

# WIND TUNNEL TRIALS TO SUPPORT FURTHER DEVELOPMENT OF ICE PELLET ALLOWANCE TIMES: WINTER 2019-20

*Prepared for:*

**Transport Canada Innovation Centre**

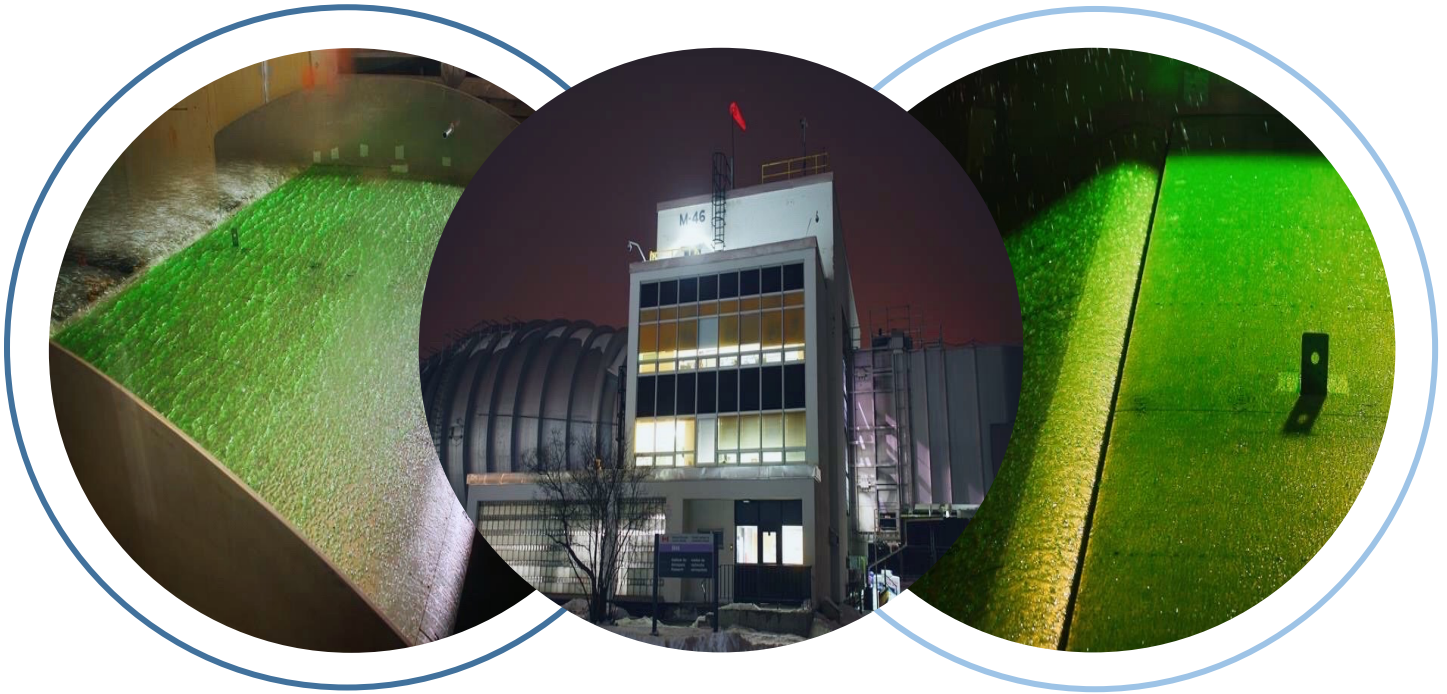
*In cooperation with:*

**Federal Aviation Administration William J. Hughes Technical Center**

**Transport Canada Civil Aviation**

**Federal Aviation Administration Flight Standards – Air Carrier Operations**





# WIND TUNNEL TRIALS TO SUPPORT FURTHER DEVELOPMENT OF ICE PELLET ALLOWANCE TIMES: WINTER 2019-20

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Un sommaire français se trouve avant la table des matières.

<p><i>This report was first provided to Transport Canada as Final Draft 1.0 in October 2020. It has been published as Final Version 1.0 in August 2021.</i></p>
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## PREFACE

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

- To develop holdover time data for all new de/anti-icing fluids;
- To conduct testing to determine holdover times for Type II and Type IV fluids in snow at temperatures below  $-14^{\circ}\text{C}$ ;
- To conduct additional testing and analysis to evaluate and/or determine appropriate holdover times for Type I fluids in snow at temperatures below  $-14^{\circ}\text{C}$ ;
- To evaluate and develop the use of artificial snow for holdover time development;
- To conduct wind tunnel testing with a thin high performance wing model to support the development of guidance material for operating in ice pellet conditions;
- To conduct wind tunnel testing with a vertical stabilizer model to characterize clean and contaminated fluid flow-off before and after a simulated takeoff;
- To conduct further research for the development of temperature-specific snow holdover time data;
- To conduct general and exploratory de/anti-icing research;
- To finalize the publication and delivery of current and historical reports;
- To update the regression information report to reflect changes made to the holdover time guidelines; and
- To update the holdover time guidance materials for annual publication by Transport Canada and the Federal Aviation Administration.

Some project timelines were impacted due to the COVID-19 pandemic. The details of these impacts are described in the individual reports, if applicable. The research activities of the program conducted on behalf of Transport Canada during the winter of 2019-20 are documented in six reports. The titles of the reports are as follows:

- TP 15450E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2019-20 Winter;
- TP 15451E Regression Coefficients and Equations Used to Develop the Winter 2020-21 Aircraft Ground Deicing Holdover Time Tables;
- TP 15452E Aircraft Ground Icing General Research Activities During the 2019-20 Winter;
- TP 15453E Wind Tunnel Trials to Support Further Development of Ice Pellet Allowance Times: Winter 2019-20;
- TP 15454E Wind Tunnel Testing to Evaluate Contaminated Fluid Flow-Off from a Vertical Stabilizer; and

- TP 15455E Artificial Snow Research Activities for the 2018-19 and 2019-20 Winters.

This report, TP 15453E, has the following objective:

- To conduct research in the National Research Council Canada Icing Wind Tunnel with a thin high-performance wing section to further support and develop the anti-icing fluid Ice Pellet Allowance Times.

This objective was met by conducting a series of full-scale tests using a thin high-performance wing model in the National Research Council Canada Icing Wind Tunnel with the cooperation of Transport Canada and the Federal Aviation Administration.

## **PROGRAM ACKNOWLEDGEMENTS**

This multi-year research program has been funded by the Transport Canada Innovation Centre, with support from the Federal Aviation Administration William J. Hughes Technical Center, Transport Canada Civil Aviation, and Federal Aviation Administration Flight Standards – Air Carrier Operations. This program could not have been accomplished without the participation of many organizations. APS Aviation Inc. would therefore like to thank Transport Canada, the Federal Aviation Administration, National Research Council Canada, and supporting members of the SAE International G-12 Aircraft Ground Deicing Committees.

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data, completion of data analysis, and preparation of reports. This includes the following people: Brandon Auclair, David Beals, Steven Baker, Stephanie Bendickson, Benjamin Bernier, Chloë Bernier, Chris D'Avirro, John D'Avirro, Peter Dawson, Jaycee Ewald, Noemie Gokhool, Benjamin Guthrie, Shaney Herrmann, Peter Kitchener, Shahdad Movaffagh, Dany Posteraro, Annaelle Reuveni, Marco Ruggi, Javad Safari, James Smyth, Saba Tariq, Jodi Wilson, Ian Wittmeyer, and David Youssef.

Special thanks are extended to Antoine Lacroix, Yvan Chabot, Deborah deGrasse, Warren Underwood, and Charles J. Enders, who on behalf of Transport Canada and the Federal Aviation Administration, have participated, contributed, and provided guidance in the preparation of these documents.

## **PROJECT ACKNOWLEDGEMENTS**

APS Aviation Inc. would like to acknowledge the team at National Research Council Canada who operate the icing wind tunnel, especially Catherine Clark, Arash Raeesi, and Richard Lee for engineering support and aerodynamic expertise. APS Aviation Inc. would like to acknowledge Andy Broeren of National Aeronautics and Space Administration whose engineering support and aerodynamic expertise have been crucial to the development of wind tunnel testing protocols used today. APS Aviation Inc. would also like to acknowledge the fluid manufacturers who have provided samples over the years to support the wind tunnel testing.



1. Transport Canada Publication No. <b>TP 15453E</b>	2. Project No. <b>B14W</b>	3. Recipient's Catalogue No.		
4. Title and Subtitle <b>Wind Tunnel Trials to Support Further Development of Ice Pellet Allowance Times: Winter 2019-20</b>		5. Publication Date <b>October 2020</b>		
		6. Performing Organization Document No. <b>300293</b>		
7. Author(s) <b>Marco Ruggi</b>		8. Transport Canada File No. <b>2450-BP-14</b>		
9. Performing Organization Name and Address <b>APS Aviation Inc. 6700 Côte-de-Liesse Rd., Suite 102 Montreal, Quebec, H4T 2B5</b>		10. PWGSC File No. <b>TOR-7-40103</b>		
		11. PWGSC or Transport Canada Contract No. <b>T8156-170044/001/TOR</b>		
12. Sponsoring Agency Name and Address <b>Transport Canada Innovation Centre 330 Sparks St., 18th Floor Ottawa, Ontario, K1A 0N5</b>		13. Type of Publication and Period Covered <b>Final</b>		
		14. Project Officer <b>Antoine Lacroix</b>		
15. Supplementary Notes (Funding programs, titles of related publications, etc.) <b>Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada (TC). These are available from the TC Innovation Centre. Several reports were produced as part of this winter's research program. Their subject matter is outlined in the preface. This project was co-sponsored by the Federal Aviation Administration.</b>				
16. Abstract <p>As part of a larger research program examining de/anti-icing fluid flow-off during simulated aircraft takeoff, APS Aviation Inc. conducted a series of full-scale wing tests in the National Research Council Canada Icing Wind Tunnel to determine the flow-off characteristics of anti-icing fluid with and without mixed precipitation conditions with ice pellets.</p> <p>A wind tunnel testing program was developed for the winter of 2019-20 with the primary objectives of conducting aerodynamic testing to substantiate the current Type IV fluid Ice Pellet Allowance Times with new fluids, and possibly extend the current Type IV fluid Ice Pellet Allowance Times for ethylene glycol (EG).</p> <p>The wind tunnel testing conducted during the winter of 2019-20 validated the current Type IV allowance times for use with the new to market fluid: Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH.</p> <p>EG fluid testing and an analysis of historical data indicated the potential for longer allowance times specific to EG fluids. It was concluded that the expansion of the allowance times for EG fluids requires additional data.</p> <p>The results of the validation and EG expansion testing did not require any changes to the current Ice Pellet Allowance Times or supporting guidance material. As such, no changes were issued to the Ice Pellet Allowance Times published in the Holdover Time Guidelines for the winter of 2020-21.</p>				
17. Key Words <b>Ice Pellet, Allowance Time, High Speed Rotation, Low Speed Rotation, Type II, Type III, Type IV, Fluid Adherence, Fluid Flow-Off, Wind Tunnel, Icing Wind Tunnel, Wing Aerodynamics.</b>		18. Distribution Statement <b>Available from the Transport Canada Innovation Centre</b>		
19. Security Classification (of this publication) <b>Unclassified</b>	20. Security Classification (of this page) <b>Unclassified</b>	21. Declassification (date) <b>—</b>	22. No. of Pages <b>xvi, 50 apps</b>	23. Price <b>—</b>



1. No de la publication de Transports Canada <b>TP 15453E</b>		2. No de l'étude <b>B14W</b>		3. No de catalogue du destinataire	
4. Titre et sous-titre <b>Wind Tunnel Trials to Support Further Development of Ice Pellet Allowance Times: Winter 2019-20</b>				5. Date de la publication <b>Octobre 2020</b>	
				6. No de document de l'organisme exécutant <b>300293</b>	
7. Auteur(s) <b>Marco Ruggi</b>				8. No de dossier - Transports Canada <b>2450-BP-14</b>	
9. Nom et adresse de l'organisme exécutant <b>APS Aviation Inc. 6700, Chemin de la Côte-de-Liesse, Bureau 102 Montréal (Québec) H4T 2B5</b>				10. No de dossier - TPSGC <b>TOR-7-40103</b>	
				11. No de contrat - TPSGC ou Transports Canada <b>T8156-170044/001/TOR</b>	
12. Nom et adresse de l'organisme parrain <b>Transports Canada Centre d'innovation 330, rue Sparks, 18ième étage Ottawa (Ontario) K1A 0N5</b>				13. Genre de publication et période visée <b>Final</b>	
				14. Agent de projet <b>Antoine Lacroix</b>	
15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.) <b>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 (TC). Ils sont disponibles auprès du Centre d'innovation de TC. De nombreux rapports ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos. Ce projet était coparrainé par la Federal Aviation Administration.</b>					
16. Résumé <b>Dans le cadre d'un plus vaste programme de recherche étudiant le ruissellement du liquide de dégivrage et d'antigivrage durant le décollage simulé d'un aéronef, APS Aviation Inc. a mené une série d'essais sur des ailes pleine grandeur dans la soufflerie de givrage du Conseil national de recherches Canada afin de déterminer les caractéristiques de ruissellement du liquide d'antigivrage avec et sans conditions de précipitations mixtes comprenant des granules de glace.</b> <b>Un programme d'essais en soufflerie a été élaboré pour l'hiver 2019-2020 avec comme principaux objectifs de réaliser des tests aérodynamiques visant à corroborer les marges de tolérance actuelles pour les granules de glace avec de nouveaux liquides de type IV, à possiblement élargir les marges de tolérance actuelles dans des conditions de granules de glace pour les liquides de type IV à base d'éthylène glycol.</b> <b>Les essais de soufflerie menés durant l'hiver 2019-2020 sur des liquides de type IV ont permis de valider les marges de tolérance actuelles à utiliser avec le nouveau liquide sur le marché : Safewing EG IV NORTH de Clariant Produkte (Deutschland) GmbH.</b> <b>Les résultats d'essais réalisés sur les liquides à base d'éthylène glycol et d'une analyse des données historiques indiquent que les marges de tolérance spécifiques à ces liquides pourraient être augmentées. Il a été conclu que l'élargissement des marges de tolérance pour les liquides à base d'éthylène glycol doit être étayé par des données supplémentaires.</b> <b>Aucun changement n'a dû être apporté aux marges de tolérance actuelles pour les granules de glace ou aux lignes directrices connexes en raison des résultats des essais de validation et d'élargissement des marges pour les liquides à base d'éthylène glycol. Par conséquent, aucun changement n'a été apporté aux marges de tolérance pour les granules de glace publiées dans les lignes directrices sur les durées d'efficacité pour l'hiver 2020-2021.</b>					
17. Mots clés <b>Granule de glace, marge de tolérance, rotation à haute vitesse, rotation à basse vitesse, type II, type III, type IV, adhérence de liquide, écoulement de liquide, soufflerie, soufflerie de givrage, aérodynamisme des ailes</b>			18. Diffusion <b>Disponible auprès du Centre d'innovation de Transports Canada</b>		
19. Classification de sécurité (de cette publication) <b>Non classifiée</b>	20. Classification de sécurité (de cette page) <b>Non classifiée</b>	21. Déclassification (date) <b>—</b>	22. Nombre de pages <b>xvi, 50 ann.</b>	23. Prix <b>—</b>	

## EXECUTIVE SUMMARY

Under contract to the Transport Canada (TC) Innovation Centre, with support from the Federal Aviation Administration (FAA) William J. Hughes Technical Center, TC Civil Aviation, and FAA Flight Standards – Air Carrier Operations, APS Aviation Inc. (APS) carried out research in the winter of 2019-20 in support of the aircraft ground icing research program.

As part of a larger research program, APS conducted a series of full-scale wing tests in the National Research Council Canada 3 m x 6 m Icing Wind Tunnel to determine the flow-off characteristics of anti-icing fluid with and without mixed precipitation conditions with ice pellets.

### Background and Objective

A wind tunnel testing program was developed for the winter of 2019-20 with the primary objectives of conducting aerodynamic testing to:

- Substantiate the current Type IV fluid Ice Pellet Allowance Times with new fluids using the thin high-performance regional jet (RJ) airfoil and, weather permitting, at temperatures close to the fluid lowest operational use temperature; and
- Possibly extend the current Type IV fluid Ice Pellet Allowance Times for ethylene glycol (EG) fluids using the thin high-performance RJ airfoil.

### Conclusions and Recommendations

The wind tunnel testing conducted during the winter of 2019-20 validated the current Type IV allowance times for use with the new to market fluid: Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH.

EG fluid testing and an analysis of historical data indicated the potential for longer allowance times specific to EG fluids. However, a technical review of this data was conducted, and the research group concluded that it was prudent to delay the expansion of the allowance times for EG fluids until some additional data could be collected to provide a more robust data set.

The results of the validation and EG expansion testing did not require any changes to the current Ice Pellet Allowance Times or supporting guidance material. As such, no changes were issued to the Ice Pellet Allowance Times published in the Holdover Time Guidelines for the winter of 2020-21.

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## SOMMAIRE

En vertu d'un contrat avec le Centre d'innovation de Transports Canada (TC) et avec le soutien du William J. Hughes Technical Center de la Federal Aviation Administration (FAA), du département de l'aviation civile de TC, et de la FAA Flight Standards – Air Carrier Operations, APS Aviation Inc. (APS) a mené des essais au cours de l'hiver 2019-2020 dans le cadre d'un programme de recherche sur le givrage d'aéronefs au sol.

Dans le cadre d'un plus vaste programme de recherche, APS a mené une série d'essais sur des ailes pleine grandeur dans la soufflerie de givrage de 3 m sur 6 m du Conseil national de recherches Canada afin de déterminer les caractéristiques de ruissellement du liquide d'antigivrage avec et sans conditions de précipitations mixtes comprenant des granules de glace.

### Contexte et objectif

Un programme d'essais en soufflerie a été élaboré pour l'hiver 2019-2020 avec comme principaux objectifs de réaliser des tests aérodynamiques visant à :

- Corroborer les marges de tolérance actuelles pour les granules de glace avec de nouveaux liquides de type IV au moyen d'une surface portante haute performance à profil mince d'un avion de transport régional à réaction et, selon les conditions météorologiques, à des températures se rapprochant de la température minimale d'utilisation opérationnelle ; et
- Possiblement élargir les marges de tolérance actuelles dans des conditions de granules de glace pour les liquides de type IV à base d'éthylène glycol au moyen d'une surface portante haute performance à profil mince d'un avion de transport régional à réaction.

### Conclusions and recommandations

Les essais de soufflerie menés durant l'hiver 2019-2020 sur des liquides de type IV ont permis de valider les marges de tolérance actuelles à utiliser avec le nouveau liquide sur le marché : Safewing EG IV NORTH de Clariant Produkte (Deutschland) GmbH.

Les résultats d'essais réalisés sur les liquides à base d'éthylène glycol et d'une analyse des données historiques indiquent que les marges de tolérance spécifiques à ces liquides pourraient être augmentées. Cependant, un examen technique de ces données a été effectué, et le groupe de recherche a conclu qu'il était prudent de



reporter l'élargissement des marges de tolérance pour les liquides à base d'éthylène glycol jusqu'à ce que des données supplémentaires viennent étayer ces recommandations.

Aucun changement n'a dû être apporté aux marges de tolérance actuelles pour les granules de glace ou aux lignes directrices connexes en raison des résultats des essais de validation et d'élargissement des marges pour les liquides à base d'éthylène glycol. Par conséquent, aucun changement n'a été apporté aux marges de tolérance pour les granules de glace publiées dans les lignes directrices sur les durées d'efficacité pour l'hiver 2020-2021.

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## **GLOSSARY**

APS	APS Aviation Inc.
AWG	Aerodynamics Working Group
EG	Ethylene Glycol
FAA	Federal Aviation Administration
FPD	Freezing Point Depressant
HOT	Holdover Time
IWT	3 m x 6 m Icing Wind Tunnel
LOUT	Lowest Operational Use Temperature
NRC	National Research Council Canada
OAT	Outside Air Temperature
RJ	Regional Jet
RTD	Resistance Temperature Detector
TC	Transport Canada

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# 1. INTRODUCTION

Under winter precipitation conditions, aircraft are cleaned prior to takeoff. This is typically done with aircraft ground deicing fluids, which are freezing point depressant (FPD) fluids developed specifically for aircraft use. If required, aircraft are then protected against further accumulation of precipitation by the application of aircraft ground anti-icing fluids, which are also FPD fluids. Most anti-icing fluids contain thickeners to extend protection time.

Prior to the 1990s, aircraft ground de/anti-icing had not been extensively researched. However, following several ground icing related incidents in the late 1980s, an aircraft ground icing research program was initiated by Transport Canada (TC). The objective of the program is to improve knowledge, improve safety, and enhance operational capabilities of aircraft operating in winter precipitation conditions.

Since its inception in the early 1990s, the aircraft ground icing research program has been managed by TC, with the co-operation of the United States Federal Aviation Administration (FAA), the National Research Council Canada (NRC), several major airlines, and de/anti-icing fluid manufacturers.

There is still an incomplete understanding of some of the hazards related to aircraft ground icing. As a result, the aircraft ground icing research program continues, with the objective of further reducing the risks posed by the operation of aircraft in winter precipitation conditions.

Under contract to the TC Innovation Centre, with support from the FAA William J. Hughes Technical Center, TC Civil Aviation, and FAA Flight Standards – Air Carrier Operations, APS Aviation Inc. (APS) carried out research in the winter of 2019-20 in support of the aircraft ground icing research program. Each major project completed as part of the 2019-20 research is documented in a separate individual report. This report documents the wind tunnel Ice Pellet Allowance Time development project.

## 1.1 Background

In 2005-06, the inability for operators to release aircraft in ice pellet conditions led TC and the FAA to begin a research campaign to develop allowance times. Developing holdover times (HOTs) was not feasible due to the properties of the ice pellets; they remain embedded in the fluid and take long to dissolve compared to snow, which is immediately absorbed and dissolved. Research was initiated through live aircraft testing with the NRC Falcon 20 in Ottawa, Canada, and later progressed to a more controlled environment with the NRC 3 m x 6 m Icing Wind Tunnel (IWT), also in Ottawa.

The early testing in 2005-06 with the Falcon 20 primarily used visual observations to evaluate fluid flow-off. During the Falcon 20 work, the wing was anti-iced and exposed to contamination, and aborted takeoff runs allowed researchers onboard to observe and evaluate the fluid flow-off. Testing in 2006-07 began in the IWT, allowing aerodynamic data to be used for evaluating fluid flow-off performance. The IWT also allowed for a more controlled environment less susceptible to the elements.

The work continued each year, and the test methods and equipment improved, allowing for real-time data analysis, better repeatability, and overall greater confidence in the results. The work conducted by TC/FAA was presented by APS to the SAE International (SAE) G-12 Aerodynamics Working Group (AWG) and the HOT Committee yearly since 2006. Additional presentations were also given at the AWG in May 2012 and May 2013 by National Aeronautics and Space Administration and the NRC that focused on the extensive calibration and characterization work performed with a generic thin high-performance airfoil. This work also helped increase confidence in how the data was used to help support the development of TC/FAA guidance material. A detailed account of the more recent work conducted is included in the TC report, TP 15232E, *Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics and to Support the Development of Ice Pellet Allowance Times, Winters 2009-10 to 2012-13* (1).

The Ice Pellet Allowance Time research has helped further develop and improve the IWT facility. As a result, a new medium is now available for aerodynamic testing of aircraft ground de/anti-icing fluids with or without contamination in a full-scale format. Several other ground deicing projects have been ongoing as a result of industry requests and are expected to continue. The IWT has evolved into a multidisciplinary facility; however, it continues to be the primary source for the development and further refinement of the ground deicing Ice Pellet Allowance Time guidance material.

For the winter of 2013-14, testing was once again focused on the development of Ice Pellet Allowance Times with intentions of conducting yearly or bi-yearly testing campaigns. During the winter of 2014-15, the Ice Pellet Allowance Time testing was suspended to allow for a European Aviation Safety Agency–led project looking at thickened fluid effects on unpowered elevators; TC and APS were also involved in this research. Ice Pellet Allowance Time testing resumed for the winter of 2015-16; however, funding was limited for the following winter and, therefore, no testing was conducted during the winter of 2016-17. Testing resumed once again for the winters of 2017-18 and 2018-19, focusing on substantiating the allowance times for new-to-market fluids and expanding the existing allowance times. During the winter of 2019-20, the research continued, and this report contains the findings from these tests.

## 1.2 Program Objectives

A wind tunnel testing program was developed for the winter of 2019-20 with the primary objectives of conducting aerodynamic testing to:

- Substantiate the current Type IV fluid Ice Pellet Allowance Times with new fluids using the thin high-performance regional jet (RJ) airfoil and, weather permitting, at temperatures close to the fluid lowest operational use temperature (LOUT); and
- Possibly extend the current Type IV fluid Ice Pellet Allowance Times for ethylene glycol (EG) fluids using the thin high-performance RJ airfoil.

In addition, baseline dry wing tests were conducted daily as well as following system changes to validate the repeatability of the wind tunnel.

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

Table 1.1 demonstrates the groupings for the global set of tests conducted at the wind tunnel during the winter of 2019-20 on the RJ wing. It should be noted that as part of the TC/FAA wind tunnel research plan for 2019-20, a new preliminary test program attempted to document fluid flow-off on a vertical stabilizer model, the results of which are documented in a separate report.

**Table 1.1: Summary of 2019-20 RJ Wing Tests by Objective**

Objective #	Objective	# of Runs
1	Baseline Tests (Dry Wing)	6
2	Ice Pellet Allowance Time Validation (New Fluids)	5
3	EG Fluids – Expansion of Allowance Times	13*
4	V-Stab Testing with Piper Seneca II Tail Model**	30
	<b>Total</b>	<b>54</b>

\*7 of 13 tests also served as validation tests.

\*\*Discussed in separate report.

## 1.3 Previous Ice Pellet Allowance Time Tables

The Type IV allowance time tables have been available since the winter of 2007-08. Each year the Type IV testing has built upon the latest version of the allowance time table published in the TC and FAA HOT Guidelines.

In the case of Type III fluid, a preliminary table was developed during the winter of 2008-09; however, high rotation speed allowance time tables have only been available and published since the winter of 2014-15 following some more extensive testing. Future testing will build upon the latest version of the allowance time table published in the TC and FAA HOT Guidelines and look to expand the table to include low-speed rotations.

## 1.4 Report Format

The wind tunnel work has been conducted since the winter of 2006-07 and has been documented in yearly reports. TP 15232E (1) contains more thorough details regarding the testing methodologies as well as links to previous historical reports. The current report has been prepared in a more abbreviated format. The following list provides short descriptions of subsequent sections of this report:

- a) Section 2 describes the methodology used in testing, as well as equipment and personnel requirements necessary to carry out testing;
- b) Section 3 describes data collected during the full-scale testing conducted;
- c) Section 4 describes the results from the validation testing for new-to-market Type IV fluids;
- d) Section 5 describes the results from the research aimed at extending the allowance times for EG fluids; and
- e) Section 6 provides a summary of the conclusions and recommendations.

## 2. METHODOLOGY

This section provides a brief description of the test methodology and equipment specific to the full-scale aerodynamic tests conducted at the NRC IWT.

NOTE: TP 15232E (1) contains more thorough details regarding the testing methodologies.

### 2.1 Test Schedule

Three overnight days of testing were organized starting January 19, 2020. An additional five overnight days of testing from February 2-6, 2020, were organized as part of a separate test objective looking at fluid flow-off from a vertical stabilizer (the results are described in a separate report). Setup and teardown times were kept to a minimum and completed during the first two hours on the first day of testing and during the last two hours on the last day of testing. Table 2.1 presents the calendar of wind tunnel allowance time tests performed with the RJ wing. At the beginning of each test day, a plan was developed that included the list of tests (taken from the global test plan) to be completed based on the weather conditions and testing priorities. This daily plan was discussed, approved, and modified (if necessary) by TC, the FAA, and APS.

**Table 2.1: 2017-18 Calendar of Tests**

<b>Date</b> (Start date of overnight)	<b># of Tests Run</b>
January 19, 2020	8
January 20, 2020	8
January 21, 2020	8
<b>Total</b>	<b>24</b>

#### 2.1.1 Wind Tunnel Procedure

To satisfy the fluid testing objective, simulated takeoff and climb-out tests were performed with the thin high-performance wing section. Different parameters including fluid thickness, wing temperature, and fluid freezing point were recorded at designated times during the tests. The thin high-performance wing section was constructed by the NRC in 2009 specifically to conduct these tests following extensive consultations with an airframe manufacturer to ensure a representative thin high-performance design.

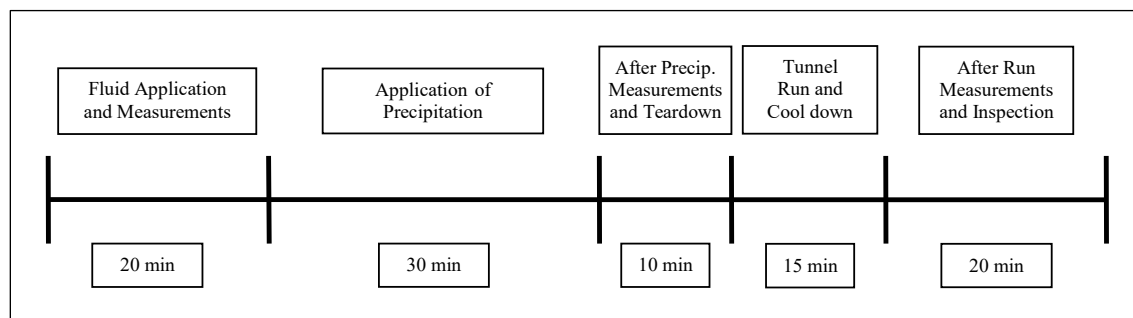
The typical procedure for each fluid test is described below.

- The wing section was treated with anti-icing fluid, poured in a one-step operation (no Type I fluid was used during the tests).
- When applicable, contamination, in the form of simulated ice pellets, freezing rain, and/or snow, was applied to the wing section. Test parameters were measured at the beginning and end of the exposure to contamination.
- 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.

The procedures for the wind tunnel trials are included in Appendix B. The procedures include details regarding the test objectives, test plan, procedure and methodology, and pertinent information and documentation.

### 2.1.2 Test Sequence

The length of each test (from start of setup to end of last measurement) varied largely due to the length of exposure to precipitation (if applicable). Time required for setup and teardown as well as preparing and configuring the wing section was relatively the same from test to test. Figure 2.1 demonstrates a sample timeline for a typical wind tunnel trial. It should be noted that a precipitation exposure time of 30 minutes was used for illustration purposes; this time varied for each test depending on the objective.



**Figure 2.1: Typical Wind Tunnel Test Timeline**

## 2.2 Methodology for Developing or Expanding New Allowance Times

Initial testing to first develop the allowance times is done with representative “grandfather” fluids (fluids with a long history of data). Testing is conducted at different temperatures and rates, and the allowance times are based on the limits where tests fail the acceptance criteria (based on visual ratings and aerodynamic performance). Much “trial and error” is needed to determine the limits of the allowance times (i.e., it may require running tests with a grandfather fluid at 15, 20, and 25 minutes to determine that the allowance time should be limited to 20 minutes). Once the target allowance times are determined, they are validated using limited spot checks with multiple fluids. This also applies to expanding allowance times for specific fluid types, like EG fluids.

## 2.3 Methodology for Validating New Fluids for Use with Allowance Times

Over the years, all new commercially available fluids have been tested. This is typically done when fluids become available commercially and are being mass produced. At a minimum, testing is conducted in a subset of conditions; the allowance times are generic, so this process is satisfactory and provides a “first alert” in the event that a fluid may be underperforming, in which case further action would be required.

## 2.4 Wind Tunnel and Airfoil Model Technical Overview

The following subsections describe the wind tunnel and major components.

### 2.4.1 Wind Tunnel Test Site

IWT tests are performed at the NRC Aerospace Facilities, Building M-46, at the NRC Montreal Road campus, located in Ottawa, Canada. Figure 2.2 provides a schematic of the NRC Montreal Road campus showing the location of the NRC IWT. Photo 2.1 shows an outside view of the wind tunnel trial facility. Photo 2.2 shows an inside view of the wind tunnel test section. The open-circuit layout, with a fan at entry, permits contaminants associated with the test articles (such as heat or de/anti-icing fluid) to discharge directly, without recirculating or contacting the fan. The test section is 3 m (10 ft.) wide by 6 m (20 ft.) high by 12 m (40 ft.) long, with a maximum wind speed of 78 knots when using the electrical turbine drive and with a maximum wind speed of just over 115 knots when using the gas turbine drive. The fan is normally driven electrically, but high-speed operation can be accommodated by a gas turbine drive system. Due to the requirements of both high-speed and



low-speed operations during the testing, the gas turbine was selected to allow for greater flexibility; the gas turbine drive can perform both low- and high-speed operations, whereas the electric drive is limited to low-speed operations. Scaffolding was constructed to allow access to the wing section, which facilitated the application of fluids and the subsequent inspection and cleaning of the airfoil.

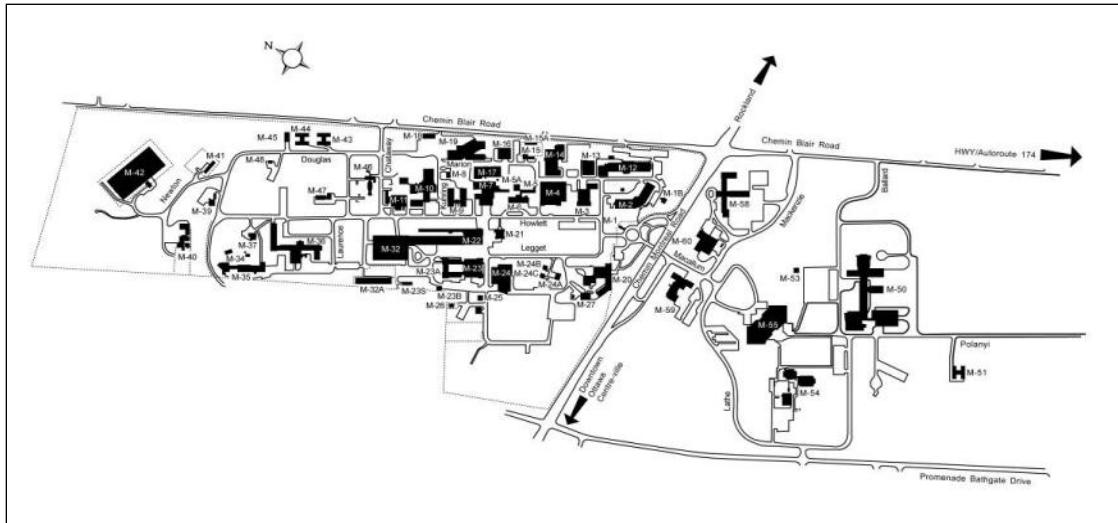


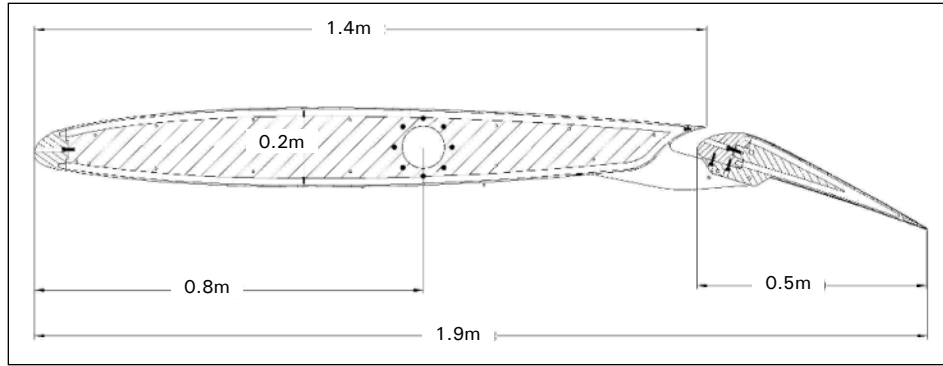
Figure 2.2: Schematic of NRC Montreal Road Campus

#### 2.4.2 Generic Thin High-Performance “RJ” Type Commuter Airfoil

The wing section used for testing was a generic high-performance commuter airfoil, also referred to as a “thin high-performance” or “RJ” type. This wing section was constructed by the NRC in 2009 specifically to conduct these tests following extensive consultations with an airframe manufacturer to ensure a representative thin high-performance design. The original wing design was representative of an outboard section and did not include a flap; the flap was later added at the request of TC, the FAA, and APS. A computational fluid dynamics analysis of the modified wing section was conducted by the airframe manufacturer, and it was confirmed that the wing section provided a good representation of a flapped section of an operational thin high-performance wing. Photo 2.3 shows the wing section used for testing.

A cross sectional view of the thin high-performance wing section used for testing is represented in Figure 2.3; the dimensions indicated are in meters. Some of the pertinent dimensions of the wing section are as follows:

- Chord length not including flap: 1.4 m (4.6 ft.); and
- Width: 2.4 m (8 ft.).

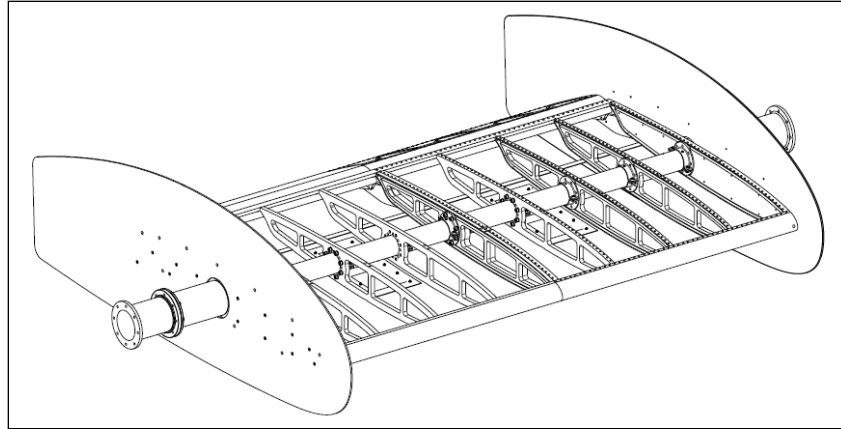


**Figure 2.3: Generic “Thin High-Performance” Wing Section**

An analysis of the wing section model was conducted by the airframe manufacturer to determine the typical rest position of this type of wing section. It was determined that on a typical commuter aircraft, this section of wing would typically be pitched forward by  $2^\circ$  when sitting on the ground. As a result, the NRC ensured the rest position of the wing model was set to  $-2^\circ$  for each test.

The wing section was fitted with a hinged flap. The flap position was fixed at  $20^\circ$  and was not intended to be changed during testing. The top surface of the flap wing section had a steeper angle, consequently a flap setting of  $20^\circ$  created close to a  $26^\circ$  slope on the top surface of the flap (with the wing pitched forward by  $2^\circ$ ). As testing progressed, the ability to change the flap setting from  $0^\circ$  to  $20^\circ$  was necessary; contrary to a nested flap, which is typically protected during precipitation, a hinged flap is always exposed, and results indicated earlier failures were due to the shallower angle of the hinged flap. Modifications were made by the NRC to allow the flap setting to alternate between  $0^\circ$  and  $20^\circ$  for the fluid application and contamination periods; however, all takeoff simulations were conducted with the flap set to  $20^\circ$ . No moveable devices were available on the wing section. Detailed coordinates for this airfoil are available upon request.

End plates were installed on the wing section to eliminate the “wall effects” from the wind tunnel walls and to provide a better aerodynamic flow-off above the test area. Figure 2.4 demonstrates the end plates installed on the thin high-performance wing section (note: the wing section is depicted without the top wing skin).



**Figure 2.4: End Plates Installed on Thin High-Performance Wing Section**

### 2.4.3 Test Area Grid

APS personnel used markers to draw a grid on the wing upper surface (excluding the flap). Each grid cell measured 5.1 cm x 5.1 cm (2 in. x 2 in.) with the cell axis positioned perpendicular and parallel to the leading edge (see Photo 2.4). The grid section was 2.4 m (8 ft.), which covered the entire wing section. The grid markings began aft of the leading edge stagnation point and continued along the length of the main chord; grid markings were not drawn on the flap section. The grid was used to facilitate observations of the fluid shearing off the wing and the movement of ice pellets during takeoff.

### 2.4.4 Wind Tunnel Measurement Capabilities

The wing section was supported on either side by 2-axis weigh scales capable of measuring drag and lift forces generated on the wing section. The wing section was attached to servo-systems capable of pitching the wing section to a static angle or generating dynamic movements. The servo-system was programmed to simulate pitch angles during takeoff and climb-out based on operational aircraft flight profiles.

The wing section was also equipped with eight resistance temperature detectors (RTDs); these were installed by NRC personnel to record the skin temperature on the leading edge (LE), mid-chord (MID), trailing edge (TE), and under-wing (UND). RTDs were placed in pairs along a chord 0.5 m (1.5 ft.) to the left and to the right of the wing centreline. The following are the locations of the RTDs for the RJ wing:

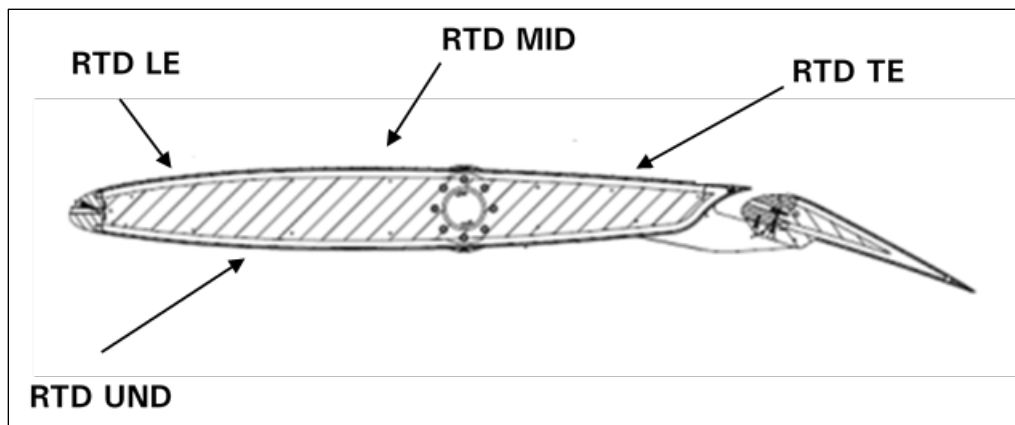
- RTD LE located approximately 25 cm from the leading edge (as measured along wing skin curvature);

- RTD MID located approximately 70 cm from the leading edge (as measured along wing skin curvature);
- RTD TE located approximately 30 cm from the trailing edge (as measured along wing skin curvature); and
- RTD UND located approximately 45 cm from the leading edge.

Figure 2.5 demonstrates the general location of the RTDs. These RTDs were primarily used to monitor the skin temperature in real-time through the NRC data display system and were recorded by APS personnel.

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

1. Ambient temperature inside the tunnel;
2. Outside air temperature (OAT);
3. Air pressure;
4. Wind speed; and
5. Relative humidity.



**Figure 2.5: Location of RTDs Installed Inside Thin High-Performance Wing**

## 2.5 Simulated Precipitation

The following types of precipitation have been simulated for aerodynamic research in the IWT:

1. Ice Pellets;
2. Snow;
3. Freezing Rain/Rain; and
4. Other conditions related to HOTs.

### **2.5.1 Ice Pellets**

Simulated ice pellets were produced with diameters ranging from 1.4 mm to 4.0 mm to represent the most common ice pellet sizes observed during natural events. The ice pellets were manufactured inside a refrigerated truck (see Photo 2.5). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.6) to obtain the required ice pellet size range. Hand-held motorized dispensers (see Photo 2.7) were used to dispense the ice pellets. The ice pellets were applied to the leading and trailing edges of the wing at the same time.

### **2.5.2 Snow**

Snow was produced using the same method for producing ice pellets. The snow used consisted of small ice crystals measuring less than 1.4 mm in diameter. Previous testing conducted by APS investigated the dissolving properties of the artificial snow versus natural snow. The artificial snow was selected as an appropriate substitute for natural snow.

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

### **2.5.3 Freezing Rain/Rain**

The same sprayer head and scanner used for HOT testing at the NRC Climatic Engineering Facility was employed for testing. The sprayer system (see Photo 2.8) uses compressed air and distilled water to produce freezing rain. The temperature of the water is controlled and is kept just above freezing temperature in order to produce freezing rain. To produce rain, the temperature of the water is raised until the precipitation no longer freezes on the test surfaces.

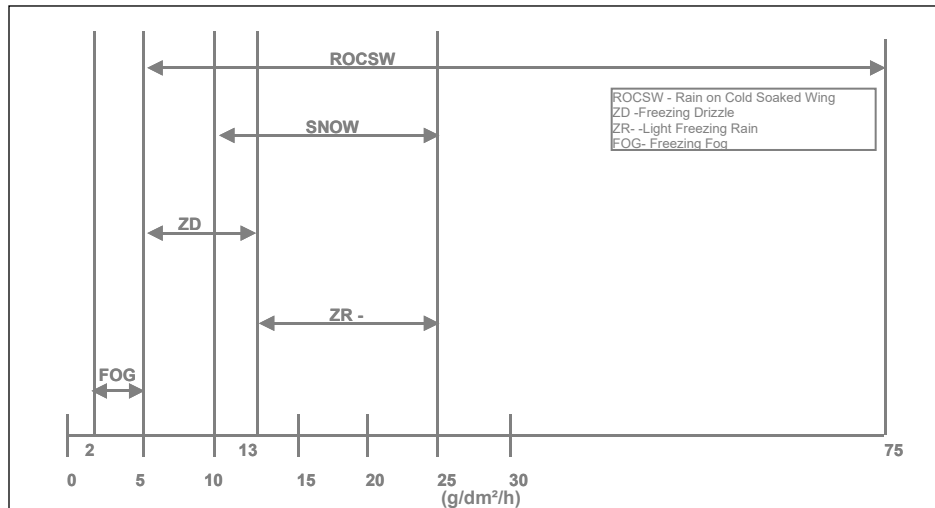
### **2.5.4 Definition of Precipitation Rates**

When simulating precipitation rates for full-scale and plate testing, the rate limits defined for standard HOT testing were referenced. Figure 2.6 demonstrates the HOT testing rate precipitation breakdown.

HOT testing protocol for ice pellets does not currently exist. As a result, ice pellet precipitation rate limits were based upon the freezing rain rate breakdown. The

following precipitation rates were used for the full-scale and flat plate testing conducted during the winter of 2008-09:

1. Light Ice Pellets: 13-25 g/dm<sup>2</sup>/h;
2. Moderate Ice Pellets: 25-75 g/dm<sup>2</sup>/h;
3. Light Freezing Rain: 13-25 g/dm<sup>2</sup>/h;
4. Freezing Drizzle (Heavy): 5-13 g/dm<sup>2</sup>/h;
5. Light Rain: 13-25 g/dm<sup>2</sup>/h;
6. Moderate Rain: 25-75 g/dm<sup>2</sup>/h;
7. Light Snow: 4-10 g/dm<sup>2</sup>/h; and
8. Moderate Snow: 10-25 g/dm<sup>2</sup>/h.



**Figure 2.6: Precipitation Rate Breakdown**

## 2.6 Test Equipment

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

### 2.6.1 Video and Photo Equipment

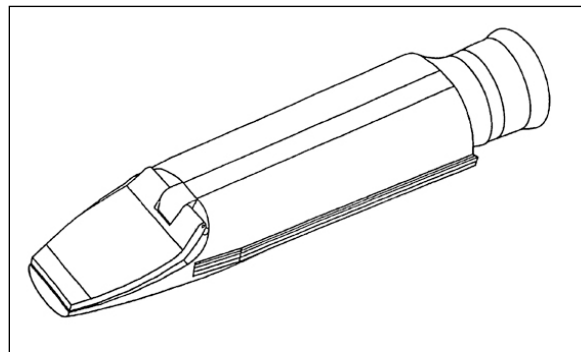
APS used the observation windows on the sides of the test section to install Canon® EOS XTi DSLR cameras and Profoto® Compact 600 flashes capable of

second-by-second photography with an intervalometer. In addition, GoPro® and Osmo® cameras were used for wide-angle filming of fluid flow-off during the test runs.

Photo 2.9 and Photo 2.10 demonstrate the camera setup used for the testing period.

### 2.6.2 Refractometer/Brixometer

Fluid freezing points were measured using a hand-held Misco 10431VP refractometer with a Brix scale (shown in Figure 2.7). The freezing points of the various fluid samples were determined using the conversion curve or table provided to APS by the fluid manufacturer.



**Figure 2.7: Hand-Held Refractometer/Brixometer**

### 2.6.3 Wet Film Thickness Gauges

Wet film thickness gauges, shown in Figure 2.8, were used to measure fluid film thickness. These gauges were selected because they provide an adequate range of thicknesses (0.1 mm to 10.2 mm) for Type I/II/III/IV fluids. The rectangular gauge has a finer scale and was used in some cases when the fluid film was thinner (toward the end of a test). The observer recorded a thickness value (in mils), as read directly from the thickness gauge. The recorded value was the last wetted tooth of the thickness gauge; however, the true thickness lies between the last wetted tooth and the next un-wetted tooth. The measured thickness was corrected accordingly.



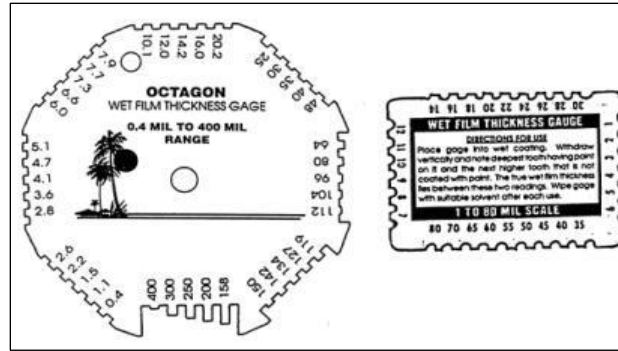


Figure 2.8: Wet Film Thickness Gauges

### 2.6.4 Temperature Sensor

When required, wing skin temperature and fluid temperature were measured using a Wahl digital heat-probe thermometer Model 392Vxc. A surface temperature probe was used for wing skin temperature measurements (however, generally the wing-mounted RTDs were used), and an immersion probe was used for measuring and monitoring fluid temperatures.

## 2.7 Personnel

During the fluid testing and exploratory research testing, four APS staff members were required to conduct the tests, and four additional persons from Ottawa were tasked to manufacture and dispense ice pellets as well as to help with general setup tasks. A professional photographer was retained to record digital images of the test setup and test runs. Representatives from TC and the FAA provided direction in testing and participated as observers. Photo 2.12 shows a portion of the research team (due to scheduling, not all participants were available for the photo).

## 2.8 Data Forms

Several different forms were used to facilitate the documentation of the various data collected in the wind tunnel trials. These forms include the following:

1. General Form;
2. Wing Temperature, Fluid Thickness and Fluid Brix Form;
3. Ice Pellet and Snow Dispensing Forms;
4. Sprayer Calibration Form;

5. Visual Evaluation Rating Form;
6. Condition of Wing and Plate Form;
7. Fluid Receipt Form; and
8. Log of Fluid Sample Bottles.

Copies of these forms are provided in the test procedure, which is included in Appendix B. Completed wing temperature, fluid thickness, and fluid Brix data forms have been included in Appendix C.

## 2.9 Data Collection

Fluid thickness, fluid Brix, and skin temperature measurements were collected by APS personnel. The measurements were collected before and after fluid application, after the application of contamination, and at the end of the test. The completed data forms have been scanned and included in Appendix C for referencing purposes.

High-speed digital photographs of each test were taken. In addition, videos were also recorded during a greater portion of the tests. Due to the large amount of data available, photos of the individual tests have not been included in this report, but rather the high-resolution photos available in electronic format have been provided to TC and can be made available upon request.

## 2.10 De/Anti-Icing Fluids

For the winter of 2019-20, no new fluids were received. Clariant Safewing EG IV NORTH fluid was received late in the 2018-19 season and could not be tested; therefore, the inventory was retained for allowance time substantiation testing in 2019-20. Several other fluids remained in inventory from previous years' testing, and, of those, the EG based fluids were used for allowance time expansion testing. The viscosity of all fluids in inventory was measured using the Brookfield Digital Viscometer Model DV-1+ to ensure the fluid was within the fluid manufacturer production specifications and comparable to previous samples received. This year, only the Stony Brook PDVdi-120 Falling Ball Viscometer was used to measure the Clariant Safewing EG IV NORTH sample. The pertinent characteristics of these fluids are given in Table 2.2.

## 2. METHODOLOGY

**Table 2.2: Wind Tunnel Fluid Viscosity Information for 2019-20 Testing**

Sample Name	Dilution	Batch #	Year Rec'd	Receiving Qty (L)	Leftover Inventory Pre	2013-14			2014-15			2015-16			2017-18			2018-19			2019-20		
						Measured Viscosity (cP)	Falling Ball Temp. (°C)	Falling Ball Time (mm:ss)	Measured Viscosity (cP)	Falling Ball Temp. (°C)	Falling Ball Time (mm:ss)	Measured Viscosity (cP)	Falling Ball Temp. (°C)	Falling Ball Time (mm:ss)	Measured Viscosity (cP)	Falling Ball Temp. (°C)	Falling Ball Time (mm:ss)	Measured Viscosity (cP)	Falling Ball Temp. (°C)	Falling Ball Time (mm:ss)	Measured Viscosity (cP)	Falling Ball Temp. (°C)	Falling Ball Time (mm:ss)
Clariant Safewing MP II FLIGHT	100/0	DEG 4145408 (EASA)	2014-15		150				13,600	22.4	0:26		22.9	0:26							14,840		
Kilfroast ABC-S Plus	100/0	WT 13-14 ABC-S +	2013-14		200	19,800	21.7	0:37				27,100	19.5	0:32	36,200	19.7	0:49				38,500		
Cryotech Polar Guard Advance	100/0	WT 13-14 PGA	2013-14		140	15,400	20.6	0:25				16040	19.5	0:24	15,980	n/a	n/a				15,400		
AllClear AeroClear MAX	100/0	TAB17-1023	2017-18	400											16,500	19.0	0:02				15,500		
CHEMCO ChemR EG IV	100/0	IV 35317-1	2017-18	400											46,000	19.6	0:13				48,400		
Clariant MaxFlight AVIA	100/0	41	2017-18	400											1,838	19.6	0:08	1,980	19.2	0:09	1,926		
Clariant MaxFlight SNEG	100/0	8	2017-18	400											18700	19.6	0:39	19,100	19.5	0:41	19,700		
Clariant Safewing EG IV NORTH	100/0	01819	2018-19	400														1,028	19.2	0:05	956	19.5	0:06
Oksayd Defrost EG 4	100/0	#1 (Lot #47)	2018-19	400														19,200	19.5	:8	18,700		
Oksayd Defrost ECO 4	100/0	#4 (Lot #48)	2018-19	300														13,300	19.9	0:34	12,300		
DOW EG106	100/0	D268IB7001	2018-19	300																	39,500		
Cryotech Polar Guard Advance	100/0	PGA181205PA	2018-19	300																	14,820		

Note: Viscosity was measured using manufacturer methods.

### 2.10.1 Viscometer

Historically, viscosity measurements have been carried out using a Brookfield viscometer (Model DV-1 + , shown in Photo 2.13) fitted with a recirculating fluid bath and small sample adapter. In recent years, on-site measurements are also done with the Stony Brook PDVdi-120 Falling Ball Viscometer whenever possible (Photo 2.14) to obtain a quick verification of the fluid integrity. The falling ball tests are much faster and more convenient to perform compared to tests with the Brookfield viscometer. The falling ball, however, does not provide the absolute value of viscosity, but rather a time interval that is compared to historical samples to identify changes in viscosity.

### 2.10.2 Type II/III/IV Fluid Application Equipment

The Type II/III/IV fluids were stored outside the wind tunnel and were kept at ambient temperature. The fluids were poured rather than sprayed so that application would not change the fluid viscosity. This methodology was appropriate given the relatively small test area of the wing section and the goal of minimizing the amount of fluid flowing off the wing.

Type II, III, and IV fluids are generally received in 20 L containers; however, some fluids are received in large 200 L barrels and larger 1000 L totes. The fluid is applied to the wing section by using smaller 2 L containers (see Photo 2.11). Approximately 16 L to 20 L of fluid were applied to the wing section for each test; less fluid was required for the less viscous Type III fluid. Due to the flat top surface of the thin high-performance wing, the thickened fluid did not easily settle and flow on the top surface. Therefore, the wing was tilted forward (by approximately  $10^\circ$ ) for 1 minute following the end of fluid application to allow for the fluid to spread out evenly over the top surface of the wing.

### 2.10.3 Waste Fluid Collection

Using a relatively small test area and applying the fluids by pouring minimized the amount of fluid falling off the wing. APS personnel used a vacuum to collect the fluid that would drip onto the tunnel floor prior to each test. The NRC also fitted the wind tunnel with appropriate drainage tubes to collect spent fluid during the takeoff test runs. At the end of the testing period, the services of a waste removal company were employed to safely dispose of the waste glycol fluid.

## 2.11 Analysis Methodology

The following provides a brief description of the analysis methodology. More details on the analysis methodology can be found in TP 15232E (1).

Each ice pellet test was analysed in detail using the following objectives:

1. Test parameters;
2. Visual ratings at the start of the test;
3. Visual ratings at rotation;
4. 8° lift loss; and
5. Overall test status.

The evaluation grades for each criterion were “good,” “review,” or “bad.” These grades were determined based on whether the criterion satisfied each test objective requirement. Figure 2.9 shows a summary of each test objective and criterion.

Several test parameters were evaluated, such as tunnel temperature before the start of the test, rate of precipitation, and exposure time of precipitation. These parameters were compared to the target parameters described in the test plan. The actual recorded ramp-up time was also evaluated and compared to the target ramp-up time to ensure representative flow-off results; this became less of an issue after 2011-12 with the use of the automated ramp-up system instead of the previous manual system.

### 2.11.1 Visual Ratings at the Start of the Test

During each of the tests conducted, visual contamination ratings were determined by three observers: one observer from the FAA and two observers from APS. The level of contamination present on the leading edge and trailing edge of the wing, as well as on the flap, was quantified using a scale of one-to-five with five being the worst case scenario; partial numbers were sometimes assigned when cases were marginally above or below a specific rating.

The visual contamination rating criteria at the start of the test on both the leading and trailing edges must be equal to 3 or less in order to pass. The flap must have a rating of 4 or less. For a review grade to be given, the leading and trailing edges must have a rating between 3 and 3.5, and the flap must have a rating between 4 and 4.5. Any rating greater than 3.5 on the leading and trailing edges is considered a fail, while anything greater than 4.5 on the flap is considered a fail.

1. TEST PARAMETERS											
2. VISUAL RATINGS AT START OF TEST											
<b>CRITERIA:</b> LE / TE $\leq 3$ <div style="margin-left: 100px;">Flap    <math>\leq 4</math></div>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: center; width: 60%;"><math>\leq 3, 3, 4</math></td> <td style="text-align: center; background-color: #00ff00;">GOOD</td> </tr> <tr> <td style="text-align: center;"><math>&gt; 3, 3, 4</math> to <math>3.5, 3.5, 4.5</math></td> <td style="text-align: center; background-color: #ffff00;">REVIEW</td> </tr> <tr> <td style="text-align: center;"><math>&gt; 3.5, 3.5, 4.5</math></td> <td style="text-align: center; background-color: #ff0000;">BAD</td> </tr> </table>		$\leq 3, 3, 4$	GOOD	$> 3, 3, 4$ to $3.5, 3.5, 4.5$	REVIEW	$> 3.5, 3.5, 4.5$	BAD			
$\leq 3, 3, 4$	GOOD										
$> 3, 3, 4$ to $3.5, 3.5, 4.5$	REVIEW										
$> 3.5, 3.5, 4.5$	BAD										
3. VISUAL RATINGS AT ROTATION											
<b>CRITERIA:</b> LE    = 1	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: center; width: 60%;">1</td> <td style="text-align: center; background-color: #00ff00;">GOOD</td> </tr> <tr> <td style="text-align: center;">1 to 1.5</td> <td style="text-align: center; background-color: #ffff00;">REVIEW</td> </tr> <tr> <td style="text-align: center;"><math>&gt; 1.5</math></td> <td style="text-align: center; background-color: #ff0000;">BAD</td> </tr> </table>		1	GOOD	1 to 1.5	REVIEW	$> 1.5$	BAD			
1	GOOD										
1 to 1.5	REVIEW										
$> 1.5$	BAD										
4. LIFT LOSS AT 8°											
<b>CRITERIA:</b>	<table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="text-align: center; width: 30%;"><math>&lt; -2 \sigma</math></td> <td style="text-align: center; width: 30%;"><math>&lt; 5.4\%</math></td> <td style="text-align: center; background-color: #00ff00;">GOOD</td> </tr> <tr> <td style="text-align: center;"><math>-2 \sigma</math> to <math>2\sigma</math></td> <td style="text-align: center;"><math>5.4\%</math> to <math>9.2\%</math></td> <td style="text-align: center; background-color: #ffff00;">REVIEW</td> </tr> <tr> <td style="text-align: center;"><math>&gt; +2 \sigma</math></td> <td style="text-align: center;"><math>&gt; 9.2\%</math></td> <td style="text-align: center; background-color: #ff0000;">BAD</td> </tr> </table>		$< -2 \sigma$	$< 5.4\%$	GOOD	$-2 \sigma$ to $2\sigma$	$5.4\%$ to $9.2\%$	REVIEW	$> +2 \sigma$	$> 9.2\%$	BAD
$< -2 \sigma$	$< 5.4\%$	GOOD									
$-2 \sigma$ to $2\sigma$	$5.4\%$ to $9.2\%$	REVIEW									
$> +2 \sigma$	$> 9.2\%$	BAD									
OVERALL STATUS											
<p style="text-align: center;"><b><i>IF ANY OF THE ABOVE CRITERIA ARE RED, TEST IS NOT ACCEPTABLE</i></b></p> <p style="text-align: center;">THEREFORE WORST OF ABOVE 3 CRITERIA, ORDER IS:</p> <div style="text-align: center; margin-top: 10px;"> <table border="1" style="margin: 0 auto; border-collapse: collapse;"> <tr style="background-color: #00ff00;"> <td style="padding: 5px;">GREEN</td> </tr> <tr style="background-color: #ffff00;"> <td style="padding: 5px;">YELLOW</td> </tr> <tr style="background-color: #ff0000;"> <td style="padding: 5px;">RED</td> </tr> </table> </div>			GREEN	YELLOW	RED						
GREEN											
YELLOW											
RED											

Figure 2.9: Ice Pellet Test Analysis Criteria

### **2.11.2 Visual Ratings at Rotation**

The visual contamination rating criteria at the time of rotation on the leading edge must be equal to 1 or less in order to pass. For a review grade to be given, the leading edge must have a rating between 1 and 1.5. Any rating on the leading edge greater than 1.5 is considered a fail.

### **2.11.3 Eight Degree Lift Loss**

For a pass, the 8° lift loss must be less than 5.4 percent. A review grade was given should the lift loss be between 5.4 percent and 9.2 percent. Any lift loss greater than 9.2 percent is considered a fail.

### **2.11.4 Overall Test Status**

After all objectives were analysed, an overall status was given a “good,” “review,” or “bad” evaluation. This provided an overall summary for each test. The overall status was determined by the worst case scenario from any of the test objectives; if any of the criteria were given a “bad” grade, the overall status would be “bad” and the test considered a fail.

### **2.11.5 Dry Wing Calibration**

To ensure the accuracy of the testing results, a dry wing calibration test was conducted at the start of each day. The dry wing test allowed the research team to ensure that the model aerodynamics did not change due to mechanical, communication, or analytical errors. Dry wing tests were also conducted following any mechanical modification to the airfoil (i.e., after applying the ice phobic wing skins). During the winter of 2019-20, the dry wing results demonstrated that the changes in dry wing performance were within the range of experimental error and did not indicate any repeatability issues with the model.

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**Photo 2.1: Outside View of the NRC Wind Tunnel Facility**



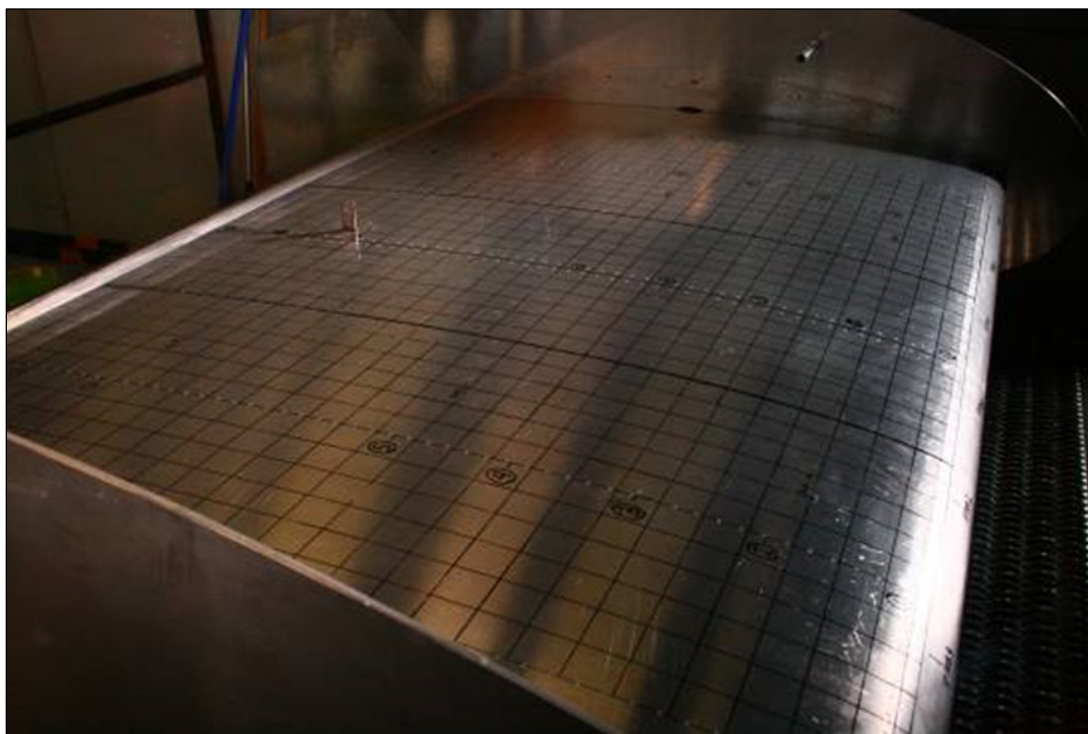
**Photo 2.2: Inside View of the NRC Wind Tunnel Test Section**



**Photo 2.3: Thin High-Performance Wing Section Used for Testing**



**Photo 2.4: Grid Markings on Thin High-Performance Wing Section**





**Photo 2.5: Refrigerated Truck Used for Manufacturing Ice Pellets**



**Photo 2.6: Calibrated Sieves Used to Obtain Desired Size Distribution**



**Photo 2.7: Ice Pellet Dispensers Operated by APS Personnel**



**Photo 2.8: Ceiling-Mounted Freezing Rain Sprayer**

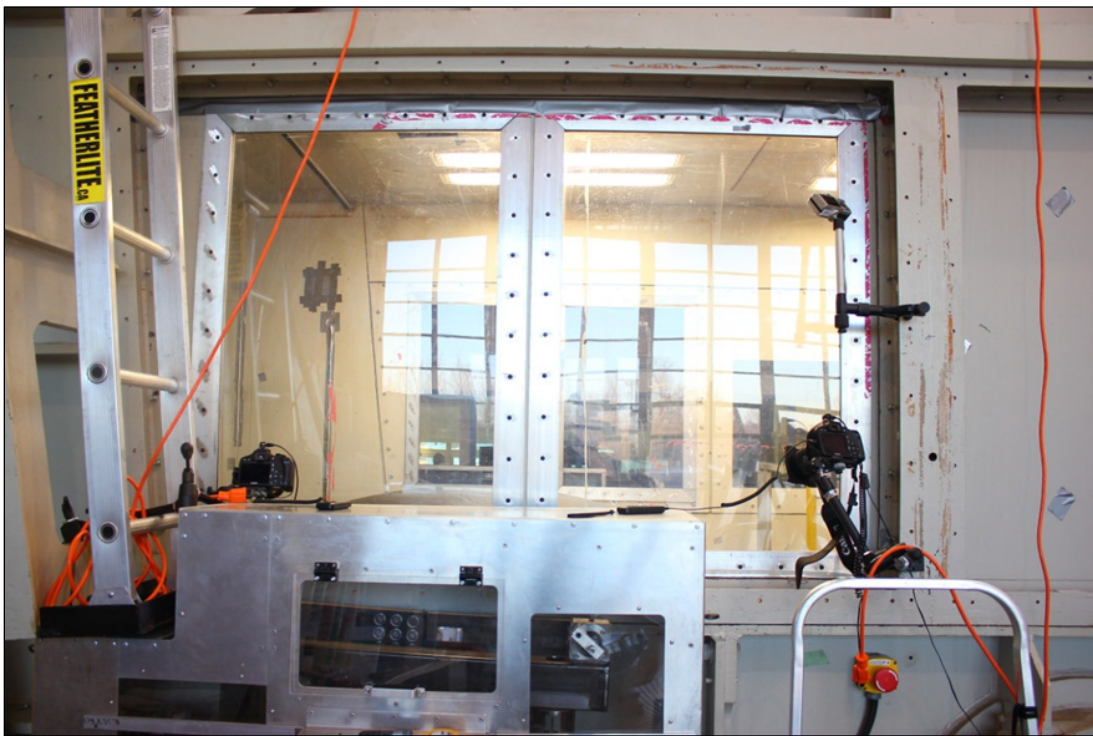




**Photo 2.9: Wind Tunnel Setup for Flashes**



**Photo 2.10: Wind Tunnel Setup for Digital Cameras**



**Photo 2.11: Fluid Pour Containers**



**Photo 2.12: 2019-20 Research Team**





**Photo 2.13: Brookfield Digital Viscometer Model DV-1 +**



**Photo 2.14: Stony Brook PDVdi-120 Falling Ball Viscometer**



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### 3. FULL-SCALE DATA COLLECTED

#### 3.1 Test Log

A calendar of the tests conducted during the winter of 2019-20 can be found in Table 2.1. A detailed log of the tests conducted in the NRC IWT during the winter of 2019-20 is included in Appendix D. The log provides relevant information for each of the tests, as well as final values used for the data analysis. Each row contains data specific to one test. The following is a brief description of the column headings for the logs included in Appendix D.

<i>Test #:</i>	Exclusive number identifying each test run.
<i>Test Year:</i>	The year in which the test was conducted.
<i>Objective:</i>	Main objective of the test.
<i>Test Condition:</i>	Description of the simulated conditions for the test.
<i>Fluid Name:</i>	Aircraft anti-icing fluid used during the test.
<i>Rotation Angle:</i>	Maximum angle of rotation obtained during simulated takeoff run; began testing with a max 8° rotation angle and increased to 20° as testing progressed.
<i>Flap Angle (0°, 20°):</i>	Positioning of the flap during the precipitation period; either 0° (retracted) or 20° (extended).  <i>Note: Flap was always extended at 20° during the takeoff run.</i>
<i>Date:</i>	Date when the test was conducted.
<i>OAT Before Test (°C):</i>	OAT recorded just before the start of the simulated takeoff test, measured in degrees Celsius.  <i>Note: This is not an important parameter as "Tunnel Temp. Before Test" was used as the actual test temperature for analysis.</i>

*Tunnel Temp. Before Test (°C):* Static tunnel air temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius.

*Note: This parameter was used as the actual test temperature for analysis.*

*Precipitation Rate (Type: [g/dm<sup>2</sup>/h]):* Simulated freezing precipitation rate (or combination of different precipitation rates). "N/A" indicates that no precipitation was applied.

*Exposure Time (min.):* Simulated precipitation period, recorded in minutes.

The visual contamination ratings are described below. Visual contamination ratings were typically reported as the average of the three observer ratings and rounded to the nearest decimal. The visual contamination ratings system is further described in Subsection 2.11.

*Visual Contamination Rating Before Takeoff (LE, TE, Flap):* Visual contamination rating determined before the start of the simulated takeoff:

- 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; and
- 5 - Contamination visible, adherence of contamination.

*Visual Contamination Rating at Rotation (LE, TE, Flap):* Visual contamination rating determined at the time of rotation:

- 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; and
- 5 - Contamination visible, adherence of contamination.

*Visual Contamination Rating  
After Takeoff (LE, TE, Flap):*

Visual contamination rating determined at the end of the test:

- 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; and
- 5 - Contamination visible, adherence of contamination.

*Corrected for 3D Effects  $C_L$  at  $8^\circ$ :*

Calculated lift coefficient at the  $8^\circ$  wing rotation angle position and corrected for 3D effects; data provided by the NRC.

*Corrected for 3D Effects %  
Lift Loss at  $8^\circ$   $C_L$  vs. Dry  $C_L$ :*

Percent lift loss calculated based on the comparison of the  $8^\circ$  lift coefficient during the test run versus the dry wing average lift coefficient.

*Speed (kts):*

Maximum speed obtained during simulated takeoff run, recorded in knots.

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## 4. VALIDATION TESTING FOR NEW-TO-MARKET TYPE IV FLUIDS

The Type IV fluid Ice Pellet Allowance Times are developed based on data collected using commercially available Type IV fluids. The Type IV fluid Ice Pellet Allowance Times are generic and, therefore, conservative. As new fluids are developed and become commercially available, it is important to evaluate these fluids against the current allowance times to ensure the validity of the generic guidance. Systematic “spot-checking” is used in order to identify any potential issues. In addition, testing is recommended with all available fluids to obtain data close to the fluid LOUT; this further allows the aerodynamic effects of ice pellet contamination at colder temperatures to be determined. To meet these requirements, testing during the winter of 2019-20 was conducted with the following Type IV EG fluid:

- Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH.

It should be noted that testing for this fluid was planned for 2018-19; however, due to shipping logistics, the fluid was not received in time for the testing. The fluid samples were retained, and testing was deferred to the winter of 2019-20.

The following subsections will provide an overview of the analysis format and a summary of the results obtained for the fluid tested.

### 4.1 Allowance Time Table Analysis Format

For the fluid tested, a table has been included that provides a summary of the tests conducted. The results from the individual tests are included in a mock-up allowance time table indicating the current Ice Pellet Allowance Times as well as the individual test information in the respective cell. The individual test information has been included in the format provided below.

- AA(BB)CC[DD]E
  - AA is the static tunnel ambient temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius and rounded to the closest degree.
  - BB is the percent Lift Loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient.
  - CC is the exposure time of the test in minutes.
  - DD is the test number to reference the data in the test logs.

- E is the status of the testing: either “G” for good, “R” for review, or “B” for bad, as per the guidelines in Subsection 2.11.4. The highlighting is in a corresponding green, yellow, or red colour.
- The test information is included in the cell for which the temperature band best corresponds to the temperature recorded during the test.

The purpose of these tables is to provide a quick reference of the test results vis-a-vis the current allowance times to better understand in which cells the times have been validated or where potential issues may be identified.

## 4.2 Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH Testing Results

A total of 10 allowance time tests were conducted with Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH. As this was an EG fluid and it was expected that the fluid would perform well in specific conditions, some tests were conducted for longer than published allowance times so the test could serve a dual purpose: validating the existing allowance times and potentially supporting the expansion of the table for EG fluids.

Table 4.1 provides a summary of the tests conducted that served strictly as validation tests (the exposure times of the tests were equivalent to the current allowance times). All tests conducted were acceptable from visual and aerodynamic perspectives.

Table 4.2 provides a summary of the tests conducted that served as expansion tests (the exposure times of the tests exceeded the current allowance times). Of the six tests conducted, three were acceptable from visual and aerodynamic perspectives. The other three tests (#6, #21, #22) fell in the “review” or “bad” category.

For tests #6 and #21, the “review” rating was due to the visual evaluation on the leading edge of the wing at the start of the test, which was 3.1 and 3.3, respectively for each test; these ratings are just above the allowed rating of 3.0. The exposure times were 15 minutes and 10 minutes longer than the current allowance times, so testing could be repeated with shorter exposure times, or repeat testing could be attempted to validate the visual ratings.

For test #22, the “bad” rating was a result of the flap being deployed during the contamination period. Previous research has shown that a significant improvement is expected if the test is conducted with the flap in the retracted position during the exposure time.

Table 4.3 provides the summary of all the tests conducted. Based on these results, the allowance times were validated for this fluid, and the results indicate a good potential to increase the times for EG fluids.

**Table 4.1: Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH  
Allowance Time Validation Tests**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C
Light Ice Pellets	50 minutes	30 minutes	30 minutes -14(2.5)30[4]G	30 minutes
Light Ice Pellets Mixed with Snow	40 minutes	15 minutes	15 minutes -15(2.8)15[5]G	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes		Caution: No allowance times currently exist
Light Ice Pellets Mixed with Freezing Rain	25 minutes	10 minutes		
Light Ice Pellets Mixed with Rain	25 minutes			
Moderate Ice Pellets (or Small Hail)	25 minutes	10 minutes	10 minutes -13(2.4)10[3]G	10 minutes
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle	10 minutes	7 minutes	Caution: No allowance times currently exist	

**Table 4.2: Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH  
Allowance Time Expansion Tests**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C
Light Ice Pellets	50 minutes -5(0.8)70[19]G	30 minutes	30 minutes -16(2.8)50[7]G	30 minutes
Light Ice Pellets Mixed with Snow	40 minutes -5(1.5)50[20]G	15 minutes	15 minutes	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes		Caution: No allowance times currently exist
Light Ice Pellets Mixed with Freezing Rain	25 minutes 5(4.7)40[22]B	10 minutes		
Light Ice Pellets Mixed with Rain	25 minutes			
Moderate Ice Pellets (or Small Hail)	25 minutes -5(1.3)35[21]R	10 minutes	10 minutes -16(2.3)25[6]R	10 minutes
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle	10 minutes -5(0.9)20[23]G	7 minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) Mixed with Rain	10 minutes			

**Table 4.3: All Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH Allowance Time Tests**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C
Light Ice Pellets	50 minutes -5(0.8)70[19]G	30 minutes	30 minutes -14(2.5)30[4]G -16(2.8)50[7]G	30 minutes
Light Ice Pellets Mixed with Snow	40 minutes -5(1.5)50[20]G	15 minutes	15 minutes -15(2.8)15[5]G	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes		Caution: No allowance times currently exist
Light Ice Pellets Mixed with Freezing Rain	25 minutes -5(4.7)40[22]B	10 minutes		
Light Ice Pellets Mixed with Rain	25 minutes			
Moderate Ice Pellets (or Small Hail)	25 minutes -5(1.3)35[21]R	10 minutes	10 minutes -13(2.4)10[3]G -16(2.3)25[6]R	10 minutes
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle	10 minutes -5(0.9)20[23]G	7 minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) Mixed with Rain	10 minutes			

### 4.3 Summary of Results

Table 4.4 provides a summary of the results from the validation testing. Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH was validated based on the data collected.

**Table 4.4: Summary of Ice Pellet Allowance Time Validation Tests**

Fluid	Status	Comments
Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH	Validated	Potential to extend allowance times. Further testing recommended in 2020-21.



## 5. POSSIBLE EXTENSION OF ALLOWANCE TIMES FOR EG FLUIDS

Type IV Ice Pellet Allowance Times are intended to be conservative, and, therefore, generic guidance is developed based on data collected using commercially available Type IV fluids. Historically, Type IV propylene glycol and EG fluids have been grouped together; however, data has indicated that EG may have an operational advantage of longer Ice Pellet Allowance Times in specific conditions. The industry requested that EG fluid-specific Ice Pellet Allowance Time tables be investigated to find potentially longer allowance times specific to these fluids. As such, an analysis of historical EG data was conducted, and some preliminary testing with EG fluids was performed, with the objective to identify or conduct tests that supported longer times for EG fluids.

### 5.1 Analysis of EG Fluid Allowance Times

An analysis was conducted based on the EG fluids tested during the winter of 2019-20, as well as historical testing that occurred between 2009 and 2019. The data included a mix of tests that were done for allowance time development, validation, and expansion. The analysis included six EG fluids:

1. ChemR EG IV;
2. Max Flight AVIA;
3. Safewing EG IV NORTH;
4. UCAR™ Endurance EG106 De/Anti-Icing Fluid;
5. LNT E450; and
6. Defrost EG 4.

The detailed data for all EG tests conducted since 2009 with the RJ wing has been reviewed. Table 5.2 provides a summary of all data points including those tested to the allowance times, as well as those tested to exposure times longer than the current allowance times. Table 5.3 includes only the validation tests, hence tests that were run to the current allowance times. Table 5.4 includes only the tests that were run longer than the current allowance times or in conditions where there are no allowance times.

For Table 5.2, Table 5.3, and Table 5.4, the individual test information has been included in the format provided below.

- AABB(CC)DD[EE]F

- AA is the fluid name designation as listed in Table 5.1.
- BB is the static tunnel ambient temperature recorded just before the start of the simulated takeoff test, measured in degrees Celsius and rounded to the closest degree.
- CC is the percent Lift Loss calculated based on the comparison of the 8° lift coefficient during the test run versus the dry wing average lift coefficient.
- DD is the exposure time of the test in minutes.
- EE is the test number to reference the data in the test logs.
- F is the status of the testing: either “G” for good, “R” for review, or “B” for bad, as per the guidelines in Subsection 2.11.4. The highlighting is in a corresponding green, yellow, or red colour.
- The test information is included in the cell for which the temperature band best corresponds to the temperature recorded during the test.

**Table 5.1: Abbreviated Fluid Name Designation for EG Expansion Analysis**

Fluid Name	Abbreviation
Chemco ChemR EG IV	CC
Clariant AVIA	CA
Clariant North	CN
EG106	DE
LNT E450	LE
Defrost EG IV	FR

Table 5.2: All EG Fluid Allowance Time Data Collected Since 2009

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16°C
Light Ice Pellets	50 minutes DE-4(0.9)50[22]G CN-5(0.8)70[19]G	30 minutes CC-7(1.3)50[40]G CC-9(1.8)50[31]G	30 minutes DE-11(1.6)30[51]G DE-13(1.1)30[67]G CC-13(2.6)30[16]G CN-14(2.5)30[4]G LE-15(5.8)30[10]R CN-16(2.8)50[7]G	30 minutes DE-17(2.3)30[80]G CA-21(5.7)30[15]R FR-22(6.7)30[17]R DE-23(3.2)30[27]G
Light Ice Pellets Mixed with Snow	40 minutes DE-3(1.2)40[23]G CC-5(3.7)50[33]R CN-5(1.5)50[20]G	15 minutes LE-7(5.4)15[21]G CC-8(2.5)15[12]G	15 minutes CC-12(3.4)15[17]G FR-13(5.2)15[42]G DE-13(2.4)15[45]G CC-14(3.2)30[12]G DE-14(1.9)30[14]G DE-14(2.7)25[78]G CA-14(4.3)15[41]R DE-15(3.2)10[79]G CN-15(2.8)15[5]G FR-15(3.4)30[16]G	0 minutes DE-17(2.0)15[310]G DE-18(4.1)15[311]R
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes CC-6(5.4)30[32]R		Caution: No allowance times currently exist
Light Ice Pellets Mixed with Freezing Rain	25 minutes LE-1(3.1)25[68]G DE-2(4.1)25[26]B DE-3(1.3)25[26A]G CN-5(4.7)40[22]B	10 minutes DE-7(1.2)10[98]G LE-8(4.9)10[20]G CC-8(3.2)10[8]G DE-10(7.2)40[126]B FR-10(4.4)10[43]G CA-10(2.9)10[46]G	0 minutes CC-12(5.8)30[43]B	
Light Ice Pellets Mixed with Rain	25 minutes LE0(4.3)25[76]G FR1(1.4)25[36]G			
Moderate Ice Pellets (or Small Hail)	25 minutes LE-2(3.3)25[69]G DE-4(0.8)25[21]G DE-4(1.8)25[124]G DE-4(1.7)25[125]G CA-4(1.9)25[31]G FR-4(2.5)25[32]G CN-5(1.3)35[21]R	10 minutes DE-7(1.6)10[364]B CC-10(1.9)10[13]G CC-10(2.3)25[42]G	10 minutes CN-13(2.4)10[3]G CC-14(2.1)25[11]R DE-15(1.1)25[13]R LE-15(6.4)10[13]R CC-15(2.7)10[18]G CN-16(2.2)25[6]R FR-16(2.8)25[15]G	10 minutes LE-17(6.0)10[11]R DE-18(1.8)10[71]G DE-21(3.1)10[26]G CA-21(5.5)10[16]R FR-21(6.6)10[18]R
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle	10 minutes CN-5(0.8)20[23]G	7 minutes CC-8(2.4)7[9]G	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) Mixed with Rain	10 minutes CC-3(7.2)10[39]B			

Table 5.3: EG Validation Tests Meeting Current Allowance Times Since 2009

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16°C
Light Ice Pellets	50 minutes DE-4(0.9)50[22]G	30 minutes	30 minutes DE-11(1.6)30[51]G DE-13(1.1)30[67]G CC-13(2.6)30[16]G CN-14(2.5)30[4]G LE-15(5.8)30[10]R	30 minutes DE-17(2.3)30[80]G CA-21(5.7)30[15]R FR-22(6.7)30[17]R DE-23(3.2)30[27]G
Light Ice Pellets Mixed with Snow	40 minutes DE-3(1.2)40[23]G	15 minutes LE-7(5.4)15[21]G CC-8(2.5)15[12]G	15 minutes CC-12(3.4)15[17]G FR-13(5.2)15[42]G DE-13(2.4)15[45]G CA-14(4.3)15[41]R CN-15(2.8)15[5]G	0 minutes
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes		Caution: No allowance times currently exist
Light Ice Pellets Mixed with Freezing Rain	25 minutes LE-1(3.1)25[68]G DE-2(4.1)25[26]B DE-3(1.3)25[26]G	10 minutes DE-7(1.2)10[98]G LE-8(4.9)10[20]G CC-8(3.2)10[8]G FR-10(4.4)10[43]G CA-10(2.9)10[46]G	0 minutes	
Light Ice Pellets Mixed with Rain	25 minutes LE0(4.3)25[76]G FR1(1.4)25[36]G			
Moderate Ice Pellets (or Small Hail)	25 minutes LE-2(3.3)25[69]G DE-4(0.8)25[21]G DE-4(1.8)25[124]G DE-4(1.7)25[125]G CA-4(1.9)25[31]G FR-4(2.5)25[32]G	10 minutes DE-7(1.6)10[364]B CC-10(1.9)10[13]G	10 minutes CN-13(2.4)10[3]G LE-15(6.4)10[13]R CC-15(2.7)10[18]G	10 minutes LE-17(6.0)10[11]R DE-18(1.8)10[71]G DE-21(3.1)10[26]G CA-21(5.5)10[16]R FR-21(6.6)10[18]R
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle	10 minutes	7 minutes CC-8(2.4)7[9]G	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) Mixed with Rain	10 minutes CC-3(7.2)10[39]B			

Table 5.4: EG Expansion Tests Exceeding Current Allowance Times Since 2009

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16°C
Light Ice Pellets	50 minutes CN-5(0.8)70[19]G	30 minutes CC-7(1.3)50[40]G CC-9(1.8)50[31]G	30 minutes CN-16(2.8)50[7]G	30 minutes
Light Ice Pellets Mixed with Snow	40 minutes CC-5(3.7)50[33]R CN-5(1.5)50[20]G	15 minutes	15 minutes CC-14(3.2)30[12]G DE-14(1.9)30[14]G DE-14(2.7)25[78]G FR-15(3.4)30[16]G	0 minutes DE-17(2.0)15[310]G DE-18(4.1)15[311]R
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes CC-6(5.4)30[32]R		Caution: No allowance times currently exist
Light Ice Pellets Mixed with Freezing Rain	25 minutes CN-5(4.7)40[22]B	10 minutes DE-10(7.2)40[126]B	0 minutes CC-12(5.8)30[43]B	
Light Ice Pellets Mixed with Rain	25 minutes			
Moderate Ice Pellets (or Small Hail)	25 minutes CN-5(1.3)35[21]R	10 minutes CC-10(2.3)25[42]G	10 minutes CC-14(2.1)25[11]R DE-15(1.1)25[13]R CN-16(2.2)25[6]R FR-16(2.8)25[15]G	10 minutes
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle	10 minutes CN-5(0.8)20[23]G	7 minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) Mixed with Rain	10 minutes			

Based on the results, each cell with tests showing room for expansion was analysed. The criteria for analysis could include the following:

- The test ran longer than the current allowance time and had a “Good” status;
- The test ran longer than the current allowance time and had a “Review” or “Bad” status that could be justified (i.e., flap down during exposure leading to bad visuals);
- The test ran to the current allowance time and had a “Good” status, indicating a margin for a longer time; and
- The test ran to the current allowance time and had a “Review” or “Bad” status that could be justified (i.e., flap down during exposure leading to bad visuals), therefore indicating a margin for a longer allowance time.

Through highlighted colours, Table 5.5 presents a summary of all EG fluid tests indicating cells with potential for longer allowance times. Note that in certain cells data may be missing, however more conservative (from a colder temperature band or higher rate of precipitation) may exist and could support the expansion of the allowance time. The coloured highlights describe the following:

- Both the green and yellow highlights indicate the longest time tested that showed a positive result;
- The “+” sign and green highlight indicate there was still capacity to go beyond the longest time tested. This is based on lift loss performance and visual evaluation of contamination (as per usual wind tunnel procedure); and
- The “ok” and yellow highlight indicate the performance is nearing the ceiling for that cell.

Table 5.6 shows the data summarized as potential marginal increases for longer allowance times. The coloured highlights describe the following:

- Both the green and yellow highlights indicate the potential for marginal increases of the allowance time;
- The “+” sign and green highlight indicate there was still capacity to go beyond the longest time tested. This is based on lift loss performance and visual evaluation of contamination (as per usual wind tunnel procedure); and
- The “ok” and yellow highlight indicate the performance is nearing the ceiling for that cell.

Additional tables providing the fluid specific analysis (similar to Table 5.5 but exclusive to each specific fluid) are included in Appendix E for reference.

**Table 5.5: Analysis of All EG Fluid Tests Indicating Cells with Potential for Longer Allowance Times**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C
Light Ice Pellets	50 minutes 70+ minutes	30 minutes 50+ minutes	30 minutes 50+ minutes	30 minutes 30 minutes ok
Light Ice Pellets Mixed with Snow	40 minutes 50 minutes ok	15 minutes 15+ minutes	15 minutes 30+ minutes	15+ minutes
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes 30+ minutes	10 minutes 30 minutes ok	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes 40 minutes ok	10 minutes 20+ minutes		
Light Ice Pellets Mixed with Rain	25 minutes 30+ minutes			
Moderate Ice Pellets (or Small Hail)	25 minutes 35 minutes ok	10 minutes 25+ minutes	10 minutes 25 minutes ok	10 minutes 10 minutes ok
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle	10 minutes	7 minutes 10+ minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) Mixed with Rain	10 minutes			

**Table 5.6: Analysis of Potential Marginal Increases for Longer Allowance Times**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C
Light Ice Pellets	↑20+ min	↑20+ min	↑20+ min	→0 min ok
Light Ice Pellets Mixed with Snow	↑10 min ok	↑0+ min	↑15+ min	↑15+ min
Light Ice Pellets Mixed with Freezing Drizzle	↑5+ min	↑20 min ok	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	↑15 min ok	↑10+ min		
Light Ice Pellets Mixed with Rain	↑5+ min			
Moderate Ice Pellets (or Small Hail)	↑10 min ok	↑15+ min	↑15 min ok	→0 min ok
Moderate Ice Pellets (or Small Hail) Mixed with Freezing Drizzle		↑3+ min	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) Mixed with Rain				

## 5.2 Summary of EG Expansion Data

The data collected to date indicates the potential for longer allowance times specific to EG fluids.

There are, however, some limitations to the data collected to date, as described below.

- Expansion data is not available for each fluid in each cell. The analysis would need to rely on the assumption that all EG fluids behave similarly and therefore if one fluid is tested, it is applicable to all EG fluids.
- Expansion data is not available for each cell. The analysis would need to reference validation tests or relative tests and rely on the assumption that if the time were increased, it would still pass.
- Some expansion data has a “Review” or “Bad” status (generally based on known factors such as flap up versus flap down). The analysis would need to assume that if parameters were changed and the tests were re-run, it would pass.

One consideration is that the test plan proposed for 2019-20 indicated that 14 days of testing were required to do a thorough assessment for EG expansion; however, based on limited resources, only 1.5 days of testing were possible. This represents roughly 10 percent of the effort proposed for a thorough and extensive testing program and analysis.

Another consideration is that the original allowance time table was developed based on an in-person review of the data with TC/FAA/APS whereby available data was used to make the best engineering decisions for each cell. The subsequent years of testing were used to further validate those times, and we still do so today. Therefore, if the full testing program and analysis cannot be completed in a timely and cost-effective manner, a more derivational approach can be considered to move forward with the expansion, similar to the initial development of the allowance time table.

A technical review of this data was conducted via web conference with TC, the FAA, and APS on May 27, 2020, and the group concluded that it was prudent to delay the expansion of the allowance times for EG fluids until additional data could be collected to provide a more robust data set.



## 6. CONCLUSIONS AND RECOMMENDATIONS

These conclusions and recommendations were derived from the testing conducted during the winters of 2017-18 and 2018-19.

### 6.1 Validation Testing for New-to-Market Type IV Fluids

The wind tunnel testing conducted during the winter of 2019-20 validated the current Type IV allowance times for use with the new-to-market fluid Clariant Produkte (Deutschland) GmbH Safewing EG IV NORTH.

### 6.2 Possible Extension of Allowance Times for EG Fluids

EG fluid testing and an analysis of historical data indicated the potential for longer allowance times specific to EG fluids. A technical review of this data was conducted, and the research group concluded that it was prudent to delay the expansion of the allowance times for EG fluids until some additional data is collected to provide a more robust data set.

### 6.3 Changes to Ice Pellet Allowance Time Guidance

The results of the validation and EG expansion testing did not require any changes to the current Ice Pellet Allowance Times or supporting guidance material. As such, no changes were issued to the Ice Pellet Allowance Times published in the HOT Guidelines for the winter of 2020-21.

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## REFERENCES

1. Ruggi, M., *Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics and to Support the Development of Ice Pellet Allowance Times, Winters 2009-10 to 2012-13*, APS Aviation Inc., Transportation Development Centre, Montreal, November 2013, TP 15232E, 1044.

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**APPENDIX A**

**TRANSPORT CANADA  
STATEMENT OF WORK EXCERPT –  
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2019-20**



**TRANSPORT CANADA  
STATEMENT OF WORK EXCERPT –  
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2019-20**

## **7. Wind Tunnel Testing – Planning and Setup Activities Only**

*Note: The NRC facility costs associated with manufacturing the test model and testing at M-46 are not included in this task and are dealt directly with TC through a M.O.U. agreement with NRC.*

*This budget associated with this project is only associated to tasks a) and b). Tasks c), d), e), and f) are budgeted as part of a separate project.*

- a) Coordinate with staff of NRC M-46 for scheduling and to organize any modifications to the wind tunnel, model, or related equipment. Review fluid requirements and request fluid samples from fluid manufacturers.
- b) Develop a procedure and test plan and coordinate with the NRC staff that operates the PIWT.
- ~~c) Perform pre-testing activities including the preparation of equipment, purchasing of equipment, training of personnel, and transportation and setup of equipment.~~
- ~~d) Perform wind tunnel tests (5 days) to explore contaminated deicing and anti-icing fluid flow properties on a vertical stabilizer model in various frozen and freezing precipitation conditions. It is anticipated that testing will be conducted during overnight hours over a period of two weeks. The typical procedure is described as follows, but may be modified to address specific testing objectives. Prior to starting each test event, correlation testing is required to calibrate the TC model and to demonstrate repeatability. Wind tunnel tests will be performed with ethylene glycol and propylene glycol anti-icing fluids at below freezing temperatures; Type I deicing fluids may also be considered. Tests will simulate low speed or high speed takeoffs and will look at simulating different cross wind conditions, rudder angles, and asymmetric contamination. During contaminated test runs, a baseline fluid only case may be run immediately before, or after the contaminated test run to provide a direct correlation of the results. High resolution photos will be taken of the fluid motion at the leading and trailing edges of the vertical stabilizer at a rate of about 3 frames per second, with lighting adequate to see the fluid waves and ripples of about 1mm in height. Observers will document the appearance of fluid on the vertical stabilizer during the simulated takeoff run and climb of the aircraft by analyzing the photographic records. The testing team will collect, among other things, the following data during the tests: type and~~

~~amount of fluid applied, type and rate of contamination applied, and extent of fluid contamination prior to the test run.~~

~~e) Analyze data.~~

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

## **9. Wind Tunnel Testing – Combined R&D Testing Including Type III Low Speed and EG-Specific Allowance Times (3 Days)**

*Note: The NRC facility costs associated with testing at M-46 are not included in this task and are dealt with directly with TC through a M.O.U. agreement with NRC.*

*This budget associated with the project is only the marginal costs for the extra 3 days of testing. Setup, planning, analysis, reporting, and presentation are budgeted as part of two separate projects.*

- a) Perform wind tunnel tests (3 days) with the RJ or LS-0417 wing to support the development of ice pellet allowance times. Testing objectives can include:
  - i. Validation of the existing Type IV fluid allowance times for use with the newly certified anti-icing fluids, or with fluids for which data is lacking;
  - ii. Development of an EG-specific allowance time table to be able to benefit from potentially longer times; and
  - iii. Expansion of the allowance for Type III fluids at low speeds to get longer times and guidance in more conditions.

It is anticipated that testing will be conducted during overnight hours over a period of one week. The typical procedure is described as follows, but may be modified to address specific testing objectives. Prior to starting each test event, correlation testing is required to calibrate the TC model and to demonstrate repeatability. Wind tunnel tests will be performed with ethylene glycol and propylene glycol anti-icing fluids at below freezing temperatures. Tests will simulate low speed or high speed takeoffs in accordance with the speed and angle of attack profiles provided by TC and airframe manufacturers. The simulated takeoff profile may target the clean wing stall angle as the maximum angle of attack in order to obtain CL<sub>max</sub> data. During contaminated test runs, a baseline fluid only case may be run immediately before, or after the contaminated test run to provide a direct correlation of the results. High resolution photos will be taken of the fluid motion at the leading and trailing edges of the wing at a rate of about 3 frames per second, with lighting adequate to see the fluid waves and ripples of about 1 mm in height, even



when the wing is at maximum angle of attack. Observers will document the appearance of fluid on the wing during the simulated takeoff run and climb of the aircraft by analyzing the photographic records. The testing team will collect, among other things, the following data during the tests: type and amount of fluid applied, type and rate of contamination applied, and extent of fluid contamination prior to the test run.

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## **APPENDIX B**

### **PROCEDURE:**

**WIND TUNNEL TESTS TO EXAMINE FLUID REMOVED FROM AIRCRAFT  
DURING TAKEOFF WITH MIXED ICE PELLET PRECIPITATION CONDITIONS  
WINTER 2019-20**



300293

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

Winter 2019-20

*Prepared for:*

**Transport Canada  
Innovation Centre**

*In cooperation with:*

**Federal Aviation Administration  
William J. Hughes Technical Center**

**Transport Canada  
Civil Aviation**

**Federal Aviation Administration  
Flight Standards – Air Carrier Operations**

Prepared by: Marco Ruggi

Reviewed by: John D’Avirro



January 16, 2020  
Final Version 1.0

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

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

Winter 2019-20

## **1. BACKGROUND**

In 2005-06, the inability of operators to release aircraft in ice pellet conditions led Transport Canada (TC) and the Federal Aviation Administration (FAA) to begin a research campaign to develop allowance times for these conditions. Developing holdover times was not feasible due to the properties of the ice pellets; they remain embedded in the fluid and take long to dissolve as compared to snow which is immediately absorbed and dissolved. Research was initiated by live aircraft testing with the National Research Council Canada (NRC) Falcon 20 in Ottawa Ontario, and later evolved to testing in a more controlled environment with the NRC Propulsion Icing Wind Tunnel (PIWT) also in Ottawa Ontario.

Early testing in 2005-06 with the Falcon 20 primarily used visual observations to evaluate fluid flow-off. During the Falcon 20 work the wing was anti-iced, exposed to contamination, and aborted takeoff runs were performed allowing researchers on-board to observe and evaluate the fluid flow-off. Testing in 2006-07 began in the PIWT allowing aerodynamic data to be used for evaluating fluid flow-off performance. The PIWT also allowed for a more controlled environment less susceptible to the elements.

The work continued each year, and the test methods and equipment improved allowing for real-time data analysis, better repeatability, and overall greater confidence in the results. The work conducted by TC/FAA was presented by APS Aviation Inc. (APS) to the SAE International (SAE) G-12 Aerodynamic Working Group (AWG) and Holdover Time (HOT) Committee yearly since 2006. Additional presentations were also given at the AWG in May 2012 and May 2013 by the National Aeronautics and Space Administration (NASA) and the NRC, which focused on the extensive calibration and characterization work performed with a generic thin high performance airfoil. This work also helped increase confidence in how the data were used to help support TC/FAA rule-making. A detailed account of the more recent work conducted is included in the TC report, TP 15232E, *Wind Tunnel Trials to Examine Anti-Icing Fluid Flow-Off Characteristics and to Support the Development of Ice Pellet Allowance Times, Winters 2009-10 to 2012-13*.

The Ice Pellet Allowance Time research has helped further develop and improve the PIWT facility. As a result, a new medium is now available for aerodynamic testing of aircraft ground icing fluids with or without contamination in a full-scale format. Several other ground deicing projects have been ongoing as a result of industry requests and are expected to continue. The PIWT has evolved into a multidisciplinary

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Final Version 1.0, January 20

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

facility; however, it continues to be the primary source for the development and further refinement of the ground deicing ice pellet allowance time guidance material. Research at the PIWT with and without ice pellets has continued on a yearly or bi-yearly basis and is performed by APS, with support of the NRC, on behalf of TC/FAA.

For the Winter 2019-20, testing will continue the development of ice pellet allowance times, and a new preliminary test program (described in a separate test procedure) will attempt to document fluid flow-off on a vertical stabilizer.

## 2. OBJECTIVES AND TIMING

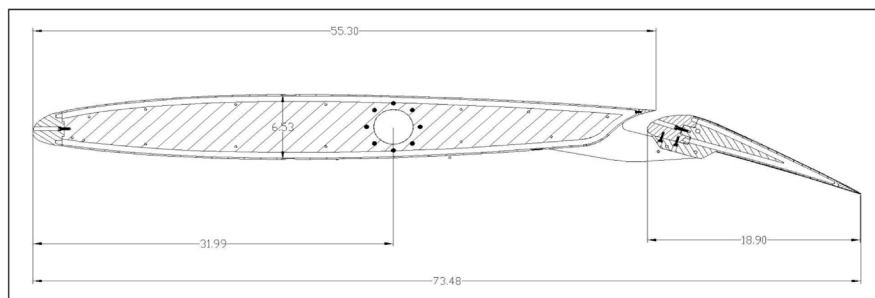
The following describes the objectives and timing of the research. Eight days of testing are being planned based on TC/FAA funding resources, three days of which are reserved for testing with the RJ wing model. The sequence of testing is fixed due to availability of the wind tunnel and NRC personnel required to swap out the aerodynamic models (RJ wing vs. vertical stabilizer).

### 2.1 Type IV Allowance Time Validation Testing

The objective of this testing is to conduct aerodynamic testing with a thin high performance airfoil to:

- Substantiate the current Type IV ice pellet allowance times with new fluids and at temperatures close to the lowest operational use temperature (LOUT).

To satisfy this objectives, a thin high performance wing section (Figure 2.1) will be subjected to a series of tests in the NRC PIWT. The dimensions indicated are in inches. This wing section was constructed by NRC in 2009 specifically for the conduct of these tests following extensive consultations with an airframe manufacturer to ensure a representative thin high performance design.



**Figure 2.1: Thin High Performance Wing Section**

One and a half days of testing are required for the conduct of these tests.

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

## 2.2 Type IV Allowance Time Expansion for Ethylene Glycol (EG) Fluids

The objective of this testing is to conduct aerodynamic testing with a thin high performance airfoil to:

- Expand the current Type IV ice pellet allowance times for EG fluids.

To satisfy this objectives, a thin high performance wing section (described in Subsection 2.1 and shown in Figure 2.1) will be subjected to a series of tests in the NRC PIWT.

One and a half days of testing are required for the conduct of these tests.

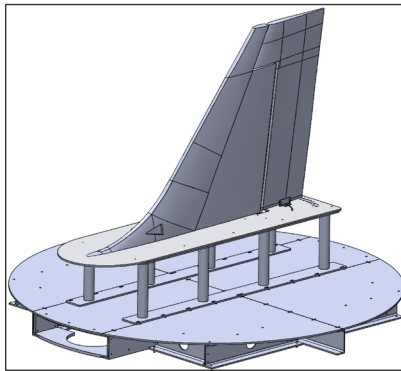
## 2.3 Documentation of Contaminated Fluid Flow-Off on a Vertical Stabilizer

The objective of this testing is to conduct aerodynamic testing with a vertical stabilizer to:

- Document contaminated fluid flow-off on a vertical stabilizer.

To satisfy this objectives, a Piper PA-34-200-2 Seneca vertical stabilizer (see Figure 2.2) will be subjected to a series of tests in the NRC PIWT.

Five days of testing are required for the conduct of these tests. The details of these tests will be described in a separate procedure.



**Figure 2.2: Vertical Stabilizer Mounted on Turntable**



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

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## 2.4 Timing

One and a half days are required for the “Type IV Allowance Time Validation Testing” (Subsection 2.1), one and a half days are required for the “Type IV Allowance Time Expansion for EG Fluids” (Subsection 2.2), and five days are required for the “Documentation of Contaminated Fluid Flow-Off on a Vertical Stabilizer ” (Subsection 2.3). This totals to eight days of testing, based on the available TC/FAA funding resources.

At the time of writing this procedure, it is expected that three days of testing with the RJ wing model will start on January 21<sup>st</sup>. Changing over of the aerodynamic models will require some down-time which will occur during the week of January 27<sup>th</sup>. Testing will resume with the vertical stabilizer model (details described in a separate procedure) for an additional five days of testing starting February 3<sup>rd</sup> (see Figure 2.3 for details).

Testing will likely be conducted during overnight periods (i.e. 9 pm – 5 am), unless temperatures are suitable for day/evening testing. The weekends will be considered only if deemed necessary. The first two hours or more of the first day will be dedicated to setup and calibration of the rain sprayer and ice pellet and snow dispensers; time permitting testing will begin as per the test plan. The precipitation that can be generated include the following:

- ZR – 25g/dm<sup>2</sup>/h;
- R – 25g/dm<sup>2</sup>/h;
- R – 75g/dm<sup>2</sup>/h;
- ZD – 5g/dm<sup>2</sup>/h;
- ZD – 13g/dm<sup>2</sup>/h;
- SN – 10g/dm<sup>2</sup>/h;
- SN – 25g/dm<sup>2</sup>/h;
- IP – 25g/dm<sup>2</sup>/h; and
- IP – 75g/dm<sup>2</sup>/h.

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

JANUARY 2020						
Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
Jan 12	13	14	15	16	17	18
				Pack up truck in YUL	Leave YUL for YOW for Preliminary Setup	
Jan 19	20	21	22	23	24	25
		<b>TEST DAY 1</b> RJ WING IP Validation New Fluids	<b>TEST DAY 2</b> RJ WING IP Validation New Fluids and IP EG Expansion	<b>TEST DAY 3</b> RJ WING IP EG Expansion		
Jan 26	31	31	31	31	31	01-Feb
	No Testing NRC Model Switchover from RJ wing to V-Stab	No Testing NRC Model Switchover from RJ wing to V-Stab	No Testing NRC Model Switchover from RJ wing to V-Stab	No Testing NRC Model Switchover from RJ wing to V-Stab	No Testing NRC Model Switchover from RJ wing to V-Stab	
02-Feb	3	4	5	6	7	8
	<b>TEST DAY 4</b> V-STAB Calibration and Validation of Procedures	<b>TEST DAY 5</b> V-STAB Dry Wing Tests	<b>TEST DAY 6</b> V-STAB Fluid Flow Off Characterization	<b>TEST DAY 7</b> V-STAB Fluid Flow Off Characterization	<b>TEST DAY 8</b> V-STAB Fluid Flow Off Characterization	

**NOTES**  
 Anticipate Mon-Fri testing, however, weekend may be considered due to temperature.  
 Testing will be conducted during overnight periods (9:00 pm - 5:00 am) i.e. Monday test day has a Sunday 9:00pm start.  
 Testing team will be JD, MR, BB, CB, BG & YOW x 5

**Figure 2.3: Test Calendar**

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

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### **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/II/III/IV propylene and ethylene fluids in Neat form (standard mix or 10-degree buffer for Type I) shall be evaluated against their uncontaminated performance.

A preliminary list of test objectives is shown in Table 3.1 (only Priority 1 objectives will be attempted unless indicated otherwise by TC/FAA directive). It should be noted that the order in which the tests will be carried out will depend on weather conditions and TC/FAA directive. A detailed test matrix (subject to change) related to Item #1, #2, and #3 are shown in Table 3.2. As some of this testing is exploratory, changes to the test plan may be made at the time of testing and will be confirmed by TC/FAA.

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

A rating system has been developed for fluid and contamination tests, and will be filled out by the on-site experts when applicable. 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.

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

**Table 3.1: Preliminary List of Testing Objectives for Winter 2019-20  
Wind Tunnel Testing**

Item #	Objective	Priority	Description	# of Days
0	Setup and Precipitation Calibration	1	Setup of equipment and calibration of the rain sprayer and the ice pellet and snow dispensers (to be done on the first day of testing)	-
1	Dry Wing Baseline Repeatability	1	Baseline test at beginning of each day to ensure repeatability (part of NRC shakedown tests so no days allotted)	N/A
2	Type IV IP AT Validation (New Fluids)	1	Substantiate current times with new fluids	1.5
3	Development of EG Specific IP Allowance Times	-	Support the development of an EG fluid specific ice pellet allowance time table to benefit of potential longer times	1.5
4	V-Stab Testing	1	Document contaminated fluid flow-off on a vertical stabilizer. Includes calibration work and procedural development.	5
5	Other R&D Activities	2	Could be selected from item # 5.1 to 5.11	0
5.1	Type III Allowance Time Expansion	-	Expand the current Type III allowance times to have increased times, or more cells	-
5.2	Snow Allowance Times Using Aerodynamic Data	-	Investigate feasibility of developing snow allowance times using the same aerodynamic based methodology used for ice pellets	-
5.3	Heavy Snow	-	Continue Heavy Snow Research comparing lift losses with Light/Moderate Snow vs. Heavy Snow	-
5.4	Heavy Contamination (Aero vs. Visual Failure)	-	Continue work looking at aerodynamic failure vs. HOT defined failure, and effect of surface roughness on lift degradation	-
5.5	Fluid + Cont @ LOU	-	Effect of contamination on fluid performance at LOU with IP, SN, ZF, Frost etc.	-
5.6	Simulate Frost in Wind Tunnel	-	Attempt to simulate frost conditions in wind tunnel.	-
5.7	130-150 Knots IP Testing	-	Conduct IP testing at 130-150 knots or validate feasibility MAY NEED TO MODIFY TUNNEL	-
5.8	2nd Wave of Fluid During Rotation	-	Investigate the aero effects of the 2nd wave of fluid created from fluid at the stagnation point which flows over the LE during rotation	-
5.9	Other	-	Any potential suggestions from industry	-

**Total # of Days for Priority 1 Tests**

**8**

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

**Table 3.2: Proposed Test Plan for Testing with the RJ Wing**

Test Plan #	Objective	Objective Priority	Test Condition	Rotation Angle	Ramp (s/fts)	Target OAT (°C)	Fluid	IP Rate (g/dm <sup>2</sup> /h)	SN Rate (g/dm <sup>2</sup> /h)	ZR Rate (g/dm <sup>2</sup> /h)	R Rate (g/dm <sup>2</sup> /h)	Exposure Time	Test Priority	COMMENT	IP QUANTITIES (g)	SN QUANTITIES (g)
P001	Baseline	1	Dry Wing	8	100	any	none	-	-	-	-	-	1	@start of day		
P002	Baseline	1	Dry Wing	22	80	any	none	-	-	-	-	-	1	@start of day		
P003	Type IV Validation and New Fluids	1	IP- / SN-	8	100	-5 to -10	Max Flight SNEG	25	10	-	-	15	2		3873	1614
P004	Type IV Validation and New Fluids	1	IP-	8	100	>-5	Safewing EG IV NORTH	25	-	-	-	50	1		12910	
P005	Type IV Validation and New Fluids	1	IP- / SN-	8	100	>-5	Safewing EG IV NORTH	25	10	-	-	40	1		10328	4304
P006	Type IV Validation and New Fluids	1	IP- / ZD	8	100	>-5	Safewing EG IV NORTH	25	-	13	-	25	2		6455	
P007	Type IV Validation and New Fluids	1	IP- / ZR-	8	100	>-5	Safewing EG IV NORTH	25	-	25	-	25	1		6455	
P008	Type IV Validation and New Fluids	1	IP- / R-	8	100	>0	Safewing EG IV NORTH	25	-	-	25	25	2		6455	
P009	Type IV Validation and New Fluids	1	IP Mod	8	100	>-5	Safewing EG IV NORTH	75	-	-	-	25	1		19365	
P010	Type IV Validation and New Fluids	1	IP Mod/ZD	8	100	>-5	Safewing EG IV NORTH	75	-	13	-	10	1		7746	
P011	Type IV Validation and New Fluids	1	IP Mod / R	8	100	>0	Safewing EG IV NORTH	75	-	-	75	10	2		7746	
P012	Type IV Validation and New Fluids	1	IP-	8	100	-5 to -10	Safewing EG IV NORTH	25	-	-	-	30	2		7746	
P013	Type IV Validation and New Fluids	1	IP- / SN-	8	100	-5 to -10	Safewing EG IV NORTH	25	10	-	-	15	2		3873	1614
P014	Type IV Validation and New Fluids	1	IP- / ZD	8	100	-5 to -10	Safewing EG IV NORTH	25	-	13	-	10	2		2582	
P015	Type IV Validation and New Fluids	1	IP- / ZR-	8	100	-5 to -10	Safewing EG IV NORTH	25	-	25	-	10	1		2582	
P016	Type IV Validation and New Fluids	1	IP Mod	8	100	-5 to -10	Safewing EG IV NORTH	75	-	-	-	10	2		7746	
P017	Type IV Validation and New Fluids	1	IP Mod/ZD	8	100	-5 to -10	Safewing EG IV NORTH	75	-	13	-	7	1		5422	
P018	Type IV Validation and New Fluids	1	IP-	8	100	-10 to -16	Safewing EG IV NORTH	25	-	-	-	30	1		7746	
P019	Type IV Validation and New Fluids	1	IP- / SN-	8	100	-10 to -16	Safewing EG IV NORTH	25	10	-	-	15	1		3873	1614
P020	Type IV Validation and New Fluids	1	IP Mod	8	100	-10 to -16	Safewing EG IV NORTH	75	-	-	-	10	1		7746	
P021	Type IV Validation and New Fluids	1	IP-	8	100	-16 to -22	Safewing EG IV NORTH	25	-	-	-	30	2		7746	
P022	Type IV Validation and New Fluids	1	IP Mod	8	100	-16 to -22	Safewing EG IV NORTH	75	-	-	-	10	2		7746	
P023	Type IV Validation and New Fluids	1	IP-	8	100	<-22	Safewing EG IV NORTH	25	-	-	-	30	2		7746	
P024	Type IV Validation and New Fluids	1	IP Mod	8	100	<-22	Safewing EG IV NORTH	75	-	-	-	10	2		7746	
P025	Type IV Validation and New Fluids	1	Fluid Only	8	100	>-5	Safewing EG IV NORTH	-	-	-	-	-	2	Baseline Test		
P026	Type IV Validation and New Fluids	1	Fluid Only	8	100	-5 to -10	Safewing EG IV NORTH	-	-	-	-	-	1	Baseline Test		
P027	Type IV Validation and New Fluids	1	Fluid Only	8	100	-10 to -16	Safewing EG IV NORTH	-	-	-	-	-	2	Baseline Test		
P028	Type IV Validation and New Fluids	1	Fluid Only	8	100	-16 to -22	Safewing EG IV NORTH	-	-	-	-	-	1	Baseline Test		
P029	Type IV Validation and New Fluids	1	Fluid Only	8	100	<-22	Safewing EG IV NORTH	-	-	-	-	-	1	Baseline Test		

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

**Table 3.2: Proposed Test Plan for Testing with the RJ Wing (cont'd)**

Test Plan #	Objective	Objective Priority	Test Condition	Rotation Angle	Ramp (s/fts)	Target OAT (°C)	Fluid	IP Rate (g/dm <sup>2</sup> /h)	SN Rate (g/dm <sup>2</sup> /h)	ZR Rate (g/dm <sup>2</sup> /h)	R Rate (g/dm <sup>2</sup> /h)	Exposure Time	Test Priority	COMMENT	IP QUANTITIES (g)	SN QUANTITIES (g)
P030	EG Type IV Expansion	1	IP-	8	100	>-5	Max Flight AVIA	25	-	-	-	70	1	Current AT is 50 min	18074	
P031	EG Type IV Expansion	1	IP- / SN-	8	100	>-5	Max Flight AVIA	25	10	-	-	50	1	Current AT is 40 min	12910	5380
P032	EG Type IV Expansion	1	IP- / ZD	8	100	>-5	Max Flight AVIA	25	-	13	-	40	2	Current AT is 25 min	10328	
P033	EG Type IV Expansion	1	IP- / ZR-	8	100	>-5	Max Flight AVIA	25	-	25	-	40	1	Current AT is 25 min	10328	
P034	EG Type IV Expansion	1	IP- / R-	8	100	>0	Max Flight AVIA	25	-	-	25	40	2	Current AT is 25 min	10328	
P035	EG Type IV Expansion	1	IP Mod	8	100	>-5	Max Flight AVIA	75	-	-	-	35	1	Current AT is 25 min	27111	
P036	EG Type IV Expansion	1	IP Mod/ZD	8	100	>-5	Max Flight AVIA	75	-	13	-	20	1	Current AT is 10 min	15492	
P037	EG Type IV Expansion	1	IP Mod / R	8	100	>0	Max Flight AVIA	75	-	-	75	20	2	Current AT is 10 min	15492	
P038	EG Type IV Expansion	1	IP-	8	100	-5 to -10	Max Flight AVIA	25	-	-	-	50	2	Current AT is 30 min	12910	
P039	EG Type IV Expansion	1	IP- / SN-	8	100	-5 to -10	Max Flight AVIA	25	10	-	-	30	2	Current AT is 15 min	7746	3228
P040	EG Type IV Expansion	1	IP- / ZD	8	100	-5 to -10	Max Flight AVIA	25	-	13	-	30	2	Current AT is 10 min	7746	
P041	EG Type IV Expansion	1	IP- / ZR-	8	100	-5 to -10	Max Flight AVIA	25	-	25	-	30	1	Current AT is 10 min	7746	
P042	EG Type IV Expansion	1	IP Mod	8	100	-5 to -10	Max Flight AVIA	75	-	-	-	25	2	Current AT is 10 min	19365	
P043	EG Type IV Expansion	1	IP Mod/ZD	8	100	-5 to -10	Max Flight AVIA	75	-	13	-	10	1	Current AT is 7 min	7746	
P044	EG Type IV Expansion	1	IP-	8	100	-10 to -16	Max Flight AVIA	25	-	-	-	50	1	Current AT is 30 min	12910	
P045	EG Type IV Expansion	1	IP- / SN-	8	100	-10 to -16	Max Flight AVIA	25	10	-	-	30	1	Current AT is 15 min	7746	3228
P046	EG Type IV Expansion	1	IP Mod	8	100	-10 to -16	Max Flight AVIA	75	-	-	-	25	1	Current AT is 10 min	19365	
P047	EG Type IV Expansion	1	IP-	8	100	-16 to -22	Max Flight AVIA	25	-	-	-	50	2	Current AT is 30 min	12910	
P048	EG Type IV Expansion	1	IP- / SN-	8	100	-16 to -22	Max Flight AVIA	25	10	-	-	30	1	No AT exists currently	7746	3228
P049	EG Type IV Expansion	1	IP Mod	8	100	-16 to -22	Max Flight AVIA	75	-	-	-	25	2	Current AT is 30 min	19365	
P050	EG Type IV Expansion	1	IP-	8	100	<-22	Max Flight AVIA	25	-	-	-	50	2	Current AT is 10 min	12910	
P051	EG Type IV Expansion	1	IP Mod	8	100	<-22	Max Flight AVIA	75	-	-	-	25	2	Current AT is - min	19365	
P052	EG Type IV Expansion	1	Fluid Only	8	100	>-5	Max Flight AVIA	-	-	-	-	-	2	Baseline Test		
P053	EG Type IV Expansion	1	Fluid Only	8	100	-5 to -10	Max Flight AVIA	-	-	-	-	-	1	Baseline Test		
P054	EG Type IV Expansion	1	Fluid Only	8	100	-10 to -16	Max Flight AVIA	-	-	-	-	-	2	Baseline Test		
P055	EG Type IV Expansion	1	Fluid Only	8	100	-16 to -22	Max Flight AVIA	-	-	-	-	-	1	Baseline Test		
P056	EG Type IV Expansion	1	Fluid Only	8	100	<-22	Max Flight AVIA	-	-	-	-	-	1	Baseline Test		
P057	EG Type IV Expansion	1	IP-	8	100	>-5	Safewing EG IV NORTH	25	-	-	-	70	1	Current AT is 50 min	18074	
P058	EG Type IV Expansion	1	IP- / SN-	8	100	>-5	Safewing EG IV NORTH	25	10	-	-	50	1	Current AT is 40 min	12910	5380

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

Table 3.2: Proposed Test Plan for Testing with the RJ Wing (cont'd)

Test Plan #	Objective	Objective Priority	Test Condition	Rotation Angle	Ramp (s/ks)	Target OAT (°C)	Fluid	IP Rate (g/dm <sup>2</sup> /h)	SN Rate (g/dm <sup>2</sup> /h)	ZR Rate (g/dm <sup>2</sup> /h)	R Rate (g/dm <sup>2</sup> /h)	Exposure Time	Test Priority	COMMENT	IP QUANTITIES (g)	SN QUANTITIES (g)
P059	EG Type IV Expansion	1	IP- / ZD	8	100	>-5	Safewing EG IV NORTH	25	-	13	-	40	2	Current AT is 25 min	10328	
P060	EG Type IV Expansion	1	IP- / ZR-	8	100	>-5	Safewing EG IV NORTH	25	-	25	-	40	1	Current AT is 25 min	10328	
P061	EG Type IV Expansion	1	IP- / R-	8	100	>0	Safewing EG IV NORTH	25	-	-	25	40	2	Current AT is 25 min	10328	
P062	EG Type IV Expansion	1	IP Mod	8	100	>-5	Safewing EG IV NORTH	75	-	-	-	35	1	Current AT is 25 min	27111	
P063	EG Type IV Expansion	1	IP Mod/ZD	8	100	>-5	Safewing EG IV NORTH	75	-	13	-	20	1	Current AT is 10 min	15492	
P064	EG Type IV Expansion	1	IP Mod / R	8	100	>0	Safewing EG IV NORTH	75	-	-	75	20	2	Current AT is 10 min	15492	
P065	EG Type IV Expansion	1	IP-	8	100	-5 to -10	Safewing EG IV NORTH	25	-	-	-	50	2	Current AT is 30 min	12910	
P066	EG Type IV Expansion	1	IP- / SN-	8	100	-5 to -10	Safewing EG IV NORTH	25	10	-	-	30	2	Current AT is 15 min	7746	3228
P067	EG Type IV Expansion	1	IP- / ZD	8	100	-5 to -10	Safewing EG IV NORTH	25	-	13	-	30	2	Current AT is 10 min	7746	
P068	EG Type IV Expansion	1	IP- / ZR-	8	100	-5 to -10	Safewing EG IV NORTH	25	-	25	-	30	1	Current AT is 10 min	7746	
P069	EG Type IV Expansion	1	IP Mod	8	100	-5 to -10	Safewing EG IV NORTH	75	-	-	-	25	2	Current AT is 10 min	19365	
P070	EG Type IV Expansion	1	IP Mod/ZD	8	100	-5 to -10	Safewing EG IV NORTH	75	-	13	-	10	1	Current AT is 7 min	7746	
P071	EG Type IV Expansion	1	IP-	8	100	-10 to -16	Safewing EG IV NORTH	25	-	-	-	50	1	Current AT is 30 min	12910	
P072	EG Type IV Expansion	1	IP- / SN-	8	100	-10 to -16	Safewing EG IV NORTH	25	10	-	-	30	1	Current AT is 15 min	7746	3228
P073	EG Type IV Expansion	1	IP Mod	8	100	-10 to -16	Safewing EG IV NORTH	75	-	-	-	25	1	Current AT is 10 min	19365	
P074	EG Type IV Expansion	1	IP-	8	100	-16 to -22	Safewing EG IV NORTH	25	-	-	-	50	2	Current AT is 30 min	12910	
P075	EG Type IV Expansion	1	IP- / SN-	8	100	-16 to -22	Safewing EG IV NORTH	25	10	-	-	30	1	No AT exists currently	7746	3228
P076	EG Type IV Expansion	1	IP Mod	8	100	-16 to -22	Safewing EG IV NORTH	75	-	-	-	25	2	Current AT is 30 min	19365	
P077	EG Type IV Expansion	1	IP-	8	100	<-22	Safewing EG IV NORTH	25	-	-	-	50	2	Current AT is 10 min	12910	
P078	EG Type IV Expansion	1	IP Mod	8	100	<-22	Safewing EG IV NORTH	75	-	-	-	25	2	Current AT is - min	19365	
P079	EG Type IV Expansion	1	Fluid Only	8	100	>-5	Safewing EG IV NORTH	-	-	-	-	-	2	Baseline Test		
P080	EG Type IV Expansion	1	Fluid Only	8	100	-5 to -10	Safewing EG IV NORTH	-	-	-	-	-	1	Baseline Test		
P081	EG Type IV Expansion	1	Fluid Only	8	100	-10 to -16	Safewing EG IV NORTH	-	-	-	-	-	2	Baseline Test		
P082	EG Type IV Expansion	1	Fluid Only	8	100	-16 to -22	Safewing EG IV NORTH	-	-	-	-	-	1	Baseline Test		
P083	EG Type IV Expansion	1	Fluid Only	8	100	<-22	Safewing EG IV NORTH	-	-	-	-	-	1	Baseline Test		
P084	EG Type IV Expansion	1	IP-	8	100	>-5	Defrost EG 4	25	-	-	-	70	1	Current AT is 50 min	18074	
P085	EG Type IV Expansion	1	IP- / SN-	8	100	>-5	Defrost EG 4	25	10	-	-	50	1	Current AT is 40 min	12910	5380
P086	EG Type IV Expansion	1	IP- / ZD	8	100	>-5	Defrost EG 4	25	-	13	-	40	2	Current AT is 25 min	10328	
P087	EG Type IV Expansion	1	IP- / ZR-	8	100	>-5	Defrost EG 4	25	-	25	-	40	1	Current AT is 25 min	10328	

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

Table 3.2: Proposed Test Plan for Testing with the RJ Wing (cont'd)

Test Plan #	Objective	Objective Priority	Test Condition	Rotation Angle	Ramp (s/fts)	Target OAT (°C)	Fluid	IP Rate (g/dm <sup>2</sup> /h)	SN Rate (g/dm <sup>2</sup> /h)	ZR Rate (g/dm <sup>2</sup> /h)	R Rate (g/dm <sup>2</sup> /h)	Exposure Time	Test Priority	COMMENT	IP QUANTITIES (g)	SN QUANTITIES (g)
P088	EG Type IV Expansion	1	IP- / R-	8	100	>0	Defrost EG 4	25	-	-	25	40	2	Current AT is 25 min	10328	
P089	EG Type IV Expansion	1	IP Mod	8	100	>-5	Defrost EG 4	75	-	-	-	35	1	Current AT is 25 min	27111	
P090	EG Type IV Expansion	1	IP Mod/ZD	8	100	>-5	Defrost EG 4	75	-	13	-	20	1	Current AT is 10 min	15492	
P091	EG Type IV Expansion	1	IP Mod / R	8	100	>0	Defrost EG 4	75	-	-	75	20	2	Current AT is 10 min	15492	
P092	EG Type IV Expansion	1	IP-	8	100	-5 to -10	Defrost EG 4	25	-	-	-	50	2	Current AT is 30 min	12910	
P093	EG Type IV Expansion	1	IP- / SN-	8	100	-5 to -10	Defrost EG 4	25	10	-	-	30	2	Current AT is 15 min	7746	3228
P094	EG Type IV Expansion	1	IP- / ZD	8	100	-5 to -10	Defrost EG 4	25	-	13	-	30	2	Current AT is 10 min	7746	
P095	EG Type IV Expansion	1	IP- / ZR-	8	100	-5 to -10	Defrost EG 4	25	-	25	-	30	1	Current AT is 10 min	7746	
P096	EG Type IV Expansion	1	IP Mod	8	100	-5 to -10	Defrost EG 4	75	-	-	-	25	2	Current AT is 10 min	19365	
P097	EG Type IV Expansion	1	IP Mod/ZD	8	100	-5 to -10	Defrost EG 4	75	-	13	-	10	1	Current AT is 7 min	7746	
P098	EG Type IV Expansion	1	IP-	8	100	-10 to -16	Defrost EG 4	25	-	-	-	50	1	Current AT is 30 min	12910	
P099	EG Type IV Expansion	1	IP- / SN-	8	100	-10 to -16	Defrost EG 4	25	10	-	-	30	1	Current AT is 15 min	7746	3228
P100	EG Type IV Expansion	1	IP Mod	8	100	-10 to -16	Defrost EG 4	75	-	-	-	25	1	Current AT is 10 min	19365	
P101	EG Type IV Expansion	1	IP-	8	100	-16 to -22	Defrost EG 4	25	-	-	-	50	2	Current AT is 30 min	12910	
P102	EG Type IV Expansion	1	IP- / SN-	8	100	-16 to -22	Defrost EG 4	25	10	-	-	30	1	No AT exists currently	7746	3228
P103	EG Type IV Expansion	1	IP Mod	8	100	-16 to -22	Defrost EG 4	75	-	-	-	25	2	Current AT is 30 min	19365	
P104	EG Type IV Expansion	1	IP-	8	100	<-22	Defrost EG 4	25	-	-	-	50	2	Current AT is 10 min	12910	
P105	EG Type IV Expansion	1	IP Mod	8	100	<-22	Defrost EG 4	75	-	-	-	25	2	Current AT is - min	19365	
P106	EG Type IV Expansion	1	Fluid Only	8	100	>-5	Defrost EG 4	-	-	-	-	-	2	Baseline Test		
P107	EG Type IV Expansion	1	Fluid Only	8	100	-5 to -10	Defrost EG 4	-	-	-	-	-	1	Baseline Test		
P108	EG Type IV Expansion	1	Fluid Only	8	100	-10 to -16	Defrost EG 4	-	-	-	-	-	2	Baseline Test		
P109	EG Type IV Expansion	1	Fluid Only	8	100	-16 to -22	Defrost EG 4	-	-	-	-	-	1	Baseline Test		
P110	EG Type IV Expansion	1	Fluid Only	8	100	<-22	Defrost EG 4	-	-	-	-	-	1	Baseline Test		
P111	EG Type IV Expansion	1	IP-	8	100	>-5	ChemR EG IV	25	-	-	-	70	1	Current AT is 50 min	18074	
P112	EG Type IV Expansion	1	IP- / SN-	8	100	>-5	ChemR EG IV	25	10	-	-	50	1	Current AT is 40 min	12910	5380
P113	EG Type IV Expansion	1	IP- / ZD	8	100	>-5	ChemR EG IV	25	-	13	-	40	2	Current AT is 25 min	10328	
P114	EG Type IV Expansion	1	IP- / ZR-	8	100	>-5	ChemR EG IV	25	-	25	-	40	1	Current AT is 25 min	10328	
P115	EG Type IV Expansion	1	IP- / R-	8	100	>0	ChemR EG IV	25	-	-	25	40	2	Current AT is 25 min	10328	
P116	EG Type IV Expansion	1	IP Mod	8	100	>-5	ChemR EG IV	75	-	-	-	35	1	Current AT is 25 min	27111	

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

Table 3.2: Proposed Test Plan for Testing with the RJ Wing (cont'd)

Test Plan #	Objective	Objective Priority	Test Condition	Rotation Angle	Ramp (s/fts)	Target OAT (°C)	Fluid	IP Rate (g/dm <sup>2</sup> /h)	SN Rate (g/dm <sup>2</sup> /h)	ZR Rate (g/dm <sup>2</sup> /h)	R Rate (g/dm <sup>2</sup> /h)	Exposure Time	Test Priority	COMMENT	IP QUANTITIES (g)	SN QUANTITIES (g)
P117	EG Type IV Expansion	1	IP Mod/ZD	8	100	>-5	ChemR EG IV	75	-	13	-	20	1	Current AT is 10 min	15492	
P118	EG Type IV Expansion	1	IP Mod / R	8	100	>0	ChemR EG IV	75	-	-	75	20	2	Current AT is 10 min	15492	
P119	EG Type IV Expansion	1	IP-	8	100	-5 to -10	ChemR EG IV	25	-	-	-	50	2	Current AT is 30 min	12910	
P120	EG Type IV Expansion	1	IP- / SN-	8	100	-5 to -10	ChemR EG IV	25	10	-	-	30	2	Current AT is 15 min	7746	3228
P121	EG Type IV Expansion	1	IP- / ZD	8	100	-5 to -10	ChemR EG IV	25	-	13	-	30	2	Current AT is 10 min	7746	
P122	EG Type IV Expansion	1	IP- / ZR-	8	100	-5 to -10	ChemR EG IV	25	-	25	-	30	1	Current AT is 10 min	7746	
P123	EG Type IV Expansion	1	IP Mod	8	100	-5 to -10	ChemR EG IV	75	-	-	-	25	2	Current AT is 10 min	19365	
P124	EG Type IV Expansion	1	IP Mod/ZD	8	100	-5 to -10	ChemR EG IV	75	-	13	-	10	1	Current AT is 7 min	7746	
P125	EG Type IV Expansion	1	IP-	8	100	-10 to -16	ChemR EG IV	25	-	-	-	50	1	Current AT is 30 min	12910	
P126	EG Type IV Expansion	1	IP- / SN-	8	100	-10 to -16	ChemR EG IV	25	10	-	-	30	1	Current AT is 15 min	7746	3228
P127	EG Type IV Expansion	1	IP Mod	8	100	-10 to -16	ChemR EG IV	75	-	-	-	25	1	Current AT is 10 min	19365	
P128	EG Type IV Expansion	1	IP-	8	100	-16 to -22	ChemR EG IV	25	-	-	-	50	2	Current AT is 30 min	12910	
P129	EG Type IV Expansion	1	IP- / SN-	8	100	-16 to -22	ChemR EG IV	25	10	-	-	30	1	No AT exists currently	7746	3228
P130	EG Type IV Expansion	1	IP Mod	8	100	-16 to -22	ChemR EG IV	75	-	-	-	25	2	Current AT is 30 min	19365	
P131	EG Type IV Expansion	1	IP-	8	100	<-22	ChemR EG IV	25	-	-	-	50	2	Current AT is 10 min	12910	
P132	EG Type IV Expansion	1	IP Mod	8	100	<-22	ChemR EG IV	75	-	-	-	25	2	Current AT is - min	19365	
P133	EG Type IV Expansion	1	Fluid Only	8	100	>-5	ChemR EG IV	-	-	-	-	-	2	Baseline Test		
P134	EG Type IV Expansion	1	Fluid Only	8	100	-5 to -10	ChemR EG IV	-	-	-	-	-	1	Baseline Test		
P135	EG Type IV Expansion	1	Fluid Only	8	100	-10 to -16	ChemR EG IV	-	-	-	-	-	2	Baseline Test		
P136	EG Type IV Expansion	1	Fluid Only	8	100	-16 to -22	ChemR EG IV	-	-	-	-	-	1	Baseline Test		
P137	EG Type IV Expansion	1	Fluid Only	8	100	<-22	ChemR EG IV	-	-	-	-	-	1	Baseline Test		
P138	EG Type IV Expansion	1	IP-	8	100	>-5	EG106	25	-	-	-	70	1	Current AT is 50 min	18074	
P139	EG Type IV Expansion	1	IP- / SN-	8	100	>-5	EG106	25	10	-	-	50	1	Current AT is 40 min	12910	5380
P140	EG Type IV Expansion	1	IP- / ZD	8	100	>-5	EG106	25	-	13	-	40	2	Current AT is 25 min	10328	
P141	EG Type IV Expansion	1	IP- / ZR-	8	100	>-5	EG106	25	-	25	-	40	1	Current AT is 25 min	10328	
P142	EG Type IV Expansion	1	IP- / R-	8	100	>0	EG106	25	-	-	25	40	2	Current AT is 25 min	10328	
P143	EG Type IV Expansion	1	IP Mod	8	100	>-5	EG106	75	-	-	-	35	1	Current AT is 25 min	27111	
P144	EG Type IV Expansion	1	IP Mod/ZD	8	100	>-5	EG106	75	-	13	-	20	1	Current AT is 10 min	15492	
P145	EG Type IV Expansion	1	IP Mod / R	8	100	>0	EG106	75	-	-	75	20	2	Current AT is 10 min	15492	

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**Table 3.2: Proposed Test Plan for Testing with the RJ Wing (cont'd)**

Test Plan #	Objective	Objective Priority	Test Condition	Rotation Angle	Ramp (s/ks)	Target OAT (°C)	Fluid	IP Rate (g/dm <sup>2</sup> /h)	SN Rate (g/dm <sup>2</sup> /h)	ZR Rate (g/dm <sup>2</sup> /h)	R Rate (g/dm <sup>2</sup> /h)	Exposure Time	Test Priority	COMMENT	IP QUANTITIES (g)	SN QUANTITIES (g)
P146	EG Type IV Expansion	1	IP-	8	100	-5 to -10	EG106	25	-	-	-	50	2	Current AT is 30 min	12910	
P147	EG Type IV Expansion	1	IP- / SN-	8	100	-5 to -10	EG106	25	10	-	-	30	2	Current AT is 15 min	7746	3228
P148	EG Type IV Expansion	1	IP- / ZD	8	100	-5 to -10	EG106	25	-	13	-	30	2	Current AT is 10 min	7746	
P149	EG Type IV Expansion	1	IP- / ZR-	8	100	-5 to -10	EG106	25	-	25	-	30	1	Current AT is 10 min	7746	
P150	EG Type IV Expansion	1	IP Mod	8	100	-5 to -10	EG106	75	-	-	-	25	2	Current AT is 10 min	19385	
P151	EG Type IV Expansion	1	IP Mod/ZD	8	100	-5 to -10	EG106	75	-	13	-	10	1	Current AT is 7 min	7746	
P152	EG Type IV Expansion	1	IP-	8	100	-10 to -16	EG106	25	-	-	-	50	1	Current AT is 30 min	12910	
P153	EG Type IV Expansion	1	IP- / SN-	8	100	-10 to -16	EG106	25	10	-	-	30	1	Current AT is 15 min	7746	3228
P154	EG Type IV Expansion	1	IP Mod	8	100	-10 to -16	EG106	75	-	-	-	25	1	Current AT is 10 min	19385	
P155	EG Type IV Expansion	1	IP-	8	100	-16 to -22	EG106	25	-	-	-	50	2	Current AT is 30 min	12910	
P156	EG Type IV Expansion	1	IP- / SN-	8	100	-16 to -22	EG106	25	10	-	-	30	1	No AT exists currently	7746	3228
P157	EG Type IV Expansion	1	IP Mod	8	100	-16 to -22	EG106	75	-	-	-	25	2	Current AT is 30 min	19385	
P158	EG Type IV Expansion	1	IP-	8	100	<-22	EG106	25	-	-	-	50	2	Current AT is 10 min	12910	
P159	EG Type IV Expansion	1	IP Mod	8	100	<-22	EG106	75	-	-	-	25	2	Current AT is - min	19385	
P160	EG Type IV Expansion	1	Fluid Only	8	100	>-5	EG106	-	-	-	-	-	2	Baseline Test		
P161	EG Type IV Expansion	1	Fluid Only	8	100	-5 to -10	EG106	-	-	-	-	-	1	Baseline Test		
P162	EG Type IV Expansion	1	Fluid Only	8	100	-10 to -16	EG106	-	-	-	-	-	2	Baseline Test		
P163	EG Type IV Expansion	1	Fluid Only	8	100	-16 to -22	EG106	-	-	-	-	-	1	Baseline Test		
P164	EG Type IV Expansion	1	Fluid Only	8	100	<-22	EG106	-	-	-	-	-	1	Baseline Test		
P165	R&D	2	Till Expansion	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	Expand Till Times		
P166	R&D	2	Snow Aero	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	Snow Allowance Times		
P168	R&D	3	S + + +	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	Heavy snow		
P169	R&D	3	Heavy Cont	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	Heavy contamination		
P171	R&D	3	LOUT w/ Cont.	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	Test w/ contamination @ LOUT		
P172	R&D	3	Frost	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	Simulated Frost		
P173	R&D	4	IP @ >130kts	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	IP testing a higher speeds		
P165	R&D	4	2nd Wave	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	2nd wave of fluid at rot.		
P166	R&D	4	Other	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	3	Other		

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PRECIPITATION CONDITIONS**

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**4. PRE-TESTING SETUP ACTIVITIES**

The activities to be performed for planning and preparation, on the first day of testing, and prior to each testing day thereafter, have been detailed in a list included in Attachment 1.

**5. DATA FORMS**

The following data forms are required for the January 2020 wind tunnel tests:

- Attachment 2: General Form;
- Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form;
- Attachment 4: Example Ice Pellet Dispensing Form;
- Attachment 5: Example Snow Dispensing Form;
- Attachment 6: Example Snow Dispensing Form (Manual Method);
- Attachment 7: Visual Evaluation Rating Form;
- Attachment 8: Fluid Receipt Form (Electronic Form); and
- Attachment 9: 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 2); and
- Record wing temperature (Attachment 3).

**6.2 Fluid Application (Pour)**

- Hand pour 20L of anti-icing fluid over the test area (fluid can be poured directly out of pails or transferred into smaller 3L jugs);

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PRECIPITATION CONDITIONS**

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- Record fluid application times and quantities (Attachment 2);
- 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 3);
- Record wing temperature (Attachment 3);
- Measure fluid Brix value (Attachment 3);
- Photograph and videotape the appearance of the fluid on the wing; and
- Begin the time-lapse camera to gather photos of the precipitation application phase.

*Note: At the request of TC/FAA, a standard aluminum test plate can 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:

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

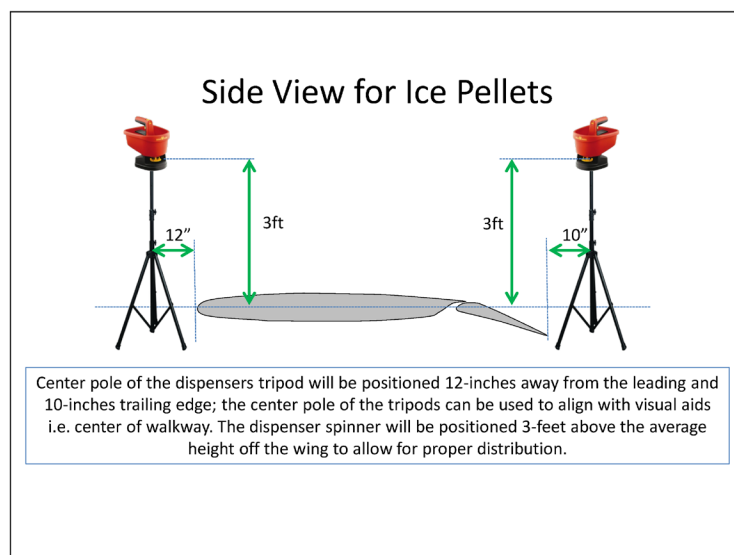
These tests were conducted using 121 collection pans, each measuring 6 x 6 inches, over an area 11 x 11 feet. Pre-measured amounts of ice pellets/snow were dispersed over this area and the amount collected by each pan was recorded. A distribution footprint of the dispenser was attained and efficiency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

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

### 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. Figure 6.1, Figure 6.2, and Figure 6.3 demonstrate the setup of the dispensers in relation to the wing. Attachment 4 and Attachment 5 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 percent based on how much of the precipitation actually made it onto the wing and a form to be used for this dispensing process along with dispensing instructions is included in Attachment 6.

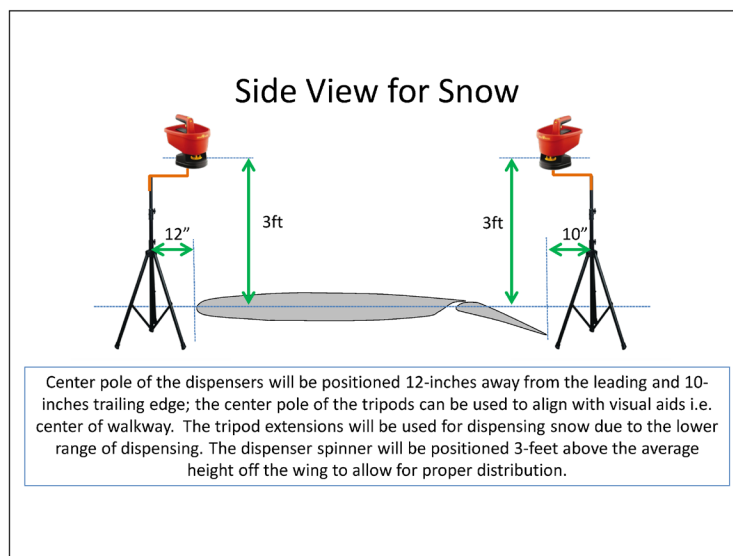
*Note: Dispensing forms should be filled out and saved for each run and pertinent information shall be included in the general form (Attachment 2). Any comments regarding dispensing activities should be documented directly on the form.*



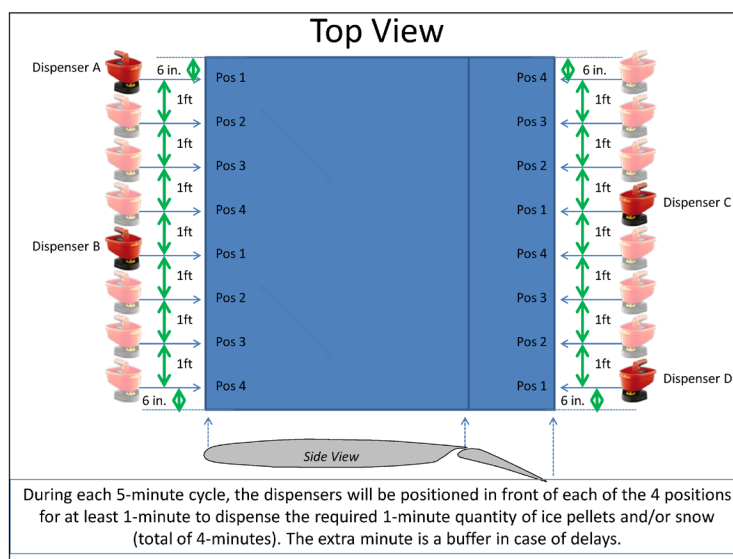
**Figure 6.1: Side View of Positioning of Dispensers  
Relative to the Wing – Ice Pellets**

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**Figure 6.2: Side View of Positioning of Dispenser  
Relative to the Wing – Snow**



**Figure 6.3: Top View of Positioning of Dispenser  
Relative to the Wing**

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**6.3.3 New Ice Pellets/Snow Dispensing Systems for 2014 Onwards**

Simulated ice pellets are distributed over a test surface using an ice pellet pitcher. The original ice pellet pitcher (Yardworks) was a modified handheld fertilizer dispenser. The rate of precipitation was controlled with the speed of rotation of the motor, as well as the size of the opening of the dispenser reservoir drop feeder.

In the winter of 2012-13, seed spreaders historically modified and used for applying ice pellets during wind tunnel and flat plate testing, were no longer available as the manufacturer stopped production of the model. A new replacement seed spreader system (Wolf Garten) was found which is similar (but not identical). Some calibration work was required to demonstrate an equivalency in the two systems; testing was conducted at the NRC Climatic Engineering Facility (CEF) prior to the wind tunnel testing to verify the distribution of the historical system versus the new replacement system the details of which are included in the TC report, TP 15230E, *Aircraft Ground Icing General Research Activities During the 2012-13 Winter*.

The data collected demonstrated that the new system is very similar to old system; some small variation was present in distribution within the footprint, but equivalent efficiency on the overall footprint. Based on this it was concluded that for ice pellets, the new system can be used as a direct replacement. For snow, the new system was more efficient, therefore a reduction of 10 percent should be used for the snow mass requested.

Comparative wind tunnel testing was conducted in the winter of 2013-14 to further validate the equivalency of the systems, the details of which are included in the TC report, TP 15274E, *Exploratory Wind Tunnel Aerodynamic Research Examination of Contaminated Anti-Icing Fluid Flow-Off Characteristics Winter 2013-14*. The results indicated that the differences in recorded lift losses were generally very small (less than 1.3 percent) when comparing back-to-back tests with no bias towards one system or the other. The differences were even smaller when looking at the average of the four comparative sequential tests (Test #330 to #337) which was 0.1 percent. In addition, the tests were visually evaluated to verify that the distribution of the ice pellets was similar, further supporting the similarity in aerodynamic results between the two dispenser systems.

In general, the wind tunnel results further supported the original distribution equivalency work conducted during the winter of 2012-13 and demonstrated that the new generation dispensers are suitable replacements for the older model dispensers.

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PRECIPITATION CONDITIONS**

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**6.4 Prior to Engines-On Wind Tunnel Test**

- Measure fluid thickness at the pre-determined locations on the wing (Attachment 3);
- Measure fluid Brix value (Attachment 3);
- Record wing temperatures (Attachment 3);
- Record start time of test (Attachment 2); and
- Fill out visual evaluation rating form (Attachment 7).

*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 consideration has been given to reducing the number of measurements that are taken for this phase (i.e. locations 2 and 5 only).*

**6.5 During Wind Tunnel Test**

- Take still pictures and video the behaviour 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 7); 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 3);
- Measure fluid Brix value (Attachment 3);
- Record wing temperatures (Attachment 3);
- Observe and record the status of the fluid/contamination (Attachment 3);
- Fill out visual evaluation rating form (Attachment 7);
- Obtain lift data (excel file) from NRC; and
- Update APS test log with pertinent information.

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**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 8) should be completed indicating quantity of fluid and date received. Any samples extracted for viscosity purposes should be documented in the fluid receipt form (Attachment 8), however an additional form (Attachment 9) is available if required. 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, NRC will organize for a glycol recovery service provider 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 2013-14. Modifications may be necessary and will be dealt with on-site. 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.

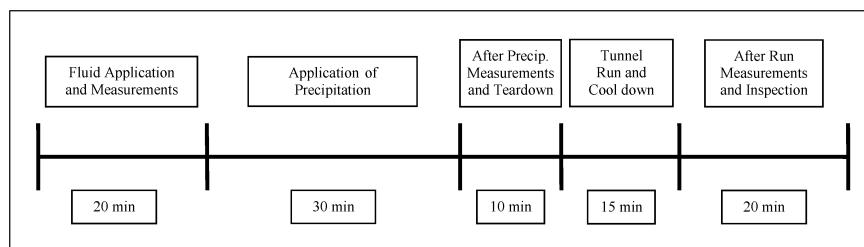
**6.10 Demonstration of a Typical Wind Tunnel Test Sequence**

Table 6.1 demonstrates a typical Wind Tunnel test sequence of activities, assuming the test starts at 08:00:00. Figure 6.4 demonstrates a typical wind tunnel run timeline.

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

**Table 6.1: Typical Wind Tunnel Test**

TIME	TASK
8:30:00	START OF TEST. ALL EQUIPMENT READY.
8:30:00	- Record test conditions.
8:35:00	- Prepare wing for fluid application (clean wing, etc.).
8:45:00	- Measure wing temperature.
	- Ensure clean wing for fluid application.
8:50:00	- Pour fluid over test area.
9:00:00	- Measure Brix, thickness, wing temperature.
	- Photograph test area.
9:05:00	- Apply contamination over test area. (i.e. 30 min)
9:35:00	- Measure Brix, thickness, wing temperature.
	- Photograph test area.
9:40:00	- Clear area and start wind tunnel.
9:55:00	- Wind tunnel stopped.
10:05:00	- Measure Brix, thickness, wing temperature.
	- Photograph test area.
	- Record test observations.
10:35:00	END OF TEST



**Figure 6.4: Typical Wind Tunnel Run Timeline**

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

## 6.11 Procedures for Testing Objectives

Details for the testing objectives have been included in the following attachments:

- Attachment 10: Procedure - Dry Wing Performance;
- Attachment 11: Procedure – Type IV Ice Pellet Allowance Time Validation with New Fluids;
- Attachment 12: Procedure – Development of EG Specific Ice Pellet Allowance Time Table;
- Attachment 13: Procedure – V-Stab Testing;
- Attachment 14: Procedure – Type III Ice Pellet Allowance Time Expansion;
- Attachment 15: Procedure – Snow Allowance Times Using Aerodynamic Data;
- Attachment 16: Procedure - Heavy Snow;
- Attachment 17: Procedure - Heavy Contamination;
- Attachment 18: Procedure - Fluid and Contamination at LOU;
- Attachment 19: Procedure - Frost Simulation in the Wind Tunnel;
- Attachment 20: Procedure - Feasibility of Ice Pellet Testing at Higher Speeds;  
and
- Attachment 21: Procedure - 2nd Wave of Fluid during Rotation.

## 7. EQUIPMENT

Equipment to be employed is shown in Table 7.1.

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

**Table 7.1: Equipment List**

EQUIPMENT	STATUS	EQUIPMENT	STATUS
<b>General Support and Testing Equipment</b>		<b>Camera Equipment</b>	
20L clean containers x 12 (if expecting totes)		AA Batteries x 48	
Adherence Probes Kit		C2032 Batteries x 10	
Barrel Opener (steel)		Digital still cameras x3 (two suitcases)	
Black Shelving Unit (or plastic)		Flashes and tripods (in APS storage)	
Blow Horns x 4		GoPro Cameras x 3 and related hardware	
Electrical tape x 5			
Envelopes and labels			
Exacto Knives x 2		<b>Ice Pellets Fabrication Equipment</b>	
Extension cords (power bars x 6 + reels x 4)		Blenders x 12 in good condition	
Falling Ball Viscometer		Folding tables (2 large, 1 small)	
Fluid pouring jugs x 60		Ice bags	
Fluids (ORDER and SHIP to Ottawa)		Ice bags storage freezer x 3	
Funnels( 1 big + 1 small)		Ice pellets sieves (base, 1.4 mm, 4 mm)	
Gloves - black and yellow		Ice pellets Styrofoam containers x40	
Gloves - cotton (1 box)		Measuring cups (1L and smaller ones for dispensing)	
Gloves - latex (2 boxes)		NCAR Scale x 1	
Grid Section + Location docs		Refrigerated Truck	
Hard water chemicals x 3 premixes		Rubber Mats x all	
Horse and tap for fluid barrel x all		Wooden Spoons	
Hot Plate x 3 and Large Pots with rubber handles for Type I			
Ice pellet box supports for railing x4		<b>Freezing Rain Equipment</b>	
Ice Pellet control wires and boxes		APS PC equipped with rate station software	
Ice pellets dispersers x 12 and stands x4		NRC Freezing rain sprayer (NRC will provide)	
Inclinometer (yellow level) x 2		Rubber suction cup feet for wooden boards	
Isopropyl x 24		White plastic rate pans (1 to 8 x 2)	
Large and small tape measure		Wooden boards for rate pans (x8)	
Large Sharpies for Grid Section			
Long Ruler for marking wing x 2			
Marker for waste x 2		<b>Office Equipment</b>	
Paper towel (blue shop towel) x 48		APS Laptops x 6 with mouse and chargers	
Protective clothing (all) and personnel clothing		APS tuques x 10	
Sample bottles for viscosity (x 3 per fluid)		Calculators x 3	
Sartorius Weigh Scale x 1		Clip boards x 8	
Scrapers x 5		Data Forms	
Shop Vac		Dry eraser markers	
Speed tape x 1 small		Envelopes (9x12) x box	
Squeegees (5 small + 3 large floor)		File box x 2	
Stands for ice pellets dispensing devices x 6		Hard drive with all WT Photos	
Stop Watches x 4		Hard Drive x 2	
Temperature probes: immersion x 3		Pencils + sharpies/markers	
Temperature probes: surface x 3		Projector for laptop	
Temperature readers x 2 + spare batteries		Scissors	
Test Plate x 1		Small 90° aluminum ruler for wing	
Thermometer for Reefer Truck		Test Procedures x 8, printer paper	
Thickness Gauges ( 5 small, 5 big)		YOW employee contracts	
Vise grip (large) + rubber opener for containers		Extra laptop for dispenser instructions PPT	
Walkie Talkies x 12			
Water (2 x 18L) for hard water			
Watmans Paper and conversion charts			
Red Thermoses for Type III Transport			
Back pack sprayer for Fluids x3			

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## 8. FLUIDS

Mid-viscosity samples of ethylene glycol and propylene glycol IV fluid will be used in the wind tunnel tests. Although the number of tests conducted will be determined based on the results obtained, the fluid quantities available are shown in Table 8.1 (no new fluids were ordered for this year's testing). Up to 2000L of 100/0 Type II/III/IV fluid are expected to be available. 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	TYPE	DILUTION	ORDERED (L)	IN STOCK (L)
ChemR EG IV	IV	100/0	-	100
EG106	IV	100/0	-	115
Max Flight AVIA	IV	100/0	-	280
Max Flight SNEG	IV	100/0	-	300
Safewing EG NORTH	IV	100/0	-	400
Defrost ECO 4	IV	100/0	-	130
Defrost EG 4	IV	100/0	-	230
ABC-S Plus	IV	100/0	-	200
Polar Guard® Advance (PGA181205PA)	IV	100/0	-	160
Polar Guard® Advance (13403/WT.13.14.PGA)	IV	100/0	-	140
AeroClear MAX	III	100/0	-	220
Safewing MP II FLIGHT	II	100/0	-	125

3600 L ordered for 2009-10 testing (18 days)  
 3200 L ordered for 2010-11 testing (15 days)  
 1800 L ordered for 2011-12 testing (7 of 15 days will be fluid testing)  
 4200 L ordered for 2012-13 testing (15 days)  
 1300L ordered for 2013-14 testing (15 days), 1900L previously in stock  
 1700L available for 2015-16 Testing (10 days)  
 3364 L available for 2017-18 Testing (10 days)  
 3245 L available for 2018-19 Testing (8 days including A4A)

## 9. PERSONNEL

Five APS staff members are required for the tests at the NRC wind tunnel. Five 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 (if requested).

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

**Table 9.1: Personnel List**

<b>Wind Tunnel 2015-16 - Tentative</b>	
<b>Person</b>	<b>Responsibility</b>
John D'Avirro (JD)	Director
Marco Ruggi (MR)	Lead Engineer and Project Coordinator
Chloë Bernier (CB)	Data documentation (forms, logs, camera setup, etc) / Ice Manufacturing Manager
Benjamin Bernier (BB)	Data Collection / Fluid Manager (inventory and application) / YOW Pers. Manager
<b>YOW Personnel</b>	
Ben Guthrie (BG)	Photography / Camera Documentation
Steve Baker (STB)	Fluids / Ice Manufacturing / Dispensing / General Support
YOW 1	Fluids / Ice Manufacturing / Dispensing
YOW 2	Fluids / Ice Manufacturing / Dispensing
YOW 3	Fluids / Ice Manufacturing / Dispensing
YOW 4	Ice Manufacturing

***NRC Aerospace Research Centre Contacts***

- Arash Raeesi (343) 542-6323;
- Catherine Clark: (613) 990-6796; and
- Cory Bates: (613) 913-9720.

**10. SAFETY**

- A safety briefing will be done on the first day of testing;
- Personnel should be familiar with NRC emergency procedures i.e. DO NOT CALL 9-1-1, instead call the NRC Emergency Center as they will contact and direct the necessary services;
- 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;
- CSA approved footwear and appropriate clothing for frigid temperatures are to be worn by all personnel;

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PRECIPITATION CONDITIONS***

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- 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.

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

**Attachment 1: Task List for Setup and Actual Tests**

No.	Task	Person	Status
<b>Planning and Preparation</b>			
1	Co-ordinate with NRC wind tunnel personnel and check status of tunnel	MR/JD	
2	Ensure fluid is received by NRC and is stored outdoors	MR/JD	
3	Arrange for hotel accommodations for APS personnel	JS	
4	Arrange truck rental	BB	
5	Arrange for ice and freezer delivery	JS	
6	Order walkie talkies	JS	
7	Organize personnel travel to Ottawa;	MR	
8	Hire YOW personnel	CB	
9	Complete contract for YOW personnel	FDL	
10	Co-ordinate with APS photographer	MR	
11	Ensure availability of freezing rain sprayer equipment;	MR	
12	Prepare and Arrange Office Materials for YOW	CB	
13	Prepare Data forms and procedure	CB	
14	Prepare historical photo hard drives and new ones	CB	
15	Prepare Test Log and Merge Historical Logs for Reference	CB	
16	Update (as necessary) fluid viscosity log, and have available	CB	
17	Finalize and complete list of equipment/materials required	MR	
18	Prepare and Arrange Site Equipment for YOW	SM	
19	Ensure proper functioning of ice pellet dispenser equipment;	MR	
20	Purchase, and label fluid pouring pitchers	SM	
21	Review IP/ZR/SN dispersal techniques and location	CB/MR	
22	Update IP/SN Order Form (if necessary)	CB/MR	
23	Check weather prior to finalizing test dates and Day vs. Night Shift, Start Time	MR/JD	
24	Arrange for pallets to lift up 1000L totes (if applicable)	MR	
25	Purchase new 20 L containers (as necessary)	SM	
26	Complete purchase list and shopping	SM	
27	Pack and leave YUL for YOW	APS	
<b>Setup Day</b>			
28	General safety briefing and update on testing	APS/NRC/YOW	
29	Collect fluid samples for viscosity at APS office and for Falling Ball	BB/CB	
30	Conduct falling ball verification	BB/CB	
31	Unload Truck and organize equipment in lower, middle, or office area	APS	
32	Verify and Organize Fluid Received (labels and fluid receipt forms)	BB/STB	
33	Transfer Fluids from 1000 L Totes to 20 L containers (if applicable)	BB/STB	
34	Confirm ice and freezer delivery	BB	
35	Setup general office and testing equipment including printer and projector	CB	
36	Setup rate station (if necessary)	CB	
37	Setup IP/SN manufacturing material in reefer truck	BB/STB	
38	Test and prepare IP dispensing equipment	BB/STB	
39	Train IP making personnel (ongoing)	STB/YOW	
40	Co-ordinate fabrication of ice pellets/snow	CB/STB	
41	Start IP manufacturing	STB	
42	Mark wing (only if requested);	CB	
43	Setup Still and Video Cameras	BG/YOW	
44	Verify photo and video angles, resolution, etc,	BG/STBD/MR	
45	Document new final camera and flash locations	CB/BG/STBD	
<b>Testing Day 1</b>			
46	Safety Briefing & Training (APS/YOW)	MR	
47	IP/SN/ZR Calibration (if necessary)	BB/CB/MR	
48	Train IP making personnel (ongoing) and continue IP manufacturing	STB/YOW	
49	Dry Run of tests with APS and NRC (if necessary)	APS/NRC	
50	Start Testing (Dry wing tests may be possible while setup occurs)	APS/NRC	
<b>Each Testing Day</b>			
51	Check with NRC the status of the testing site, tunnel, weather etc	MR	
52	Decide personnel requirements for following day for 24hr notice	MR	
53	Prepare equipment and fluid to be used for test	BB	
54	Manufacture ice pellets	STB/YOW	
55	Prepare photography equipment	BG	
56	Prepare data forms for test	CB	
57	Conduct tests based on test plan	APS	
58	Modify test plan based on results obtained	TC/FAA/JD/MR	
59	Update ice pellet, snow, raw ice, and fluid Inventory (end of day)	CB/STB	
60	Update Test Log and Test Plan (ongoing and end of day)	CB	

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

**Attachment 2: General Form**

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°): _____			
<input type="checkbox"/> Check if additional notes provided on a separate sheet			
FLUID APPLICATION			
Actual start time: _____	Actual End Time: _____		
Fluid Brk: _____	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 <sup>2</sup> /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 <sup>2</sup> /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 <sup>2</sup> /h): _____	Snow Size (mm): _____	<1.4 mm	
Exposure Time: _____	Method: <input type="checkbox"/> Dispenser <input type="checkbox"/> Sieve		
Total SN Required per Dispenser: _____			
COMMENTS			
<div style="border-top: 1px solid black; border-bottom: 1px solid black; height: 10px; margin-bottom: 5px;"></div> <div style="border-top: 1px solid black; border-bottom: 1px solid black; height: 10px; margin-bottom: 5px;"></div> <div style="border-top: 1px solid black; border-bottom: 1px solid black; height: 10px; margin-bottom: 5px;"></div> <div style="border-top: 1px solid black; border-bottom: 1px solid black; height: 10px; margin-bottom: 5px;"></div>			
MEASUREMENTS BY: _____		HANDWRITTEN BY: _____	

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

**Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form**

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: \_\_\_\_\_ Run: \_\_\_\_\_

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2					2				1			
T5					8				2			
TU					Flap				3			
Time:					Time:				4			
									5			
									6			
									7			
									8			
									Flap			
									Time:			

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

**TRAILING EDGE**

8
7
6
5
4
3
2
1

**LEADING EDGE**

Comments: \_\_\_\_\_

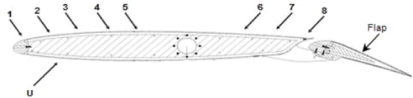
Wing and Plate Condition After the Takeoff Run  
Time: \_\_\_\_\_

**TRAILING EDGE**

8
7
6
5
4
3
2
1

**LEADING EDGE**

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.

**General Comments:** \_\_\_\_\_

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

**OBSERVER:** \_\_\_\_\_  
**ASSISTED BY:** \_\_\_\_\_

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

## Attachment 4: Example Ice Pellet Dispensing Form

		WING TRAILING EDGE																
		8 ft = 24.4 dm																
		DISPENSER #3								DISPENSER #4								
		1	2	3	4					1	2	3	4					
6 ft = 18.3 dm		14.9	16.5	18.2	17.4	18.5	17.6	18.5	17.6	18.5	17.6	18.5	17.6	18.5	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	27.5	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	29.4	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	29.6	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	29.5	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	29.6	29.1	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		
		DISPENSER #2								DISPENSER #1								
		4	3	2	1					4	3	2	1					
		WING LEADING EDGE																

Precipitation Type

Date

Run #

\* *Field to be manipulated*

Target Rate	25	g/dm <sup>2</sup> /h
Duration	5	minutes

Footprint Rate	25	g/dm <sup>2</sup> /h
Stdev of Rate (+/-)	5	g/dm <sup>2</sup> /h

*IP needed per 5min*

In each position	81	g
In each Dispenser	323	g

*IP needed for entire test*

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

**NOTE:**

- Leading Edge (LE): Centre Pole of the Dispenser Stands must be 1-foot (12 inches) from the Leading Edge (LE)
- Trailing Edge (TE): Centre Pole of the Dispenser Stands must be 10-inches from the Trailing Edge (TE) Flap.
- Dispenser Spinner must be 3-feet above the average height of the wing.

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 Dispenser" in grams. (Each Dispenser 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 Dispenser 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...)

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

## Attachment 5: Example Snow Dispensing Form

		WING TRAILING EDGE																			
		DISPENSER #3										DISPENSER #4									
		1	1R	2	1R	3	1R	4		1	1R	2	1R	3	1R	4					
6 ft = 18.3 dm		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	11.4	11.3	11.0	10.9	9.8				
		7.9	9.8	10.9	11.0	11.3	11.2	11.4	11.2	11.4	11.2	11.4	11.2	11.4	11.2	10.6	9.4				
		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	38.4	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	25.6	27.4	25.6	27.4	25.6	27.4	25.6	27.4	25.5	27.2	24.8	23.1					
		DISPENSER #2										DISPENSER #1									
		4	1R	3	1R	2	1R	1		4	1R	3	1R	2	1R	1					
		WING LEADING EDGE																			

Precipitation Type 
 Date 
 Run #

**\* Field to be manipulated**

Target Rate	25	g/dm <sup>2</sup> /h
Duration	5	minutes

Footprint Rate	25	g/dm <sup>2</sup> /h
Slidev of Rate	10	g/dm <sup>2</sup> /h

**Snow needed per 5 minutes**

In each position	84	76	g
In each Dispenser	336	305	g

**Snow needed for entire test**

In each Dispenser	336	305	g
Total Amount Snow Needed for Entire Test	1344	1222	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 Dispenser" in grams. (Each Dispenser 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 Dispenser 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 Dispenser Stands must be 1-foot (12 inches) from the Leading Edge (LE)
- Trailing Edge (TE): Centre Pole of the Dispenser Stands must be 10-inches from the Trailing Edge (TE) Flap. The use of Dispenser Stand Extension is needed.
- Dispenser Spinner must be 3-feet above the average height of the wing.

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

**Attachment 6: Example Snow Dispensing Form (Manual Method)**

Precipitation Type	Sifted Snow	Date		Run #	
--------------------	-------------	------	--	-------	--

**\* Field to be manipulated**

Target Rate	25	g/dm <sup>2</sup> /h
Duration	5	minutes

Footprint Rate	25	g/dm <sup>2</sup> /h
Stdev of Rate	10	g/dm <sup>2</sup> /h

**Snow needed per 5 minutes**

In each position	66
In each Dispenser	265

**Snow needed for entire test**

In each Dispenser	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 Dispenser" in grams. (Each Dispenser 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 Dispenser 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...)

- 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.

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

**Attachment 7: 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 - Contamination visible, adherence of contamination  <i>Note: Ratings can include decimals i.e. 1.4 or 3.5</i>													
<b>Before Take-off Run</b>													
	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%; padding: 5px;">Area</th> <th style="width: 50%; padding: 5px;">Visual Severity Rating (1-5)</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">Leading Edge</td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;">Trailing Edge</td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;">Flap</td> <td style="padding: 5px;"></td> </tr> </tbody> </table>	Area	Visual Severity Rating (1-5)	Leading Edge		Trailing Edge		Flap		>3 = Review, >3.5=Bad >3 = Review, >3.5=Bad >4 = Review, >4.5=Bad			
Area	Visual Severity Rating (1-5)												
Leading Edge													
Trailing Edge													
Flap													
<b>At Rotation</b>													
	<table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="width: 50%; padding: 5px;">Area</th> <th style="width: 50%; padding: 5px;">Visual Severity Rating (1-5)</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">Leading Edge</td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;">Trailing Edge</td> <td style="padding: 5px;"></td> </tr> <tr> <td style="padding: 5px;">Flap</td> <td style="padding: 5px;"></td> </tr> </tbody> </table>	Area	Visual Severity Rating (1-5)	Leading Edge		Trailing Edge		Flap		>1= Review >1.5 = Bad  <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th style="padding: 5px;">Expected Lift Loss (%)</th> </tr> </thead> <tbody> <tr> <td style="padding: 5px;">&gt;5.4 = Review</td> </tr> <tr> <td style="padding: 5px;">&gt;9.2 = Bad</td> </tr> </tbody> </table>	Expected Lift Loss (%)	>5.4 = Review	>9.2 = Bad
Area	Visual Severity Rating (1-5)												
Leading Edge													
Trailing Edge													
Flap													
Expected Lift Loss (%)													
>5.4 = Review													
>9.2 = Bad													
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Area	Visual Severity Rating (1-5)												
Leading Edge													
Trailing Edge													
Flap													
<b>Additional Observations:</b> _____ _____ _____													
<b>OBSERVER:</b> _____													

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

## Attachment 8: Fluid Receipt Form (Electronic Form)

**FORM 1**  
**GENERAL FORM FOR RECEIVING FLUID**

<b>Receiving Location:</b> <input type="checkbox"/> APS Site <input type="checkbox"/> Other: _____		<b>Date of Receipt:</b> _____
<b>Fluid Characteristics:</b> Type: _____ Colour: _____		<b>Date of Production:</b> _____
<b>Manufacturer:</b> _____		<b>Batch #:</b> _____
<b>Fluid Name:</b> _____		<b>Project Task:</b> _____

**Fluid Quantities / Fluid Brix / Falling Ball Info:**

Fluid Dilution: _____	Fluid Dilution: _____	Fluid Dilution: _____
Fluid Code: _____	Fluid Code: _____	Fluid Code: _____
Fluid Quantity: _____ x _____ L = _____ L	Fluid Quantity: _____ x _____ L = _____ L	Fluid Quantity: _____ x _____ L = _____ L
Fluid Brix: _____°	Fluid Brix: _____°	Fluid Brix: _____°
Falling Ball Time: _____:_____:_____ (mm:ss:cs)	Falling Ball Time: _____:_____:_____ (mm:ss:cs)	Falling Ball Time: _____:_____:_____ (mm:ss:cs)
Falling Ball Temp: _____°C	Falling Ball Temp: _____°C	Falling Ball Temp: _____°C
Sample from Container #: _____ of _____	Sample from Container #: _____ of _____	Sample from Container #: _____ of _____

<b>Sample Collection:</b> <div style="border: 1px solid black; padding: 5px; margin-top: 5px;"> HOT Fluids: Extract 4 L 100 / 75 / 50 and 2 L Type I  Other Fluids: Extract 3 L 100 / 75 / 50 / Type I </div>	<b>Sample Distribution:</b> <div style="border: 1px solid black; padding: 5px; margin-top: 5px;"> Viscosity: 2 L 100 / 75 / 50 to third party and in-house for testing  WSET: 1 L 100 / 75 / 50 / Type I to AMIL for WSET (HOT samples only)  Office: 1 L 100 / 75 / 50 / Type I to be retained in office </div>
--	---

**Photo Documentation:** (take photos of all that apply)

☐ Palette (as received)
☐ 100/0 MFR Fluid Label
☐ 75/25 MFR Fluid Label
☐ 50/50 MFR Fluid Label
☐ Type I MFR Fluid Label

**Additional Info/Notes:** (additional information included on fluid containers, paperwork received, etc.)

**Received by:** \_\_\_\_\_
**Date:** \_\_\_\_\_
**Verified by:** \_\_\_\_\_

Fluid Receipt Form (Oct 2018)

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

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**Attachment 9: Log of Fluid Sample Bottles**

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

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

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**Attachment 10: Procedure - Dry Wing Performance*****Background***

A significant amount of work has been done in conjunction with NASA and NRC in order to calibrate and characterize the wind tunnel and airfoil model during the last two winter seasons. This work has further increased the confidence in the data produced, however ongoing verification is necessary in order to identify potential changes in the system performance.

***Objective***

Verify that clean model aerodynamic data agree with the data acquired in previous years with the same model. Given the various issues with repeatability and angle of attack offsets in the past, this is an important step prior to fluids testing.

***Methodology***

- Ensure the wing is clean and dry;
- Conduct a dry wing test using the regular takeoff profile;
- Conduct a dry wing test using a takeoff profile with rotation to stall;
- Compare lift performance to historical data; and
- Address potential discrepancies accordingly.

***Test Plan***

This testing should be conducted at the start of each testing day.

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

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**Attachment 11: Procedure – Type IV Ice Pellet Allowance Time Validation with  
New Fluids*****Background***

The Type IV ice pellet allowance times are conservative, generic guidance developed based on data collected using commercially available Type IV fluids. As new fluids are developed and become commercially available, it is important to evaluate these fluids against the current allowance times to ensure the validity of the generic guidance. Systematic “spot-checking” is used in order to identify any potential issues. In addition, testing is recommended with all fluids available to obtain data close to the fluid LOUT to determine the aerodynamic effects of ice pellet contamination at these colder temperatures.

***Objective***

To evaluate newly commercialized Type IV fluids against the existing allowance times, and to collect data close to the fluid LOUT.

***Methodology***

- Conduct testing with any new commercially available Type IV fluids in each of the cells of the ice pellet allowance times table;
- Record lift data, visual observations, and manually collected data;
- Adjust testing plan accordingly based on aerodynamic data collected; and
- Weather permitting, conduct testing close to the fluid LOUT (-25 to -30°C) with appropriate conditions to address data gaps.

***Test Plan***

One and half a days of testing are planned.

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

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**Attachment 12: Procedure – Development of EG Specific Ice Pellet Allowance Time  
Table**

***Background***

Type IV ice pellet allowance times are also intended to be conservative, and therefore generic guidance is developed based on data collected using commercially available Type IV fluids. Historically both Type IV PG and EG fluids have been grouped together, however data has indicated that EG may have an operational advantage of longer ice pellet allowance times in specific conditions. The industry requested that EG specific fluid ice pellet allowance time tables be generated to be able to benefit from any potential longer allowance times specific to Type EG fluids.

***Objective***

To conduct testing to investigate the feasibility of developing an EG specific ice pellet allowance time table.

***Methodology***

- Determine what EG data exists and any potential data gaps which need to be filled;
- Conduct testing with commercially available EG Type IV fluids in each of the cells of the ice pellet allowance times table, as required;
- Record lift data, visual observations, and manually collected data; and
- Adjust testing plan accordingly based on aerodynamic data collected.

***Test Plan***

One and a half days of testing are planned.

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

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**Attachment 13: Procedure – V-Stab Testing**

***Background***

The details of this testing will be included in a separate test procedure.

***Test Plan***

Five days of testing are planned.

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PRECIPITATION CONDITIONS**

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**Attachment 14: Procedure – Type III Ice Pellet Allowance Time Expansion*****Background***

Allowance times for Type III fluids have just recently been developed. Similar to the Type IV ice pellet allowance times, the Type III allowance times are also intended to be conservative, generic guidance developed based on data collected using commercially available Type III fluids. In cases where the allowance times are too restrictive, additional data may be used to support an increase to the existing times, or new cells at different temperatures. This testing can be done at both 80 knots and 100 knots.

***Objective***

To conduct testing to support the expansion of the Type III ice pellet allowance times.

***Methodology***

- Conduct testing with commercially available Type III fluids in each of the cells of the ice pellet allowance times table at 80 knots and 100 knots rotation speed;
- Record lift data, visual observations, and manually collected data; and
- Adjust testing plan accordingly based on aerodynamic data collected.

***Test Plan***

Ten to twenty tests would provide a suitable dataset for analysis.

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

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**Attachment 15: Procedure – Snow Allowance Times Using Aerodynamic Data*****Background***

Holdover times are developed based on a visual evaluation of fluid failure on test plate surfaces measuring 30x50cm (12x20in.). The industry requested an investigation into the feasibility of using the same aerodynamic testing methodology used to develop ice pellet allowance times, to develop snow allowance times. It is believed that using this methodology would provide longer “snow allowance times” as compared to the current existing snow holdover times.

***Objective***

To conduct testing to investigate the feasibility of developing snow allowance times.

***Methodology***

- Conduct testing with commercially available Type IV fluids using the current methodology used to develop ice pellet allowance times;
- Record lift data, visual observations, and manually collected data; and
- Adjust testing plan accordingly based on aerodynamic data collected.

***Test Plan***

No tests are anticipated.

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

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**Attachment 16: 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 deicing operations globally. Secondly, there has been a recent industry interest for holdover time for heavy snow conditions. Preliminary aerodynamic testing was conducted during the winters of 2006-07 and 2008-2011.

**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/dm<sup>2</sup>/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/dm<sup>2</sup>/h or higher) 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 severe 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**

Two to four comparative tests would provide a suitable dataset for analysis. See previous reports for suggested test plan.

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PRECIPITATION CONDITIONS**

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**Attachment 17: Procedure - Heavy Contamination*****Background***

Previous testing in the wind tunnel demonstrated that although very heavy ice pellet and/or snow contamination was applied to a fluid covered wing section, significant lift losses were not apparent. The initial testing indicated that after a certain level of contamination, the dry loose ice pellets or snow no longer absorb into the fluid and easily fly off during the acceleration. The protection is due to a thin layer of fluid present underneath the contamination that prevents adherence. Questions of which point the lift losses become detrimental have been raised.

***Objective***

To continue previous research investigating heavy contamination effects on fluid flow-off.

***Methodology***

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

- For a chosen fluid, conduct a test simulating ice pellets, snow, or freezing rain, for an exposure time far exceeding the recommended HOT or allowance time;
- Record lift data, visual observations, and manually collected data; and
- Compare aerodynamic performance results to fluid only or fluid and contamination tests at the same temperature.

***Test Plan***

One to four tests would provide a suitable dataset for analysis. Previous work should be referenced to identify starting levels of heavy contamination.

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

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**Attachment 18: Procedure - Fluid and Contamination at LOUT*****Background***

Recent changes to the frost HOT guidance material allowing fluids to be used to the LOUT have raised concerns about whether or not this is an appropriate practice. In frost the major concern was the effect of radiation cooling and how it could affect the LOUT, however the concern also includes contamination at LOUT. This issue was also raised from the AWG for the ice pellet testing which allows fluids to be used to LOUT: will the added ice pellet contamination at the LOUT not bust BLDT? It was recommended that some testing be conducted at the fluid LOUT to investigate how contamination can affect the aerodynamic performance of the fluid.

***Objective***

To investigate the fluid aerodynamic flow-off characteristics of anti-icing fluid with contamination at the LOUT.

***Methodology***

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

- For a chosen fluid, conduct a test simulating ice pellets, snow, freezing fog, or frost, for an exposure time derived from the HOT table at the fluid LOUT;
- Record lift data, visual observations, and manually collected data;
- Conduct a fluid only baseline test at the same temperature (at LOUT); and
- Compare the aerodynamic performance.

***Test Plan***

Four or more tests would provide a suitable dataset for analysis. If LOUT temperatures for neat fluids are not likely to occur, investigate the possibility of using diluted fluids to obtain a higher LOUT.

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

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**Attachment 19: Procedure - Frost Simulation in the Wind Tunnel**

***Background***

Frost is an important consideration in aircraft deicing. The irregular and rough frost accretion patterns can result in a significant loss of lift on critical aircraft surfaces. This potential hazard is amplified by the frequent occurrence of frost accretion in winter operations. Frost is an area of research that has yet to be fully explored. Discussions regarding the aerodynamic effects of frost have been raised, and the possibility of doing wind tunnel testing has been considered. It was recommended that initial testing be performed to investigate whether it would be feasible to simulate frost conditions in the PIWT.

***Objective***

To investigate the feasibility of simulating frost conditions in the PIWT.

***Methodology***

This work is exploratory, so no exact procedure exists. It is recommended that the frost generating parameters be explored to try and stimulate frost accretion. This can be done by causing a negative temperature differential between the wing and the ambient air i.e. air is warmer than skin. A more specific methodology may be determined on site following a brain-storm with on-site technicians.

***Test Plan***

One or two tests would provide a suitable dataset for analysis.

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

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**Attachment 20: Procedure - Feasibility of Ice Pellet Testing at Higher Speeds*****Background***

Historically, the ice pellet allowance time testing conducted in the wind tunnel simulated typical aircraft rotation of 100 knots, and more recently some limited work at 115 knots. As a result of some of the higher lift losses observed at colder temperatures with PG fluids applied to a thin high performance airfoil, it was recommended that higher speed testing be conducted to verify if the limitations in the allowance times would need to be applied to commercial aircraft with rotation speeds well above 115 knots. It was recommended that 130-150 knots be targeted, however modifications to the wind tunnel may be required as those higher speeds may increase stress on the wind tunnel engine and other structural systems.

***Objective***

To investigate the feasibility of conducting ice pellet testing at higher speeds of 130-150 knots.

***Methodology***

This work is exploratory, so no exact procedure exists. A more specific methodology may be determined on site following a brain-storm with on-site technicians. It is expected that a series of tests may be conducted to try and achieve speeds above 115 knots without rotating the wing model.

***Test Plan***

One or two tests would provide a suitable dataset for analysis, however more tests may be required based on the results.

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

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**Attachment 21: Procedure - 2nd Wave of Fluid during Rotation*****Background***

Previous wind tunnel testing has shown that during a simulated takeoff roll following de/anti-icing, fluid will shear off the wing section; however a small amount of fluid can remain trapped along the leading edge at the stagnation point. This “trapped” fluid begins to flow over the wing only once the wing is rotated; the stagnation point shifts below the leading edge, and the “trapped” fluid begins to shear off as a second wave. Previous testing was simulated in a static model using strips of speed tape and cork tape strategically located on the leading edge of the wing section (along the span where the separation bubble will typically occur). A separate set of dynamic tests simulated the second wave with actual anti-icing fluid; sheared fluid prior to rotation was left only in select areas either below or above the stagnation point and then the flow was observed during a typical rotation. The results showed the stalling characteristics of the wing with fluid (or fluid with contamination) appear to be driven by secondary wave effects near the leading edge; these effects are difficult to interpret on the two-dimensional model relative to a fully three-dimensional wing and should not be used in developing allowance times. Additional testing may be useful to better understand this effect.

***Objective***

To investigate the aerodynamic effects of the second wave of fluid flow during rotation.

***Methodology***

- Simulate the 2<sup>nd</sup> wave of fluid using strips of tape applied at specific areas at different thicknesses on the wing, or with fluid; and
- Compare the different results.

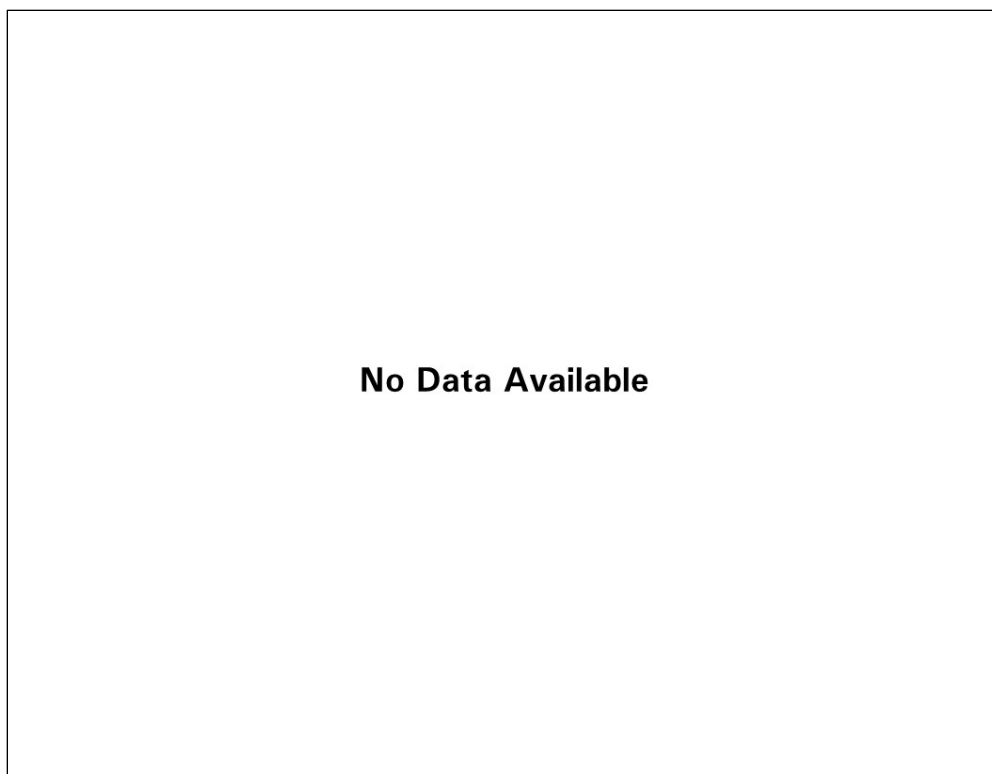
***Test Plan***

One to four tests would provide a suitable dataset for analysis.

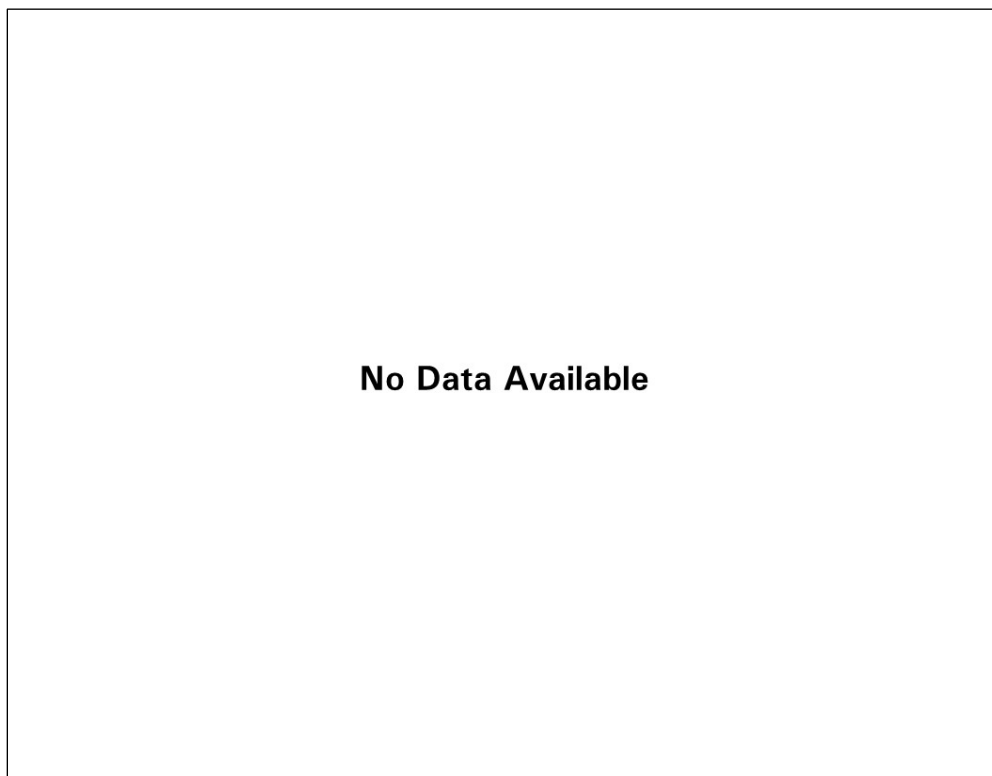
## **APPENDIX C**

### **HIGH SPEED TESTING 2019-20 FLUID THICKNESS, TEMPERATURE, AND BRIX DATA FORMS**





**Figure C1: Run # 1**



**Figure C2: Run # 2**

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 19, 2020 Run: 3 (P020)

Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2	-11.75	-12.0	-19.45	-14.9
T5	-12.7	-12.75	-18.7	-14.7
TU	-12.45	-12.7	-13.68	-14.2
Time:	22:40	22:50	23:06	23:17

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.0	24.75	dry
8		25.75	28.0
Flap		17.5	29.0
Time:	22:50	23:07	23:23

Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	80	112	< 1
3			
4			
5	142	200	2
6			
7			
8	127	150	10
Flap	50	20	8
Time:	22:51	23:07	23:23

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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

Observer: EE / CE

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Figure C3: Run # 3

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 19, 2020 Run: 4 (P018)

Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2	-13.25	-12.75	-17.5	-14.5
T5	-13.5	-13.45	-17.9	-14.5
TU	-13.15	-13.32	-14.65	-14.5
Time:	23:35	23:46	00:17	00:31

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.25	24.5	dry
8		23.75	26.5
Flap		20.75	29.5
Time:	23:45	00:18	00:32

Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	80	112	< 1
3			
4			
5	158	200	3
6			
7			
8	134	134	12
Flap	55	3	5
Time:	23:45	00:18	00:32

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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

Observer: EE / CE

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Figure C4: Run # 4



**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 20, 2020 Run: 5 (P019)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-14.15	-13.0	-17.6	-15.45	2	33.25	28.5	31.5	1			
T5	-14.3	-13.5	-17.7	-16.0	8		23.0	26.5	2	96	134	1
TU	-13.9	-13.5	-14.25	-15.2	Flap		18.15	29.75	3			
Time:	00:41	00:52	1:10	1:19	Time:	00:53	1:10	1:26	4			

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After 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.

**General Comments:** \_\_\_\_\_

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

OBSERVER: BP / CR

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Figure C5: Run # 5

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 20, 2020 Run: 6 (P073)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-14.3	-13.9	-19.25	-17.0	2	33.25	22.5	dry	1			
T5	-15.0	-14.2	-19.75	-16.6	8		22.25	26.5	2	104	150	<1
TU	-14.6	-14.9	-16.6	-16.3	Flap		17.75	27.25	3			
Time:	1:35	1:47	2:14	2:25	Time:	1:47	2:15	2:30	4			

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After 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.

**General Comments:** \_\_\_\_\_

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

OBSERVER: BP / CR

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Figure C6: Run # 6

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 20, 2020 Run: 7(P071)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
LE T2	-15.5	-13.92	-18.4	-16.75	2	33.25	21.5	26	1			
TE T5	-15.48	-14.25	-18.7	-17.3	8		22.25	26.25	2	80	119	1
TU	-15.42	-15.25	-17.18	-16.7	Flap		20	27.5	3			
Time:	02:41	02:49	03:44	03:57	Time:	02:49	03:47	04:01	4			

Wing and Plate Condition Before the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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

Observer: PK (CB)

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Figure C7: Run # 7

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 20, 2020 Run: 8(P027)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-16.4	-14.4		-16.5	2	37.25		34	1			
T5	-16.9	-15.3		-17.5	8			34	2	80		6
TU	-16.5	-16.3		-16.7	Flap			34	3			
Time:	04:08	04:20		04:27	Time:	04:18		04:35	4			

Wing and Plate Condition Before the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run Time: \_\_\_\_\_

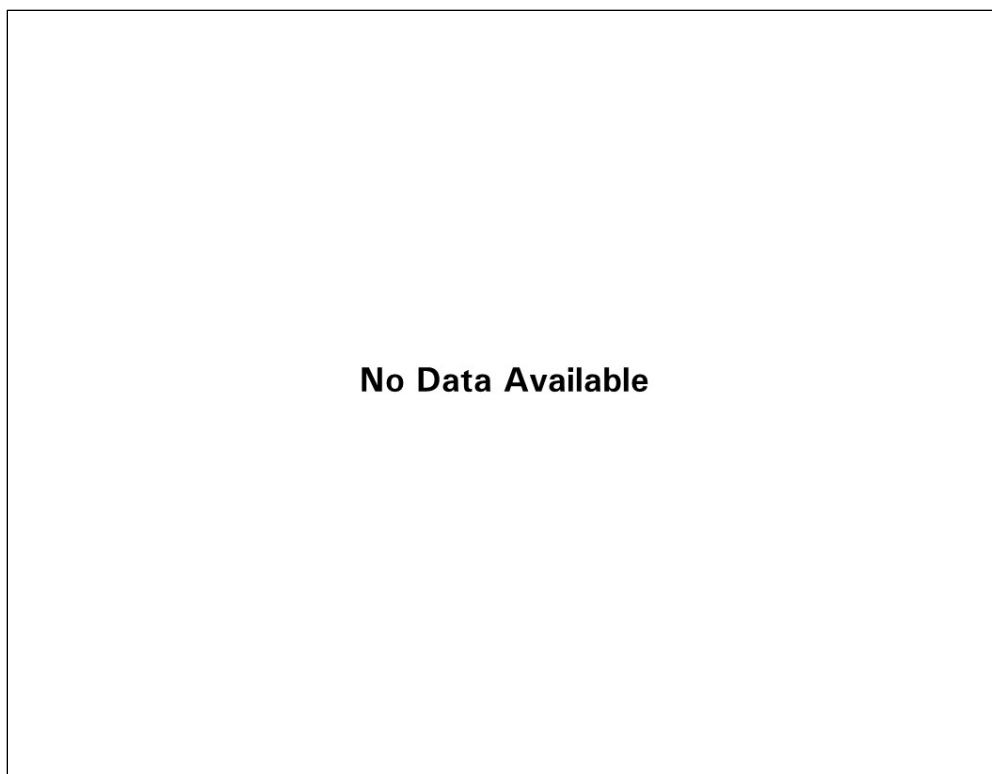
Comments: \_\_\_\_\_

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

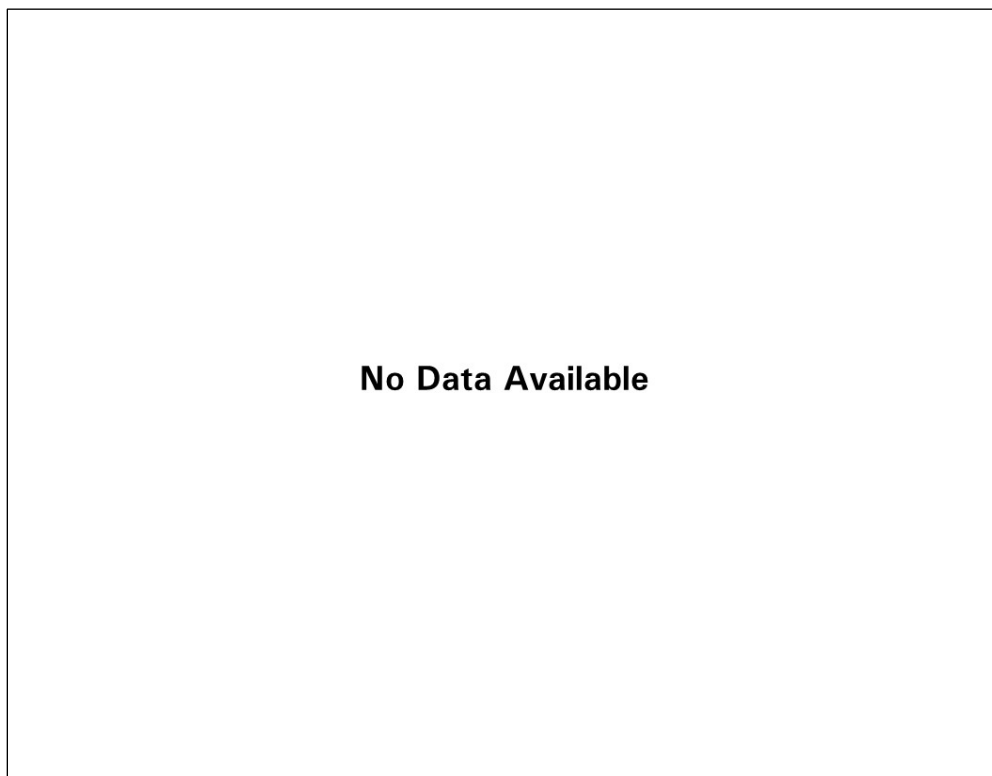
Observer: PK

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Figure C8: Run # 8



**Figure C9: Run # 9**



**Figure C10: Run # 10**

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 20, 2020 Run: 11 (P122)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-11.7	-12.7	-18.9	-14.7	2	35.5	21.0	31	1			
T5	-12.4	-13.5	-17.9	-15.1	8		21.25	26.5	2	80	127	3
TU	-11.7	-12.79	-14.95	-14.6	Flap		14.75	27.25	3			
Time:	21:16	21:25	21:56	22:09	Time:	21:30	21:59	22:17	4	150	200	7
									5			
									6			
									7			
									8	127	150	10
									Flap	35	5	6
									Time:	21:30	21:59	22:16

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After 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.

General Comments: \_\_\_\_\_

Observer: PK

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Figure C11: Run # 11

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 20, 2020 Run: 12 (P126)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-14.05	-13.6	-17.7	-13.9	2	35.25	17.75	29.5	1			
T5	-14.54	-14.3	-17.2	-14.3	8		22	29	2	96	127	3
TU	-14.04	-14.1	-14.7	-14.4	Flap		17.5	27.25	3			
Time:	22:28	22:59	23:12	23:31	Time:	22:41	23:15	23:28	4	127	200	10
									5			
									6			
									7			
									8	134	158	11
									Flap	46	3	6
									Time:	22:41	23:15	23:28

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After 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.

General Comments: \_\_\_\_\_

Observer: PK

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Figure C12: Run # 12

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 20, 2020 Run: 13 (P154)

Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2	-14.27	-15.8	-19.69	-15.28
T5	-14.48	-14.7	-18.86	-15.25
TU	-14.43	-14.8	-16.3	-15.46
Time:	23:35	23:57	00:26	00:42

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.5	22.75	29
8		20.5	28.75
Flap		19	28.25
Time:	23:58	00:29	00:43

Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	119	158	1
3			
4			
5	200	250	4
6			
7			
8	150	158	8
Flap	35	2	6
Time:	23:59	00:29	00:43

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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

OBSERVER: PK

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Figure C13: Run # 13

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 21, 2020 Run: 14 (P153)

Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2	-14.4	-14.25	-18.27	-14.7
T5	-15.0	-14.83	-17.3	-15.0
TU	-14.9	-15.14	-15.63	-15.3
Time:	00:55	01:10	01:44	02:01

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.5	20.25	27.5
8		22.75	25.5
Flap		14	27.0
Time:	01:11	01:44	02:03

Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	119	158	1
3			
4			
5	150	200	4
6			
7			
8	142	150	8
Flap	40	7	3
Time:	01:12	01:46	02:04

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run  
Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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

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Figure C14: Run # 14

## FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 21, 2022

Run: 15 (A00)

WING TEMPERATURE (Taken From NRC Logger)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application After Takeoff Run
T2	-14.6	-14.3	-14.75
T5	-15.1	-14.8	-14.75
TU	-15.0	-15.1	-15.64
Time:	02:10	02:25	02:56

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.5	24.5	24.75
8		23	27.5
Flap		19	26.25
Time:	02:28	03:00	03:15

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	158	158	7
3			
4			
5	158	300	12
6			
7			
8	158	200	8
Flap	70	1	5
Time:	02:28	02:54	03:14

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_

**TRAILING EDGE**

**LEADING EDGE**

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run  
Time: \_\_\_\_\_

**TRAILING EDGE**

**LEADING EDGE**

Comments: \_\_\_\_\_

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

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

**General Comments:**

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**OBSERVER:**

\_\_\_\_\_

**Figure C15: Run # 15**

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 21, 2020 Run: 16 (P099)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2	-15.1	-14.6	-18.08	-16.33
T5	-15.5	-15.1	-18.78	-15.9
TU	-15.59	-15.8	-16.41	-14.2
Time:	03:20	03:34	04:07	04:20

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33.5	22	26.25
8		20.5	30
Flap		17	27.5
Time:	03:35	04:09	04:22

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	115	158	6
3			
4			
5	200	250	11
6			
7			
8	158	158	12
Flap	70	1	6
Time:	03:36	04:10	04:23

Wing and Plate Condition Before the Takeoff Run Time:

Comments: \_\_\_\_\_

Wing and Plate Condition After 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

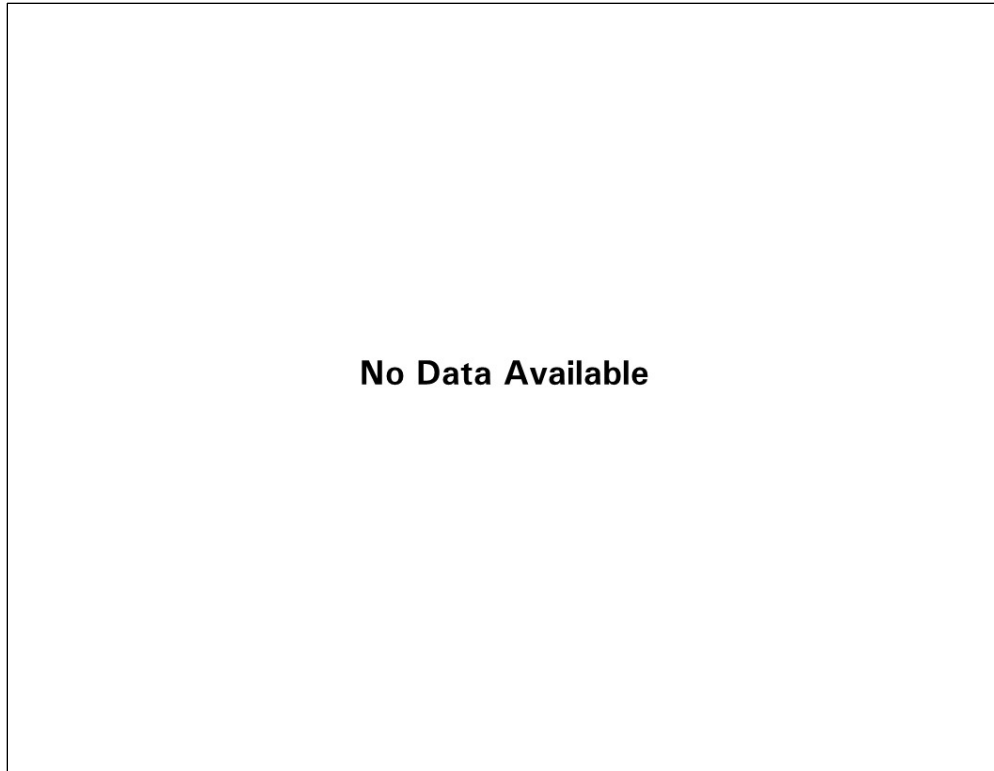
Underide: Approximately 40 cm up from the leading edge stagnation point.

**General Comments:** \_\_\_\_\_

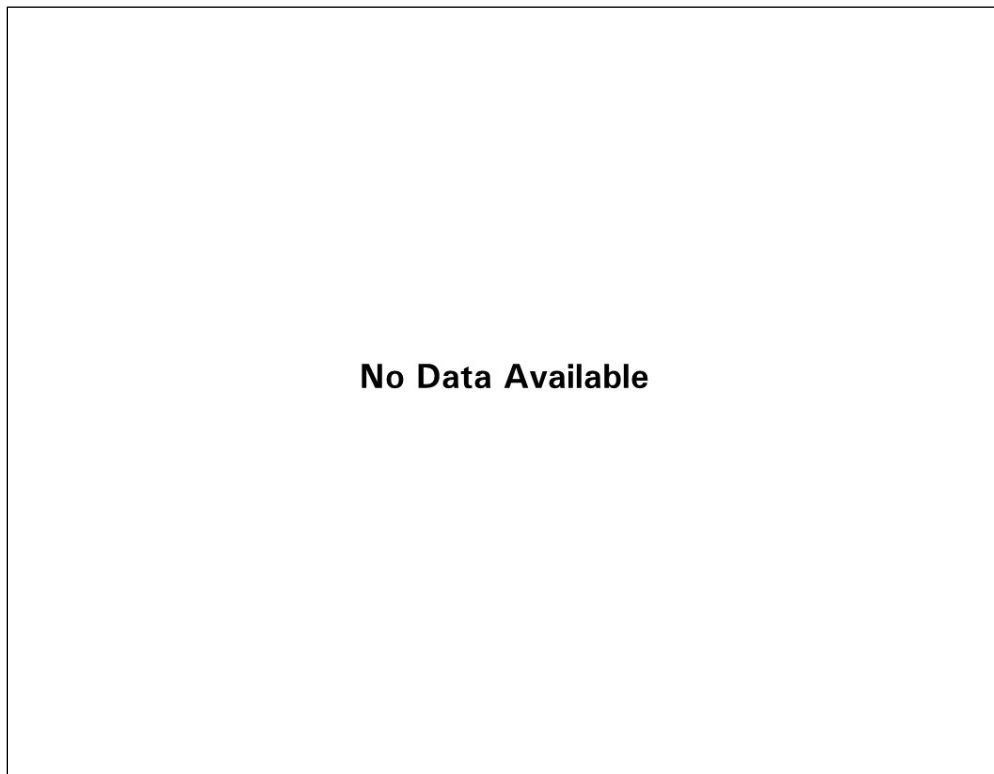
Note: In an attempt to optimize timing of tests, shaded box measurements can be omitted with approval of the project coordinator

Observer: pu

**Figure C16: Run # 16**



**Figure C17: Run # 17**



**Figure C18: Run # 18**

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 21, 2020 Run: 19 (P057)

Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2	-5.56	-7.5	-11.39	-5.97
T5	-6.20	-7.84	-11.9	-6.82
TU	-5.52	-5.79	-8.19	-6.08
Time:	21:15	21:24	22:38	22:49

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33	15	Dry
8		15.25	26.25
Flap		10.75	Dry
Time:	21:25	22:42	22:58

Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	64	70	less than 1
3			
4			
5	150	200	3
6			
7			
8	134	80	1
Flap	30	2	less than 1
Time:	21:27	22:41	22:58

Wing and Plate Condition Before the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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

OBSERVER: BB

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Figure C19: Run # 19

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 21, 2020 Run: 20 (P058)

Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
T2	-5.74	-6.99	-11.42	-6.11
T5	-5.88	-7.89	-12.78	-6.33
TU	-5.70	-6.20	-8.02	-6.08
Time:	23:04	23:18	00:12	00:28

Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
2	33	11.25	Dry
8		15.0	20.75
Flap		10.75	26.5
Time:	23:19	00:15	00:30

Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	65	96	less than 1
3			
4			
5	80	158	less than 1
6			
7			
8	119	112	1
Flap	30	2	1
Time:	23:20	00:15	00:29

Wing and Plate Condition Before the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

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

OBSERVER: PK

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Figure C20: Run # 20

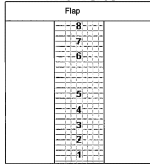


**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 22, 2020 Run: 21 (R062)

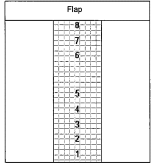
WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-5.97	-7.71	-15.21	-6.92	2	33.0	20.75	Dry	1			
T5	-6.24	-8.37	-14.75	-6.70	8		15.25	21.75	2	80	158	less than 1
TU	-5.96	-6.32	-9.24	-6.57	Flap		7.5	24.5	3			
Time:	00:35	00:46	01:24	01:31	Time:	00:47	01:27	01:41	4			

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_




Comments: \_\_\_\_\_

Wing and Plate Condition After 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 omitted with approval of the project coordinator

OBSERVER: PK

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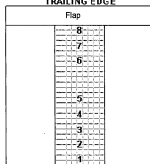
Figure C21: Run # 21

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 22, 2020 Run: 22 (R060)

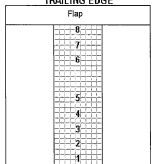
WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-6.24	-6.09	-7.8	-5.76	2	33.0	11.25	Dry	1			
T5	-6.27	-7.83	-9.18	-6.14	8		15.75	15.25	2	65	22	less than 1
TU	-6.19	-6.41	-7.04	-5.85	Flap		n/a	Dry	3			
Time:	01:45	02:03	02:47	03:05	Time:	02:04	02:50	03:06	4			

Wing and Plate Condition Before the Takeoff Run  
Time: \_\_\_\_\_




Comments: \_\_\_\_\_

Wing and Plate Condition After 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 omitted with approval of the project coordinator

OBSERVER: BB

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Figure C22: Run # 22

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 22, 2020 Run: 23 (P063)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-5.62	-6.86	-13.6	-6.68	2	33.25	14.25	0.0	1			
T5	-6.10	-8.00	-12.79	-6.53	8		17.0	21.25	2	65	158	1.25
TU	-5.80	-6.17	-8.27	-6.43	Flap		7.75	23.75	3			
Time:	03:10	03:28	03:51	04:05	Time:	03:29	03:54	04:09	4			
									5	104	200	1.25
									6			
									7			
									8	142	134	1
									Flap	40	7	1
									Time:	03:29	03:54	04:10

Wing and Plate Condition Before the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After 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 omitted with approval of the project coordinator

OBSERVER: PK

General Comments: \_\_\_\_\_

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Figure C23: Run # 23

**FLUID THICKNESS, TEMPERATURE AND BRIX FORM**

Date: January 22, 2020 Run: 24 (P25)

WING TEMPERATURE (Taken From NRC Logger)					FLUID BRIX				FLUID THICKNESS (mil)			
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run	Wing Position	After Fluid Application	After Precip Application	After Takeoff Run	Wing Position	After fluid Application	After Precip Application	After Takeoff Run
T2	-6.01	-7.26		-4.87	2	33.0		33.25	1			
T5	-6.01	-7.69		-5.21	8			33.0	2	70		2
TU	-5.95	-6.08		-4.81	Flap			33.0	3			
Time:	04:15	04:27		04:42	Time:	04:30		04:43	4			
									5	127		8
									6			
									7			
									8	142		10
									Flap	35		6
									Time:	04:31		04:43

Wing and Plate Condition Before the Takeoff Run Time: \_\_\_\_\_

Comments: \_\_\_\_\_

Wing and Plate Condition After 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 omitted with approval of the project coordinator

OBSERVER: PK

General Comments: \_\_\_\_\_

M:\Projects\300293 (TC Deicing 2019-20)\Procedures\Wind Tunnel\Supporting Docs\Data Forms\IU Tests\Fluid Thickness, Temperature and Brix Form Version 7.0

Figure C24: Run # 24

## **APPENDIX D**

### **2019-20 LOG OF TESTS CONDUCTED WITH THIN HIGH PERFORMANCE WING SECTION – RJ WING**



## Log of Tests Conducted with Thin High Performance Wing Section – RJ Wing

Test #	Date	Test Plan #	Objective	Test Condition	Fluid Name	Fluid Batch #	Rotation Angle	Speed Kts	Flap Angle (0°, 20°)	Corrected for 3D Effects CL At 8°	Corrected for 3D Effects % Lift Loss On 8° Clvs Dry Cl	Time from 40kts to Rotation (sec)	Max Speed At Approx. Time of Rot. (kts)	Target OAT (°C)	Tunnel Temp. Before Test (°C)	Fluid Amount (L)	OAT Before Test (°C)	AVG Wing Temp Before Fluid Appl. (°C)	AVG Wing Temp Before Test (°C)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	ZR Rate (g/dm²/h)	R Rate (g/dm²/h)	Exposure Time (min)	Rating Before Take-Off Run LE	Rating Before Take-Off Run TE	Rating Before Take-Off Run Flap	Rating At Rotation LE	Rating At Rotation TE	Rating At Rotation Flap	Rating After Take-Off Run LE	Rating After Take-Off Run TE	Rating After Take-Off Run Flap
1	19-Jan-20	P001	Baseline	Dry Wing	none	n/a	8	100	20	1.46	0.10%	19.71	100.29	any	-11.94	-	-11.3	n/a	n/a	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2	19-Jan-20	P002	Baseline	Dry Wing	none	n/a	22	80	20	1.44	1.31%	17.52	83.24	any	-12.56	-	-11.5	n/a	n/a	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
3	19-Jan-20	P020	Type IV Validation and New Fluids	IP Mod	Safewing EG IV NORTH	01819	8	100	20	1.43	2.41%	19.75	101.73	-10 to -16	-12.91	17	-12.3	-12.30	-17.28	75	-	-	-	10	2.2	1.9	3.3	1.0	1.0	1.5	1.0	1.0	1.0
4	19-Jan-20	P018	Type IV Validation and New Fluids	IP-	Safewing EG IV NORTH	01819	8	100	20	1.43	2.48%	19.91	102.2	-10 to -16	-13.84	16	-13.4	-13.30	-16.68	25	-	-	-	30	2.0	1.9	3.0	1.0	1.0	1.5	1.0	1.0	1.0
5	20-Jan-20	P019	Type IV Validation and New Fluids	IP- / SN-	Safewing EG IV NORTH	01819	8	100	20	1.42	2.84%	19.85	102.68	-10 to -16	-14.9	16	-14	-14.12	-16.52	25	10	-	-	15	2.0	1.9	2.9	1.0	1.1	1.5	1.0	1.0	1.0
6	20-Jan-20	P073	EG Type IV Expansion	IP Mod	Safewing EG IV NORTH	01819	8	100	20	1.43	2.25%	19.6	102.36	-10 to -16	-15.68	16.5	-14.7	-14.63	-18.53	75	-	-	-	25	3.1	3.0	4.0	1.0	1.1	2.4	1.0	1.0	1.0
7	20-Jan-20	P071	EG Type IV Expansion	IP-	Safewing EG IV NORTH	01819	8	100	20	1.42	2.79%	19.88	102.53	-10 to -16	-16.35	16	-15.7	-15.47	-18.09	25	-	-	-	50	2.3	2.1	4.0	1.0	1.1	1.7	1.0	1.0	1.1
8	20-Jan-20	P027	Type IV Validation and New Fluids	Fluid Only	Safewing EG IV NORTH	01819	8	100	20	1.41	3.30%	19.45	103.16	-10 to -16	-17.03	16	-15.9	-16.60	-15.33	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
9	20-Jan-20	P001	Baseline	Dry Wing	none	n/a	8	100	20	1.45	0.89%	19.91	101.02	any	-10.27	-	-11.8	n/a	n/a	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
10	20-Jan-20	P002	Baseline	Dry Wing	none	n/a	22	80	20	1.44	1.37%	2.75	84.41	any	n/a	-	-11.8	n/a	n/a	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
11	20-Jan-20	P127	EG Type IV Expansion	IP Mod	ChemR EG IV	35317-1	8	100	20	1.43	2.11%	19.49	102.34	-10 to -16	-13.8	18	-12.5	-11.93	-17.25	75	-	-	-	25	3.3	2.7	4.0	1.0	1.4	1.7	1.0	1.1	1.1
12	20-Jan-20	P126	EG Type IV Expansion	IP- / SN-	ChemR EG IV	35317-1	8	100	20	1.42	3.19%	19.69	101.96	-10 to -16	-13.56	17	-13.4	-14.21	-16.53	25	10	-	-	30	2.4	2.4	4.0	1.0	1.7	2.1	1.0	1.1	1.3
13	20-Jan-20	P154	EG Type IV Expansion	IP Mod	EG106	D268IB7 001	8	100	20	1.45	1.09%	19.48	101.67	-10 to -16	-15.47	19	-14.1	-14.56	-18.28	75	-	-	-	25	3.1	2.7	4.0	1.0	1.1	1.5	1.0	1.0	1.1
14	21-Jan-20	P153	EG Type IV Expansion	IP- / SN-	EG106	D268IB7 001	8	100	20	1.43	1.95%	19.59	103.08	-10 to -16	-14.39	19	-14.4	-14.77	-17.07	25	10	-	-	30	2.5	2.3	4.0	1.0	1.4	1.7	1.0	1.1	1.2
15	21-Jan-20	P100	EG Type IV Expansion	IP Mod	Defrost EG 4	1 (LOT #47)	8	100	20	1.42	2.83%	19.61	101.72	-10 to -16	-15.65	17	-14.5	-14.90	-18.53	75	-	-	-	25	3.0	3.0	4.0	1.0	1.2	1.7	1.0	1.0	1.0
16	21-Jan-20	P099	EG Type IV Expansion	IP- / SN-	Defrost EG 4	1 (LOT #47)	8	100	20	1.41	3.42%	19.63	101.41	-10 to -16	-15.11	18	-15.3	-15.40	-17.59	25	10	-	-	30	2.5	2.3	3.8	1.0	1.1	1.4	1.0	1.0	1.1
17	21-Jan-20	P001	Baseline	Dry Wing	none	n/a	8	100	20	1.45	0.57%	20.03	101.72	any	-5.53	-	-4.6	n/a	n/a	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

## Log of Tests Conducted with Thin High Performance Wing Section – RJ Wing (cont'd)

Test #	Date	Test Plan #	Objective	Test Condition	Fluid Name	Fluid Batch #	Rotation Angle	Speed Kts	Flap Angle (0°, 20°)	Corrected for 3D Effects CL At 8°	Corrected for 3D Effects % Lift Loss On 8° Cl vs Dry Cl	Time from 40kts to Rotation (sec)	Max Speed At Approx. Time of Rot. (kts)	Target OAT (°C)	Tunnel Temp. Before Test (°C)	Fluid Amount (L)	OAT Before Test (°C)	AVG Wing Temp Before Fluid Appl. (°C)	AVG Wing Temp Before Test (°C)	IP Rate (g/dm²/h)	SN Rate (g/dm²/h)	ZR Rate (g/dm²/h)	R Rate (g/dm²/h)	Exposure Time (min)	Rating Before Take-Off Run LE	Rating Before Take-Off Run TE	Rating Before Take-Off Run Flap	Rating At Rotation LE	Rating At Rotation TE	Rating At Rotation Flap	Rating After Take-Off Run LE	Rating After Take-Off Run TE	Rating After Take-Off Run Flap
18	21-Jan-20	P002	Baseline	Dry Wing	none	n/a	22	80	20	1.45	0.57%	2.69	81.92	any	n/a	-	-4.6	n/a	n/a	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
19	21-Jan-20	P057	EG Type IV Expansion	IP-	Safewing EG IV NORTH	01819	8	100	20	1.45	0.83%	19.6	103.65	>-5	-5.34	16	-3.8	-5.76	-10.49	25	-	-	-	70	2.8	2.2	4.0	1.0	1.0	1.0	1.0	1.0	1.0
20	21-Jan-20	P058	EG Type IV Expansion	IP- / SN-	Safewing EG IV NORTH	01819	8	100	20	1.44	1.53%	19.61	101.9	>-5	-4.67	14	-3.6	-5.77	-10.74	25	10	-	-	50	3.0	2.5	4.0	1.0	1.1	1.3	1.0	1.0	1.0
21	22-Jan-20	P062	EG Type IV Expansion	IP Mod	Safewing EG IV NORTH	01819	8	100	20	1.44	1.27%	19.37	102.42	>-5	-5.44	16	-3.7	-6.06	-13.07	75	-	-	-	35	3.3	2.8	4.0	1.0	1.0	1.1	1.0	1.0	1.0
22	22-Jan-20	P060	EG Type IV Expansion	IP- / ZR-	Safewing EG IV NORTH	01819	8	100	20	1.39	4.67%	19.07	104.21	>-5	-5.24	16	-3.8	-6.23	-8.01	25	-	25	-	40	3.0	2.2	5.0	1.0	1.0	5.0	1.0	1.0	5.0
23	22-Jan-20	P063	EG Type IV Expansion	IP Mod/ ZD	Safewing EG IV NORTH	01819	8	100	20	1.45	0.85%	19.44	103.11	>-5	-5.32	17	-3.6	-5.84	-11.55	75	-	13	-	20	3.0	2.6	4.0	1.0	1.0	1.4	1.0	1.0	1.0
24	22-Jan-20	P025	Type IV Validation and New Fluids	Fluid Only	Safewing EG IV NORTH	01819	8	100	20	1.42	2.84%	19.84	103.46	>-5	-5.04	16	-3.6	-5.99	-7.01	-	-	-	-	-	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

## **APPENDIX E**

### **EG WIND TUNNEL DATA ANALYSIS WITH THIN HIGH PERFORMANCE WING – 2009-10 TO 2019-20**





**Table 1: EG106** (Lift losses for this data in the range of 1 to 4% \*, with exception of failed IP-/ZR- test at 7%)

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes 50+ minutes	30 minutes	30 minutes <sup>3</sup> 30+ minutes	30 minutes <sup>3</sup> 30+ minutes
Light Ice Pellets Mixed with Snow	40 minutes 40+ minutes	15 minutes	15 minutes <sup>3</sup> 30+ minutes	15+ minutes
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes same as ↓	10 minutes Same as ↓	<b>Caution:</b> No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes 25+ minutes, but by default could be 30-35 = or > than →	10 minutes 40 minutes just failed, 30-35 should be ok		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup> same as ↑			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25+ minutes	10 minutes	10 minutes <sup>3</sup> 25 minutes ok	10 minutes <sup>7</sup> 10+ minutes
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	<b>Caution:</b> No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Rain	10 minutes <sup>8</sup>			

**Table 2: LNT E450** (Lift losses for this data in the range of 3 to 6% \*)

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes	30 minutes <sup>3</sup> 30+ minutes	30 minutes <sup>3</sup>
Light Ice Pellets Mixed with Snow	40 minutes	15 minutes 15+ minutes	15 minutes <sup>3</sup>	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes same as ↓	10 minutes same ↓	<b>Caution:</b> No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes 25+ minutes	10 minutes 10+ minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup> same as ↑			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25 minutes ok	10 minutes	10 minutes <sup>3</sup> 10+ minutes	10 minutes <sup>7</sup> 10+ minutes
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	<b>Caution:</b> No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Rain	10 minutes <sup>8</sup>			

**Table 3: ChemR EG IV** (Lift losses for this data in the range of 1 to 6% \*)

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes 50+ minutes	30 minutes <sup>3</sup> 30+ minutes	30 minutes <sup>3</sup>
Light Ice Pellets Mixed with Snow	40 minutes 50 minutes ok	15 minutes 15+ minutes	15 minutes <sup>3</sup> 30+ minutes	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes 30 minutes ok	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes	10 minutes 10+ minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup>			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup>	10 minutes 25+ minutes	10 minutes <sup>3</sup> 25 minutes ok	10 minutes <sup>7</sup>
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes 10+ minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Rain	10 minutes <sup>8</sup>			

**Table 4: Clariant AVIA** (Lift losses for this data in the range of 2 to 6% \*)

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes	30 minutes <sup>3</sup>	30 minutes <sup>3</sup> 30 minutes ok
Light Ice Pellets Mixed with Snow	40 minutes	15 minutes	15 minutes <sup>3</sup> 15+ minutes	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes 10+ minutes	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes	10 minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup>			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25+ minutes	10 minutes	10 minutes <sup>3</sup>	10 minutes <sup>7</sup> 10 minutes ok
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Rain	10 minutes <sup>8</sup>			

**Table 5: Defrost EG 4** (Lift losses for this data in the range of 1 to 7% \*)

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes	30 minutes <sup>3</sup>	30 minutes <sup>3</sup> 30 minutes ok
Light Ice Pellets Mixed with Snow	40 minutes	15 minutes	15 minutes <sup>3</sup> 30 + minutes	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes	10 minutes 10 + minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup> 25 + minutes			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25 + minutes	10 minutes	10 minutes <sup>3</sup> 25 + minutes	10 minutes <sup>7</sup> 10 minutes ok
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Rain	10 minutes <sup>8</sup>			

**Table 6: EG IV NORTH** (Lift losses for this data in the range of 1 to 3% \*)

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes 70 + minutes	30 minutes	30 minutes <sup>3</sup> 50 + minutes	30 minutes <sup>3</sup>
Light Ice Pellets Mixed with Snow	40 minutes 50 + minutes	15 minutes	15 minutes <sup>3</sup>	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes 40 minutes ok *	10 minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup>			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 35 minutes ok	10 minutes	10 minutes <sup>3</sup> 25 minutes ok	10 minutes <sup>7</sup>
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes 20 + minutes	7 minutes	Caution: No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Rain	10 minutes <sup>8</sup>			

\*The test had adhered contamination on flap leading edge (was down). If test would have been repeated with flap up, expect the test would have been good.

**Table 7: EG106 (Lift losses for this data in the range of 1 to 4%\*, with exception of failed IP-/ZR- test at 7%)**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes 50+ minutes	30 minutes	30 minutes <sup>3</sup> 30+ minutes	30 minutes <sup>3</sup> 30+ minutes
Light Ice Pellets Mixed with Snow	40 minutes 40+ minutes	15 minutes	15 minutes <sup>3</sup> 25+ minutes	15+ minutes
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes same as ↓	10 minutes Same as ↓	<b>Caution:</b> No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes 25+ minutes, but by default could be 30-35 = or > than →	10 minutes 40 minutes just failed, 30-35 should be ok		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup> same as ↑			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25+ minutes	10 minutes	10 minutes <sup>3</sup>	10 minutes <sup>7</sup> 10+ minutes
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	<b>Caution:</b> No allowance times currently exist	
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Rain	10 minutes <sup>8</sup>			

**Table 8: LNT E450 (Lift losses for this data in the range of 3 to 6%\*)**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes	30 minutes <sup>3</sup> 30+ minutes	30 minutes <sup>3</sup>
Light Ice Pellets Mixed with Snow	40 minutes	15 minutes 15+ minutes	15 minutes <sup>3</sup>	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes same as ↓	10 minutes same ↓	<b>Caution:</b> No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes 25+ minutes	10 minutes 10+ minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup> same as ↑			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25 minutes ok	10 minutes	10 minutes <sup>3</sup> 10+ minutes	10 minutes <sup>7</sup> 10+ minutes
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	<b>Caution:</b> No allowance times currently exist	

**Table 9: ChemR EG IV (Lift losses for this data in the range of 1 to 6%\*)**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes 50+ minutes	30 minutes <sup>3</sup> 30+ minutes	30 minutes <sup>3</sup>
Light Ice Pellets Mixed with Snow	40 minutes 50 minutes ok	15 minutes 15+ minutes	15 minutes <sup>3</sup> 15+ minutes	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes 30 minutes ok	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes	10 minutes 10+ minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup>			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup>	10 minutes 25+ minutes	10 minutes <sup>3</sup> 10+ minutes	10 minutes <sup>7</sup>
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes 10+ minutes	Caution: No allowance times currently exist	

**Table 10: Clariant AVIA (Lift losses for this data in the range of 2 to 6%\*)**

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes	30 minutes <sup>3</sup>	30 minutes <sup>3</sup> 30 minutes ok
Light Ice Pellets Mixed with Snow	40 minutes	15 minutes	15 minutes <sup>3</sup> 15+ minutes	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes 10+ minutes	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes	10 minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup>			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25+ minutes	10 minutes	10 minutes <sup>3</sup>	10 minutes <sup>7</sup> 10 minutes ok
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	Caution: No allowance times currently exist	

Table 11: Defrost EG 4 (Lift losses for this data in the range of 1 to 7%\*)

Precipitation Type	Outside Air Temperature			
	-5°C and above	Below -5 to -10°C	Below -10 to -16°C	Below -16 to -22°C <sup>2</sup>
Light Ice Pellets	50 minutes	30 minutes	30 minutes <sup>3</sup>	30 minutes <sup>3</sup> 30 minutes ok
Light Ice Pellets Mixed with Snow	40 minutes	15 minutes	15 minutes <sup>3</sup> 15 + minutes	
Light Ice Pellets Mixed with Freezing Drizzle	25 minutes	10 minutes	Caution: No allowance times currently exist	
Light Ice Pellets Mixed with Freezing Rain	25 minutes	10 minutes 10 + minutes		
Light Ice Pellets Mixed with Rain	25 minutes <sup>4</sup> 25 + minutes			
Moderate Ice Pellets (or Small Hail) <sup>5</sup>	25 minutes <sup>6</sup> 25 + minutes	10 minutes	10 minutes <sup>3</sup>	10 minutes <sup>7</sup> 10 minutes ok
Moderate Ice Pellets (or Small Hail) <sup>5</sup> Mixed with Freezing Drizzle	10 minutes	7 minutes	Caution: No allowance times currently exist	