These results indicate a potential to develop guidance material for heavy snow conditions, however a more extensive analysis of this and previous years data, along with flat plate testing data is required.
- MULTIPLE FLUID COMPARISON: It should be noted that although similar amounts of residual fluids were present in all the thickened fluid cases, the fluid dye provided a different visual indication as to how much fluid was present. For example, EG106 and AD-49 both use a very bright dye. If comparing these fluids to ABC-S+ or Launch, one might misinterpret the bright fluid remaining on the wing as an indication of poor fluid flow off, whereas all fluid generates similar residual thicknesses on the wing.

17. Key Words
Ice Pellet, Allowance Time, Fluid Adherence, Fluid Flow-Off, Wind Tunnel, Surface Roughness, Contaminated Flap, Inadequate Anti-Icing Application, Mixed Precipitation, Snow on an Un-Protected Wing, Heavy Snow

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
xxii, 72 apps

23. Price
—

CDT/TDC 79-005
Rev. 96

Canada

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. Nº de la publication de Transports Canada

TP 15160E

2. Nº de l'étude

B14W

3. Nº de catalogue du destinataire

4. Titre et sous-titre

Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2010-11

5. Date de la publication

Mars 2012

6. Nº de document de l'organisme exécutant

CM2169.003

7. Auteur(s)

Marco Ruggi

8. Nº de dossier - Transports Canada

2450-BP-14

9. Nom et adresse de l'organisme exécutant

APS Aviation Inc.
6700, Chemin de la Côte-de-Liesse, Bureau 105
Montréal (Québec) H4T 2B5

10. Nº de dossier - TPSGC

MTB-8-25519

11. Nº de contrat - TPSGC ou Transports Canada

T8200-088510/001/MTB

12. Nom et adresse de l'organisme parrain

Centre de développement des transports
Transports Canada
330, rue Sparks, 26ième étage
Ottawa (Ontario) K1A 0N5

13. Genre de publication et période visée

Final

14. Agent de projet

Antoine Lacroix pour Howard Posluns

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. Les travaux décrits dans ce rapport ont été en partie coparrainés par la Federal Aviation Administration.

16. Résumé

Cet objectif a été atteint en réalisant une série d'essais pleine grandeur dans la soufflerie à circuit ouvert du Conseil national de recherches Canada (CNRC) visant à examiner les propriétés de ruissellement de liquides d'antigivrage contaminés par diverses formes de précipitations givrantes simulées dans le but d'étudier de récentes préoccupations opérationnelles du secteur. Les travaux ont été réalisés en même temps que la recherche sur les granules de glace menée dans la soufflerie de givrage à propulsion du CNRC.

- RUGOSITÉ DES SURFACES ET FORTES CONTAMINATIONS : Sur les ailes sèches, la contamination par la pluie verglaçante légère lisse ayant adhéré à la surface n'a pas eu d'incidence considérable sur la performance aérodynamique ; toutefois, l'ajout de granules de glace a généré une surface beaucoup plus rugueuse, ce qui s'est traduit par des pertes de portance plus importantes. Les résultats des essais menés avec du liquide ont démontré que la présence d'une forte contamination peut entraîner des pertes d'aérodynamisme importantes.

- BORD D'ATTAQUE PROPRE : Les résultats des essais ont démontré que la perte de portance était légèrement réduite lorsque le liquide était enlevé du bord d'attaque. Il convient toutefois de noter que dans un scénario opérationnel, le réchauffeur de bord d'attaque peut entraîner la « cuisson » du liquide et, par le fait même, la formation de résidus. Ces résidus potentiels peuvent présenter une épaisseur et une rugosité mesurables et donner lieu à une perte de portance.

- APPLICATION DE QUANTITÉS INADÉQUATES DE LIQUIDE : Les observations visuelles ont confirmé les données sur la perte de portance, lesquelles n'ont pas démontré de différences considérables sur le plan de la performance aérodynamique selon l'application de 2 L ou de 16 à 20 L de liquide. Les résultats démontrent que l'amélioration de la performance aérodynamique lorsqu'une quantité moindre de liquide est appliquée n'est pas suffisamment importante pour compenser les pertes de portance potentielles engendrées par la contamination attribuable à la perte d'efficacité précoce du liquide.

- EFFETS DU TEMPS D'ACCÉLÉRATION : Lors des essais menés avec du liquide non contaminé, les liquides à base de propylène glycol ont démontré que la perte de portance était réduite d'environ 0,08 pour cent par seconde d'accélération supplémentaire. Pour les liquides à base de propylène glycol, ce pourcentage était d'environ la moitié (0,03 pour cent). Lors des essais avec contamination, les liquides à base de propylène glycol ont démontré que la perte de portance était réduite de 0,22 pour cent et de 0,64 pour cent par seconde d'accélération supplémentaire. Ces résultats indiquent qu'un temps d'accélération plus long pourrait avoir une incidence plus importante sur la perte de portance qui en découle en présence de contamination.

- CONDITIONS DE PRÉCIPITATIONS MIXTES : Les essais ont indiqué la possibilité de déterminer des marges de tolérance dans des conditions mixtes de granules de glace légers, de pluie légère et de neige, de granules de glace légers, de pluie verglaçante légère et de neige et de pluie verglaçante légère et de neige ; il serait toutefois nécessaire de réaliser des essais supplémentaires. Le positionnement du volet durant l'essai pourrait jouer un rôle important dans l'élaboration des lignes directrices, lesquelles pourraient exiger de garder les volets rentrés pendant aussi longtemps que nécessaire.

- NEIGE OU PLUIE SUR UNE AILE NON PROTÉGÉE : Les essais menés avec de la neige sèche ont démontré que celle-ci ne serait pas facilement balayée des ailes durant l'accélération, même lorsque la température du revêtement de la voilure est basse. La neige a presque totalement été éliminée, mais une mince couche était toujours présente au moment de la rotation. Durant l'essai, il a semblé difficile de déterminer le niveau d'adhérence de la neige et de prédire si celle-ci serait balayée au moment de la rotation. L'essai mené avec de la pluie a quant à lui démontré un excellent ruissellement de la pluie se trouvant sur l'aile durant l'accélération.

- NEIGE LOURDE : En général, les essais menés avec de la neige lourde ont généré des résultats semblables sur le plan visuel et aérodynamique (par rapport aux essais menés avec de la neige modérée) pour des quantités équivalentes de contaminants, peu importe le temps d'exposition. Ces résultats indiquent la possibilité de développer des lignes directrices pour les conditions de neige lourde ; une analyse plus approfondie des données de cette année et des années précédentes, de même que des essais menés sur plaque plane, est toutefois requise.

- COMPARAISON DE PLUSIEURS LIQUIDES : Il convient de noter que même si tous les essais menés avec du liquide épaissi ont donné lieu à des quantités semblables de liquide résiduel, le colorant a fourni une indication visuelle différente quant à la quantité de liquide présente. Par exemple, les liquides EG106 et AD-49 utilisent tous deux un colorant très vif. Une personne qui compare ces liquides aux liquides ABC-S+ ou Launch pourrait croire à tort que le liquide vif qui reste sur l'aile est un signe d'un mauvais ruissellement, alors que tous les liquides génèrent des épaisseurs résiduelles semblables sur l'aile.

17. Mots clés

Granule de glace, marge de tolérance, adhérence de liquide, écoulement de liquide, soufflerie, rugosité de surface, volet contaminé, application antigivrage inadéquate, précipitation mixte, neige sur une aile non protégée, neige lourde

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

xxii, 72 ann

23. Prix

—

CDT/TDC 79-005
Rev. 96

EXECUTIVE SUMMARY

Background

Under contract to the Transportation Development Centre (TDC), with financial support from the Federal Aviation Administration (FAA), APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology. APS conducted a series of full-scale tests in the National Research Council Canada (NRC) 3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel (PIWT) to determine the flow-off characteristics of anti-icing fluid with and without simulated frozen precipitation contamination

As a result of the large fixed costs associated with the aerodynamic portion of the research, and to benefit from economies of scale, Transport Canada (TC) and the FAA opted to conduct a series of preliminary tests to investigate several recent industry operational concerns. This work was completed in conjunction with the ice pellet research being conducted at the NRC PIWT, details of which are described 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 in a future winter.

Effects of Surface Roughness and Heavy Contamination

For dry wing cases, the smooth light freezing rain adhered contamination did not have a significant impact on aerodynamic performance, however, the addition of ice pellets generated a much rougher surface, which translated into larger lift losses. In the case of testing done with fluid, the results indicated that when severe levels of contamination are present, this can result in significant aerodynamic penalties.

Effects of a Clean Leading Edge Simulating Leading Edge Dry-Out

The test results demonstrated that the lift loss improved slightly as a result of the fluid being removed from the leading edge. However, it should be noted that in an operational scenario, the leading edge heater may result in “cooking” the fluid on the leading edge, and may cause residues to form. This potential residue may have a measurable thickness and roughness, and a resulting effect on lift loss.

Effects of Applying Inadequate Amounts of Anti-Icing Fluid

The visual observations supported the lift loss data, which did not indicate significant differences in aerodynamic performance whether 2 L or 16-20 L were used. The results indicate that the improvement in aerodynamic performance when applying less fluid is not significant enough to offset the potential lift losses incurred from contamination due to early fluid failure.

Effects of Ramp-Up Time on Fluid Flow-Off

For fluid only cases, propylene glycol (PG) fluids demonstrated approximately 0.08 percent decrease in lift loss per extra second in ramp-up time. For ethylene glycol (EG) fluid, this was approximately half (0.03 percent). For the contamination cases, the PG fluids demonstrated a 0.22 percent and 0.64 percent decrease in lift loss per extra second in ramp-up time. This result indicated that in the case of contamination runs, the extra ramp-up time could have a more significant impact on resulting lift loss.

Effects Mixed Precipitation Conditions

The tests indicated a potential for allowance times for Mixed Light Ice Pellets, Light Rain, and Snow, for Mixed Light Ice Pellets, Light Freezing Rain, and Snow, and for Mixed Light Freezing Rain, and Snow; however, further testing would be required. The flap positioning during the test may play an important role on the development of the guidance, as a requirement to maintain flaps in a stowed position for as long as practical may be necessary.

Effects of Snow or Rain on an Unprotected Wing

The dry snow test demonstrated that even with the cold wing skin temperature, snow would not easily be blown off the wing during the ramp up. The majority of the snow was removed; however, a thin layer was still present at the time of rotation. During the test, it seemed difficult to ascertain the level of adhesion of the snow and difficult to predict whether it would be removed at rotation.

The rain test however demonstrated an excellent flow-off of the rain present on the wing during the ramp-up.

Heavy Snow

In general, the heavy snow testing results demonstrated similar visual and aerodynamic results (when compared to the moderate snow tests) for equivalent amounts of contamination, regardless of exposure time. These results indicate a potential to develop guidance material for heavy snow conditions. However, a more extensive analysis of this and previous year’s data, along with flat plate testing data, is required.

Comparison of Multiple Fluid Flow-Off Properties

It should be noted that although similar amounts of residual fluids were present in all the thickened fluid cases, the fluid dye provided a different visual indication as to how much fluid was present. For example, EG106 and AD-49 both use a very bright dye. If comparing these fluids to ABC-S+ or Launch, one might misinterpret the bright fluid remaining on the wing as an indication of poor fluid flow-off, whereas all fluids generate similar residual thicknesses on the wing.

This page intentionally left blank.

SOMMAIRE

Contexte

Dans le cadre d'un contrat avec le Centre de développement des transports (CDT) et avec l'appui financier de la Federal Aviation Administration (FAA), APS Aviation Inc. (APS) a entrepris des activités de recherche visant à faire progresser les technologies associées au dégivrage et à l'antigivrage d'aéronefs au sol. APS a mené une série d'essais pleine grandeur dans la soufflerie de givrage à propulsion et à circuit ouvert de 3 m sur 6 m du Conseil national de recherches Canada (CNRC) afin de déterminer les caractéristiques de ruissellement du liquide d'antigivrage avec et sans contamination par des précipitations gelées simulées.

En raison des importants coûts fixes associés à la partie aérodynamique de la recherche et pour profiter des économies d'échelle, Transports Canada (TC) et la FAA ont décidé de mener une série d'essais préliminaires afin d'étudier plusieurs préoccupations opérationnelles récentes du secteur. Ces travaux ont été réalisés en même temps que la recherche sur les granules de glace menée dans la soufflerie de givrage à propulsion du CNRC, dont les détails figurent dans un rapport provisoire, lequel a été transmis à TC et à la FAA. Une version définitive devrait être publiée une fois la recherche terminée, dans un hiver à venir.

Effets de la rugosité des surfaces et des fortes contaminations

Sur les ailes sèches, la contamination par la pluie verglaçante légère lisse ayant adhéré à la surface n'a pas eu d'incidence considérable sur la performance aérodynamique ; toutefois, l'ajout de granules de glace a généré une surface beaucoup plus rugueuse, ce qui s'est traduit par des pertes de portance plus importantes. Les résultats des essais menés avec du liquide ont démontré que la présence d'une forte contamination peut entraîner des pertes d'aérodynamisme importantes.

Effets d'un bord d'attaque propre simulant l'accumulation de résidus

Les résultats des essais ont démontré que la perte de portance était légèrement réduite lorsque le liquide était enlevé du bord d'attaque. Il convient toutefois de noter que dans un scénario opérationnel, le réchauffeur de bord d'attaque peut entraîner la « cuisson » du liquide et, par le fait même, la formation de résidus. Ces résidus potentiels peuvent présenter une épaisseur et une rugosité mesurables et donner lieu à une perte de portance.

Effets de l'application de quantités inadéquates de liquide d'antigivrage

Les observations visuelles ont confirmé les données sur la perte de portance, lesquelles n'ont pas démontré de différences considérables sur le plan de la performance aérodynamique selon l'application de 2 L ou de 16 à 20 L de liquide. Les résultats démontrent que l'amélioration de la performance aérodynamique lorsqu'une quantité moindre de liquide est appliquée n'est pas suffisamment importante pour compenser les pertes de portance potentielles engendrées par la contamination attribuable à la perte d'efficacité précoce du liquide.

Effets du temps d'accélération sur le ruissellement du liquide

Lors des essais menés avec du liquide non contaminé, les liquides à base de propylène glycol ont démontré que la perte de portance était réduite d'environ 0,08 pour cent par seconde d'accélération supplémentaire. Pour les liquides à base de propylène glycol, ce pourcentage était d'environ la moitié (0,03 pour cent). Lors des essais avec contamination, les liquides à base de propylène glycol ont démontré que la perte de portance était réduite de 0,22 pour cent et de 0,64 pour cent par seconde d'accélération supplémentaire. Ces résultats indiquent qu'un temps d'accélération plus long pourrait avoir une incidence plus importante sur la perte de portance qui en découle en présence de contamination.

Effets des conditions de precipitations mixtes

Les essais ont indiqué la possibilité de déterminer des marges de tolérance dans des conditions mixtes de granules de glace légers, de pluie légère et de neige, de granules de glace légers, de pluie verglaçante légère et de neige et de pluie verglaçante légère et de neige ; il serait toutefois nécessaire de réaliser des essais supplémentaires. Le positionnement du volet durant l'essai pourrait jouer un rôle important dans l'élaboration des lignes directrices, lesquelles pourraient exiger de garder les volets rentrés pendant aussi longtemps que nécessaire.

Effets de la neige ou de la pluie sur une aile non protégée

Les essais menés avec de la neige sèche ont démontré que celle-ci ne serait pas facilement balayée des ailes durant l'accélération, même lorsque la température du revêtement de la voilure est basse. La neige a presque totalement été éliminée, mais une mince couche était toujours présente au moment de la rotation. Durant l'essai, il a semblé difficile de déterminer le niveau d'adhérence de la neige et de prédire si celle-ci serait balayée au moment de la rotation.

L'essai mené avec de la pluie a quant à lui démontré un excellent ruissellement de la pluie se trouvant sur l'aile durant l'accélération.

Neige lourde

En général, les essais menés avec de la neige lourde ont généré des résultats semblables sur le plan visuel et aérodynamique (par rapport aux essais menés avec de la neige modérée) pour des quantités équivalentes de contaminants, peu importe le temps d'exposition. Ces résultats indiquent la possibilité de développer des lignes directrices pour les conditions de neige lourde ; une analyse plus approfondie des données de cette année et des années précédentes, de même que des essais menés sur plaque plane, est toutefois requise.

Comparaison des propriétés de ruissellement de plusieurs liquides

Il convient de noter que même si tous les essais menés avec du liquide épaissi ont donné lieu à des quantités semblables de liquide résiduel, le colorant a fourni une indication visuelle différente quant à la quantité de liquide présente. Par exemple, les liquides EG106 et AD-49 utilisent tous deux un colorant très vif. Une personne qui compare ces liquides aux liquides ABC-S+ ou Launch pourrait croire à tort que le liquide vif qui reste sur l'aile est un signe d'un mauvais ruissellement, alors que tous les liquides génèrent des épaisseurs résiduelles semblables sur l'aile.

This page intentionally left blank.

CONTENTS Page

LIST OF APPENDICES

LIST OF FIGURES Page

LIST OF TABLES Page

LIST OF PHOTOS Page

GLOSSARY

APS	APS Aviation Inc.
BLDT	Boundary Layer Displacement Thickness
CEF	Climatic Engineering Facility
FAA	Federal Aviation Administration
HOT	Holdover Time
MSC	Meteorological Service of Canada
NRC	National Research Council Canada
OAT	Outside Air Temperature
PIWT	3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel
TC	Transport Canada
TDC	Transportation Development Centre

This page intentionally left blank.

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.

1.1 Background

Due to the recent industry requirement for guidance material for aircraft operations in mixed precipitation conditions with ice pellets, APS conducted a series of plate tests in the NRC Climatic Engineering Facility (CEF) and full-scale aerodynamic testing in the NRC 3 m x 6 m Open-Circuit Propulsion Icing Wind Tunnel (PIWT) and with the NRC Falcon 20 aircraft. This ongoing research was conducted during the winters of 2005-06 to 2010-11 to characterize fluid failure mechanisms, to determine the flow-off properties of anti-icing fluid contaminated with mixed conditions including ice pellets, and to substantiate and possibly expand the newly developed ice pellet allowance times.

As a result of the large fixed costs associated with the aerodynamic portion of the research, and to benefit from economies of scale, TC and the FAA opted to conduct a series of preliminary tests to investigate several recent industry operational concerns. This work was completed in conjunction with the ice pellet research being conducted at the NRC PIWT. Details of the 2010-11 ice pellet allowance time related research can be found in an interim report documenting wind tunnel research to support the development of ice pellet allowance time tables, which was provided to TC and the FAA. A final report is expected to be published once the research is completed in a future winter.

1.2 Previous Reports

Previous reports describing the research and development objectives conducted in previous years in the NRC wind tunnel have been compiled and are available. In 2008-09 and 2009-10, comprehensive reports describing the R&D objectives were compiled and can be referenced as TC report, TP 14939E, *Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09* (1) and TC report, TP 15057E, *Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2009-10* (2). In 2006-07, a feasibility report describing the potential for using the wind tunnel and Falcon 20 aircraft for R&D testing initiatives was compiled and can be referenced as TC report, TP 14778E, *Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report* (3).

1.3 Program Objectives

APS conducted a series of preliminary tests during the winter of 2010-11 to investigate several recent industry concerns. Aerodynamic research was focused towards the fluid flow-off properties of contaminated and uncontaminated fluid simulating different operational scenarios. Aerodynamic testing was conducted in conjunction with the ice pellet allowance time research program.

A preliminary test plan was developed for the winter of 2010-11. Testing was conducted with and without contamination. Research was conducted to satisfy the following objectives:

- Examination of the effects of surface roughness and heavy contamination on aerodynamic performance;
- Examination of the aerodynamic effects of a clean leading edge simulating leading edge heater dry-out;
- Examination of the aerodynamic effects of applying inadequate amounts of anti-icing fluid;
- Examination of the aerodynamic effects of ramp-up time on fluid flow-off;
- Examination of mixed precipitation conditions;
- Examination of the aerodynamic effects of snow or rain on an unprotected wing;
- Effects of wing geometry on fluid settling properties and resulting flow-off;
- Examination of the aerodynamic effects of heavy snow; and
- Comparison of multiple fluid flow-off properties.

The results from this work are reported in Sections 2 to 10 of this report. The work statement for these tests is provided in Appendix A.

An additional test with Type III fluid was attempted, but due to technical issues with the wind tunnel, no data was collected and therefore the results are not described in this report.

1.4 Overview of 2010-11 Testing

Full-scale testing during the winter of 2010-11 was conducted using the NRC PIWT. The primary testing conducted aimed at validating the current allowance times for use with newer generation aircraft with supercritical wing designs and to develop a correlation between the lift losses observed in the wind tunnel and the boundary layer displacement thickness (BLDT) results used as the basis of the aerodynamic acceptance for fluid certification.

In addition, some preliminary work was conducted as a lower priority to address current industry concerns. These secondary research objectives have been outlined in Subsection 1.2, and the details of this work are described in this report.

Table 1.1 demonstrates the groupings for the global set of tests conducted at the wind tunnel during the winter of 2010-11. Tests listed in group #4 are described in this report (some baseline tests from groups #2 and #3 are also referenced). Table 1.2 demonstrates in greater detail the groupings for the secondary R&D objective tests.

Table 1.1: Summary of 2010-11 Wind Tunnel Tests by Objective

1. ICE PELLET ALLOWANCE TIMES **TOTAL RUNS: 61** 6, 7, 8, 10, 14, 15, 15A, 15B, 20, 22, 23, 24, 25, 26, 27, 28, 31, 35, 37, 38, 40, 41, 41A, 44, 45, 46, 47, 51, 53, 56, 58, 59, 59A, 69, 70, 72, 73, 74, 78, 79, 82, 83, 84, 85, 92, 92A, 93, 102, 103, 104, 105, 106, 115, 116, 117, 121, 126, 128, 129, 131, 132	**3. BASELINE (BLDT)** **TOTAL RUNS: 42** 5, 5A, 9, 12, 21, 29, 30, 32, 33, 34, 36, 39, 42, 43, 48, 49, 50, 52, 54, 55, 57, 60, 61, 62, 63, 66, 67, 68, 71, 75, 76, 77, 80, 81, 86, 86A, 94, 95, 95A, 96, 97, 107
2. DRY WING **TOTAL RUNS: 8** 1, 2, 3, 65, 100, 112, 119, 120	**4. RESEARCH & DEVELOPMENT** **TOTAL RUNS: 37** 4, 11, 13, 16, 17, 18, 19, 64, 64A, 87, 88, 89, 90, 91, 98, 99. 101, 108, 108A, 109, 110, 111, 113, 114, 118, 122, 123, 124, 125, 127, 127A, 130, 133, 134, 135, 136, 137
TOTAL NUMBER OF RUNS **148**	

Table 1.2: Summary of 2010-11 Secondary R&D Objectives

OBJECTIVE	RUN #	TOTAL RUNS
Surface Roughness and Heavy Contamination	64, 64A, 111, 125, 127, 127A, 137	**7**
LE Heater (Clean LE)	99	**1**
Inadequate Fluid Application	98	**1**
Effect of Ramp-up Time	11, 13, 122, 123, 124	**5**
Mixed Precipitation	114, 118, 133, 134, 135, 136	**6**
Snow or Rain with No Fluid	101, 113	**2**
Wing Geometry	130	**1**
Heavy Snow	16, 17, 18, 19, 87, 88, 89, 108, 108A, 109, 110	**11**
Multiple Fluids	90, 91	**2**
Type III	4	**1**
	TOTAL	**37**

1.5 General Methodology

To satisfy the program objective, simulated takeoff and climb-out tests were performed with the supercritical wing section, and different parameters, including fluid thickness, wing temperature, and fluid freezing point, were recorded at designated times during the tests. The supercritical wing section was constructed by the NRC specifically to conduct these tests following extensive consultations with an airframe manufacturer to ensure a representative supercritical design was used.

The typical procedure for each test was as follows:

a) The wing section was treated with anti-icing 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 high-speed still cameras. In addition, windows overlooking the wing section allowed observers to document the fluid elimination performance in real-time. Aerodynamic data was collected by the NRC and used to further analyse the tests.

The procedure for the wind tunnel tests is included in Appendix B. The procedure includes details regarding the test objectives, test plan, procedure and methodology, and pertinent information and documentation.

This general methodology was modified as necessary in order to satisfy the individual test objectives. Deviation from this methodology will be described in the individual test results section.

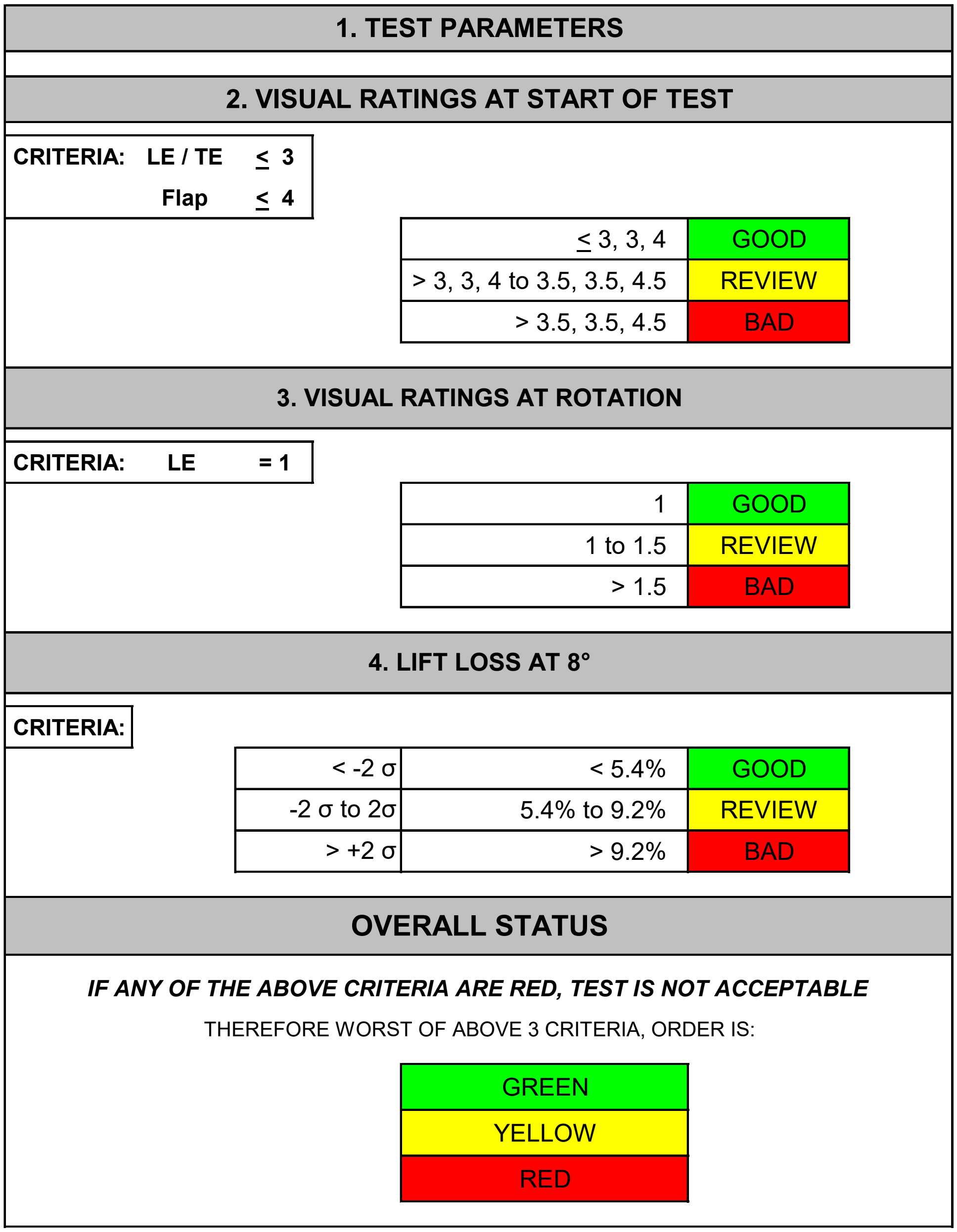
1.6 General Analysis Methodology

A thorough and extensive analysis methodology has been developed and applied for the ice pellet allowance time testing. This is described in an interim report documenting wind tunnel research to support the development of ice pellet allowance time tables, which was provided to TC and the FAA. A final report is expected to be published once the research is completed in a future winter. This analysis methodology has been applied when applicable for analysing the tests described in this report.

Typically, each test is analysed in detail using the following objectives:

a) Test parameters;
b) Visual ratings at the start of the test;
c) Visual ratings at rotation;
d) 8° lift loss; and
e) Overall test status.

The evaluation grades for each criterion were “good,” “review,” or “bad.” These grades were determined based on whether the criteria satisfied each test objective requirement. Figure 1.1 shows a summary of each test objective and criteria. These evaluation criteria were applied as necessary to the analysis of the tests described in this report.



1. TEST PARAMETERS

2. VISUAL RATINGS AT START OF TEST

CRITERIA: **LE / TE** **≤ 3**
Flap **≤ 4**

≤ 3, 3, 4	GOOD
> 3, 3, 4 to 3.5, 3.5, 4.5	REVIEW
> 3.5, 3.5, 4.5	BAD

3. VISUAL RATINGS AT ROTATION

CRITERIA: **LE** **= 1**

1	GOOD
1 to 1.5	REVIEW
> 1.5	BAD

4. LIFT LOSS AT 8°

CRITERIA:

< -2 σ	< 5.4%	GOOD
-2 σ to 2σ	5.4% to 9.2%	REVIEW
> +2 σ	> 9.2%	BAD

OVERALL STATUS

IF ANY OF THE ABOVE CRITERIA ARE RED, TEST IS NOT ACCEPTABLE

THEREFORE WORST OF ABOVE 3 CRITERIA, ORDER IS:

GREEN
YELLOW
RED

Figure 1.1: Wind Tunnel Test Analysis Criteria

1.7 General Data

For documentation purposes, data that was collected during the wind tunnel tests has been included in this report regardless of whether or not the information was used for analysis. Appendix C contains the general test log that includes all tests conducted during the winter of 2010-11. Appendix D contains the photo summaries for each of the R&D tests. Additional data provided by the NRC (aerodynamic data), as well as the data forms filled out by APS that include fluid thickness, Brix, and skin temperature information, is available in electronic format, and a copy has been included in a DVD along with this report.

1.8 Report Format

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

a) Section 2 describes the data, results, and observations for the surface roughness and heavy contamination tests;

b) Section 3 describes the data, results, and observations for the clean leading edge due to the simulated leading edge heater dry-out tests;

c) Section 4 describes the data, results, and observations for the inadequate fluid application tests;

d) Section 5 describes the data, results, and observations for the effects of ramp-up time tests;

e) Section 6 describes the data, results, and observations for the mixed precipitation conditions tests;

f) Section 7 describes the data, results, and observations for the snow or rain on an unprotected wing tests;

g) Section 8 describes the data, results, and observations for the effects of wing geometry on fluid tests;

h) Section 9 describes the data, results, and observations for the heavy snow tests; and

i) Section 10 describes the data, results, and observations for the comparison of multiple fluid flow-off properties tests.

It should be noted that the format of this year’s report is more abbreviated compared to previous years as a result of budgetary restrictions. The report has been abbreviated to include a summary of the results obtained. Data for each respective test is available if additional analysis is required.

This page intentionally left blank.

2. EFFECTS OF SURFACE ROUGHNESS AND HEAVY CONTAMINATION

2.1 Background

The current generation of "regional jet" aircraft were developed with thin, flat, high-performance wing designs. Some of these aircraft require strict maintenance procedures to ensure a polished leading edge, as minimal amounts of contamination (in the form of bugs, etc.) can result in serious aerodynamic penalties. The same requirement applies for the removal of contamination in the form of frozen precipitation.

Previous testing in the wind tunnel with NACA 23012 and LS-0417 airfoils demonstrated that although contamination was present on the wing section, significant lift losses were not apparent. Lift losses were incurred upon application of anti-icing fluid (when compared to a bare wing). The presence of contamination, whether adhered or not, did not generate significant list losses when compared to the uncontaminated fluid. Although the presence of adhered contamination may be hazardous with regards to control surfaces, the impact of the surface roughness on the overall aerodynamic performance of the wing needs to be investigated.

It was recommended that some preliminary work be conducted with a new generation of thin high-performance wings to investigate the effects of various types of adhered frozen contamination on the aerodynamic performance of the airfoil.

2.2 Objective

The objective is to investigate wing surface roughness, with and without fluid, and how it affects lift loss.

2.3 General Methodology

The following is a brief summary of the methodology used for this testing:

- Ensure outside air temperature (OAT) is below -5°C to ensure cold-adhered contamination;
- Apply fluid to wing section (if part of test objective) and begin the application of precipitation for a pre-determined amount of time;
- Run wind tunnel tests and collect lift loss data; and
- Compare results to typical dry wing results.

2.4 Data Collected

Seven tests were conducted: four tests with contamination applied to a bare dry wing, and three tests with fluid exposed to heavy contamination. A summary of the test data is included in Table 2.1.

2.5 Summary of Test Results

2.5.1 Bare Dry Wing Results

Four tests were conducted: Tests #127 and #127A with light freezing rain only applied to a dry wing, and Tests #64 and #64A with freezing rain and ice pellets applied to a dry wing. Photos 2.1 to 2.4 show the condition of the wing before the start of the takeoff run for these four tests.

Test #127, conducted with light freezing rain only, demonstrated that although a significant amount of frozen contamination was present on the wing, the contamination was relatively smooth and completely adhered to the wing throughout the whole takeoff test. The test results indicated a lift loss of 2.88 percent.

Test #127A was a continuation of the previous test (#127), where additional light freezing rain was applied to the wing section. The overall result was that the additional freezing rain further smoothed out the roughness. The test results from test #127A demonstrated that the aerodynamic performance improved with a lift loss of only 1.13 percent (compared to 2.88 percent in Test #127).

Test #64 was conducted with light freezing rain and ice pellets. This combination generated a rougher type of adhered contamination compared to light freezing rain alone; the ice pellets would adhere to the surface and protrude due to their size. The test results demonstrated that a higher lift loss of 5.2 percent was incurred as a result of the frozen contamination, indicating that the frozen ice pellets in addition to the light freezing rain had an impact on the aerodynamic performance.

Test #64A was a continuation of the previous test (#64), where additional ice pellets and light freezing rain were applied to the wing leading edge stagnation point. As expected, the test results from test #64A demonstrated that the aerodynamic performance worsened with a lift loss of 8.72 percent (compared to 5.2 percent in Test #64).

Table 2.1: Summary of 2010-11 Surface Roughness and Heavy Contamination Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm^2/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8º Rotation	% Lift Loss	Comments
64	27-Jan-11	Dry	N/A	ZR/IP	IP 10, ZR 25	10	-5.1	0.3	5, 5, 5	5, 5, 5	1.348	5.20	
64A	27-Jan-11	Dry	N/A	ZR/IP	IP 10, ZR 25	10	-5.6	-0.9	5, 5, 5	5, 5, 5	1.298	8.72	Cont. From #64 plus added extra cont to LE Stag by Hand
111	3-Feb-11	2031 - Cold	N/A	S mixed and also applied	Extra S 10	Extra 5	-6.3	-15.3	2.5, 2.5, 3	1.25, 2, 2.25	1.325	6.82	10L fluid mixed with 10kg snow, then added more snow
125	8-Feb-11	2031	N/A	S	Mixed Two Buckets: 5L of 2031 with 15L NATURAL Snow		-11.8	-17.2	4, 4, 4	1.4, 2.4, 2.5	1.156	18.71	Snow/Fluid Mixture spread on wing
127	8-Feb-11	None	N/A	ZR	ZR 25	Approx 5	-10.7	-6.2	5, 5, 5	5, 5, 5	1.381	2.88	
127A	8-Feb-11	None	N/A	ZR	ZR 35	Approx 12	-8.8	-3.7	5, 5, 5	5, 5, 5	1.406	1.13	Cont. Added to left over from 127 as little came off
137	10-Feb-11	ABC-S+	N/A	IP+/SN+	IP 200, SN 100	30	-3.5	-10.1	4.3, 4.3, 4.3	1.8, 2.3, 4.3	1.113	21.73	

In general, the results were as expected. Similar to previous wind tunnel test results, the smooth light freezing rain adhered contamination did not have a significant impact on aerodynamic performance. However, the addition of ice pellets generated a much rougher surface, which translated to larger lift losses.

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further substantiate these observations.

2.5.2 Fluid Results

Three tests were conducted: Tests #111 and #125 with Type III fluid and snow, and Test #137 with PG Type IV fluid exposed to heavy snow and ice pellets. Photos 2.5 to 2.10 show the condition of the wing before the start of the takeoff run and just before rotation for these three tests.

Test #111 aimed at saturating a fluid with snow. A total of 10 L of fluid were mixed with approximately 10 kg of natural snow. Once the mixture was homogenous, the thick slush was applied to the wing surface by pouring, and additional snow was applied over top. The test results demonstrated that a lift loss of 6.82 percent was incurred as a result of the frozen contamination, indicating that the condition was not severe. The test was repeated as #125.

Test #125 aimed at generating a more severe level of contamination than #111. A total of 5 L of fluid were mixed with 15 L of natural snow (approximately 8 kg to 9 kg of natural snow). Once the mixture was homogenous, the thick slush was applied to the wing surface; however, it needed to be spread due to the thick density of the slush. The test results indicated a lift loss of 18.71 percent. This result was as expected due to the density of the slush applied to the wing.

Test #137 aimed at generating a severely contaminated fluid on a wing. The fluid was exposed to a combined precipitation rate of 300 g/dm^2/h, which resulted in severely failed fluid and a blanket of white bridging precipitation on the top of the fluid. During acceleration, the loose bridging contamination was removed first, and then the fluid began to shear. The test results indicated a lift loss of 21.73 percent. The visual observations indicated that the snow may have been a factor in the poor flow-off; however, this needs to be further investigated.

In general, the results indicated that when severe levels of contamination are present, this can result in significant aerodynamic penalties.

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further substantiate these observations.

Photo 2.1: Test #64 – Before Start of Takeoff Run

Photo 2.2: Test #64A – Before Start of Takeoff Run

Photo 2.3: Test #127 – Before Start of Takeoff Run

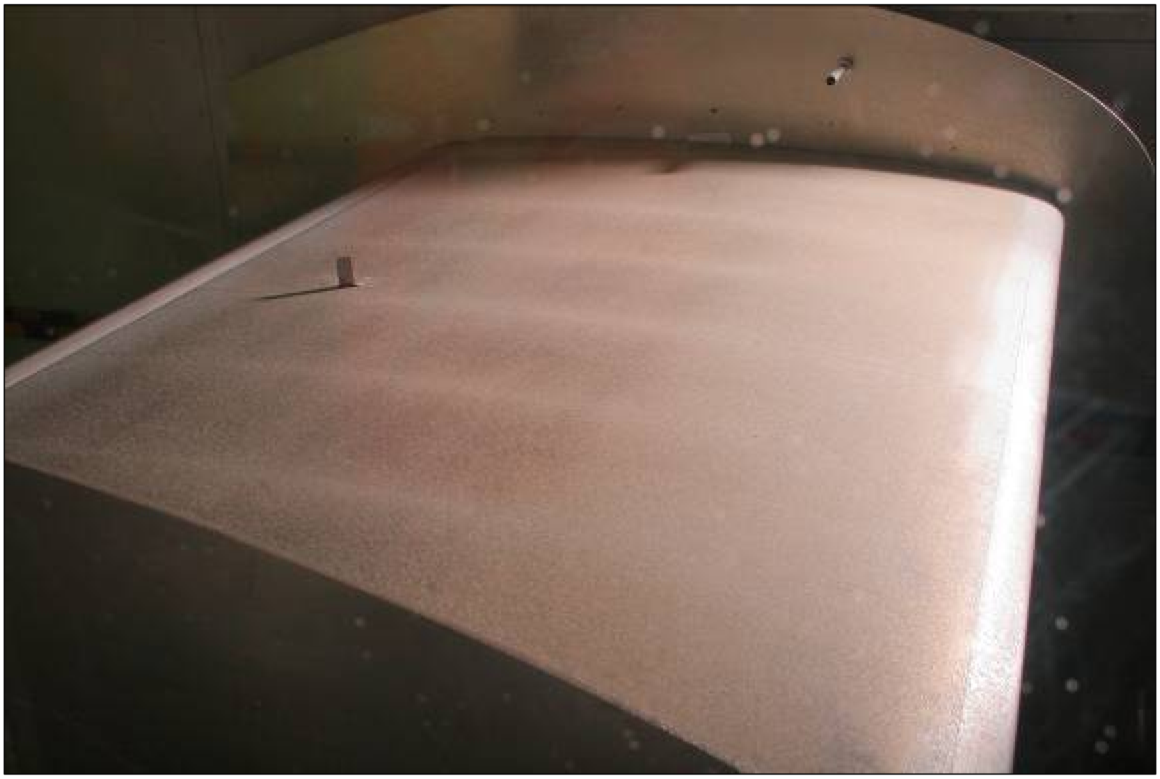


Photo 2.4: Test #127A – Before Start of Takeoff Run

Photo 2.5: Test #111– Before Start of Takeoff Run

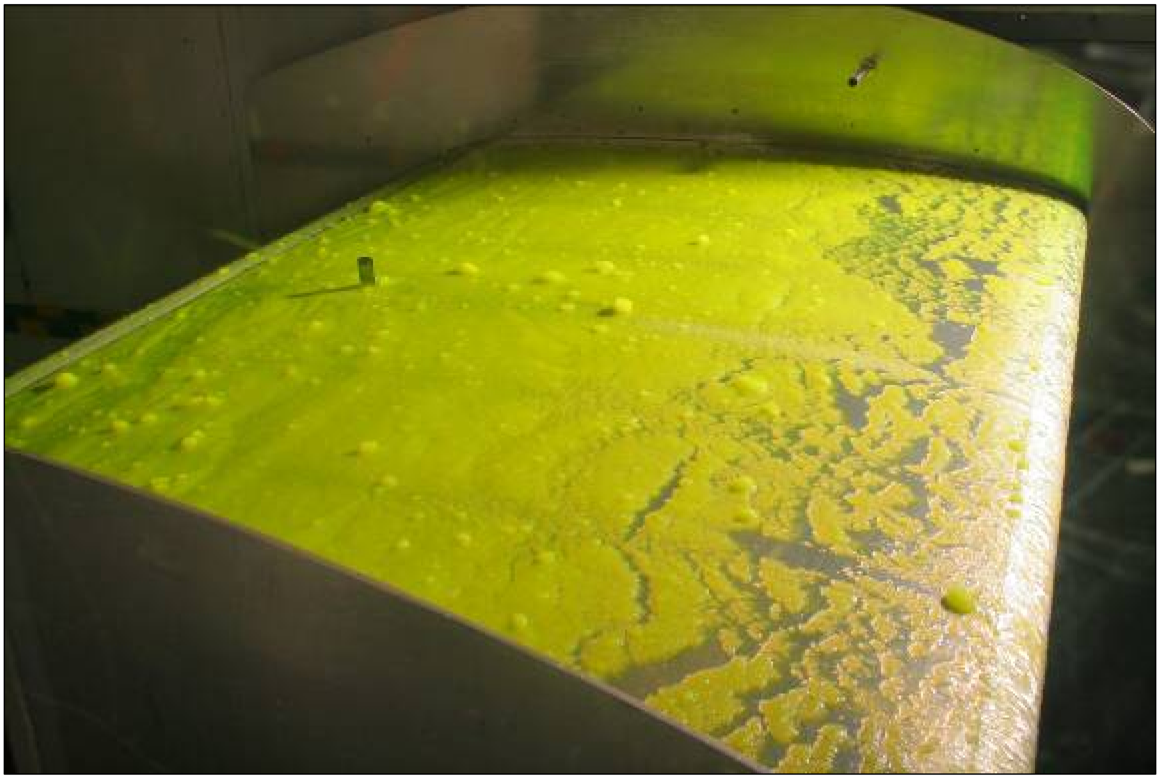


Photo 2.6: Test #111 – Before Rotation

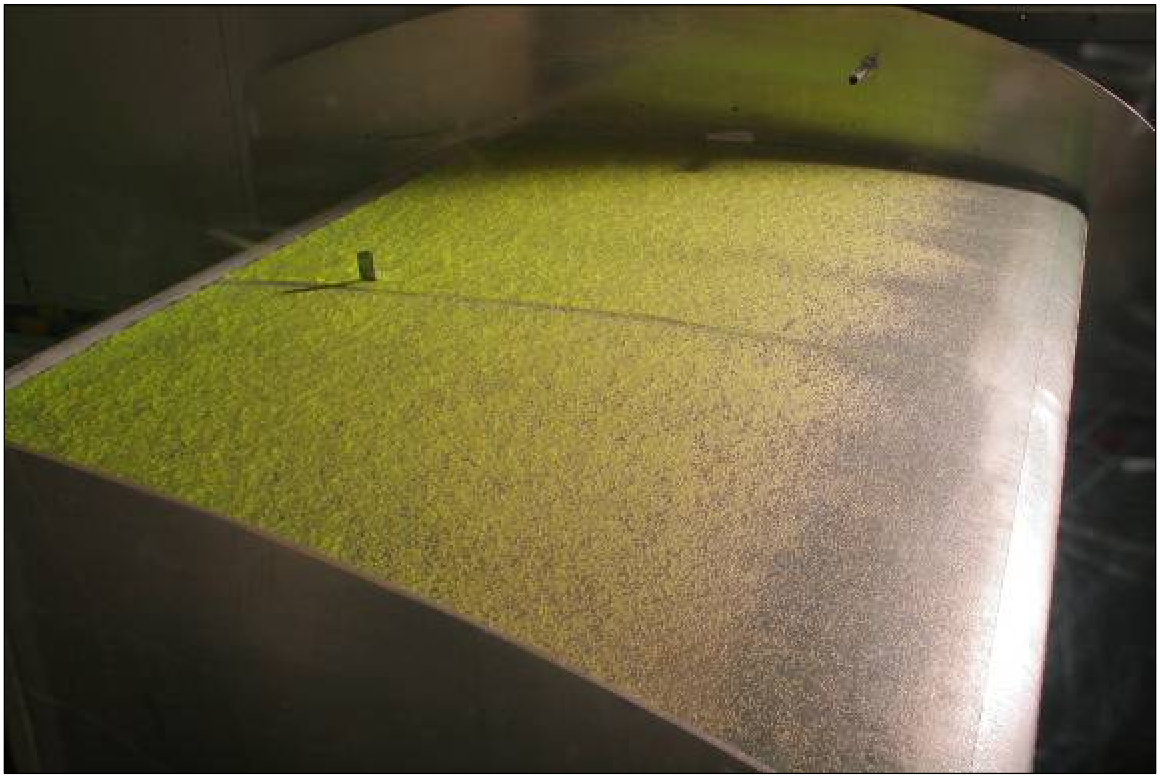
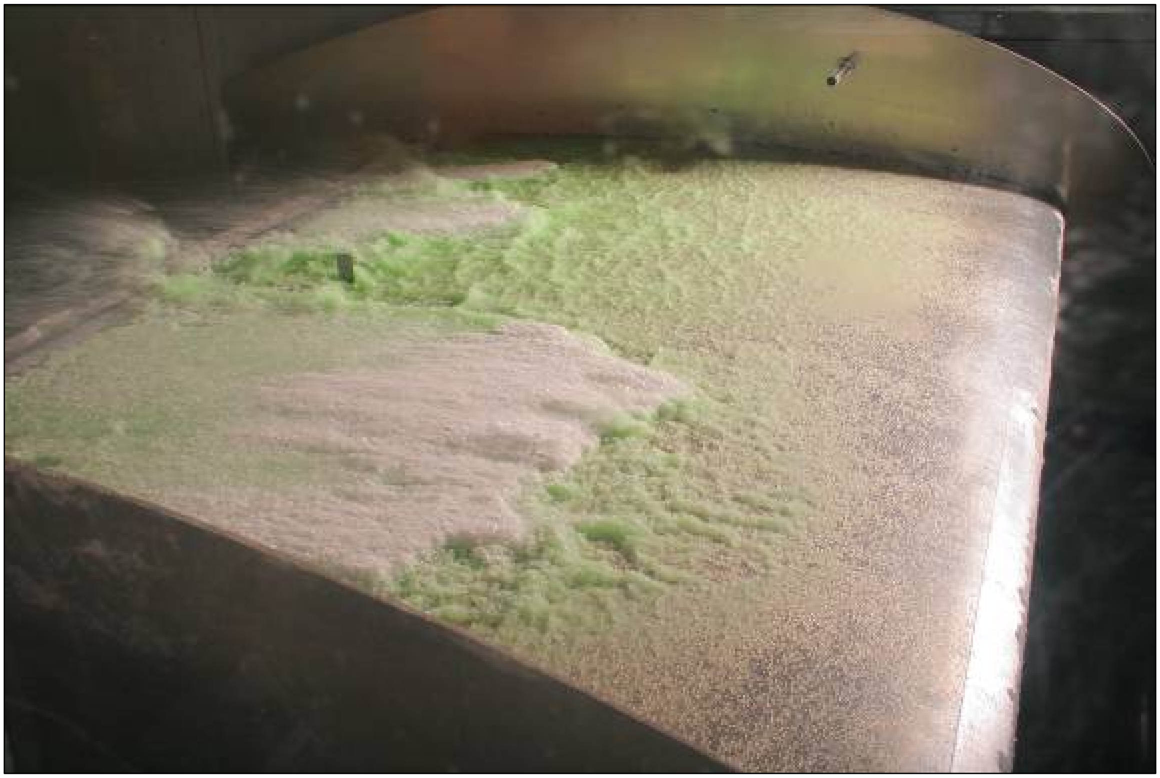


Photo 2.7: Test #125 – Before Start of Takeoff Run

Photo 2.8: Test #125 – Before Rotation

Photo 2.9: Test #137 – Before Start of Takeoff Run

Photo 2.10: Test #137 – Before Rotation



This page intentionally left blank.

3. EFFECTS OF A CLEAN LEADING EDGE SIMULATING LEADING EDGE HEATER DRY-OUT

3.1 Background

Prior to takeoff, some operators require pilots to perform a test to ensure that the wing anti-ice heating system is working. A major aircraft manufacturer indicated that on their aircraft, hot bleed air from the engine is passed through the piccolo tubes at the leading edge of the wing for 30 seconds while on the ground. The bleed air leaving the engine is approximately 200°C; however, the air reaching the leading edge may be significantly cooler (approximately 100°C). Currently, there is a lack of understanding of the effect of this test on de/anti-icing fluid protection times, and as a result, some airframe manufacturers recommend not performing the test due to potential adverse effects on de/anti-icing fluid.

3.2 Objective

The objective of this test was to investigate the aerodynamic effects of having the anti-icing fluid dry out on the leading edge as a result of the wing anti-ice system.

Flat plate testing was also conducted during the winter of 2010-11 and is described in the general and exploratory TC report, TP 15158E, *Aircraft Ground Icing General Research Activities During the 2010-11 Winter* (4).

3.3 General Methodology

The following is a brief summary of the methodology used for this testing:

- Type IV fluid was applied using the typical application procedures and allowed to settle for 5 minutes;
- Just prior to tear down, the fluid from the first 30.5 cm (12 in.) was squeegeed clean. In addition, work towels were used to fully clean the dry leading edge area of the wing;
- Wind tunnel was run and lift loss data collected; and
- Results were compared to a typical fluid only test conducted with the same fluid in similar conditions.

3.4 Data Collected

One test run was conducted. In addition, data from a fluid only test was used as a baseline comparison. A summary of the test data is included in Table 3.1.

3.5 Summary of Test Results

The test results demonstrated that the lift loss improved slightly (less than 1 percent lift loss difference) as a result of the fluid being removed from the leading edge. These results were as expected, as contamination present on the leading edge, even in the form of sheared residual fluid, would lead to lift losses. Photo 3.1 shows the condition of the wing during Test #99 prior to the start of the wind tunnel, and Photo 3.2 shows the condition of the wing just before rotation.

It should be noted that in an operational scenario, the leading edge heater may result in “cooking” the fluid on the leading edge, which may cause residues to form. This potential residue may have a measurable thickness and roughness, resulting in an effect on lift loss. This scenario has not been investigated; therefore, future tests should simulate a similar condition, however with some representative sandpaper on the leading edge to simulate the residue that may be formed.

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further substantiate these observations.

Table 3.1: Summary of 2010-11 Leading Edge Heater Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (ºC)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8º Rotation	% Lift Loss	Comments
99	2-Feb-11	ABC-S+	97	Fluid Only	N/A	N/A	-9.1	-9.5	1, 1, 1	1, 1, 1	1.349	5.13	12" of LE were squeegeed prior to run
97	2-Feb-11	ABC-S+	N/A	Fluid Only	N/A	N/A	-11.9	-10.4	1, 1, 1	1, 1, 1	1.338	5.91	N/A

This page intentionally left blank.

Photo 3.1: Test #99 – Before Start of Takeoff Run

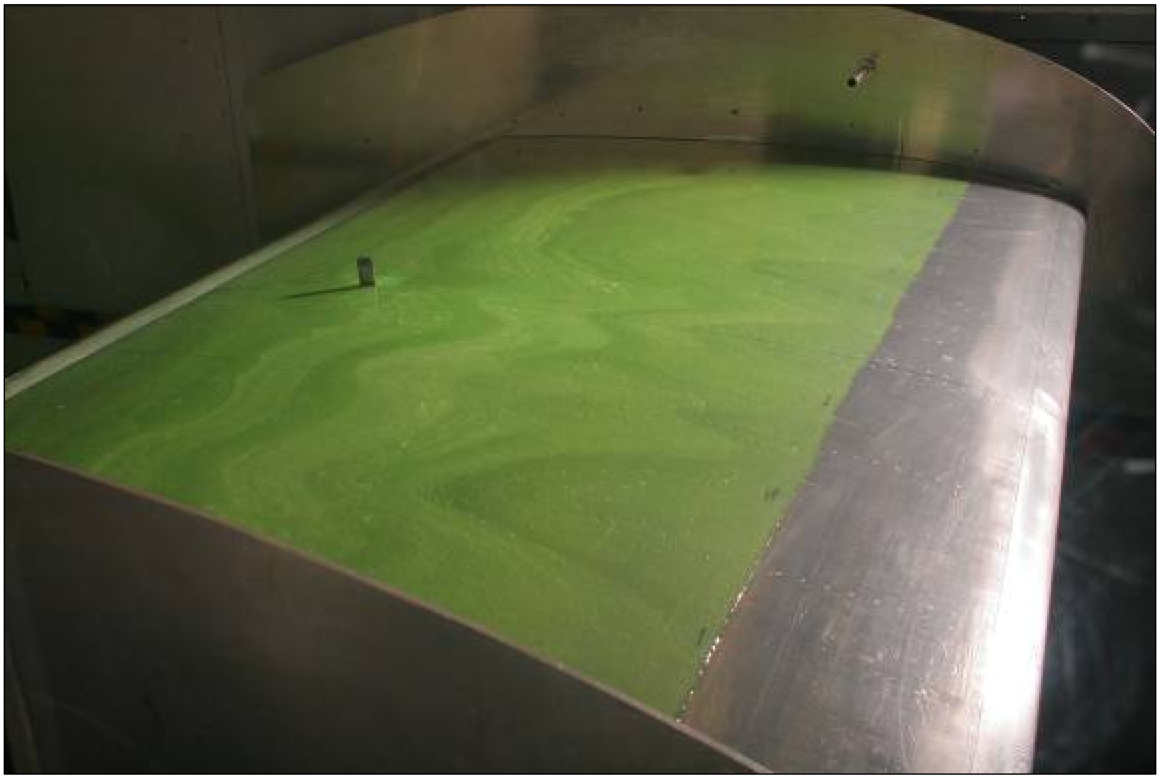


Photo 3.2: Test #99 – Before Rotation

This page intentionally left blank.

4. EFFECTS OF APPLYING INADEQUATE AMOUNTS OF ANTI-ICING FLUID

4.1 Background

There has been recent industry concern as to the consistency of anti-icing fluid applications in actual aircraft ground deicing operations. Although current industry standards recommend a 1 mm to 3 mm layer of fluid for a typical ethylene glycol (EG) Type IV anti-icing fluid, human error or inadequate training can lead to insufficient application of fluid. In addition, improperly stored anti-icing fluids can result in a degradation of the fluid viscosity, resulting in large reductions in fluid thickness. Fluid thickness is a main contributor to the fluid's endurance.

As it is very difficult to simulate the numerous potential human errors that can occur during an anti-icing application or the various types of fluid degradation, it was recommended that testing be done to simulate varying anti-icing fluid thicknesses and their effects on fluid holdover times (HOTs). Previous work conducted during the winter of 2008-09 indicated a potential for reductions in HOT protection time. During the wind tunnel tests conducted, a significant amount of contamination was found on the wing by the time of rotation when inadequate amounts of fluid were applied.

The question was asked whether a smaller amount of fluid applied would result in less lift loss compared to a typical fluid application. If so, improvement in lift loss could help compensate for lift losses incurred by contamination present due to earlier fluid failure.

4.2 Objective

The objective of this test was to investigate the aerodynamic effects of applying inadequate amounts of anti-icing fluid and to see if any lift loss improvement could potentially offset the lift losses incurred from contamination.

4.3 General Methodology

The following is a brief summary of the methodology used for this testing:

- Apply an inadequate amount of anti-icing fluid to the wing section using a wetted brush;
- Run wind tunnel and collect visual and lift coefficient data; and
- Compare results to a proper fluid application test.

Typically, the wing was treated with 16 L to 20 L of anti-icing fluid to achieve appropriate coverage and to obtain an acceptable fluid thickness; this translates to approximately 4.5 L/m^{2}on the wing. To simulate the inadequate anti-icing application, one-tenth of the typical fluid used (or 2 L over the whole wing) was applied; this resulted in approximately 0.45 L/m^2. During a typical HOT plate test, approximately 6.5 L/m^{2}is applied. The quantity applied to a test plate is higher than the amount of fluid applied during a typical wing test. This is a result of the fluid run-off from the sides of the plate; much more fluid is dripped in excess during a plate test compared to a wing test.

4.4 Data Collected

One test run was conducted. In addition, data from a fluid only test was used as a baseline comparison. A summary of the test data is included in Table 4.1.

4.5 Summary of Test Results

Test #98 demonstrated that the lift loss improved slightly (less than 1 percent lift loss difference) as a result of applying less fluid to the wing section when compared to Test #97 (baseline fluid only). Due to the thin fluid layer during Test #98, shearing began only at higher speeds (greater than 40 knots); however, at approximately 80 knots to 90 knots, the flow-off properties were very similar to those of the baseline Test #97. The visual observations supported the lift loss data, which did not indicate significant differences in aerodynamic performance whether 2 L or 16 L to 20 L were used. The results indicate that the improvement in aerodynamic performance when applying less fluid is not significant enough to offset the potential lift losses incurred from contamination due to early fluid failure.

These results were as expected, as contamination present on the leading edge, even in the form of sheared residual fluid, should result in lift losses. Photo 4.1 shows the condition of the wing during Test #98 prior to the start of the wind tunnel, and Photo 4.2 shows the condition of the wing just before rotation. Photo 4.3 shows the condition of the baseline wing Test #97 prior to the start of the wind tunnel, and Photo 4.4 shows the condition of the wing just before rotation.

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further substantiate these observations.

Table 4.1: Summary of 2010-11 Inadequate Anti-Icing Fluid Application Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
98	2-Feb-11	ABC-S+	97	Fluid Only	N/A	N/A	-10.6	-7.6	1, 1, 1	1, 1, 1	1.351	4.99	2 L of fluid applied using brushes to evenly distribute
97	2-Feb-11	ABC-S+	N/A	Fluid Only	N/A	N/A	-11.9	-10.4	1, 1, 1	1, 1, 1	1.338	5.91	16 L of fluid applied.

This page intentionally left blank.

Photo 4.1: Test #98 – Before Start of Takeoff Run

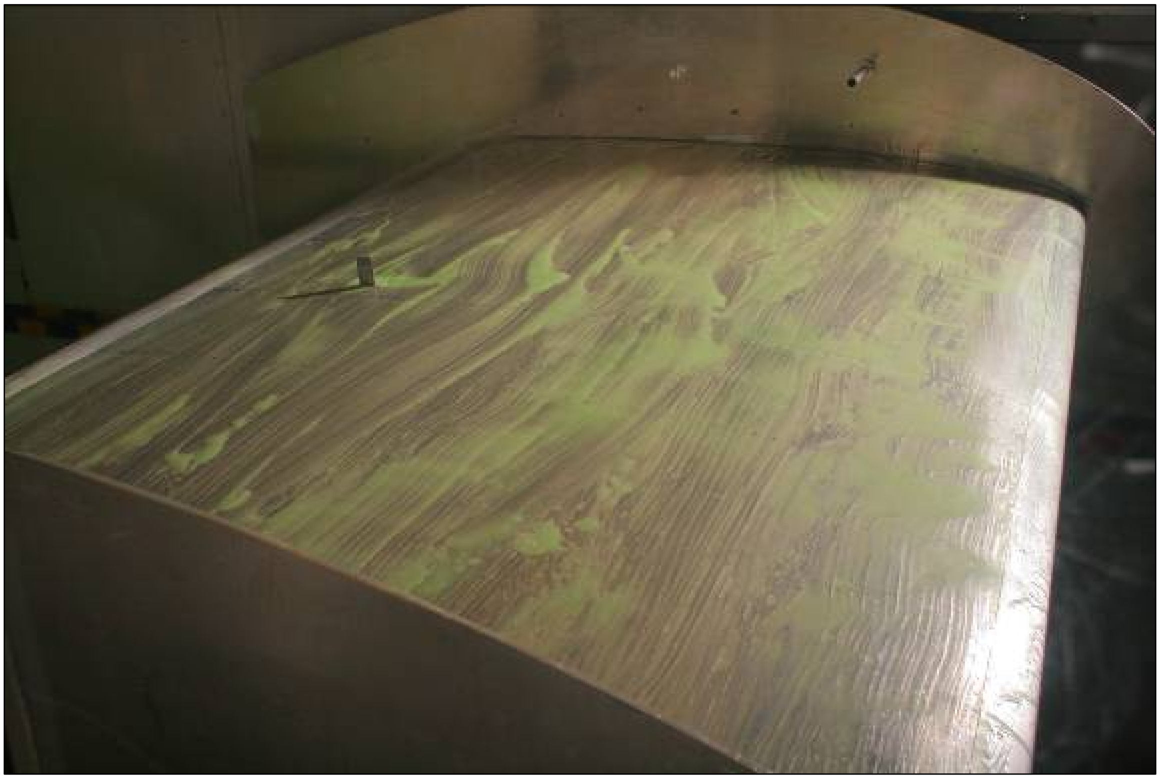


Photo 4.2: Test #98 – Before Rotation

Photo 4.3: Test #97 – Before Start of Takeoff Run

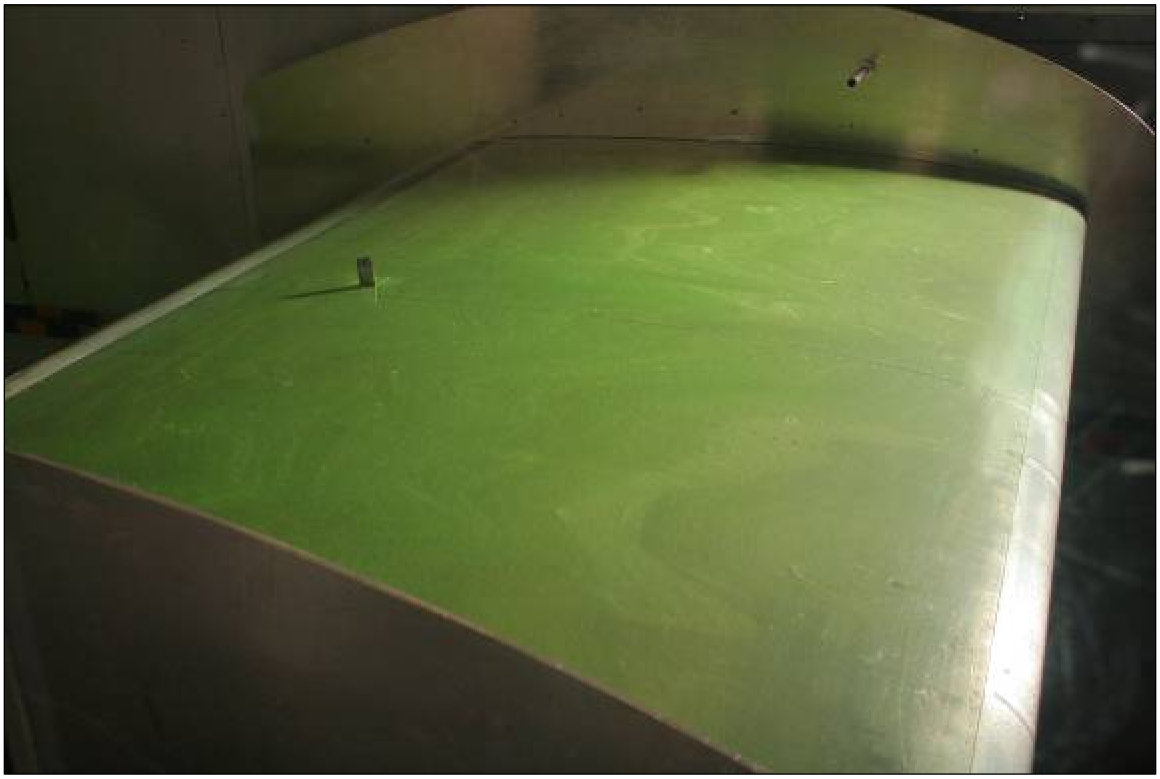
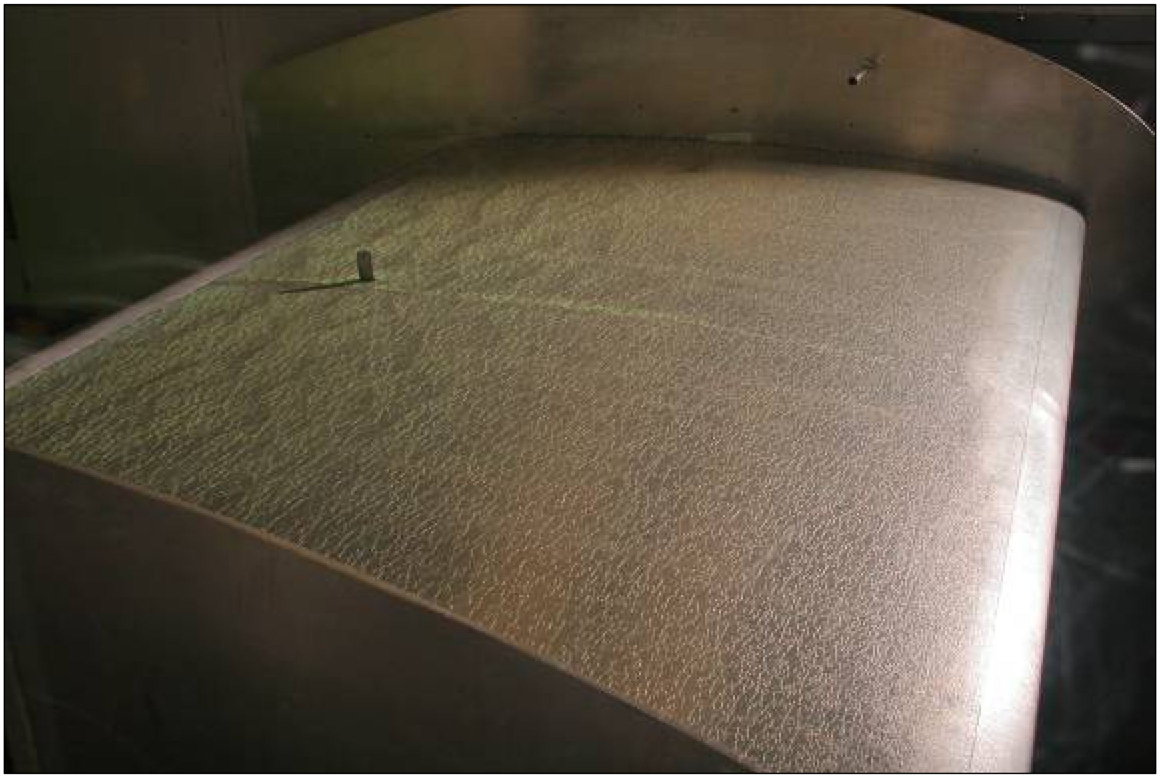


Photo 4.4: Test #97 – Before Rotation



5. EFFECTS OF RAMP-UP TIME ON FLUID FLOW-OFF

5.1 Background

The PIWT has a jet engine-driven turbine that accelerates based on a human operator input. The acceleration rate is dependent on factors such as temperature and humidity; however, a human error element also exists, as the operator has direct control of the engine throttle. The end result is a variance in the time it takes for the wind tunnel to reach the desired speed.

Based on the average of previous tests, it was determined that the wind tunnel would typically require 19 seconds to accelerate from 40 knots to 100 knots. Due to the variance in these acceleration rates, it was recommended that testing be done to verify the impact of the time to accelerate on the fluid flow-off and lift loss.

It should be noted that modifications to the throttle system will be made for the winter of 2011-12 to eliminate the human error aspect and to move towards a fully automated system, thus minimizing some of the variance.

5.2 Objective

The objective of this test was to investigate the aerodynamic effects of the time required to ramp-up to rotation speed.

5.3 General Methodology

The following is a brief summary of the methodology used for this testing:

- Apply fluid to the wing section;
- Apply contamination;
- Run wind tunnel using typical acceleration profile (target 40 knots to 100 knots in 19 seconds);
- Repeat test; however, once maximum speed of 100 knots is reached, hold for 10-20 seconds, then rotate; and
- Evaluate increase in lift coefficient as a result of the extra 10-20 seconds of holding at 100 knots by comparing the two runs.

5.4 Data Collected

Ten comparative test runs were completed. A summary of the test data is included in Table 5.1.

Table 5.1: Summary of 2010-11 Effect of Ramp-Up Time Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
11	20-Jan-11	Max-Flight	12	Fluid Only	N/A	N/A	-13.6	-12.2	1, 1, 1	1, 1, 1	1.37	3.66	Ramp-up to 100 Kts, Hold for 20 sec. Then Rotate
13	20-Jan-11	Max-Flight	14	IP Mod	IP 75	10	-12.4	-13.9	2.3, 2.5, 3.3	1, 1.3, 1.7	1.369	3.73	Ramp-up to 100 Kts, Hold for 20 sec. Then Rotate
122	8-Feb-11	ABC-S+	54	Fluid Only	N/A	N/A	-12.8	-10.8	1, 1, 1	1, 1, 1	1.347	5.27	Ramp-up to 100 Kts, Hold for 10 sec. Then Rotate
123	8-Feb-11	EG 106	77	Fluid Only	N/A	N/A	-12.5	-10	1, 1, 1	1, 1, 1	1.388	2.39	Ramp-up to 100 Kts, Hold for 10 sec. Then Rotate
124	8-Feb-11	ABC-S+	92	IP Mod	IP 75	10	-11.3	-12.9	2.5, 2.5, 3.3	1, 1.7, 2.2	1.318	7.31	Ramp-up to 100 Kts, Hold for 10 sec. Then Rotate
12	20-Jan-11	Max-Flight	N/A	Fluid Only	N/A	N/A	-14.2	-12.3	1, 1, 1	1, 1, 1	1.336	6.05	N/A
14	20-Jan-11	Max-Flight	N/A	IP Mod	IP 75	10	-12.3	-13.8	2.3, 2.5, 3.3	1.4, 2.5, 3	1.308	8.02	N/A
54	26-Jan-11	ABC-S+	N/A	Fluid Only	N/A	N/A	-12.1	-13.3	1, 1, 1	1, 1, 1	1.321	5.78	N/A
77	30-Jan-11	EG 106	N/A	Fluid Only	N/A	N/A	-11.8	-9.6	1, 1, 1	1, 1, 1	1.385	2.60	N/A
92	1-Feb-11	ABC-S+	N/A	IP Mod	IP 75	10	-13.6	-13.1	2.5, 2.6, 3.4	1.2, 1.8, 2.6	1.24	12.80	N/A

In addition, Figures 5.1 to 5.5 demonstrate the lift coefficient data for each of the comparative runs (these figures have been included as provided by the NRC and have not been modified).

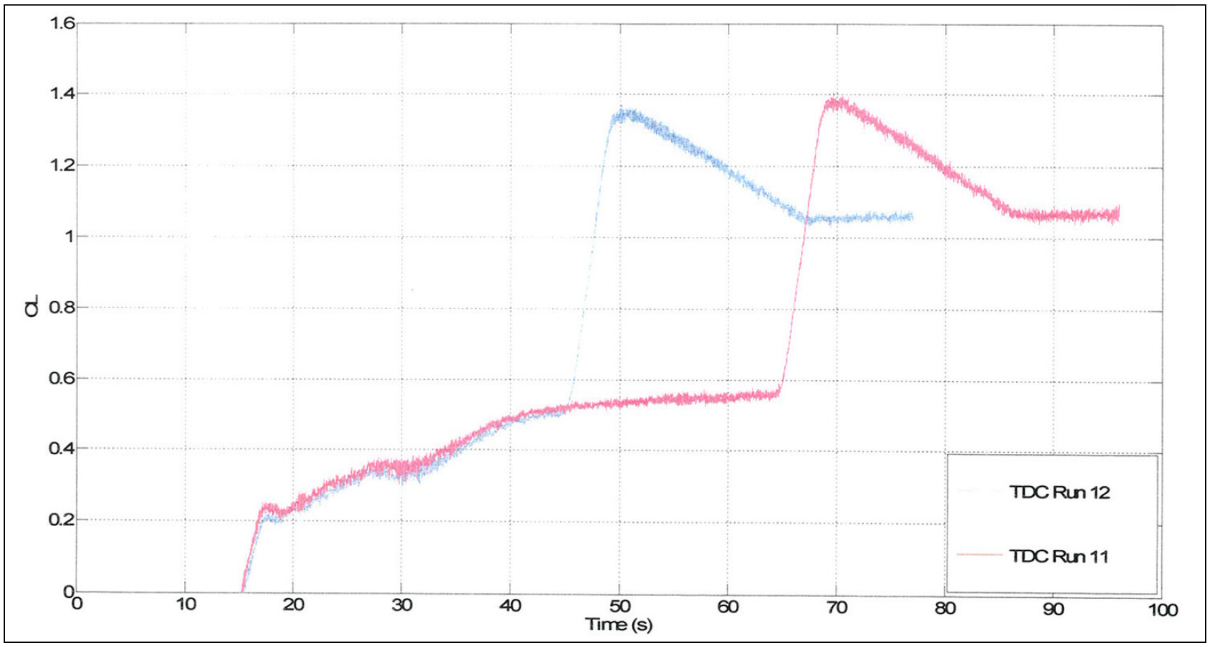


Figure 5.1: Test #11 vs. #12 – Fluid Only Lift Data Comparison

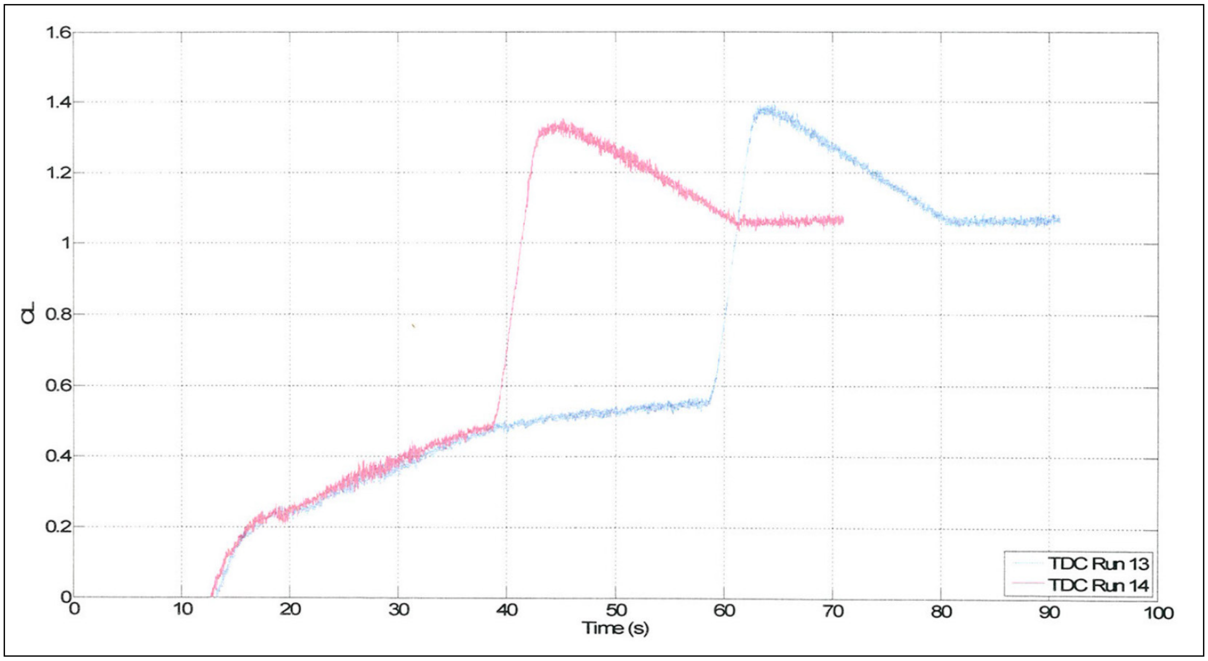


Figure 5.2: Test #13 vs. #14 – Moderate Ice Pellets Lift Data Comparison

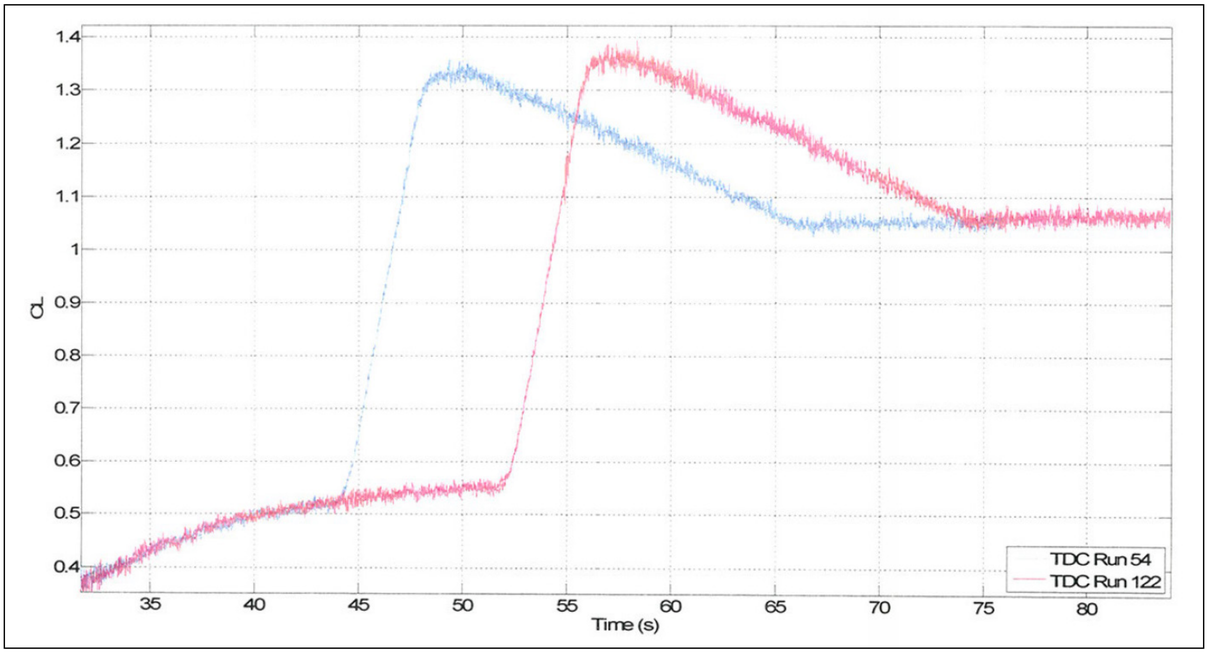


Figure 5.3: Test #122 vs. #54 – Fluid Only Lift Data Comparison

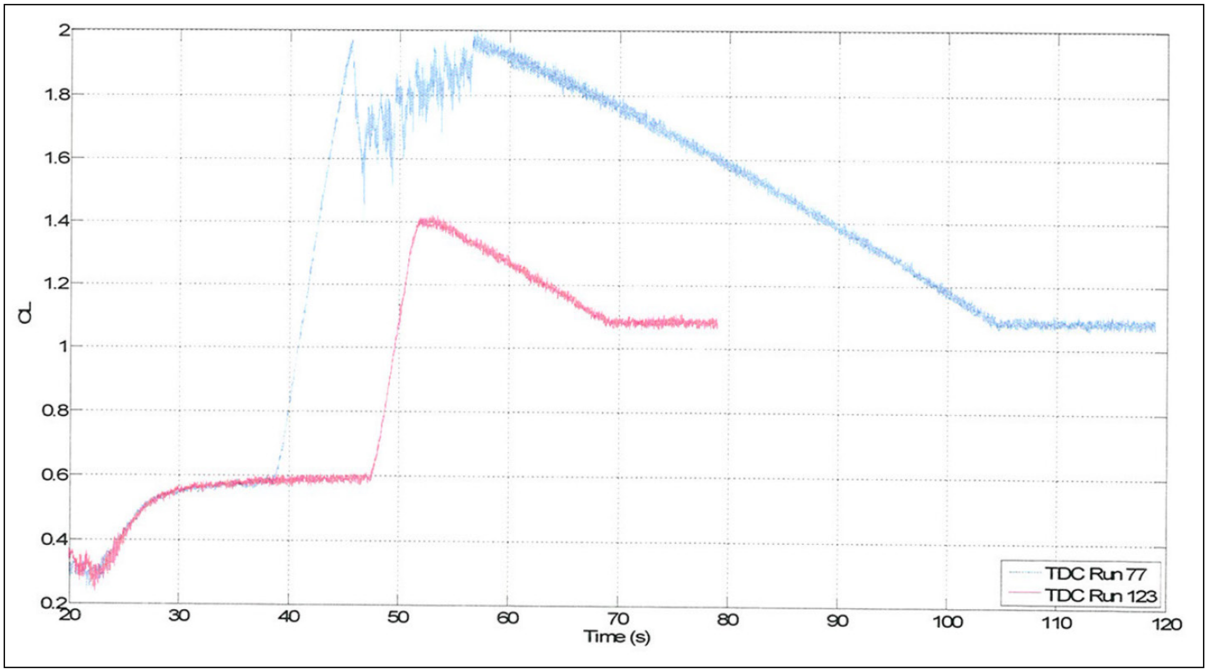


Figure 5.4: Test #123 vs. #77 – Fluid Only Lift Data Comparison

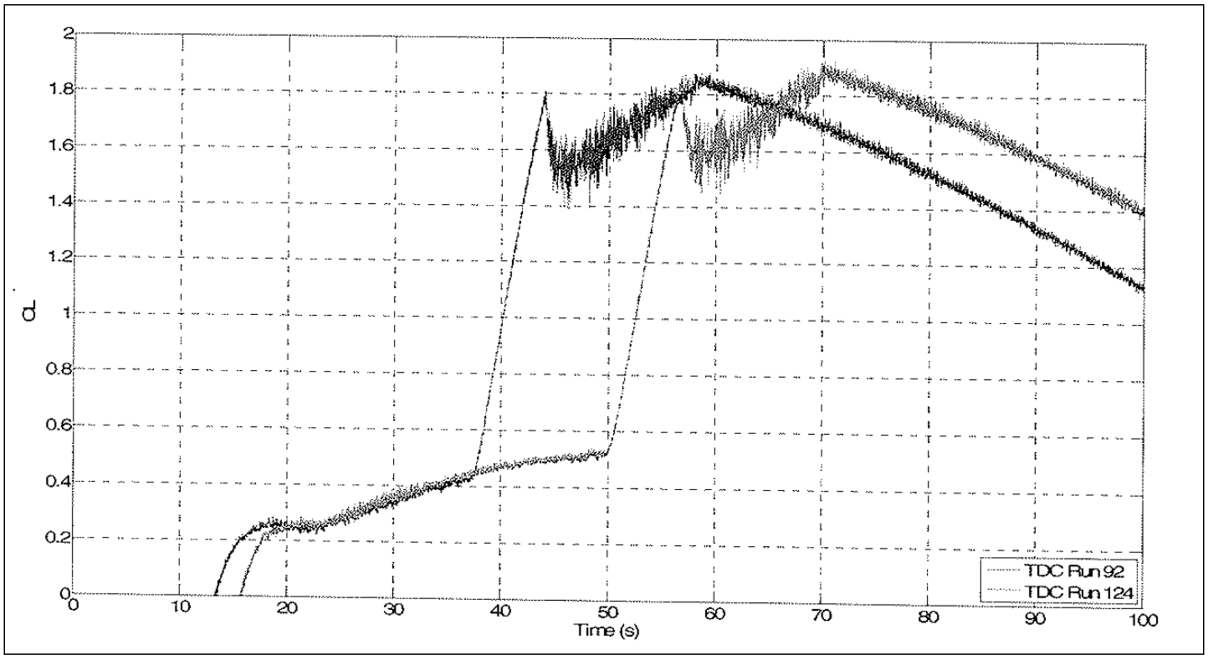


Figure 5.5: Test #124 vs. #92 – Moderate Ice Pellets Lift Data Comparison

5.5 Summary of Test Results

For each of the comparative test runs, the improvement in percentage lift loss for Tests #11, #13, #122, #123, and #124 was analysed against the respective baseline Tests #12, #14, #54, #77, and #92. The improvement in lift loss was calculated as a function of the extra time (10-20 seconds) held at 100 knots prior to rotation. A summary of these analysis results is included in Table 5.2.

Table 5.2: Summary of Lift Loss Decrease as a Function of Extra Ramp-Up Time

Test #	Fluid	Condition	Extra Ramp-Up Time (sec.)	8° Lift Loss Decrease per Extra Second Held at 100 knots
11/12	Max-Flight	Fluid Only	19.8	**0.12%**
13/14	Max-Flight	IP Mod	19.3	**0.22%**
122/54	ABC-S+	Fluid Only	10.8	**0.05%**
123/77	EG 106	Fluid Only	8.3	**0.03%**
124/92	ABC-S+	IP Mod	8.6	**0.64%**

For fluid only cases, propylene glycol (PG) fluids demonstrated an approximately 0.08 percent decrease in lift loss as a function of the extra ramp-up time. For the EG fluid, this was approximately half (0.03 percent). This difference is likely due to the differences in EG versus PG fluids and can also be explained by the generally higher lift losses observed with PG fluids. It would follow that the impact of extra ramp-up time would be more significant for PG fluids.

For the contamination cases, the PG fluids demonstrated 0.22 percent and 0.64 percent decreases in lift loss as a function of the extra ramp-up time. These results indicated that in the case of contamination runs, the extra ramp-up time could have a more significant impact by reducing lift loss.

Based on the results in Table 5.2, the results were grouped and generalized (see Table 5.3) in order to serve as a preliminary tool when analysing future test runs. If additional work is conducted, this table should be updated and further refined.

Table 5.3: Approximated Lift Loss Increase As a Function of Extra Ramp-Up Time

Condition	**Approximate 8° Lift Loss Decrease per Extra Second in Ramp-Up Time**
EG Fluid Only	**0.03%**
PG Fluid Only	**0.10%**
PG Fluid and Contamination	**0.22 to 0.64%**

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further substantiate these observations.

6. EFFECTS OF MIXED PRECIPITATION CONDITIONS

6.1 Background

As the accuracy of meteorological reporting continues to improve and the HOT guidance is applied more rigorously, there has been a need to provide better guidance material during transitional periods of mixed precipitation. The objective of these tests is to collect preliminary data to determine the feasibility of expanding the current HOT Guidelines to include mixed conditions that may be of particular interest to industry based on reported history of occurrence.

6.2 Objective

To investigate the aerodynamic effects of fluid contaminated with various forms of mixed precipitation for which no explicit HOT Guidelines exist.

6.3 General Methodology

The general methodology used during these tests was in accordance with the methodologies used for typical snow, ice pellet, or light freezing rain tests conducted in the wind tunnel. Aerodynamic performance was evaluated against the dry wing condition. Lift data and visual observations were recorded for each test.

6.4 Data Collected

Six tests runs were conducted: Tests #114 and #118 with mixed light ice pellets, light rain, and snow; Tests #133, #134, and #135 with mixed light ice pellets, light freezing rain, and snow; and Test #136 with mixed light freezing rain and snow. A summary of the test data is included in Table 6.1.

Table 6.1: Summary of 2010-11 Mixed Precipitation Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (ºC)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8º Rotation	% Lift Loss	Comments
114	7-Feb-11	Launch	N/A	IP/R/SN	IP 25, R, 25, SN 25	25	1.8	-2.2	2.5, 2.5, 4	1, 1, 1.4	1.391	2.18	N/A
118	7-Feb-11	EG 106	N/A	IP/R/SN	IP 25, R, 25, SN 25	25	1	-0.5	2, 1.3, 3.5	1, 1, 1.2	1.403	1.34	N/A
133	9-Feb-11	ABC-S+	N/A	IP/ZR/SN	IP 25, ZR 25, SN 25	20	-3.3	-4.4	2.7, 2.8, 4	1, 1.4, 4.3	1.324	6.89	Flap heavily contaminated
134	9-Feb-11	ABC-S+	N/A	IP/ZR/SN	IP 25, ZR 25, SN 25	20	-2.5	-4.6	2.3, 2.5, 2.7	1, 1.6, 1.9	1.343	5.56	Flap at 0º for contamination
135	10-Feb-11	EG 106	N/A	IP/ZR/SN	IP 25, ZR 25, SN 25	20	-3.9	-8.2	2.2, 2.3, 4.3	1, 1, 5	1.347	5.27	Flap heavily contaminated
136	10-Feb-11	ABC-S+	N/A	ZR/SN	ZR 25, SN 25	20	-3.5	-4.7	2, 2, 3.6	1, 1.6, 3.8	1.33	6.47	Flap heavily contaminated

6.5 Summary of Test Results

6.5.1 Mixed Light Ice Pellets, Light Rain, and Snow

Two tests were conducted: one with PG and one with EG fluid. In both cases, the visual observations were satisfactory, and the aerodynamic performance supported the visual observations indicating lift losses of 2.18 percent and 1.34 percent, respectively. A combination of the ambient temperature and the temperature of the rain likely prevented the cooling and ultimately the freezing of contamination. Photos 6.1 to 6.4 show the condition of the wing before the start of the takeoff run and before rotation for these two tests.

These two tests indicated a potential for an allowance time; however, further testing would be required.

6.5.2 Mixed Light Ice Pellets, Light Freezing Rain, and Snow

Three tests were conducted with both PG and EG fluids. In Tests #133 and #135 conducted with PG and EG fluids respectively, the condition of the main wing section was acceptable at the end of the contamination period; however, the flap demonstrated significant signs of frozen contamination, which was not completely eliminated by the time of rotation. In both cases, however, the aerodynamic performance demonstrated lift losses of 6.89 percent and 5.27 percent respectively, indicating that the frozen contamination on the flap was likely smooth and did not cause a significant degradation in performance.

Test #134 with Type I PG fluid was a repeat of #133; however, the flap was positioned at 0° during the contamination and returned to 20° for the takeoff run. The results from this test indicated an improvement in lift loss (5.56 percent versus 6.89 percent in Test #133); however, the most obvious improvement was the condition of the flap at the end of the precipitation, which showed far fewer signs of frozen contamination and which cleaned off much more easily during the takeoff ramp.

Photos 6.5 to 6.10 show the condition of the wing before the start of the takeoff run and before rotation for these three tests.

These three tests indicated a potential for an allowance time; however, the flap positioning during the test may play an important role in the development of the guidance material. A requirement to maintain flaps in a stowed position for as long as practical may be necessary.

6.5.3 Mixed Light Freezing Rain, and Snow

Test #136 was conducted with PG fluid. The condition of the main wing section was acceptable at the end of the contamination period; however, the flap demonstrated significant signs of frozen contamination, most of which was not completely eliminated by the time of rotation. The aerodynamic performance demonstrated a lift loss of 6.47 percent, indicating that the frozen contamination on the flap was likely smooth and did not cause a significant degradation in performance. Photos 6.11 to 6.12 show the condition of the wing before the start of the takeoff run and before rotation for this test.

Similar to the light ice pellets, light freezing rain, and snow condition, there is a potential for an allowance time; however, the flap positioning during the test may play an important role in the development of the guidance material. A requirement to maintain flaps in a stowed position for as long as practical may be necessary.

Photo 6.1: Test #114 – Before Start of Takeoff Run

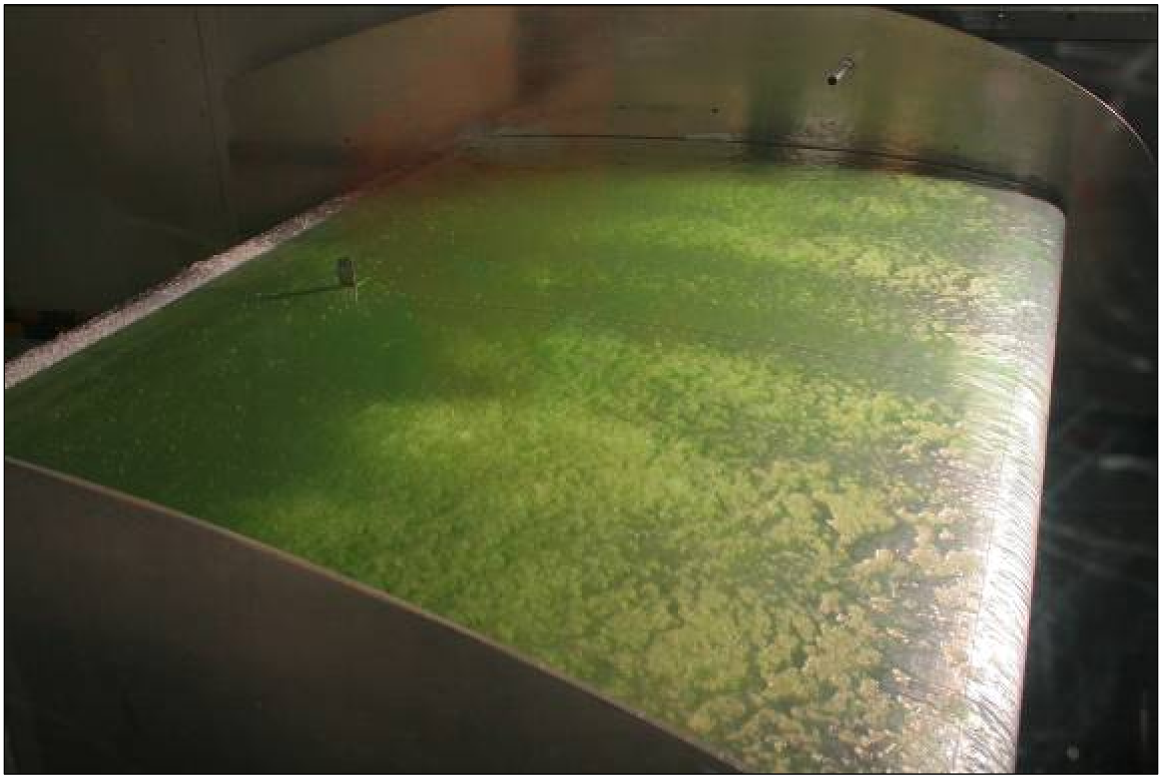


Photo 6.2: Test #114 – Before Rotation

Photo 6.3: Test #118 – Before Start of Takeoff Run

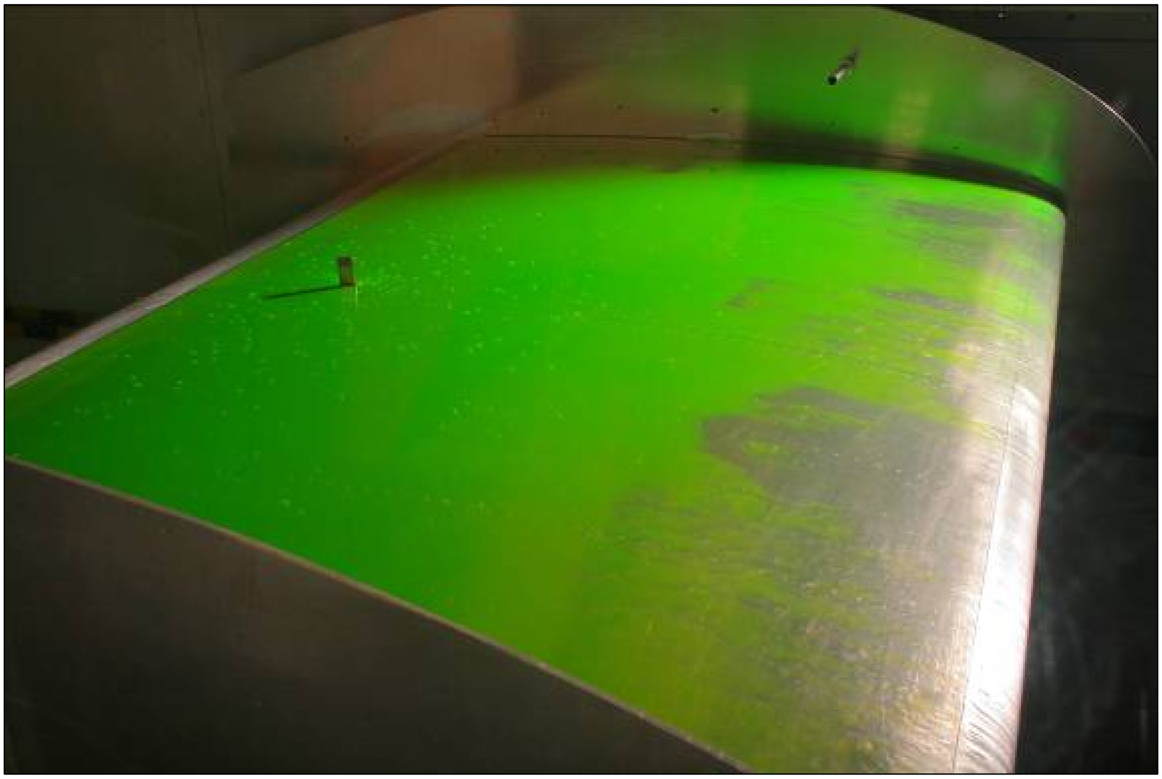


Photo 6.4: Test #118 – Before Rotation

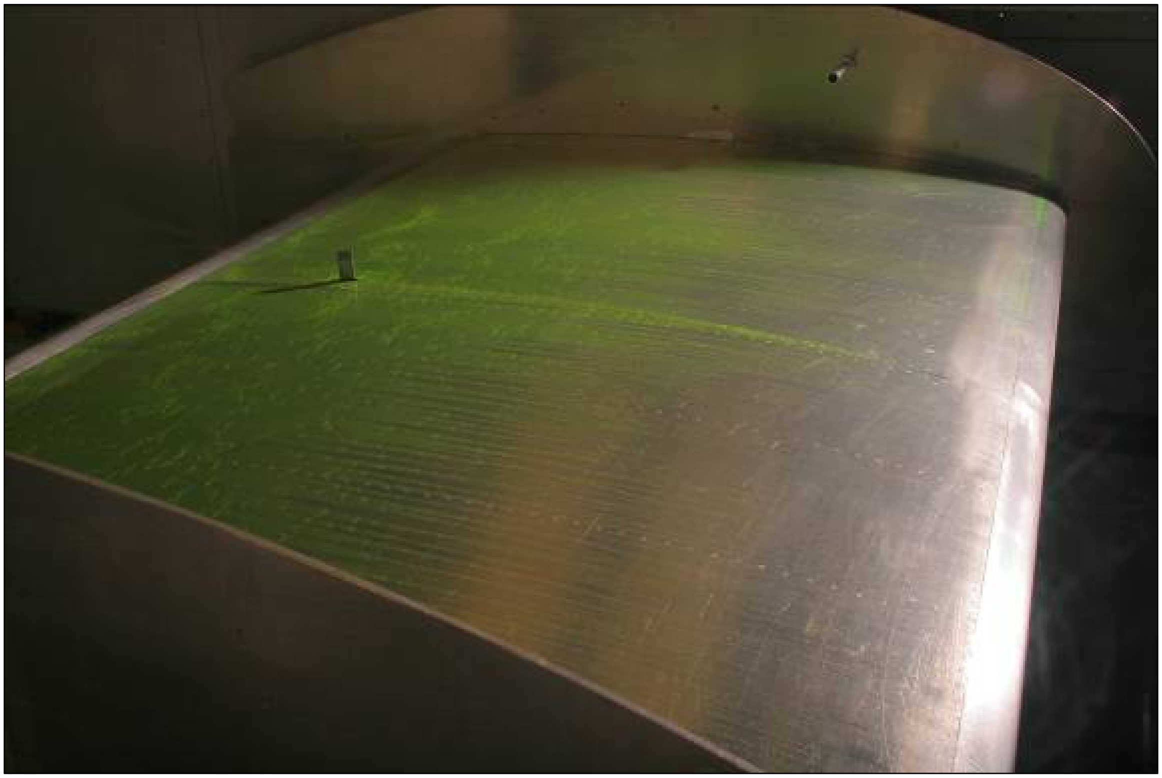


Photo 6.5: Test #133 – Before Start of Takeoff Run

Photo 6.6: Test #133 – Before Rotation

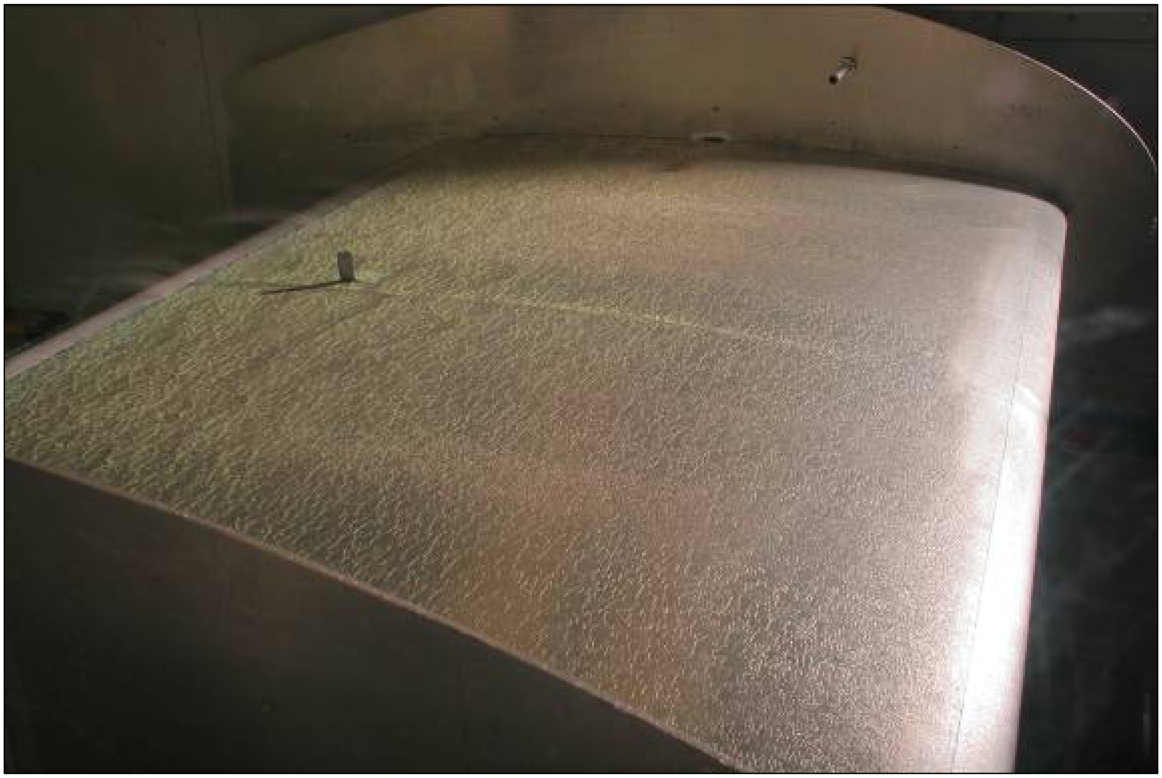


Photo 6.7: Test #134 – Before Start of Takeoff Run

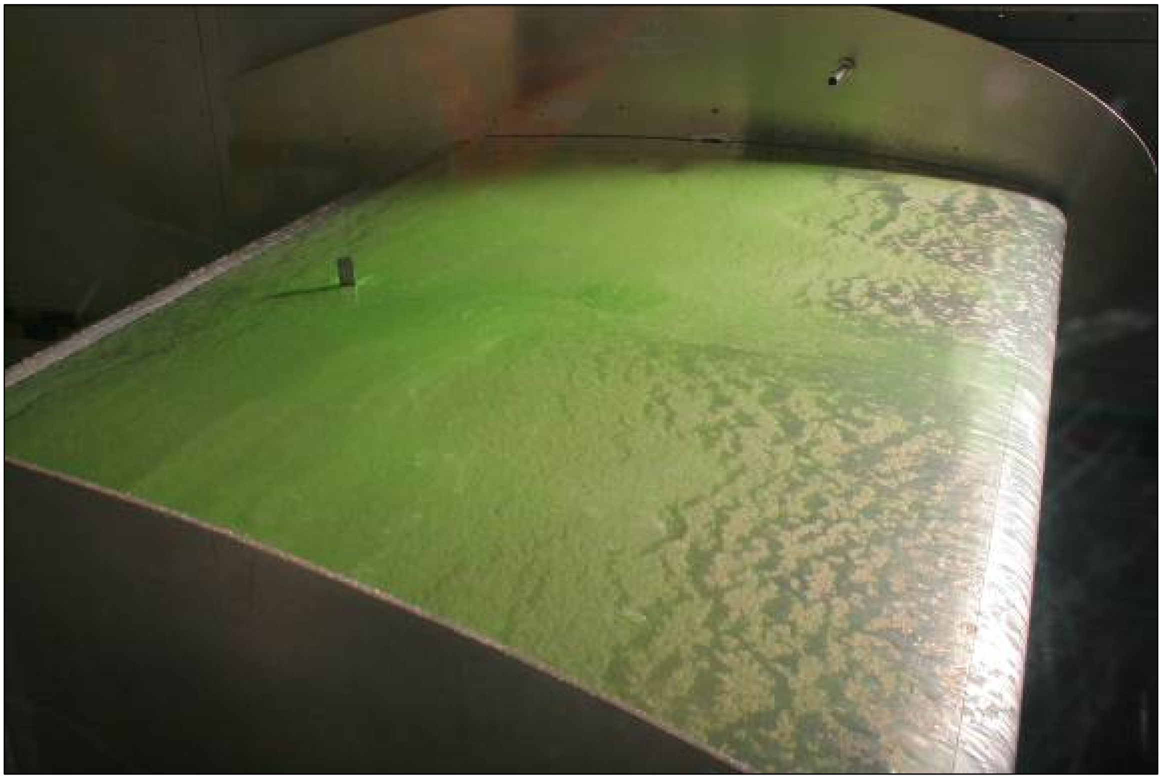


Photo 6.8: Test #134 – Before Rotation

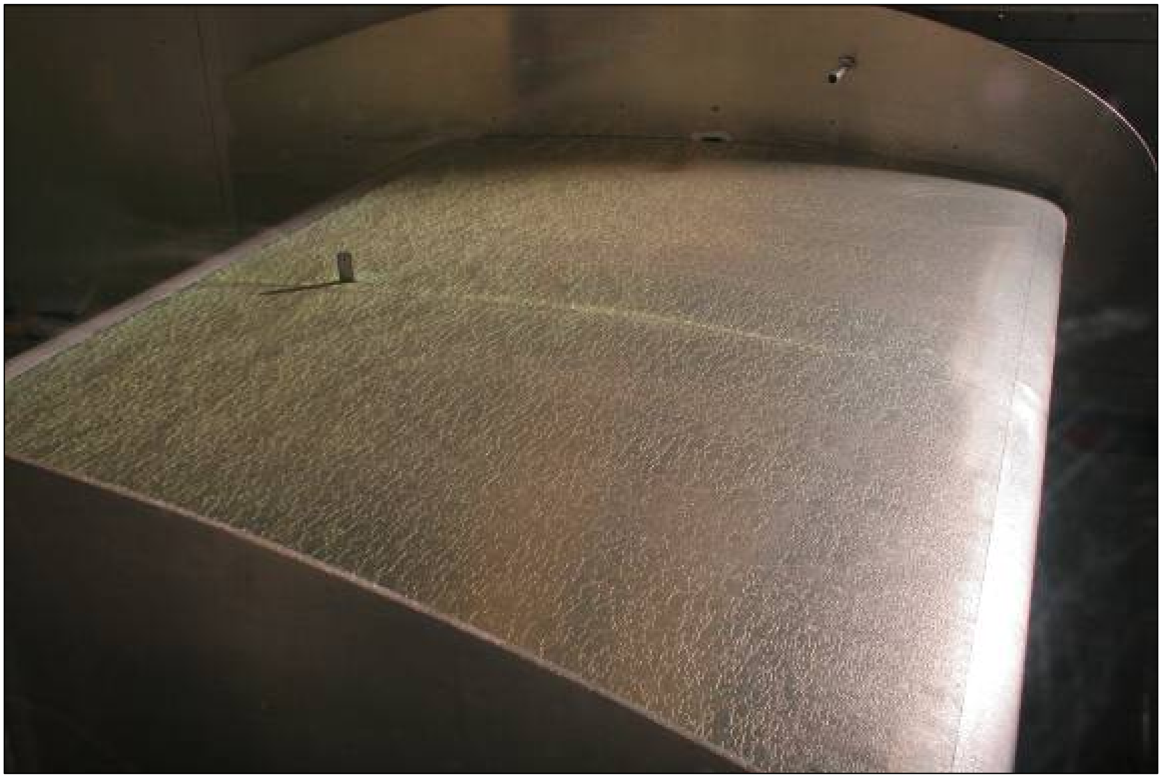


Photo 6.9: Test #135 – Before Start of Takeoff Run

Photo 6.10: Test #135 – Before Rotation

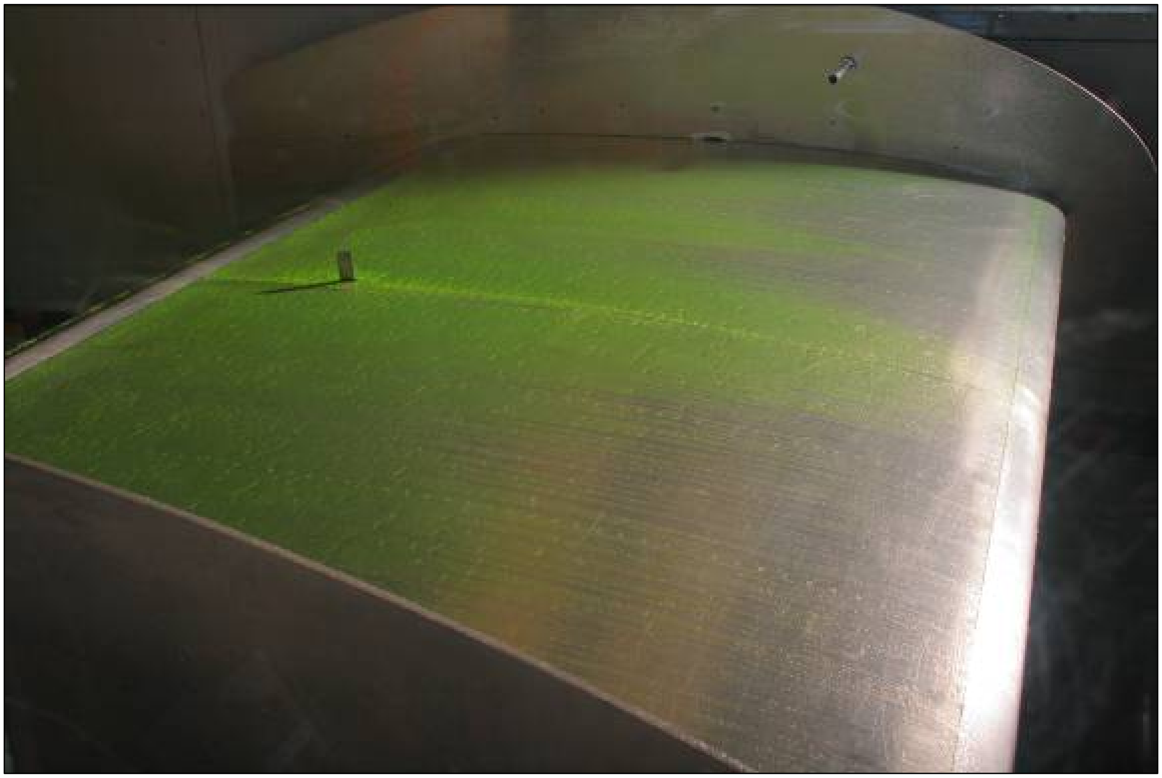


Photo 6.11: Test #136 – Before Start of Takeoff Run

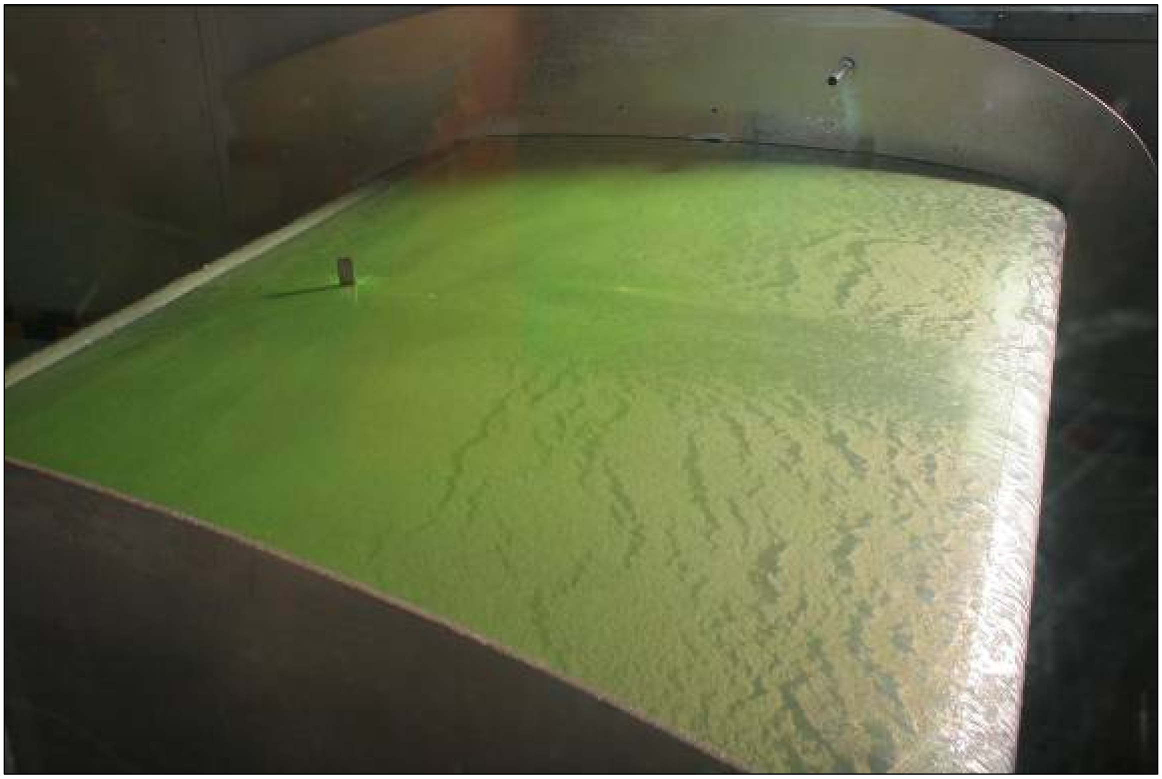


Photo 6.12: Test #136 – Before Rotation

7. EFFECTS OF SNOW OR RAIN ON AN UNPROTECTED WING

7.1 Background

In colder northern operations, it is believed to be common for aircraft to depart with loose, dry, un-adhered snow resent on their wing sections. Although it is assumed that most or all of this contamination will be removed at the time of rotation, it is unknown whether a certain level of residual contamination will reduce aerodynamic performance. Two preliminary tests were conducted in 2009-10: one at warmer temperatures and one at colder temperatures. The results from this testing indicated that a takeoff with dry, loose snow on the wings may be feasible at colder temperatures; however, it is not recommended at warmer temperatures where the risk of melting and refreezing is high. It was recommended that additional testing be conducted with colder wing temperatures to ensure a completely frozen state of contamination. The cold wing test conducted in 2009-10 still had some contamination adhere to the wing, possibly due to hot spots, high moisture, or residual fluid.

In order to determine an acceptable level of lift loss, it was recommended that aerodynamic testing be conducted under known conditions that are safe for flying. The condition of rain (non-freezing) on an unprotected wing could provide insight into an acceptable level of lift loss (if any) present during a typical takeoff scenario. Full-scale testing was conducted to investigate the aerodynamic performance of a wing section during rain conditions.

7.2 Objectives

a) To investigate the aerodynamic performance of a wing section contaminated with loose, dry, un-adhered snow.

b) To investigate the aerodynamic performance of a wing section during rain conditions.

7.3 General Methodology

The general methodology for the snow test is as follows:

- Ensure the wing section and tunnel temperature are well below freezing (-5°C and below);
- Ensure the wing section is clean, dry, and free of any forms of contamination;
- Apply loose, dry snow contamination to the wing section;
- Record lift data, visual observations, and manually collected data; and

- Compare the results to baseline fluid only or dry wing test results.

The general methodology for the rain test is as follows:

- Ensure the wing section, tunnel temperature, and OAT are above freezing (+1°C and above);
- Ensure the wing section is clean, dry, and free of any forms of contamination;
- Apply rain using the freezing rain sprayer. Keep the rain sprayer working during the ramp-up to ensure the wing remains as wetted as possible;
- Record lift data, visual observations, and manually collected data; and
- Compare the results to baseline fluid only and dry wing test results.

7.4 Data Collected

One test run was conducted for each condition. The results were compared to the dry wing case; therefore, no specific baseline test runs were identified. A summary of the test data is included in Table 7.1.

7.5 Summary of Test Results

Test #101 demonstrated that even with the cold wing skin temperature, the snow would not easily be blown off the wing during the ramp-up. The majority of the snow was removed; however, a thin layer was still present at the time of rotation and resulted in significant lift losses (almost 16 percent lift loss compared to the dry wing). Additional work may be required at even colder temperatures, similar to those in which operators are taking off with cold, loose snow on the wings, in order to obtain data to substantiate this practice. During the test, it seemed difficult to ascertain the level of adherence of the snow and difficult to predict whether it would be removed at rotation.

Photo 7.1 shows the condition of the wing during Test #101 prior to the start of the wind tunnel, and Photo 7.2 shows the condition of the wing just before rotation.

Test #113 demonstrated an excellent flow-off of the rain present on the wing during the ramp-up. The lift losses were less than 1 percent compared to the dry wing cases. This preliminary result indicates that rain has very little effect on aerodynamic performance.

Photo 7.3 shows the condition of the baseline wing Test #113 prior to the start of the wind tunnel, and Photo 7.4 shows the condition of the wing just before rotation.

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further examine the dry, loose snow issue.

Table 7.1: Summary of 2010-11 Snow or Rain on an Unprotected Wing Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
101	2-Feb-11	N/A	N/A	SN w/ No Fluid	200	5	-6.8	-6.4	4, 4, 4	4, 3.7, 4	1.197	15.82	Snow on a cold, dry wing
113	7-Feb-11	N/A	N/A	R w/ No Fluid	75	5+ (ongoing)	1.3	N/A	N/A	N/A	1.416	0.42	Rain with no fluid

This page intentionally left blank.

Photo 7.1: Test #101 – Before Start of Takeoff Run

Photo 7.2: Test #101 – Before Rotation

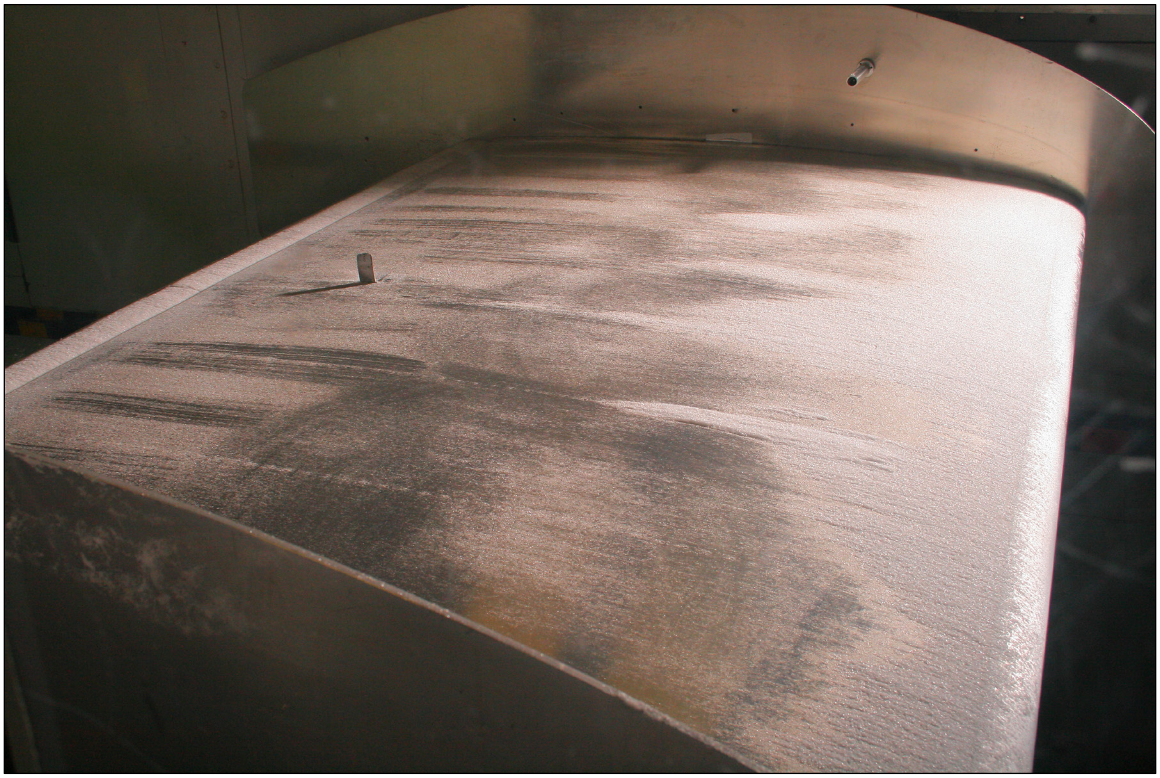


Photo 7.3: Test #113 – Before Start of Takeoff Run

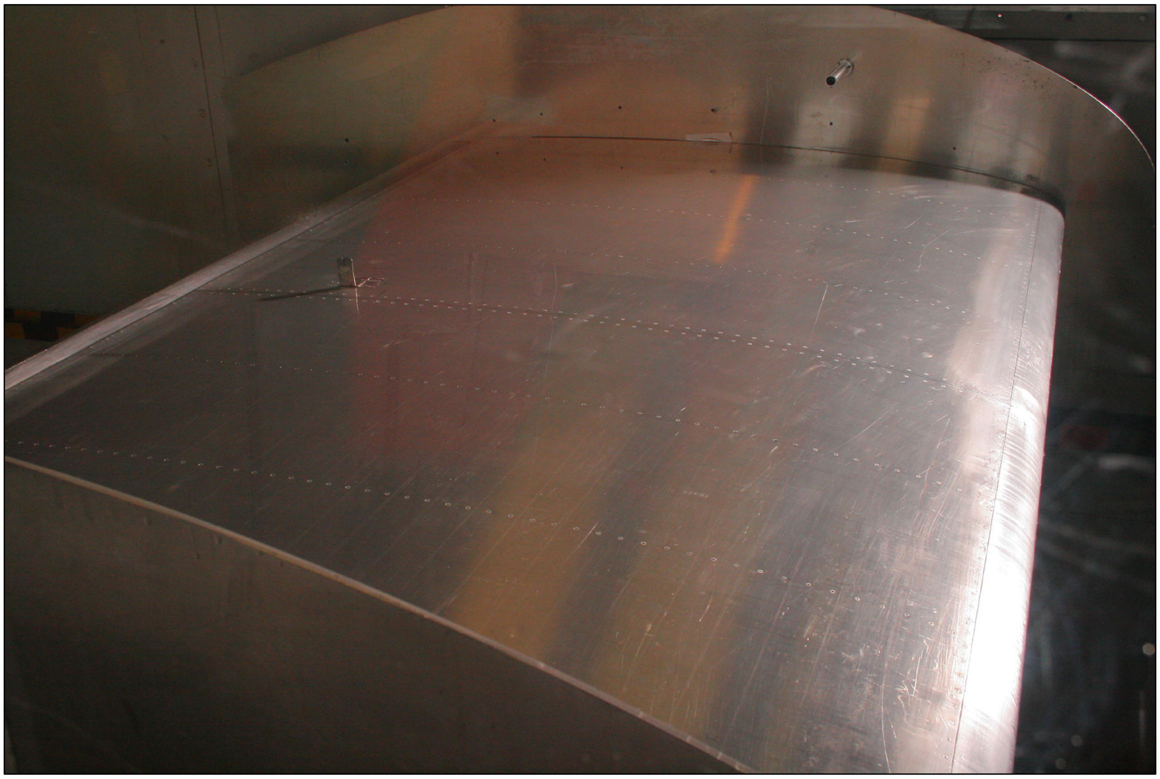
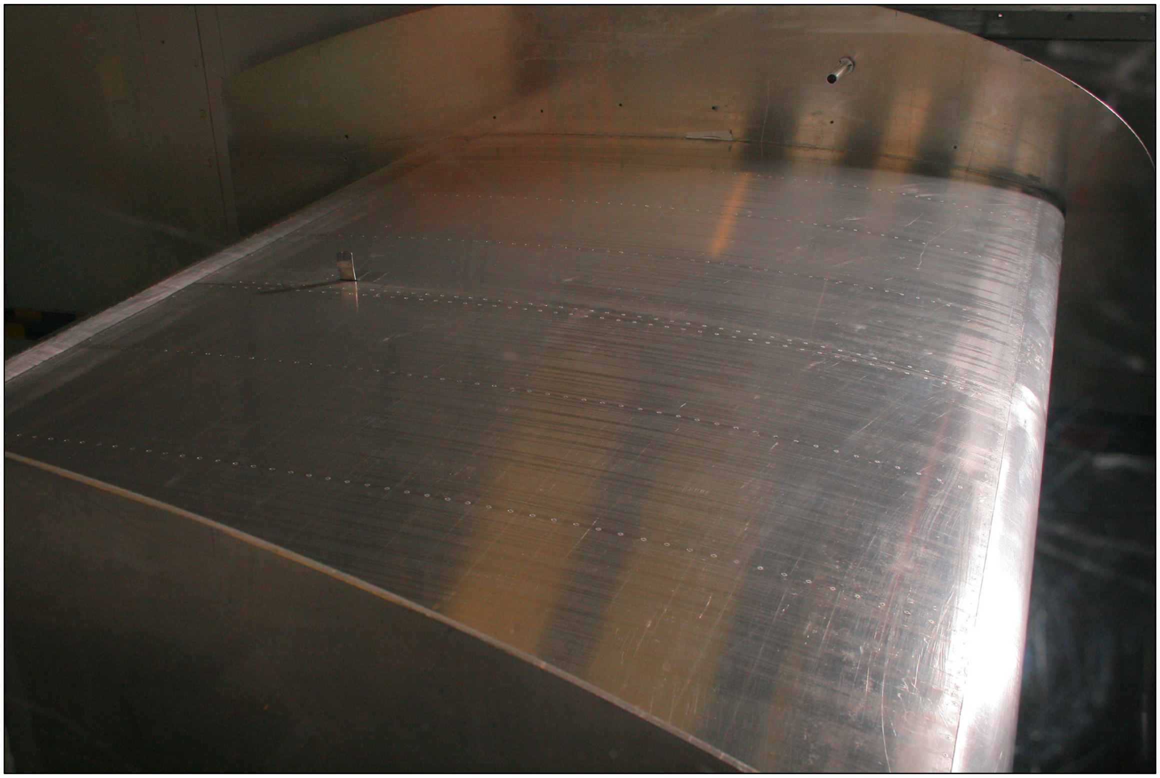


Photo 7.4: Test #113 – Before Rotation



8. EFFECTS OF WING GEOMETRY ON FLUID FLOW-OFF PROPERTIES

8.1 Background

A limitation of conducting testing with a two-dimensional wing section is the inability to recreate fluid flow-off due to the varying geometry found on a real wing section. An operational aircraft wing will have twist (dependent on chord location), dihedral effect (dependent on distance from fuselage), and varying chord thickness and upper skin slope (based on chord location). Testing during the winter of 2009-10 with the thin high-performance wing section demonstrated that fluid flow-off was reduced due to the relatively flat top surface of that type of wing. It was recommended that preliminary testing be conducted with different wing rest angles during contamination to simulate different geometries typically found on an aircraft wing.

8.2 General Methodology

The following is a brief summary of the methodology used for this testing:

- Conduct a typical wind tunnel test with contamination using the typical rest angle (-2 degrees for the wing);
- Repeat the test with a steeper rest angle of +3 degrees, simulating a different section of the wing;
    - Note: The wing position was returned to -2 degrees just before the start of the wind tunnel ramp-up; and
- Compare results and document.

8.3 Objective

To investigate the impact on fluid failure and aerodynamic performance with different wing rest angles during contamination.

8.4 Data Collected

One test run (#130) was conducted. In addition, data from a fluid and contamination test (#129) was used as a baseline comparison. A summary of the test data is included in Table 8.1.

Table 8.1: Summary of 2010-11 Wing Geometry Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
130	9-Feb-11	AD-49	129	IP- / ZR-	IP 25, ZR 25	25	-2.4	-3.3	2.3, 2.3, 2.8	1, 1.2, 1.6	1.357	4.57	Wing Rest Position to +3 Degree
128	9-Feb-11	AD-49	N/A	IP- / ZR-	IP 25, ZR 25	25	-3.2	-3.8	2.5, 2.5, 2.7	1.1, 1.3, 1.5	1.363	4.15	N/A

8.5 Summary of Test Results

Test #130 demonstrated slightly better visual ratings before the start of the test and at the time of rotation compared to the baseline Test #128. This result may be an indication that the increased angle promoted fluid flow-off and that the fluid was able to absorb more precipitation, resulting in less visually bridging contamination. This observation is supported by the Brix measurements taken after the precipitation period, which indicate lower Brix values for Test #130 compared to Test #128. The more contamination is absorbed, the lower the Brix values become.

The aerodynamic data collected indicated slightly higher lift losses (less than 0.5 percent) for Test #130 compared to Test #128. Although the differences may be minimal, it may be an indication that an improvement in fluid flow-off and absorption of contamination could result in slightly higher lift losses as the fluid dilutes.

Photo 8.1 shows the condition of the wing during Test #130 prior to the start of the wind tunnel, and Photo 8.2 shows the condition of the wing just before rotation. Photo 8.3 shows the condition of the baseline wing Test #128 prior to the start of the wind tunnel, and Photo 8.4 shows the condition of the wing just before rotation.

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further substantiate these observations.

This page intentionally left blank.

Photo 8.1: Test #130 – Before Start of Takeoff Run

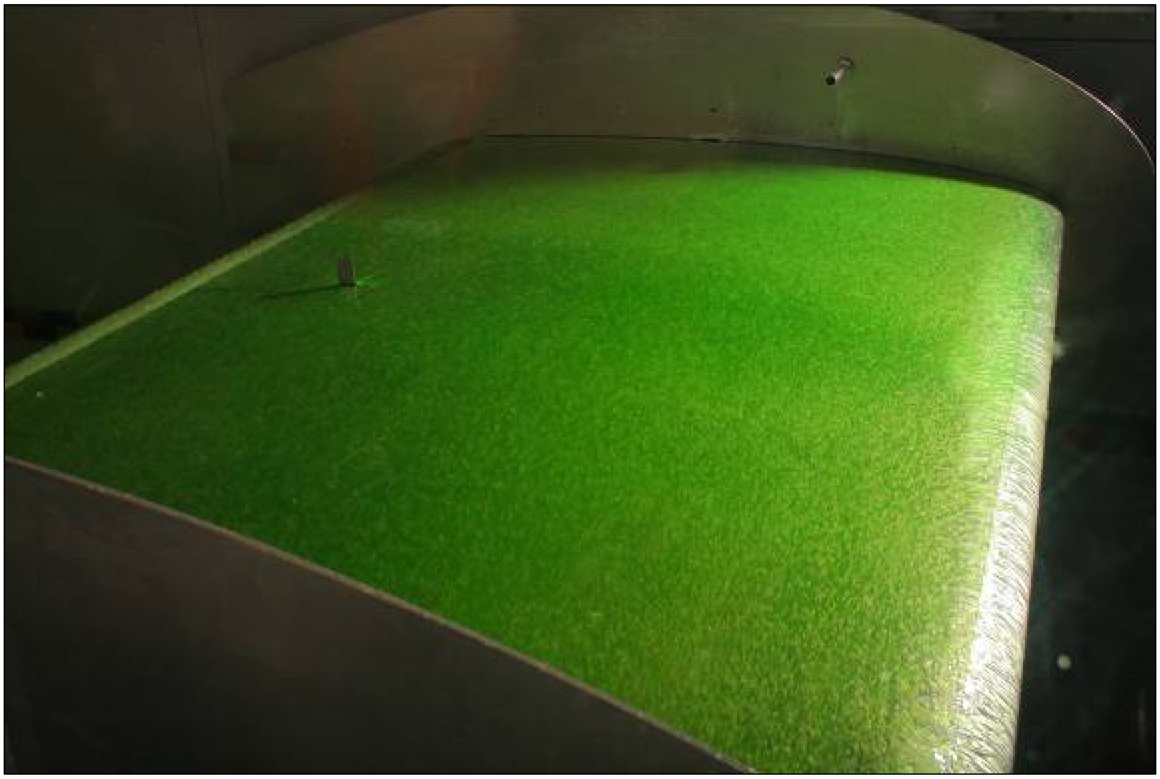


Photo 8.2: Test #130 – Before Rotation

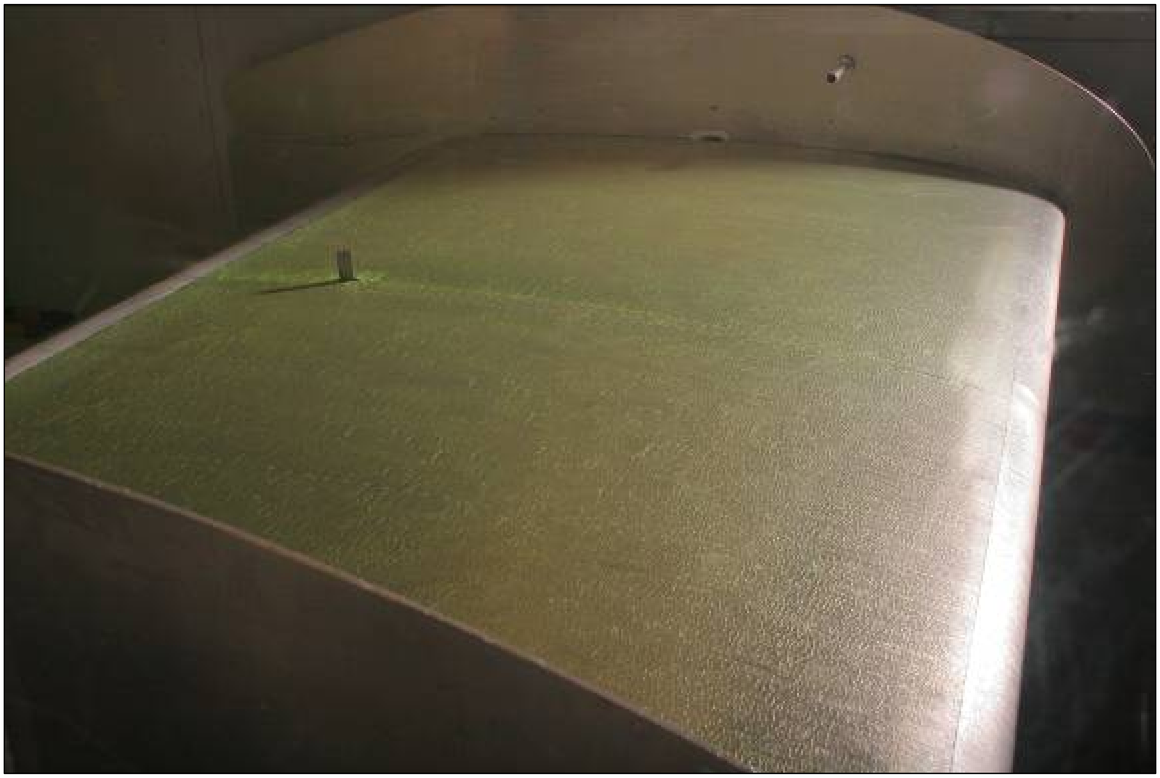
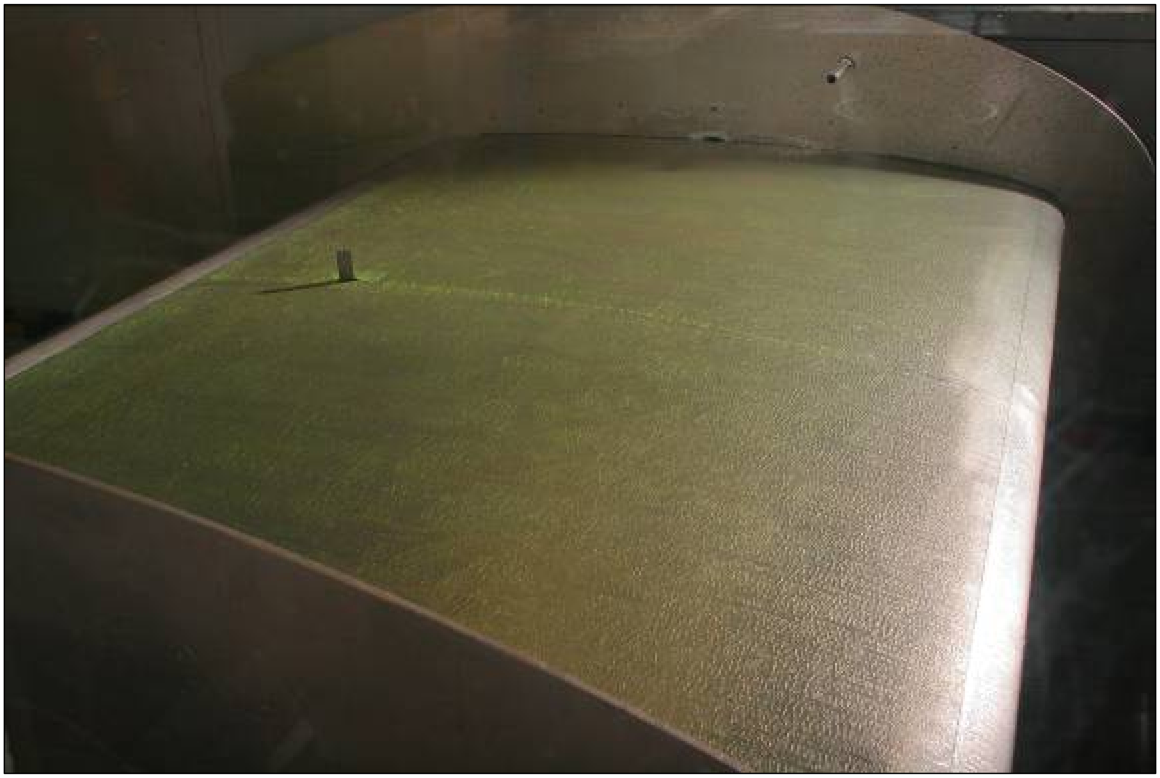


Photo 8.3: Test #128 – Before Start of Takeoff Run

Photo 8.4: Test #128 – Before Rotation



9. HEAVY SNOW

9.1 Background

Due to the recent industry requirement for guidance material for aircraft operations in mixed precipitation conditions with ice pellets, APS conducted a series of plate tests and full-scale tests with the NRC open-circuit wind tunnel and the Falcon 20 aircraft during the winters of 2004-05 to 2010-11. Aerodynamic testing was required due to the melting properties of ice pellets, as the embedded ice pellets required a significantly longer time in comparison to snow to dissolve in anti-icing fluid. Consequently, HOTs were not applicable for ice pellet conditions because contamination was present at the start of the HOT. The criterion for fluid failure (or the end of the HOT) is determined by contamination present on 30 percent of the test plate.

As a direct result of the ice pellet research conducted, the use of fluid endurance times for determining the protection time provided by anti-icing fluids was questioned. The focus was turned towards “aerodynamic failure,” defined as a significant lift loss resulting from contaminated anti-icing fluid. Heavy snow conditions were selected for this study for two reasons. First, snow conditions account for the most significant portion of deicing operations globally. Second, there has been a recent industry interest in HOTs for heavy snow conditions. Preliminary aerodynamic testing was conducted during the winter of 2006-07, and results are described in an interim report documenting aircraft deicing research in heavy snow conditions, which was provided to TC and the FAA. A final report is expected to be published once the research is completed in a future winter. This research was also continued during the winters of 2008-09 and 2009-10. The previous results obtained using three different types of fluid (Type III, Type IV EG, and Type IV PG) indicated that using half the moderate snow HOT for heavy snow conditions (rate of 50 g/dm^2/h) could be a viable approach for providing guidance in heavy snow conditions. In all cases, the visual and aerodynamic performance for the heavy snow test (50 g/dm^2/h) with half the HOT was comparable to the moderate snow test (25 g/dm^2/h) with the full HOT. Limited data collected with the Type III and Type IV EG fluids also indicated that the HOT could potentially be increased to three-quarters of the moderate snow HOT. It was recommended that the work continue in order to obtain more data to support the conclusions made.

9.2 General Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow condition tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating moderate snow conditions (rate of 25 g/dm²/h) for an exposure time derived from the HOT table based on the tunnel temperature at the time of the test.
- Record lift data, visual observations, and manually collected data.
- Conduct two comparative tests simulating heavy snow conditions (rate of 50 g/dm²/h or higher) for a relative fraction of the exposure time used during the moderate snow test.
- Record lift data, visual observations, and manually collected data.
- Compare the heavy snow results to the moderate snow results.
- Identify when similar lift data and visual observations are achieved for both heavy snow and moderate snow conditions.

9.3 Objective

To investigate the aerodynamic flow-off characteristics of anti-icing fluid contaminated with simulated heavy snow versus moderate snow.

9.4 Data Collected

Three comparative test sets were conducted, for a total of ten tests (an additional test was conducted but was not valid and was dismissed). Fluid only conditions were not referenced, as the baseline level of acceptable contamination was determined instead by the moderate snow case simulating the HOT for each test set. A summary of the test data is included in Table 9.1.

Table 9.1: Summary of 2010-11 Heavy Snow Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm^2/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (°C)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8° Rotation	% Lift Loss	Comments
16	21-Jan-11	Max-Flight	N/A	S	S 25	35	-11.5	-11.7	3.3, 2.7, 3.8	1.2, 1.6, 1.8	1.31	7.88	115 Knots Simulate HOT
17	22-Jan-11	Max-Flight	16	S++	S 50	17.5	-15	-14.9	2.7, 3.1, 3.3	1.2, 1.7, 1.9	1.313	6.35	115 Knots 2x Rate, 1/2 HOT
18	22-Jan-11	Max-Flight	16	S++	S 100	8.75	-14.7	-16	3, 2.8, 4	1.5, 1.9, 2.5	1.296	7.56	115 Knots 4x Rate, 1/4 HOT
19	22-Jan-11	Max-Flight	16	S++	S 50	17.5	-16.7	-16.7	3.2, 3.2, 3.8	1.5, 1.8, 2.5	1.273	9.20	**100 Knots** 2x Rate, 1/2 HOT
87	31-Jan-11	ABC-S+	N/A	S	S 25	60	-11.1	-11	3.8, 3.3, 4	1.9, 2.2, 3.2	1.252	11.95	115 Knots Simulate HOT
88	1-Feb-11	ABC-S+	87	S++	S 50	30	-11.8	-14.3	3.8, 3.2, 4	1.9, 2.2, 2.9	1.23	13.50	115 Knots 2x Rate, 1/2 HOT
89	1-Feb-11	ABC-S+	87	S++	S 100	15	-13.4	-13.4	3.8, 3.4, 4	1.9, 2.6, 3.3	1.2	15.61	115 Knots 4x Rate, 1/4 HOT
108	3-Feb-11	2031 - Cold	-	-	-	-	-	-	-	-	-	-	Test Not Valid. Redone as 108A
108A	3-Feb-11	2031 - Cold	N/A	S	S 25	15	-11.5	-12.2	3.5, 1.8, 4	1.25, 1.5, 2.25	1.331	6.40	100 Knots Simulate HOT
109	3-Feb-11	2031 - Cold	108A	S++	S 50	7.5	-11	-13.1	3.25, 2.75, 3.75	1.1, 1.75, 2.35	1.33	6.47	100 Knots 2x Rate, 1/2 HOT
110	3-Feb-11	2031 - Cold	108A	S++	S 100	7.5	-10.3	-13.4	3.5, 3, 4	1.1, 2.25, 2.5	1.307	8.09	100 Knots 4x Rate, 1/2 HOT

9.5 Summary of Test Results

A total of three comparative test sets were completed. Two sets of comparative test runs were conducted with Type IV PG fluid, and one set was conducted with Type III PG fluid. The first two sets of tests (Tests #16, #17, and #18, and Tests #87, #88, and #89) were conducted at 115 knots due to the large lift losses observed. An additional Test #19 was conducted for the first test set to obtain a comparative 100 knots data point. Due to the Type III fluid being predominantly designed for low-speed aircraft, Tests #108A, #109, and #110 were conducted at 100 knots.

Photo summaries of each of these tests can be found in Appendix D of this report.

9.5.1 MaxFlight Type IV PG Tests

Test #16, the baseline test for this first set of tests, exposed the fluid to 35 minutes of moderate snow; this exposure time was based on the current HOTs for MaxFlight. The results demonstrated a generally acceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation. The aerodynamic performance indicated a lift loss of 7.88 percent compared to the dry wing, which confirmed visual observations.

Test #17 was conducted in heavy snow conditions (twice the rate) for half the exposure time; this resulted in an equivalent amount of contamination being dispensed in both Tests #16 and #17. The results were similar and slightly better than Test #16 in that the test demonstrated an acceptable level of visual contamination at the end of the precipitation period, as well as at the time of rotation. The aerodynamic performance also showed a comparable lift loss of 6.35 percent.

Test #18 was conducted in very heavy snow conditions (four times the rate) for one-quarter the exposure time; this again resulted in an equivalent amount of contamination being dispensed in both Tests #16 and #18. The visual contamination ratings were similar to Test #16 at the end of the precipitation period; however, they were slightly worse at the time of rotation. The aerodynamic performance also showed a comparable lift loss of 7.56 percent.

Test #19 was conducted as a repeat of Test #17; however, it was conducted at 100 knots instead of 115 knots. The visual contamination results were similar to Test #16 at the end of the precipitation period; however, the results were slightly worse at the time of rotation (likely due to the lower rotation speed). The aerodynamic performance also showed a higher lift loss of 9.20 percent.

In general, the MaxFlight results demonstrated similar visual and aerodynamic results for equivalent amounts of contamination, regardless of exposure time. These results indicate that an inverse linear relationship between HOT and rate of precipitation can be possible for MaxFlight. The results also indicate that performance worsens as the rotation speed is decreased.

9.5.2 ABC-S+ Type IV PG Tests

Test #87, the baseline 115 knots test for this second set of test runs, exposed the fluid to 60 minutes of moderate snow; this exposure time was based on the current HOTs for ABC-S+. The results demonstrated unacceptable levels of visual contamination at the end of the precipitation period, as well as at the time of rotation. The aerodynamic performance indicated a lift loss of 11.95 percent, which confirmed the poor visual observations.

Test #88 was conducted in heavy snow conditions (twice the rate) for half the exposure time; this resulted in an equivalent amount of contamination being dispensed in both Tests #87 and #88. The visual contamination results were similar to Test #87 at the end of the precipitation period, as well as at the time of rotation. The aerodynamic performance, however, indicated a higher lift loss of 13.5 percent.

Test #89 was conducted in very heavy snow conditions (four times the rate) for one-quarter the exposure time. This resulted in an equivalent amount of contamination being dispensed in both Tests #87 and #89. Again, the visual contamination ratings were similar to Test #87 at the end of the precipitation period and at the time of rotation. The aerodynamic performance, however, indicated a higher lift loss of 15.61 percent.

In general, the ABC-S+ results demonstrated similar visuals results for equivalent amounts of contamination, regardless of exposure time; however, the aerodynamic performance indicated an increase in lift loss as the exposure time was decreased.

9.5.3 2031 Type III PG Tests

Test #108 was dismissed due to technical complications and was repeated as #108A.

Test #108A, the baseline test for this third set of tests, exposed the fluid to 15 minutes of moderate snow; this exposure time was based on the current HOTs for 2031 Type III fluid. The results demonstrated marginally unacceptable levels of visual contamination at the end of the precipitation period; however, they were acceptable at the time of rotation. The aerodynamic performance indicated a lift loss of 6.4 percent, which confirmed the visual observations at the time of rotation.

Test #109 was conducted in heavy snow conditions (twice the rate) for half the exposure time; this resulted in an equivalent amount of contamination being dispensed in both Tests #108A and #109. The visual contamination results were similar to Test #108A at the end of the precipitation period, as well as at the time of rotation. The aerodynamic performance also showed a comparable lift loss of 6.47 percent, confirming the visual observations.

Test #110 was conducted in very heavy snow conditions (four times the rate) for half the exposure time; this resulted in twice the amount of contamination being dispensed compared to Test #108A. The intent was to explore how much worse the end condition would get if significantly greater amounts of contamination were applied. In this case, the visual contamination ratings were slightly worse at the end of the precipitation period and at the time of rotation. The aerodynamic performance also indicated a higher lift loss of 8.09 percent.

In general, the 2031 results demonstrated similar visual and aerodynamic results for equivalent amounts of contamination, regardless of exposure time. Even twice the amount of contamination in half the time generated only marginally worse conditions.

9.5.4 General Observations

When analysing current HOT values for any given condition, a fluid will be able to absorb higher amounts of contamination when exposed to higher precipitation rates. This is likely a factor of fluid drainage and thinning. Using the same logic, it would be expected that in heavy snow conditions with double the rate of precipitation of a moderate snow condition, the fluid HOT should be half or more of the moderate snow HOT.

In general, the heavy snow testing results demonstrated similar visual and aerodynamic results (compared to the moderate snow tests) for equivalent amounts of contamination, regardless of exposure time. These results indicate a potential to develop guidance material for heavy snow conditions; however, a more extensive analysis of this and the previous year's data, along with flat plate testing, is required.

Note: These results are preliminary and based on limited data; therefore, additional testing and more extensive analysis of previous work conducted would be required to further substantiate these observations.

10. COMPARISON OF MULTIPLE FLUID FLOW-OFF PROPERTIES

10.1 Background

Each fluid has specific flow-off properties, with the most obvious differences existing between EG and PG fluids; however, even amongst PG fluids, differences can be observed. It was recommended that tests be conducted with side-by-side fluids to obtain visual insight into the differences of the fluids tested. Aerodynamic data was collected but was of little value to these tests due to the multiple fluids tested per run.

10.2 Objective

The objective of this test was to obtain visual data regarding flow-off properties of the different fluids tested.

10.3 General Methodology

The following is a brief summary of the methodology used for this testing:

- Pour four separate strips of fluid using 4 L of fluid per strip;
- Run wind tunnel and collect visual data (lift coefficient data will be collected but is of no value); and
- Visually compare results of different fluids tested.

10.4 Data Collected

Two test runs were conducted, each with four different fluids applied to the wing section. A summary of the test data is included in Table 10.1. In addition, Figures 10.1 and 10.2 demonstrate the order in which the fluids were applied to the wing section.

Table 10.1: Summary of 2010-11 Multiple Fluids Testing

Test No.	Date	Fluid	Associated Baseline Run	Condition	Precip. Rate (g/dm²/h)	Precip. Time (min.)	Tunnel Temp. at Start of Test (°C)	AVG Wing Temp. Before Test (ºC)	Visual Cont. Rating Before Takeoff (LE, TE, Flap)	Visual Cont. Rating at Rotation (LE, TE, Flap)	CL at 8º Rotation	% Lift Loss	Comments
90	1-Feb-11	EG106 ABC-S+ 09 ABC-S+ 10 Max-Flight	N/A	N/A	N/A	N/A	-11.9	-12.3	N/A	N/A	1.33	6.47	N/A
91	1-Feb-11	Octaflo Launch 2031 AD-49	N/A	N/A	N/A	N/A	-14.8	-11.6	N/A	N/A	1.346	5.34	N/A

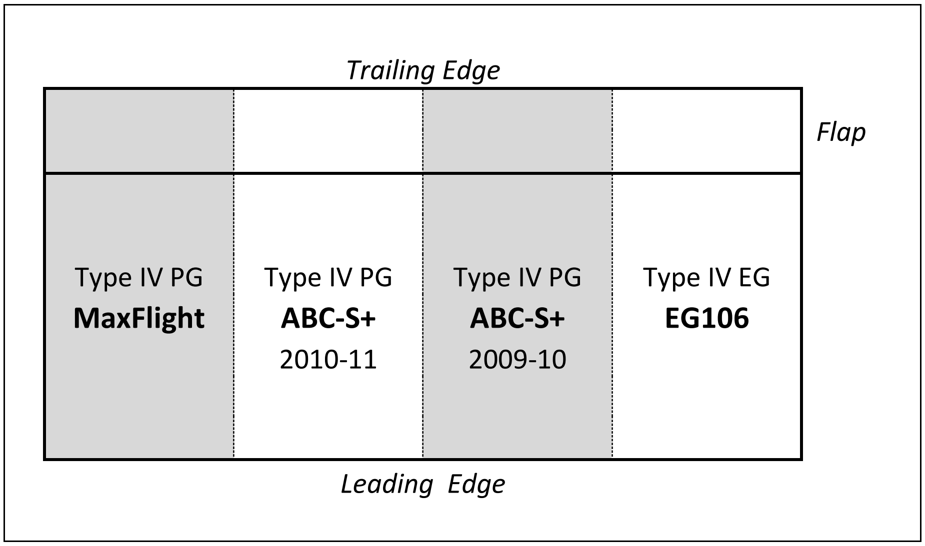


Figure 10.1: Run #90 – Map of Fluid Application Order

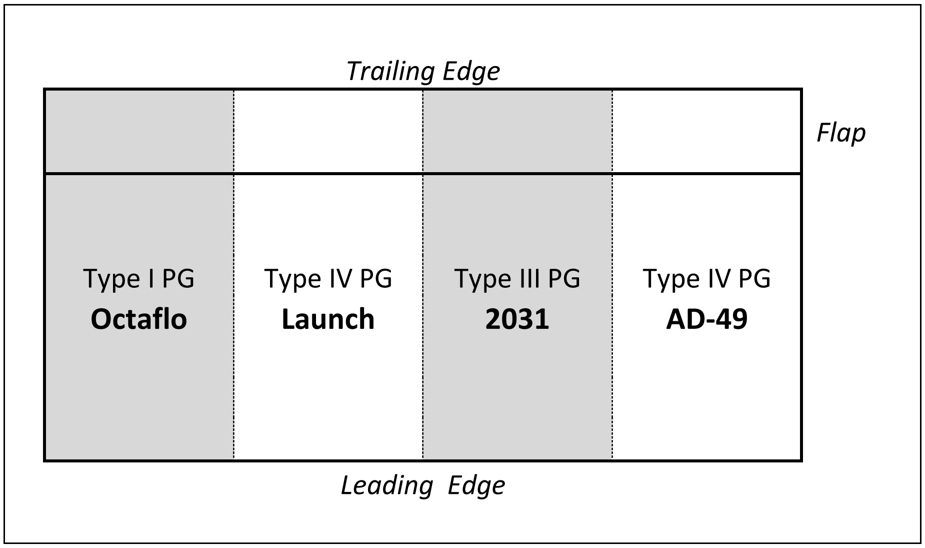


Figure 10.2: Run #91 – Map of Fluid Application Order

10.5 Summary of Test Results

Test #90 demonstrated that there were no significant differences in the appearance and flow-off of the three PG fluids tested (MaxFlight, ABC-S+ 2010-11 batch, and ABC-S+ 2009-10 batch). However, differences were observed with the EG fluid, particularly on how waves form in the fluid. After most of the fluid had been sheared off, the remaining PG fluid generated waves perpendicular to the chord length, whereas the EG fluid generated waves parallel to the chord line. This phenomenon is likely due to the different chemical compositions of the fluids and how they react to shear forces. Photo 10.1 shows the condition of the wing during Test #90 prior to the start of the wind tunnel, and Photo 10.2 shows the condition of the wing just before rotation.

Test #91 demonstrated similarities in the appearance and flow-off of the two PG fluids tested (Launch and AD-49), which also were comparable to the behaviour of the PG fluids tested in Run #90. However, the Type I fluid behaved differently and was completely clean much earlier compared to the thickened fluids; this is to be expected due to the low viscosity of the fluid. Also, the Type III fluid sheared off at a faster rate compared to the two Type IV fluids, again likely a function of the fluid viscosity. Photo 10.3 shows the condition of the baseline wing Test #91 prior to the start of the wind tunnel, and Photo 10.4 shows the condition of the wing just before rotation.

It should be noted that although similar amounts of residual fluids were present in all thickened fluid cases, the fluid dye provided a different visual indication as to how much fluid was present. For example, EG106 and AD-49 both contain a very bright dye. If comparing these fluids to ABC-S+ or Launch which had more sedate dyes, one might misinterpret the bright fluid remaining on the wing as an indication of poor fluid flow-off, whereas all fluids generate similar residual thicknesses on the wing.

Note: These results are preliminary and based on limited data; therefore, additional testing would be required to further substantiate these observations.

Photo 10.1: Test #90 – Before Start of Takeoff Run

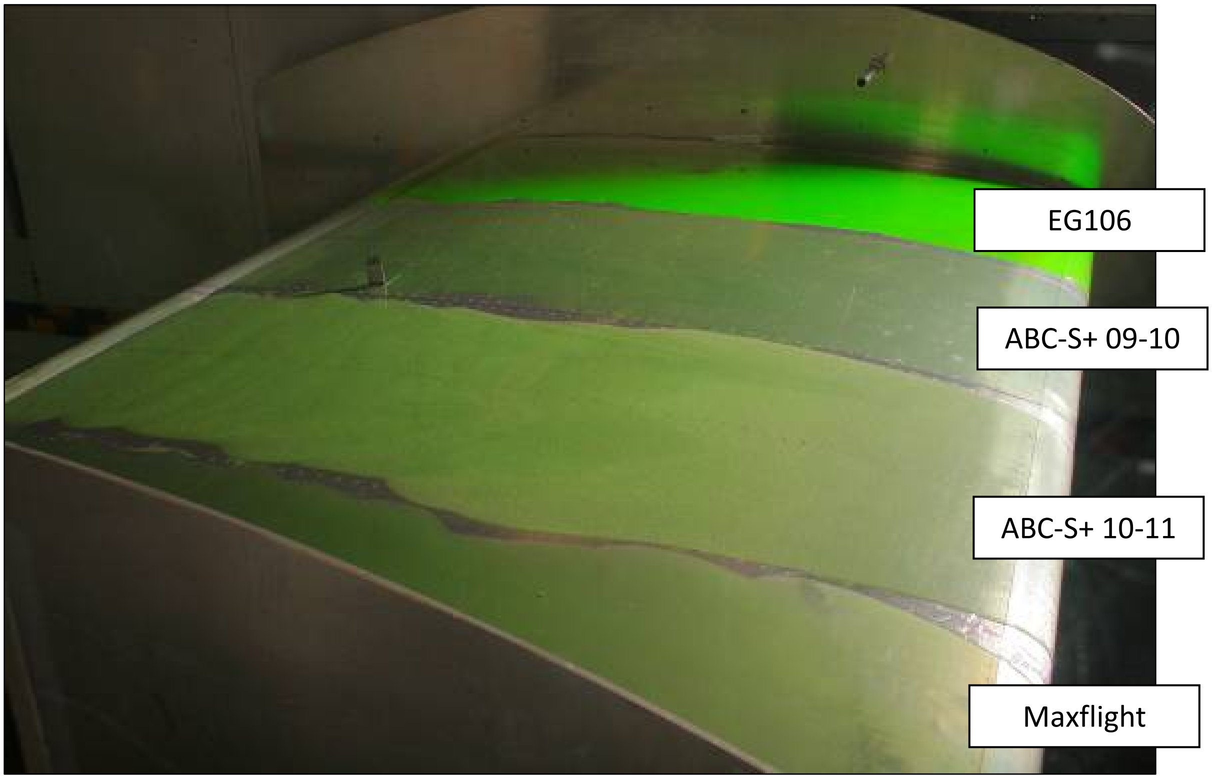


Photo 10.2: Test #90– Before Rotation

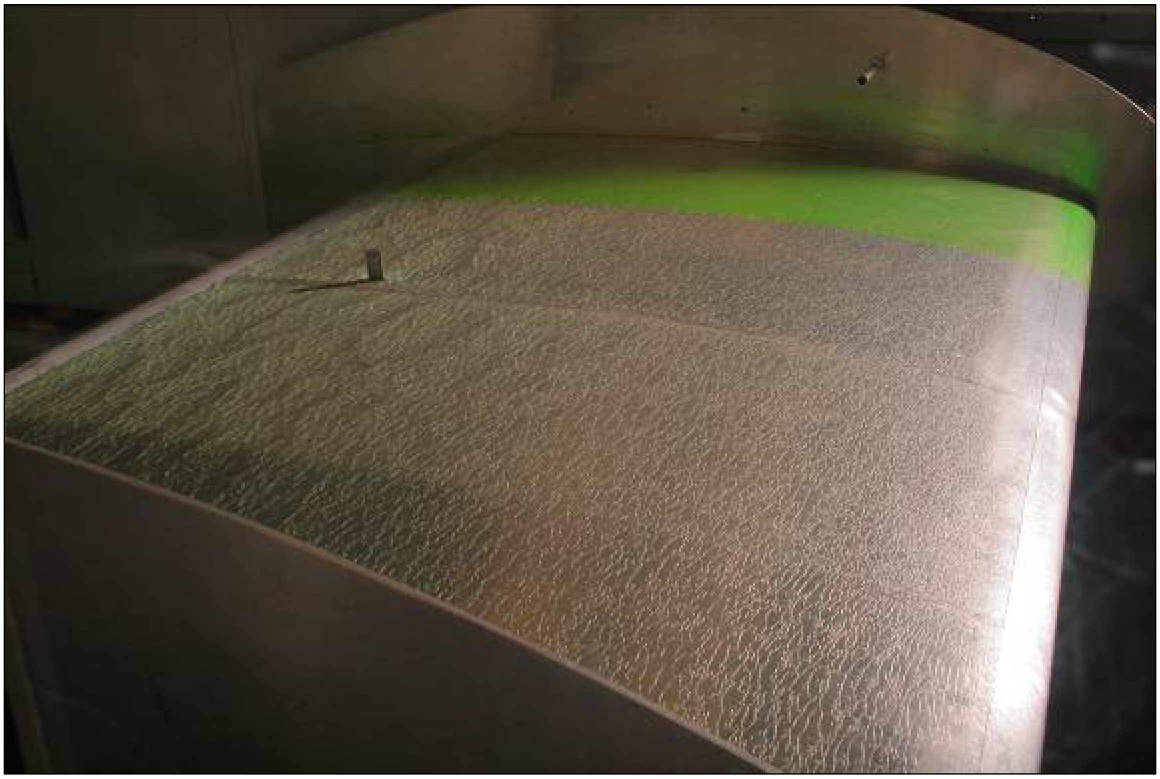


Photo 10.3: Test #91 – Before Start of Takeoff Run

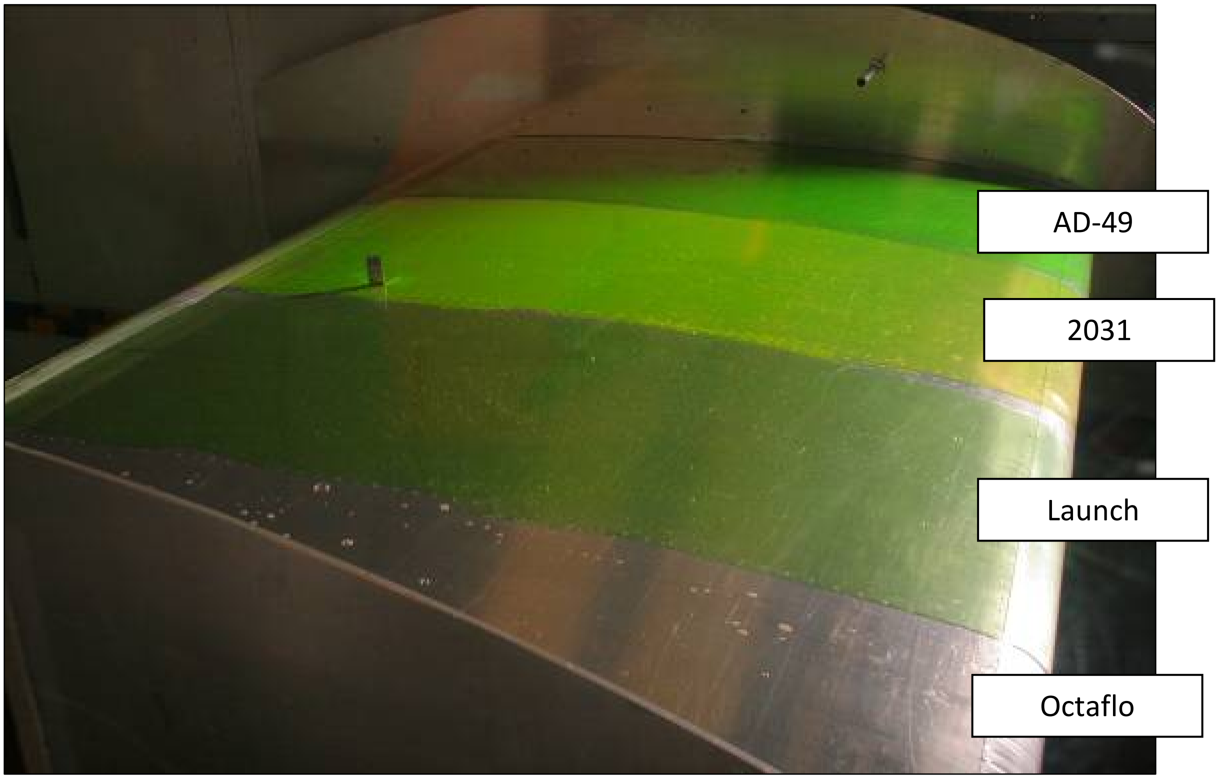
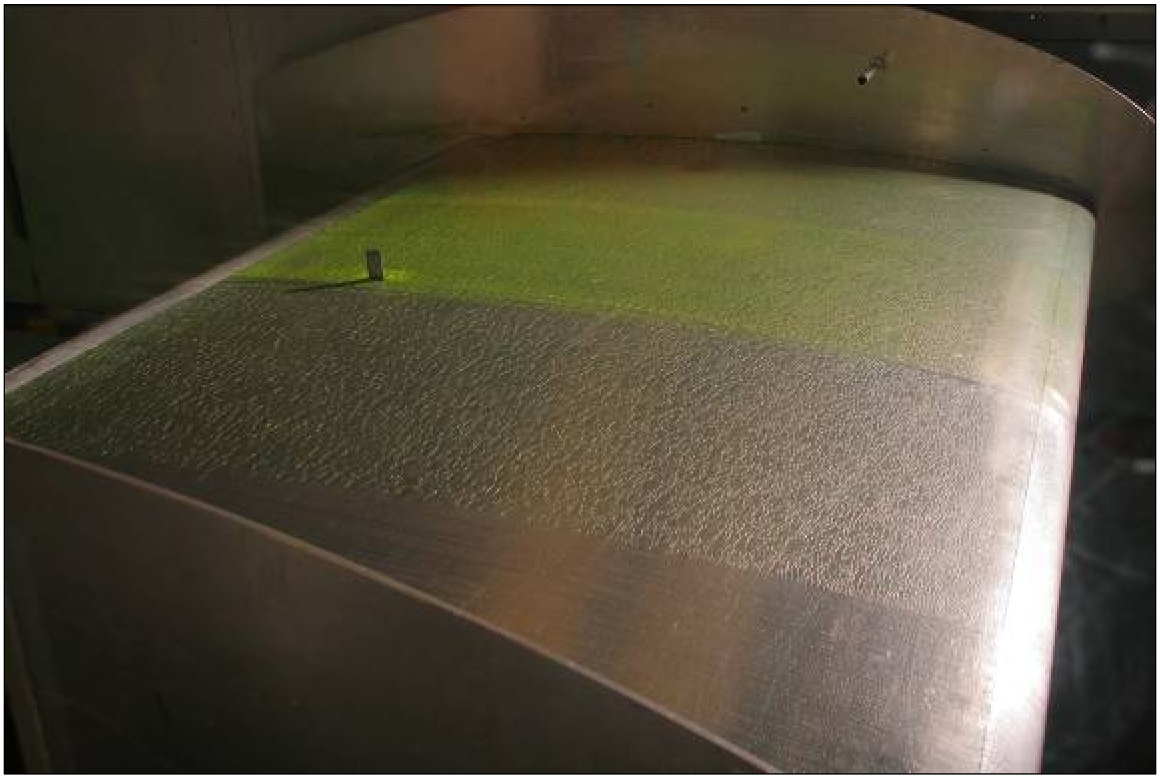


Photo 10.4: Test #91 – Before Rotation



REFERENCES

1. Ruggi, M., *Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2008-09*, APS Aviation Inc., Transportation Development Centre, Montreal, March 2010, TP 14939E, XX (to be published).

2. Ruggi, M., *Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2009-10*, APS Aviation Inc., Transportation Development Centre, Montreal, August 2011, TP 15057E, XX (to be published).

3. Balaban, G., *Flow of Contaminated Fluid from Aircraft Wings: Feasibility Report*, APS Aviation Inc., Transportation Development Centre, Montreal, January 2008, TP 14778E, XX (to be published).

4. APS Aviation Inc., *Aircraft Ground Icing General Research Activities During the 2010-11 Winter,* APS Aviation Inc., Transportation Development Centre, Montreal, January 2012, TP 15158E, XX (to be published).

This page intentionally left blank.

APPENDIX A

TRANSPORTATION DEVELOPMENT CENTRE WORK STATEMENT EXCERPT – AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2010-11

TRANSPORTATION DEVLOPMENT
CENTRE WORK STATEMENT EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2010-11

6.3 AIRCRAFT PERFORMANCE RESEARCH

6.3.4 Additional Wind Tunnel Research

It is anticipated that wind tunnel testing during the winter of 2010-11 will be conducted in accordance with the objectives described in 1.3.1. This item (1.3.2) has been included in the event that additional testing is required and is budgeted to account for one additional week of testing.

a) Develop a procedure and test plan with the NRC staff who operates the PWT;

b) Perform wind tunnel tests to determine aerodynamic failure;

c) Conduct testing to investigate surface roughness of a wing surface as it pertains to lift loss;

d) Investigate aerodynamic effects of mixed light freezing rain and snow conditions, simulated snow pellet conditions, low speed ramp fluid flow off, bare wing and snow contamination take-off (both cold and warm temperatures), ice phobic products, fluid contaminated with runway deicer fluid, rehydrated residues (Flybe issue), and reduced Type I endurance times on composite surfaces;

e) Conduct testing to investigate fluid flow off properties of heavily contaminated fluid during simulated heavy snow conditions; and

f) Report the findings and prepare presentation material for the SAE G-12 meetings.

This page intentionally left blank.

APPENDIX B

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

CM2169.003

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

Winter 2010-11

Prepared for

Transportation Development Centre
Transport Canada

Prepared by: Marco Ruggi

Reviewed by: John D'Avirro

APS Aviation Inc.

January 14, 2011
Final Version 1.0

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

1. BACKGROUND

Prior to the winter of 2006-07, 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 take off 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-take off contamination checks by the on-board crew were not possible. FedEx had been faced with similar problems in Memphis. Following this event, in October 2005, the FAA issued two notices restricting take offs in ice pellet conditions.

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. During the winter of 2004-05, aerodynamic and endurance time testing were conducted in simulated ice pellet conditions. APS also conducted some preliminary flat plate research (see TP 14718E). Based on the preliminary data, an allowance of 20 minutes in light ice pellet conditions was proposed, however no changes to the HOT guidelines were made.

During the following winter of 2006-07, the FAA provided a 25 minute allowance as a preliminary guideline; TC issued a note indicating that no changes would be made to the HOT guidelines. This allowance was based on the previous research conducted during the winter of 2005-06, primarily as a result of Falcon 20 aerodynamic research (see TP 14716E); these results were presented at the Society of Automotive Engineers (SAE) meeting in Lisbon in May 2006. To address the option of a pre-take off contamination check, the 20 minute targeted allowance was extended to 25 minutes; pre-take off 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.

During the winter of 2007-08, the TC and FAA provided allowance time guidance material for operations in mixed conditions with ice pellets guideline. These allowance times were based on the research conducted during the winter of 2006-07 (see TP 14779E). The recommended allowance times were based on aerodynamic research conducted using the 3 m x 6 m Open Circuit Propulsion and Icing Wind Tunnel (PIWT) and the NRC Falcon 20 aircraft; these results were presented at the SAE meeting in San Diego in May 2007. These allowance time guidelines were followed by a list of restrictions based on the results obtained through the research conducted, and the lack of data in specific conditions.

During the winter of 2008-09, additional endurance time testing and aerodynamic research was conducted to support and further expand the ice pellet allowance times (see TP 14935E). Full-scale testing with the NRC PIWT was conducted in mixed conditions with ice pellets and in non precipitation conditions. Testing was geared towards validating the current ice pellet allowance times, and potentially expanding the guidance material to include different conditions, fluids, and acceleration profiles. A revised version of the ice pellet allowance times was published for the winter of 2009-10; changes were made to the high speed table allowance times only.

During the winter of 2009-10, additional aerodynamic research using a generic super-critical wing model was conducted at the NRC PIWT to support and further expand the ice pellet allowance times for use with newer generation aircraft. During the testing, fluid flow-off issues with the supercritical wing were observed with PG fluids at the lower temperatures; more specifically during light ice pellets and moderate ice pellet conditions below -10°C. In addition fluid failure issues with the supercritical wing were observed with PG fluids during moderate ice pellets above -5°C; the relatively flat surface of the wing had less fluid flow off during contamination and resulted in an earlier fluid failure for PG fluids. In general, higher lift losses were observed with the supercritical wing as compared to previous wings tested. A revised version of the ice pellet allowance times was published for the winter of 2009-10.

It was recommended that testing continue with the supercritical wing in the PIWT during the winter of 2010-11. The objective of the testing is to validate the current allowance times for aircraft with supercritical airfoils, to correlate the lift losses observed the fluid aerodynamic acceptance test, to validate the analysis methodologies developed following the winter 2009-10 testing, and to potentially expand the results to include different conditions, fluids, and acceleration profiles.

2. OBJECTIVES

The objective of this testing is to conduct aerodynamic testing with a super critical airfoil to:

- Validate the current allowance times (using new fluids) for newer generation aircraft (with super critical wings);
- Validate the analysis methodologies developed following the Winter 2009-10 testing (i.e. extrapolation of data to 115 knots);
- To correlate the lift losses observed in the NRC PIWT with the fluid aerodynamic acceptance test protocol (5.24% LL);

As lower priority objectives, testing will be conducted to investigate the following:

- Potentially expand the current allowance times for the following conditions:
    - IP-/SN-;
    - IP-/SN;
    - Type III Fluid in all conditions, heated and un-heated.
- Heavily contaminated fluid during heavy snow conditions;
- Effect of CL Max on recorded lift losses;
- Surface roughness as a result of adhered contamination;
- Effect of wing geometry on fluid failure and aerodynamic performance;
- Low speed testing for Aero Certification Test (67 vs. 80 knots);
- Snow on an Un-Protected Wing;
- Feasibility of conducting horizontal stabilizer testing;
- Rain on an un-protected wing;
- Effect of ice phobic coatings on contaminated airfoil aerodynamic performance ;
- Degraded Anti-icing Fluid Performance Following Contamination with Runway Deicing Fluid; and
- Heavily contaminated vertical stabilizer;

- Frost CSW Spot Deicing;
- Light Freezing Rain and Snow;
- Ice pellet allowance times for low speed aircraft using Type IV fluid;
- Ice pellet allowance times for Type II fluid.

Testing will objectively determine the level of contamination of anti-icing fluid at which the aerodynamic shear forces during takeoff ground roll, rotation and lift off fail to remove the resultant slush.

To satisfy these objectives, a super-critical wing section (Figure 2.1) will be subjected to a series of tests in the NRC wind tunnel. The dimensions indicated are in inches. This wing section was constructed by NRC specifically for the conduct of these tests following extensive consultations with an airframe manufacturer to ensure a representative super-critical design.

Three weeks of testing (over a four week period) have been scheduled for the conduct of these tests. The start date for testing is currently scheduled for January 18th and testing will continue until February 11th (see table 2.1).

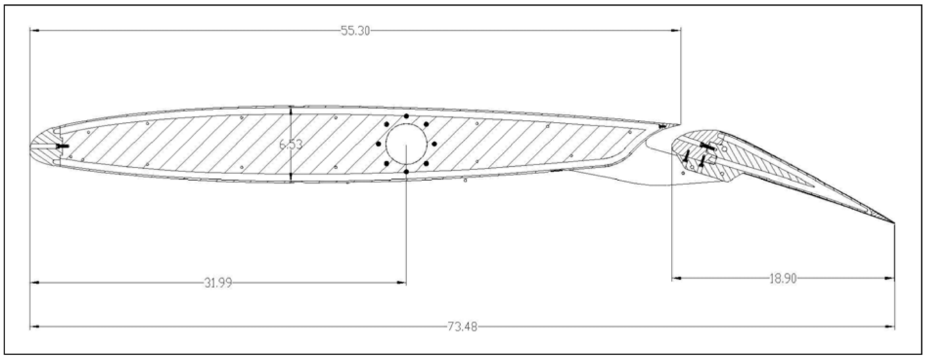


Figure 2.1: Super-Critical Wing Section

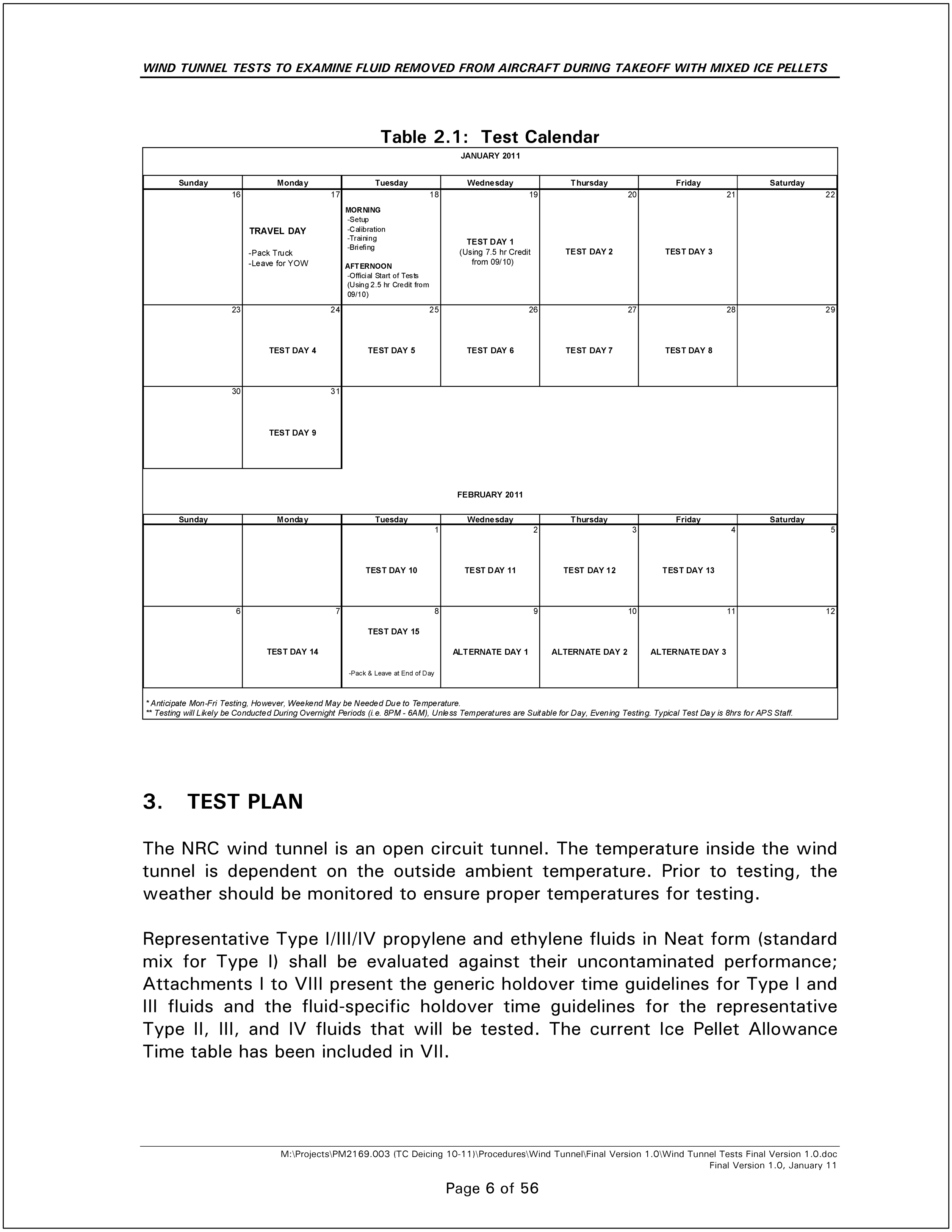


Table 2.1: Test Calendar

JANUARY 2011

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
16	17 **TRAVEL DAY** -Pack Truck -Leave for YOW	18 **MORNING** -Setup -Calibration -Training -Briefing **AFTERNOON** -Official Start of Tests (Using 2.5 hr Credit from 09/10)	19 **TEST DAY 1** (Using 7.5 hr Credit from 09/10)	20 **TEST DAY 2**	21 **TEST DAY 3**	22
23	24 **TEST DAY 4**	25 **TEST DAY 5**	26 **TEST DAY 6**	27 **TEST DAY 7**	28 **TEST DAY 8**	29
30	31 **TEST DAY 9**					

FEBRUARY 2011

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
		1 **TEST DAY 10**	2 **TEST DAY 11**	3 **TEST DAY 12**	4 **TEST DAY 13**	5
6	7 **TEST DAY 14**	8 **TEST DAY 15** -Pack & Leave at End of Day	9 **ALTERNATE DAY 1**	10 **ALTERNATE DAY 2**	11 **ALTERNATE DAY 3**	12

** Anticipate Mon-Fri Testing, However, Weekend May be Needed Due to Temperature.*
*** Testing will Likely be Conducted During Overnight Periods (i.e. 8PM - 6AM), Unless Temperatures are Suitable for Day, Evening Testing. Typical Test Day is 8hrs for APS Staff.*

3. TEST PLAN

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

Representative Type I/III/IV propylene and ethylene fluids in Neat form (standard mix for Type I) shall be evaluated against their uncontaminated performance; Attachments I to VIII present the generic holdover time guidelines for Type I and III fluids and the fluid-specific holdover time guidelines for the representative Type II, III, and IV fluids that will be tested. The current Ice Pellet Allowance Time table has been included in VII.

A preliminary list of test objectives is shown in Table 3.1. It should be noted that the order in which the tests will be carried out will be depend on weather conditions and TC/FAA directive. A detailed preliminary test matrix is shown in Table 3.2.

NOTE: The numbering of the test runs will be done in a sequential order starting with number 1.

Each test shall be comprised of one fluid at one temperature and one contamination scenario. A test series will be comprised of one fluid at one temperature, using one form of contamination, with varying levels of exposure to the contamination. Baseline fluid-only tests are to be conducted following each contaminated test (or series of sequential tests conducted during similar conditions).

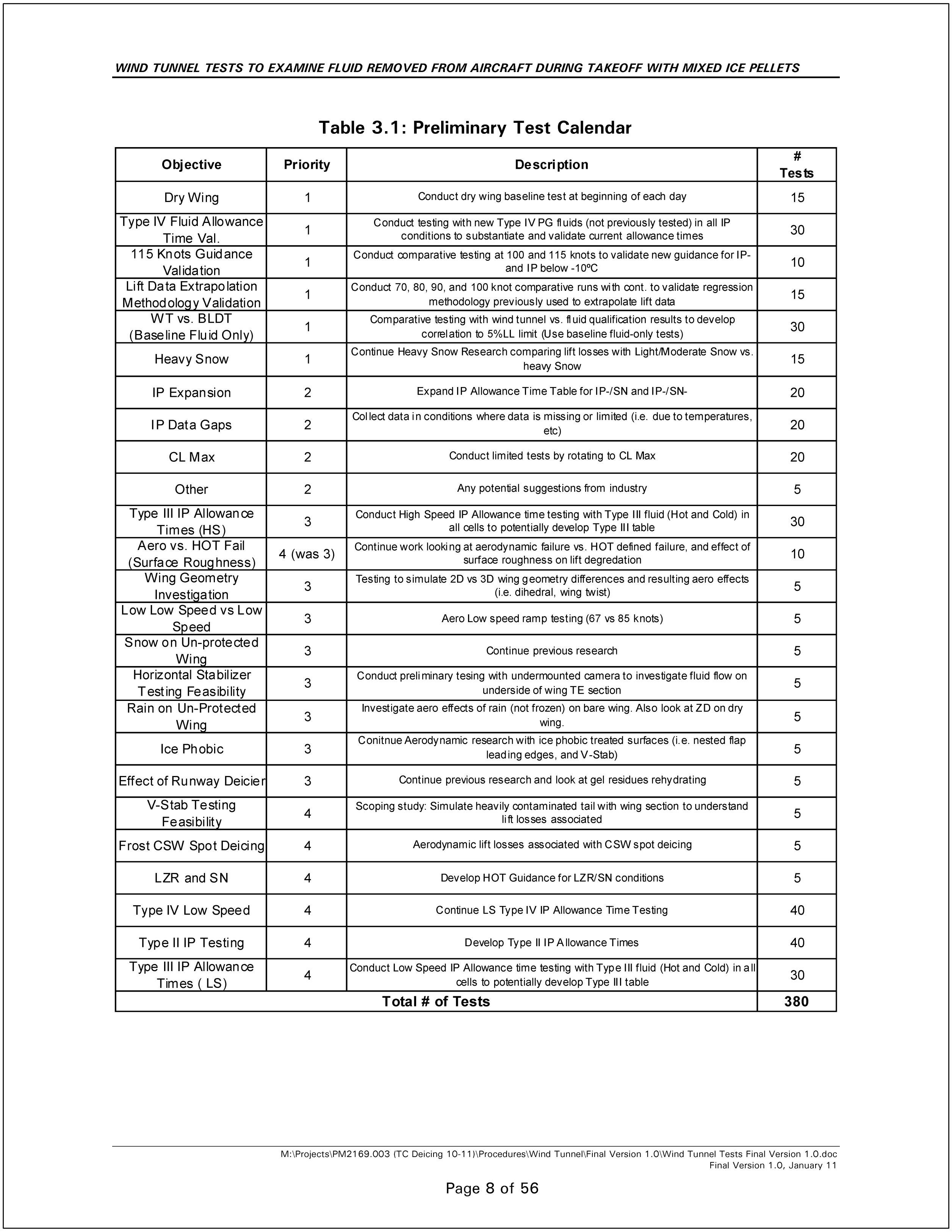


Table 3.1: Preliminary Test Calendar

Objective	Priority	Description	# Tests
Dry Wing	1	Conduct dry wing baseline test at beginning of each day	15
Type IV Fluid Allowance Time Val.	1	Conduct testing with new Type IV PG fluids (not previously tested) in all IP conditions to substantiate and validate current allowance times	30
115 Knots Guidance Validation	1	Conduct comparative testing at 100 and 115 knots to validate new guidance for IP- and IP below -10ºC	10
Lift Data Extrapolation Methodology Validation	1	Conduct 70, 80, 90, and 100 knot comparative runs with cont. to validate regression methodology previously used to extrapolate lift data	15
WT vs. BLDT (Baseline Fluid Only)	1	Comparative testing with wind tunnel vs. fluid qualification results to develop correlation to 5%LL limit (Use baseline fluid-only tests)	30
Heavy Snow	1	Continue Heavy Snow Research comparing lift losses with Light/Moderate Snow vs. heavy Snow	15
IP Expansion	2	Expand IP Allowance Time Table for IP-/SN and IP-/SN-	20
IP Data Gaps	2	Collect data in conditions where data is missing or limited (i.e. due to temperatures, etc)	20
CL Max	2	Conduct limited tests by rotating to CL Max	20
Other	2	Any potential suggestions from industry	5
Type III IP Allowance Times (HS)	3	Conduct High Speed IP Allowance time testing with Type III fluid (Hot and Cold) in all cells to potentially develop Type III table	30
Aero vs. HOT Fail (Surface Roughness)	4 (was 3)	Continue work looking at aerodynamic failure vs. HOT defined failure, and effect of surface roughness on lift degredation	10
Wing Geometry Investigation	3	Testing to simulate 2D vs 3D wing geometry differences and resulting aero effects (i.e. dihedral, wing twist)	5
Low Low Speed vs Low Speed	3	Aero Low speed ramp testing (67 vs 85 knots)	5
Snow on Un-protected Wing	3	Continue previous research	5
Horizontal Stabilizer Testing Feasibility	3	Conduct preliminary tesing with undermounted camera to investigate fluid flow on underside of wing TE section	5
Rain on Un-Protected Wing	3	Investigate aero effects of rain (not frozen) on bare wing. Also look at ZD on dry wing.	5
Ice Phobic	3	Conitnue Aerodynamic research with ice phobic treated surfaces (i.e. nested flap leading edges, and V-Stab)	5
Effect of Runway Deicier	3	Continue previous research and look at gel residues rehydrating	5
V-Stab Testing Feasibility	4	Scoping study: Simulate heavily contaminated tail with wing section to understand lift losses associated	5
Frost CSW Spot Deicing	4	Aerodynamic lift losses associated with CSW spot deicing	5
LZR and SN	4	Develop HOT Guidance for LZR/SN conditions	5
Type IV Low Speed	4	Continue LS Type IV IP Allowance Time Testing	40
Type II IP Testing	4	Develop Type II IP Allowance Times	40
Type III IP Allowance Times (LS)	4	Conduct Low Speed IP Allowance time testing with Type III fluid (Hot and Cold) in all cells to potentially develop Type III table	30
Total # of Tests			**380**

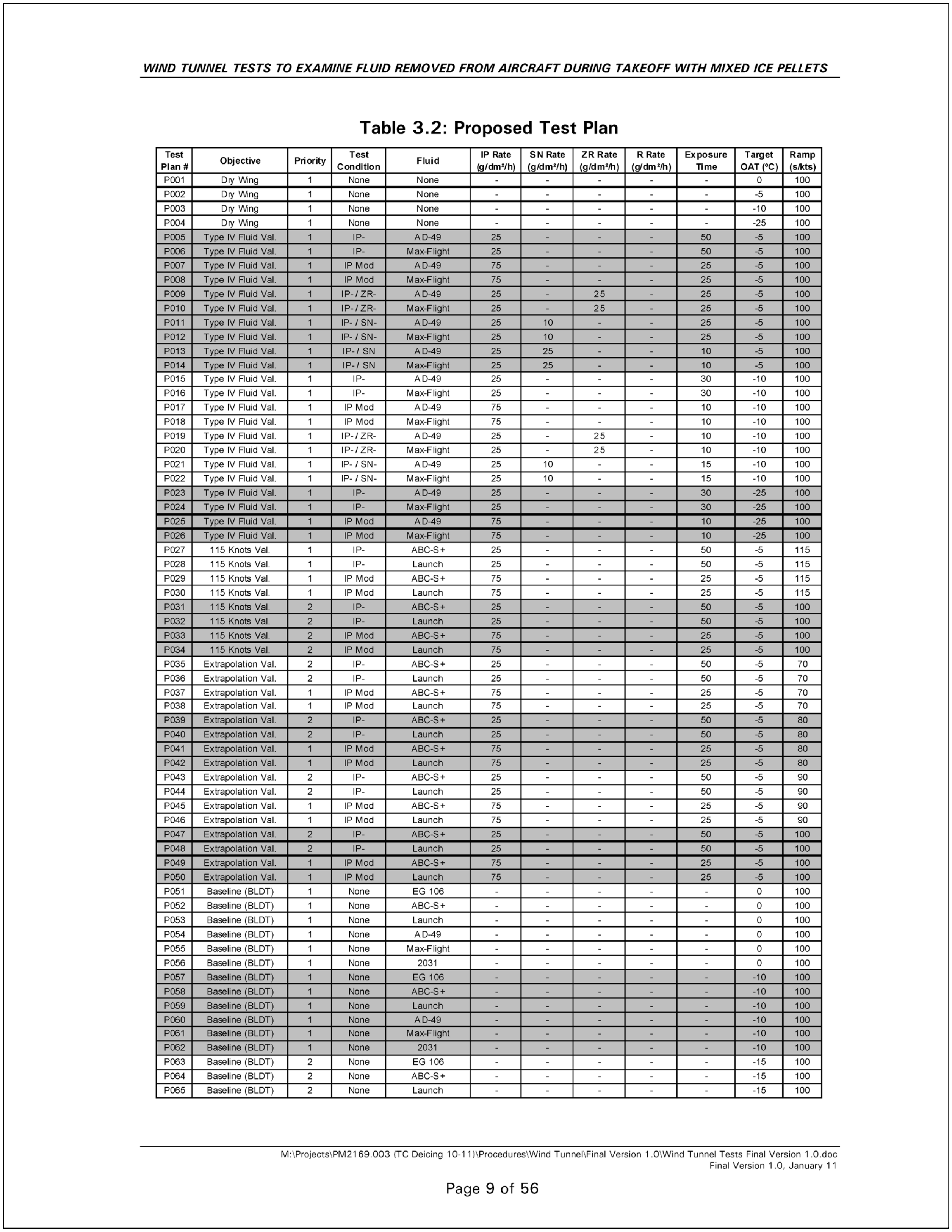


Table 3.2: Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm^2/h)	SN Rate (g/dm^2/h)	ZR Rate (g/dm^2/h)	R Rate (g/dm^2/h)	Exposure Time	Target OAT (ºC)	Ramp (s/kts)
P001	Dry Wing	1	None	None	-	-	-	-	-	0	100
P002	Dry Wing	1	None	None	-	-	-	-	-	-5	100
P003	Dry Wing	1	None	None	-	-	-	-	-	-10	100
P004	Dry Wing	1	None	None	-	-	-	-	-	-25	100
P005	Type IV Fluid Val.	1	IP-	AD-49	25	-	-	-	50	-5	100
P006	Type IV Fluid Val.	1	IP-	Max-Flight	25	-	-	-	50	-5	100
P007	Type IV Fluid Val.	1	IP Mod	AD-49	75	-	-	-	25	-5	100
P008	Type IV Fluid Val.	1	IP Mod	Max-Flight	75	-	-	-	25	-5	100
P009	Type IV Fluid Val.	1	IP- / ZR-	AD-49	25	-	25	-	25	-5	100
P010	Type IV Fluid Val.	1	IP- / ZR-	Max-Flight	25	-	25	-	25	-5	100
P011	Type IV Fluid Val.	1	IP- / SN-	AD-49	25	10	-	-	25	-5	100
P012	Type IV Fluid Val.	1	IP- / SN-	Max-Flight	25	10	-	-	25	-5	100
P013	Type IV Fluid Val.	1	IP- / SN	AD-49	25	25	-	-	10	-5	100
P014	Type IV Fluid Val.	1	IP- / SN	Max-Flight	25	25	-	-	10	-5	100
P015	Type IV Fluid Val.	1	IP-	AD-49	25	-	-	-	30	-10	100
P016	Type IV Fluid Val.	1	IP-	Max-Flight	25	-	-	-	30	-10	100
P017	Type IV Fluid Val.	1	IP Mod	AD-49	75	-	-	-	10	-10	100
P018	Type IV Fluid Val.	1	IP Mod	Max-Flight	75	-	-	-	10	-10	100
P019	Type IV Fluid Val.	1	IP- / ZR-	AD-49	25	-	25	-	10	-10	100
P020	Type IV Fluid Val.	1	IP- / ZR-	Max-Flight	25	-	25	-	10	-10	100
P021	Type IV Fluid Val.	1	IP- / SN-	AD-49	25	10	-	-	15	-10	100
P022	Type IV Fluid Val.	1	IP- / SN-	Max-Flight	25	10	-	-	15	-10	100
P023	Type IV Fluid Val.	1	IP-	AD-49	25	-	-	-	30	-25	100
P024	Type IV Fluid Val.	1	IP-	Max-Flight	25	-	-	-	30	-25	100
P025	Type IV Fluid Val.	1	IP Mod	AD-49	75	-	-	-	10	-25	100
P026	Type IV Fluid Val.	1	IP Mod	Max-Flight	75	-	-	-	10	-25	100
P027	115 Knots Val.	1	IP-	ABC-S+	25	-	-	-	50	-5	115
P028	115 Knots Val.	1	IP-	Launch	25	-	-	-	50	-5	115
P029	115 Knots Val.	1	IP Mod	ABC-S+	75	-	-	-	25	-5	115
P030	115 Knots Val.	1	IP Mod	Launch	75	-	-	-	25	-5	115
P031	115 Knots Val.	2	IP-	ABC-S+	25	-	-	-	50	-5	100
P032	115 Knots Val.	2	IP-	Launch	25	-	-	-	50	-5	100
P033	115 Knots Val.	2	IP Mod	ABC-S+	75	-	-	-	25	-5	100
P034	115 Knots Val.	2	IP Mod	Launch	75	-	-	-	25	-5	100
P035	Extrapolation Val.	2	IP-	ABC-S+	25	-	-	-	50	-5	70
P036	Extrapolation Val.	2	IP-	Launch	25	-	-	-	50	-5	70
P037	Extrapolation Val.	1	IP Mod	ABC-S+	75	-	-	-	25	-5	70
P038	Extrapolation Val.	1	IP Mod	Launch	75	-	-	-	25	-5	70
P039	Extrapolation Val.	2	IP-	ABC-S+	25	-	-	-	50	-5	80
P040	Extrapolation Val.	2	IP-	Launch	25	-	-	-	50	-5	80
P041	Extrapolation Val.	1	IP Mod	ABC-S+	75	-	-	-	25	-5	80
P042	Extrapolation Val.	1	IP Mod	Launch	75	-	-	-	25	-5	80
P043	Extrapolation Val.	2	IP-	ABC-S+	25	-	-	-	50	-5	90
P044	Extrapolation Val.	2	IP-	Launch	25	-	-	-	50	-5	90
P045	Extrapolation Val.	1	IP Mod	ABC-S+	75	-	-	-	25	-5	90
P046	Extrapolation Val.	1	IP Mod	Launch	75	-	-	-	25	-5	90
P047	Extrapolation Val.	2	IP-	ABC-S+	25	-	-	-	50	-5	100
P048	Extrapolation Val.	2	IP-	Launch	25	-	-	-	50	-5	100
P049	Extrapolation Val.	1	IP Mod	ABC-S+	75	-	-	-	25	-5	100
P050	Extrapolation Val.	1	IP Mod	Launch	75	-	-	-	25	-5	100
P051	Baseline (BLDT)	1	None	EG 106	-	-	-	-	-	0	100
P052	Baseline (BLDT)	1	None	ABC-S+	-	-	-	-	-	0	100
P053	Baseline (BLDT)	1	None	Launch	-	-	-	-	-	0	100
P054	Baseline (BLDT)	1	None	AD-49	-	-	-	-	-	0	100
P055	Baseline (BLDT)	1	None	Max-Flight	-	-	-	-	-	0	100
P056	Baseline (BLDT)	1	None	2031	-	-	-	-	-	0	100
P057	Baseline (BLDT)	1	None	EG 106	-	-	-	-	-	-10	100
P058	Baseline (BLDT)	1	None	ABC-S+	-	-	-	-	-	-10	100
P059	Baseline (BLDT)	1	None	Launch	-	-	-	-	-	-10	100
P060	Baseline (BLDT)	1	None	AD-49	-	-	-	-	-	-10	100
P061	Baseline (BLDT)	1	None	Max-Flight	-	-	-	-	-	-10	100
P062	Baseline (BLDT)	1	None	2031	-	-	-	-	-	-10	100
P063	Baseline (BLDT)	2	None	EG 106	-	-	-	-	-	-15	100
P064	Baseline (BLDT)	2	None	ABC-S+	-	-	-	-	-	-15	100
P065	Baseline (BLDT)	2	None	Launch	-	-	-	-	-	-15	100

Table 3.2 (cont'd): Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	ZR Rate (g/dm²/h)	R Rate (g/dm²/h)	Exposure Time	Target OAT (ºC)	Ramp (s/kts)
P066	Baseline (BLDT)	2	None	AD-49	-	-	-	-	-	-15	100
P067	Baseline (BLDT)	2	None	Max-Flight	-	-	-	-	-	-15	100
P068	Baseline (BLDT)	2	None	2031	-	-	-	-	-	-15	100
P069	Baseline (BLDT)	1	None	EG 106	-	-	-	-	-	-20	100
P070	Baseline (BLDT)	1	None	ABC-S+	-	-	-	-	-	-20	100
P071	Baseline (BLDT)	1	None	Launch	-	-	-	-	-	-20	100
P072	Baseline (BLDT)	1	None	AD-49	-	-	-	-	-	-20	100
P073	Baseline (BLDT)	1	None	Max-Flight	-	-	-	-	-	-20	100
P074	Baseline (BLDT)	1	None	2031	-	-	-	-	-	-20	100
P075	Baseline (BLDT)	1	None	EG 106	-	-	-	-	-	-30	100
P076	Baseline (BLDT)	1	None	ABC-S+	-	-	-	-	-	-30	100
P077	Baseline (BLDT)	1	None	Launch	-	-	-	-	-	-30	100
P078	Baseline (BLDT)	1	None	AD-49	-	-	-	-	-	-30	100
P079	Baseline (BLDT)	1	None	Max-Flight	-	-	-	-	-	-30	100
P080	Baseline (BLDT)	1	None	2031	-	-	-	-	-	-30	100
P081	Heavy Snow	2	S	Max-Flight	-	25	-	-	See HOT	< -5	100
P082	Heavy Snow	2	S++	Max-Flight	-	50	-	-	1/2 of HOT	< -5	100
P083	Heavy Snow	2	S++	Max-Flight	-	50	-	-	3/4 of HOT	< -5	100
P084	Heavy Snow	2	S	AD-49	-	25	-	-	See HOT	< -5	100
P085	Heavy Snow	2	S++	AD-49	-	50	-	-	1/2 of HOT	< -5	100
P086	Heavy Snow	2	S++	AD-49	-	50	-	-	3/4 of HOT	< -5	100
P087	Heavy Snow	3	S	EG 106	-	25	-	-	See HOT	< -5	100
P088	Heavy Snow	3	S++	EG 106	-	50	-	-	1/2 of HOT	< -5	100
P089	Heavy Snow	3	S++	EG 106	-	50	-	-	3/4 of HOT	< -5	100
P090	Heavy Snow	2	S	2031 - Cold	-	25	-	-	See HOT	< -5	100
P091	Heavy Snow	2	S++	2031 - Cold	-	50	-	-	1/2 of HOT	< -5	100
P092	Heavy Snow	2	S++	2031 - Cold	-	50	-	-	3/4 of HOT	< -5	100
P093	Heavy Snow (HHS)	2	S	ABC-S+	-	25	-	-	See HOT	< -5	115
P094	Heavy Snow (HHS)	2	S++	ABC-S+	-	50	-	-	1/2 of HOT	< -5	115
P095	Heavy Snow (HHS)	2	S++	ABC-S+	-	50	-	-	3/4 of HOT	< -5	115
P096	Heavy Snow (HHS)	2	S	Launch	-	25	-	-	See HOT	< -5	115
P097	Heavy Snow (HHS)	2	S++	Launch	-	50	-	-	1/2 of HOT	< -5	115
P098	Heavy Snow (HHS)	2	S++	Launch	-	50	-	-	3/4 of HOT	< -5	115
P099	IP Expansion	2	IP- / SN-	EG 106	25	10	-	-	40	-5	100
P100	IP Expansion	2	IP- / SN-	ABC-S+	25	10	-	-	40	-5	100
P101	IP Expansion	3	IP- / SN-	Launch	25	10	-	-	40	-5	100
P102	IP Expansion	2	IP- / SN	EG 106	25	25	-	-	25-30	-5	100
P103	IP Expansion	2	IP- / SN	ABC-S+	25	25	-	-	20	-5	100
P104	IP Expansion	3	IP- / SN	Launch	25	25	-	-	20	-5	100
P105	IP Expansion	2	IP- / SN-	EG 106	25	10	-	-	20-25	-10	100
P106	IP Expansion	2	IP- / SN-	ABC-S+	25	10	-	-	18	-10	100
P107	IP Expansion	3	IP- / SN-	Launch	25	10	-	-	18	-10	100
P108	IP Expansion	2	IP- / SN	EG 106	25	25	-	-	5-10	-10	100
P109	IP Expansion	2	IP- / SN	ABC-S+	25	25	-	-	5-10	-10	100
P110	IP Expansion	3	IP- / SN	Launch	25	25	-	-	5-10	-10	100
P111	IP Expansion	2	IP- / SN-	EG 106	25	10	-	-	10-15	-25	100
P112	IP Expansion	2	IP- / SN-	ABC-S+	25	10	-	-	5	-25	100
P113	IP Expansion	3	IP- / SN-	Launch	25	10	-	-	5	-25	100
P114	IP Expansion	2	IP- / SN	EG 106	25	25	-	-	5	-25	100
P115	IP Expansion	2	IP- / SN	ABC-S+	25	25	-	-	5	-25	100
P116	IP Expansion	3	IP- / SN	Launch	25	25	-	-	5	-25	100
P117	IP Data Gap	2	IP- / R Mod	EG 106	25	-	-	75	25	0	100
P118	IP Data Gap	2	IP- / R Mod	ABC-S+	25	-	-	75	25-40	0	100
P119	IP Data Gap	2	IP- / R Mod	Launch	25	-	-	75	25-40	0	100
P120	IP Data Gap	3	IP- / R Mod	AD-49	25	-	-	75	25+	-5	100
P120	IP Data Gap	3	IP- / R Mod	Max-Flight	25	-	-	75	25+	-5	100
P120	IP Data Gap	2	IP Mod	EG 106	75	-	-	-	25	-5	100
P121	IP Data Gap	2	IP-	EG 106	25	-	-	-	30	-25	100
P122	IP Data Gap	2	IP-	ABC-S+	25	-	-	-	30	-25	100
P123	IP Data Gap	2	IP Mod	EG 106	75	-	-	-	10	-25	100
P124	IP Data Gap	2	IP Mod	ABC-S+	75	-	-	-	10	-25	100
P125	CL MAX	2	Any	EG 106	-	-	-	-	TBD	<-5	100
P126	CL MAX	2	Any	ABC-S+	-	-	-	-	TBD	<-5	100
P127	CL MAX	2	Any	Launch	-	-	-	-	TBD	<-5	100
P128	CL MAX	2	Any	AD-49	-	-	-	-	TBD	<-5	100
P129	CL MAX	2	Any	Max-Flight	-	-	-	-	TBD	<-5	100
P130	CL MAX	2	Any	2031	-	-	-	-	TBD	<-5	100

Table 3.2 (cont'd): Proposed Test Plan

Test Plan #	Objective	Priority	Test Condition	Fluid	IP Rate (g/dm^2/h)	SN Rate (g/dm^2/h)	ZR Rate (g/dm^2/h)	R Rate (g/dm^2/h)	Exposure Time	Target OAT (ºC)	Ramp (s/kts)
P131	Industry Request	2	TBD	TBD	-	-	-	-	-	TBD	100
P132	Type III HS (HOT)	3	IP-	2031 - Hot	25	-	-	-	10	-5	100
P133	Type III HS (HOT)	3	IP Mod	2031 - Hot	75	-	-	-	5	-5	100
P134	Type III HS (HOT)	3	IP- / ZR-	2031 - Hot	25	-	25	-	7	-5	100
P135	Type III HS (HOT)	3	IP- / SN-	2031 - Hot	25	10	-	-	10	-5	100
P136	Type III HS (HOT)	3	IP- / SN	2031 - Hot	25	25	-	-	10	-5	100
P137	Type III HS (HOT)	3	IP-	2031 - Hot	25	-	-	-	10	-10	100
P138	Type III HS (HOT)	3	IP Mod	2031 - Hot	75	-	-	-	5	-10	100
P139	Type III HS (HOT)	3	IP- / ZR-	2031 - Hot	25	-	25	-	5	-10	100
P140	Type III HS (HOT)	3	IP- / SN-	2031 - Hot	25	10	-	-	10	-10	100
P141	Type III HS (HOT)	3	IP- / SN	2031 - Hot	25	25	-	-	5	-10	100
P142	Type III HS (HOT)	3	IP-	2031 - Hot	25	-	-	-	10	-25	100
P143	Type III HS (HOT)	3	IP Mod	2031 - Hot	75	-	-	-	5	-25	100
P144	Type III HS (COLD)	3	IP-	2031 - Cold	25	-	-	-	10	-5	100
P145	Type III HS (COLD)	3	IP Mod	2031 - Cold	75	-	-	-	5	-5	100
P146	Type III HS (COLD)	3	IP- / ZR-	2031 - Cold	25	-	25	-	7	-5	100
P147	Type III HS (COLD)	3	IP- / SN-	2031 - Cold	25	10	-	-	10	-5	100
P148	Type III HS (COLD)	3	IP- / SN	2031 - Cold	25	25	-	-	10	-5	100
P149	Type III HS (COLD)	3	IP-	2031 - Cold	25	-	-	-	10	-10	100
P150	Type III HS (COLD)	3	IP Mod	2031 - Cold	75	-	-	-	5	-10	100
P151	Type III HS (COLD)	3	IP- / ZR-	2031 - Cold	25	-	25	-	5	-10	100
P152	Type III HS (COLD)	3	IP- / SN-	2031 - Cold	25	10	-	-	10	-10	100
P153	Type III HS (COLD)	3	IP- / SN	2031 - Cold	25	25	-	-	5	-10	100
P154	Type III HS (COLD)	3	IP-	2031 - Cold	25	-	-	-	10	-25	100
P155	Type III HS (COLD)	3	IP Mod	2031 - Cold	75	-	-	-	5	-25	100
P156	Roughness	4 (was 3)	ZR/IP/SN	Dry	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	-	< -5	100
P157	Wing Geometry	3	None	Type IV	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	See HOT	< -5	100
P158	67 vs 80	3	None	Type IV	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	-	< -5	100
P159	SN w/ No Fluid	3	None	Dry - Cold Wing	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	-	< -5	100
P160	SN w/ No Fluid	3	None	Dry - Warm Wing	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	-	< -5	100
P161	H-Stab Feasability	3	None	Any	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	-	< -5	100
P162	Rain No Fluid	3	R	None	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	-	< -5	100
P163	Ice Phobic	3	ZR	Type IV	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	See HOT	< -5	100
P164	Runway Deicier	3	ZR	Safeway +Any	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	See HOT	< -5	100
P165	V-Stab	4	S++	Type IV	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	See HOT	< -5	100
P166	Frost Spot Deicing	4	Frost	Any	See Details in Procedure	See Details in Procedure	See Details in Procedure	See Details in Procedure	until Failure	<-5	100
P167	LZR / SN	4	LZR / SN	Type IV	-	25	25	-	See HOT	< -5	100
P168	LS Type IV IP	4	IP-	Type IV	Extra tests in separate log	Extra tests in separate log	Extra tests in separate log	Extra tests in separate log	-	< -5	80
P169	Type II IP	4	All	Type IV	Need T II fluid to conduct tests	Need T II fluid to conduct tests	Need T II fluid to conduct tests	Need T II fluid to conduct tests	-	< -5	100
P170	Type III LS (HOT)	4	IP-	2031 - Hot	25	-	-	-	10	-5	80
P171	Type III LS (HOT)	4	IP Mod	2031 - Hot	75	-	-	-	5	-5	80
P172	Type III LS (HOT)	4	IP- / ZR-	2031 - Hot	25	-	25	-	7	-5	80
P173	Type III LS (HOT)	4	IP- / SN-	2031 - Hot	25	10	-	-	10	-5	80
P174	Type III LS (HOT)	4	IP- / SN	2031 - Hot	25	25	-	-	10	-5	80
P175	Type III LS (HOT)	4	IP-	2031 - Hot	25	-	-	-	10	-10	80
P176	Type III LS (HOT)	4	IP Mod	2031 - Hot	75	-	-	-	5	-10	80
P177	Type III LS (HOT)	4	IP- / ZR-	2031 - Hot	25	-	25	-	5	-10	80
P178	Type III LS (HOT)	4	IP- / SN-	2031 - Hot	25	10	-	-	10	-10	80
P179	Type III LS (HOT)	4	IP- / SN	2031 - Hot	25	25	-	-	5	-10	80
P180	Type III LS (HOT)	4	IP-	2031 - Hot	25	-	-	-	10	-25	80
P181	Type III LS (HOT)	4	IP Mod	2031 - Hot	75	-	-	-	5	-25	80
P182	Type III LS (COLD)	4	IP-	2031 - Cold	25	-	-	-	10	-5	80
P183	Type III LS (COLD)	4	IP Mod	2031 - Cold	75	-	-	-	5	-5	80
P184	Type III LS (COLD)	4	IP- / ZR-	2031 - Cold	25	-	25	-	7	-5	80
P185	Type III LS (COLD)	4	IP- / SN-	2031 - Cold	25	10	-	-	10	-5	80
P186	Type III LS (COLD)	4	IP- / SN	2031 - Cold	25	25	-	-	10	-5	80
P187	Type III LS (COLD)	4	IP-	2031 - Cold	25	-	-	-	10	-10	80
P188	Type III LS (COLD)	4	IP Mod	2031 - Cold	75	-	-	-	5	-10	80
P189	Type III LS (COLD)	4	IP- / ZR-	2031 - Cold	25	-	25	-	5	-10	80
P190	Type III LS (COLD)	4	IP- / SN-	2031 - Cold	25	10	-	-	10	-10	80
P191	Type III LS (COLD)	4	IP- / SN	2031 - Cold	25	25	-	-	5	-10	80
P192	Type III LS (COLD)	4	IP-	2031 - Cold	25	-	-	-	10	-25	80
P193	Type III LS (COLD)	4	IP Mod	2031 - Cold	75	-	-	-	5	-25	80

A rating system has been developed and will be filled out by the onsite experts (Attachment XIV). The overall rating will provide insight into the severity of the conditions observed. A test failure (failure to shed the fluid at time of rotation) shall be determined by the on-site experts based on residual contamination. The first test in each series will closely emulate expected holdover time or allowance time. The second test will effectively double or halve the first time depending on whether failure to clear has occurred. The third test will double or halve the previous time or halve the interval to the previous test depending on the failure history. This decision matrix is shown in Figure 3.1 with a beginning exposure time of 60 minutes.

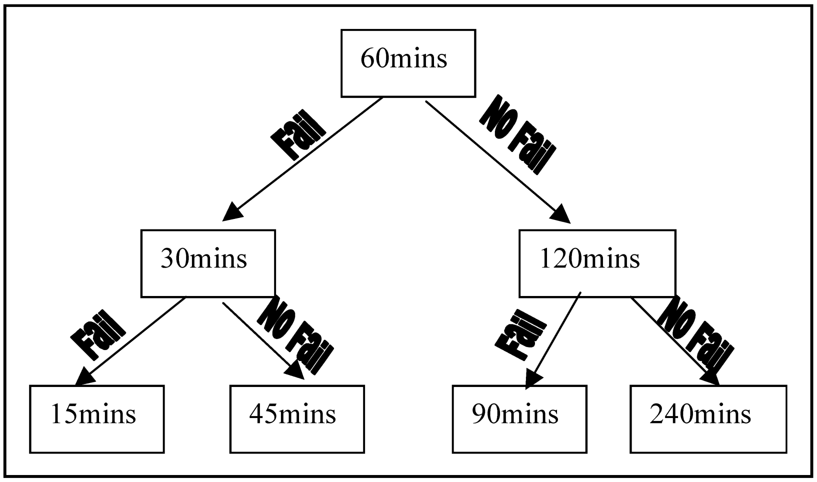


Figure 3.1: Decision Matrix for Each Test Series

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;
- Co-ordinate with APS photographer;
- Conduct dry photography test of old vs. new camera positioning;
- Document new final camera and flash locations;
- Arrange for hotel accommodations for APS personnel;
- Ensure availability of de/anti-icing fluid (shipped directly to NRC);
- Conduct falling ball tests on received fluids;

- Collect fluid samples for viscosity verification at APS office;
- Arrange personnel travel to Ottawa;
- Ensure proper functioning of ice pellet dispenser equipment;
- Ensure proper functioning of freezing rain sprayer equipment;
- Mark wing data collection locations and draw grid on the wing (refer to Feasibility report for diagrams);
- Prepare and arrange for transport of equipment to Ottawa;
- Co-ordinate fabrication of ice pellets/snow/snow pellets; and
- Arrange for storage of ice pellets/snow/snow pellets.

The task list for setup and testing is included as Attachment VIII.

5. DATA FORMS

The following data forms are required for the January – February 2010 wind tunnel tests:

- Attachment IX – General Form;
- Attachment X – Wing Temperature, Fluid Thickness and Fluid Brix Form;
- Attachment XI & XII – Ice Pellet and Snow Dispensing Forms;
- Attachment XIII– Sprayer Calibration Form;
- Attachment XIV – Visual Evaluation Rating Form
- Attachment XV– Condition of Wing and Plate Form; and
- Attachment XVI – Fluid Receipt Form (Generic form used by APS; will be used for this project as appropriate);
- Attachment XVII – Log of Fluid Sample Bottles.

When and how the data forms will be used is described throughout Section 6.

6. PROCEDURE

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

6.1 Initial Test Conditions Survey

- Record ambient conditions of the test (Attachment IX); and
- Record wing temperature (Attachment X).

6.2 Fluid Application (Pour)

- Hand pour 20L of anti-icing fluid over the test area (fluid can be poured directly out of pales or transferred into smaller 3L jugs);
- Record fluid application times (Attachment IX);
- Record fluid application quantities (Attachment IX);
- Let fluid settle for 5 minutes (as the wing section is relatively flat, last winter it required tilting the wing for 1-minute to enable fluid to be uniform);
- Measure fluid thickness at pre-determined locations on the wing (Attachment X);
- Record wing temperature (Attachment X).
- Measure fluid Brix value (Attachment X); and
- Photograph and videotape the appearance of the fluid on the wing;

Note: At the request of TC/FAA, a standard aluminum test plate will be positioned on the wing in order to run a simultaneous endurance time test.

6.3 Application of Contamination

6.3.1 Ice Pellet/Snow Dispenser Calibration and Set-Up

Calibration work was performed during the winter of 2007-08 on the modified ice pellet/snow dispensers prior to testing with the Falcon 20. The purpose of this calibration work was to attain the dispenser's distribution footprint for both ice pellets and snow. A series of tests were performed in various conditions:

1. Ice Pellets, Low Winds (0 to 5 km/h);
2. Ice Pellets, Moderate Winds (10 km/h);
3. Snow, Low Wind (0 to 5 km/h); and
4. Snow, Moderate Wind (10 km/h).

These tests were conducted using 121 collection pans, each measuring 6 x 6 inches, over an area 11 x 11 feet. Pre-measured amounts of ice pellets/snow were dispersed over this area and the amount collected by each pan was recorded. A distribution footprint of the dispenser was attained and efficiency for the dispenser was computed.

6.3.2 Dispensing Ice Pellets/Snow for Wind Tunnel Tests

Using the results from these calibration tests, a decision was made to use two dispensers on each of the leading and trailing edges of wing; each of the four dispensers are moved to four different positions along each edge during the dispensing process. Attachments XIII and XIV display the data sheets that will be used during testing in the wind tunnel. These data sheets will provide all the necessary information related to the amount of ice pellets/snow needed, effective rates and dispenser positions. During the winter of 2009-10, snow was also dispensed manually using sieves. This technique was used when higher rates of precipitation were required (for heavy snow) or when winds in the tunnel made dispensing difficult. The efficiency of this technique was estimated at 90% and a form to be used for this dispensing process along with dispensing instructions is included in Attachment XV.

Note: Dispensing forms should be filled out and saved for each run and included and pertinent information shall be included in the general form (Attachment XI). Any comments regarding dispensing activities should be documented directly on the form.

6.3.3 Application of Freezing Rain/Drizzle

- Ensure correct rate of precipitation is being generated by NRC freezing precipitation sprayer (see Attachment XVI);
- Record rate of precipitation dispersed (Attachment XI);
- Record application times (Attachment XI); and
- Photograph and videotape the appearance of the fluid on the wing.

6.4 Prior to Engines-On Wind Tunnel Test

- Measure fluid thickness at the pre-determined locations on the wing (Attachment XII);
- Measure fluid Brix value (Attachment XII);
- Record wing temperatures (Attachment XII);
- Record start time of test (Attachment XI); and
- Fill out visual evaluation rating form (Attachment XVII).

Note: In order to minimize the measurement time post precipitation, temperature should be measured 5 minutes before the end of precipitation, thickness measured 3 minutes before the end of precipitation, and Brix measured when the precipitation ends. Also consider reducing the number of measures that are taken for this phase (i.e. locations 2 and 5 only).

6.5 During Wind Tunnel Test:

- Take still pictures/videotape the behavior of the fluid on the wing during the takeoff run, capturing any movement of fluid/contamination;
- Fill out visual evaluation rating form at the time of rotation (Attachment XVII); and
- Record wind tunnel operation start and stop times.

6.6 After the Wind Tunnel Test:

- Measure fluid thickness at the pre-determined locations on the wing (Attachment XII);
- Measure fluid Brix value (Attachment XII);
- Record wing temperatures (Attachment XII);
- Observe and record the status of the fluid/contamination (Attachment XII);
- Fill out visual evaluation rating form (Attachment XVII);
- Obtain lift data (excel file) from NRC; and
- Update APS test log with pertinent information.

6.7 Fluid Sample Collection for Viscosity Testing

Two litres of each fluid to be tested are to be collected on the first day of testing. The fluid receipt form (Attachment XVIII) should be completed indicating quantity of fluid and date received. Any samples extracted for viscosity purposes should be documented in the log of fluid samples data form (Attachment XIX). A falling ball viscosity test should be performed on site to confirm that fluid viscosity is appropriate before testing.

6.8 At the End of Each Test Session

If required, APS personnel will collect the waste solution. At the end of the testing period, the services of Safety-Kleen (or other glycol recovery service) will be employed to safely dispose of the waste glycol fluid.

6.9 Camera Setup

It is anticipated that the camera setup will be similar to the setup used during the winter of 2008-09. Modifications may be necessary to account for the different airfoil. The flashes will be positioned on the control-room side of the tunnel, and the cameras will be positioned on the opposite side. The final positioning of the cameras and flashes should be documented to identify any deviation from the previous year’s setup.

6.10 Demonstration of a Typical Wind Tunnel Test Sequence

Table 6.1 demonstrates a typical Wind Tunnel test sequence of activities, assuming the test starts at 08:00:00. Figure 6.1 demonstrates a typical wind tunnel run timeline.

Table 6.1: Typical Wind Tunnel Test

TIME	TASK
8:00:00	START OF TEST. ALL EQUIPMENT READY.
8:00:00	- Record test conditions.
8:05:00	- Prepare wing for fluid application (clean wing, etc).
8:15:00	- Measure wing temperature. - Ensure clean wing for fluid application
8:20:00	- Pour fluid over test area.
8:30:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
8:35:00	- Apply contamination over test area. (i.e. 30 min)
9:05:00	- Measure Brix, thickness, wing temperature. - Photograph test area.
9:10:00	- Clear area and start wind tunnel
9:25:00	- Wind tunnel stopped
9:35:00	- Measure Brix, thickness, wing temperature. - Photograph test area. - Record test observations
9:45:00	END OF TEST

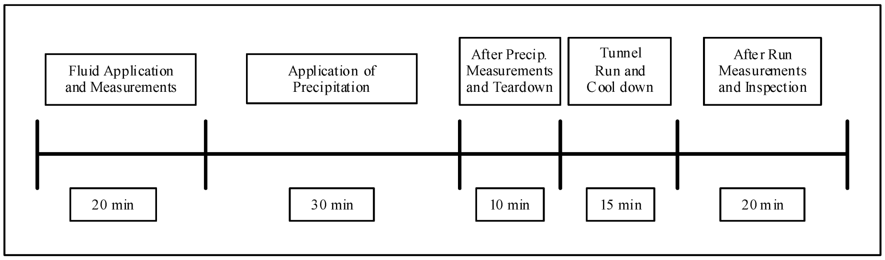


Figure 6.1: Typical Wind Tunnel Run Timeline

6.11 Procedure for Application of Heated Type III Fluid for Wind Tunnel Tests

Testing with Type III fluid will require testing with both fluid at ambient temperature, and heated fluid. A procedure has been developed to describe the heating and application methods for the Type III heated tests and is included in Attachment XX.

6.12 Procedures for R&D Activities

It is anticipated that testing will be conducted to support several research and development (R&D) activities. The objectives of these lower priority activities are as follows:

- Heavily contaminated fluid during heavy snow conditions (Attachment XXI);
- Effect of CL Max on recorded lift losses (Attachment XXII);
- Surface roughness as a result of adhered contamination (Attachment XXIII);
- Effect of wing geometry on fluid failure and aerodynamic performance (Attachment XXIV);
- Low speed testing for Aero Certification Test: 67 vs. 80 knots (Attachment XXV);
- Snow on an Un-Protected Wing (Attachment XXVI);;
- Feasibility of conducting horizontal stabilizer testing (Attachment XXVII);
- Rain on an un-protected wing (Attachment XXVIII);
- Effect of ice phobic coatings on contaminated airfoil aerodynamic performance (Attachment XXIX);
- Degraded Anti-icing Fluid Performance Following Contamination with Runway Deicing Fluid (Attachment XXX);
- Heavily contaminated vertical stabilizer (Attachment XXXI);
- Frost CSW Spot Deicing (Attachment XXXII);
- Light Freezing Rain and Snow (Attachment XXXIII);
- Ice pellet allowance times for low speed aircraft using Type IV fluid (Attachment XXXIIV); and
- Ice pellet allowance times for Type II fluid (Attachment XXXV).

As these full-scale R&D activities have in general not been previously attempted, brief summaries of the anticipated procedures have been prepared to provide guidance at the time of testing. These procedures are attached to this document as indicated in parentheses above. The procedures are preliminary and may change based on the quality of the results obtained in the wind tunnel.

7. EQUIPMENT

Equipment to be employed is shown in Table 7.1.

8. FLUIDS

Mid-viscosity samples of ethylene glycol and propylene glycol III and IV fluids will be used in the wind tunnel tests. Although the number off tests conducted will be determined based on the results obtained, the fluid quantities available are estimated and are shown in Table 8.1. Fluid application will be performed by pouring the fluid (rather than spraying) to reduce any shearing to the fluid.

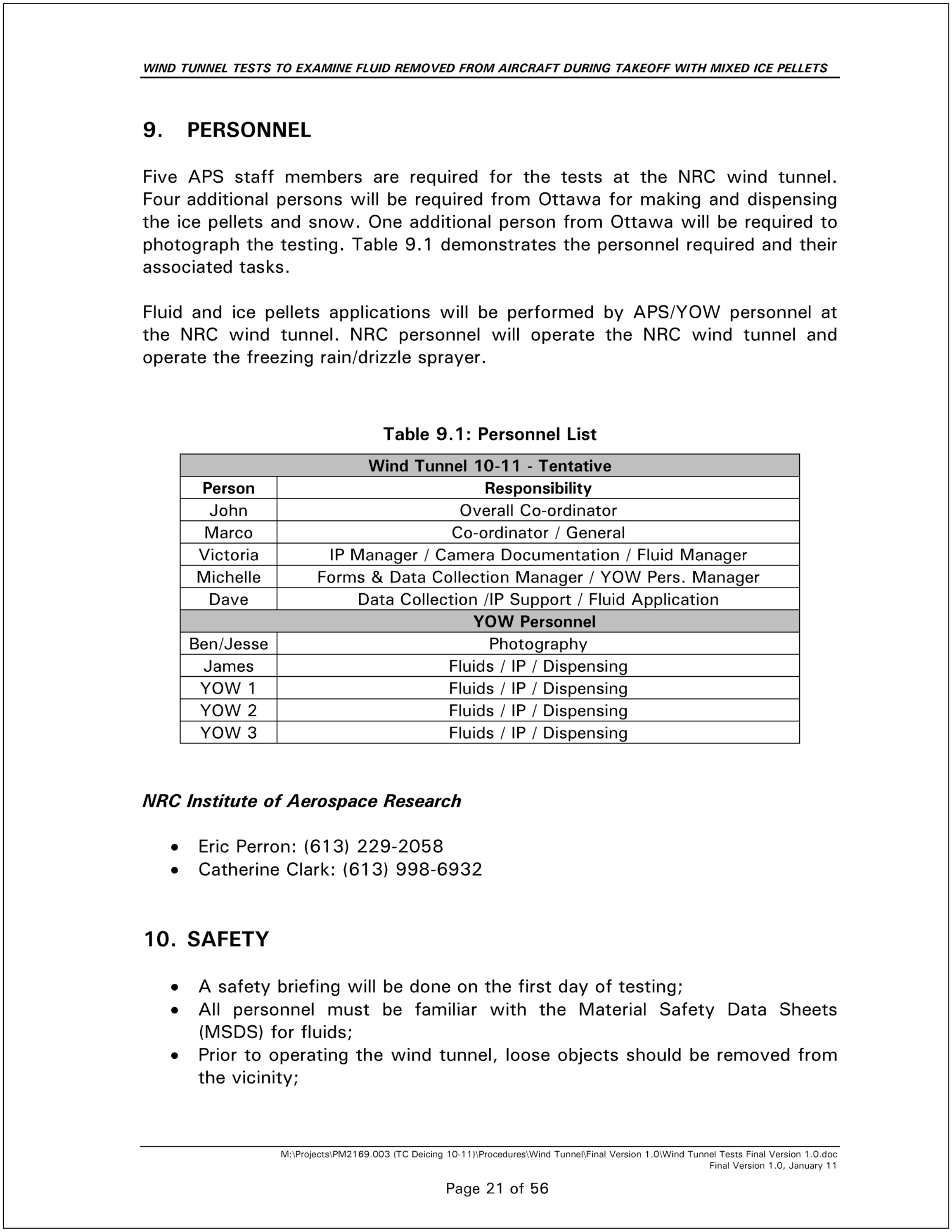
Table 8.1: Fluid Available for Wind Tunnel Tests

Fluid Manufacturer	Fluid Name	Type	2010-11 Quantity Leftover From 2009-10 (L)	2010-11 Quantity Ordered (L)
Dow Checmical Company	EG106	IV	400	600
Kilfrost Limited	ABC-S PLUS	IV	-	1000
Clariant Produkte	Launch	IV	475	-
Clariant Produkte	2031	III	-	400
Dow Checmical Company	AD-49	IV	-	600
Octagon Process Inc.	Max-Flight 04	IV	-	600
Octagon Process Inc.	Octaflo EF (Conc.)	I	100	-

Table 7.1: Test Equipment Checklist

EQUIPMENT	STATUS
General Support Equipment	
Large tape measure	
Fluids (ORDER and SHIP to Ottawa)	
Horse and tap for fluid barrel x 2	
Funnels	
Sample bottles for viscosity measurement	
Squeegees	
Isopropyl	
Gloves, paper towel	
Extension cords	
Clipboards, pencils, wing markers for sample locations and solvent	
Large Clock x1	
Printer, printer paper, and ink cartridge	
Walkie Talkies x8	
Envelopes and labels	
Previous 05-06, 06-07, 07-08, and 08-09 F20/WT reports	
Grid Section + Location docs	
Large Sharpies for Gird Section	
Projector for laptop	
YOW employee contracts	
Blow Horns x4	
Camera Equipment	
Digital still cameras x4 (with lenses, chargers, batteries, etc)	
Flashes and tripods	
Test Equipment	
Test Procedures, data forms, printer paper	
Electronic copy of the whole wind tunnel procedure folder, incl all forms and working docs (maybe Falcon too).	
Hard Drive	
Test Plate	
Speed tape (large and small)	
Thickness Gauges	
Temperature Probe x 2 and spare batteries	
Brixometers X3	
Adherence Probes (Oral B) x4 with tips and charger	
Fluid pouring jugs x40 (6 per fluid + extra)	
Ice pellets dispersers x6	
Stands for ice pellets dispensing devices x6	
Ice Pellet control wires and boxes (all)	
Ice pellet box supports for railing x4	
Hot Plate x3 and Large Pots with rubber handles	
Watmans Paper and conversion charts	
Long Ruler for marking wing x2	
Small 90° aluminum ruler for wing	
20L containers (DY order from YUL)	
hard water chemicals	
Poster board (8"x3") for flap section	

EQUIPMENT	STATUS
Ice Pellets Fabrication Equipment	
Refrigerated Truck	
Ice pellets Styrofoam containers x20++	
Ice bags	
Ice bags storage freezer	
Blenders x6+	
Ice pellets sieves	
Folding tables	
Measuring cups	
Wooden Spoons	
Rubber Mats	
Extension Cords	
Freezing Rain Equipment	
NRC Freezing rain sprayer	
APS PC equipped with rate station software	
White plastic rate pans (100) wooden boards, and rubber suction cup feet	
Sartorius Wiegh Scale x1 + NCAR Scale x 1	
Black Shelving Unit	
Portable hard drive and memory card reader	



9. PERSONNEL

Five APS staff members are required for the tests at the NRC wind tunnel. Four additional persons will be required from Ottawa for making and dispensing the ice pellets and snow. One additional person from Ottawa will be required to photograph the testing. Table 9.1 demonstrates the personnel required and their associated tasks.

Fluid and ice pellets applications will be performed by APS/YOW personnel at the NRC wind tunnel. NRC personnel will operate the NRC wind tunnel and operate the freezing rain/drizzle sprayer.

Table 9.1: Personnel List

Wind Tunnel 10-11 - Tentative	
Person	**Responsibility**
John	Overall Co-ordinator
Marco	Co-ordinator / General
Victoria	IP Manager / Camera Documentation / Fluid Manager
Michelle	Forms & Data Collection Manager / YOW Pers. Manager
Dave	Data Collection /IP Support / Fluid Application
YOW Personnel	
Ben/Jesse	Photography
James	Fluids / IP / Dispensing
YOW 1	Fluids / IP / Dispensing
YOW 2	Fluids / IP / Dispensing
YOW 3	Fluids / IP / Dispensing

NRC Institute of Aerospace Research

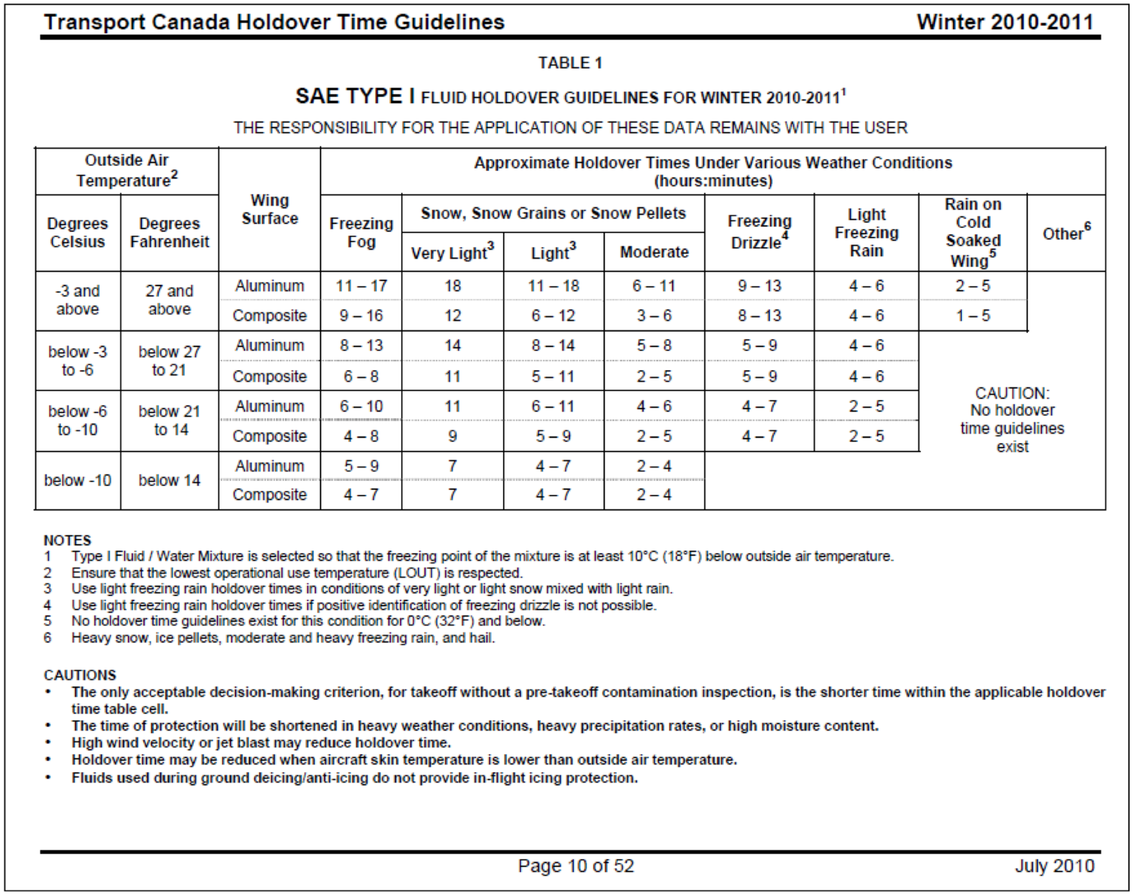
- Eric Perron: (613) 229-2058
- Catherine Clark: (613) 998-6932

10. SAFETY

- A safety briefing will be done on the first day of testing;
- All personnel must be familiar with the Material Safety Data Sheets (MSDS) for fluids;
- Prior to operating the wind tunnel, loose objects should be removed from the vicinity;

- When wind tunnel is operating, ensure that ear plugs are worn if necessary 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;
- Caution should be taken when walking in the test section due to slippery floors, and dripping fluid from the wing section;
- 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 I – Generic Type I Holdover Time Table



Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 1

SAE TYPE I FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]

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

Outside Air Temperature[2]		Wing Surface	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets			Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
				Very Light[3]	Light[3]	Moderate				
-3 and above	27 and above	Aluminum	11 – 17	18	11 – 18	6 – 11	9 – 13	4 – 6	2 – 5	CAUTION: No holdover time guidelines exist
		Composite	9 – 16	12	6 – 12	3 – 6	8 – 13	4 – 6	1 – 5	
below -3 to -6	below 27 to 21	Aluminum	8 – 13	14	8 – 14	5 – 8	5 – 9	4 – 6		
		Composite	6 – 8	11	5 – 11	2 – 5	5 – 9	4 – 6		
below -6 to -10	below 21 to 14	Aluminum	6 – 10	11	6 – 11	4 – 6	4 – 7	2 – 5		
		Composite	4 – 8	9	5 – 9	2 – 5	4 – 7	2 – 5		
below -10	below 14	Aluminum	5 – 9	7	4 – 7	2 – 4				
		Composite	4 – 7	7	4 – 7	2 – 4				

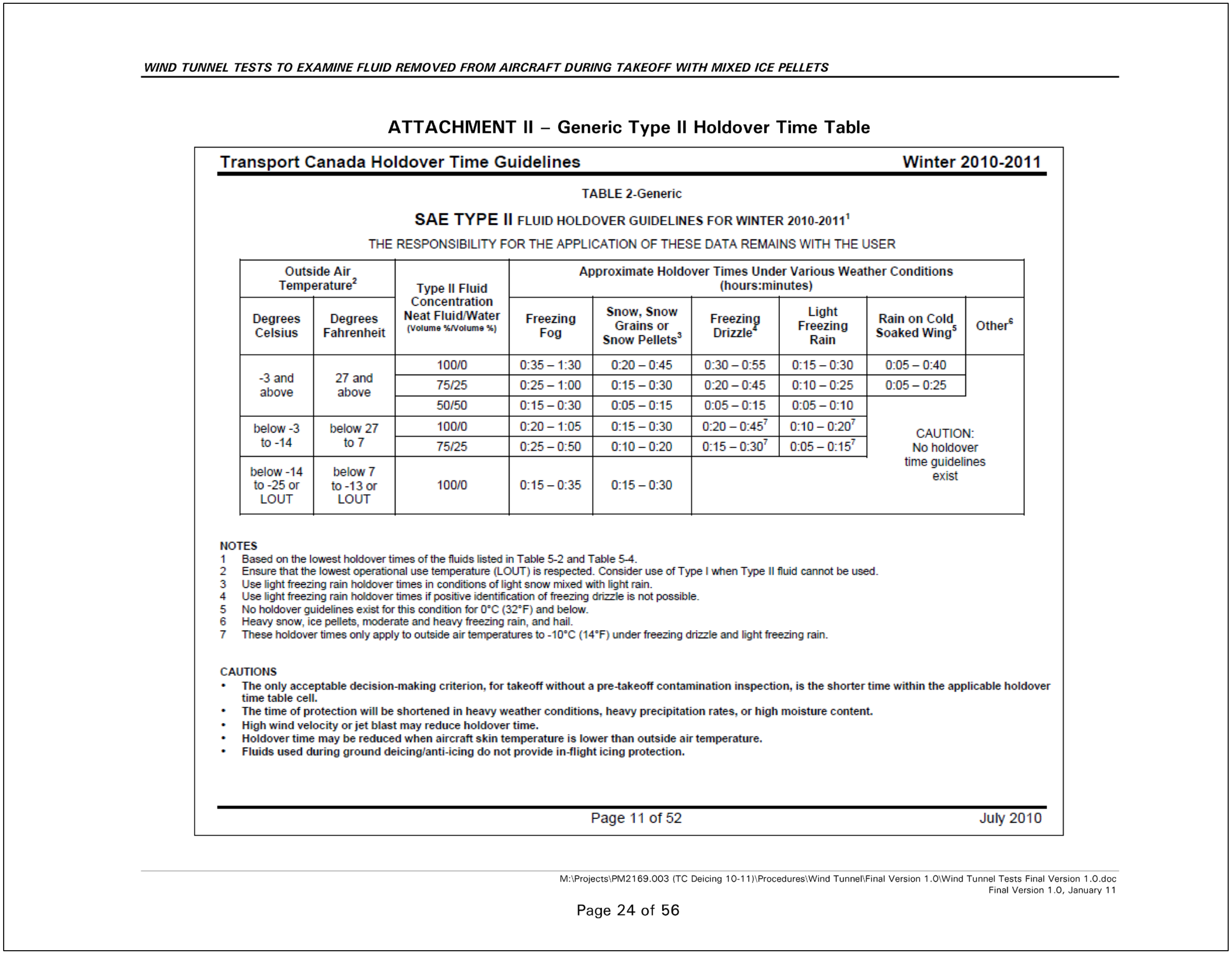
NOTES

1 Type I Fluid / Water Mixture is selected so that the freezing point of the mixture is at least 10°C (18°F) below outside air temperature.
2 Ensure that the lowest operational use temperature (LOUT) is respected.
3 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover time guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter 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.**

Page 10 of 52 July 2010



ATTACHMENT II – Generic Type II Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 2-Generic

SAE TYPE II FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]

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

Outside Air Temperature[2]		Type II Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	**Degrees Fahrenheit**		**Freezing Fog**	**Snow, Snow Grains or Snow Pellets[3]**	**Freezing Drizzle[4]**	**Light Freezing Rain**	**Rain on Cold Soaked Wing[5]**	**Other[6]**
-3 and above	27 and above	100/0	0:35 – 1:30	0:20 – 0:45	0:30 – 0:55	0:15 – 0:30	0:05 – 0:40	CAUTION: No holdover time guidelines exist
		75/25	0:25 – 1:00	0:15 – 0:30	0:20 – 0:45	0:10 – 0:25	0:05 – 0:25	
		50/50	0:15 – 0:30	0:05 – 0:15	0:05 – 0:15	0:05 – 0:10		
below -3 to -14	below 27 to 7	100/0	0:20 – 1:05	0:15 – 0:30	0:20 – 0:45[7]	0:10 – 0:20[7]		
		75/25	0:25 – 0:50	0:10 – 0:20	0:15 – 0:30[7]	0:05 – 0:15[7]		
below -14 to -25 or LOUT	below 7 to -13 or LOUT	100/0	0:15 – 0:35	0:15 – 0:30				

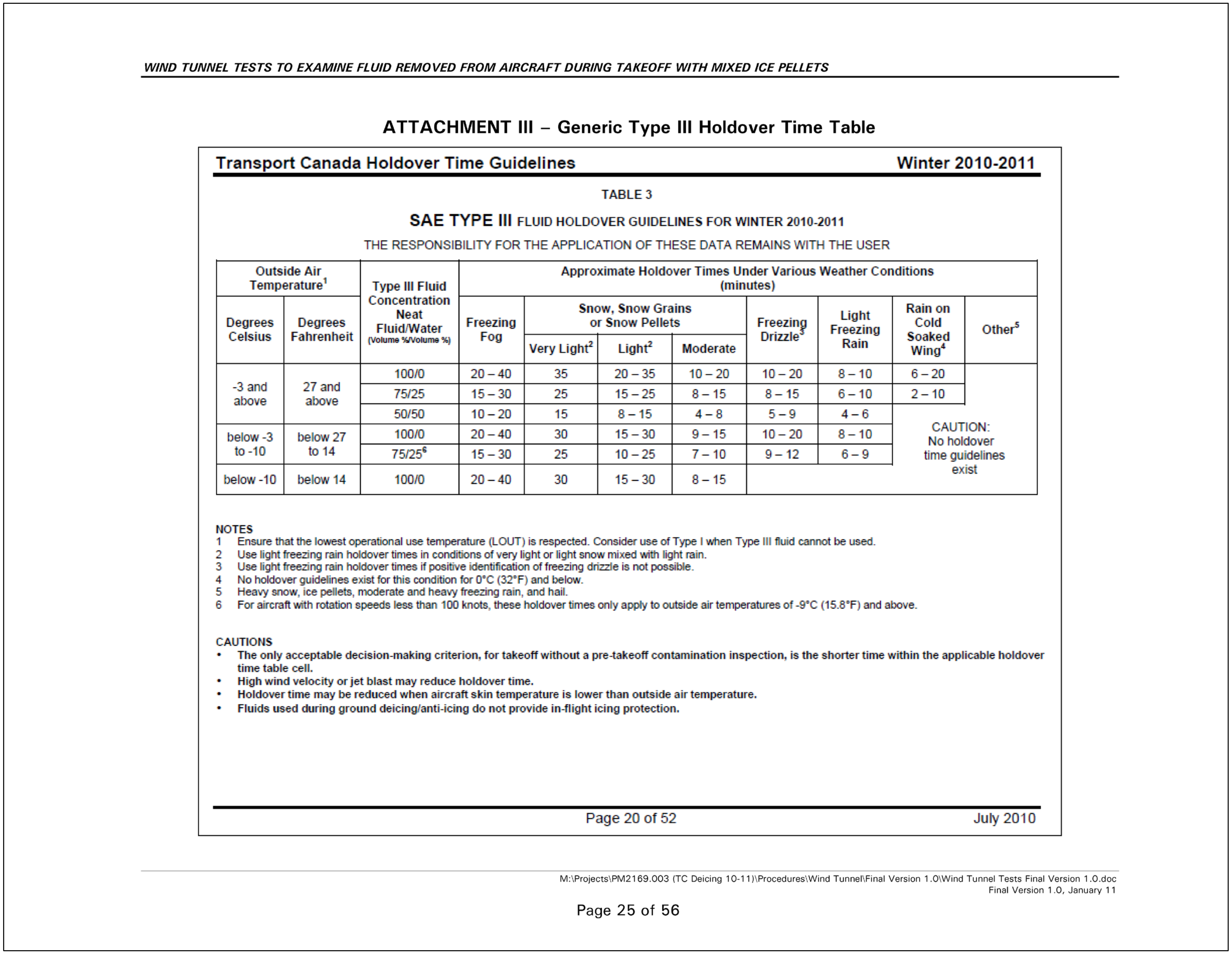
NOTES

1 Based on the lowest holdover times of the fluids listed in Table 5-2 and Table 5-4.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type II fluid cannot be used.
3 Use light freezing rain holdover times in conditions of light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter 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.**

Page 11 of 52 July 2010



ATTACHMENT III – Generic Type III Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 3

SAE TYPE III FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011

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

Outside Air Temperature[1]		Type III Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (minutes)							
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets			Freezing Drizzle[3]	Light Freezing Rain	Rain on Cold Soaked Wing[4]	Other[5]
				Very Light[2]	Light[2]	Moderate				
-3 and above	27 and above	100/0	20 – 40	35	20 – 35	10 – 20	10 – 20	8 – 10	6 – 20	CAUTION: No holdover time guidelines exist
		75/25	15 – 30	25	15 – 25	8 – 15	8 – 15	6 – 10	2 – 10	
		50/50	10 – 20	15	8 – 15	4 – 8	5 – 9	4 – 6		
below -3 to -10	below 27 to 14	100/0	20 – 40	30	15 – 30	9 – 15	10 – 20	8 – 10		
		75/25[6]	15 – 30	25	10 – 25	7 – 10	9 – 12	6 – 9		
below -10	below 14	100/0	20 – 40	30	15 – 30	8 – 15				

NOTES

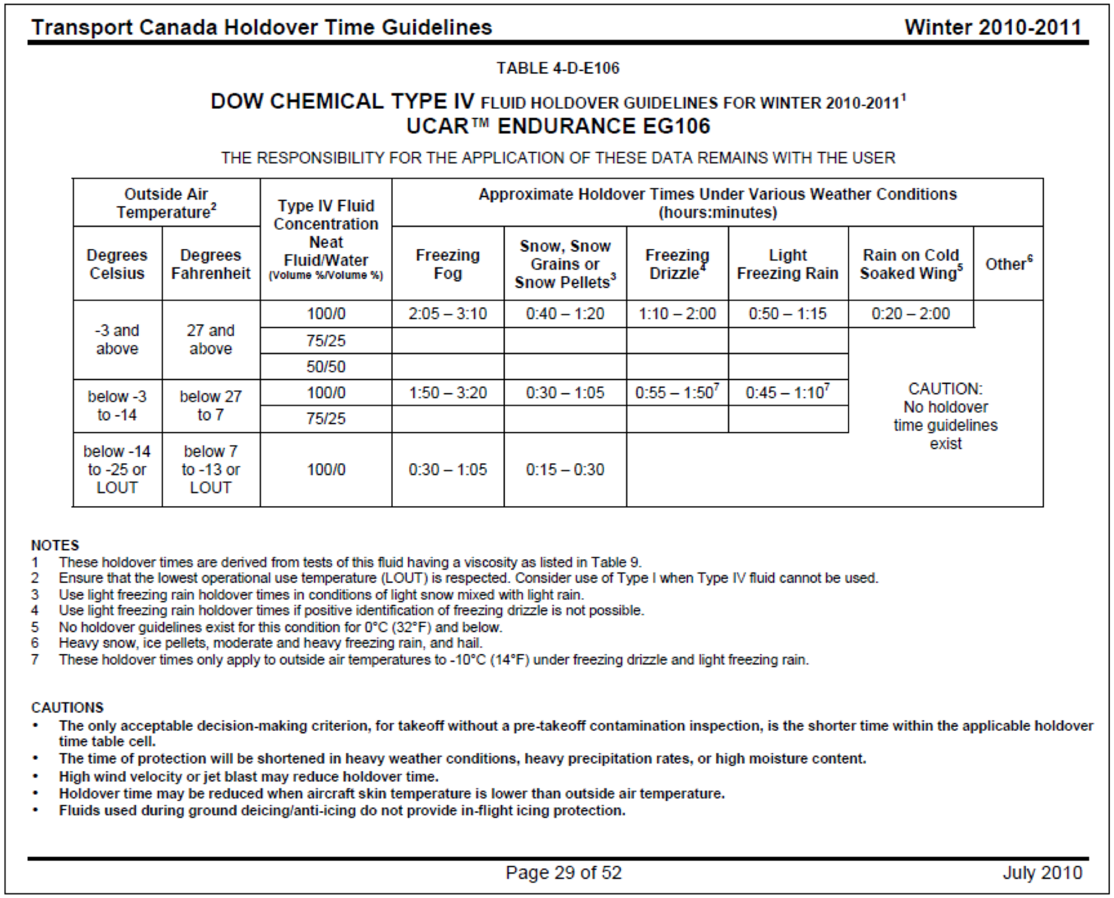
1 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type III fluid cannot be used.
2 Use light freezing rain holdover times in conditions of very light or light snow mixed with light rain.
3 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
4 No holdover guidelines exist for this condition for 0°C (32°F) and below.
5 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
6 For aircraft with rotation speeds less than 100 knots, these holdover times only apply to outside air temperatures of -9°C (15.8°F) and above.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter time within the applicable holdover time table cell.**
- **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.**

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

ATTACHMENT IV – Dow Chemical UCAR Endurance EG106 Type IV Holdover Time Table



Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 4-D-E106

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]
UCAR™ ENDURANCE EG106

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

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets[3]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	2:05 – 3:10	0:40 – 1:20	1:10 – 2:00	0:50 – 1:15	0:20 – 2:00	CAUTION: No holdover time guidelines exist
		75/25						
		50/50						
below -3 to -14	below 27 to 7	100/0	1:50 – 3:20	0:30 – 1:05	0:55 – 1:50[7]	0:45 – 1:10[7]		
		75/25						
below -14 to -25 or LOUT	below 7 to -13 or LOUT	100/0	0:30 – 1:05	0:15 – 0:30				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3 Use light freezing rain holdover times in conditions of light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

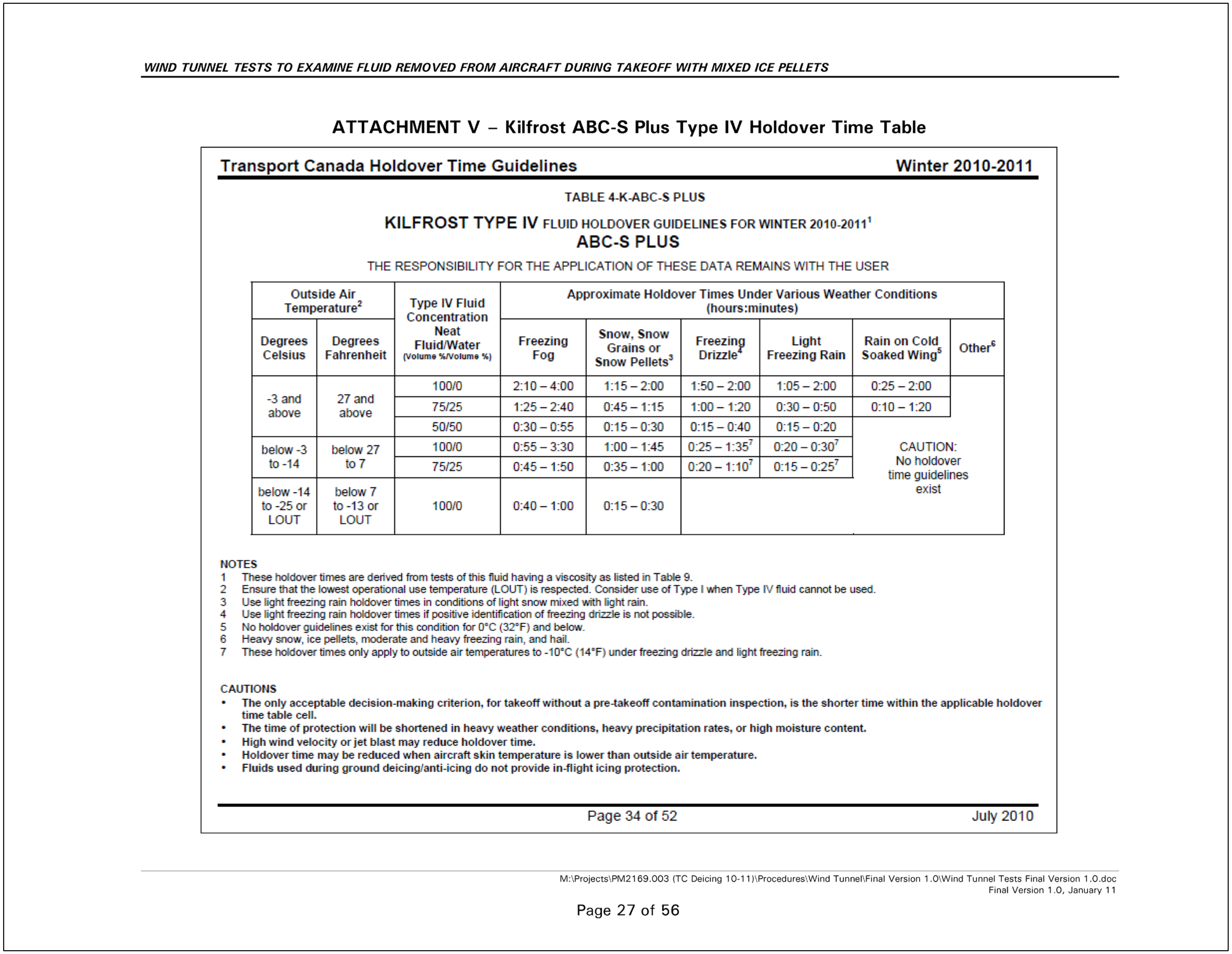
CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter 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.**

Page 29 of 52 July 2010

M:\Projects\PM2169.003 (TC Deicing 10-11)\Procedures\Wind Tunnel\Final Version 1.0\Wind Tunnel Tests Final Version 1.0.doc
Final Version 1.0, January 11

Page 26 of 56



ATTACHMENT V – Kilfrost ABC-S Plus Type IV Holdover Time Table

TABLE 4-K-ABC-S PLUS

KILFROST TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]
ABC-S PLUS

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

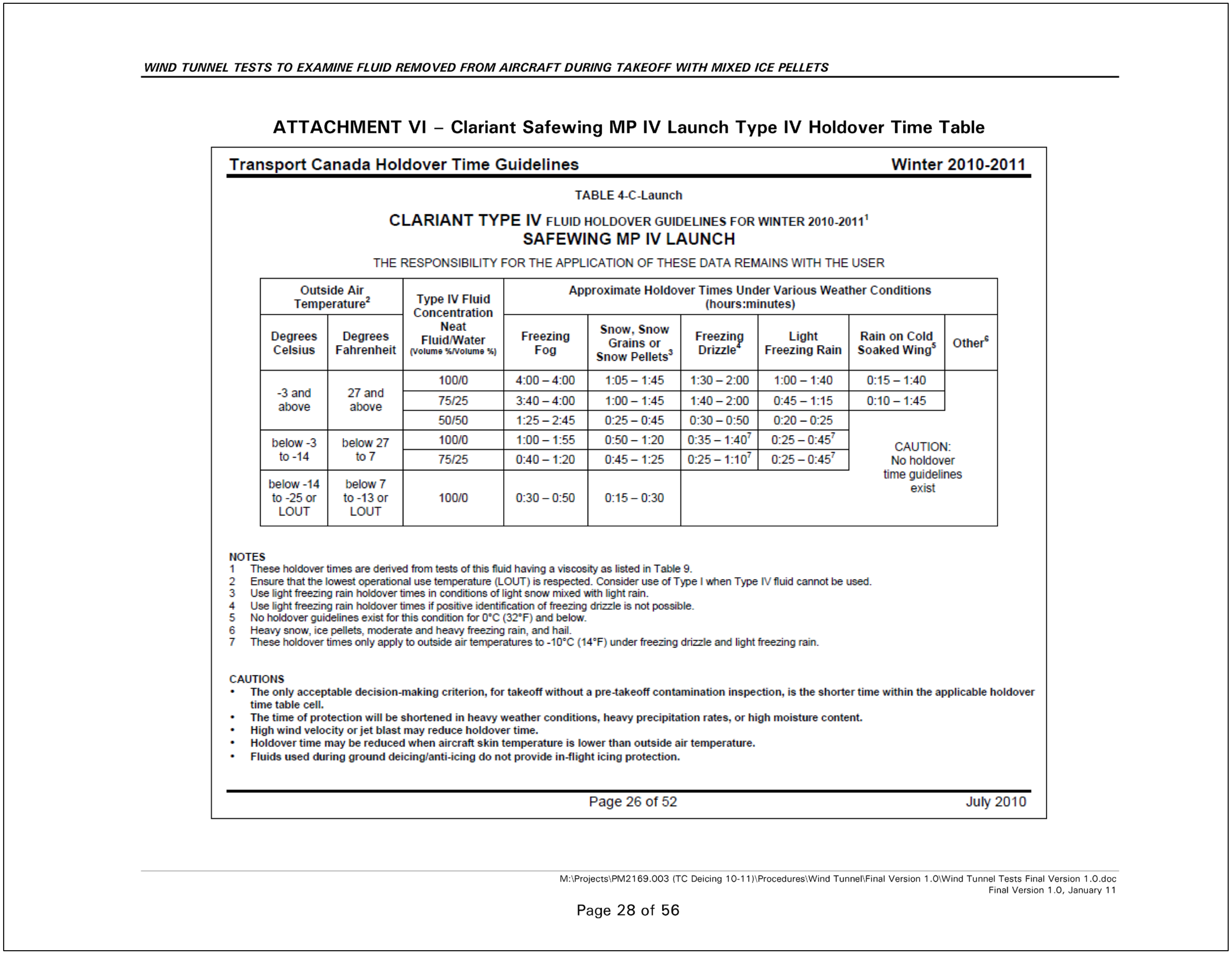
Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets[3]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	2:10 – 4:00	1:15 – 2:00	1:50 – 2:00	1:05 – 2:00	0:25 – 2:00	CAUTION: No holdover time guidelines exist
		75/25	1:25 – 2:40	0:45 – 1:15	1:00 – 1:20	0:30 – 0:50	0:10 – 1:20	
		50/50	0:30 – 0:55	0:15 – 0:30	0:15 – 0:40	0:15 – 0:20		
below -3 to -14	below 27 to 7	100/0	0:55 – 3:30	1:00 – 1:45	0:25 – 1:35[7]	0:20 – 0:30[7]		
		75/25	0:45 – 1:50	0:35 – 1:00	0:20 – 1:10[7]	0:15 – 0:25[7]		
below -14 to -25 or LOUT	below 7 to -13 or LOUT	100/0	0:40 – 1:00	0:15 – 0:30				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3 Use light freezing rain holdover times in conditions of light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter 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.**



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

ATTACHMENT VI – Clariant Safewing MP IV Launch Type IV Holdover Time Table

Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 4-C-Launch

CLARIANT TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]
SAFEWING MP IV LAUNCH

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

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets[3]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	4:00 – 4:00	1:05 – 1:45	1:30 – 2:00	1:00 – 1:40	0:15 – 1:40	CAUTION: No holdover time guidelines exist
		75/25	3:40 – 4:00	1:00 – 1:45	1:40 – 2:00	0:45 – 1:15	0:10 – 1:45	
		50/50	1:25 – 2:45	0:25 – 0:45	0:30 – 0:50	0:20 – 0:25		
below -3 to -14	below 27 to 7	100/0	1:00 – 1:55	0:50 – 1:20	0:35 – 1:40[7]	0:25 – 0:45[7]		
		75/25	0:40 – 1:20	0:45 – 1:25	0:25 – 1:10[7]	0:25 – 0:45[7]		
below -14 to -25 or LOUT	below 7 to -13 or LOUT	100/0	0:30 – 0:50	0:15 – 0:30				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3 Use light freezing rain holdover times in conditions of light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

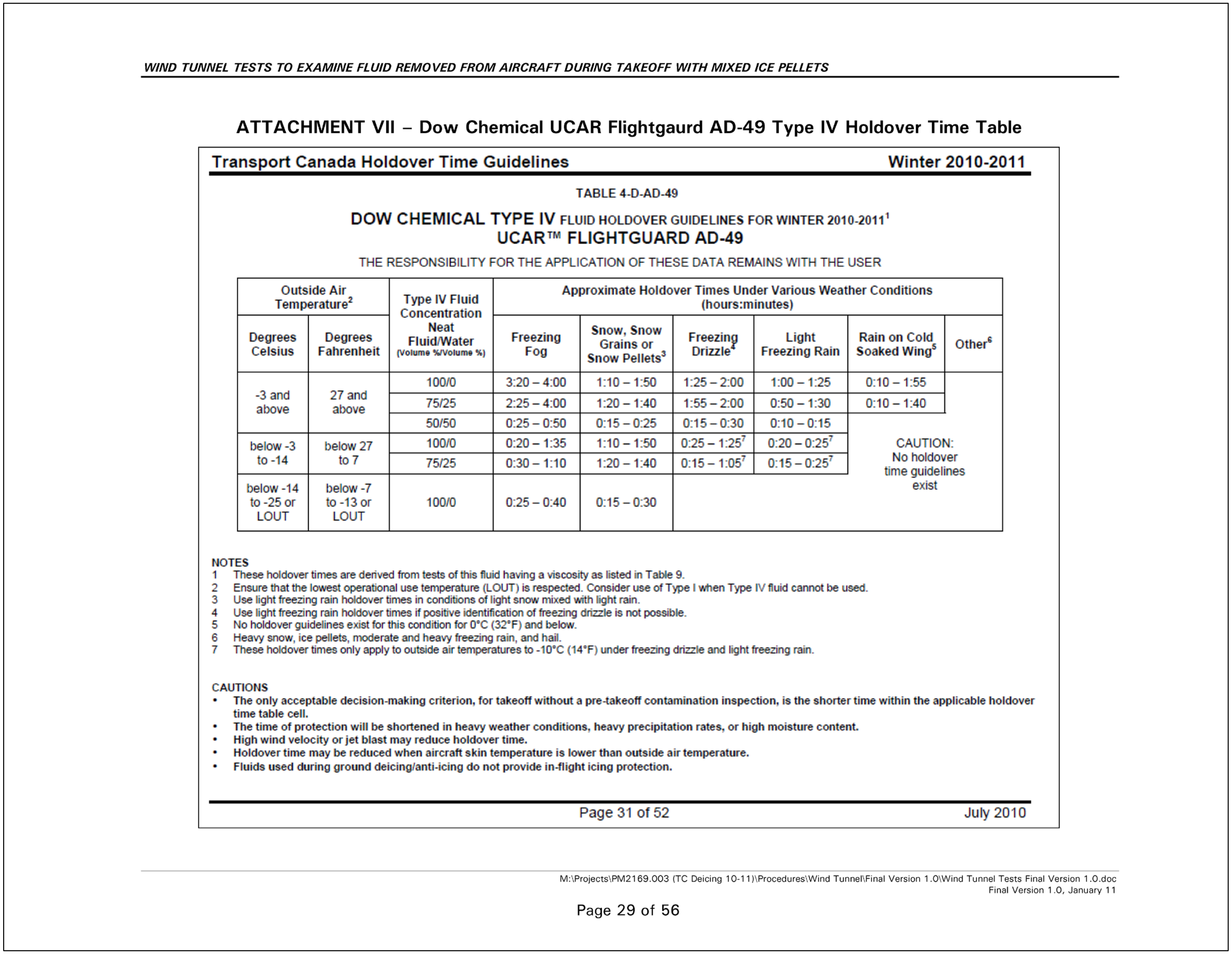
CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter 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.**

Page 26 of 52 July 2010

M:\Projects\PM2169.003 (TC Deicing 10-11)\Procedures\Wind Tunnel\Final Version 1.0\Wind Tunnel Tests Final Version 1.0.doc
Final Version 1.0, January 11

Page 28 of 56



ATTACHMENT VII – Dow Chemical UCAR Flightgaurd AD-49 Type IV Holdover Time Table

TABLE 4-D-AD-49

DOW CHEMICAL TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]
UCAR™ FLIGHTGUARD AD-49

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

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets[3]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	3:20 – 4:00	1:10 – 1:50	1:25 – 2:00	1:00 – 1:25	0:10 – 1:55	
		75/25	2:25 – 4:00	1:20 – 1:40	1:55 – 2:00	0:50 – 1:30	0:10 – 1:40	
		50/50	0:25 – 0:50	0:15 – 0:25	0:15 – 0:30	0:10 – 0:15	CAUTION: No holdover time guidelines exist	
below -3 to -14	below 27 to 7	100/0	0:20 – 1:35	1:10 – 1:50	0:25 – 1:25[7]	0:20 – 0:25[7]		
		75/25	0:30 – 1:10	1:20 – 1:40	0:15 – 1:05[7]	0:15 – 0:25[7]		
below -14 to -25 or LOUT	below -7 to -13 or LOUT	100/0	0:25 – 0:40	0:15 – 0:30				

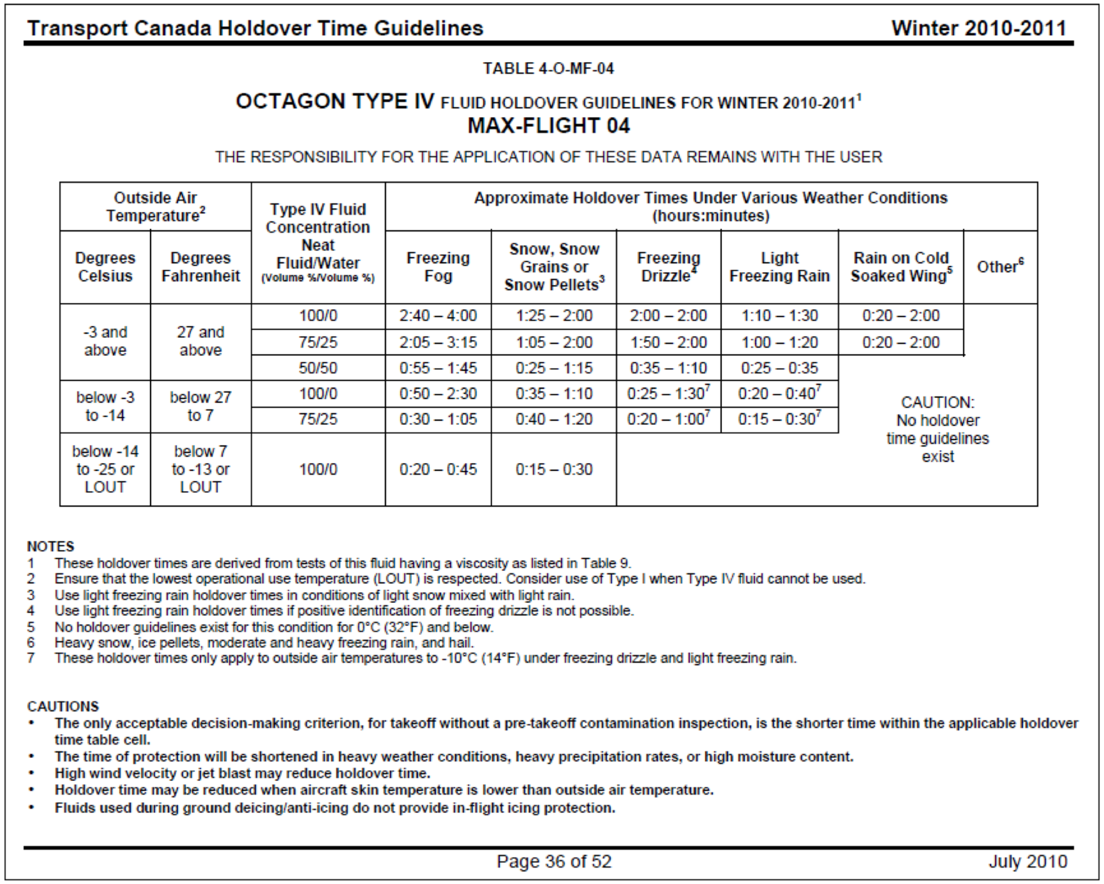
NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3 Use light freezing rain holdover times in conditions of light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter 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 VIII - Octagon Max-Flight 04 Type IV Holdover Time Table



Transport Canada Holdover Time Guidelines **Winter 2010-2011**

TABLE 4-O-MF-04

OCTAGON TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2010-2011[1]

MAX-FLIGHT 04

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

Outside Air Temperature[2]		Type IV Fluid Concentration Neat Fluid/Water (Volume %/Volume %)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)					
Degrees Celsius	Degrees Fahrenheit		Freezing Fog	Snow, Snow Grains or Snow Pellets[3]	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing[5]	Other[6]
-3 and above	27 and above	100/0	2:40 – 4:00	1:25 – 2:00	2:00 – 2:00	1:10 – 1:30	0:20 – 2:00	CAUTION: No holdover time guidelines exist
		75/25	2:05 – 3:15	1:05 – 2:00	1:50 – 2:00	1:00 – 1:20	0:20 – 2:00	
		50/50	0:55 – 1:45	0:25 – 1:15	0:35 – 1:10	0:25 – 0:35		
below -3 to -14	below 27 to 7	100/0	0:50 – 2:30	0:35 – 1:10	0:25 – 1:30[7]	0:20 – 0:40[7]		
		75/25	0:30 – 1:05	0:40 – 1:20	0:20 – 1:00[7]	0:15 – 0:30[7]		
below -14 to -25 or LOUT	below 7 to -13 or LOUT	100/0	0:20 – 0:45	0:15 – 0:30				

NOTES

1 These holdover times are derived from tests of this fluid having a viscosity as listed in Table 9.
2 Ensure that the lowest operational use temperature (LOUT) is respected. Consider use of Type I when Type IV fluid cannot be used.
3 Use light freezing rain holdover times in conditions of light snow mixed with light rain.
4 Use light freezing rain holdover times if positive identification of freezing drizzle is not possible.
5 No holdover guidelines exist for this condition for 0°C (32°F) and below.
6 Heavy snow, ice pellets, moderate and heavy freezing rain, and hail.
7 These holdover times only apply to outside air temperatures to -10°C (14°F) under freezing drizzle and light freezing rain.

CAUTIONS

- **The only acceptable decision-making criterion, for takeoff without a pre-takeoff contamination inspection, is the shorter 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.**

Page 36 of 52 July 2010

ATTACHMENT IX– Ice Pellet Allowance Time Table

Transport Canada Holdover Time Guidelines Winter 2010-2011

TABLE 11

ICE PELLET ALLOWANCE TIMES FOR WINTER 2010-2011

	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[1]
Moderate Ice Pellets	25 minutes[2]	10 minutes	10 minutes[1]
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 Moderate Rain	25 minutes		
Light Ice Pellets Mixed with Light Snow	25 minutes	15 minutes	
Light Ice Pellets Mixed with Moderate Snow	10 minutes		

NOTES

1 No allowance times exist for propylene glycol (PG) fluids, when used on aircraft with rotation speeds less than 115 knots. (For these aircraft, if the fluid type is not known, assume zero allowance time).

2 Allowance time is 15 minutes for propylene glycol (PG) fluids, or when the fluid type is unknown.

ATTACHMENT X – Task List for Setup and Actual Tests

No.	Task	Person	Status
	Planning and Preparation		
1	Co-ordinate with NRC wind tunnel personnel	MR/JD	
2	Ensure fluid is received and is stored outdoors	MR/JD	
3	Co-ordinate with APS photographer	MR	
4	Arrange for hotel accommodations for APS personnel	MP	
5	Arrange personnel travel to Ottawa;	MP/VZ	
6	Hire YOW personnel	DY/MP	
7	Complete contract for YOW personnel	MP/YOW	
8	Ensure proper functioning of ice pellet dispenser equipment;	MR/VZ	
9	Ensure availability of freezing rain sprayer equipment;	MR	
10	Prepare and Arrange Office Materials to YOW	MP	
11	Prepare and Arrange Site Equipment to YOW	DY/VZ	
12	Prepare Data forms and procedure	MP	
13	Prepare Test Log (See JD with it)	MP	
14	Finalize and complete list of equipment/materials required	DY/MR	
15	Arrange for freezer storage of ice pellets/snow/snow pellets.	DY	
16	Investigate IP/ZR/SN dispersal techniques and location	VZ/MR	
17	Update IP Rate File	VZ/MR	
18	Check with NRC the status of the testing site, tunnel etc	MR	
19	Check weather prior to establishing test dates	MR	
20	Arrange for pallets to lift up 1000L totes	MR	
21	Purchase new 20 L containers (as necessary)	DY	
	Monday Jan 17		
22	Pack and leave YUL for YOW on Jan 17th	APS	
23	Unload Truck	APS	
24	Organize all Equipment in Lower Level of Wind Tunnel	APS	
25	Verify fluids received		
26	Ice and freezer delivery	DY	
27	Setup general office and testing equipment (time permitting)	APS	
	Tuesday Jan 18		
28	Safety Briefing & Training (APS/YOW)	MR	
29	Setup rate station	DY	
30	Setup Projector	MP	
31	Setup printer	MP	
32	Setup IP/SN manufacturing material	VZ	
33	Test and prepare IP dispensing equipment	VZ	
34	Organize Fluid Outside (labels and fluid receipt forms)	MP/DY/YOW	
35	Transfer Fluids from 1000 L Totes to 20 L containers.	MP/DY/YOW	
36	Verify ZR sprayer installation	MR	
37	Train IP making personnel	VZ/YOW	James will help train others
38	Conduct dry photography test of old vs. new camera positioning;	BG/MR	Jessie
39	Document new final camera and flash locations	VZ/BG	
40	Conduct falling ball tests on received fluids;	MP/DY	
41	Collect fluid samples for viscosity verification at APS office;	MP/DY	
42	Mark wing data collection locations and draw grid on the wing (refer to Feasibility report for diagrams);	VZ/DY	
43	Co-ordinate fabrication of ice pellets/snow/snow pellets	VZ	
44	ZR Calibration	DY/MP	
45	IP/SN Calibration (confirm rates with spot check with rate pan)	DY/VZ	
46	IP manufacturing	YOW's	
47	General safety briefing and update on testing	APS/NRC/YOW	
48	Dry Run of tests (APS / NRC)	APS/NRC	
	Each Testing Day		
49	Check with NRC the status of the testing site, tunnel etc	MR	
50	Check weather prior to establishing test dates	MR	
51	Prepare equipment and fluid to be used for test	DY	
52	Manufacture ice pellets	VZ/YOW	
53	Arrange for photo doc. of the test	MR	
54	Prepare data forms for test	MP	
55	Conduct tests based on test plan	APS	
56	Modify test plan based on results obtained	WU/JD/MR	
57	Update IP/S Inventory	VZ/YOW	
58	Update Ice Quantity	VZ/YOW	
59	Update Fluid Quantity	MP/DY	
60	Update Test Plan	MP	

ATTACHMENT XI – General Form (to be filled by MP)

Form 1

GENERAL FORM (EVERY TEST)

DATE: ______________ FLUID APPLIED: ______________ RUN # (Plan #): ________

AIR TEMPERATURE (°C) BEFORE TEST: ________
AIR TEMPERATURE (°C) AFTER TEST: ________
TUNNEL TEMPERATURE (°C) BEFORE TEST: ________
TUNNEL TEMPERATURE (°C) AFTER TEST: ________
WIND TUNNEL START TIME: ________
PROJECTED SPEED (S/KTS): ________
ROTATION ANGLE: ________
EXTRA RUN INFO: ________
FLAP SETTING (20°, 0°): ________

FLUID APPLICATION

Actual start time: ________
Actual End Time: ________
Fluid Brix: ________
Amount of Fluid (L): ________
Fluid Temperature (°C): ________
Fluid Application Method: POUR

ICE PELLETS APPLICATION (if applicable)

Actual start time: ________
Actual End Time: ________
Rate of Ice Pellets Applied (g/dm^2/h): ________
Ice Pellets Size (mm): 1.4 - 4.0 mm
Exposure Time: ________
Total IP Required per Dispenser: ________

FREEZING RAIN/DRIZZLE APPLICATION (if applicable)

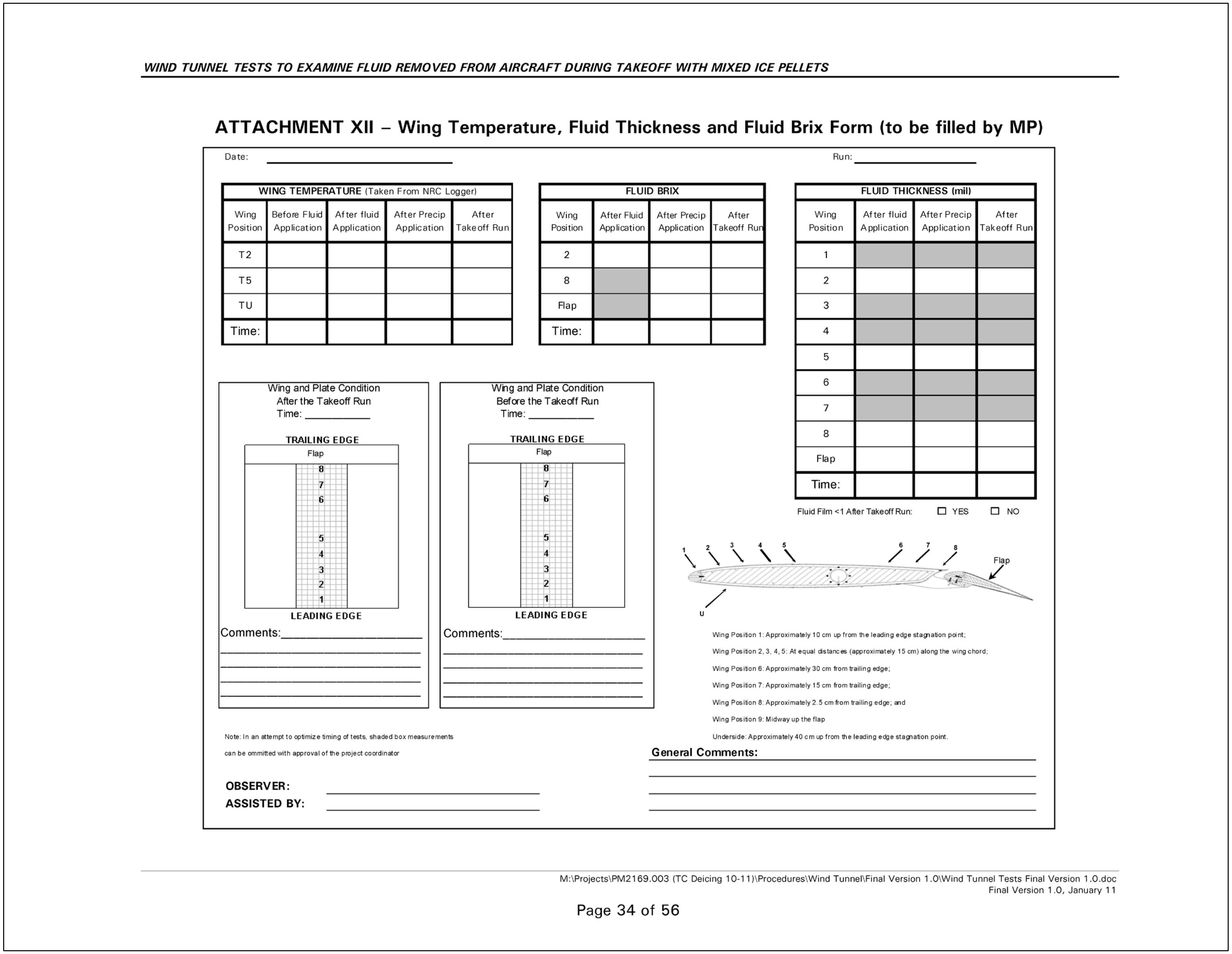
Actual start time: ________
Actual End Time: ________
Rate of Precipitation Applied (g/dm^2/h): ________
Droplet Size (mm): ________
Exposure Time: ________
Needle: ________
Flow: ________
Pressure ________

SNOW APPLICATION (if applicable)

Actual start time: ________
Actual End Time: ________
Rate of Snow Applied (g/dm^2/h): ________
Snow Size (mm): <1.4 mm
Exposure Time: ________
Method: ☐ Dispenser ☐ Sieve
Total SN Required per Dispenser: ________

COMMENTS ________

MEASUREMENTS BY: ________ **HANDWRITTEN BY:** ________



ATTACHMENT XII – Wing Temperature, Fluid Thickness and Fluid Brix Form (to be filled by MP)

Date: ______________________ Run: ______________

WING TEMPERATURE (Taken From NRC Logger)

Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2				
T5				
TU				
Time:				

FLUID BRIX

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2			
8	▨		
Flap	▨		
Time:			

FLUID THICKNESS (mil)

Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	▨	▨	▨
2			
3	▨	▨	▨
4	▨	▨	▨
5			
6	▨	▨	▨
7	▨	▨	▨
8			
Flap			
Time:			

Fluid Film <1 After Takeoff Run: ☐ YES ☐ NO

Wing and Plate Condition
After the Takeoff Run
Time: __________

Comments:____________________

Wing and Plate Condition
Before the Takeoff Run
Time: __________

Comments:____________________

Wing Position 1: Approximately 10 cm up from the leading edge stagnation point;

Wing Position 2, 3, 4, 5: At equal distances (approximately 15 cm) 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

Wing Position 9: Midway up the flap

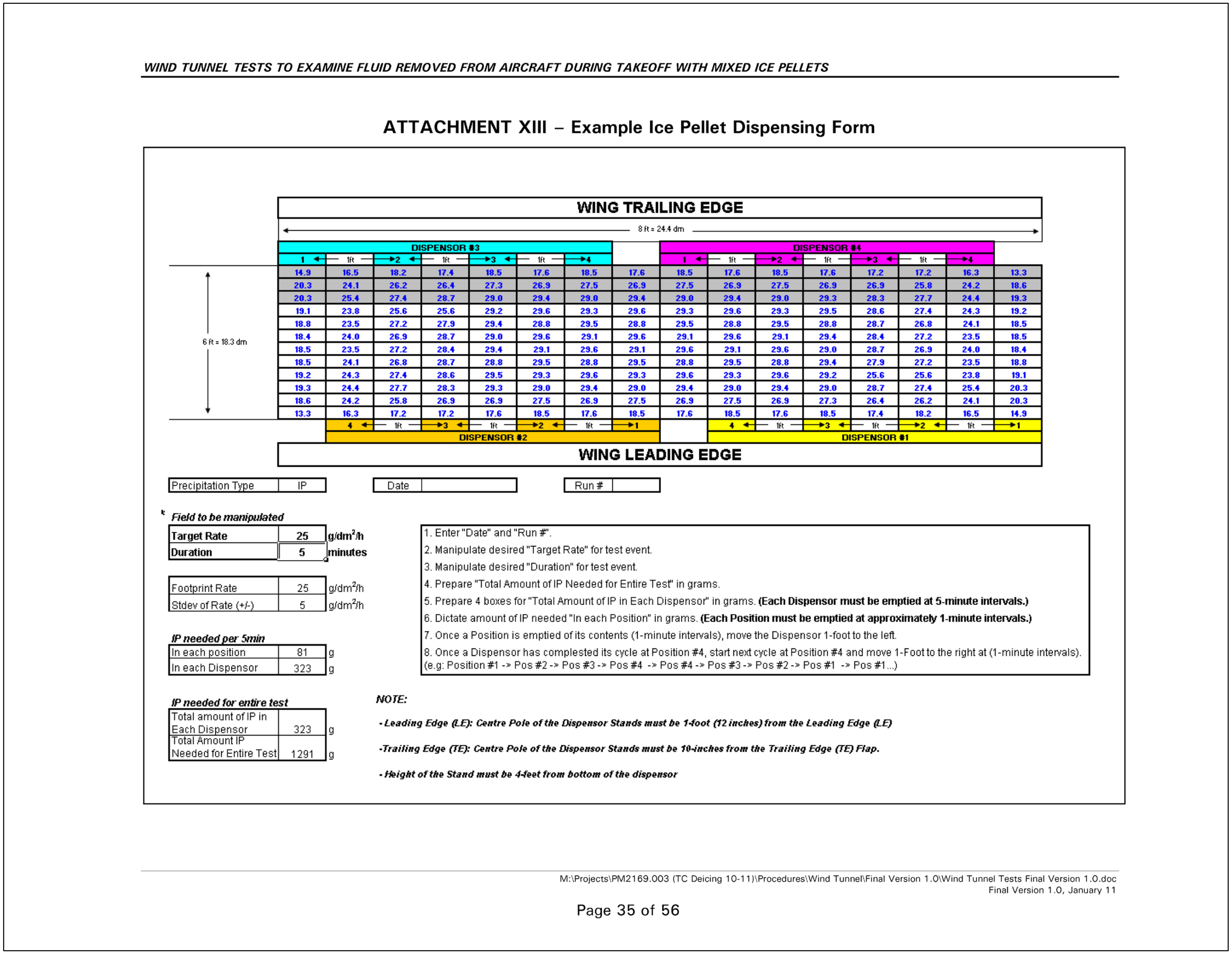
Underside: Approximately 40 cm up from the leading edge stagnation point.

Note: In an attempt to optimize timing of tests, shaded box measurements can be ommitted with approval of the project coordinator

General Comments:

OBSERVER: ______________________

ASSISTED BY: ______________________



ATTACHMENT XIII – Example Ice Pellet Dispensing Form

WING TRAILING EDGE

8 ft = 24.4 dm

6 ft = 18.3 dm

DISPENSOR #3								**DISPENSOR #4**							
1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4		1 ←	1ft	→ 2 ←	1ft	→ 3 ←	1ft	→ 4	
14.9	16.5	18.2	17.4	18.5	17.6	18.5	17.6	18.5	17.6	18.5	17.6	17.2	17.2	16.3	13.3
20.3	24.1	26.2	26.4	27.3	26.9	27.5	26.9	27.5	26.9	27.5	26.9	26.9	25.8	24.2	18.6
20.3	25.4	27.4	28.7	29.0	29.4	29.0	29.4	29.0	29.4	29.0	29.3	28.3	27.7	24.4	19.3
19.1	23.8	25.6	25.6	29.2	29.6	29.3	29.6	29.3	29.6	29.3	29.5	28.6	27.4	24.3	19.2
18.8	23.5	27.2	27.9	29.4	28.8	29.5	28.8	29.5	28.8	29.5	28.8	28.7	26.8	24.1	18.5
18.4	24.0	26.9	28.7	29.0	29.6	29.1	29.6	29.1	29.6	29.1	29.4	28.4	27.2	23.5	18.5
18.5	23.5	27.2	28.4	29.4	29.1	29.6	29.1	29.6	29.1	29.6	29.0	28.7	26.9	24.0	18.4
18.5	24.1	26.8	28.7	28.8	29.5	28.8	29.5	28.8	29.5	28.8	29.4	27.9	27.2	23.5	18.8
19.2	24.3	27.4	28.6	29.5	29.3	29.6	29.3	29.6	29.3	29.6	29.2	25.6	25.6	23.8	19.1
19.3	24.4	27.7	28.3	29.3	29.0	29.4	29.0	29.4	29.0	29.4	29.0	28.7	27.4	25.4	20.3
18.6	24.2	25.8	26.9	26.9	27.5	26.9	27.5	26.9	27.5	26.9	27.3	26.4	26.2	24.1	20.3
13.3	16.3	17.2	17.2	17.6	18.5	17.6	18.5	17.6	18.5	17.6	18.5	17.4	18.2	16.5	14.9
	4 ←	1ft	→ 3 ←	1ft	→ 2 ←	1ft	→ 1		4 ←	1ft	→ 3 ←	1ft	→ 2 ←	1ft	→ 1
	DISPENSOR #2								**DISPENSOR #1**						

WING LEADING EDGE

Precipitation Type	IP	Date		Run #	

Field to be manipulated

Target Rate	**25**	**g/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm²/h
Stdev of Rate (+/-)	5	g/dm²/h

IP needed per 5min

In each position	81	g
In each Dispensor	323	g

IP needed for entire test

Total amount of IP in Each Dispensor	323	g
Total Amount IP Needed for Entire Test	1291	g

1. Enter "Date" and "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of IP Needed for Entire Test" in grams.
5. Prepare 4 boxes for "Total Amount of IP in Each Dispensor" in grams. **(Each Dispensor must be emptied at 5-minute intervals.)**
6. Dictate amount of IP needed "In each Position" in grams. **(Each Position must be emptied at approximately 1-minute intervals.)**
7. Once a Position is emptied of its contents (1-minute intervals), move the Dispensor 1-foot to the left.
8. Once a Dispensor has completed its cycle at Position #4, start next cycle at Position #4 and move 1-Foot to the right at (1-minute intervals).
(e.g: Position #1 -> Pos #2 -> Pos #3 -> Pos #4 -> Pos #4 -> Pos #3 -> Pos #2 -> Pos #1 -> Pos #1...)

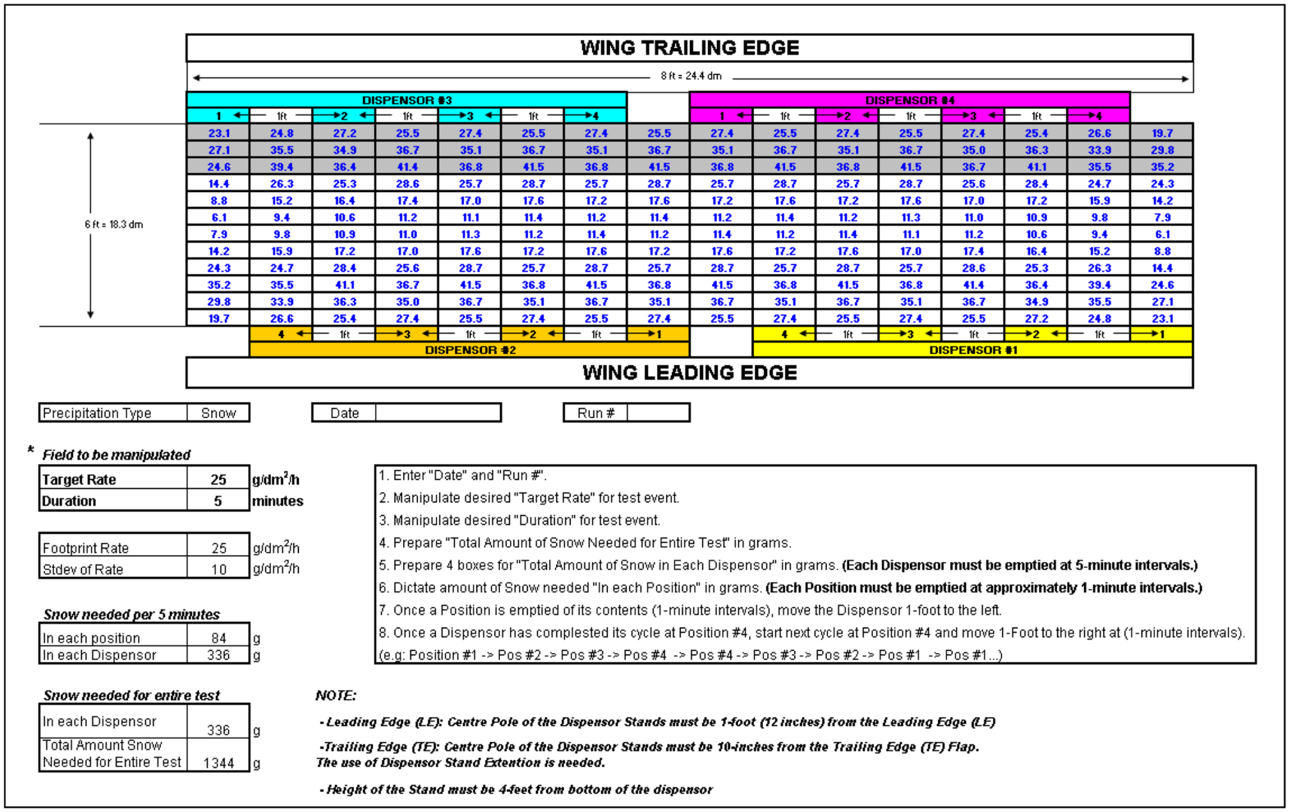
NOTE:

- Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap.

- Height of the Stand must be 4-feet from bottom of the dispensor

ATTACHMENT XIV – Example Snow Dispensing Form



WING TRAILING EDGE

8 ft = 24.4 dm

6 ft = 18.3 dm

DISPENSOR #3								DISPENSOR #4							
1	1ft	2	1ft	3	1ft	4		1	1ft	2	1ft	3	1ft	4	
23.1	24.8	27.2	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.4	26.6	19.7
27.1	35.5	34.9	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.0	36.3	33.9	29.8
24.6	39.4	36.4	41.4	36.8	41.5	36.8	41.5	36.8	41.5	36.8	41.5	36.7	41.1	35.5	35.2
14.4	26.3	25.3	28.6	25.7	28.7	25.7	28.7	25.7	28.7	25.7	28.7	25.6	28.4	24.7	24.3
8.8	15.2	16.4	17.4	17.0	17.6	17.2	17.6	17.2	17.6	17.2	17.6	17.0	17.2	15.9	14.2
6.1	9.4	10.6	11.2	11.1	11.4	11.2	11.4	11.2	11.4	11.2	11.3	11.0	10.9	9.8	7.9
7.9	9.8	10.9	11.0	11.3	11.2	11.4	11.2	11.4	11.2	11.4	11.1	11.2	10.6	9.4	6.1
14.2	15.9	17.2	17.0	17.6	17.2	17.6	17.2	17.6	17.2	17.6	17.0	17.4	16.4	15.2	8.8
24.3	24.7	28.4	25.6	28.7	25.7	28.7	25.7	28.7	25.7	28.7	25.7	28.6	25.3	26.3	14.4
35.2	35.5	41.1	36.7	41.5	36.8	41.5	36.8	41.5	36.8	41.5	36.8	41.4	36.4	39.4	24.6
29.8	33.9	36.3	35.0	36.7	35.1	36.7	35.1	36.7	35.1	36.7	35.1	36.7	34.9	35.5	27.1
19.7	26.6	25.4	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.4	25.5	27.2	24.8	23.1
	4	1ft	3	1ft	2	1ft	1		4	1ft	3	1ft	2	1ft	1
	DISPENSOR #2								DISPENSOR #1						

WING LEADING EDGE

Precipitation Type	Snow		Date		Run #	

* *Field to be manipulated*

Target Rate	**25**	**g/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm²/h
Stdev of Rate	10	g/dm²/h

Snow needed per 5 minutes

In each position	84	g
In each Dispensor	336	g

Snow needed for entire test

In each Dispensor	336	g
Total Amount Snow Needed for Entire Test	1344	g

1. Enter "Date" and "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of Snow Needed for Entire Test" in grams.
5. Prepare 4 boxes for "Total Amount of Snow in Each Dispensor" in grams. **(Each Dispensor must be emptied at 5-minute intervals.)**
6. Dictate amount of Snow needed "In each Position" in grams. **(Each Position must be emptied at approximately 1-minute intervals.)**
7. Once a Position is emptied of its contents (1-minute intervals), move the Dispensor 1-foot to the left.
8. Once a Dispenser has completed its cycle at Position #4, start next cycle at Position #4 and move 1-Foot to the right at (1-minute intervals).
(e.g: Position #1 -> Pos #2 -> Pos #3 -> Pos #4 -> Pos #4 -> Pos #3 -> Pos #2 -> Pos #1 -> Pos #1...)

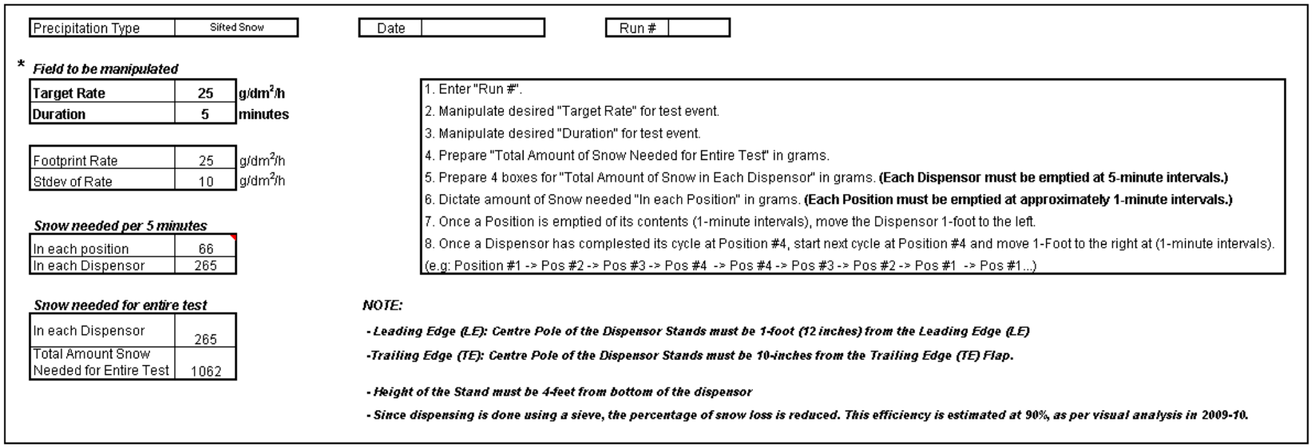
NOTE:

-Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap.
The use of Dispensor Stand Extention is needed.

-Height of the Stand must be 4-feet from bottom of the dispensor

ATTACHMENT XV – Example Snow Dispensing Form



Precipitation Type	Sifted Snow

Date	

Run #	

* ***Field to be manipulated***

Target Rate	**25**	**g/dm²/h**
Duration	**5**	**minutes**

Footprint Rate	25	g/dm²/h
Stdev of Rate	10	g/dm²/h

Snow needed per 5 minutes

In each position	66
In each Dispensor	265

Snow needed for entire test

In each Dispensor	265
Total Amount Snow Needed for Entire Test	1062

1. Enter "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of Snow Needed for Entire Test" in grams.
5. Prepare 4 boxes for "Total Amount of Snow in Each Dispensor" in grams. **(Each Dispensor must be emptied at 5-minute intervals.)**
6. Dictate amount of Snow needed "In each Position" in grams. **(Each Position must be emptied at approximately 1-minute intervals.)**
7. Once a Position is emptied of its contents (1-minute intervals), move the Dispensor 1-foot to the left.
8. Once a Dispensor has complested its cycle at Position #4, start next cycle at Position #4 and move 1-Foot to the right at (1-minute intervals).

(e.g: Position #1 -> Pos #2 -> Pos #3 -> Pos #4 -> Pos #4 -> Pos #3 -> Pos #2 -> Pos #1 -> Pos #1...)

NOTE:

- Leading Edge (LE): Centre Pole of the Dispensor Stands must be 1-foot (12 inches) from the Leading Edge (LE)

-Trailing Edge (TE): Centre Pole of the Dispensor Stands must be 10-inches from the Trailing Edge (TE) Flap.

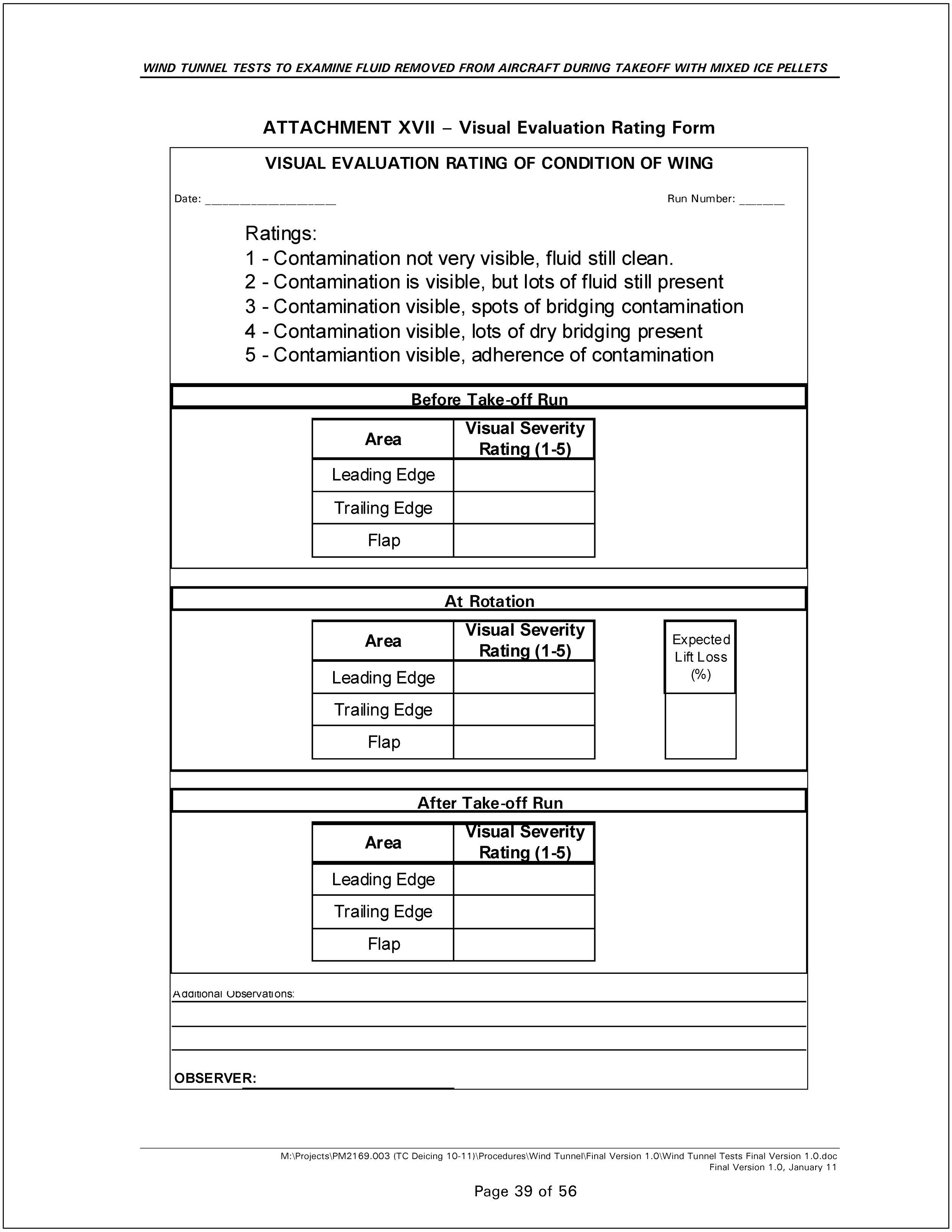
- Height of the Stand must be 4-feet from bottom of the dispensor

- Since dispensing is done using a sieve, the percentage of snow loss is reduced. This efficiency is estimated at 90%, as per visual analysis in 2009-10.

ATTACHMENT XVI – Sprayer Calibration Form

WIND TUNNEL FREEZING RAIN SPRAYER CALIBRATION

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							
2-Feb-09		Full 24 Scans	Full 335 Steps	2x20		500 mL/min	45		50	x-axis=24 Scans, 66.24º. y-axis=60.3º
4-Feb-09		Full 24 Scans	Full 335 Steps	2x20		250 mL/min	45		25	MVD=1-1.2mm. x-axis=24 Scans, 66.24º. y-axis=60.3º
25-Feb-09		Full 24 Scans	Full 335 Steps	2x17		750 mL/min	45		75	x-axis=24 Scans, 66.24º. y-axis=60.3º
1-Mar-09		Full 24 Scans	Full 335 Steps	2x20		150 mL/min	45		15	x-axis=24 Scans, 66.24º. y-axis=60.3º



ATTACHMENT XVII – Visual Evaluation Rating Form

VISUAL EVALUATION RATING OF CONDITION OF WING

Date: ____________________ Run Number: _______

Ratings:
1 - Contamination not very visible, fluid still clean.
2 - Contamination is visible, but lots of fluid still present
3 - Contamination visible, spots of bridging contamination
4 - Contamination visible, lots of dry bridging present
5 - Contamiantion visible, adherence of contamination

Before Take-off Run

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	
Flap	

At Rotation

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	
Flap	

Expected Lift Loss (%)

After Take-off Run

Area	Visual Severity Rating (1-5)
Leading Edge	
Trailing Edge	
Flap	

Additional Observations:

OBSERVER: ____________________

ATTACHMENT XVIII – Fluid Receipt Form

SECTION A - SITE

☐ HOT SAMPLE ☐ RESEARCH/OTHER SAMPLE

Receiving Location: ____________________ **Date of Receiving:** ____________________

Manufacturer: ________________ **Fluid Name:** ____________________ **Fluid Type:** ______

Date of Production: ____________________ **Batch #:** ____________________

Fluid Dilution:	______	______	______
Fluid Quantity:	___ x ___ L = _____ L	___ x ___ L = _____ L	___ x ___ L = _____ L
APS Measured BRIX:	______	______	______

Note any additional information included on fluid containers:

Received by: ____________________
(PRINT NAME)
on: ____________________
(DATE)

SECTION B - OFFICE

Fluid Code Assigned: 100/0 ______ 75/25 ______ 50/50 ______ Type I ______

Viscosity Information Received:[1] ☐ **Viscosity Measured:**[1] ☐

WSET Sample Sent to AMIL: ☐ **WSET Result Received:** ☐

FFP Curves Received:[2] ☐

---

[1] Type II/III/IV fluids only

[2] Type I fluids only

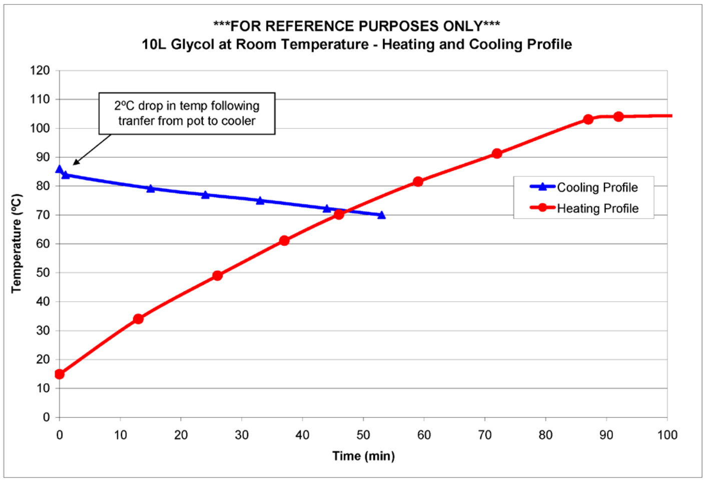
ATTACHMENT XIX – Log of Fluid Sample Bottles

Date of Extraction	Fluid and Dilution	Batch #	Sample Source (i.e. Drum)	Falling Ball Fluid Temp (°C)	Falling Ball Time (sec)	Comments

ATTACHMENT XX– Application Procedure - Heated Type III Fluid for Wind Tunnel Tests

Heating

- Type III should be stored indoors at room temperature to minimize heating required;
- Heat Type III fluid 10L at a time using a hotplate and an aluminum cooking pot with a lid. The hotplate should be set to the "Max" setting. Two pots should be heated simultaneously to prepare the 20L required for each test;
- Fluid temperature should be monitored every 10 minutes, and the fluid should be stirred frequently;
- Once a temperature of 70ºC is achieved (approx 45 minutes), the two 10L pots of fluid should be transferred to individual warm insulated coolers.
- *Note: Although 60ºC is the target application temperature, the fluid will be transferred into the coolers at 70ºC to allow for some cooling during transportation to the test section and transfer into the pouring jug*s.



Application

NOTE: It is critical that all precipitation dispensing equipment be ready to go prior to fluid application. Application of precipitation should occur immediately after the fluid application is complete to minimize heat loss from the wing.

- Heated Type III fluid should be transferred from the insulated coolers into hand held 2-3L pour containers;
- 20 L (see "Application Quantity" section for details) of fluid should be applied evenly to the whole wing section using the typical methodology for applying

fluid in the wind tunnel. Two people will be required to pour 10L from the leading edge and 10L from the trailing edge.

- Precipitation shall be timed to start immediately after the completion of the fluid application. Thickness and Brix measures can be omitted for the "after pour" application.

Application Quantity

Note: Quantities in brackets (xx L) will be total volume required based on wind tunnel wing section area.

- HOT guidelines recommend 1L/m² (3.7L) as final step
- Original APS assumption was to use about five times the amount, so about 5.4L/m(20L)
- FAA original recommendation was < (20L), but > (3.7L), and suggested (6-8 L)
- A review was conducted of operator data for “one-step de/anti-icing procedures using Type I”
    - Details in the report “Research Data to Support the Development of the Airport De-Icer Management System Model (ADMS)

Fluid quantities for one-step de/anti-icing procedures using Type I
Based on review of report data for Moderate Snow and Freezing Rain conditions

- Large Canadian Operator for Commuter Aircraft (Dash 8 or CRJ)
    - 5 L/m² (19L) and 10L/m² (37L)
- Large US Operator for Commuter Aircraft (Dash 8 or CRJ)
    - 2L/m² (7L) and 3L/m² (11L)
- Large Canadian Operator for Large W/B Aircraft (A340)
    - 3 L/m² (11L) and 6L/m² (22L)
- Servisair Recommended Spray Quantities for Commuter Aircraft (Dash 8 or CRJ)
    - Waiting on data, will update once received.

Conclusion:

Review of data provides a range of 2L/m² (7L) to 10L/m² (37L).

Following a discussion of this data, it is recommended that initial testing be conducted with both 2.7L/m² (10L) and 5.4L/m² (20L) to evaluate the severity of the heat involved. Following a review of the test data, a decision may be made to proceed with either the larger or smaller amount.

ATTACHMENT XXI – Procedure: Heavy Snow

Background

As a direct result of the ice pellet research conducted, the use of HOTs for determining the protection time provided by anti-icing fluids was questioned. The focus has turned towards "aerodynamic failure" which can be defined as a significant lift loss resulting from contaminated anti-icing fluid. Heavy snow conditions have been selected for this study for two reasons. First, snow conditions account for the most significant portion of de-icing operations globally. Secondly, there has been a recent industry interest for holdover time for heavy snow conditions. Preliminary aerodynamic testing was conducted during the winter of 2006-07, 2008-09, and 2009-10.

Objective

To investigate the fluid aerodynamic flow-off characteristics of anti-icing fluid contaminated with simulated heavy snow versus moderate snow.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow condition tests conducted in the wind tunnel.

- For a chosen fluid, conduct a test simulating moderate snow conditions (rate of 25 g/dm²/h) for an exposure time derived from the HOT table based on the tunnel temperature at the time of the test
- Record lift data, visual observations, and manually collected data;
- Conduct two comparative tests simulating heavy snow conditions (rate of 50 g/dm²/h) for the same exposure time used during the moderate snow test.
    - NOTE: previous testing has indicated that using half, to ¾ of the moderate snow HOT generates similar end conditions, whereas using the full moderate HOT for heavy snow conditions generates a more sever fluid failure which behaves worse aerodynamically. ;
- Record lift data, visual observations, and manually collected data;
- Compare the heavy snow results to the moderate snow results. If the heavy snow results are worse, repeat the heavy snow test with a reduced exposure time, if the results are better, repeat the heavy snow test with an increased exposure time.
- Repeat until similar lift data, and visual observations are achieved for both heavy snow and moderate snow; and
- Document the percentage of the moderate snow HOT that is acceptable for heavy snow conditions.

Test Plan

Ten to twelve comparative tests are anticipated.

ATTACHMENT XXII – Procedure: Aerodynamic Impact of Rotation Wing to CL Max

Background

Historically, the ice pellet allowance time testing conducted in the wind tunnel simulated typical aircraft rotation angles and evaluated the lift losses at the max angle achieved. During the winter of 2009-10, the max rotation angle was selected to be approximately mid way between the typical rotation angle and the stall angle to simulate a worse case condition. Discussions with SAE Aerodynamics working group led to the recommendation to conduct some limited testing rotating the wing section to CL Max during the takeoff profile as this a more common approach used by aerodynamicists. The objective is to verify the differences in results as compared to the protocol that has been historically used in the wind tunnel.

Objective

To investigate the lift loss at CL max with and without fluid and contamination.

Methodology

- Conduct a test simulating an ice pellet allowance time condition and rotate the wing to a angle of rotation typical of aircraft operations (8 deg was used in 2009-10);
- Conduct a comparative test in the same conditions, however rotate the wing section to CL Max;
- Conduct comparative baseline fluid only test for both cases (8 deg max rotation and CL max)
- Calculate the lift losses for both contamination tests at the maximum angle of rotation and compare the results to the baseline fluid only tests;
- Document the results.

Test Plan

Five tests are anticipated, however more tests may be required based on the results.

ATTACHMENT XXIII – Procedure: Aerodynamic Impact of Wing Surface Roughness

Background

Previous testing in the wind tunnel demonstrated that although contamination was present on the wing section, significant lift losses were not apparent. Lift losses were incurred upon application of anti-icing fluid (when compared to a bare wing) however, the presence of contamination, whether adhered or not, did not generate significant list losses when compared to the uncontaminated fluid. Although the presence of adhered contamination may be hazardous with regards to control surfaces, the impact of the surface roughness on the overall aerodynamic performance of the wing needs to be investigated.

Objective

To investigate wing surface roughness and how it pertains to lift loss.

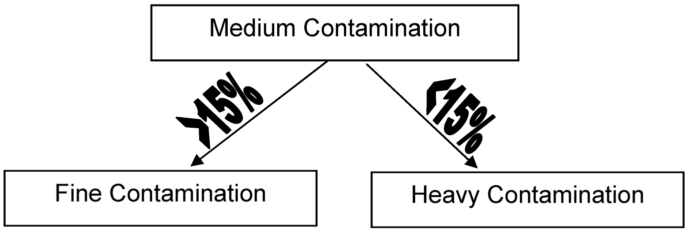
Methodology

Contamination can be in the form of abrasive sandpaper (similar to what is used by the NRC Flight Laboratory) or frozen precipitation on a bare wing. During the winter of 2008-09 and 2009-10, adhered freezing rain, ice pellets, and snow were used to create a rough surface on the wing section.

- Apply abrasive material or contamination to full length of the leading edge of wing section;
- Run wind tunnel test, collect lift loss data, compare to fluid only results;
- Increase grit of sandpaper or level of frozen contamination until appreciable lift losses are observed; and
- Document type and level of contamination and resulting effects on lift loss.

Test Plan

Three to four tests are anticipated. Testing will proceed according to the following decision matrix.



ATTACHMENT XXIV – Procedure: Effects of Wing Geometry on Fluid Failure and Aerodynamic Flow Off

Background

A limitation of conducting testing with a 2-dimesnional wing section is the inability to recreate fluid flow off due to the varying geometry found on a real wing section. An operational aircraft wing will have twist (based on chord location), dihedral effect (based on distance from fuselage), and will have varying chord thickness and upper skin slope (based on chord location. Testing during the winter of 2009-10 with the supercritical wing section demonstrated that fluid flow off was reduced due to the relatively flat top surface inherent of that type of wing. It was recommended that preliminary testing be conducted with different wing rest angles during contamination to simulate the different geometries typically found on an aircraft wing.

Objective

To investigate the impact on fluid failure and aerodynamic performance with different wing rest angles during contamination.

Methodology

- Conduct a typical wind tunnel test with contamination using the typical rest angle (-2 degrees for the supercritical wing);
- Repeat the test with steeper rest angle simulating a different section of the wing;
- Compare results and document.

Test Plan

Two preliminary tests are anticipated.

ATTACHMENT XXV – Procedure: Low Speed Ramp Testing

Background

The current low speed aerodynamic acceptance test for anti-icing fluids simulates a rotation speed of 67 knots on a flat plate; this takeoff profile was developed based on older generation low speed aircraft. In recent years, the newer generation low speed aircraft have rotation speeds closer to 80 to 85 knots. As all of the low speed testing conducted in the wind tunnel has been performed simulating an 80 knot rotation speed (representing the newer generation aircraft), it was recommended to verify the fluid flow-off properties of anti-icing fluid using the historical 67 knot rotation speed takeoff profile used for the aerodynamic acceptance tests.

Objective

To investigate the fluid flow-off performance during low speed ramp take-off.

Methodology

- Testing should be conducted in fluid only conditions;
- Testing will consist of two comparative tests done sequentially with the same fluid in similar weather conditions:
    - 67 knots rotation;
    - 85 knots rotation;
- Compare lift data, visual observations, and manually collected data;

Test Plan

Four to six tests are anticipated with two to three different fluids.

ATTACHMENT XXVI – Procedure: Snow on an Un-Protected Wing

Background

In colder northern operations, it is common for aircraft to depart with "loose, dry, un-adhered snow" on present on their wing sections. Although it is assumed most or all of this contamination will be removed at the time of rotation, it is unknown whether a certain level of contamination will reduce aerodynamic performance. Full-scale testing is required to investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered snow.

Objective

To investigate the aerodynamic performance of a wing section contaminated with dry, un-adhered snow.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow condition tests conducted in the wind tunnel.

- Ensure the wing section and tunnel temperature are well below freezing (-5ºC and below);
- Ensure the wing section is clean, dry, and free of any forms of contamination;
- Apply loose, dry snow contamination to the wing section;
- Record lift data, visual observations, and manually collected data;
- Compare the results to baseline fluid only and dry wing test results;

Test Plan

Three to four comparative tests are anticipated.

ATTACHMENT XXVII – Procedure: Scoping Study for the Feasibility of Conducting H-Stab Tests in the Wind Tunnel

Background

Several incidents have been reported of aircraft with un-powered elevator controls failing to rotate, or requiring excessive amounts of stick-force to be able to rotate. The primary suspect is thickened fluid being sucked through the gap of the H-Stab and the elevator and disrupting the aerodynamic flow. This is an ongoing going concern in the industry and an issue for many turbo-prop aircraft currently in service. Although testing will not be conducted in the wind tunnel during the winter of 2009-10, the purpose of this study is to investigate the feasibility of conducting these types of tests in the future.

Objective

To conduct a scoping study to investigate the feasibility of conducting aerodynamic tests with a horizontal stabilizer section in the NRC wind tunnel.

Methodology

- Discuss with NRC the possibility of installing and instrumenting a H-Stab section, and the possibility of having control over the elevator during a test run;
- Discuss with airframe manufacturer possibility of obtaining a H-Stab section for testing;
- Perform preliminary photographic tests (using the current wing section and flap as a surrogate for a H-Stab) to investigate if photos of the underside of the H-Stab would be possible and if any modifications to the wind tunnel would be required.

Test Plan

No testing is required, however a dry run with photography would be recommended.

ATTACHMENT XXVIII – Procedure: Rain on an Un-Protected Wing (Also do with Freezing Drizzle)

Background

In order to determine an acceptable level of lift loss, it was recommended that aerodynamic testing be conducted under known conditions which are safe for flying. The condition of rain (non-freezing) on an un-protected wing could provide insight into an acceptable level of lift loss (if any) which is present during a typical aircraft takeoff scenario. Full-scale testing is required to investigate the aerodynamic performance of a wing section during rain conditions.

It was also recommended that some preliminary testing be done with freezing drizzle on a dry wing surface. Due to the roughness of drizzle when precipitation first begins (before it becomes smoothed out after extensive exposure), the aerodynamic severity may be closer to what is observed with frost as compared to freezing rain which is generally smooth.

Objective

To investigate the aerodynamic performance of a wing section during rain conditions. As a secondary objective, conduct testing with freezing drizzle on a dry wing section.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow condition tests conducted in the wind tunnel.

- Ensure the wing section, tunnel temperature, and outside ambient temperature are ABOVE freezing (+1°C and above);
- Ensure the wing section is clean, dry, and free of any forms of contamination;
- Apply rain using the freezing rain sprayer. If possible, keep the rain sprayer working during the ramp up;
- Record lift data, visual observations, and manually collected data;
- Compare the results to baseline fluid only and dry wing test results;
- Consider conducted similar tests in below 0°C with freezing drizzle on a dry wing.

Test Plan

Three to four comparative tests are anticipated.

ATTACHMENT XXIX – Procedure: Effect of Ice Phobic Coatings on Contaminated Airfoil Aerodynamic Performance

Background

There has been a recent industry interest in the use of ice phobic coatings to protect aircraft critical surfaces. Currently, some non-commercial operators are using ice phobic coatings on the aircraft radome and other aircraft surfaces. Previous work was conducted during the winter of 2009-10 with a severely contaminated wing section. It was recommended that application of these materials on different parts of the wing surface be investigated i.e. wing and flap leading edge, quiet areas, etc. It was recommended that testing be continued to investigate the protective properties of these coatings in precipitation conditions, and to verify the compatibility of these products with glycol de/anti-icing fluids.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with a wing section treated with ice-phobic coatings following contamination, with and without anti-icing fluid.

Methodology

- The wing should be clean and dry before the start of test;
- The wing section should be covered with speed tape. If it is not feasible to cover the entire wing, the first 12-24" of the leading edge should be covered with speed tape;
- The wing should be sectioned in half: un-treated and treated with ice-phobic coating;
- One side should be treated with the ice phobic coating as per the manufacturer specification. The other side should be left untreated;
- The first test should be conducted with no fluid protection during light freezing rain conditions;
- Run wind tunnel and collect data;
- The following test should be conducted with anti-icing fluid protection. The wing should be exposed to simulated light freezing rain at a rate of 25 g/dm^2/h and the time of exposure should be chosen based on OAT and fluid specific HOT's;
- Run wind tunnel and collect data;
- The performance of the treated and un-treated sections of the wing should be compared.

Test Plan

Two to four tests are anticipated.

ATTACHMENT XXX – Procedure: Degraded Anti-icing Fluid Performance Following Contamination with Runway Deicing Fluid

Background

Recent operational reports have indicated a significant degradation effect as a result of cross-contamination of thickened anti-icing fluids with runway deicing fluids. This is especially of concern for landings on a wet runway with reverse thrusters followed by preventative anti-icing applications. Full-scale data is required to verify the aerodynamic impact of degraded anti-icing fluid flow off following contamination.

Objective

To investigate the aerodynamic flow-off characteristics and lift losses associated with degraded anti-icing fluid flow off following contamination.

Methodology

- The wing should be clean and dry before the start of test;
- The wing should be sectioned in half: good side and degraded fluid side;
- The degraded fluid side should be treated with a spray of diluted runway deicer fluid;
- Anti-icing fluid should be applied to the whole wing (both good and degraded fluid side);
- Expose wing section to simulated light freezing rain at a rate of 25 g/dm²/h. Time of exposure should be chosen based on OAT and fluid specific HOT's;
- Run wind tunnel and collect data;
- Repeat test and reduce or increase amount of runway deicer fluid applied.
- Consider running tests with rehydrated residues.
- Consider simulated preventative anti-icing and contamination during taxi to runway prior to takeoff.

Test Plan

Four to six tests are anticipated with various Type III and Type IV fluids.

ATTACHMENT XXXI – Procedure: Heavily Contaminated Vertical Stabilizer (Testing Feasibility)

Background

Preliminary flat plate testing has indicated that fluid endurance times can be significantly reduced on vertical surfaces, primarily due to fluid flow off and increased "catch-factor" resulting from high winds. The preliminary endurance time testing indicated that during snow conditions, a vertical surface failure is similar to a heavy snow condition due to the increased "catch-factor". It was recommended that preliminary testing be conducted on the current wing section to investigate the lift losses associated, which could then be translated to a vertical stabilizer.

Objective

To investigate the aerodynamic effects of a heavily contaminated vertical stabilizer.

Methodology

- Conduct a heavy snow test on the upper surface of the wing;
- Once the contamination is complete, apply a generous coating of the same anti-icing fluid to the underside of the wing;
- Run the wind tunnel to obtain aerodynamic data;
- Repeat test with un-contaminated fluid on both the upper and underside of the wing;
- Document results and develop methodology to translate the results to a vertical surface to simulate un-even contamination due to cross winds.

Test Plan

Testing should be limited due to the preliminary nature of the procedure. If results are promising, investigate feasibility of using a vertical stabilizer wing section for future wind tunnel testing.

ATTACHMENT XXXII – Procedure: Type I Deicing and Spot During CSW Frost Conditions

Background

The fundamental difference between both types of frost is how the wing skin temperature is cooled below ambient: radiation cooling versus conduction cooling. During natural active frost, the wing skin temperature will be cooled below ambient temperature as a result of radiation cooling from the cold clear sky. During cold soak wing conditions, however, the wing skin temperature is cooled and maintained at a temperature below ambient as a result of conduction cooling from the cold fluid stored inside the wing; either the aircraft was refueled with cold fuel, or following a flight, the wing and fluid will be cold soaked. Full-scale data is recommended to investigate the aerodynamic effects of CSW frost on a deiced airfoil protected with Type I fluid.

Objective

To investigate the aerodynamic effects of CSW frost on a deiced airfoil protected with Type I fluid.

Methodology

- Dilute Type I fluid to a 0°C buffer with respect to the wing skin temperature (to simulate CSW);
- Apply fluid heated to 60°C to wing section;
- Wait 45 minutes (the Type I HOT in frost) or until fluid fails;
- Run the wind tunnel and collect data; and
- Compare results to baseline uncontaminated Type I tests.

Test Plan

Two to three tests are anticipated; frost contamination tests and one fluid only test.

ATTACHMENT XXXIII – Procedure: Light Freezing Rain and Moderate Snow

Background

As the accuracy of meteorological reporting continues to improve, there has been a need to provide improved guidance material during these transitional periods of mixed precipitation. During the winter of 2008-09, guidance material was developed for operations during light snow mixed with light rain conditions. As a result of this work, there was industry interest in guidance material for operations during light freezing rain and moderate snow conditions. The objective of these tests is to collect data to determine if the current HOT guidelines can be expanded to include mixed conditions of light freezing rain and moderate snow conditions.

Objective

To investigate if the current HOT guidelines can be expanded to include mixed conditions of light freezing rain and moderate snow conditions.

Methodology

The general methodology to be used during these tests is in accordance with the methodologies used for typical snow and light freezing rain tests conducted in the wind tunnel. The light freezing rain and moderate snow endurance times will be compared to the light freezing rain only HOT's.

- For a chosen fluid, conduct a test simulating light freezing rain and moderate snow conditions for an exposure time derived from the HOT table based on light freezing rain conditions.
- Record lift data, visual observations, and manually collected data;
- Conduct a comparative test simulating light freezing rain conditions for the same exposure time used during the light freezing rain and moderate snow test;
- Record lift data, visual observations, and manually collected data;
- Compare the light freezing rain and moderate snow conditions results to the light freezing rain results. If the light freezing rain and moderate snow results are worse, repeat the test with a reduced exposure time, if the results are better, repeat the test with a increased exposure time.
- Repeat until similar lift data, and visual observations are achieved for both heavy snow and moderate snow; and
- Document the percentage of the moderate snow HOT that is acceptable for heavy snow conditions.

Test Plan

Four to six comparative tests are anticipated.

APPENDIX C

2010-11 WIND TUNNEL DATA LOG

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
1	2010-11	*Dry Wing*	*None*	*None*	*8*	*20*	*18-Jan-11*	*N/A*	*N/A*	*-8.6*	*-6.9*	*N/A*	-	-	-, -, -	-, -, -	-, -, -	-	*1.274*	*1.442*	-	*-1.41*
2	2010-11	*Dry Wing*	*None*	*None*	*8*	*20*	*18-Jan-11*	*N/A*	*N/A*	*-8.6*	*-5.9*	*N/A*	-	-	-, -, -	-, -, -	-, -, -	-	*1.252*	*1.43*	-	*-0.56*
3	2010-11	*Dry Wing*	*None*	*None*	*16*	*20*	*18-Jan-11*	*N/A*	*N/A*	*-8.6*	*-4.6*	*N/A*	-	-	-, -, -	-, -, -	-, -, -	-	*1.262*	*1.438*	-	*-1.13*
4	2010-11	*Type III HS (COLD)*	*IP-*	*2031 - Cold*	*8*	*20*	*18-Jan-11*	*16:23*	*16:31*	*-7.7*	*-4.9*	*-5.1*	IP:25	*10*	2.3 , 2.3 , 3.5	1 , 1 , 1.5	1 , 1 , 1	-	*N/A*	*N/A*	-	-
5	2010-11	*Baseline (BLDT)*	*None*	*AD-49*	*8*	*20*	*19-Jan-11*	*N/A*	*8:53*	*-12.3*	*-10.3*	*-8.5*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*N/A*	*N/A*	-	-
5A	2010-11	*Baseline (BLDT)*	*None*	*AD-49*	*8*	*20*	*19-Jan-11*	*N/A*	*9:39*	*-12.4*	*-10.4*	*-8.2*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.167*	*1.367*	-	*3.87*
6	2010-11	*Type IV Fluid Val.*	*IP-*	*AD-49*	*8*	*20*	*19-Jan-11*	*10:40*	*10:47*	*-12.6*	*-10.9*	*-8.4*	IP:25	*30*	2.4 , 2.5 , 3.3	1.1 , 2 , 2.3	1 , 1.2 , 1.25	-	*1.163*	*1.321*	-	*7.10*
7	2010-11	*Type IV Fluid Val.*	*IP Mod*	*AD-49*	*8*	*20*	*19-Jan-11*	*11:30*	*11:37*	*-12.2*	*-10.4*	*-11.3*	IP:75	*10*	2.7 , 2.7 , 3.4	1.3 , 2.2 , 2.4	1 , 1.3 , 1.4	-	*1.171*	*1.321*	-	*7.10*
8	2010-11	*115 Knots Val.*	*IP-*	*AD-49*	*8*	*20*	*19-Jan-11*	*12:52*	*12:59*	*-11.4*	*-8.5*	*-10.5*	IP:25	*30*	2.5 , 2.3 , 3.25	1 , 1.7 , 1.9	1 , 1.25 , 1.6	-	*1.221*	*1.381*	-	*2.88*
9	2010-11	*Baseline (BLDT)*	*None*	*AD-49*	*8*	*20*	*19-Jan-11*	*N/A*	*14:00*	*-10*	*-6.7*	*-6.1*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.226*	*1.387*	-	*2.46*
10	2010-11	*Type IV Fluid Val.*	*IP Mod*	*Max-Flight*	*8*	*20*	*19-Jan-11*	*15:14*	*15:22*	*-9.7*	*-6.8*	*-10.3*	IP:75	*25*	3.5 , 3.5 , 3.9	1 , 1.6 , 1.7	1 , 1 , 1	-	*1.222*	*1.393*	-	*2.04*
11	2010-11	*Effect of Ramp-up Time*	*None*	*Max-Flight*	*8*	*20*	*20-Jan-11*	*N/A*	*8:44*	*-16.5*	*-13.6*	*-12.2*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.203*	*1.37*	-	*3.66*
12	2010-11	*Baseline (BLDT)*	*None*	*Max-Flight*	*8*	*20*	*20-Jan-11*	*N/A*	*9:19*	*-16*	*-14.2*	*-12.3*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.181*	*1.336*	-	*6.05*

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
13	2010-11	Type IV Fluid Val.	IP Mod	Max-Flight	8	20	20-Jan-11	10:04	10:09	-15	-12.4	-13.9	IP:75	10	2.3 , 2.5 , 3.3	1 , 1.3 , 1.7	1 , 1 , 1.5	-	1.221	1.369	-	3.73
14	2010-11	Type IV Fluid Val.	IP Mod	Max-Flight	8	20	20-Jan-11	10:46	10:51	-14.2	-12.3	-13.8	IP:75	10	2.3 , 2.5 , 3.3	1.4 , 2.5 , 3	1 , 1 , 1.2	-	1.139	1.308	-	8.02
15	2010-11	115 Knots Val.	IP Mod	Max-Flight	8	20	20-Jan-11	11:32	11:38	-13.3	-10.8	-13.3	IP:75	10	2.3 , 2.3 , 3.2	1 , 1.3 , 1.4	1 , 1 , 1.1	-	1.188	1.355	-	4.71
15A	2010-11	115 Knots Val.	IP Mod	Max-Flight	8	20	20-Jan-11	12:18	12:23	-12.8	-10.4	-12.5	IP:75	10	2.3 , 2.3 , 2.9	1 , 1 , 1.3	1 , 1 , 1	-	1.216	1.378	-	3.09
15B	2010-11	115 Knots Val.	IP Mod	Max-Flight	8	20	20-Jan-11	13:06	13:10	-12.7	-10.8	-12.1	IP:75	10	2.4 , 2.3 , 2.9	1 , 1.4 , 1.5	1 , 1 , 1.1	-	1.167	1.347	-	5.27
16	2010-11	Heavy Snow (HHS)	S	Max-Flight	8	20	21-Jan-11	23:17	23:21	-14.5	-11.5	-11.7	SN:25	35	3.3 , 2.7 , 3.8	1.2 , 1.6 , 1.8	1.1 , 1.2 , 1.3	-	1.15	1.31	-	7.88
NRC 1	2010-11	-	-	-	-	-	22-Jan-11	-	-	-	-	-	-	-	-, -, -	-, -, -	-, -, -	-	-	-	-	-
NRC 2	2010-11	-	-	ABC-S+	-	-	22-Jan-11	-	-	-	-	-	-	-	-, -, -	-, -, -	-, -, -	-	-	-	-	-
17	2010-11	Heavy Snow (HHS)	S++	Max-Flight	8	20	22-Jan-11	4:42	4:47	-17.7	-15	-14.9	SN:50	17.5	2.7 , 3.1 , 3.3	1.2 , 1.7 , 1.9	1.1 , 1.3 , 1.6	-	1.156	1.313	-	6.35
18	2010-11	Heavy Snow (HHS)	S++	Max-Flight	8	20	22-Jan-11	5:22	5:30	-18.4	-14.7	-16	SN:100	8.75	3 , 2.8 , 4	1.5 , 1.9 , 2.5	1.2 , 1.6 , 1.9	-	1.145	1.296	-	7.56
19	2010-11	Heavy Snow	S++	Max-Flight	8	20	22-Jan-11	6:17	6:23	-19.7	-16.7	-16.7	SN:50	17.5	3.2 , 3.2 , 3.8	1.5 , 1.8 , 2.5	1.2 , 1.6 , 2	-	1.121	1.273	-	9.20
20	2010-11	115 Knots Val.	IP-	ABC-S+	8	20	23-Jan-11	1:24	1:28	-20	-17.5	-15.9	IP:25	30	2.5 , 2.75 , 3.5	1.15 , 1.5 , 2	1 , 1 , 1.25	-	1.134	1.286	-	8.27
21	2010-11	Baseline (BLDT)	None	ABC-S+	8	20	23-Jan-11	N/A	2:07	-20.4	-18.2	-16.4	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.154	1.31	-	6.56

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
22	2010-11	IP Data Gap	IP-	ABC-S+	8	20	23-Jan-11	3:07	3:14	-21.3	-19.3	-17.7	IP:25	30	2.75 , 2.75 , 3.5	1.4 , 2 , 2.75	1 , 1.15 , 1.5	-	1.101	1.251	-	10.77
23	2010-11	115 Knots Val.	IP-	Launch	8	20	23-Jan-11	5:28	5:32	-23.6	-21.5	-20	IP:25	30	3 , 2.75 , 4	1.4 , 2 , 2.75	1 , 1.1 , 1.35	-	1.148	1.301	-	7.20
24	2010-11	IP Data Gap	IP-	Launch	8	20	23-Jan-11	6:34	6:38	-24.7	-22.5	-21.2	IP:25	30	3 , 2.75 , 4	1.2 , 2 , 2.5	1.05 , 1.15 , 1.5	-	1.137	1.299	-	7.35
25	2010-11	IP Data Gap	IP Mod	ABC-S+	8	20	23-Jan-11	22:34	22:37	-25.1	-22.3	-21.2	IP:75	10	2.75 , 2.75 , 4	1.6 , 2 , 2.75	1.1 , 1.2 , 2.35	-	1.085	1.251	-	10.77
26	2010-11	IP Data Gap	IP Mod	EG 106	8	20	23-Jan-11	23:19	23:24	-25.4	-21	-21	IP:75	10	2.35 , 2.35 , 3	1 , 1.2 , 1.5	1 , 1 , 1.1	-	1.197	1.359	-	3.07
27	2010-11	IP Data Gap	IP-	EG 106	8	20	23-Jan-11	0:22	0:24	-26.4	-22.6	-21.3	IP:25	30	2.35 , 2.35 , 3	1 , 1.2 , 1.5	1 , 1 , 1.1	-	1.208	1.357	-	3.21
28	2010-11	115 Knots Val.	IP Mod	Launch	8	20	24-Jan-11	0:59	1:01	-27.3	-24.5	-22.5	IP:75	10	3 , 3 , 4	1.25 , 1.75 , 2.25	1 , 1.1 , 1.35	-	1.151	1.296	-	7.56
29	2010-11	Baseline (BLDT)	None	Launch	8	20	24-Jan-11	N/A	1:26	-27.4	-23.9	-21.1	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.157	1.31	-	6.56
30	2010-11	Baseline (BLDT)	None	ABC-S+	8	20	24-Jan-11	N/A	1:54	-27.1	-23.5	-22.4	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.125	1.288	-	8.13
31	2010-11	115 Knots Val.	IP Mod	ABC-S+	8	20	24-Jan-11	2:30	2:33	-27.2	-22.8	-21.8	IP:75	10	3 , 2.75 , 3.75	1.35 , 2 , 2.75	1 , 1.15 , 1.45	-	1.101	1.256	-	10.41
32	2010-11	Baseline (BLDT)	None	AD-49	8	20	24-Jan-11	N/A	3:44	-27.1	-22.5	-22.4	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.208	1.347	-	3.92
33	2010-11	Baseline (BLDT)	None	Max-Flight	8	20	24-Jan-11	N/A	4:23	-27.4	-24.1	-22.6	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.138	1.286	-	8.27
34	2010-11	Baseline (BLDT)	None	EG 106	8	20	24-Jan-11	N/A	4:57	-27.4	-23.3	-22.7	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.185	1.342	-	4.28

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
35	2010-11	*Type IV Fluid Val.*	*IP-*	*AD-49*	*8*	*20*	*24-Jan-11*	*5:55*	*5:59*	*-27.6*	*-23.2*	*-21.5*	IP:25	*30*	3 , 3 , 4	1.35 , 2 , 2.5	1.1 , 1.25 , 1.6	-	*1.154*	*1.313*	-	*6.35*
36	2010-11	*Baseline (BLDT)*	*None*	*2031*	*8*	*20*	*24-Jan-11*	*N/A*	*6:31*	*-27.7*	*-24.5*	*-22*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.184*	*1.323*	-	*5.63*
37	2010-11	*Type IV Fluid Val.*	*IP Mod*	*Max-Flight*	*8*	*20*	*24-Jan-11*	*7:09*	*7:12*	*-28.5*	*-24.5*	*-23.2*	IP:75	*10*	3 , 3 , 4	1.35 , 1.75 , 2.25	1 , 1.1 , 1.35	-	*1.124*	*1.266*	-	*9.70*
38	2010-11	*115 Knots Val.*	*IP Mod*	*ABC-S+*	*8*	*20*	*24-Jan-11*	*7:48*	*7:54*	*-28.3*	*-24.2*	*-23.2*	IP:75	*10*	3 , 3 , 4	1.2 , 1.5 , 2	1 , 1.15 , 1.5	-	*1.1*	*1.259*	-	*10.20*
39	2010-11	*Baseline (BLDT)*	*None*	*Max-Flight*	*8*	*20*	*24-Jan-11*	*N/A*	*22:41*	*-21.1*	*-16*	*-17.3*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.142*	*1.301*	-	*7.20*
40	2010-11	*Type IV Fluid Val.*	*IP-*	*Max-Flight*	*8*	*20*	*24-Jan-11*	*23:39*	*23:42*	*-21*	*-15.2*	*-15*	IP:25	*30*	3 , 3 , 3.5	1.2 , 2 , 2.5	1 , 1.1 , 1.35	-	*1.01*	*1.264*	-	*9.84*
41	2010-11	*Type IV Fluid Val.*	*IP Mod*	*AD-49*	*8*	*20*	*25-Jan-11*	*0:19*	*0:57*	*-20.6*	*-16.5*	*-16.1*	IP:75	*10*	3.1 , 3 , 4	1.1 , 1.5 , 2	1 , 1.1 , 1.25	-	*N/A*	*N/A*	-	-
41A	2010-11	*Type IV Fluid Val.*	*IP Mod*	*AD-49*	*8*	*20*	*25-Jan-11*	*0:54*	*0:57*	*-20.6*	*-15.4*	*-16.2*	IP:75	*10*	3 , 3.1 , 4	1.1 , 2 , 2.75	1 , 1.2 , 1.35	-	*1.159*	*1.323*	-	*5.63*
42	2010-11	*Baseline (BLDT)*	*None*	*AD-49*	*8*	*20*	*25-Jan-11*	*N/A*	*1:25*	*-20.5*	*-15.7*	*-16.3*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.186*	*1.352*	-	*3.57*
43	2010-11	*Baseline (BLDT)*	*None*	*EG 106*	*8*	*20*	*25-Jan-11*	*N/A*	*2:07*	*-20.2*	*-15*	*-16*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.204*	*1.359*	-	*3.07*
44	2010-11	*IP Expansion*	*IP- / SN*	*EG 106*	*8*	*20*	*25-Jan-11*	*2:50*	*3:00*	*-19.8*	*-13.2*	*-15.4*	IP:25 , SN:25	*10*	2.25 , 2 , 3.5	1.15 , 1.35 , 1.1	1 , 1.1 , 1	-	*1.214*	*1.362*	-	*2.85*
45	2010-11	*IP Expansion*	*IP- / SN-*	*EG 106*	*8*	*20*	*25-Jan-11*	*3:47*	*3:54*	*-19.4*	*-12.9*	*-15.7*	IP:25 , SN:10	*15*	2.25 , 2 , 3	1 , 1.1 , 1.25	1 , 1 , 1	-	*1.228*	*1.369*	-	*2.35*
46	2010-11	*IP Expansion*	*IP- / SN-*	*Launch*	*8*	*20*	*25-Jan-11*	*4:26*	*4:32*	*-19.1*	*-13.5*	*-13.8*	IP:25 , SN:10	*5*	1.75 , 1.75 , 3	1.25 , 1.6 , 2.25	1 , 1 , 1.15	-	*1.144*	*1.303*	-	*7.06*

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
47	2010-11	IP Expansion / CL Max	IP- / SN	Launch	16	20	25-Jan-11	5:02	5:10	-19	-13.3	-14.9	IP:25, SN:25	5	2.25 , 2 , 3.5	1.3 , 1.75 , 2.25	1 , 1.1 , 1.15	-	1.139	1.287	-	8.20
48	2010-11	Baseline (BLDT) / CL MAX	None	Launch	14	20	25-Jan-11	N/A	5:52	-18.7	-13.1	-14.4	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.206	1.345	-	4.07
49	2010-11	Baseline (BLDT)	None	2031	8	20	25-Jan-11	N/A	6:20	-18.7	-14.1	-16	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.186	1.352	-	3.57
50	2010-11	Baseline (BLDT)	None	2031	8	20	25-Jan-11	N/A	6:41	-18.5	-13.3	18.9	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.199	1.363	-	2.78
51	2010-11	Type IV Fluid Val.	IP-	EG 106	8	20	25-Jan-11	23:28	23:31	-16.2	-11.1	-12.9	IP:25	30	2.2 , 2 , 2.8	1 , 1.2 , 1.3	1 , 1 , 1.1	-	1.219	1.379	-	1.64
52	2010-11	Baseline (BLDT)	None	EG 106	8	20	25-Jan-11	N/A	0:01	-15.8	-13.4	-12.6	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.216	1.363	-	2.78
53	2010-11	Type IV Fluid Val.	IP-	ABC-S+	8	20	26-Jan-11	1:01	1:04	-15.6	-12.4	-12.8	IP:25	30	2.5 , 2.5 , 3.2	1.1 , 2 , 2.5	1 , 1.1 , 1.2	-	1.137	1.277	-	8.92
54	2010-11	Baseline (BLDT)	None	ABC-S+	8	20	26-Jan-11	N/A	1:33	-15.4	-12.1	-13.3	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.153	1.321	-	5.78
55	2010-11	Baseline (BLDT)	None	AD-49	8	20	26-Jan-11	N/A	2:04	-15	-11.4	-10.8	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.207	1.366	-	2.57
56	2010-11	Type IV Fluid Val.	IP- / SN-	AD-49	8	20	26-Jan-11	2:46	2:51	-14.6	-9.6	N/A	IP:25, SN:10	15	3 , 2.8 , 4	1.5 , 2 , 2.5	1.1 , 1.7 , 1.9	-	1.149	1.307	-	6.78
57	2010-11	Baseline (BLDT)	None	Max-Flight	8	20	26-Jan-11	N/A	3:25	-14.5	-9.9	-11	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.152	1.306	-	6.85
58	2010-11	Type IV Fluid Val.	IP- / SN-	Max-Flight	8	20	26-Jan-11	4:10	4:14	-13.7	-11.2	-10.9	IP:25, SN:10	15	2.3 , 2.3 , 3.2	1.3 , 1.7 , 2.2	1 , 1 , 1.2	-	1.148	1.295	-	7.63
59	2010-11	115 Knots Val.	IP Mod	Max-Flight	8	20	26-Jan-11	5:00	5:05	-13.7	-10.9	-12.5	IP:75	10	2.5 , 2.5 , 2.9	1.6 , 1.7 , 2.25	1 , 1 , 1	-	1.15	1.302	-	7.13

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
59A	2010-11	115 Knots Val.	IP Mod	Max-Flight	8	20	26-Jan-11	5:47	5:52	-13.9	-9.4	-12.4	IP:75	10	2.5 , 2.5 , 3	1.2 , 1.3 , 1.6	1 , 1 , 1.1	-	1.181	1.345	-	4.07
60	2010-11	Baseline (BLDT)	None	Launch	8	20	26-Jan-11	N/A	22:46	-7.4	-4.2	-4.2	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.168	1.336	-	4.71
61	2010-11	Baseline (BLDT)	None	Launch	8	20	26-Jan-11	N/A	23:24	-7.3	-3.5	-4.6	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.181	1.339	-	4.49
62	2010-11	Baseline (BLDT)	None	Launch	8	20	27-Jan-11	N/A	1:03	-7.4	-4.9	-4.3	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.191	1.35	-	5.06
63	2010-11	Baseline (BLDT)	None	Launch	8	20	27-Jan-11	N/A	1:32	-7.3	-4.5	-4.2	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.193	1.346	-	5.34
64	2010-11	Roughness	ZR/IP	Dry	20	20	27-Jan-11	2:34	2:49	-7	-5.1	0.3	IP:10 , ZR:25	10	5 , 5 , 5	5 , 5 , 5	4.8 , 4.8 , 4.8	-	1.302	1.348	-	5.20
64A	2010-11	Roughness	ZR/IP	Dry	20	20	27-Jan-11	3:36	3:49 3:58	-6.6	-5.6	-0.9	IP:10 ,ZR:25	10	5 , 5 , 5	5 , 5 , 5	5 , 5 , 5	-	1.155	1.298	-	8.72
65	2010-11	Dry CL MAX	None	Dry	23	20	27-Jan-11	N/A	4:39	-6.1	-3.1	-2.8	-	-	-, -, -	-, -, -	-, -, -	-	1.27	1.418	-	0.28
66	2010-11	Baseline (BLDT)	None	Launch	23	23	27-Jan-11	N/A	5:10	-6.7	-4.3	-4.7	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.19	1.336	-	6.05
67	2010-11	Baseline (BLDT)	None	Launch	20	20	27-Jan-11	N/A	5:48	-6.9	-3.7	-5.1	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.182	1.346	-	5.34
68	2010-11	Baseline (BLDT)	None	AD-49	17	20	27-Jan-11	N/A	23:12	-5.7	-1.8	-1	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.219	1.37	-	3.66
69	2010-11	Type IV Fluid Val.	IP Mod	AD-49	18	20	27-Jan-11	0:20	0:25	-5.6	-3.6	-8.2	IP:75	25	3.3 , 2.8 , 3.7	1.2 , 1.6 , 1.6	1 , 1.4 , 1.2	-	1.195	1.362	-	4.22
70	2010-11	Type IV Fluid Val.	IP Mod	AD-49	18	20	28-Jan-11	1:13	1:17	-5.8	-4.2	-7.8	IP:75	15	2.3 , 2.5 , 3	1.2 , 1.6 , 1.6	1 , 1.1 , 1	-	1.208	1.366	-	3.94

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
71	2010-11	*Baseline (BLDT)*	*None*	*Max-Flight*	*18*	*20*	*28-Jan-11*	*N/A*	*1:57*	*-6*	*-3.7*	*-2.3*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.172*	*1.332*	-	*6.33*
72	2010-11	*Type IV Fluid Val.*	*IP Mod*	*Max-Flight*	*18*	*20*	*28-Jan-11*	*2:46*	*2:50*	*-6.9*	*-3.2*	*-6.5*	IP:75	*15*	2.4 , 2.4 , 2.8	1 , 1.5 , 1.6	1 , 1 , 1	-	*1.178*	*1.33*	-	*6.47*
73	2010-11	*Type IV Fluid Val.*	*IP- / SN*	*Max-Flight*	*18*	*20*	*28-Jan-11*	*3:38*	*3:44*	*-7.7*	*-4.2*	*N/A*	IP:25 , SN:25	*10*	2.7 , 2.3 , 3.1	1 , 1.6 , 1.7	1 , 1 , 1	-	*1.177*	*1.33*	-	*6.47*
74	2010-11	*Type IV Fluid Val.*	*IP- / SN-*	*Max-Flight*	*18*	*20*	*28-Jan-11*	*4:55*	*5:04*	*-8.4*	*-4.8*	*-6.8*	IP:25 , SN:10	*25*	2.5 , 2.3 , 3	1 , 1.5 , 1.6	1 , 1 , 1	-	*1.181*	*1.326*	-	*6.75*
75	2010-11	*Baseline (BLDT)*	*None*	*Max-Flight*	*8*	*20*	*28-Jan-11*	*N/A*	*5:42*	*-8.9*	*-5.8*	*-4.2*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.163*	*1.316*	-	*7.45*
76	2010-11	*Baseline (BLDT)*	*None*	*Max-Flight*	*18*	*20*	*28-Jan-11*	*N/A*	*6:12*	*-8.8*	*-5.5*	*-3.4*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.171*	*1.328*	-	*6.61*
77	2010-11	*Baseline (BLDT)*	*None*	*EG 106*	*16.5*	*20*	*30-Jan-11*	*N/A*	*22:48*	*-15.1*	*-11.8*	*-9.6*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.228*	*1.385*	-	*2.60*
78	2010-11	*IP Expansion*	*IP- / SN-*	*EG 106*	*8*	*20*	*30-Jan-11*	*23:35*	*23:45*	*-16.3*	*-13.8*	*-14.2*	IP:25 , SN:10	*25*	2.7 , 2.2 , 4	1 , 1.6 , 1.8	1 , 1 , 1.2	-	*1.247*	*1.384*	-	*2.67*
79	2010-11	*IP Expansion*	*IP- / SN*	*EG 106*	*8*	*20*	*31-Jan-11*	*0:32*	*0:40*	*-17.3*	*-15.1*	*-12.9*	IP:25 , SN:25	*15*	2.8 , 2.6 , 4	1.1 , 1.4 , 1.8	1 , 1 , 1.2	-	*1.223*	*1.379*	-	*3.02*
80	2010-11	*Baseline (BLDT)*	*None*	*ABC-S+*	*14.5*	*20*	*31-Jan-11*	*N/A*	*1:18*	*-18*	*-15.1*	*-12.3*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.167*	*1.323*	-	*6.96*
81	2010-11	*Baseline (BLDT)*	*None*	*ABC-S+*	*8*	*20*	*31-Jan-11*	*N/A*	*1:48*	*-18*	*-14.7*	*-12.4*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.171*	*1.321*	-	*7.10*
82	2010-11	*IP Expansion*	*IP- / SN-*	*ABC-S+*	*8*	*20*	*31-Jan-11*	*2:35*	*2:46*	*-18.7*	*-16*	*-13.8*	IP:25 , SN:10	*15*	2.8 , 2.5 , 3.7	1.3 , 1.8 , 2.7	1 , 1.1 , 1.5	-	*1.128*	*1.303*	-	*8.37*
83	2010-11	*IP Expansion*	*IP- / SN*	*ABC-S+*	*8*	*20*	*31-Jan-11*	*3:32*	*3:35*	*-19.6*	*-15.2*	*-13.3*	IP:25 , SN:25	*10*	3 , 2.5 , 4	1.4 , 1.8 , 2.6	1.1 , 1.2 , 1.9	-	*1.12*	*1.283*	-	*9.77*

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
84	2010-11	*IP Expansion*	*IP- / SN-*	*Launch*	*8*	*20*	*31-Jan-11*	*4:20*	*4:26*	*-20.3*	*-17.4*	*-15.1*	IP:25, SN:10	*10*	3 , 2.8 , 3.9	1.2 , 1.8 , 2.5	1 , 1.2 , 1.7	-	*1.141*	*1.303*	-	*8.37*
85	2010-11	*IP Expansion*	*IP- / SN*	*Launch*	*8*	*20*	*31-Jan-11*	*5:07*	*5:15*	*-20.7*	*-17.4*	*-15.3*	IP:25, SN:25	*5*	2.6 , 2.5 , 3.5	1.1 , 1.7 , 2.3	1 , 1.1 , 1.6	-	*1.145*	*1.307*	-	*8.09*
86	2010-11	*Baseline (BLDT)*	*None*	*2031*	*8*	*20*	*31-Jan-11*	*N/A*	*5:39*	*-20.7*	*-18*	*-14.7*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.169*	*1.335*	-	*6.12*
86A	2010-11	*Baseline (BLDT)*	*None*	*2031*	*8*	*20*	*31-Jan-11*	*N/A*	*6:03*	*-21.1*	*-17.9*	*-14.8*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.169*	*1.333*	-	*6.26*
87	2010-11	*Heavy Snow (HHS)*	*S*	*ABC-S+*	*8*	*20*	*31-Jan-11*	*0:00*	*0:03*	*-16.9*	*-11.1*	*-11*	SN:25	*60*	3.8 , 3.3 , 4	1.9 , 2.2 , 3.2	1.3 , 2.2 , 2.7	-	*1.099*	*1.252*	-	*11.95*
88	2010-11	*Heavy Snow (HHS)*	*S++*	*ABC-S+*	*8*	*20*	*1-Feb-11*	*1:05*	*1:07*	*-17.2*	*-11.8*	*-14.3*	SN:50	*30*	3.8 , 3.2 , 4	1.9 , 2.2 , 2.9	1.3 , 2 , 2.4	-	*1.065*	*1.23*	-	*13.50*
89	2010-11	*Heavy Snow (HHS)*	*S++*	*ABC-S+*	*8*	*20*	*1-Feb-11*	*1:55*	*1:59*	*-17.4*	*-13.4*	*-13.4*	SN:100	*15*	3.8 , 3.4 , 4	1.9 , 2.6 , 3.3	1.3 , 1.8 , 2.7	-	*1.038*	*1.2*	-	*15.61*
90	2010-11	*Multiple Fluids*	*None*	*EG106* *ABC-S+ 09* *ABC-S+ 10* *Max-Flight*	*8*	*20*	*1-Feb-11*	*N/A*	*2:56*	*-17.2*	*-11.9*	*-12.3*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.177*	*1.33*	-	*6.47*
91	2010-11	*Multiple Fluids*	*None*	*Octaflo* *Launch* *2031* *AD-49*	*8*	*20*	*1-Feb-11*	*N/A*	*3:29*	*-17.5*	*-14.8*		-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.187*	*1.346*	-	*5.34*
92	2010-11	*CL MAX/ IP VAL*	*IP Mod*	*ABC-S+*		*20*	*1-Feb-11*	*4:18*	*4:22*	*-17.3*	*-13.6*	*-13.1*	IP:75	*10*	2.5 , 2.6 , 3.4	1.2 , 1.8 , 2.6	1 , 1 , 1	-	*1.083*	*1.24*	-	*12.80*
92A	2010-11	*IP Val*	*IP Mod*	*ABC-S+*	*8*	*20*	*1-Feb-11*	*5:04*	*5:08*	*-17.1*	*-14.2*	*-14*	IP:75	*10*	2.8 , 2.5 , 3.3	1.2 , 2 , 2.7	1 , 1.2 , 1.5	-	*1.081*	*1.232*	-	*13.36*

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
93	2010-11	*CL MAX/ IP VAL*	*IP-*	*ABC-S+*	*18*	*20*	*1-Feb-11*	*6:10*	*6:13*	*-16.6*	*-12*	*-12.8*	IP:25	*30*	2.6 , 1.8 , 3	1.2 , 1.8 , 1	1 , 1 , 1.1	-	*1.11*	*1.282*	-	*9.85*
94	2010-11	*Baseline (BLDT)*	*None*	*EG106 Old 09-10*	*18*	*20*	*1-Feb-11*	*N/A*	*22:50*	*-14.4*	*-7.8*	*-7.2*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.227*	*1.395*	-	*1.90*
95	2010-11	*Baseline (BLDT)*	*None*	*EG 106*	*18*	*20*	*1-Feb-11*	*N/A*	*23:38*	*-14.4*	*-10.2*	*-7.4*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.22*	*1.37*	-	*3.66*
95A	2010-11	*Baseline (BLDT)*	*None*	*EG 106*	*18*	*20*	*2-Feb-11*	*N/A*	*0:24*	*-15.2*	*-10.4*	*-7.6*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.215*	*1.386*	-	*2.53*
96	2010-11	*Baseline (BLDT)*	*None*	*ABC-S+ Old 09-10*	*18*	*20*	*2-Feb-11*	*N/A*	*0:59*	*-14.6*	*-11.2*	*-9.1*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.198*	*1.346*	-	*5.34*
97	2010-11	*Baseline (BLDT)*	*None*	*ABC-S+*	*18*	*20*	*2-Feb-11*	*N/A*	*1:31*	*-14.7*	*-11.9*	*-10.4*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.184*	*1.338*	-	*5.91*
98	2010-11	*Inadequate Application/ CL MAX*	*None*	*ABC-S+*	*18*	*20*	*2-Feb-11*	*N/A*	*2:03*	*-14.8*	*-10.6*	*-7.6*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.191*	*1.351*	-	*4.99*
99	2010-11	*LE Heater (Clean LE)*	*None*	*ABC-S+*	*18*	*20*	*2-Feb-11*	*N/A*	*2:47*	*-14.4*	*-9.1*	*-9.5*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.198*	*1.349*	-	*5.13*
100	2010-11	*Dry Wing*	*None*	*Dry*	*23*	*20*	*2-Feb-11*	*N/A*	*3:14*	*-13.9*	*-10.1*	*N/A*	-	-	-, -, -	-, -, -	-, -, -	-	*1.284*	*1.416*	-	*0.42*
101	2010-11	*SN w/ No Fluid*	*None*	*Dry - Cold Wing*	*18*	*20*	*2-Feb-11*	*3:51*	*4:00*	*-13.5*	*-6.8*	*-6.4*	SN:200	*5*	4 , 4 , 4	4 , 3.7 , 4	4 , 3.7 , 4	-	*1.043*	*1.197*	-	*15.82*
102	2010-11	*Type IV Fluid Val.*	*IP- / ZR-*	*AD-49*	*8*	*20*	*2-Feb-11*	*4:56*	*5:01*	*-13.4*	*-6.2*	*-7.1*	IP:25 , ZR:25	*10*	3.2 , 2.1 , 2.8	1.1 , 1.6 , 1.6	1 , 1 , 1.1	-	*1.163*	*1.326*	-	*6.75*
103	2010-11	*Type IV Fluid Val.*	*IP- / ZR-*	*Max-Flight*	*8*	*20*	*2-Feb-11*	*5:56*	*6:03*	*-14*	*-6.5*	*-8.6*	IP:25 ,ZR:25	*10*	2.5 , 2.4 , 3.1	1.1 , 1.5 , 1.8	1 , 1 , 1	-	*1.172*	*1.314*	-	*7.59*
104	2010-11	*IP Expansion*	*IP- / SN*	*Launch*	*8*	*20*	*2-Feb-11*	*22:52*	*22:59*	*-12*	*-7.5*	*-8.7*	IP:25 , SN:25	*7*	2.8 , 2.5 , 3.1	1.1 , 1.6 , 1.9	1 , 1 , 1	-	*1.181*	*1.33*	-	*6.47*

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
105	2010-11	IP Expansion	IP- / SN	ABC-S+	18	20	3-Feb-11	0:50	0:57	-13.3	-9.3	-9.6	IP:25 , SN:25	7	2.3 , 2.2 , 2.8	1.1 , 1.6 , 2	1 , 1 , 1	-	1.146	1.301	-	8.51
106	2010-11	IP Expansion	IP- / SN	AD-49	8	20	3-Feb-11	1:43	1:48	-13.8	-9.4	-9.2	IP:25 , SN:25	7	1.4 , 2.2 , 3.1	1.2 , 1.8 , 2.3	1 , 1.1 , 1.2	-	1.16	1.319	-	7.24
107	2010-11	Baseline (BLDT)	None	2031	18	20	3-Feb-11	N/A	2:19	-14.1	-11.1	-8.3	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	1.201	1.368	-	3.80
108	2010-11	Heavy Snow	S	2031 - Cold	18	20	3-Feb-11	2:58	3:02	-14.4	-11.5	-10.5	SN:12.5	10	1.7 , 1.6 , 2.3	1 , 1.2 , 1.6	1 , 1 , 1	-	1.204	1.357	-	4.57
108A	2010-11	Heavy Snow	S	2031 - Cold	18	20	3-Feb-11	3:43	3:53	-14.8	-11.5	-12.2	SN:25	15	3.5 , 1.8 , 4	1.25 , 1.5 , 2.25	1.1 , 1.1 , 1.1	-	1.176	1.331	-	6.40
109	2010-11	Heavy Snow	S++	2031 - Cold	18	20	3-Feb-11	4:31	4:37	-15.4	-11	-13.1	SN:50	7.5	3.25 , 2.75 , 3.75	1.1 , 1.75 , 2.35	1 , 1.2 , 1.1	-	1.156	1.33	-	6.47
110	2010-11	Heavy Snow	S++	2031 - Cold	18	20	3-Feb-11	5:20	5:27	-15.6	-10.3	-13.4	SN:100	7.5	3.5 , 3 , 4	1.1 , 2.25 , 2.5	1 , 1.75 , 2.6	-	1.146	1.307	-	8.09
111	2010-11	Heavy Cont.	S	2031 - Cold	18	20	3-Feb-11	6:19	6:24	-16.4	-6.3	-15.3	SN:10	5	2.5 , 2.5 , 3	1.25 , 2 , 2.25	1.1 , 1.3 , 1.1	-	1.162	1.325	-	6.82
112	2010-11	Dry Wing	None	None	23	20	7-Feb-11	N/A	12:55	0.9	2.3	N/A	-	-	-, -, -	-, -, -	-, -, -	-	1.262	1.44	-	-1.27
113	2010-11	Rain No Fluid	R	None	18	20	7-Feb-11	At Ramp	13:28	0.5	1.3	N/A	R:75	-	-, -, -	-, -, -	-, -, -	-	1.261	1.416	-	0.42
114	2010-11	IP/R/SN	IP/R/SN	Launch	8	20	7-Feb-11	14:28	14:39	0.1	1.8	-2.2	IP:25 , SN:25 , R:25	25	2.3 , 2.5 , 4	1 , 1 , 1.4	1 , 1 , 1	-	1.24	1.391	-	2.18
115	2010-11	IP Data Gap	IP- / R Mod	EG 106	8	20	7-Feb-11	15:42	15:48	0.7	1.4	1.5	IP:25 , R:75	25	2.3 , 1.3 , 1.6	1 , 1 , 1	1 , 1 , 1	-	1.252	1.416	-	0.42
116	2010-11	IP Data Gap	IP- / R Mod	ABC-S+	8	20	7-Feb-11	16:52	16:59	-0.1	3	2.9	IP:25 , R:75	25	1.2 , 1.3 , 1.3	1 , 1 , 1.1	1 , 1 , 1	-	1.234	1.388	-	2.39

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
117	2010-11	*IP Data Gap*	*IP- / R-*	*Launch*	*8*	*20*	*7-Feb-11*	*18:05*	*18:12*	*-0.6*	*2.3*	*0.2*	IP:25, R:25	*25*	1.3 , 1.3 , 1.3	1 , 1 , 1	1 , 1 , 1	-	*1.227*	*1.381*	-	*2.88*
118	2010-11	*IP/R/SN*	*IP/R/SN*	*EG 106*	*8*	*20*	*7-Feb-11*	*19:21*	*19:28*	*-0.3*	*1*	*-0.5*	IP:25, SN:25, R:25	*25*	2 , 1.3 , 3.5	1 , 1 , 1.2	1 , 1 , 1	-	*1.25*	*1.403*	-	*1.34*
119	2010-11	*Dry Wing*	*None*	*None*	*23*	*20*	*7-Feb-11*	*N/A*	*19:52*	*-1.9*	*-0.1*	*N/A*	-	-	-, -, -	-, -, -	-, -, -	-	*1.278*	*1.44*	-	*-1.27*
120	2010-11	*Dry Wing*	*None*	*None*	*23*	*20*	*8-Feb-11*	*N/A*	*12:08*	*-15*	*-13.2*	*N/A*	-	-	-, -, -	-, -, -	-, -, -	-	*1.285*	*1.433*	-	*-0.77*
121	2010-11	*Type IV Fluid Val.*	*IP-*	*Max-Flight*	*18*	*20*	*8-Feb-11*	*13:14*	*13:19*	*-14.8*	*-12.9*	*-14.1*	IP:25	*30*	2.5 , 2.5 , 3	1.2 , 1.8 , 2.3	1 , 1 , 1	-	*1.135*	*1.301*	-	*8.51*
122	2010-11	*Effect of Ramp-up Time*	*None*	*ABC-S+*	*8*	*20*	*8-Feb-11*	*N/A*	*14:00*	*-14.5*	*-12.8*	*-10.8*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.196*	*1.347*	-	*5.27*
123	2010-11	*Effect of Ramp-up Time*	*None*	*EG 106*	*8*	*20*	*8-Feb-11*	*N/A*	*14:45*	*-14.4*	*-12.5*	*-10*	-	-	1 , 1 , 1	1 , 1 , 1	1 , 1 , 1	-	*1.223*	*1.388*	-	*2.39*
124	2010-11	*Effect of Ramp-up Time*	*IP Mod*	*ABC-S+*	*18*	*20*	*8-Feb-11*	*15:32*	*15:37*	*-13.9*	*-11.3*	*-12.9*	IP:75	*10*	2.5 , 2.5 , 3.3	1 , 1.7 , 2.2	1 , 1 , 1.1	-	*1.158*	*1.318*	-	*7.31*
125	2010-11	*Heavy Cont.*	*S (Mixed In)*	*2031*	*18*	*20*	*8-Feb-11*	*N/A*	*16:22*	*-14.7*	*-11.8*	*-17.2*	-	-	4 , 4 , 4	1.4 , 2.4 , 2.5	1 , 1.5 , 1.5	-	*1.031*	*1.156*	-	*18.71*
126	2010-11	*Heavy Cont.*	*IP-/ ZR-*	*EG 106*	*18*	*20*	*8-Feb-11*	*17:52*	*17:56*	*-15.5*	*-10.1*	*-9.4*	IP:25, ZR:25	*40*	3.7 , 3 , 4.3	1.2 , 1.5 , 5	1 , 1.2 , 5	-	*1.163*	*1.319*	-	*7.24*
127	2010-11	*Heavy Cont.*	*ZR-*	*None*	*23*	*20*	*8-Feb-11*	*18:44:30*	*18:46*	*-15.7*	*-10.7*	*-6.2*	ZR:25	*Approx 5*	5 , 5 , 5	5 , 5 , 5	5 , 5 , 5	-	*1.221*	*1.381*	-	*2.88*
127A	2010-11	*Heavy Cont.*	*ZR-*	*None*	*23*	*20*	*8-Feb-11*	*19:13*	*19:15*	*-16*	*-8.8*	*-3.7*	ZR:75 (Then 35)	*Approx 12*	5 , 5 , 5	5 , 5 , 5	5 , 5 , 5	-	*1.227*	*1.406*	-	*1.13*
128	2010-11	*Type IV Fluid Val.*	*IP- / ZR-*	*AD-49*	*8*	*20*	*9-Feb-11*	*11:58*	*12:04*	*-6.2*	*-3.2*	*-3.8*	IP:25 ,ZR:25	*25*	2.5 , 2.5 , 2.7	1.1 , 1.3 , 1.5	1 , 1 , 1	-	*1.201*	*1.363*	-	*4.15*

Run #	Year	Objective	Test Condition	Fluid	Rotation Angle	Flap Angle (0°, 20°)	Date	Precip. End Time	Tunnel Start Time	OAT Before Test (°C)	Tunnel Temp. Before Test (°C)	AVG Wing Temp. Before Test (°C)	Precipitation Rate ($g/dm^2/h$)	Exposure Time (min)	Rating Before Takeoff (LE, TE, Flap)	Rating at Rotation (LE, TE, Flap)	Rating After Takeoff (LE, TE, Flap)	CL at -2° Before Rotation	Cl at 6° During Rotation	Cl at 8°	CL at 4° Following End of Rotation	% Lift Loss (8°Cl vs Dry Cl AVG = 1.7213)
129	2010-11	*Type IV Fluid Val.*	*IP-*	*AD-49*	*8*	*20*	*9-Feb-11*	*13:32*	*13:37*	*-5.7*	*-3.6*	*-5.2*	IP:25	*50*	2.8 , 2.3 , 3	1 , 1.5 , 1.7	1 , 1 , 1	-	*1.215*	*1.354*	-	*4.78*
130	2010-11	*Wing Geometry*	*None*	*AD-49*	*8*	*20*	*9-Feb-11*	*14:44*	*14:48*	*-6.1*	*-2.4*	*-3.3*	IP:25 , ZR:25	*25*	2.3 , 2.3 , 2.8	1 , 1.2 , 1.6	1 , 1 , 1	-	*1.213*	*1.357*	-	*4.57*
131	2010-11	*Type IV Fluid Val.*	*IP Mod*	*Launch*	*8*	*20*	*9-Feb-11*	*12:51*	*15:55*	*-7.5*	*-4.5*	*-8.5*	IP:75	*25*	2.8 , 3.3 , 3.9	1 , 1.5 , 2.2	1 , 1 , 1	-	*1.199*	*1.35*	-	*5.06*
132	2010-11	*Type IV Fluid Val.*	*IP Mod*	*Max-Flight*	*8*	*20*	*9-Feb-11*	*17:09*	*17:13*	*-7.4*	*-5.9*	*-8.5*	IP:75	*25*	2.8 , 3 , 3.9	1 , 1.6 , 2	1 , 1 , 1.1	-	*1.157*	*1.324*	-	*6.89*
133	2010-11	*IP/ZR/SN*	*IP/ZR/SN*	*ABC-S+*	*8*	*20*	*9-Feb-11*	*18:53:30*	*19:01*	*-8.5*	*-3.3*	*-4.4*	IP:25 , SN:25 ,ZR:25	*20*	2.7 , 2.8 , 4	1 , 1.4 , 4.3	1 , 1 , 4.3	-	*1.176*	*1.324*	-	*6.89*
134	2010-11	*IP/ZR/SN*	*IP/ZR/SN*	*ABC-S+*	*8*	*0*	*9-Feb-11*	*20:15*	*20:23*	*-8.8*	*-2.5*	*-4.6*	IP:25 , SN:25 ,ZR:25	*20*	2.3 , 2.5 , 2.7	1 , 1.6 , 1.9	1 , 1 , 1	-	*1.184*	*1.343*	-	*5.56*
135	2010-11	*IP/ZR/SN*	*IP/ZR/SN*	*EG 106*	*8*	*20*	*10-Feb-11*	*12:07:30*	*12:12*	*-10*	*-3.9*	*-8.2*	IP:25 , SN:25 ,ZR:25	*20*	2.2 , 2.3 , 4.3	1 , 1 , 5	1 , 1 , 5	-	*1.179*	*1.347*	-	*5.27*
136	2010-11	*ZR/S*	*ZR/S*	*ABC-S+*	*8*	*20*	*10-Feb-11*	*13:12:30*	*13:16*	*-10*	*-3.5*	*-4.7*	SN:25 ,ZR:25	*20*	2 , 2 , 3.6	1 , 1.6 , 3.8	1 , 1 , 5	-	*1.174*	*1.33*	-	*6.47*
137	2010-11	*Heavy Cont.*	*IP+/SN+*	*ABC-S+*	*18*	*20*	*10-Feb-11*	*14:37*	*14:47*	*-8.6*	*-3.5*	*-10.1*	IP:200 , SN:100	*30*	4.3 , 4.3 , 4.3	1.8 , 2.3 , 4.3	1 , 1.7 , 4.7	-	*0.958*	*1.113*	-	*21.73*

APPENDIX D

PHOTO SUMMARIES

List of Photos

This page intentionally left blank.

EFFECT OF SURFACE ROUGHNESS AND HEAVY CONTAMINIATION

Photo D1: Run #64 – Start of Test

Test #64
No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min
-5.1°C, 20° Rotation, 100 kts
Visual Contamination Rating (5, 5, 5)

Start of Test

Photo D2: Run #64 – Before Rotation

Test #64
No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min
-5.1°C, 20° Rotation, 100 kts
Visual Contamination Rating (5, 5, 5), 8 Lift Loss = 5.2%

Before Rotation

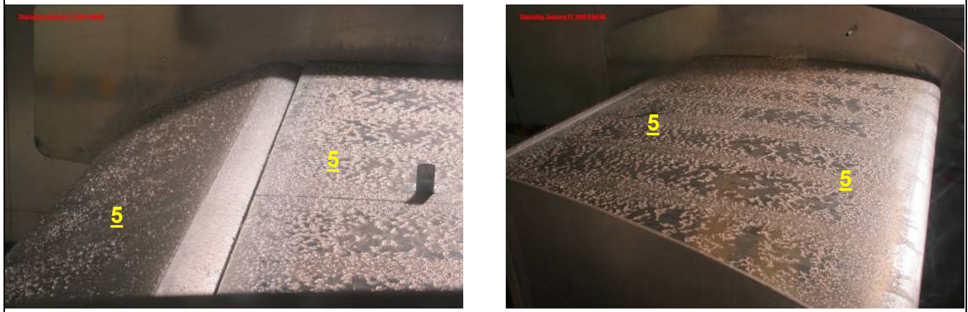


Photo D3: End of Rotation

Test #64

No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min

-5.1°C, 20° Rotation, 100 kts

Visual Contamination Rating (5, 5, 5), 8 Lift Loss = 5.2%

End of Rotation

Photo D4: Run #64 – End of Test

Test #64

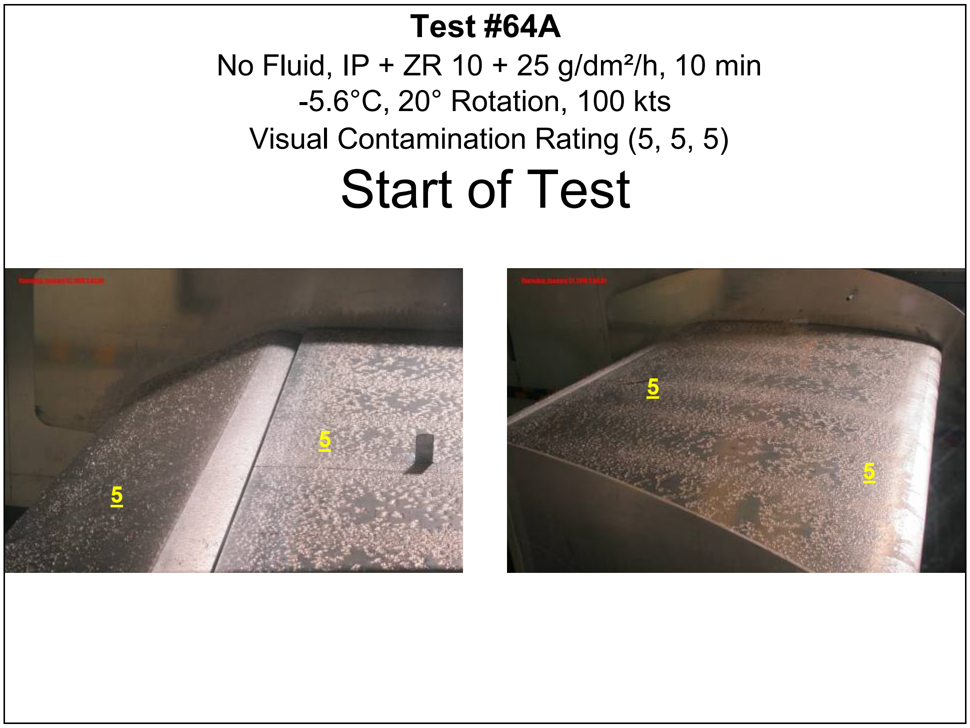
No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min

-5.1°C, 20° Rotation, 100 kts

Visual Contamination Rating (4.8, 4.8, 4.8)

End of Test

Photo D5: Run #64A – Start of Test



Test #64A

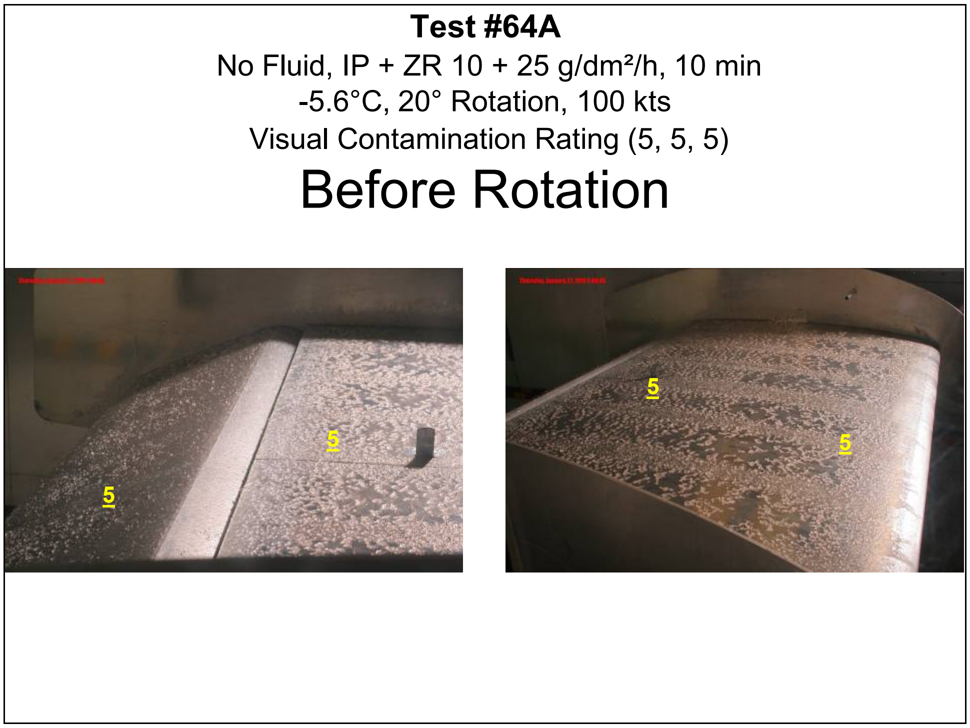
No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min

-5.6°C, 20° Rotation, 100 kts

Visual Contamination Rating (5, 5, 5)

Start of Test

Photo D6: Run #64A – Before Rotation



Test #64A

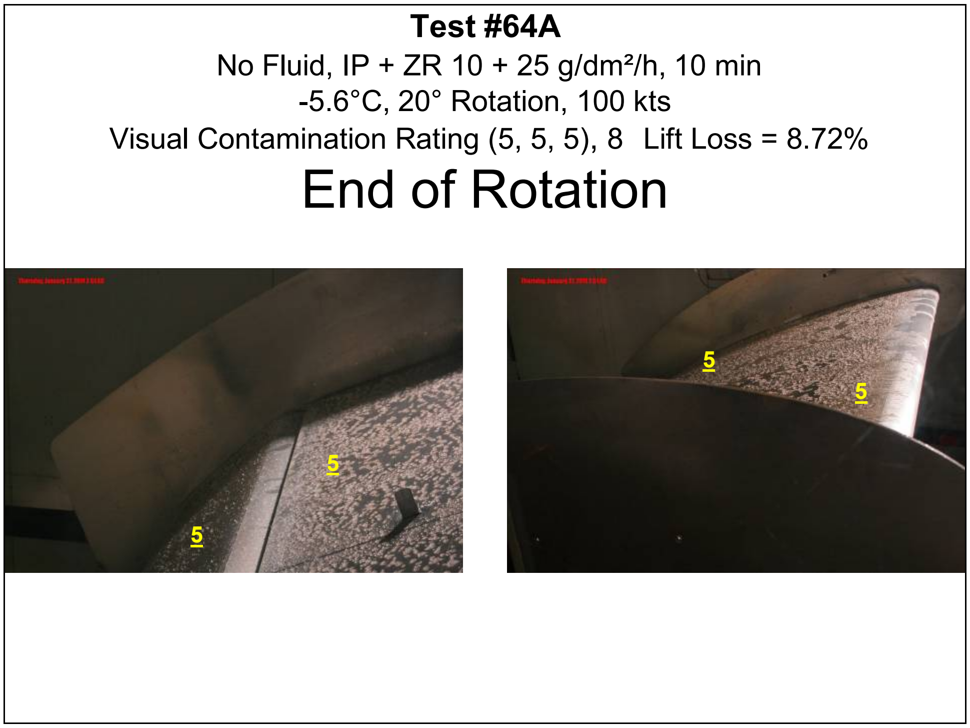
No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min

-5.6°C, 20° Rotation, 100 kts

Visual Contamination Rating (5, 5, 5)

Before Rotation

Photo D7: Run #64A – End of Rotation



Test #64A

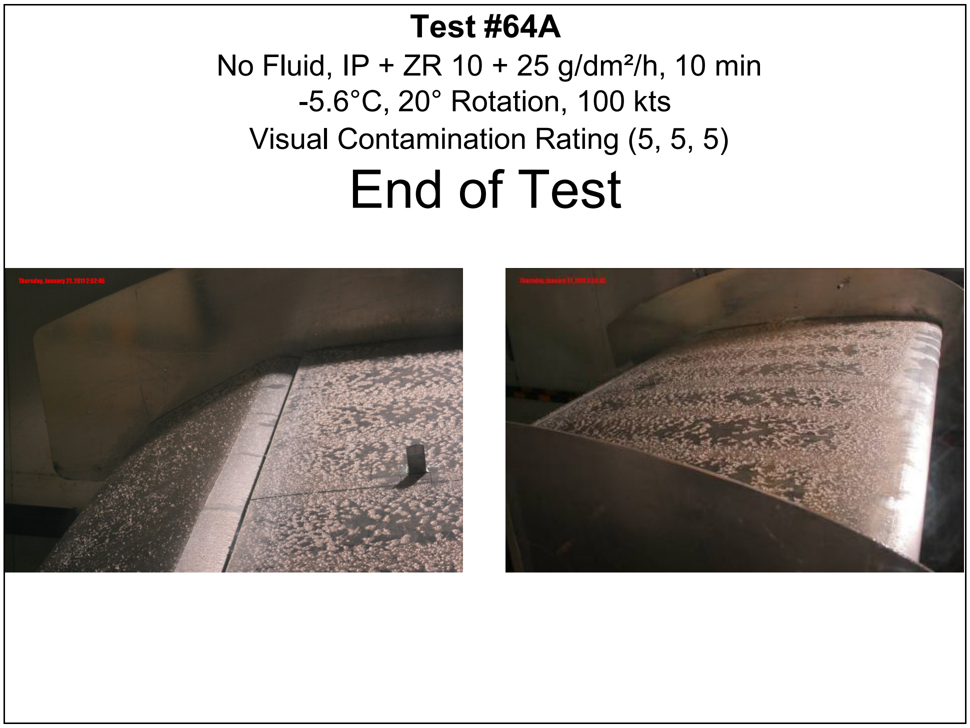
No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min

-5.6°C, 20° Rotation, 100 kts

Visual Contamination Rating (5, 5, 5), 8 Lift Loss = 8.72%

End of Rotation

Photo D8: Run #64A – End of Test



Test #64A

No Fluid, IP + ZR 10 + 25 g/dm²/h, 10 min

-5.6°C, 20° Rotation, 100 kts

Visual Contamination Rating (5, 5, 5)

End of Test

Photo D9: Run #111 – Start of Test

Test #111

2031 Cold, SN- 10 g/dm²/h, 5 min

-6.3°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (2.5, 2.5, 3)

Start of Test

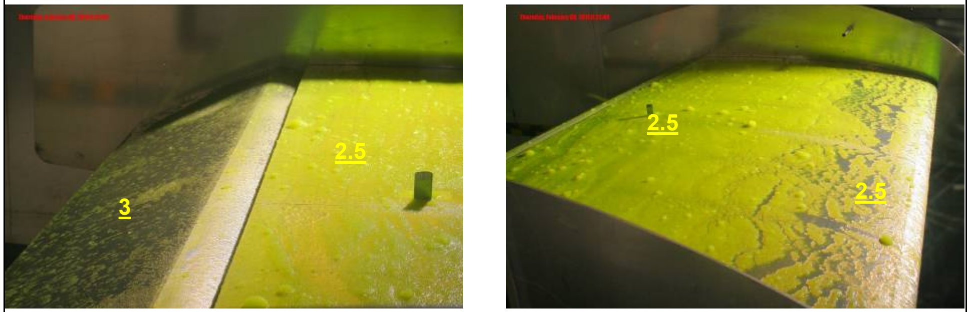


Photo D10: Run #111 – Before Rotation

Test #111

2031 Cold, SN- 10 g/dm²/h, 5 min

-6.3°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.25, 2, 2.25), 8 Lift Loss = 6.82%

Before Rotation

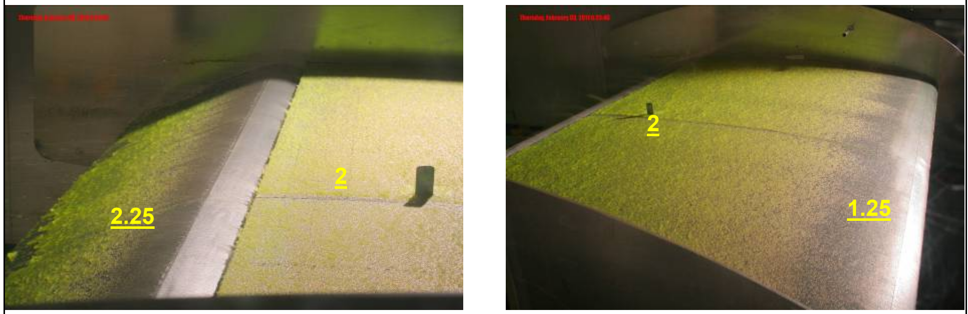
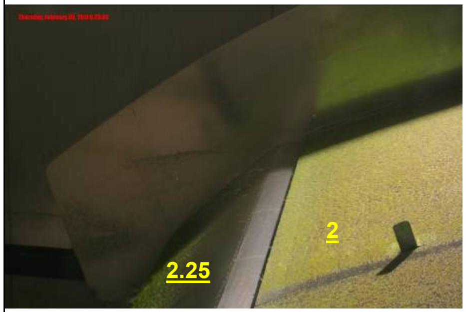


Photo D11: Run #111 – End of Rotaton

Test #111
2031 Cold, SN- 10 g/dm²/h, 5 min
-6.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1.25, 2, 2.25), 8 Lift Loss = 6.82%

End of Rotation



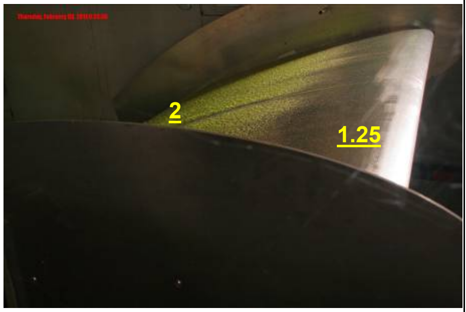
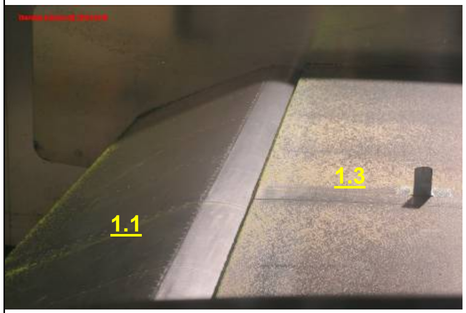


Photo D12: Run #111 – End of Test

Test #111
2031 Cold, SN- 10 g/dm²/h, 5 min
-6.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1.1, 1.3, 1.1)

End of Test



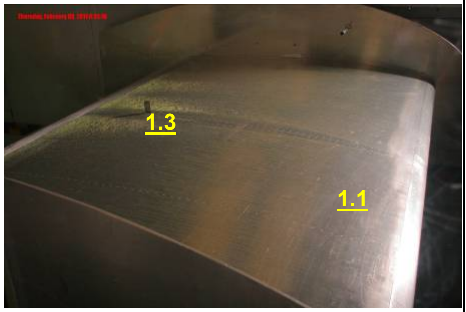
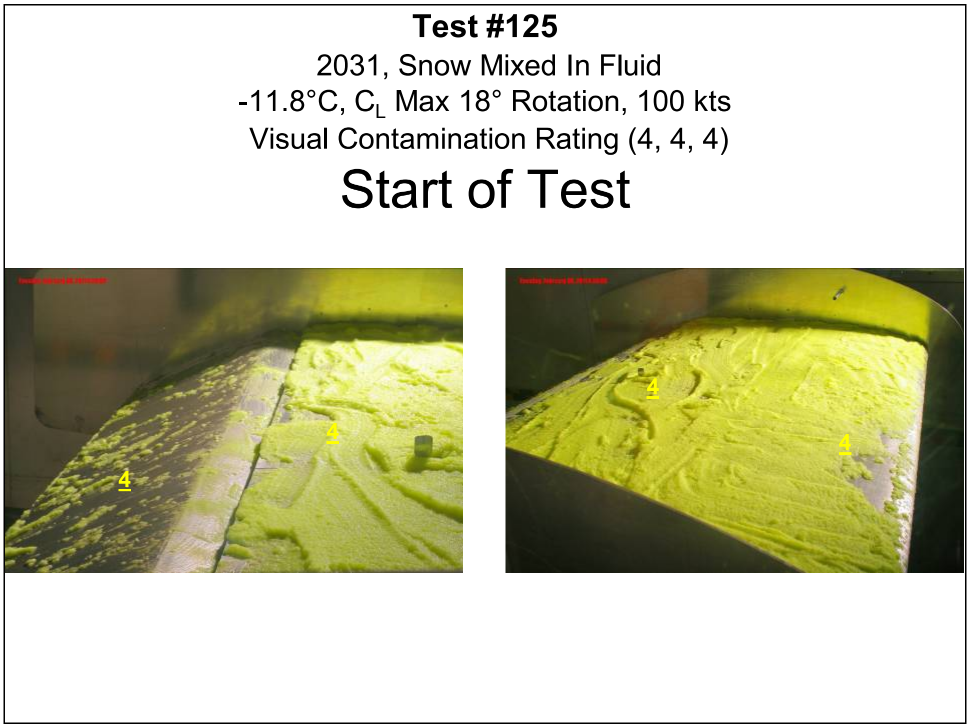


Photo D13: Run #125 – Start of Test



Test #125

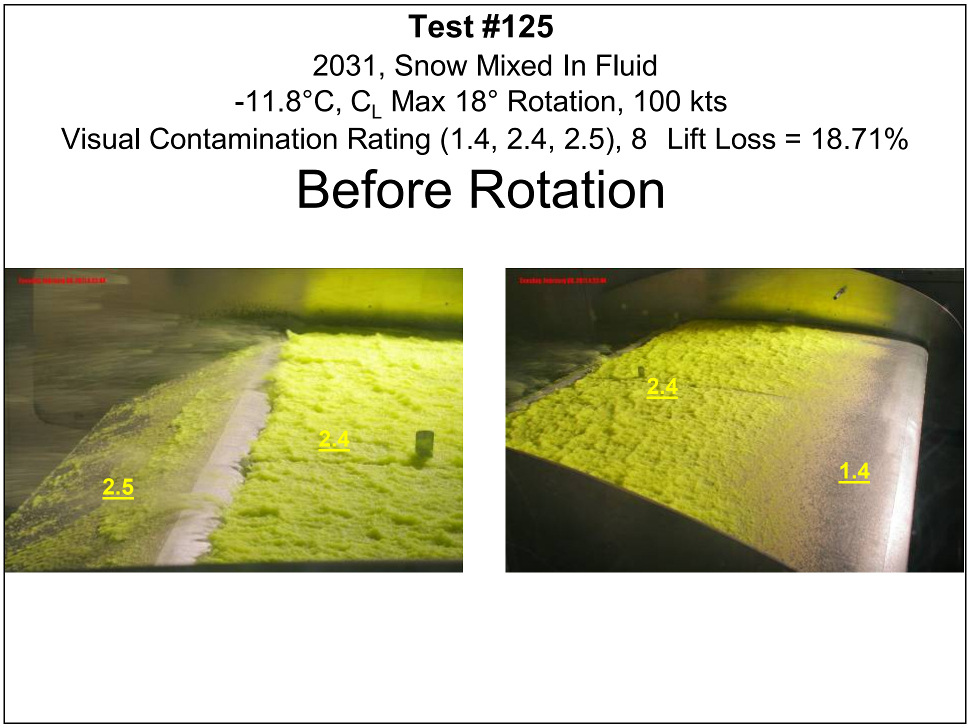
2031, Snow Mixed In Fluid

-11.8°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (4, 4, 4)

Start of Test

Photo D14: Run #125 – Before Rotation



Test #125

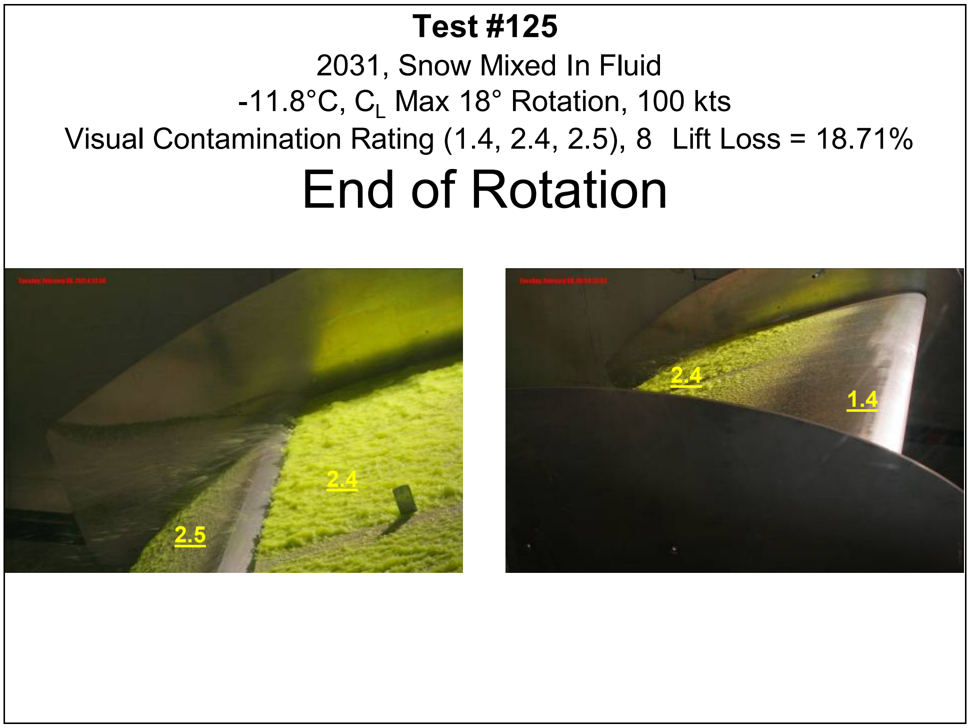
2031, Snow Mixed In Fluid

-11.8°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.4, 2.4, 2.5), 8 Lift Loss = 18.71%

Before Rotation

Photo D15: Run #125 – End of Rotation



Test #125

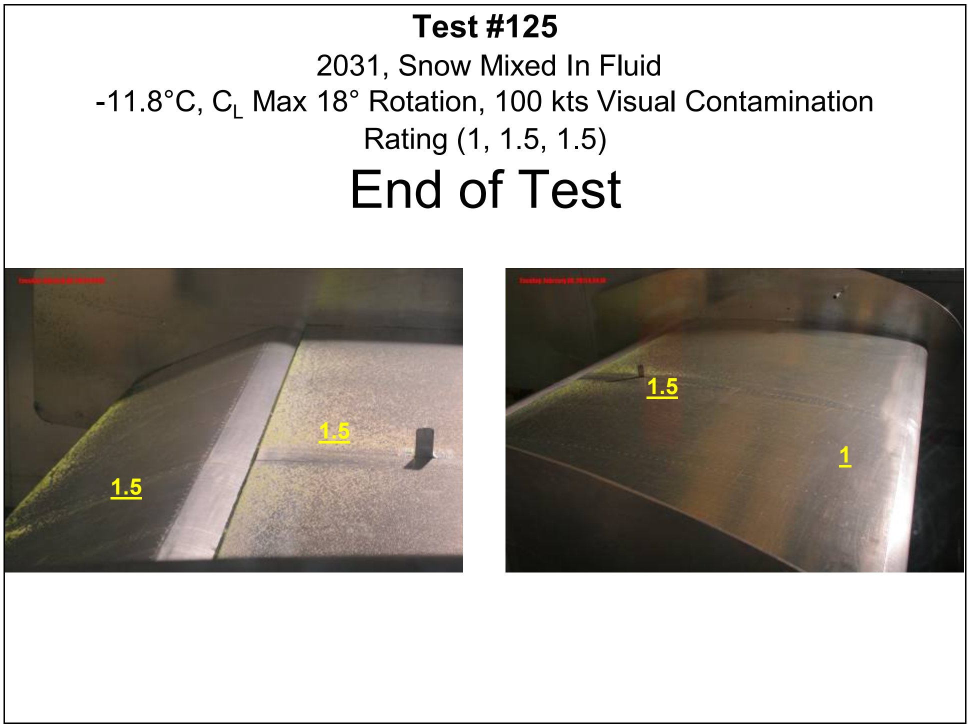
2031, Snow Mixed In Fluid

-11.8°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.4, 2.4, 2.5), 8 Lift Loss = 18.71%

End of Rotation

Photo D16: Run #125 – End of Test



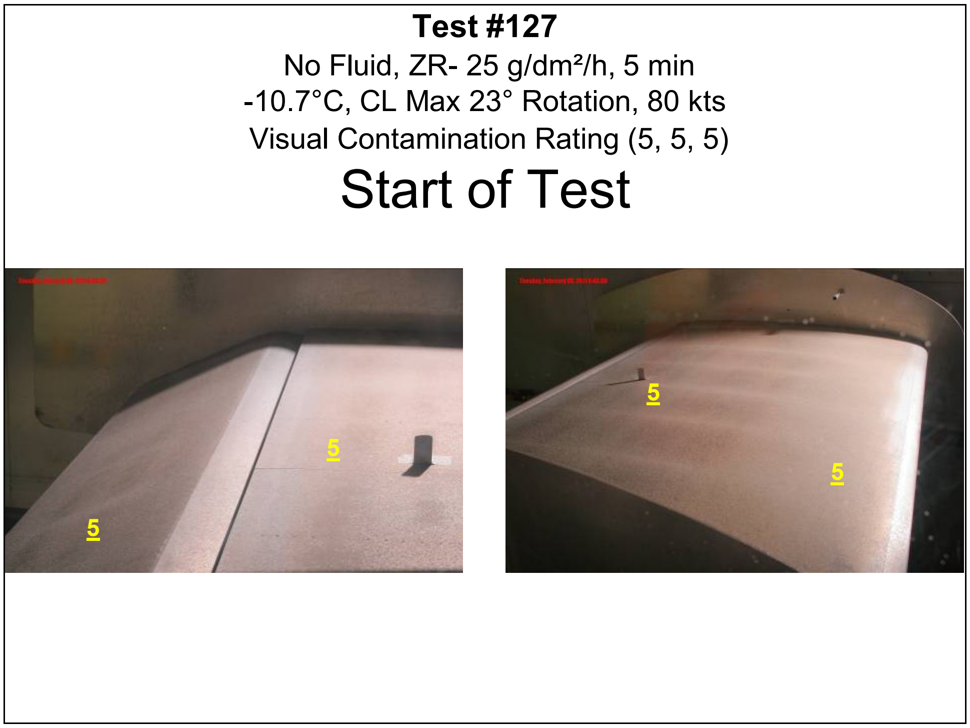
Test #125

2031, Snow Mixed In Fluid

-11.8°C, C_L Max 18° Rotation, 100 kts Visual Contamination Rating (1, 1.5, 1.5)

End of Test

Photo D17: Run #127 – Start of Test



Test #127

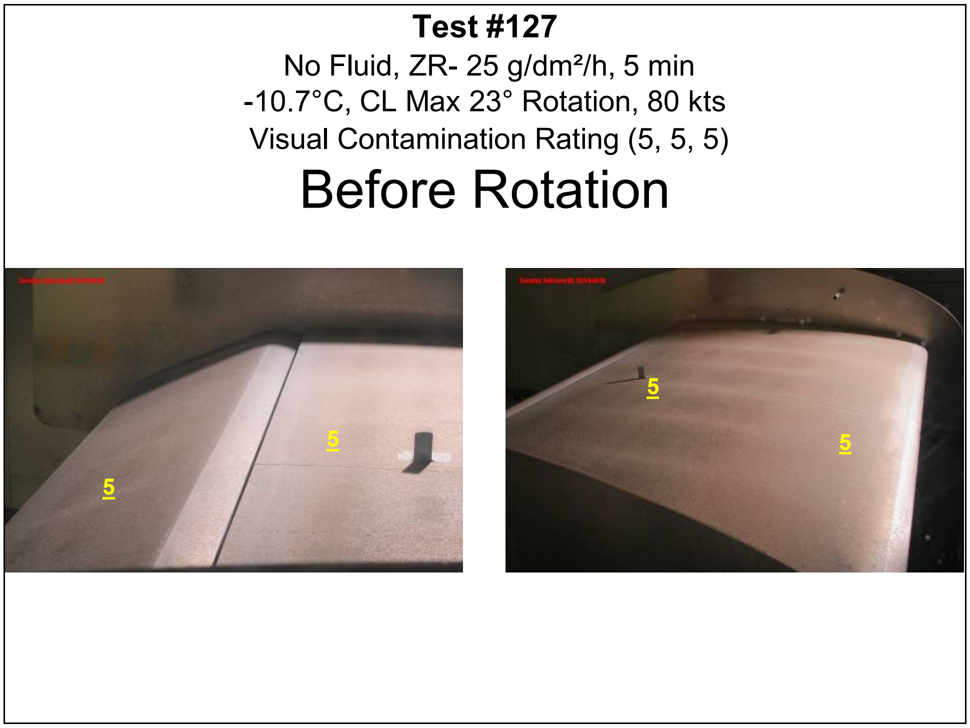
No Fluid, ZR- 25 g/dm²/h, 5 min

-10.7°C, CL Max 23° Rotation, 80 kts

Visual Contamination Rating (5, 5, 5)

Start of Test

Photo D18: Run #127 – Before Rotation



Test #127

No Fluid, ZR- 25 g/dm²/h, 5 min

-10.7°C, CL Max 23° Rotation, 80 kts

Visual Contamination Rating (5, 5, 5)

Before Rotation

Photo D19: Run #127 – End of Rotation

Test #127
No Fluid, ZR- 25 g/dm²/h, 5 min
-10.7°C, CL Max 23° Rotation, 80 kts
Visual Contamination Rating (5, 5, 5), 8 Lift Loss = 2.88%

End of Rotation

Photo D20: Run #127 – End of Test

Test #127
No Fluid, ZR- 25 g/dm²/h, 5 min
-10.7°C, CL Max 23° Rotation, 80 kts
Visual Contamination Rating (5, 5, 5)

End of Test

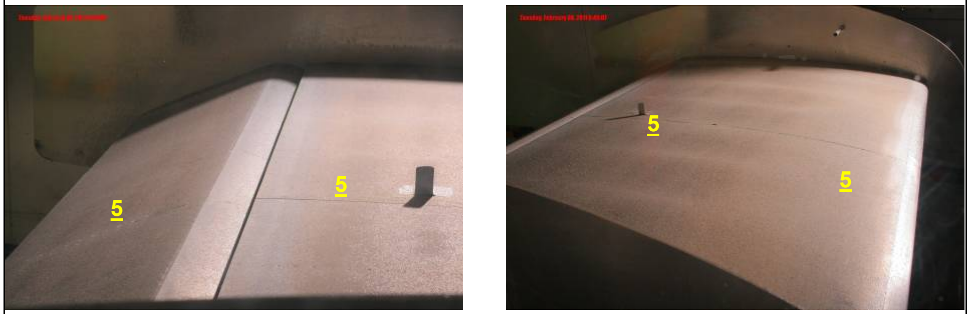


Photo D21: Run #127A – Start of Test

Test #127A

No Fluid, ZR 75 g/dm²/h, 12 min

-8.8°C, CL Max 23° Rotation, 80 kts

Visual Contamination Rating (5, 5, 5)

Start of Test

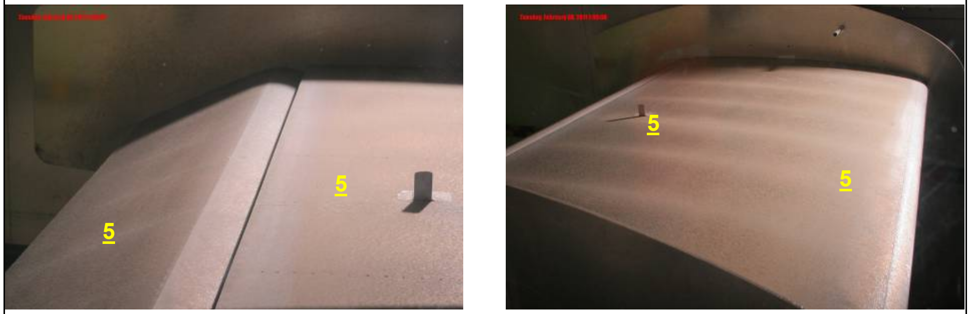


Photo D22: Run #127A – Before Rotation

Test #127A

No Fluid, ZR 75 g/dm²/h, 12 min

-8.8°C, CL Max 23° Rotation, 80 kts

Visual Contamination Rating (5, 5, 5), 8   Lift Loss = 1.13%

Before Rotation

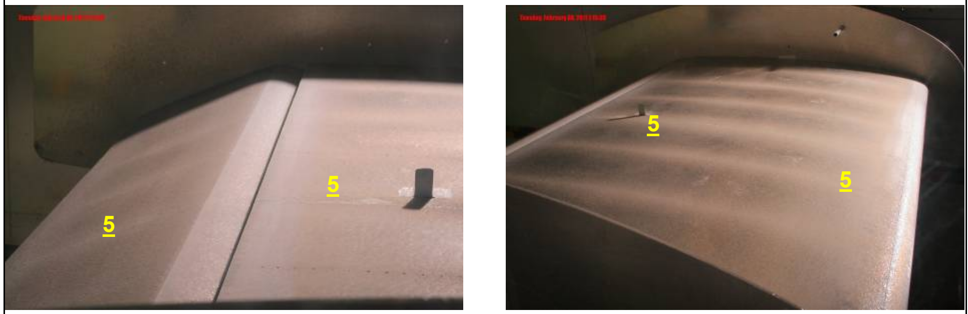


Photo D23: Run #127A – End of Rotation

Test #127A

No Fluid, ZR 75 g/dm²/h, 12 min

-8.8°C, CL Max 23° Rotation, 80 kts

Visual Contamination Rating (5, 5, 5), 8 Lift Loss = 1.13%

End of Rotation

Photo D24: Run #127A – End of Test

Test #127A

No Fluid, ZR 75 g/dm²/h, 12 min

-8.8°C, CL Max 23° Rotation, 80 kts

Visual Contamination Rating (5, 5, 5)

End of Test

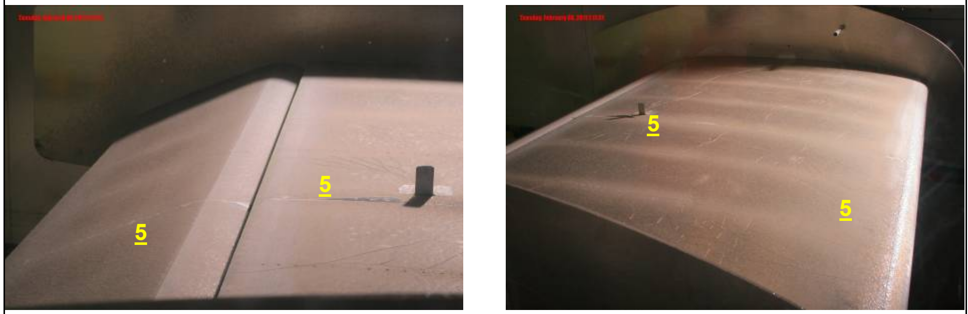


Photo D25: Run #137 – Start of Test

Test #137
ABC-S Plus, IP+ + SN+ 200 + 100 g/dm²/h, 30 min
-3.5°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (4.3, 4.3, 4.3)

Start of Test

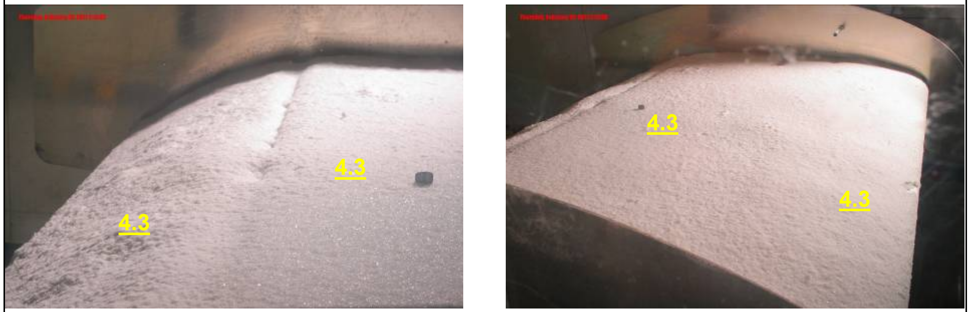


Photo D26: Run #137 – Before Rotation

Test #137
ABC-S Plus, IP+ + SN+ 200 + 100 g/dm²/h, 30 min
-3.5°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1.8, 2.3, 4.3), 8 Lift Loss = 21.73%

Before Rotation

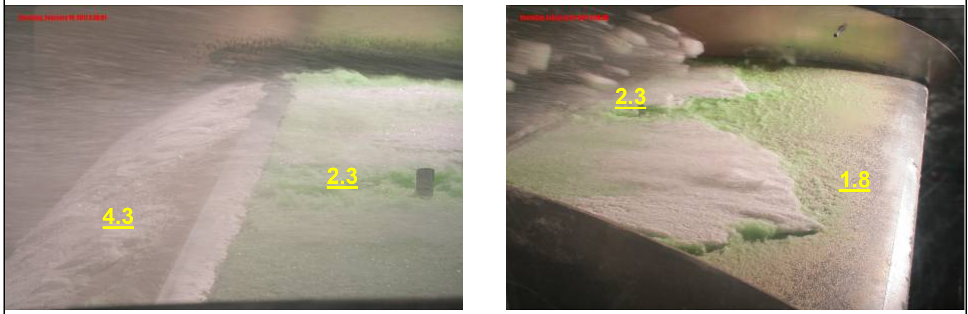


Photo D27: Run #137 – End of Rotation

Test #137

ABC-S Plus, IP+ + SN+ 200 + 100 g/dm^2/h, 30 min
-3.5°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1.8, 2.3, 4.3), 8 Lift Loss = 21.73%

End of Rotation

Photo D28: Run #137 – End of Test

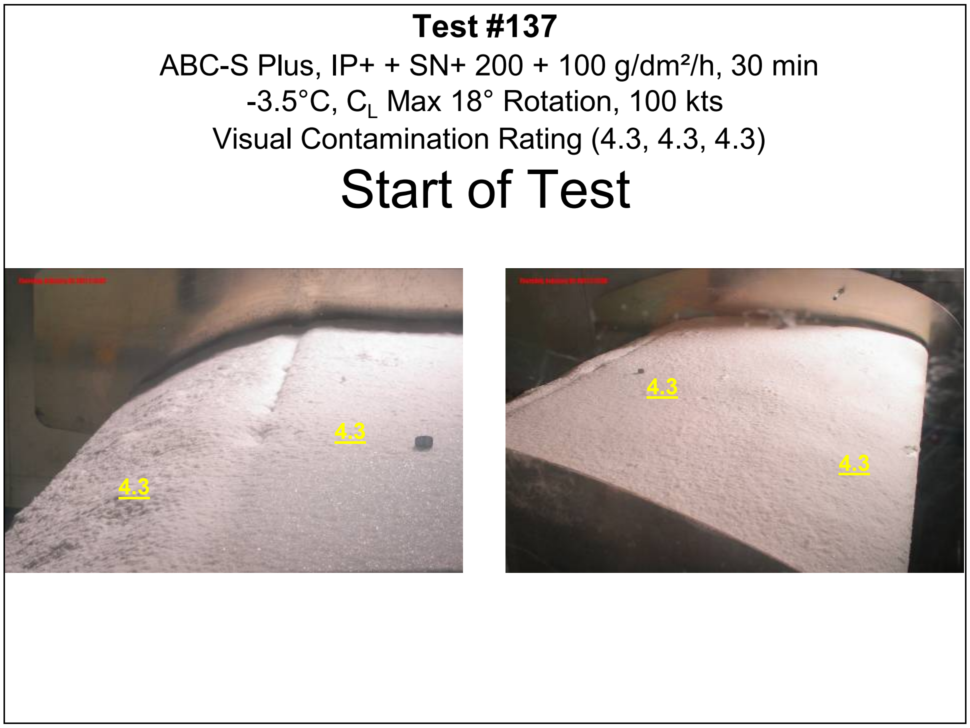
Test #137

ABC-S Plus, IP+ + SN+ 200 + 100 g/dm^2/h, 30 min
-3.5°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1, 1.7, 4.7)

End of Test

EFFECT OF A CLEAN LEADING EDGE SIMULATING LEADING EDGE HEATER DRY OUT

Photo D29: Run #99 – Start of Test



Test #137

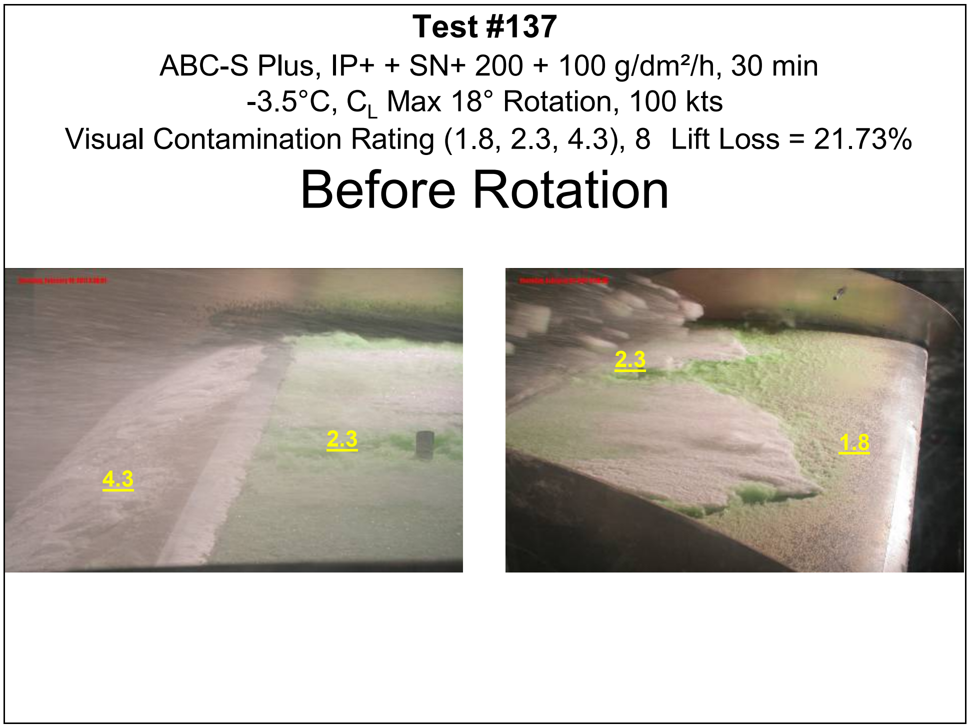
ABC-S Plus, IP+ + SN+ 200 + 100 g/dm²/h, 30 min

-3.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (4.3, 4.3, 4.3)

Start of Test

Photo D30: Run #99 – Before Rotation



Test #137

ABC-S Plus, IP+ + SN+ 200 + 100 g/dm²/h, 30 min

-3.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.8, 2.3, 4.3), 8 Lift Loss = 21.73%

Before Rotation

Photo D31: Run #99 – End of Rotation

Test #137

ABC-S Plus, IP+ + SN+ 200 + 100 g/dm²/h, 30 min

-3.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.8, 2.3, 4.3), 8 Lift Loss = 21.73%

End of Rotation

Photo D32: Run #99 – End of Test

Test #137

ABC-S Plus, IP+ + SN+ 200 + 100 g/dm²/h, 30 min

-3.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1.7, 4.7)

End of Test

EFFECTS OF APPLYING INADEQUATE AMOUNTS OF ANTI-ICING FLUID

Photo D33: Run #98 – Start of Test

Test #98

ABC-S Plus, Fluid Only

-10.6°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

Start of Test

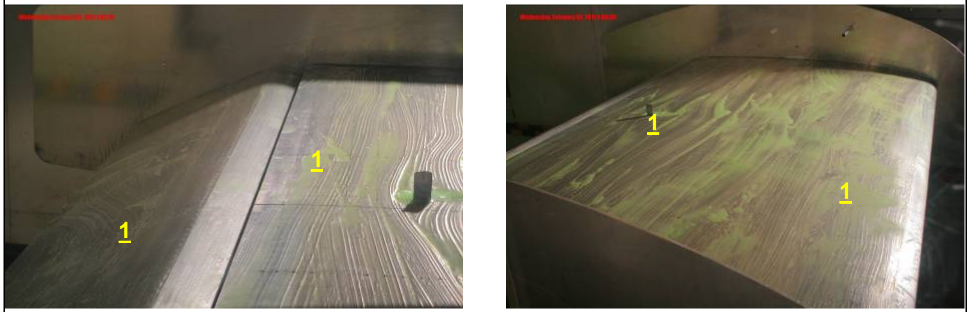


Photo D34: Run #98 – Before Rotation

Test #98

ABC-S Plus, Fluid Only

-10.6°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 4.99%

Before Rotation

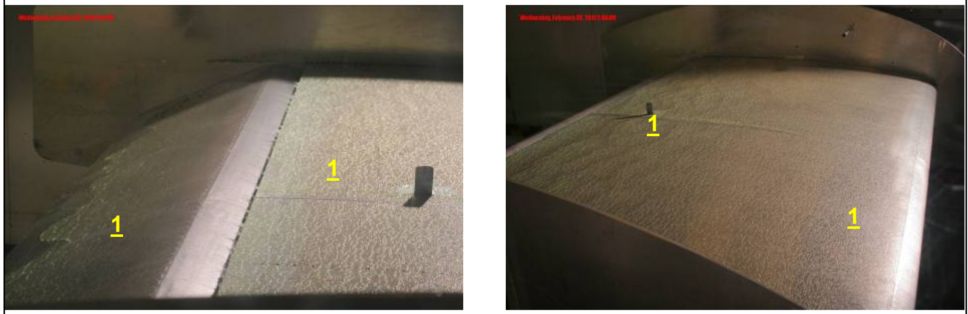
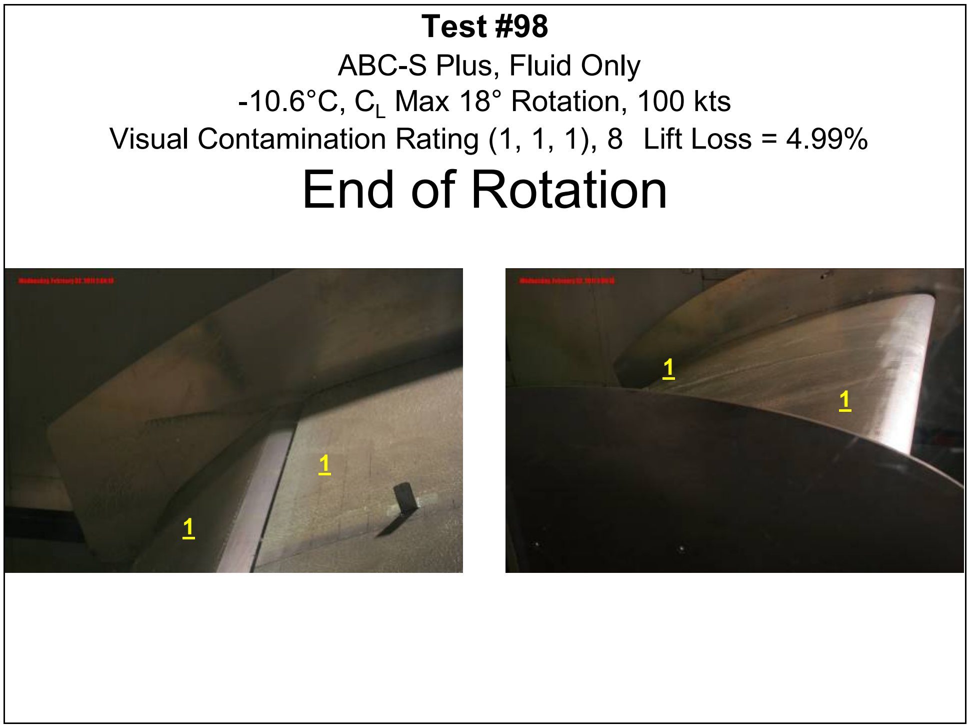


Photo D35: Run #98 – End of Rotation



Test #98

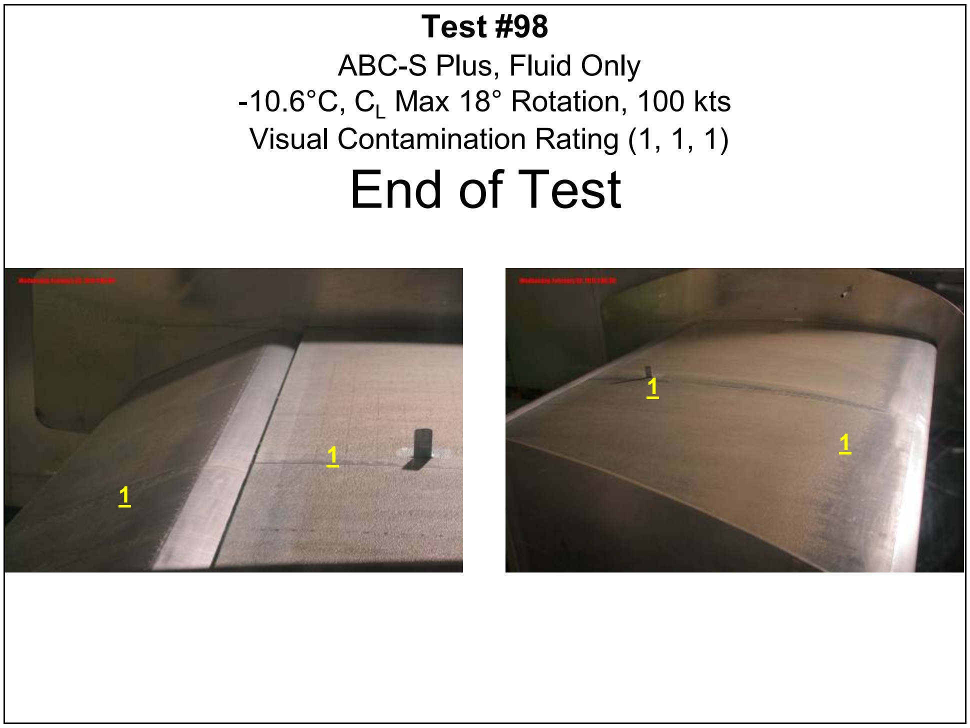
ABC-S Plus, Fluid Only

-10.6°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 4.99%

End of Rotation

Photo D36: Run #98 – End of Test



Test #98

ABC-S Plus, Fluid Only

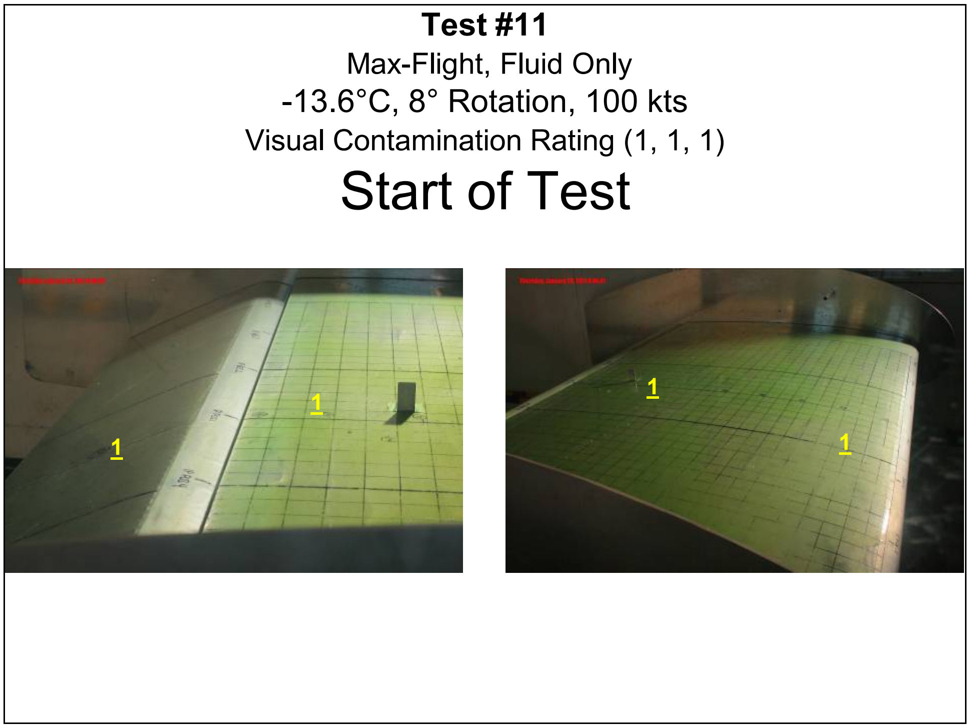
-10.6°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

End of Test

EFFECT OF RAMP-UP TIME ON FLUID FLOW OFF

Photo D37: Run #11 – Start of Test



Test #11

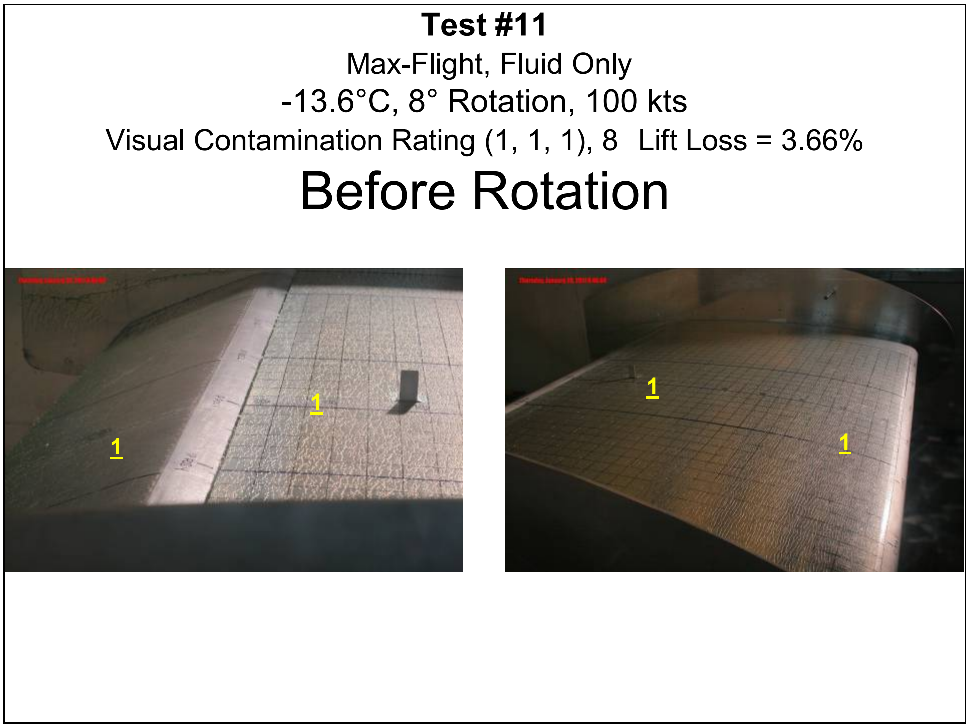
Max-Flight, Fluid Only

-13.6°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

Start of Test

Photo D38: Run #11 – Before Rotation



Test #11

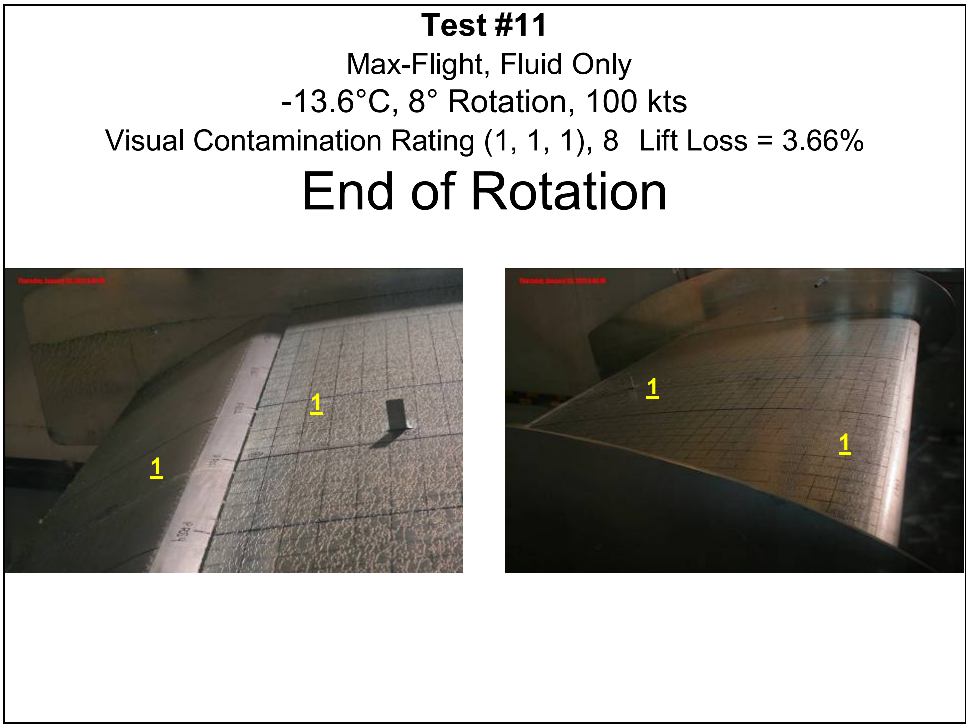
Max-Flight, Fluid Only

-13.6°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 3.66%

Before Rotation

Photo D39: Run #11 – End of Rotation



Test #11

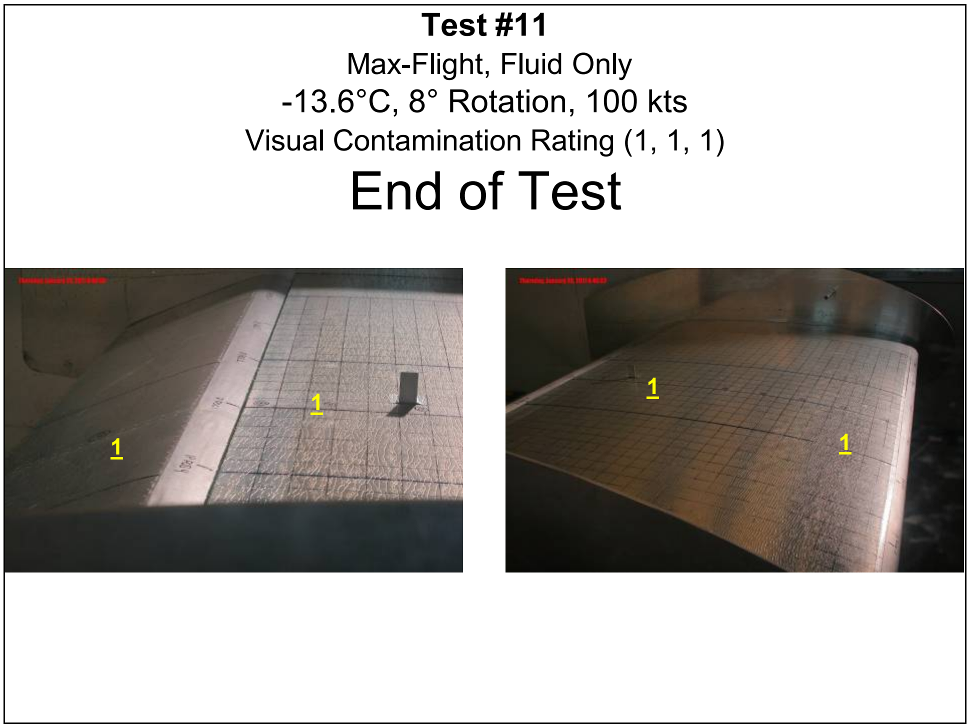
Max-Flight, Fluid Only

-13.6°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 3.66%

End of Rotation

Photo D40: Run #11 – End of Test



Test #11

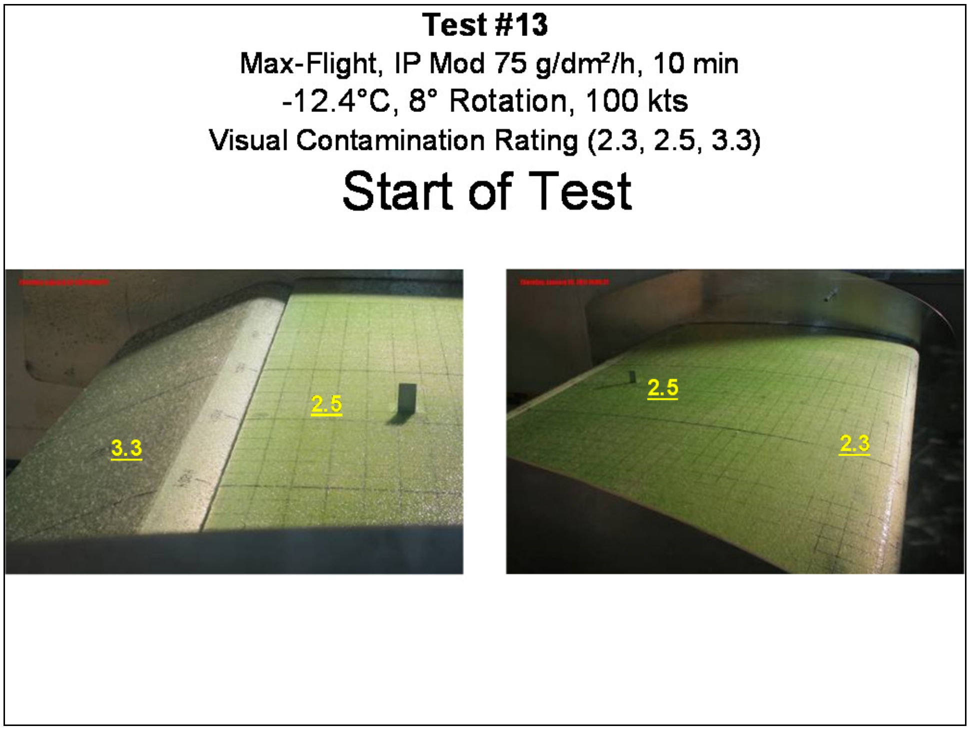
Max-Flight, Fluid Only

-13.6°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

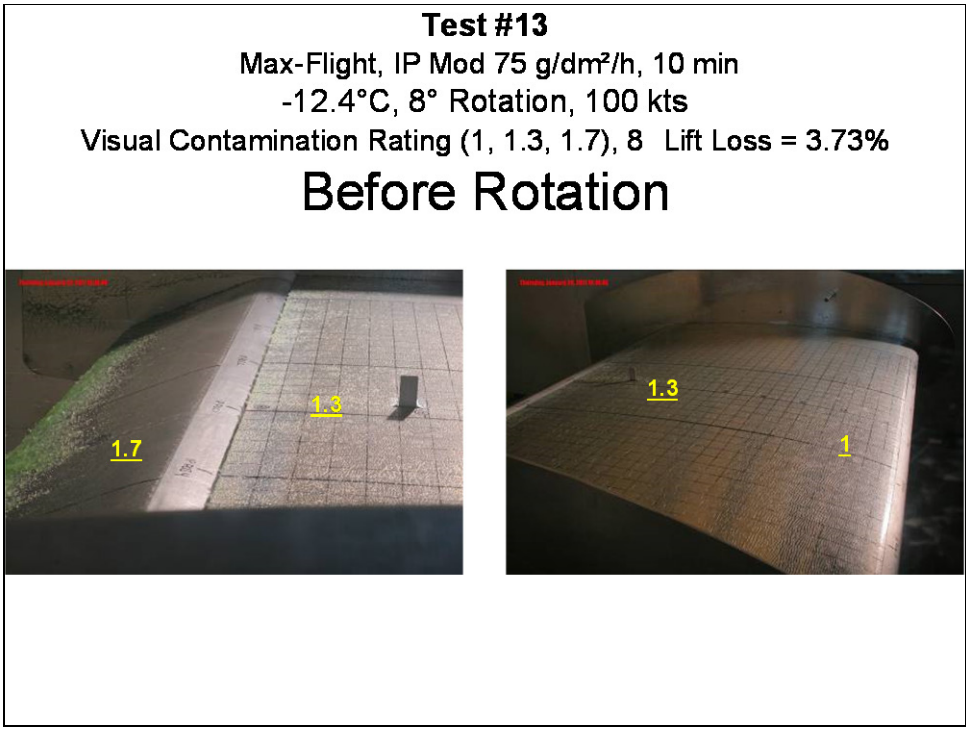
End of Test

Photo D41: Run #13 – Start of Test



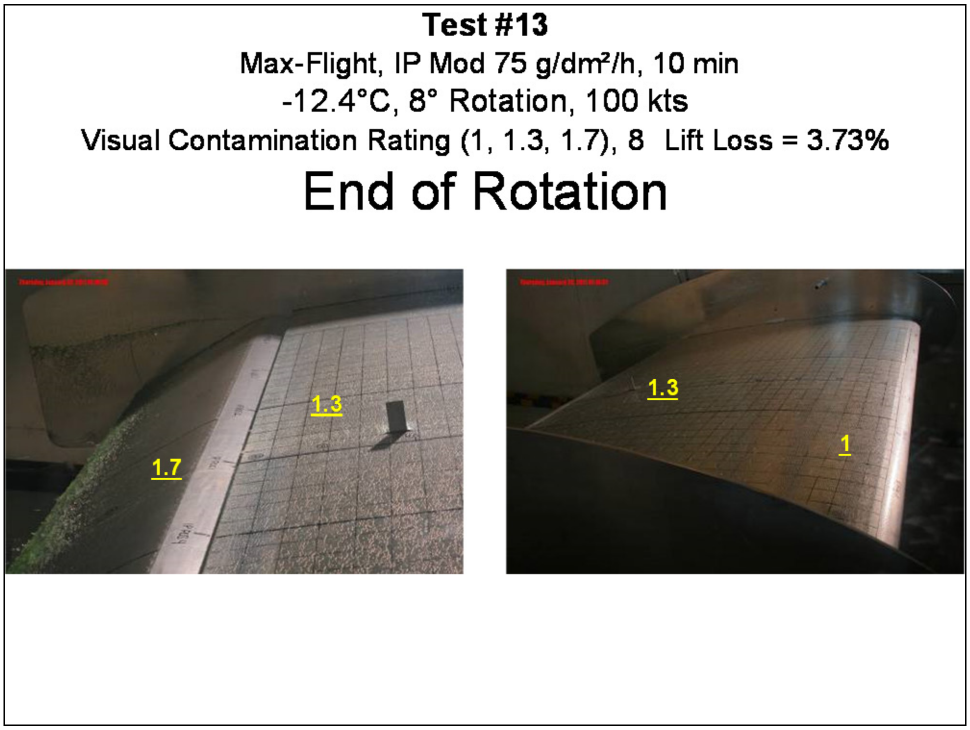
Test #13
Max-Flight, IP Mod 75 g/dm²/h, 10 min
-12.4°C, 8° Rotation, 100 kts
Visual Contamination Rating (2.3, 2.5, 3.3)
Start of Test

Photo D42: Run #13 – Before Rotation



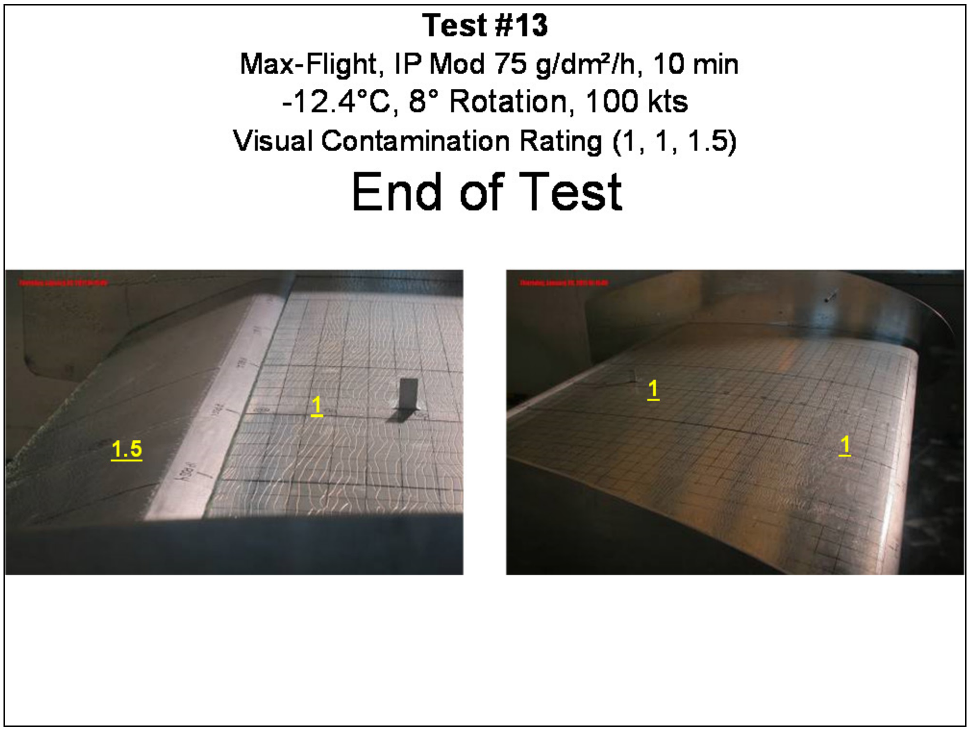
Test #13
Max-Flight, IP Mod 75 g/dm²/h, 10 min
-12.4°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1.3, 1.7), 8 Lift Loss = 3.73%
Before Rotation

Photo D43: Run #13 – End of Rotation



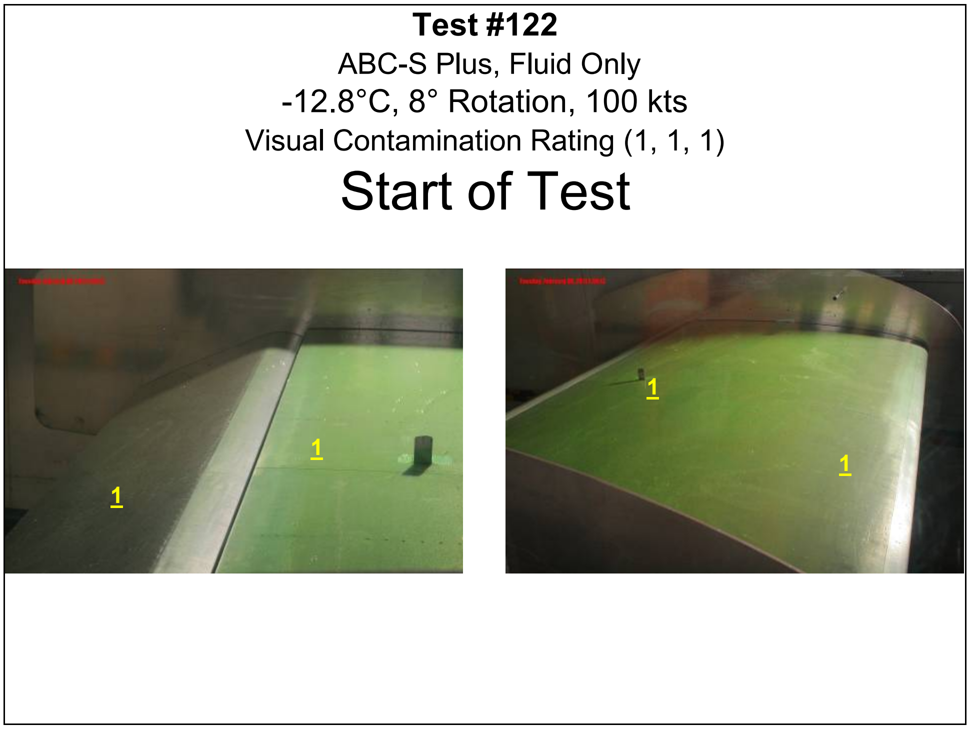
Test #13
Max-Flight, IP Mod 75 g/dm²/h, 10 min
-12.4°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1.3, 1.7), 8 Lift Loss = 3.73%
End of Rotation

Photo D44: Run #13 – End of Test



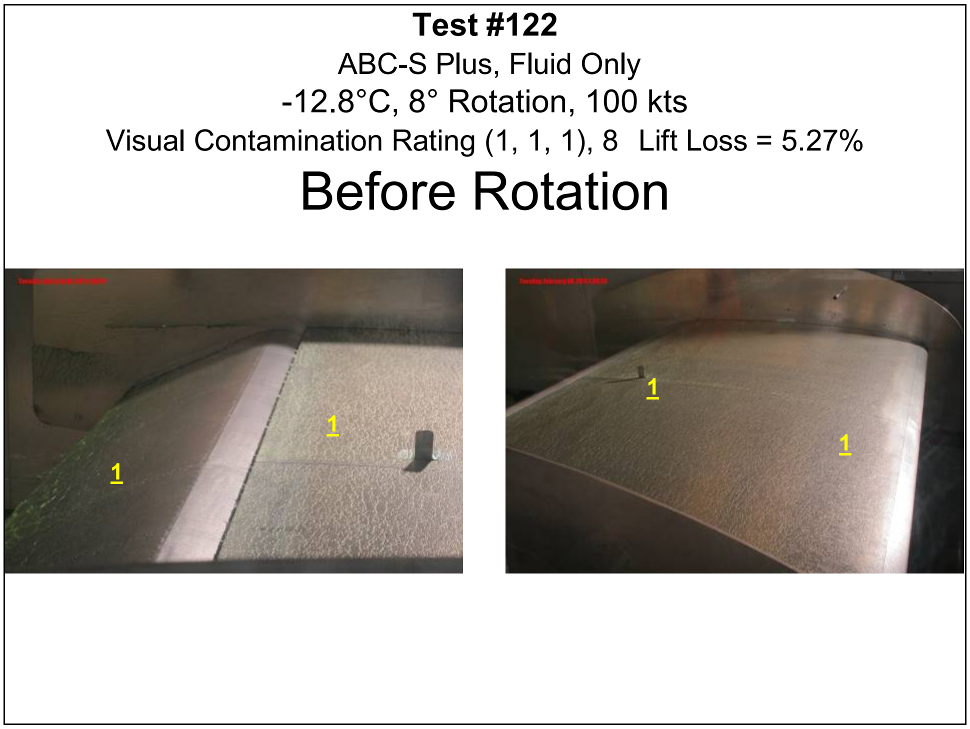
Test #13
Max-Flight, IP Mod 75 g/dm²/h, 10 min
-12.4°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1.5)
End of Test

Photo D45: Run #122 – Start of Test



Test #122
ABC-S Plus, Fluid Only
-12.8°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1)
Start of Test

Photo D46: Run #122 – Before Rotation



Test #122
ABC-S Plus, Fluid Only
-12.8°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 5.27%
Before Rotation

Photo D47: Run # 122 – End of Rotation

Test #122

ABC-S Plus, Fluid Only

-12.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 5.27%

End of Rotation

Photo D48: Run #122 – End of Test

Test #122

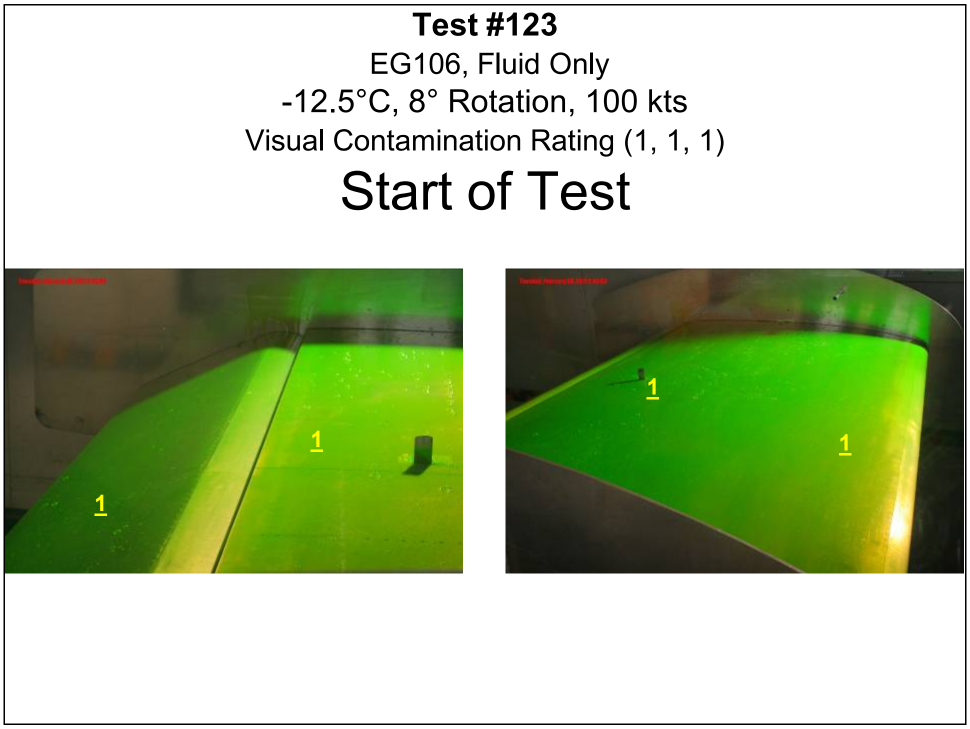
ABC-S Plus, Fluid Only

-12.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

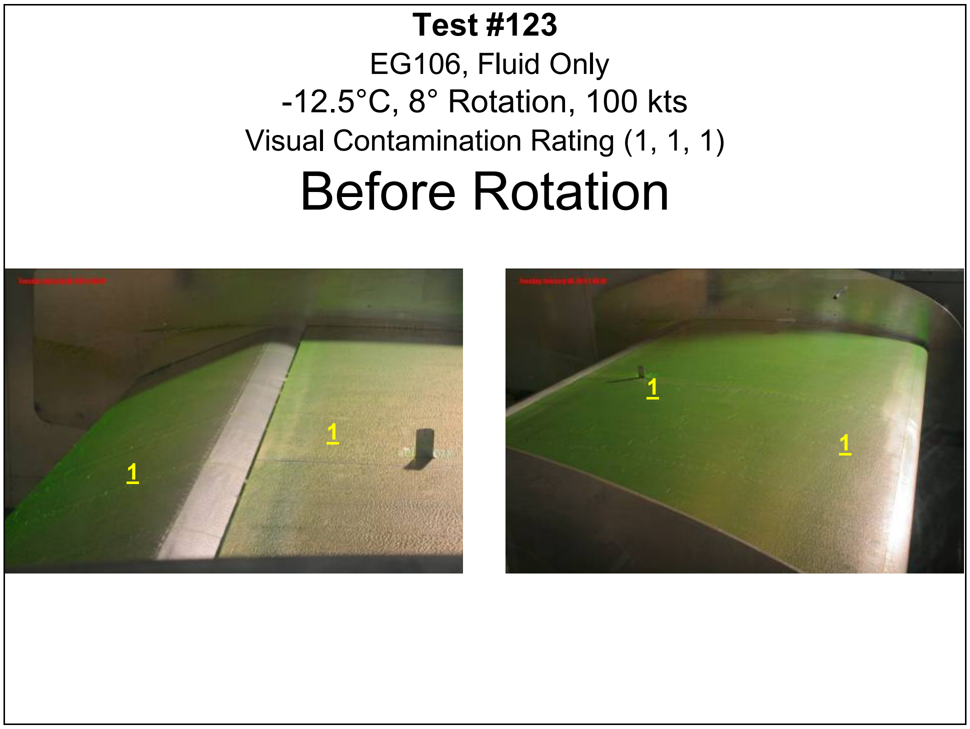
End of Test

Photo D49: Run #123 – Start of Test



Test #123
EG106, Fluid Only
-12.5°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1)
Start of Test

Photo D50: Run #123 – Before Rotation



Test #123
EG106, Fluid Only
-12.5°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1)
Before Rotation

Photo D51: Run #123 – End of Rotation

Test #123
EG106, Fluid Only
-12.5°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 2.39%
End of Rotation

Photo D52: Run #123 – End of Test

Test #123
EG106, Fluid Only
-12.5°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1)
End of Test

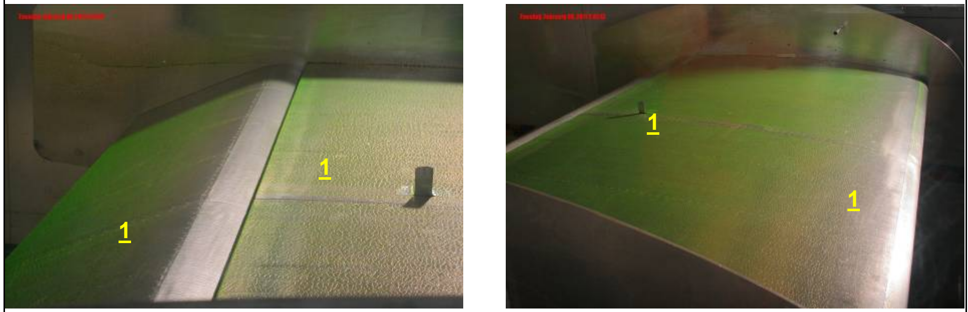


Photo D53: Run #124 – Start of Test

Test #124

ABC-S Plus, IP Mod 75 g/dm²/h, 10 min

-11.3°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (2.5, 2.5, 3.3)

Start of Test

Photo D54: Run #124 – Before Rotation

Test #124

ABC-S Plus, IP Mod 75 g/dm²/h, 10 min

-11.3°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1.7, 2.2), 8 Lift Loss = 7.31%

Before Rotation

Photo D55: Run #124 – End of Rotation

Test #124

ABC-S Plus, IP Mod 75 g/dm^2/h, 10 min

-11.3°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1.7, 2.2), 8 Lift Loss = 7.31%

End of Rotation

Photo D56: Run #124 – End of Test

Test #124

ABC-S Plus, IP Mod 75 g/dm^2/h, 10 min

-11.3°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1.1)

End of Test

EFFECT OF MIXED PRECIPITATION CONDITIONS

Photo D57: Run #114 – Start of Test

Test #114

Launch, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min

1.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (2.3, 2.5, 4)

Start of Test

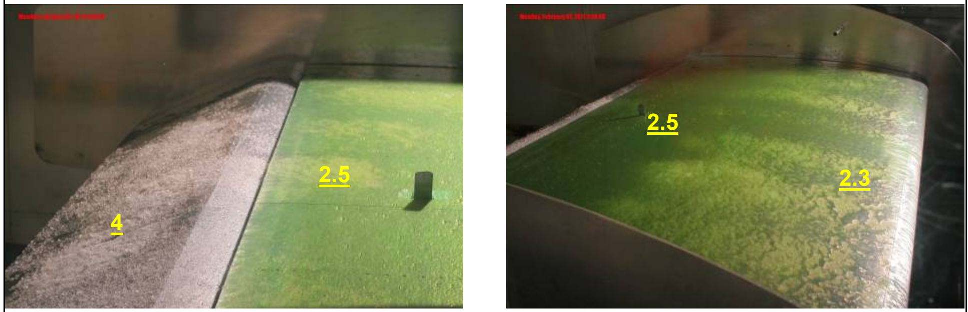


Photo D58: Run #114 – Before Rotation

Test #114

Launch, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min

1.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1.4), 8 Lift Loss = 2.18%

Before Rotation

Photo D59: Run #114 – End of Rotation

Test #114

Launch, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min

1.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1.4), 8 Lift Loss = 2.18%

End of Rotation

Photo D60: Run #114 – End of Test

Test #114

Launch, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min

1.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

End of Test

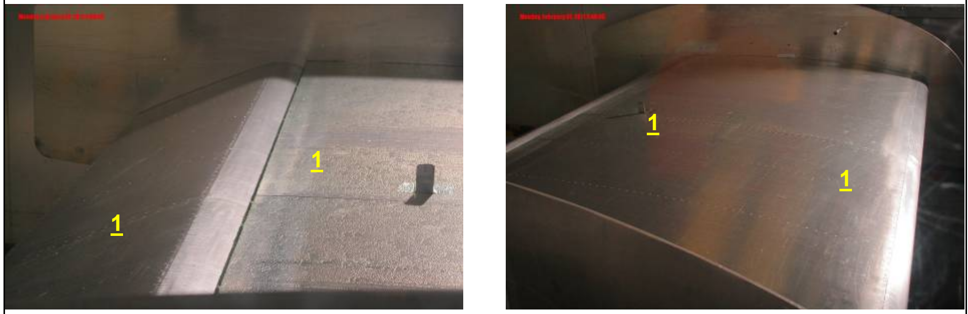


Photo D61: Run #118 – Start of Test

Test #118
EG106, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min
1°C, 8° Rotation, 100 kts
Visual Contamination Rating (2, 1.3, 3.5)

Start of Test

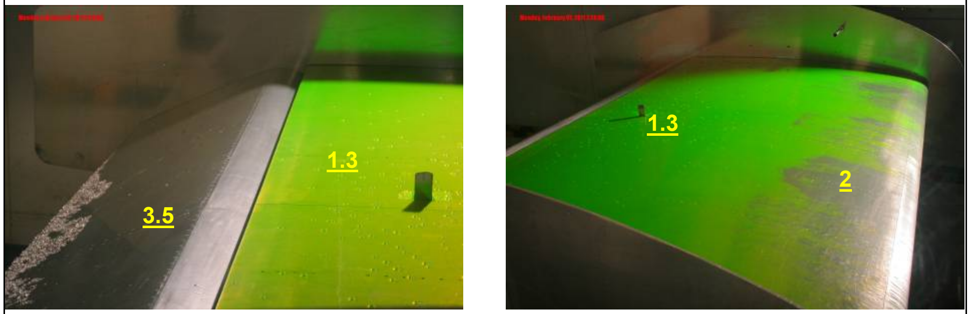


Photo D62: Run #118 – Before Rotation

Test #118
EG106, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min
1°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1.2), 8 Lift Loss = 1.34%

Before Rotation

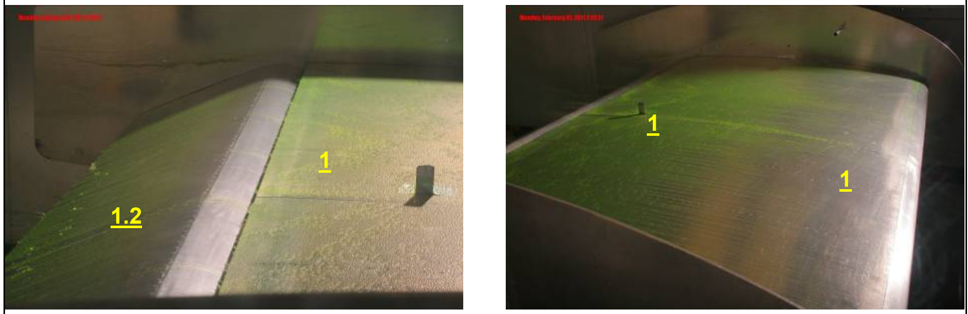


Photo D63: Run #118 – End of Rotation

Test #118

EG106, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min
1°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1.2), 8 Lift Loss = 1.34%

End of Rotation

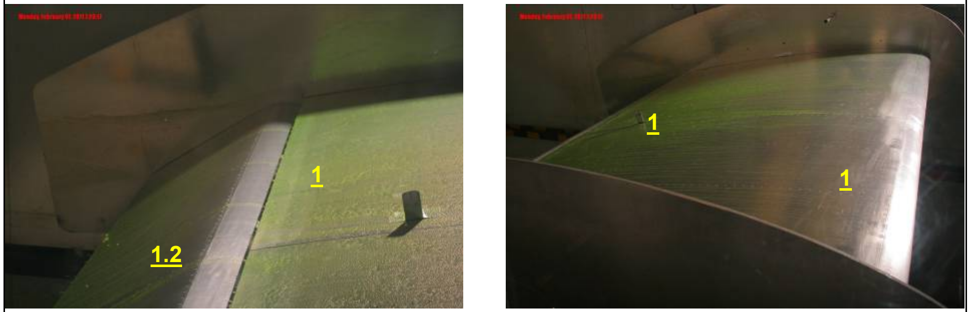


Photo D64: Run #118 – End of Test

Test #118

EG106, IP + R + SN 25 + 25 + 25 g/dm²/h, 25 min
1°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1)

End of Test

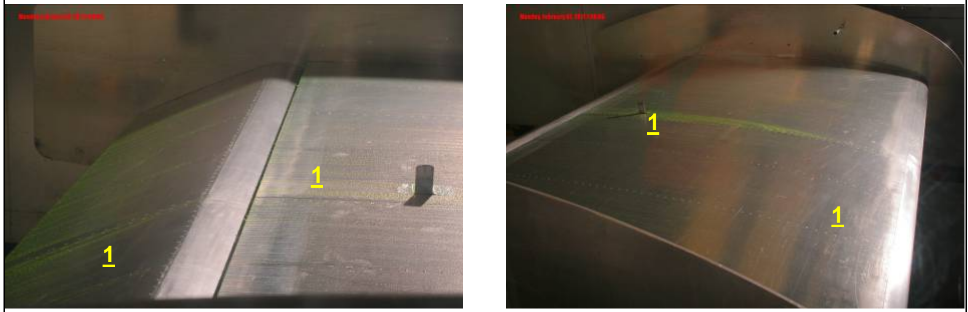


Photo D65: Run #133 – Start of Test

Test #133

ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-3.3°C, 8° Rotation, 100 kts

Visual Contamination Rating (2.7, 2.8, 4)

Start of Test

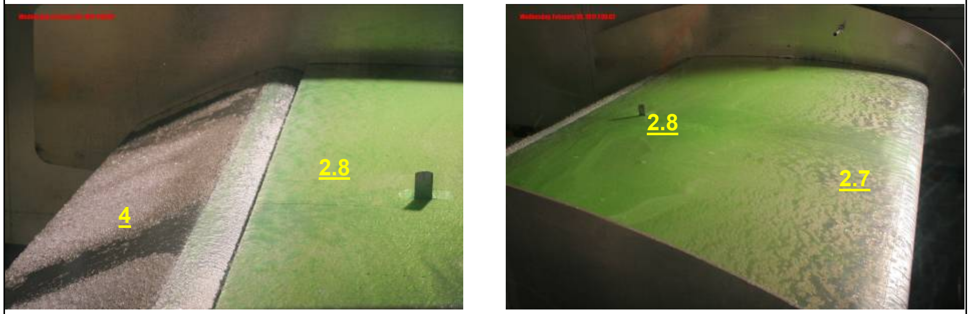


Photo D66: Run #133 – Before Rotation

Test #133

ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-3.3°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1.4, 4.3), 8 Lift Loss = 6.89%

Before Rotation

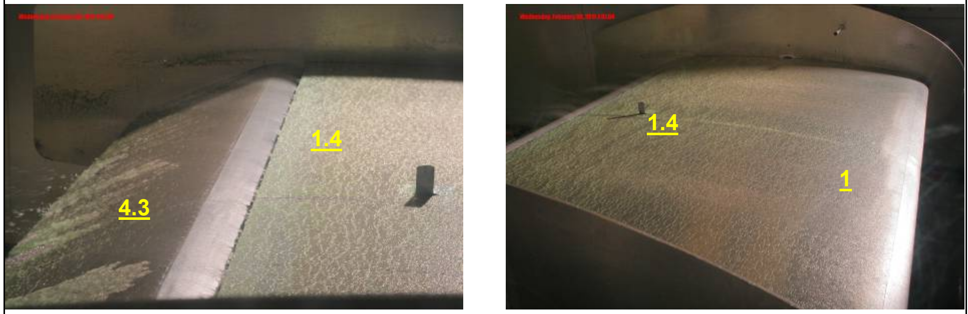
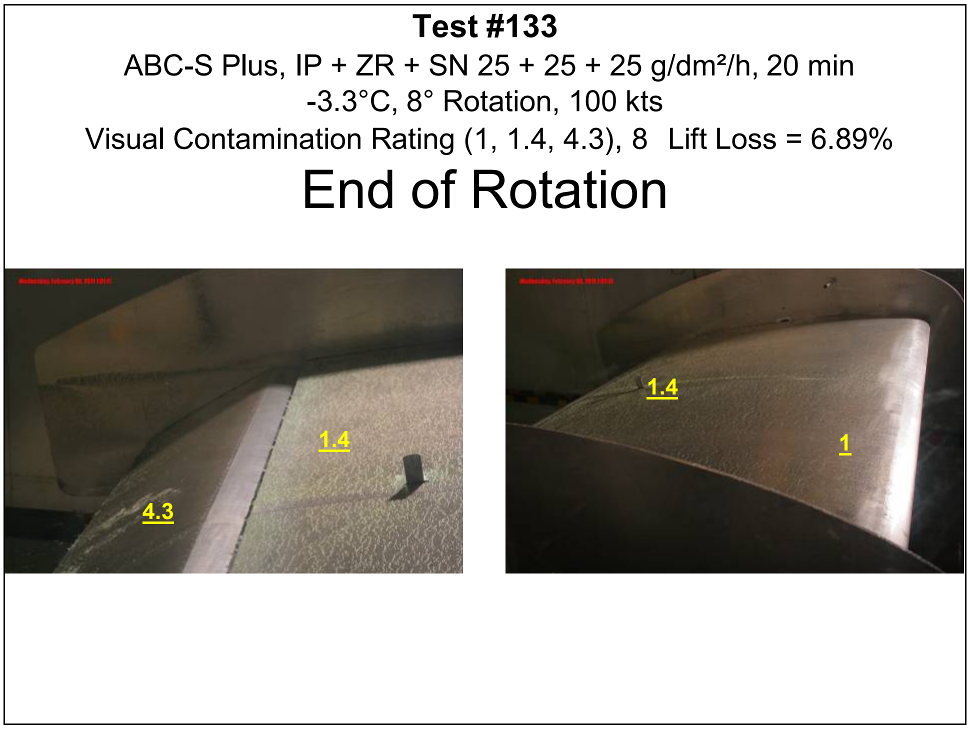


Photo D67: Run #133 – End of Rotation



Test #133

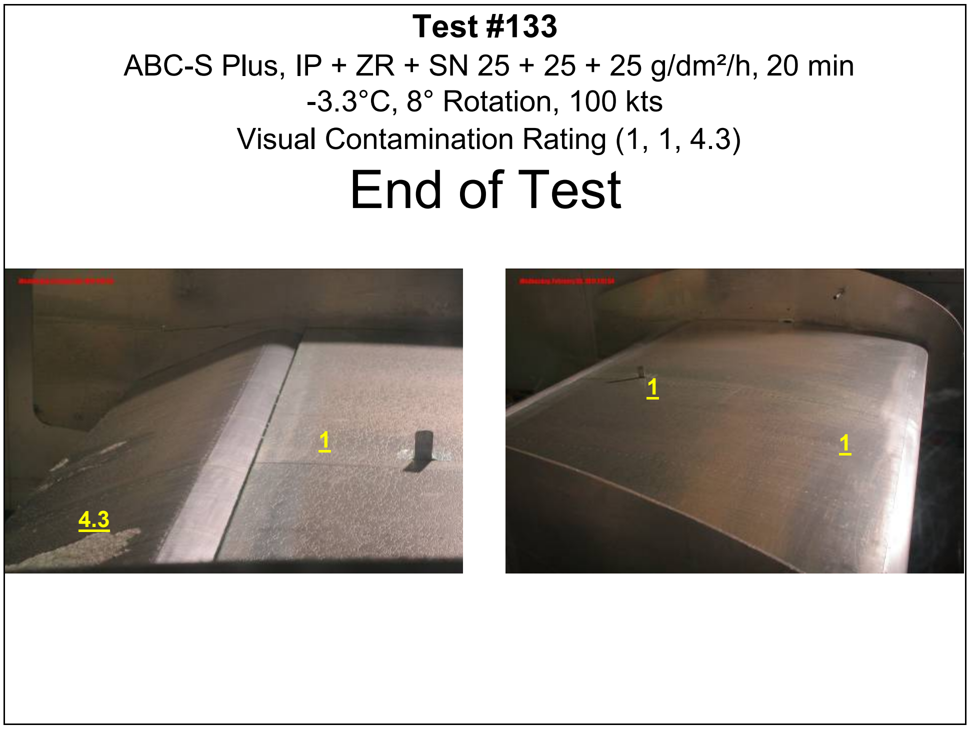
ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-3.3°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1.4, 4.3), 8 Lift Loss = 6.89%

End of Rotation

Photo D68: Run #133 – End of Test



Test #133

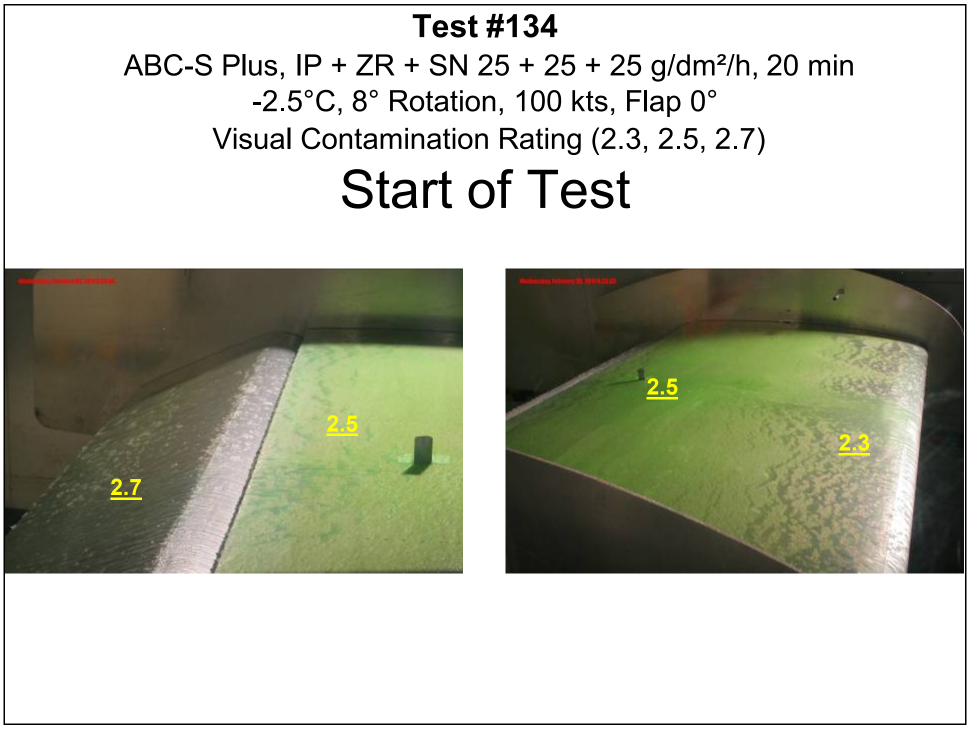
ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-3.3°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 4.3)

End of Test

Photo D69: Run #134 – Start of Test



Test #134

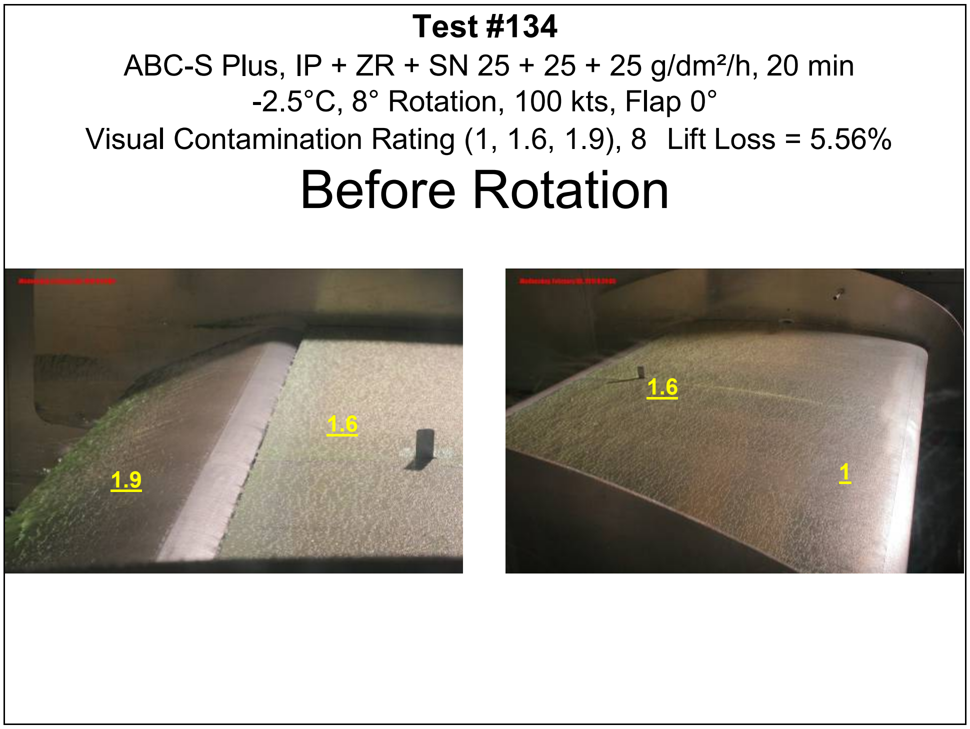
ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-2.5°C, 8° Rotation, 100 kts, Flap 0°

Visual Contamination Rating (2.3, 2.5, 2.7)

Start of Test

Photo D70: Run #134 – Before Rotation



Test #134

ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-2.5°C, 8° Rotation, 100 kts, Flap 0°

Visual Contamination Rating (1, 1.6, 1.9), 8 Lift Loss = 5.56%

Before Rotation

Photo D71: Run #134 – End of Rotation

Test #134

ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-2.5°C, 8° Rotation, 100 kts, Flap 0°

Visual Contamination Rating (1, 1.6, 1.9), 8 Lift Loss = 5.56%

End of Rotation

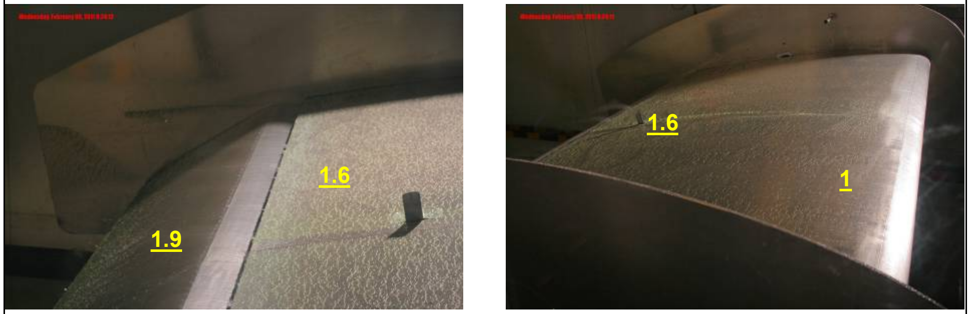


Photo D72: Run #134 – End of Test

Test #134

ABC-S Plus, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-2.5°C, 8° Rotation, 100 kts, Flap 0°

Visual Contamination Rating (1, 1, 1)

End of Test

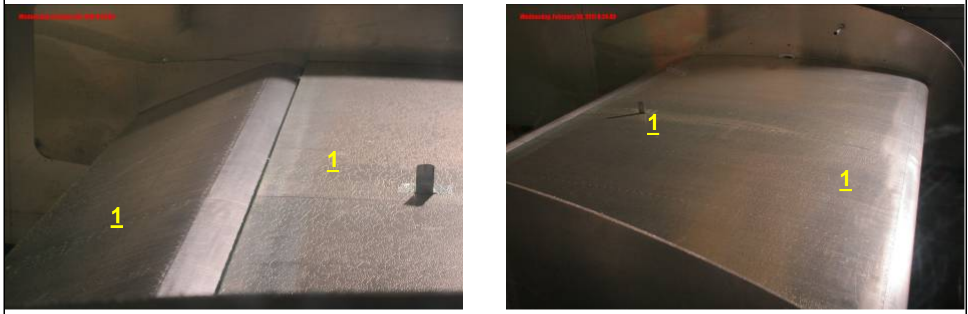
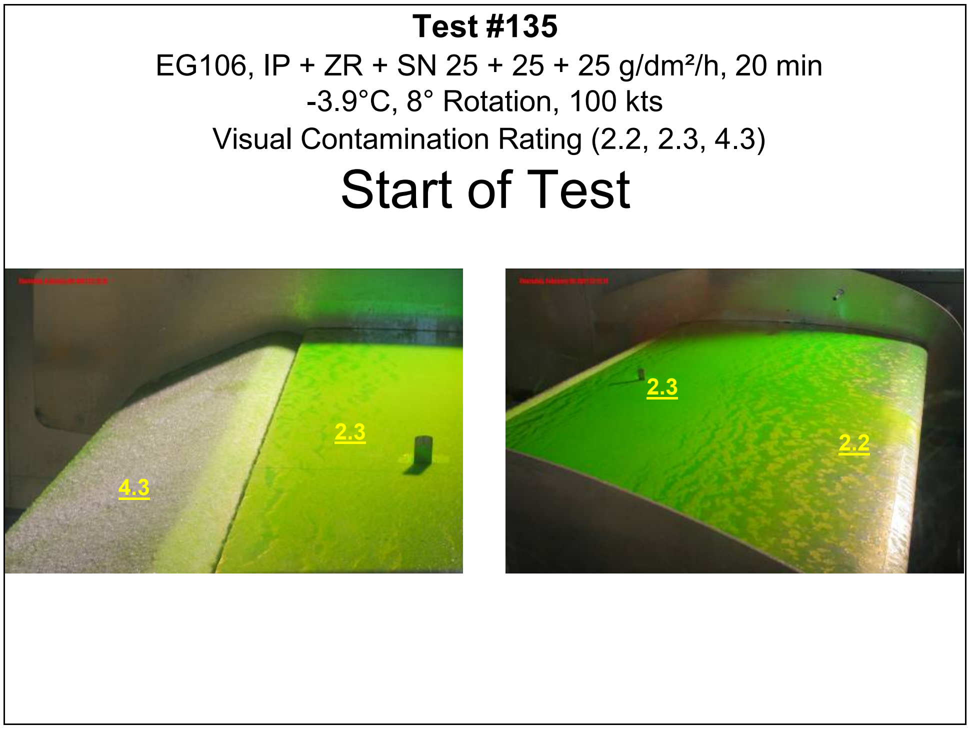
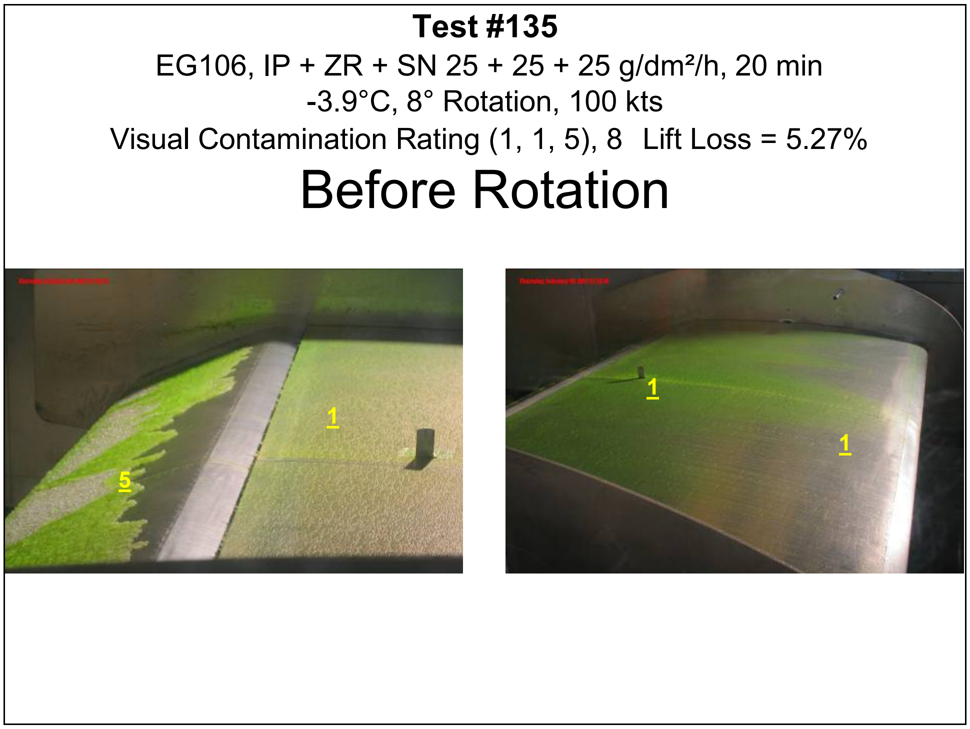


Photo D73: Run #135 – Start of Test



Test #135
EG106, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min
-3.9°C, 8° Rotation, 100 kts
Visual Contamination Rating (2.2, 2.3, 4.3)
Start of Test

Photo D74: Run #135 – Before Rotation



Test #135
EG106, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min
-3.9°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 5), 8 Lift Loss = 5.27%
Before Rotation

Photo D75: Run #135 – End of Rotation

Test #135

EG106, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-3.9°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 5), 8   Lift Loss = 5.27%

End of Rotation

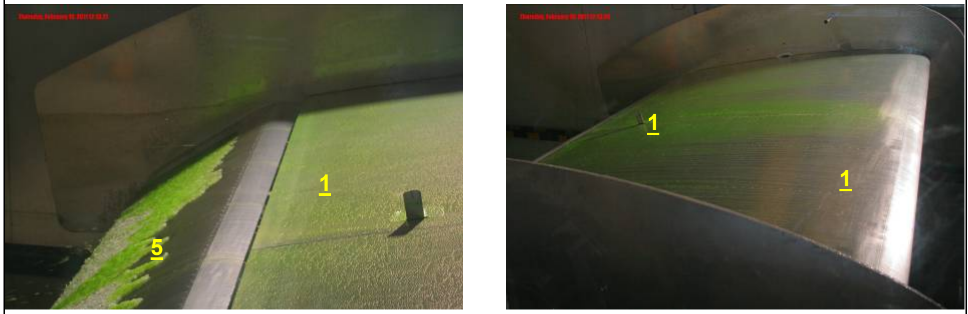


Photo D76: Run #135 – End of Test

Test #135

EG106, IP + ZR + SN 25 + 25 + 25 g/dm²/h, 20 min

-3.9°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 5)

End of Test

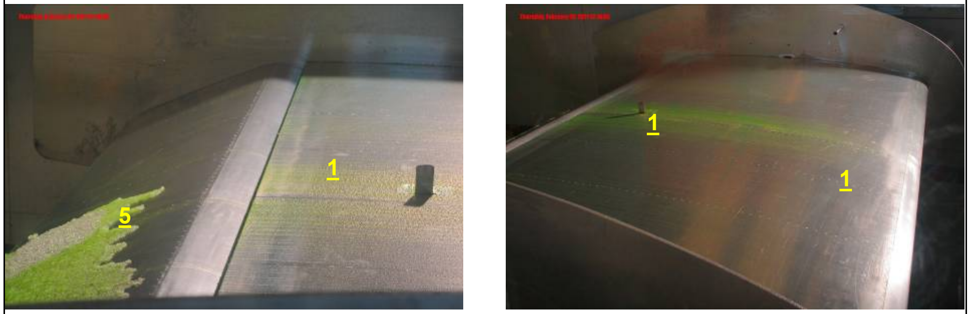
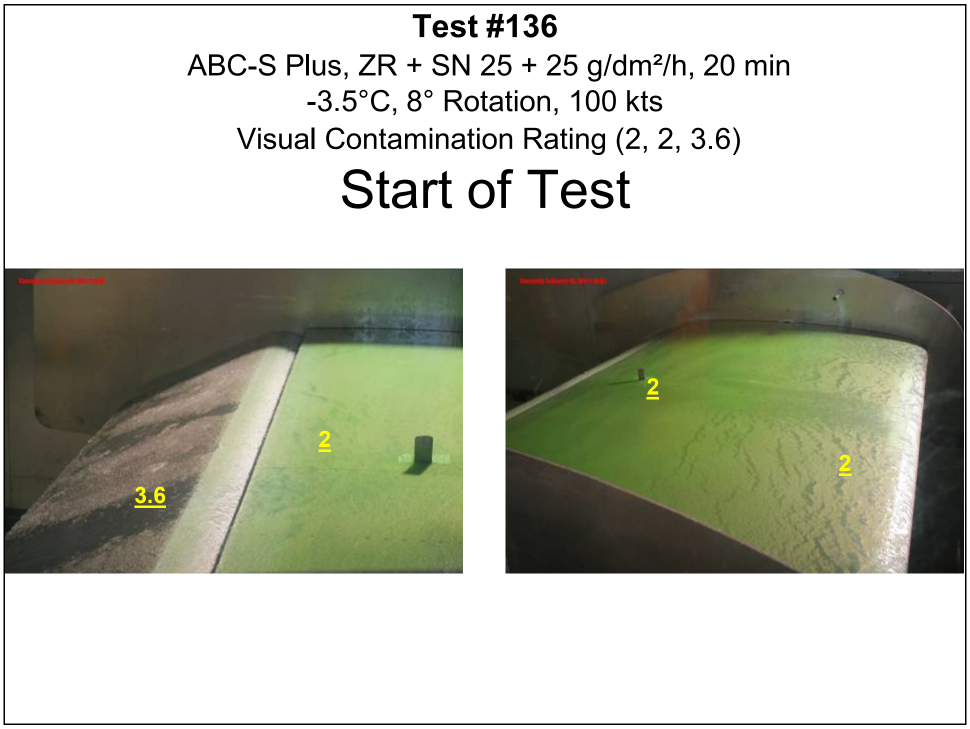


Photo D77: Run #136 – Start of Test



Test #136

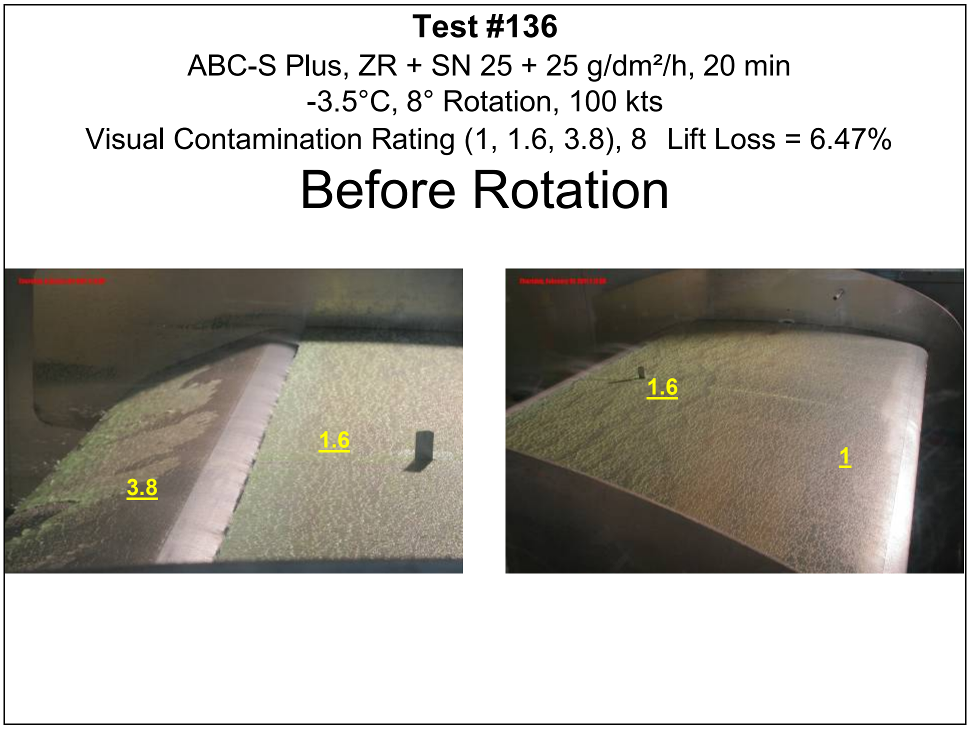
ABC-S Plus, ZR + SN 25 + 25 g/dm²/h, 20 min

-3.5°C, 8° Rotation, 100 kts

Visual Contamination Rating (2, 2, 3.6)

Start of Test

Photo D78: Run #136 – Before Rotation



Test #136

ABC-S Plus, ZR + SN 25 + 25 g/dm²/h, 20 min

-3.5°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1.6, 3.8), 8 Lift Loss = 6.47%

Before Rotation

Photo D79: Run #136 – End of Rotation

Test #136
ABC-S Plus, ZR + SN 25 + 25 g/dm²/h, 20 min
-3.5°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1.6, 3.8), 8 Lift Loss = 6.47%

End of Rotation

Photo D80: Run #136 – End of Test

Test #136
ABC-S Plus, ZR + SN 25 + 25 g/dm²/h, 20 min
-3.5°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 5)

End of Test

EFFECTS OF SNOW OR RAIN ON AN UNPROTECTED WING

Photo D81: Run #101 – Start of Test

Test #101

No Fluid, SN 200 g/dm^2/h, 5 min

-6.8°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (4, 4, 4)

Start of Test

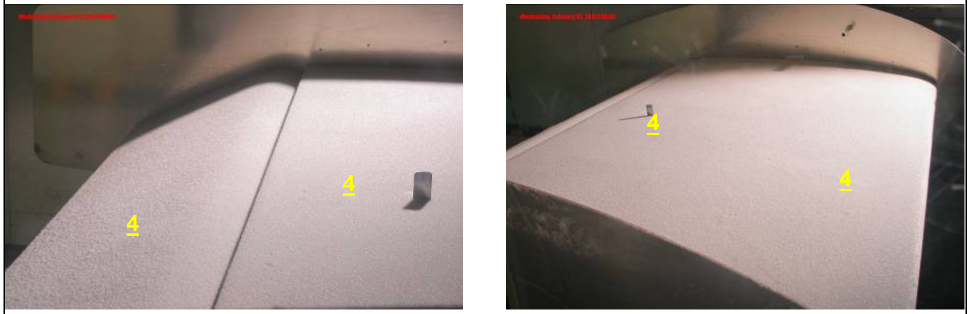


Photo D82: Run #101 – Before Rotation

Test #101

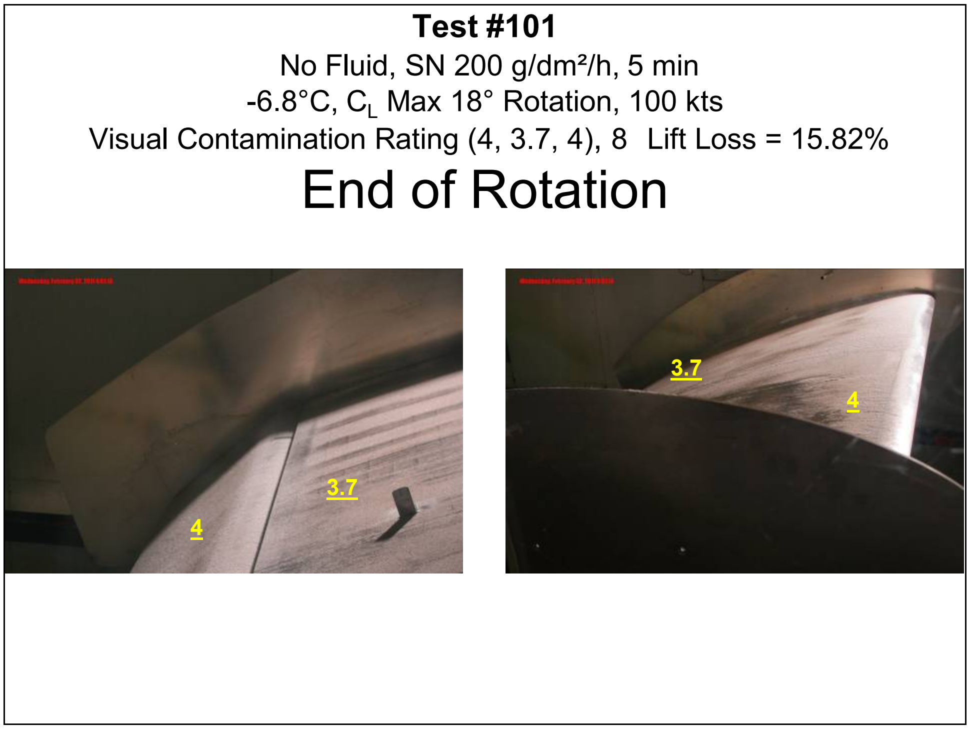
No Fluid, SN 200 g/dm^2/h, 5 min

-6.8°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (4, 3.7, 4), 8 Lift Loss = 15.82%

Before Rotation

Photo D83: Run #101 – End of Rotation



Test #101

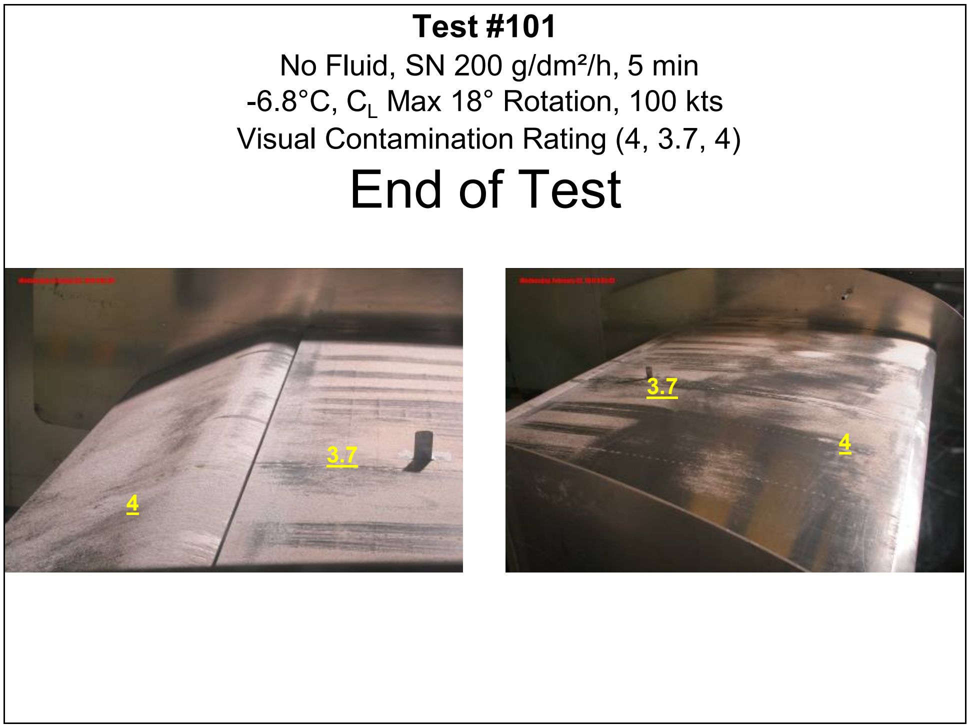
No Fluid, SN 200 g/dm²/h, 5 min

-6.8°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (4, 3.7, 4), 8 Lift Loss = 15.82%

End of Rotation

Photo D84: Run #101 – End of Test



Test #101

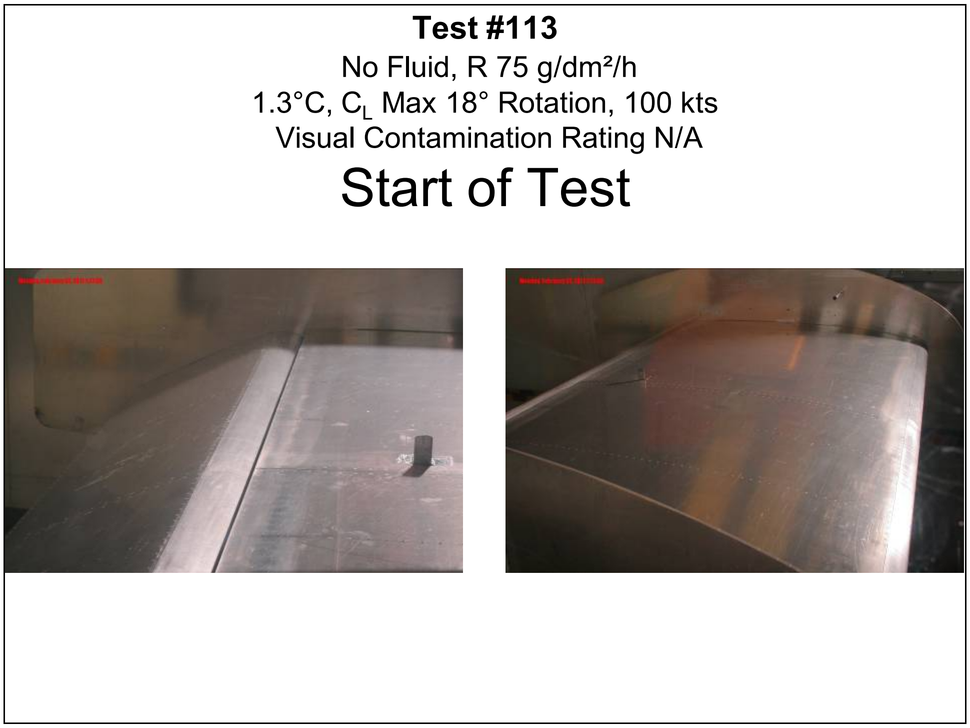
No Fluid, SN 200 g/dm²/h, 5 min

-6.8°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (4, 3.7, 4)

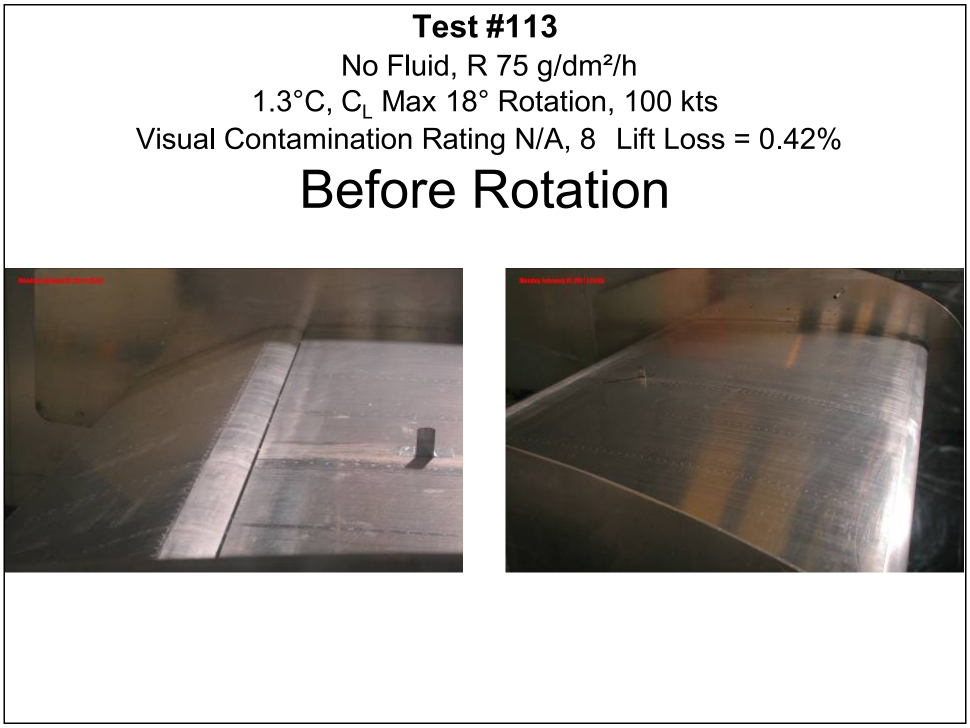
End of Test

Photo D85: Run #113 – Start of Test



Test #113
No Fluid, R 75 $g/dm^2/h$
1.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating N/A
Start of Test

Photo D86: Run #113 – Before Rotation



Test #113
No Fluid, R 75 $g/dm^2/h$
1.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating N/A, 8 Lift Loss = 0.42%
Before Rotation

Photo D87: Run #113 – End of Rotation

Test #113

No Fluid, R 75 g/dm²/h

1.3°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating N/A, 8 Lift Loss = 0.42%

End of Rotation

Photo D88: Run #113 – End of Test

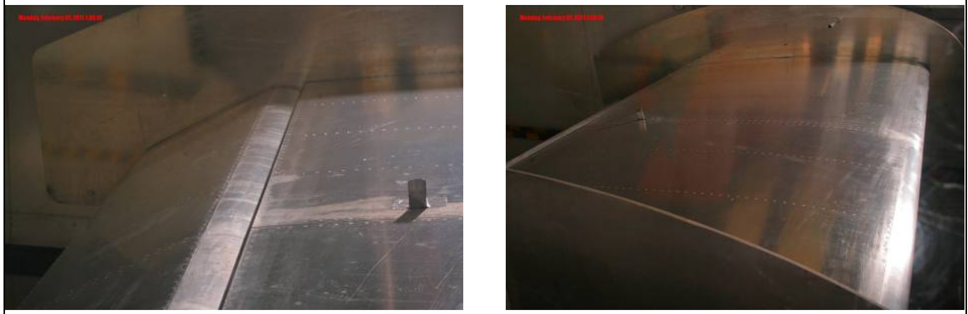
Test #113

No Fluid, R 75 g/dm²/h

1.3°C, C_L Max 18° Rotation, 100 kts

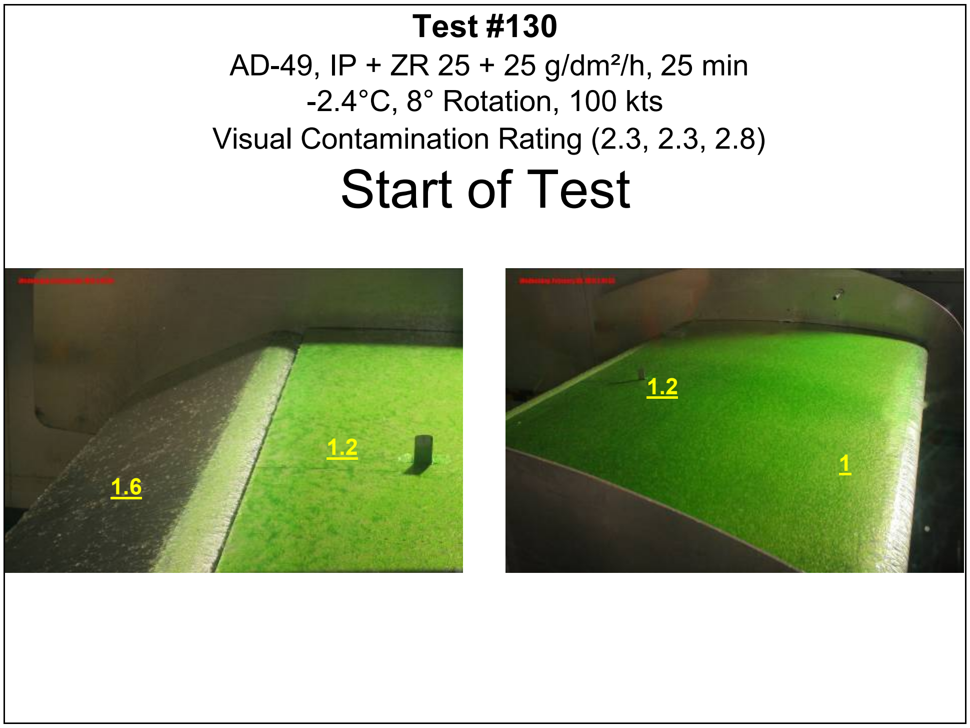
Visual Contamination Rating N/A

End of Test



EFFECTS OF WING GEOMETRY ON FLUID SETTLING PROPERTIES

Photo D89: Run #130 – Start of Test



Test #130

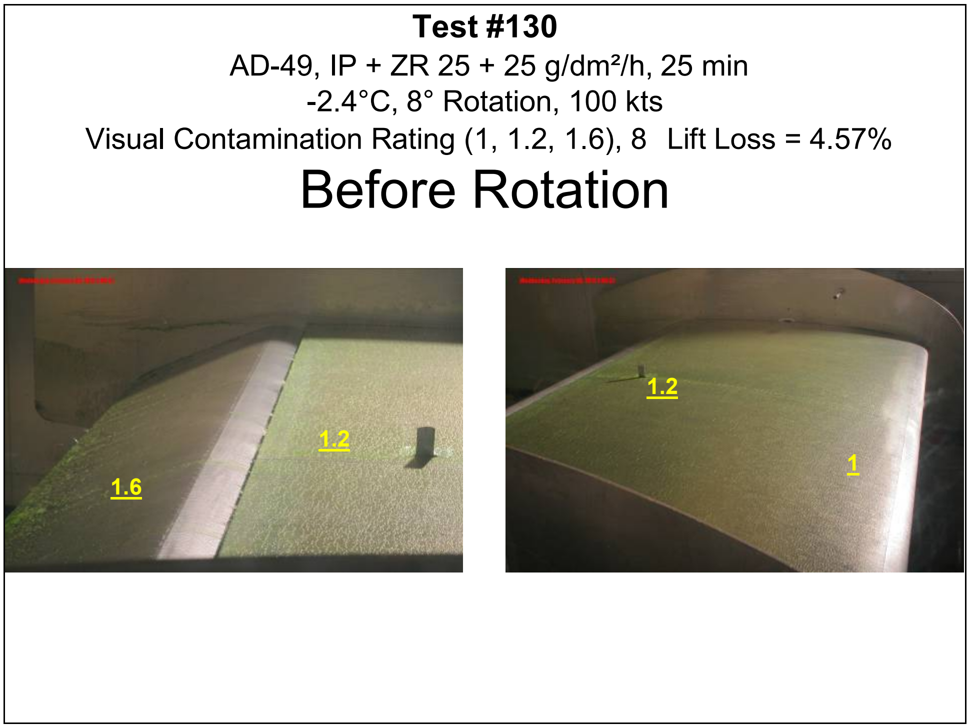
AD-49, IP + ZR 25 + 25 g/dm²/h, 25 min

-2.4°C, 8° Rotation, 100 kts

Visual Contamination Rating (2.3, 2.3, 2.8)

Start of Test

Photo D90: Run #130 – Before Rotation



Test #130

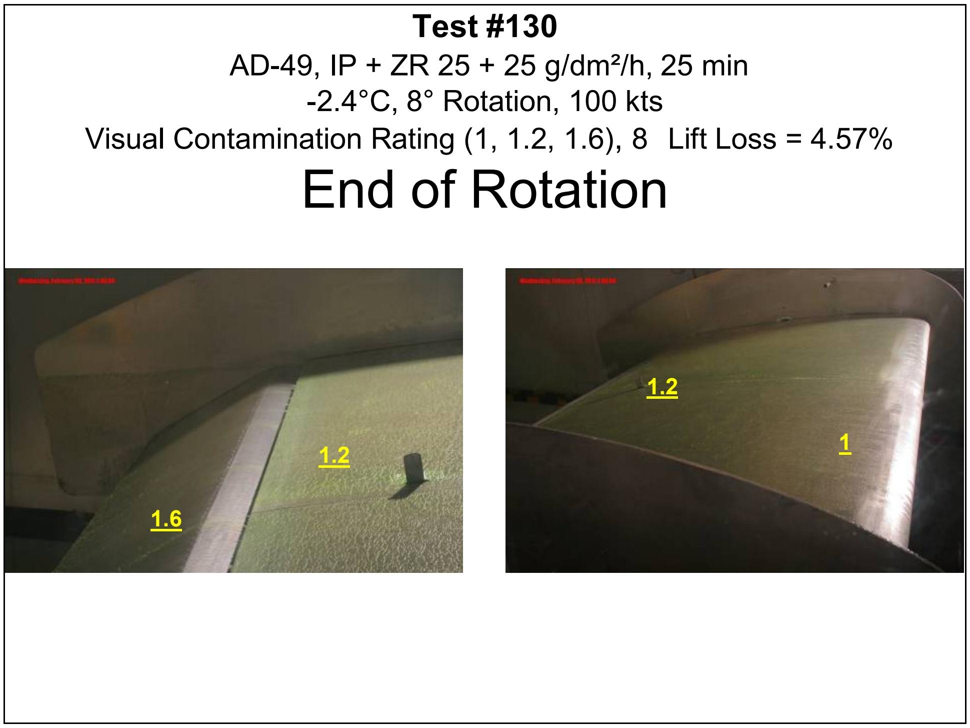
AD-49, IP + ZR 25 + 25 g/dm²/h, 25 min

-2.4°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1.2, 1.6), 8 Lift Loss = 4.57%

Before Rotation

Photo D91: Run #130 – End of Rotation



Test #130

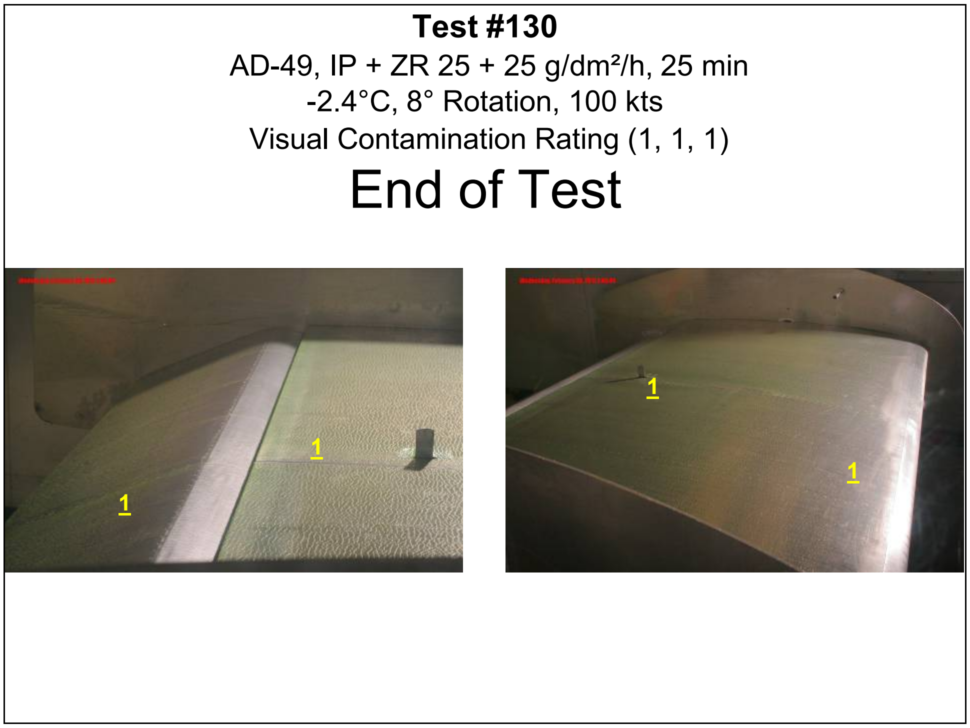
AD-49, IP + ZR 25 + 25 g/dm²/h, 25 min

-2.4°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1.2, 1.6), 8 Lift Loss = 4.57%

End of Rotation

Photo D92: Run #130 – End of Test



Test #130

AD-49, IP + ZR 25 + 25 g/dm²/h, 25 min

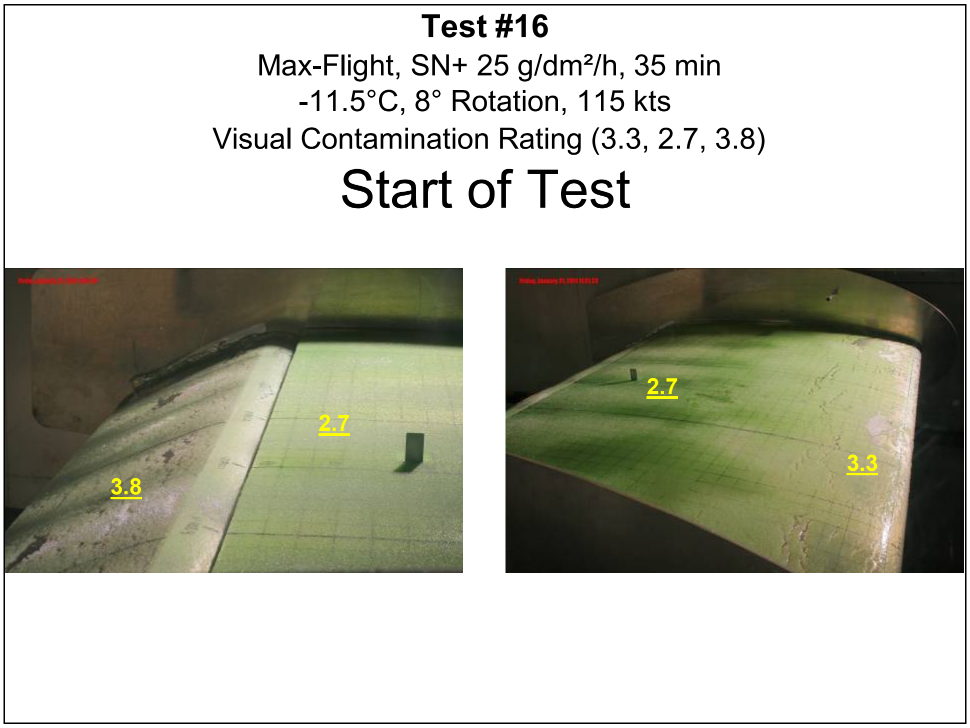
-2.4°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

End of Test

HEAVY SNOW

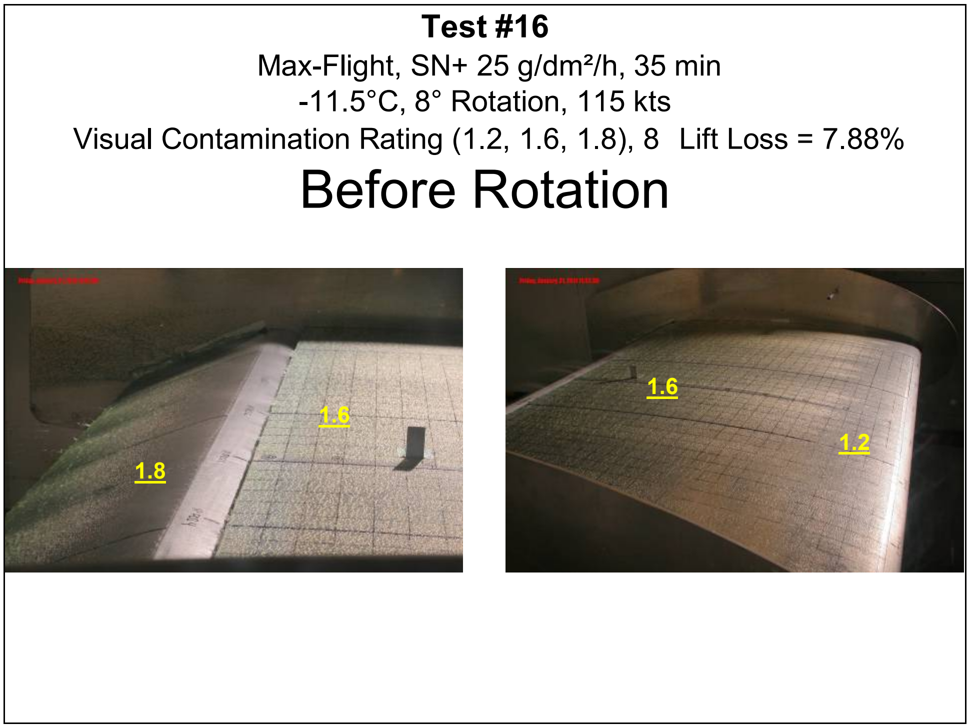
Photo D93: Run #16 – Start of Test



Test #16
Max-Flight, SN+ 25 g/dm²/h, 35 min
-11.5°C, 8° Rotation, 115 kts
Visual Contamination Rating (3.3, 2.7, 3.8)

Start of Test

Photo D94: Run #16 – Before Rotation



Test #16
Max-Flight, SN+ 25 g/dm²/h, 35 min
-11.5°C, 8° Rotation, 115 kts
Visual Contamination Rating (1.2, 1.6, 1.8), 8 Lift Loss = 7.88%

Before Rotation

Photo D95: Run #16 – End of Rotation

Test #16

Max-Flight, SN+ 25 g/dm²/h, 35 min

-11.5°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.2, 1.6, 1.8), 8 Lift Loss = 7.88%

End of Rotation

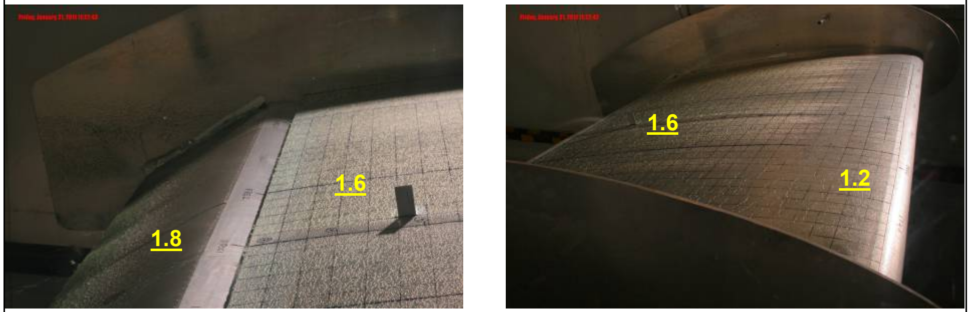


Photo D96: Run #16 – End of Test

Test #16

Max-Flight, SN+ 25 g/dm²/h, 35 min

-11.5°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.1, 1.2, 1.3)

End of Test

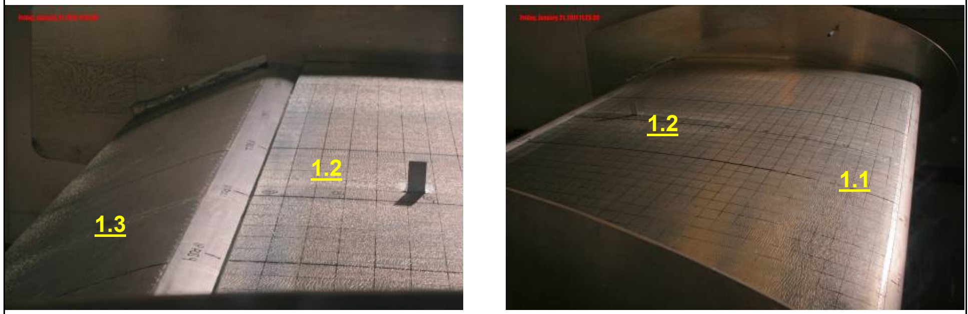


Photo D97: Run #17 – Start of Test

Test #17
Max-Flight, SN++ 50 g/dm²/h, 17.5 min
-15°C, 8° Rotation, 115 kts
Visual Contamination Rating (2.7, 3.1, 3.3)

Start of Test

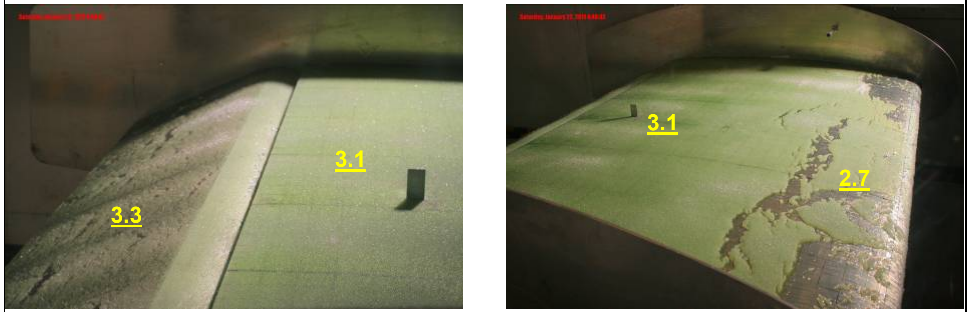


Photo D98: Run #17 – Before Rotation

Test #17
Max-Flight, SN++ 50 g/dm²/h, 17.5 min
-15°C, 8° Rotation, 115 kts
Visual Contamination Rating (1.2, 1.7, 1.9)

Before Rotation

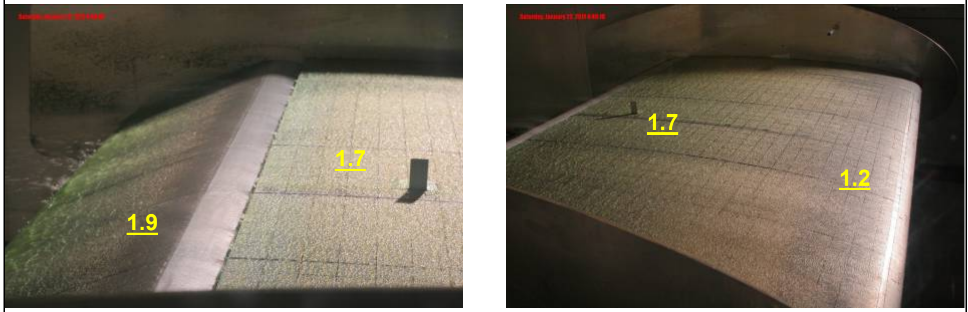


Photo D99: Run #17 – End of Rotation

Test #17
Max-Flight, SN++ 50 g/dm²/h, 17.5 min
-15°C, 8° Rotation, 115 kts
Visual Contamination Rating (1.2, 1.7, 1.9), 8 Lift Loss = 6.35%

End of Rotation

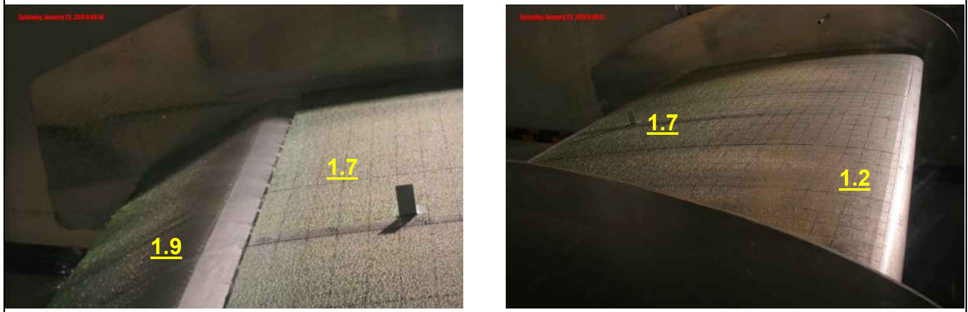


Photo D100: Run #17 – End of Test

Test #17
Max-Flight, SN++ 50 g/dm²/h, 17.5 min
-15°C, 8° Rotation, 115 kts
Visual Contamination Rating (1.1, 1.3, 1.6)

End of Test

Photo D101: Run #18 – Start of Test

Test #18
Max-Flight, SN++ 100 g/dm²/h, 8.75 min
-14.7°C, 8° Rotation, 115 kts
Visual Contamination Rating (3, 2.8, 4)

Start of Test

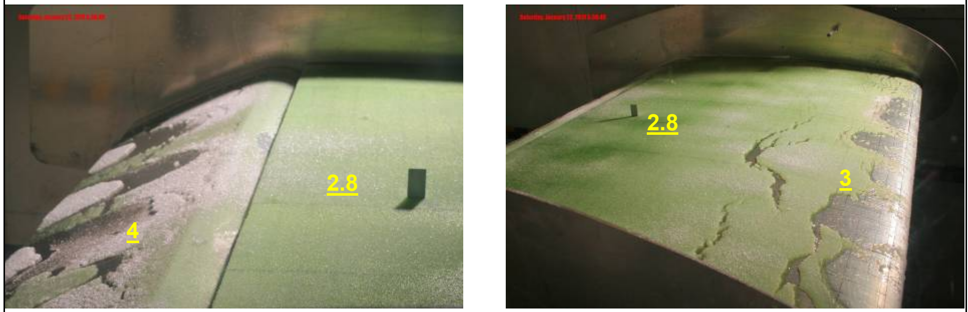


Photo D102: Run #18 – Before Rotation

Test #18
Max-Flight, SN++ 100 g/dm²/h, 8.75 min
-14.7°C, 8° Rotation, 115 kts
Visual Contamination Rating (1.5, 1.9, 2.5), 8 Lift Loss = 7.56%

Before Rotation

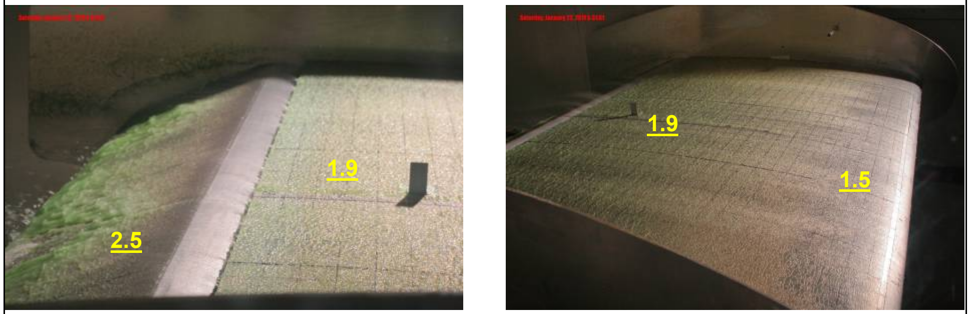
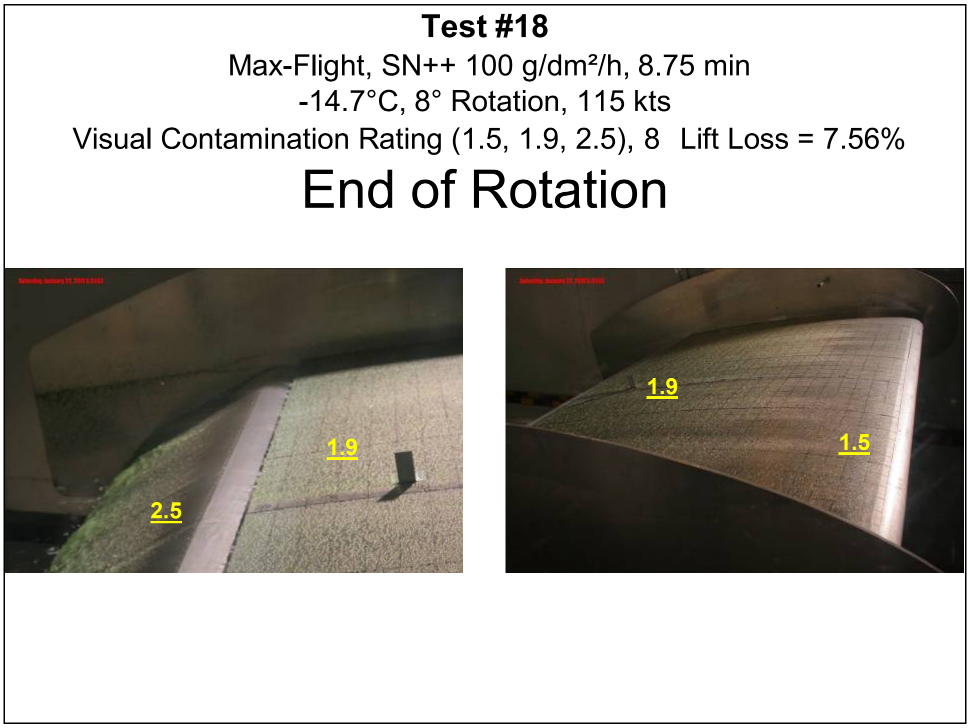


Photo D103: Run #18 – End of Rotation



Test #18

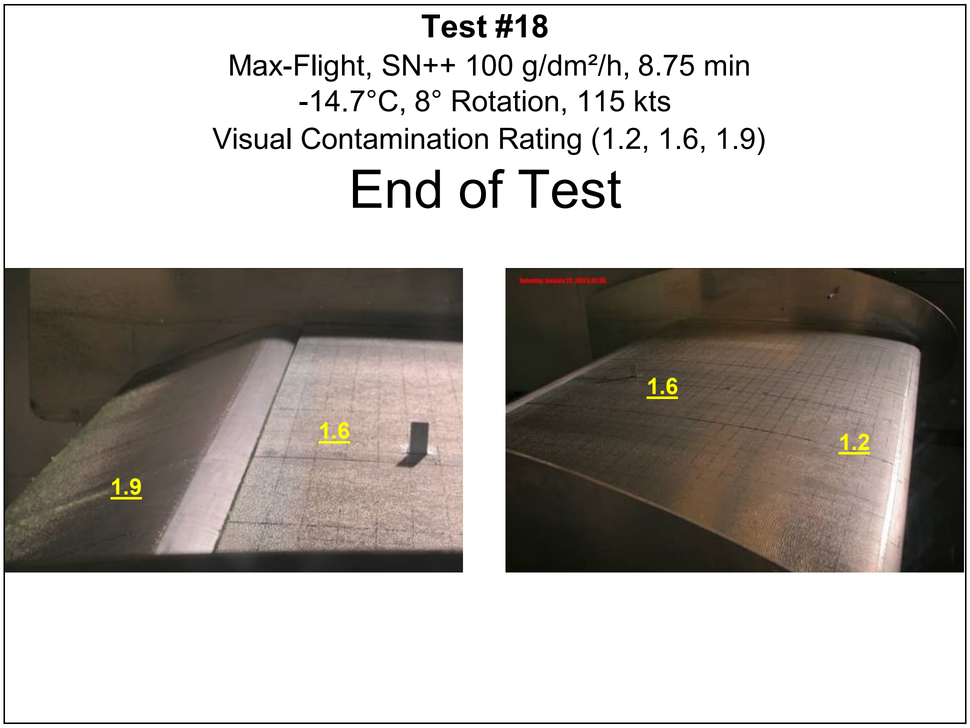
Max-Flight, SN++ 100 g/dm²/h, 8.75 min

-14.7°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.5, 1.9, 2.5), 8 Lift Loss = 7.56%

End of Rotation

Photo D104: Run #18 – End of Test



Test #18

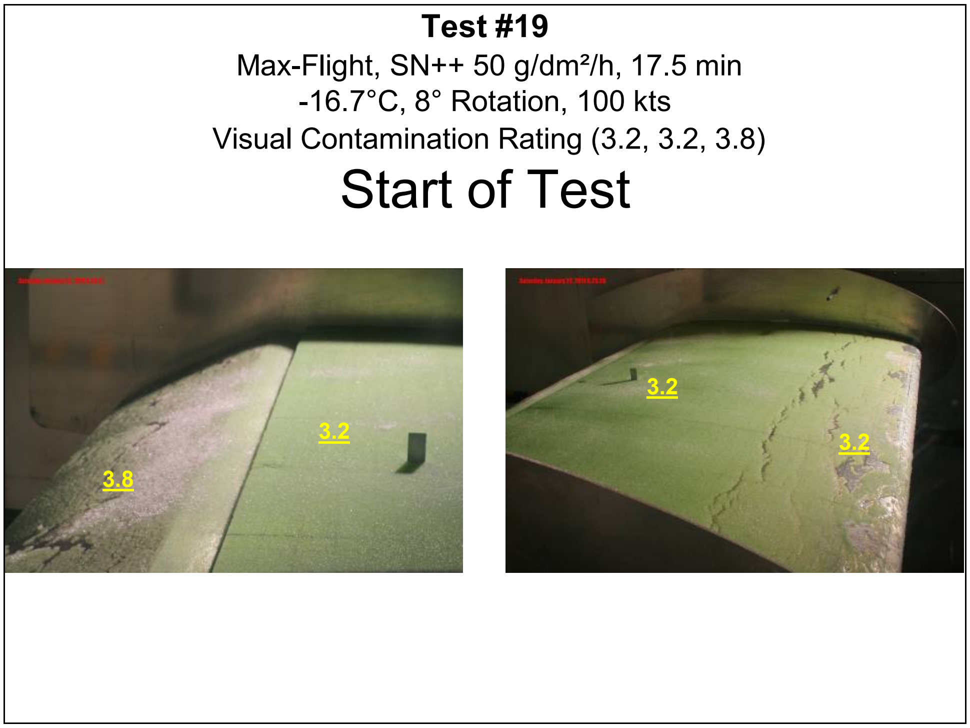
Max-Flight, SN++ 100 g/dm²/h, 8.75 min

-14.7°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.2, 1.6, 1.9)

End of Test

Photo D105: Run #19 – Start of Test



Test #19

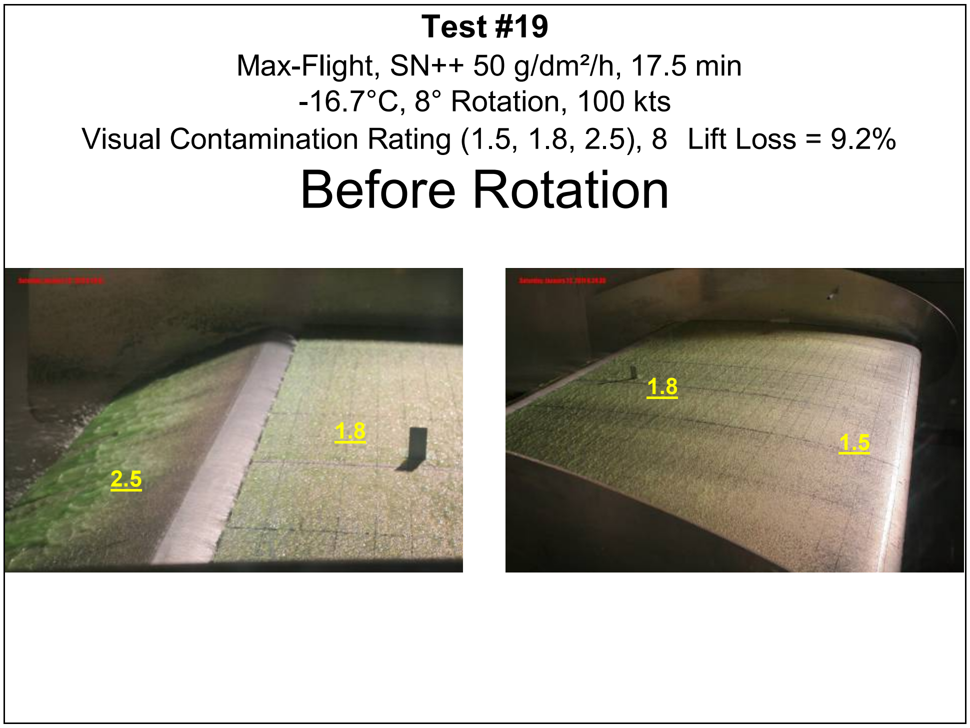
Max-Flight, SN++ 50 g/dm²/h, 17.5 min

-16.7°C, 8° Rotation, 100 kts

Visual Contamination Rating (3.2, 3.2, 3.8)

Start of Test

Photo D106: Run #19 – Before Rotation



Test #19

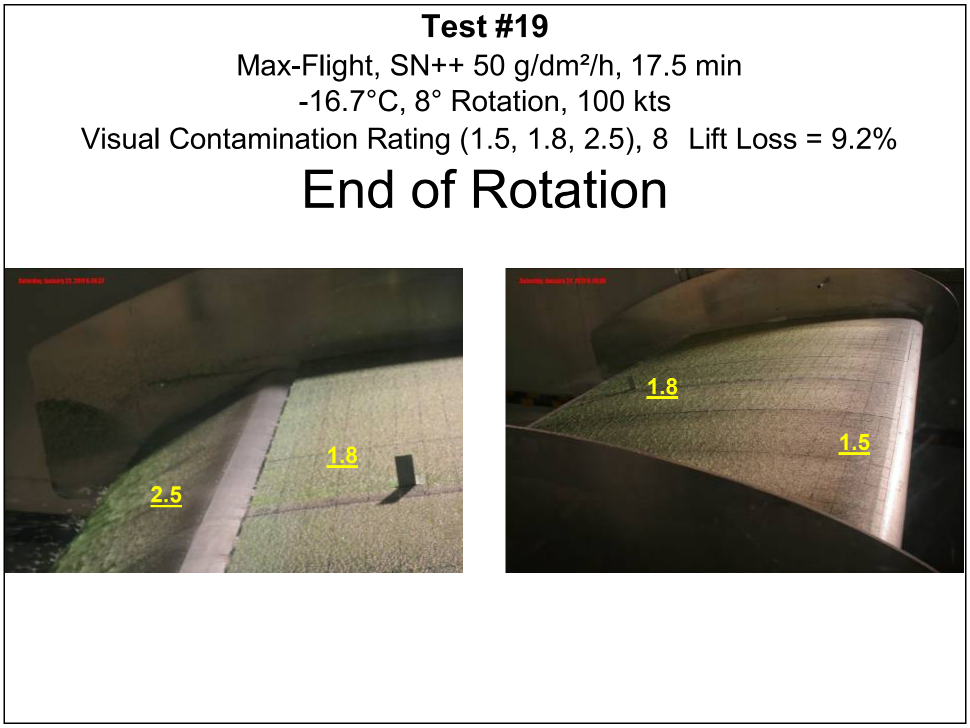
Max-Flight, SN++ 50 g/dm²/h, 17.5 min

-16.7°C, 8° Rotation, 100 kts

Visual Contamination Rating (1.5, 1.8, 2.5), 8 Lift Loss = 9.2%

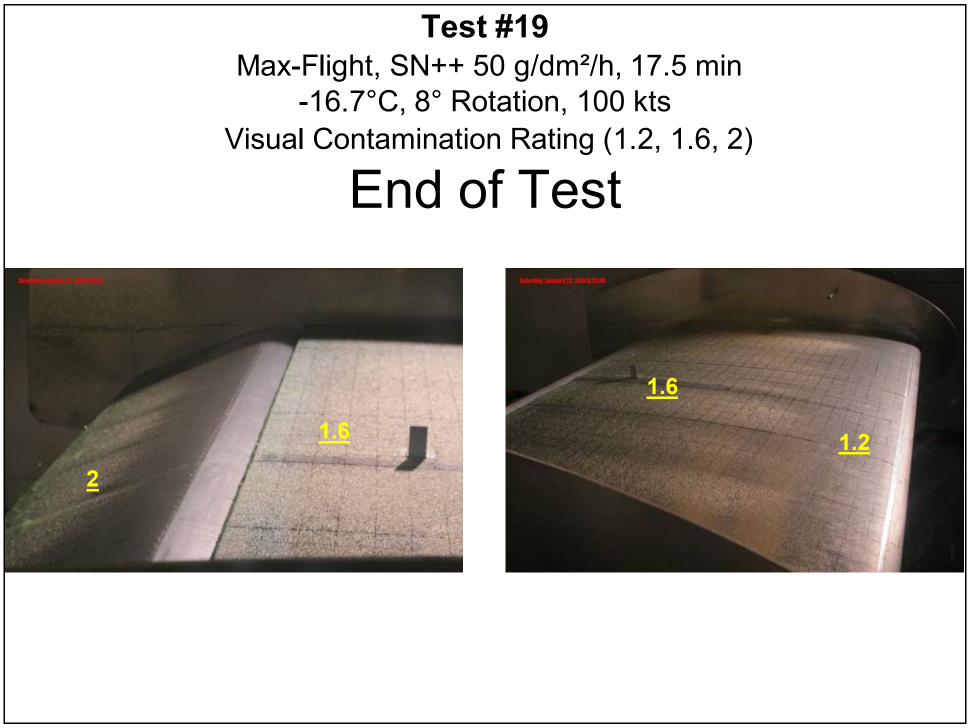
Before Rotation

Photo D107: Run #19 – End of Rotation



Test #19
Max-Flight, SN++ 50 g/dm²/h, 17.5 min
-16.7°C, 8° Rotation, 100 kts
Visual Contamination Rating (1.5, 1.8, 2.5), 8 Lift Loss = 9.2%
End of Rotation

Photo D108: Run #19 – End of Test



Test #19
Max-Flight, SN++ 50 g/dm²/h, 17.5 min
-16.7°C, 8° Rotation, 100 kts
Visual Contamination Rating (1.2, 1.6, 2)
End of Test

Photo D109: Run #87 – Start of Test

Test #87

ABC-S Plus, SN 25 g/dm²/h, 60 min

-11.1°C, 8° Rotation, 115 kts

Visual Contamination Rating (3.8, 3.3, 4)

Start of Test

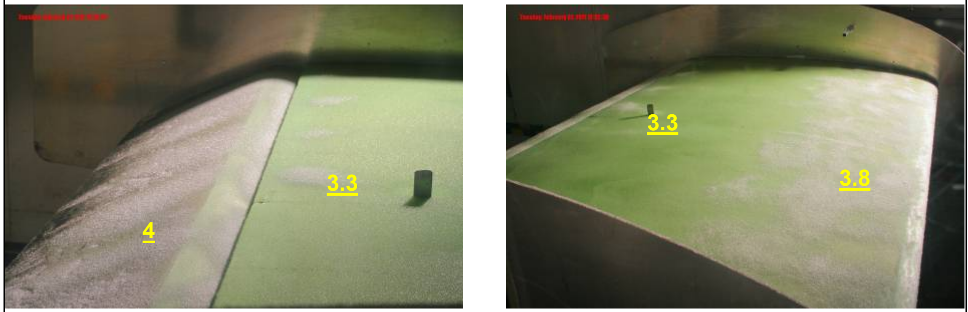


Photo D110: Run #87 – Before Rotation

Test #87

ABC-S Plus, SN 25 g/dm²/h, 60 min

-11.1°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.9, 2.2, 3.2), 8 Lift Loss = 11.95%

Before Rotation

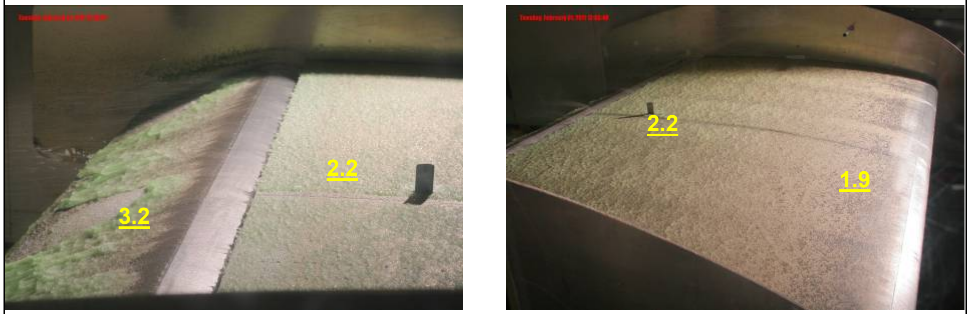
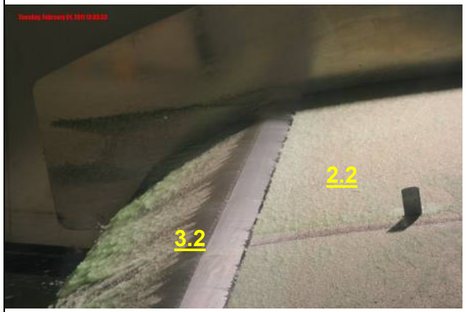


Photo D111: Run #87 – End of Rotation

Test #87
ABC-S Plus, SN 25 g/dm²/h, 60 min
-11.1°C, 8° Rotation, 115 kts
Visual Contamination Rating (1.9, 2.2, 3.2), 8 Lift Loss = 11.95%

End of Rotation



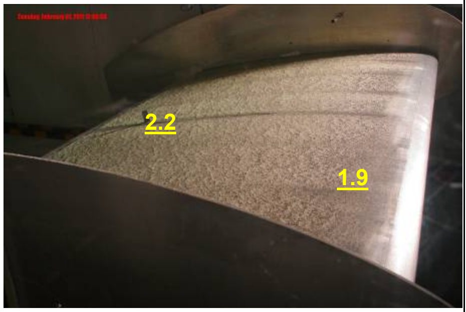


Photo D112: Run #87 – End of Test

Test #87
ABC-S Plus, SN 25 g/dm²/h, 60 min
-11.1°C, 8° Rotation, 115 kts
Visual Contamination Rating (1.3, 2.2, 2.7)

End of Test

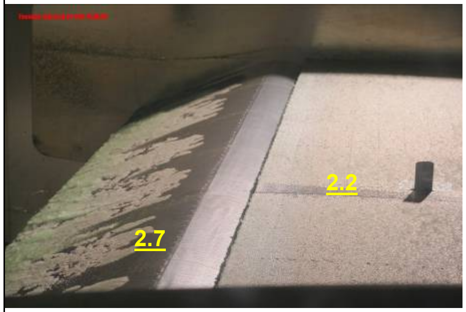


Photo D113: Run #88 – Start of Test

Test #88

ABC-S Plus, SN++ 50 g/dm²/h, 30 min

-11.8°C, 8° Rotation, 115 kts

Visual Contamination Rating (3.8, 3.2, 4)

Start of Test

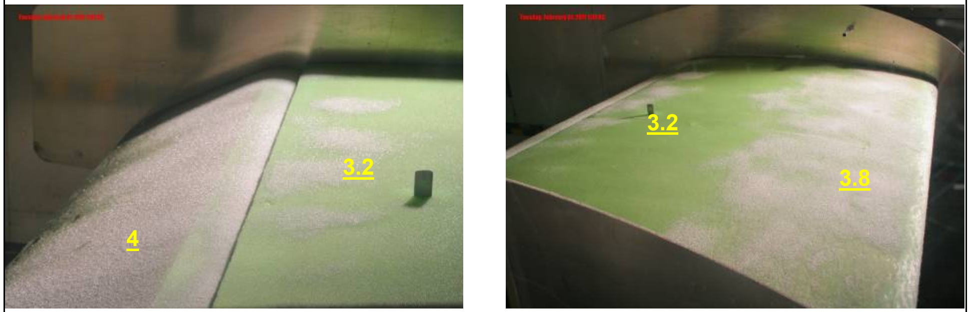


Photo D114: Run #88 – Before Rotation

Test #88

ABC-S Plus, SN++ 50 g/dm²/h, 30 min

-11.8°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.9, 2.2, 2.9), 8 Lift Loss = 13.5%

Before Rotation

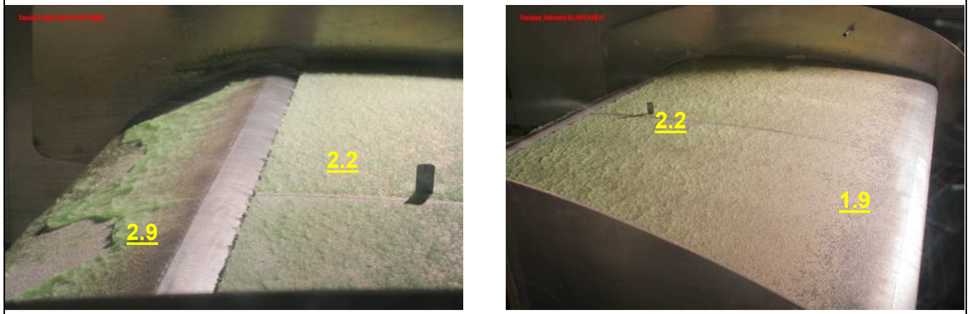


Photo D115: Run #88 – End of Rotation

Test #88

ABC-S Plus, SN++ 50 g/dm²/h, 30 min

-11.8°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.9, 2.2, 2.9), 8 Lift Loss = 13.5%

End of Rotation

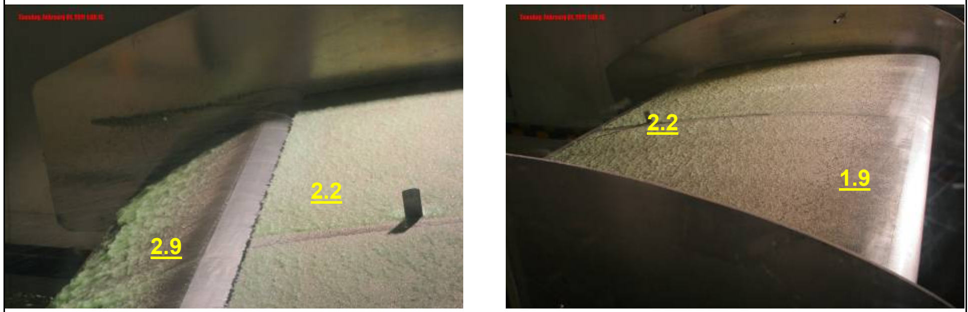


Photo D116: Run #88 – End of Test

Test #88

ABC-S Plus, SN++ 50 g/dm²/h, 30 min

-11.8°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.3, 2, 2.4)

End of Test

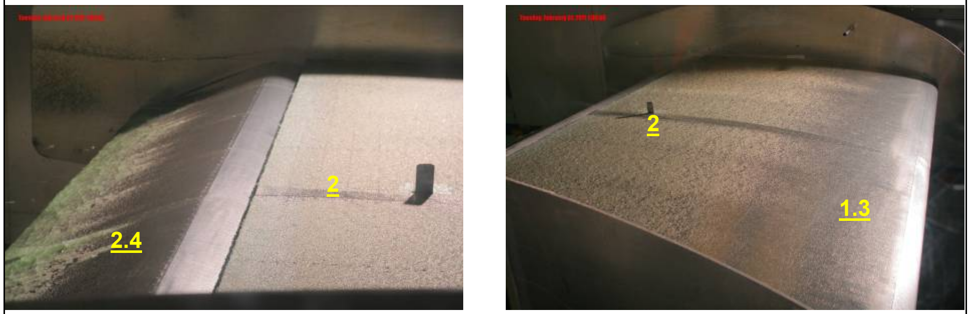


Photo D117: Run #89 – Start of Test

Test #89

ABC-S Plus, SN++ 100 g/dm²/h, 15 min

-13.4°C, 8° Rotation, 115 kts

Visual Contamination Rating (3.8, 3.4, 4)

Start of Test

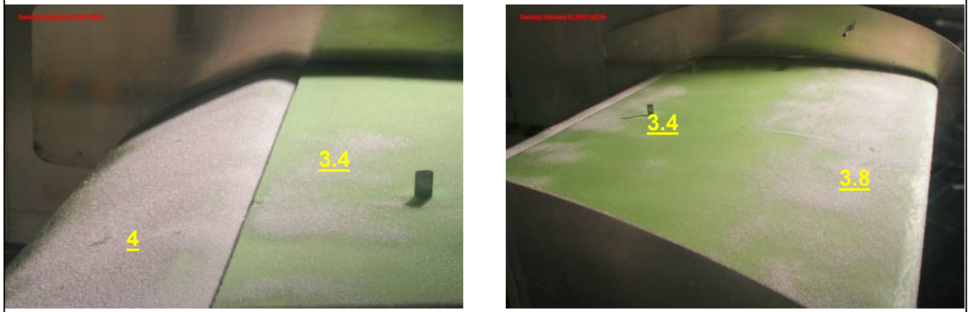


Photo D118: Run #89 – Before Rotation

Test #89

ABC-S Plus, SN++ 100 g/dm²/h, 15 min

-13.4°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.9, 2.6, 3.3)

Before Rotation

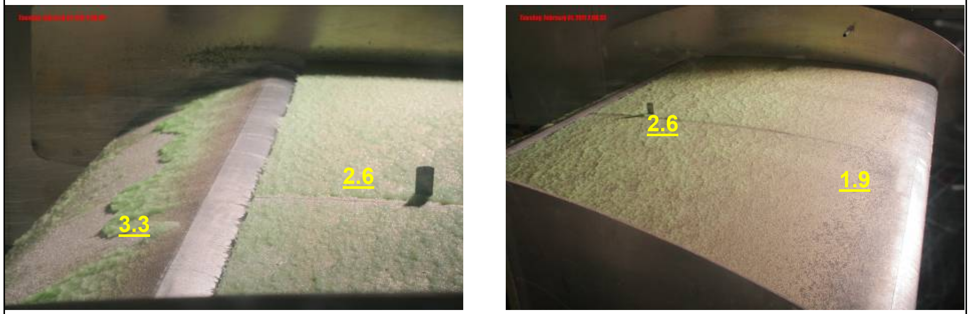
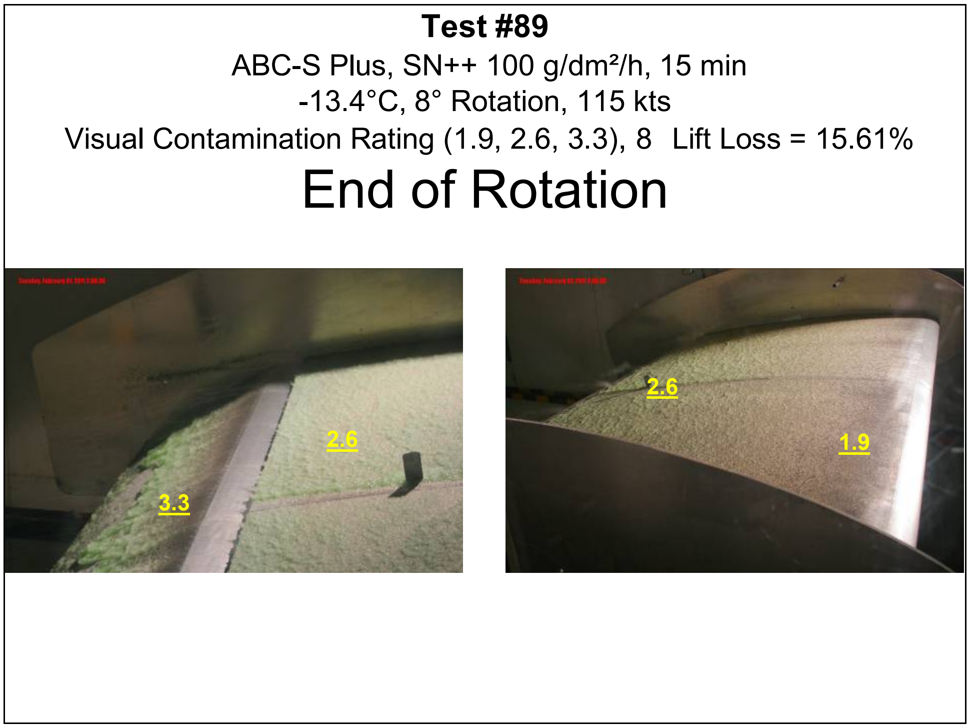


Photo D119: Run #89 – End of Rotation



Test #89

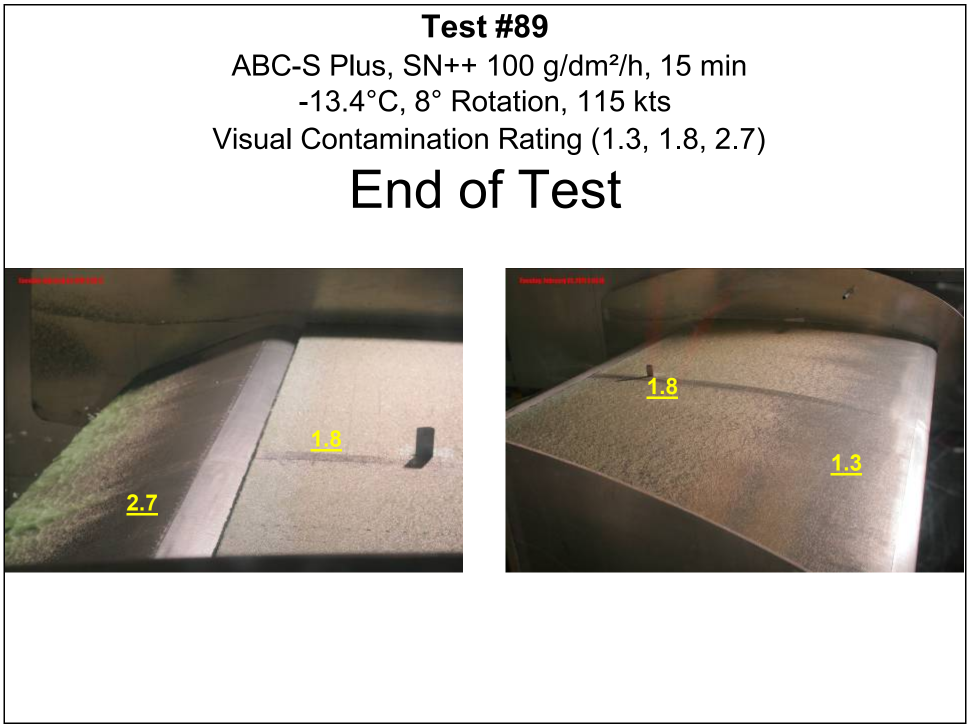
ABC-S Plus, SN++ 100 g/dm²/h, 15 min

-13.4°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.9, 2.6, 3.3), 8 Lift Loss = 15.61%

End of Rotation

Photo D120: Run #89 – End of Test



Test #89

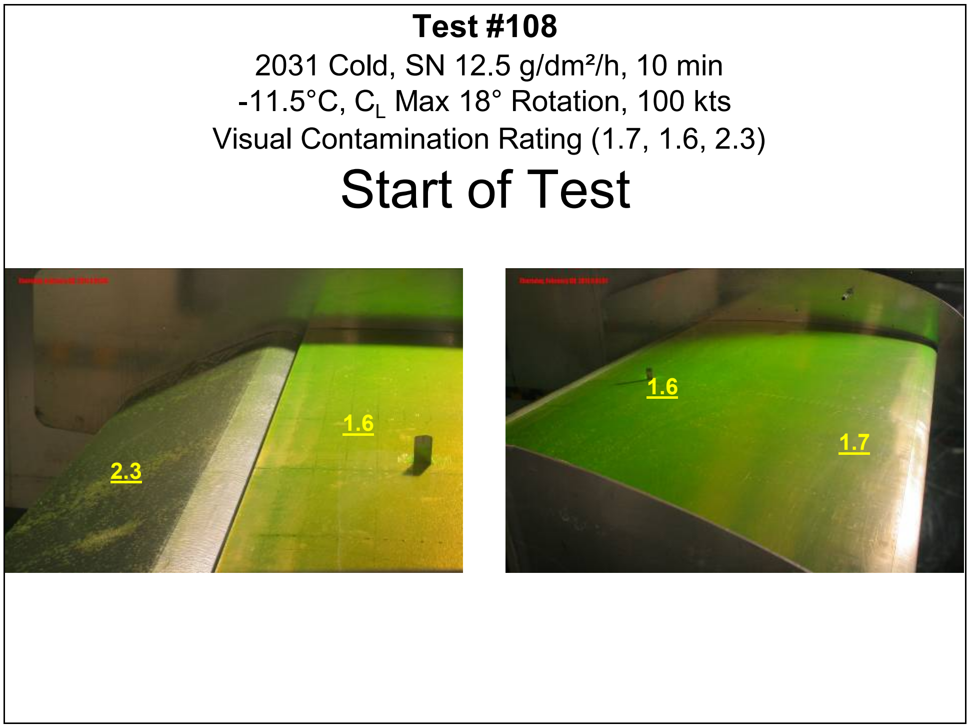
ABC-S Plus, SN++ 100 g/dm²/h, 15 min

-13.4°C, 8° Rotation, 115 kts

Visual Contamination Rating (1.3, 1.8, 2.7)

End of Test

Photo D121: Run 108 – Start of Test



Test #108

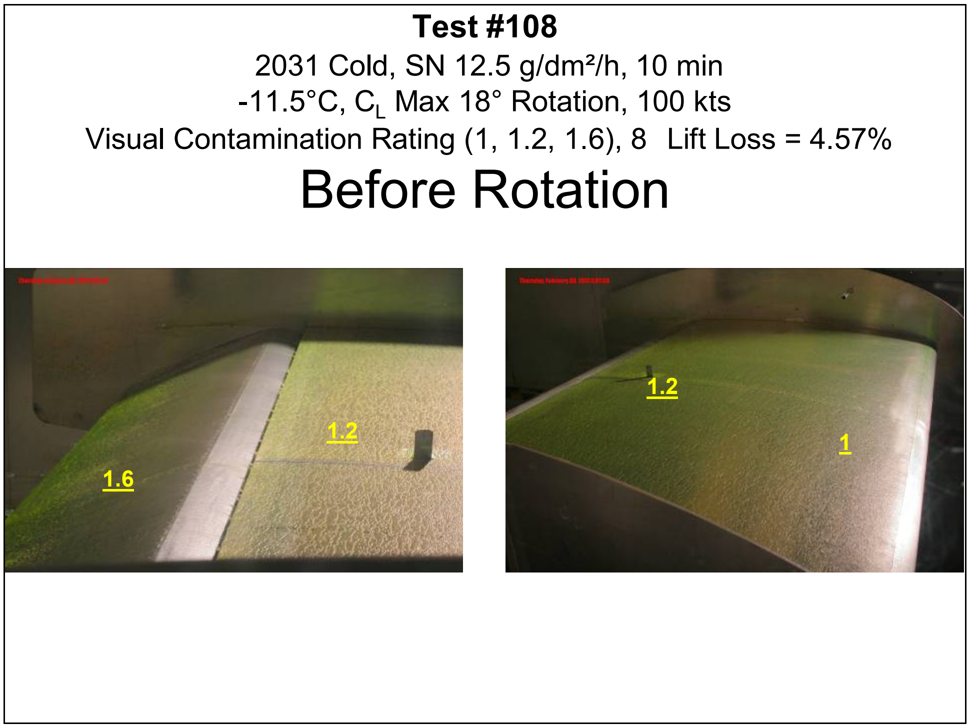
2031 Cold, SN 12.5 g/dm²/h, 10 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.7, 1.6, 2.3)

Start of Test

Photo D122: Run #108 – Before Rotation



Test #108

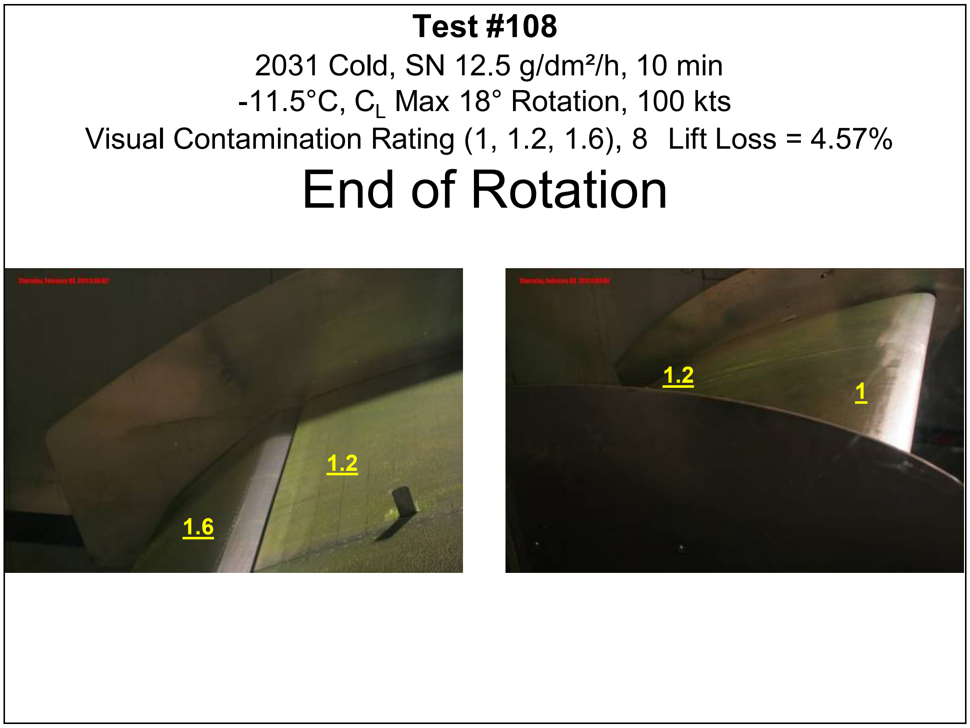
2031 Cold, SN 12.5 g/dm²/h, 10 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1.2, 1.6), 8 Lift Loss = 4.57%

Before Rotation

Photo D123: Run #108 – End of Rotation



Test #108

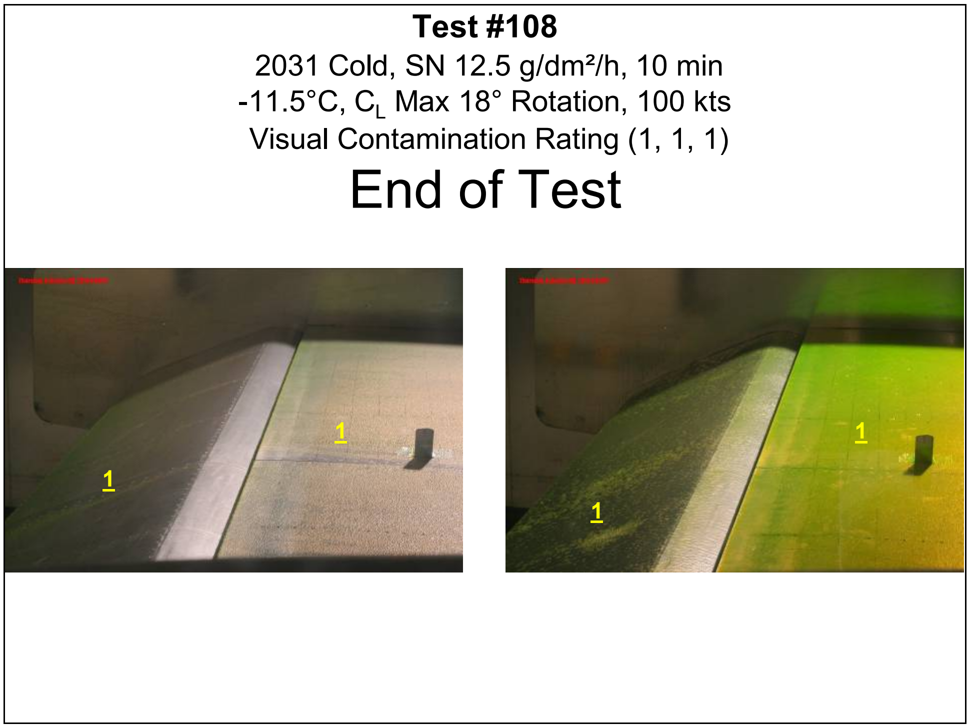
2031 Cold, SN 12.5 g/dm²/h, 10 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1.2, 1.6), 8 Lift Loss = 4.57%

End of Rotation

Photo D124: Run #108 – End of Test



Test #108

2031 Cold, SN 12.5 g/dm²/h, 10 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

End of Test

Photo D125: Run #108A – Start of Test

Test #108A

2031 Cold, SN 25 g/dm²/h, 15 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (3.5, 1.8, 4)

Start of Test

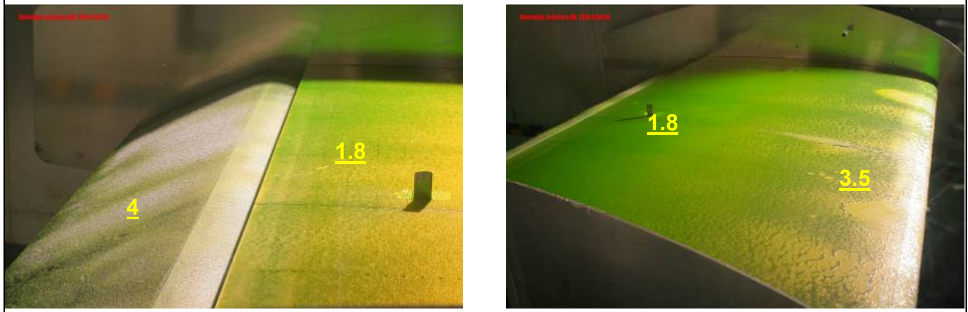


Photo D126: Run #108A – Before Rotation

Test #108A

2031 Cold, SN 25 g/dm²/h, 15 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.25, 1.5, 2.25), 8 Lift Loss = 6.4%

Before Rotation

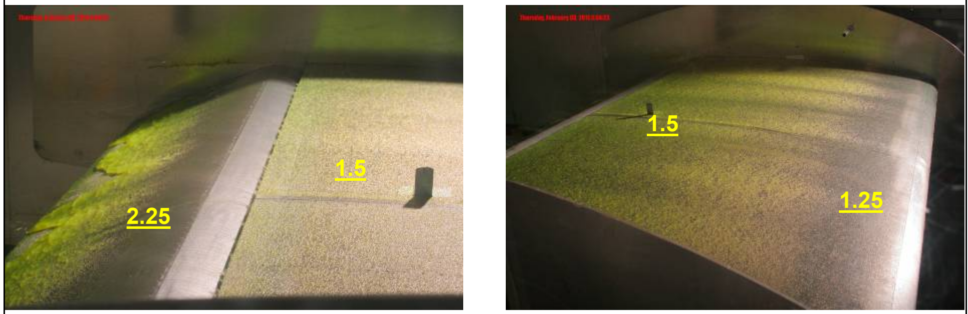


Photo D127: Run #108A – End of Rotation

Test #108A

2031 Cold, SN 25 g/dm²/h, 15 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.25, 1.5, 2.25), 8 Lift Loss = 6.4%

End of Rotation

Photo D128: Run #108A – End of Test

Test #108A

2031 Cold, SN 25 g/dm²/h, 15 min

-11.5°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.1, 1.1, 1.1)

End of Test

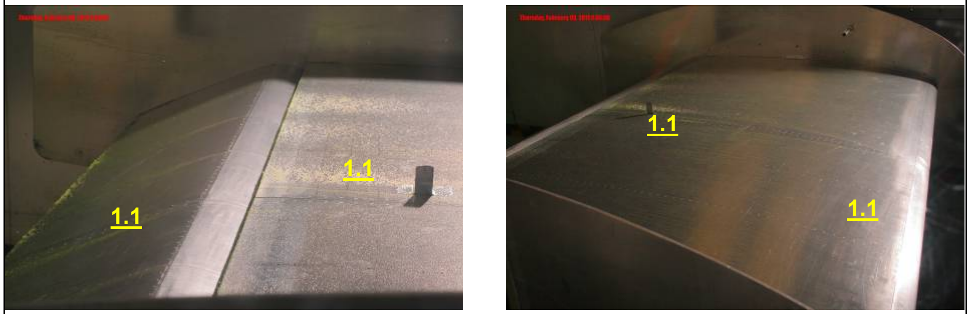
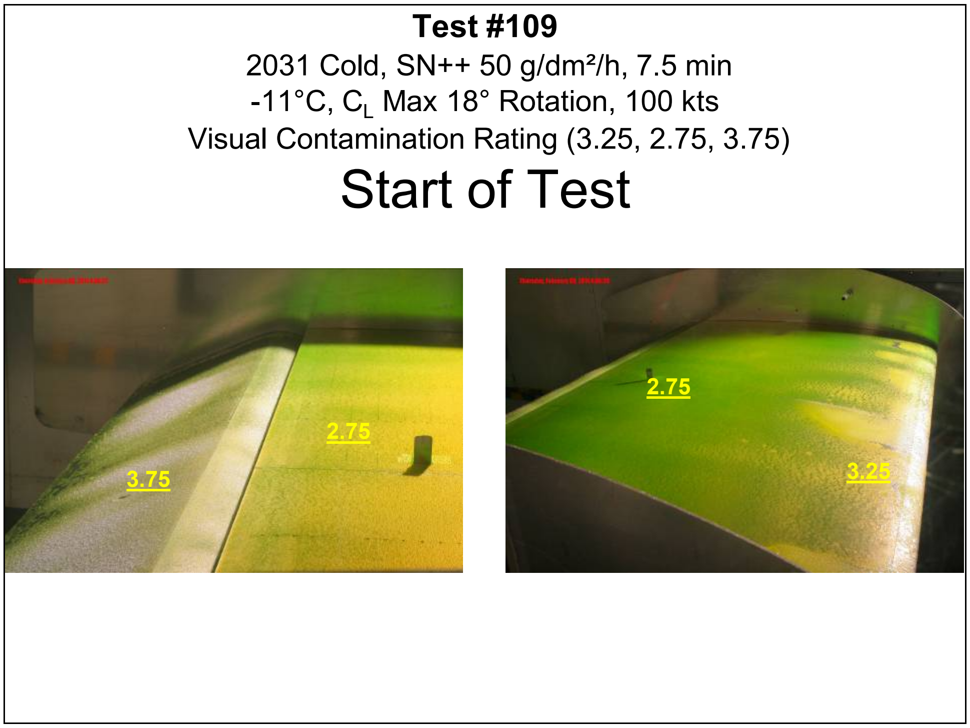


Photo D129: Run #109 – Start of Test



Test #109

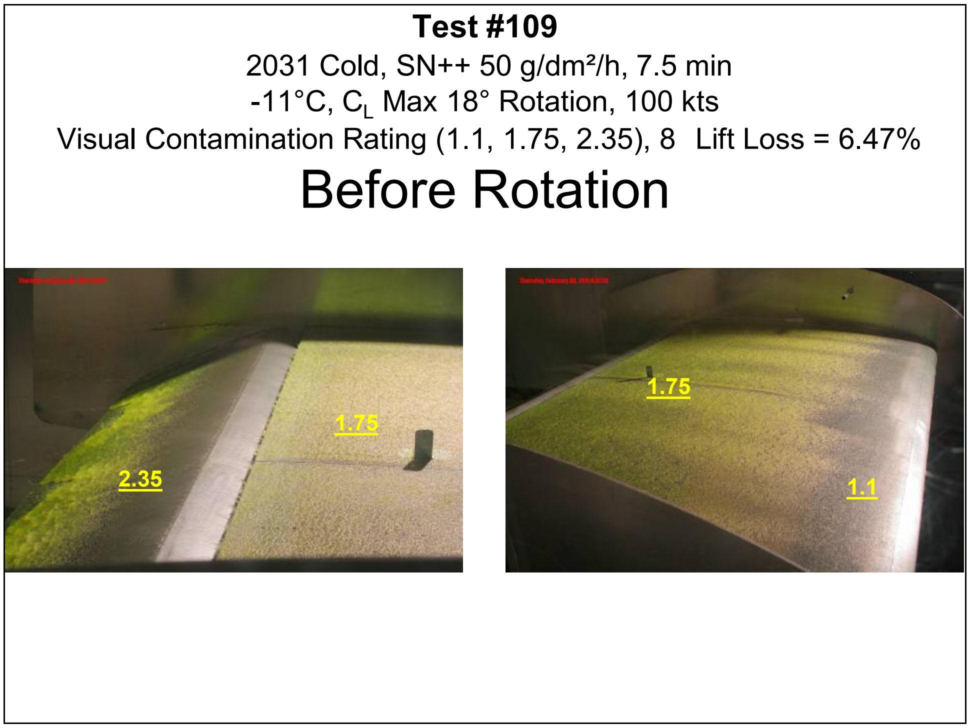
2031 Cold, SN++ 50 g/dm²/h, 7.5 min

-11°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (3.25, 2.75, 3.75)

Start of Test

Photo D130: Run #109 – Before Rotation



Test #109

2031 Cold, SN++ 50 g/dm²/h, 7.5 min

-11°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.1, 1.75, 2.35), 8 Lift Loss = 6.47%

Before Rotation

Photo D131: Run #109 – End of Rotation

Test #109

2031 Cold, SN++ 50 g/dm²/h, 7.5 min

-11°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1.1, 1.75, 2.35), 8 Lift Loss = 6.47%

End of Rotation

Photo D132: Run #109 – End of Test

Test #109

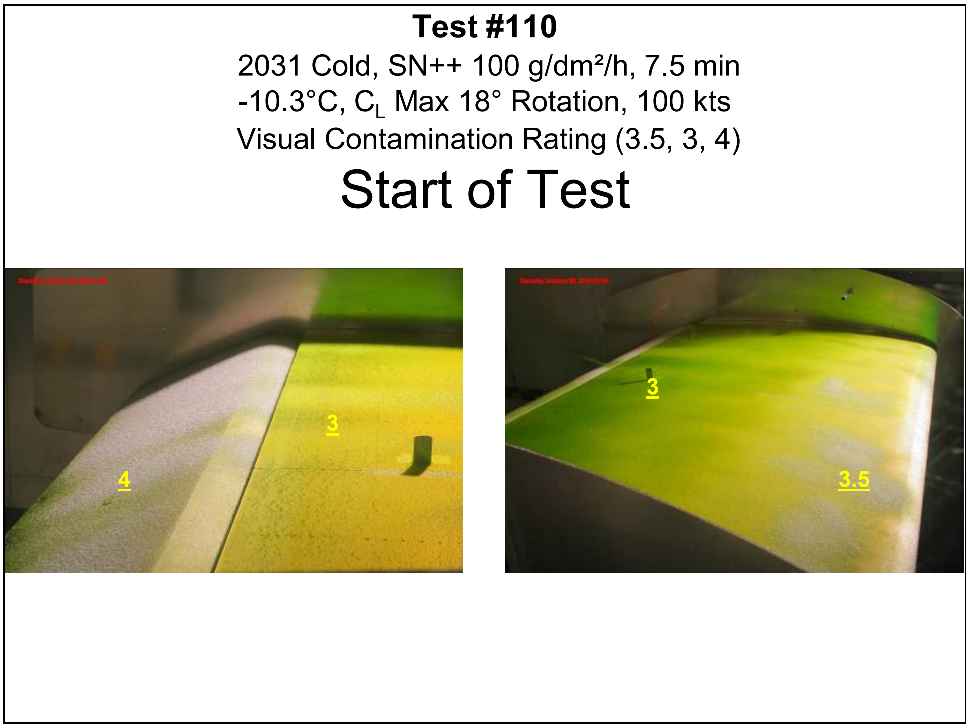
2031 Cold, SN++ 50 g/dm²/h, 7.5 min

-11°C, C_L Max 18° Rotation, 100 kts

Visual Contamination Rating (1, 1.2, 1.1)

End of Test

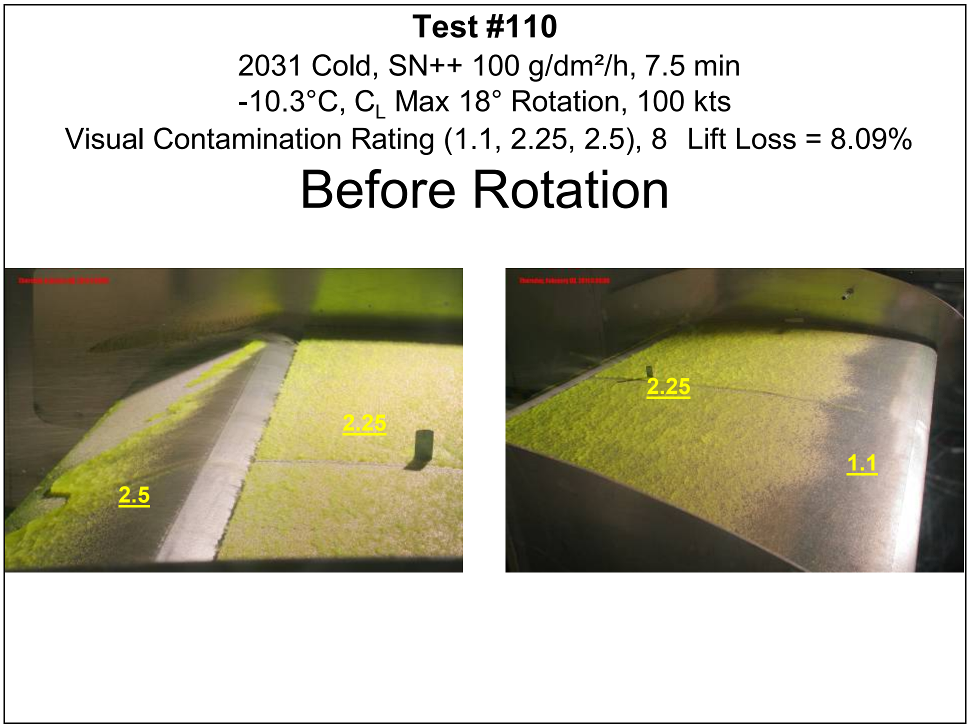
Photo D133: Run #110 – Start of Test



Test #110
2031 Cold, SN++ 100 $g/dm^2/h$, 7.5 min
-10.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (3.5, 3, 4)

Start of Test

Photo D134: Run #110 – Before Rotation



Test #110
2031 Cold, SN++ 100 $g/dm^2/h$, 7.5 min
-10.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1.1, 2.25, 2.5), 8 Lift Loss = 8.09%

Before Rotation

Photo D135: Run #110 – End of Rotation

Test #110
2031 Cold, SN++ 100 g/dm²/h, 7.5 min
-10.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1.1, 2.25, 2.5), 8 Lift Loss = 8.09%

End of Rotation

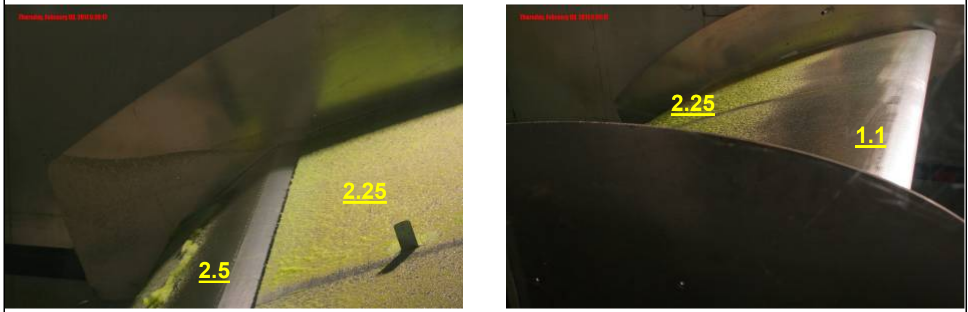


Photo D136: Run #110 – End of Test

Test #110
2031 Cold, SN++ 100 g/dm²/h, 7.5 min
-10.3°C, C_L Max 18° Rotation, 100 kts
Visual Contamination Rating (1, 1.75, 2.6)

End of Test

COMPARISON OF MULTIPLE FLUID FLOW OFF PROPERTIES

Photo D137: Run #90 – Start of Test

Test #90

EG106 + ABC-S Plus 09 + ABC-S Plus 10 + Max-Flight , Fluid Only

-11.9°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

Start of Test

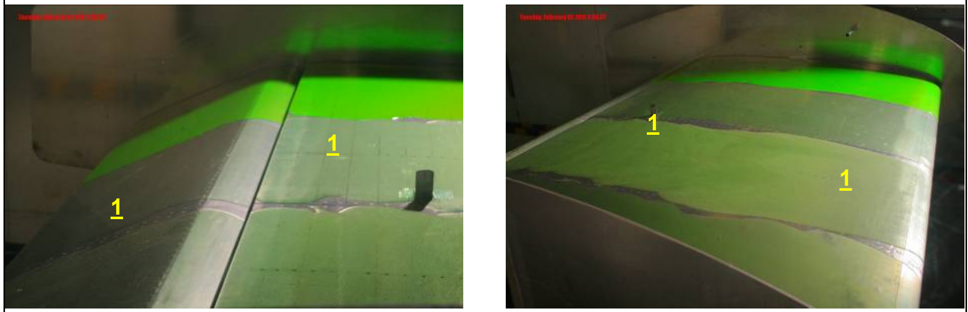


Photo D138: Run #90 – Before Rotation

Test #90

EG106 + ABC-S Plus 09 + ABC-S Plus 10 + Max-Flight , Fluid Only

-11.9°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 6.47%

Before Rotation

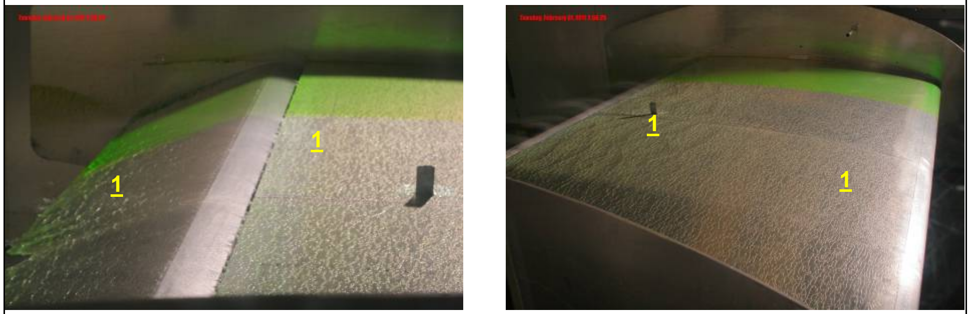


Photo D139: Run #90 – End of Rotation

Test #90

EG106 + ABC-S Plus 09 + ABC-S Plus 10 + Max-Flight , Fluid Only
-11.9°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 6.47%

End of Rotation

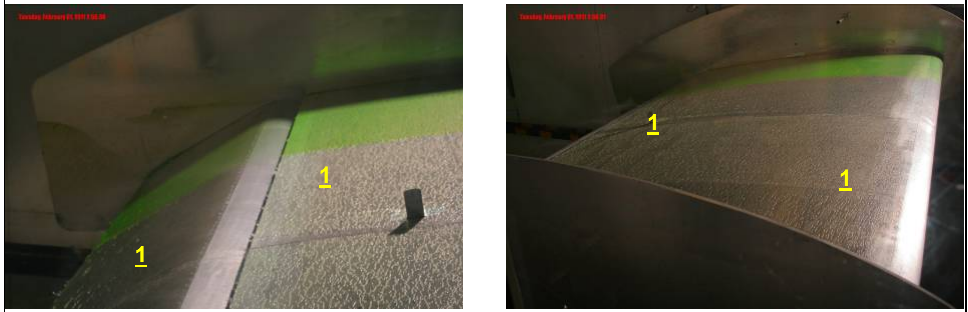


Photo D140: Run #90 – End of Test

Test #90

EG106 + ABC-S Plus 09 + ABC-S Plus 10 + Max-Flight , Fluid Only
-11.9°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1)

End of Test

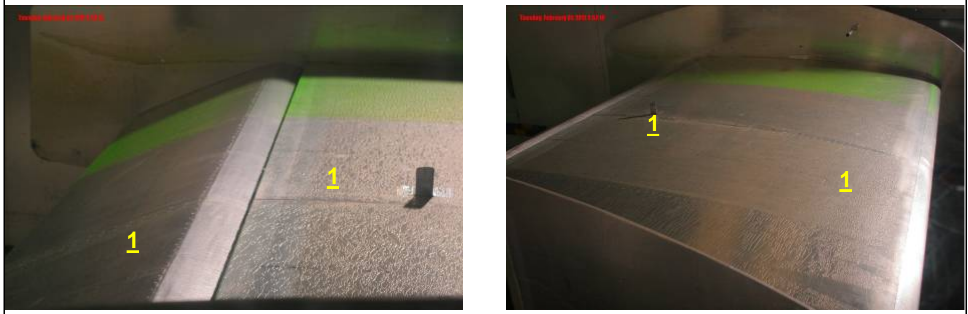
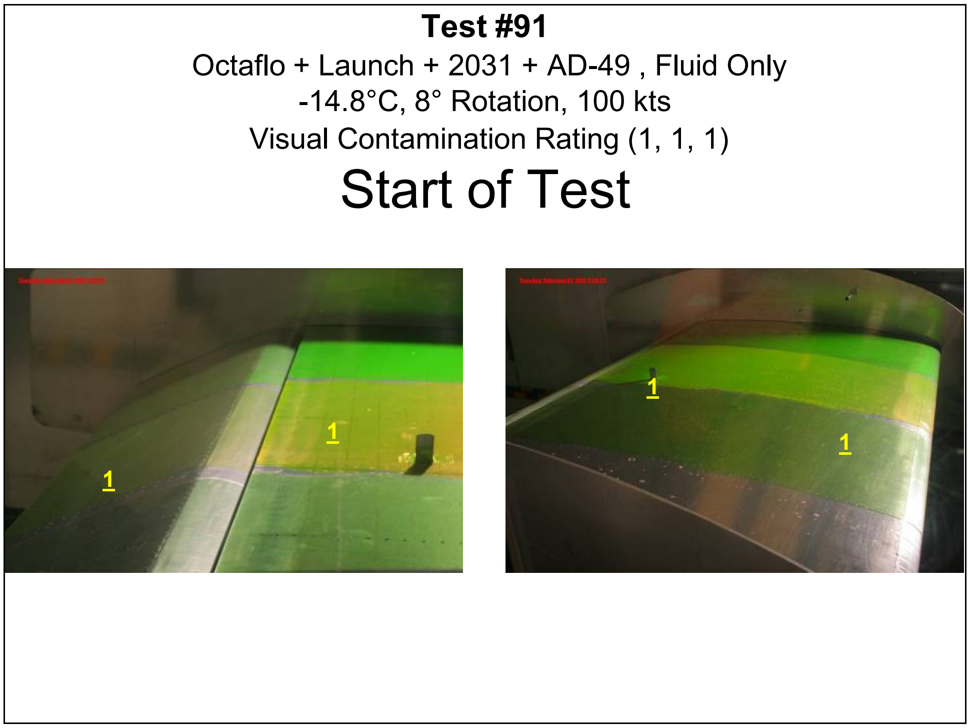


Photo D141: Run #91 – Start of Test



Test #91

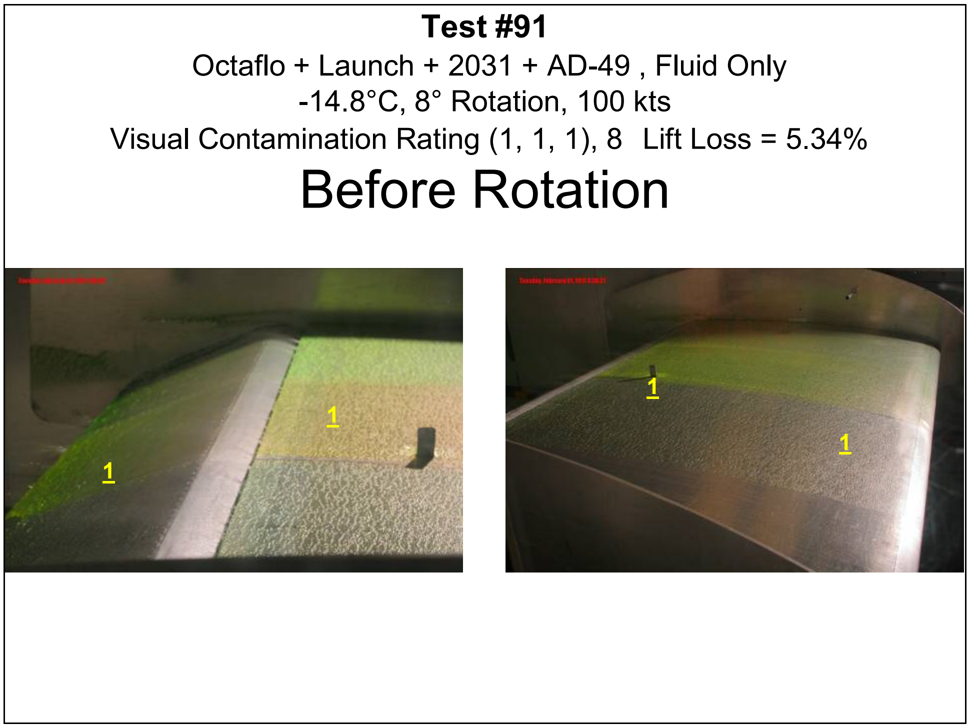
Octaflo + Launch + 2031 + AD-49 , Fluid Only

-14.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1)

Start of Test

Photo D142: Run #91 – Before Rotation



Test #91

Octaflo + Launch + 2031 + AD-49 , Fluid Only

-14.8°C, 8° Rotation, 100 kts

Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 5.34%

Before Rotation

Photo D143: Run #91 – End of Rotation

Test #91
Octaflo + Launch + 2031 + AD-49 , Fluid Only
-14.8°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1), 8 Lift Loss = 5.34%

End of Rotation

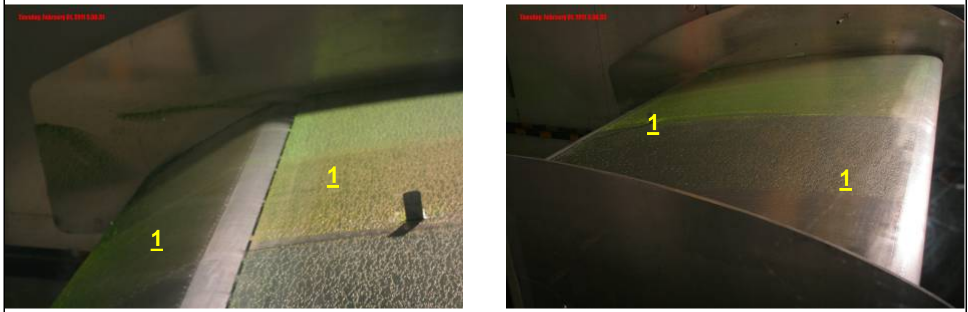


Photo D144: Run #91 – End of Test

Test #91
Octaflo + Launch + 2031 + AD-49 , Fluid Only
-14.8°C, 8° Rotation, 100 kts
Visual Contamination Rating (1, 1, 1)

End of Test