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December 2020

WIND TUNNEL TESTING TO EVALUATE CONTAMINATED FLUID FLOW-OFF FROM A VERTICAL STABILIZER

Prepared for:

Transport Canada Innovation Centre

In cooperation with:

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Transport Canada Civil Aviation

Federal Aviation Administration Flight Standards – Air Carrier Operations

APS Aviation Inc.

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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°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°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 15454E, has the following objective:

- To evaluate contaminated fluid flow-off from a vertical stabilizer.

This objective was met by conducting a series of full-scale wind tunnel tests at the National Research Council Canada Icing Wind Tunnel located in Ottawa, Canada.

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.

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- The team at the National Research Council Canada who operate the Icing Wind Tunnel, especially Catherine Clark, Arash Raeesi, and Richard Lee for their engineering support and aerodynamic expertise;
- 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;
- John Macomber from Boeing whose participation and aerodynamic expertise provided valuable operational insight into the data collected; and
- The fluid manufacturers who have provided samples over the years in support of the wind tunnel testing.

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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.

16. Abstract

As part of a larger research program, APS Aviation Inc. (APS) conducted a series of full-scale tests in the National Research Council Canada (NRC) 3 m x 6 m Icing Wind Tunnel evaluating contaminated fluid flow-off from a vertical stabilizer.

The calibration and validation of procedures ensured safety and repeatability in the testing protocols. The dry wing testing and tuft visualization testing allowed the researchers to gain insight into the aerodynamic behaviour of the vertical stabilizer model in advance of testing with fluids and contamination.

The fluid testing and flow-off characterization testing demonstrated that fluid and contamination was always present at the end of each test run. The amount of residual increased or decreased based on the severity of the condition tested and was affected by the sideslip and rudder deflection, the level of contamination, the temperature at which the test was run, the type of fluid used, and other factors.

Testing conducted in snow conditions, demonstrated that failed fluid which had a slushy consistency generally had poor flow-off. In contrast, fluid that was not failed, because it was either clean, or limited amounts of contamination were applied, demonstrated adequate flow-off. Freezing rain tests demonstrated similar results to snow, but had the added complexity of adherence to the surface making flow-off more difficult in some conditions. However, ice pellet tests cleaned off well compared to snow, mainly due to the fact that the pellets do not readily dissolve and may have been bouncing off or sliding down the model leaving behind a cleaner fluid at takeoff.

Discussions should continue with the SAE International G-12 Aerodynamics Working Group with the goal of getting agreement on the design of the vertical stabilizer common research model. The objective is to have agreement on a common research model by end of 2020 so that APS and NRC, under contract to Transport Canada and the Federal Aviation Administration, can begin the construction in 2021 and allow for testing in the winter of 2021-22. Future testing should build upon the testing matrix developed for this testing. Testing should also focus on areas not extensively explored during this preliminary phase of testing including asymmetric contamination, different fluids, et cetera.

17. Key Words Vertical Stabilizer, V-Stab, High Speed Rotation, Low Speed Rotation, Type II, Type III, Type IV, Fluid Adherence, Fluid Flow-Off, Wind Tunnel, Icing Wind Tunnel, Wing Aerodynamics	18. Distribution Statement Available from the Transport Canada Innovation Centre

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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.

16. Résumé

Dans le cadre d'un plus vaste programme de recherche, APS Aviation Inc. (APS) a mené une série d'essais pleine grandeur dans la soufflerie de givrage de 3 m sur 6 m du Conseil national de recherches Canada (CNRC) afin d'évaluer les propriétés de ruissellement de liquides contaminés sur la surface d'un stabilisateur vertical.

La sécurité et la répétabilité des protocoles d'essai ont été assurées par des processus de calibration et de validation. Des essais sur aile sèche et de visualisation à l'aide de fils ont permis aux chercheurs de mieux comprendre le comportement aérodynamique du modèle de dérive avant de procéder aux évaluations à l'aide de liquides et de contaminants.

Les essais réalisés sur les liquides et ceux visant à caractériser le ruissellement ont démontré qu'il y avait toujours présence de liquide et de contamination au terme de chaque séance de test. Les manœuvres de glissade et de débattement de la direction, le degré de contamination, la température au moment de l'essai, le type de liquide utilisé et d'autres facteurs se sont avérés avoir une incidence sur la quantité de matière résiduelle, qui augmentait ou diminuait selon la gravité des conditions d'essai.

Les essais menés dans des conditions de neige ont démontré que le ruissellement d'un liquide défaillant ayant la consistance de neige fondante était généralement mauvais. En revanche, un liquide non défaillant, c'est-à-dire intact ou auquel seule une quantité limitée de contaminants avait été appliquée, s'est avéré ruisseler de façon adéquate. Les essais se rapportant à la pluie verglaçante ont généré des résultats semblables à ceux pour la neige, mais la complexité accrue amenée par l'adhérence à la surface rendait le ruissellement plus difficile dans certaines conditions. Par ailleurs, les essais dans des conditions de granules de glace ont permis de constater une bonne élimination comparativement à la neige. Cela s'explique principalement par le fait que les granules ne se dissolvaient pas d'emblée et rebondissaient ou glissaient probablement le long du modèle, laissant ainsi un liquide plus net au décollage.

Les discussions avec le groupe de travail G-12 de la SAE sur l'aérodynamisme devraient se poursuivre pour en arriver à un consensus sur les paramètres d'un modèle de stabilisateur vertical général pour la recherche. L'objectif est de conclure, d'ici la fin de l'année 2020, une entente permettant l'élaboration d'un modèle de recherche faisant l'unanimité, afin qu'APS et CNRC, dans le cadre d'un contrat avec Transports Canada et la Federal Aviation Administration, puissent amorcer la construction en 2021 et réaliser des essais durant l'hiver 2021-2022. Les futurs essais se baseraient sur la matrice élaborée à cet effet. Ils devraient également être axés sur des aspects n'ayant pas été explorés de façon approfondie dans le cadre de cette phase préliminaire d'essais, y compris la contamination asymétrique, l'utilisation de différents liquides, etc.

17. Mots clés Stabilisateur vertical, v-stab, 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	18. Diffusion Disponible auprès du Centre d'innovation de Transports Canada

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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 tests in the National Research Council Canada (NRC) 3 m x 6 m Icing Wind Tunnel (IWT) evaluating contaminated fluid flow-off from a vertical stabilizer.

Background and Objective

There is a lack of standardization in the treatment of vertical surfaces during deicing operations. A wind tunnel testing program was developed for the winter of 2019-20 with the primary objectives of conducting aerodynamic testing to document contaminated fluid flow-off on a Piper PA-34-200T Seneca II vertical stabilizer.

Conclusions

The calibration and validation of procedures ensured safety and repeatability in the testing protocols. The dry wing testing and tuft visualization testing allowed the researchers to gain insight into the aerodynamic behaviour of the vertical stabilizer model in advance of testing with fluids and freezing or frozen precipitation. The IWT provided an effective means to carry out the anticipated research accommodating the installation of an appropriate size model and allowing the application of fluids.

The fluid testing and flow-off characterization testing demonstrated that fluid and contamination was always present at the end of each test run. The amount of residual increased or decreased based on the severity of the condition tested and was affected by the sideslip and rudder deflection, the level of contamination, the temperature at which the test was run, the type of fluid used, and other factors.

Testing conducted in snow conditions, demonstrated that failed fluid which had a slushy consistency generally had poor flow-off. In contrast, fluid that was not failed, because it was either clean, or limited amounts of contamination were applied, demonstrated adequate flow-off. Freezing rain tests demonstrated similar results to snow, but had the added complexity of adherence to the surface making flow-off more difficult in some conditions. However, ice pellet tests cleaned off well compared to snow, mainly because the pellets do not readily dissolve and may have been bouncing off or sliding down the model leaving behind a cleaner fluid at takeoff.

Recommendations

Discussions should continue with the SAE International G-12 Aerodynamics Working Group with the goal of getting agreement on the design of the vertical stabilizer common research model. The objective is to have agreement on a common research model by the end of 2020, so that APS and NRC, under contract to TC and the FAA, can begin the construction in 2021 and conduct testing in the winter of 2021-22. Future testing should build upon the testing matrix developed for this testing. Testing should also focus on areas not extensively explored during this preliminary phase of testing including asymmetric contamination, different fluids, et cetera.

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 pleine grandeur dans la soufflerie de givrage de 3 m sur 6 m du Conseil national de recherches Canada (CNRC) afin d'évaluer les propriétés de ruissellement de liquides contaminés sur la surface d'un stabilisateur vertical.

Contexte et objectif

On constate l'absence de normalisation dans le traitement des surfaces verticales durant les opérations de dégivrage. Un programme d'essais en soufflerie a été élaboré pour l'hiver 2019-2020 avec comme principaux objectifs de réaliser des tests aérodynamiques pour documenter le ruissellement d'un liquide contaminé sur la dérive d'un avion Piper PA-34-200T Seneca II.

Conclusions

La sécurité et la répétabilité des protocoles d'essai ont été assurées par des processus de calibration et de validation. Des essais sur aile sèche et de visualisation à l'aide de fils ont permis aux chercheurs de mieux comprendre le comportement aérodynamique du modèle de dérive avant de procéder aux évaluations à l'aide de liquides et dans des conditions de précipitations verglaçantes ou gelées. La soufflerie de givrage s'est avérée un excellent moyen de poursuivre les activités de recherche prévues, puisqu'elle peut accueillir l'installation d'un modèle aux dimensions adéquates et permettre l'application de liquides.

Les essais réalisés sur les liquides et ceux visant à caractériser le ruissellement ont démontré qu'il y avait toujours présence de liquide et de contamination au terme de chaque séance de test. Les manœuvres de glissade et de débattement de la direction, le degré de contamination, la température au moment de l'essai, le type de liquide utilisé et d'autres facteurs se sont avérés avoir une incidence sur la quantité de matière résiduelle, qui augmentait ou diminuait selon la gravité des conditions d'essai.

Les essais menés dans des conditions de neige ont démontré que le ruissellement d'un liquide défaillant ayant la consistance de neige fondante était généralement

mauvais. En revanche, un liquide non défaillant, c'est-à-dire intact ou auquel seule une quantité limitée de contaminants avait été appliquée, s'est avéré ruisseler de façon adéquate. Les essais se rapportant à la pluie verglaçante ont généré des résultats semblables à ceux pour la neige, mais la complexité accrue amenée par l'adhérence à la surface rendait le ruissellement plus difficile dans certaines conditions. Par ailleurs, les essais dans des conditions de granules de glace ont permis de constater une bonne élimination comparativement à la neige. Cela s'explique principalement par le fait que les granules ne se dissolvaient pas d'emblée et rebondissaient ou glissaient probablement le long du modèle, laissant ainsi un liquide plus net au décollage.

Recommandations

Les discussions avec le groupe de travail G-12 de la SAE sur l'aérodynamisme devraient se poursuivre pour en arriver à un consensus sur les paramètres d'un modèle de stabilisateur vertical général pour la recherche. L'objectif est de conclure, d'ici la fin de l'année 2020, une entente permettant l'élaboration d'un modèle de recherche faisant l'unanimité, afin qu'APS et CNRC, dans le cadre d'un contrat avec TC et la FAA, puissent amorcer la construction en 2021 et réaliser des essais durant l'hiver 2021-2022. Les futurs essais se baseraient sur la matrice élaborée à cet effet. Ils devraient également être axés sur des aspects n'ayant pas été explorés de façon approfondie dans le cadre de cette phase préliminaire d'essais, y compris la contamination asymétrique, l'utilisation de différents liquides, etc.

CONTENTS Page

LIST OF APPENDICES

LIST OF TABLES Page

LIST OF FIGURES Page

LIST OF PHOTOS Page

GLOSSARY

APS	APS Aviation Inc.
AWG	Aerodynamics Working Group
CRM	Common Research Model
EG	Ethylene Glycol
FAA	Federal Aviation Administration
FFP	Fluid Freezing Point
FPD	Freezing Point Depressant
HOT	Holdover Time
IWT	3 m x 6 m Icing Wind Tunnel
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
OAT	Outside Air Temperature
PG	Propylene Glycol
RTD	Resistance Temperature Detector
SAE	SAE International
TC	Transport Canada
β	Effective Sideslip (degrees)
δ_r	Rudder Deflection (degrees)

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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 research performed to evaluate contaminated fluid flow-off from a vertical stabilizer.

1.1 Background

There is a lack of standardization in the treatment of vertical surfaces during deicing operations. Some operators in the United States and Canada exclude the treatment of vertical surfaces, including the tail, while others only consider treatment during ongoing freezing precipitation. In some cases, the tail may only be deiced while the wings are being deiced and anti-iced. Some reports have also indicated that treatment of the tail may worsen takeoff performance as the anti-icing fluid on the tail may lead to increased accumulation of contamination in active precipitation conditions.

Current TC and FAA rules and regulations require that critical surfaces be free of contamination prior to takeoff, and the vertical stabilizer is defined as a critical surface by both TC and the FAA. However, from a regulatory implementation and enforcement standpoint, there is currently no standardized guidance that offers inspectors a means to determine if an air operator is complying with operational rules. If current operational rules aim to achieve the clean aircraft concept – which requires the tail to have zero adhering frozen contamination – the question remains: How can this be adequately achieved, or appropriately mitigated by operators, to ensure a satisfactory level of safety?

1.2 Previous Related Research

The research conducted to date has demonstrated the variability in the fluid protection times and characteristics of contamination that can be present on vertical surfaces. Refer to TC report, TP 15340E, *Aircraft Ground Icing General Research Activities During the 2015-16 Winter* (1). Additional research would provide a better understanding of the influence of the different variables, including the rate and type of precipitation, along with wind conditions and other meteorological conditions.

1.3 Working Group Discussion

The overall aerodynamic impact of contamination on vertical surfaces has yet to be fully understood. A working group was started in June 2019 that included the FAA, TC, National Aeronautics and Space Administration (NASA), Boeing, and APS with the objective to determine the best plan forward for testing in 2019-20 to quantify the aerodynamic impacts of contamination on vertical surfaces. A preliminary plan was developed to use the TC-owned Piper Seneca II tail model and conduct testing at the NRC 3 m x 6 m Icing Wind Tunnel (IWT) in Ottawa, Canada to qualify the contaminated fluid flow-off characteristics. The goal of this and future research is to collect data that can be used by aircraft manufacturers to better understand the expected impacts of a contaminated vertical stabilizer on their specific aircraft types.

1.4 Project Objectives

A wind tunnel testing program was developed for the winter of 2019-20 with the primary objectives of conducting aerodynamic testing to document contaminated fluid flow-off on a Piper PA-34-200T Seneca II vertical stabilizer.

Table 1.1 demonstrates the groupings for the global set of tests conducted at the wind tunnel during the winter of 2019-20 using the vertical stabilizer model. It should be noted that this research was coordinated in conjunction with the yearly TC/FAA wind tunnel ice pellet research campaign.

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

Table 1.1: Summary of 2019-20 Vertical Stabilizer Tests by Objective

Objective #	Objective	# of Runs
1	Calibration and Validation of Procedures	-
2	Dry Wing Testing and Tuft Visualization	6
3	Fluid Testing and Flow-Off Characterization	24
	Total	**30**

1.5 Report Format

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

a) Section 2 describes the methodology used in testing, as well as equipment and personnel requirements necessary to carry out testing;
b) Section 3 describes data collected during the wind tunnel testing conducted;
c) Section 4 describes the results from the calibration and validation of procedures;
d) Section 5 describes the results from the dry wing testing and tuft visualization;
e) Section 6 describes the results from the fluid testing and flow-off characterization;
f) Section 7 describes the ongoing discussions about developing a vertical stabilizer common research model;
g) Section 8 provides a summary of the conclusions; and
h) Section 9 provides a summary of the recommendations.

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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.

2.1 Test Schedule

Five days of overnight testing were organized starting February 2, 2020. An initial three days of testing starting January 19, 2020, were organized as part of a separate test objective related to ice pellet allowance times. Setup and teardown times were kept to a minimum and done during the first two hours on the first day of testing and during the last two hours on the last day of testing, respectively. Table 2.1 presents the calendar of wind tunnel allowance time tests performed with the vertical stabilizer model. 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: 2019-20 Calendar of Tests

Date (Start date of overnight testing)	**# of Tests Run**
February 2, 2020	0
February 3, 2020	12
February 4, 2020	5
February 5, 2020	9
February 6, 2020	4
Total	30

2.1.1 Wind Tunnel Procedure

To satisfy the fluid testing objective, simulated takeoff and climb-out tests were performed with the vertical stabilizer. Different parameters including fluid thickness, wing temperature, and fluid freezing point (FFP) were recorded at designated times during the tests.

The typical procedure for each fluid test is described below.

- The vertical stabilizer was treated with deicing or anti-icing fluid, applied over a clean dry surface.

- When applicable, contamination, in the form of simulated ice pellets, freezing rain, and/or snow, was applied to the vertical stabilizer. 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 video cameras and 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, methodologies, 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 vertical stabilizer was relatively consistent 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 illustrative purposes; this time varied for each test depending on the objective.

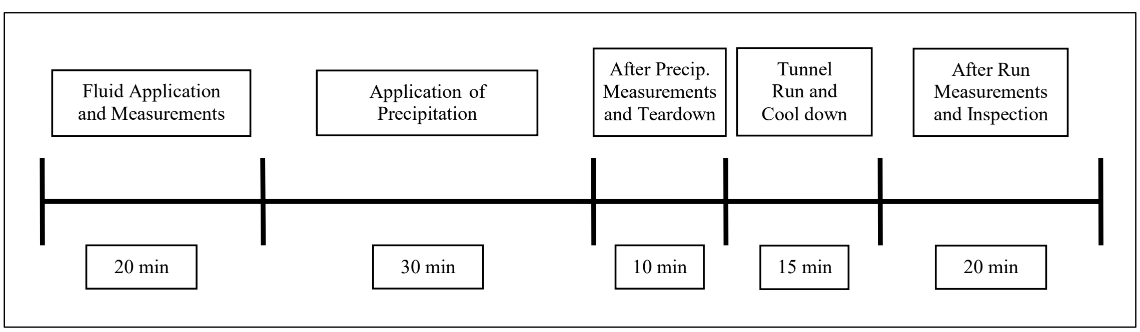

Figure 2.1: Typical Wind Tunnel Test Timeline

2.2 Wind Tunnel and Vertical Stabilizer Model Technical Overview

The following subsections describe the wind tunnel and major test components.

2.2.1 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.

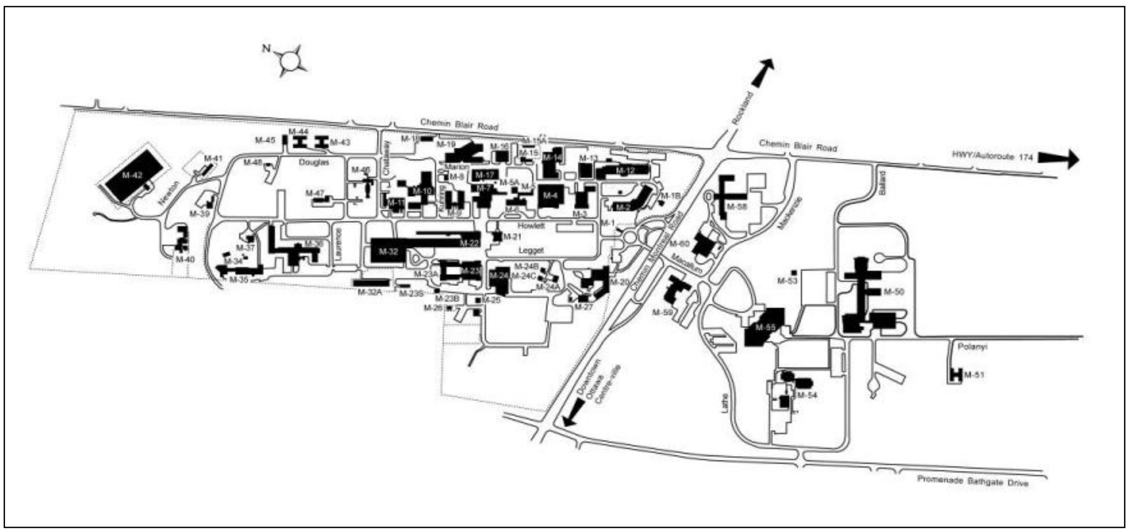

Figure 2.2: Schematic of the NRC Montreal Road Campus

2.2.2 Piper PA-34-200T Seneca II Vertical Stabilizer Model

The model used for testing was constructed using salvaged parts from a Piper PA-34-200T Seneca II aircraft (see Photo 2.3 and Photo 2.4). The model was originally obtained by TC in 2015-16 and modified for outdoor fluid endurance time testing (see Photo 2.5). The NRC was tasked with retrofitting the vertical stabilizer as a wind tunnel model. Figure 2.3 provides a schematic plan developed by the NRC for mounting the model, and Photo 2.6 shows the vertical stabilizer mounted in the

NRC IWT. The model was approximately 1.6 m tall and 1.5 m wide at the base without the fairing.

The vertical stabilizer was selected as a research model based on several positive factors:

- The model was readily available (previously used for TC/FAA research), and parts are easily available for purchase through an online supplier;
- It was light weight and compact in size and, therefore, easily accessed for fluid application and able to be handled by personnel;
- The small size allowed the use of the full vertical stabilizer without having to cut it down to size;
- It was easily mountable using existing hardware and mounting bolts; and
- The shape (not size) was generally representative of commercial aircraft.

There were also some known negative factors:

- The leading edge rubber boot caused inconsistency in material finish;
- The thickness of the protruding fasteners may affect localized fluid flow-off; and
- The rudder overhang is not common to most commercial aircraft.

Nonetheless, the positive factors outweighed the negative ones, and the research group decided to proceed with the Piper PA-34-200T Seneca II vertical tail as the research model for this project.

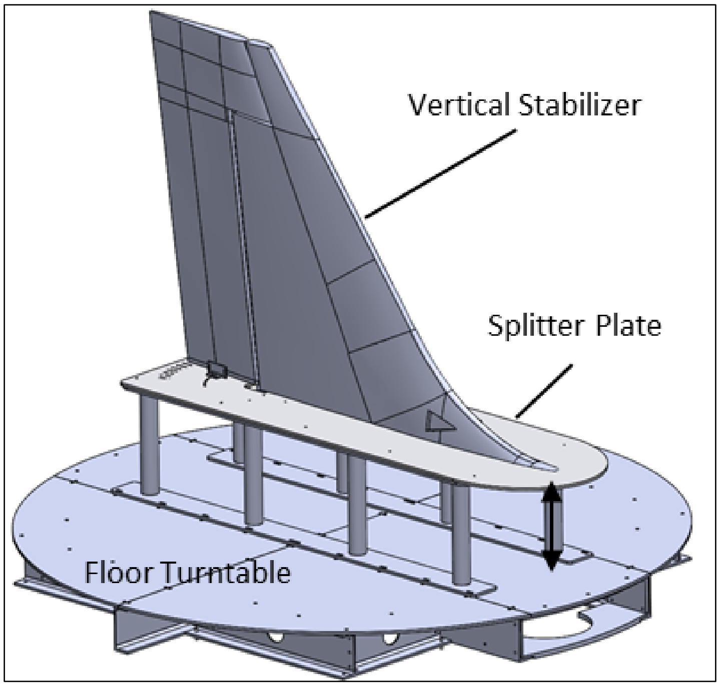

Figure 2.3: Piper PA-34-200T Seneca II Vertical Stabilizer Model

As shown in Figure 2.3, the vertical stabilizer was mounted on a splitter plate to minimize the aerodynamic effects from the tunnel floor. The splitter plate was attached to a turntable in the floor that allowed the effective sideslip angle of the model to be changed dynamically prior to and during a test. The effective sideslip (B) of the model ranged from -7.5 to +7.5 degrees. The rudder was also moveable but had to be manually set prior to the test and therefore could not be changed during the test. The rudder deflection (δ_r) of the model ranged from -30 to +30 degrees. The sideslip and rudder limits provided adequate safety margins in the tunnel. The limits were deemed representative based on anecdotal information provided by Piper engineering and supported by research papers available in the public domain. Crosswind effects were simulated through the effective sideslip. Figure 2.4 demonstrates the effective sideslip and rudder deflection angles that would be experienced during a crosswind takeoff. Figure 2.5 demonstrates the simulated crosswind takeoff configuration used in the NRC IWT for the scenario shown in Figure 2.4.

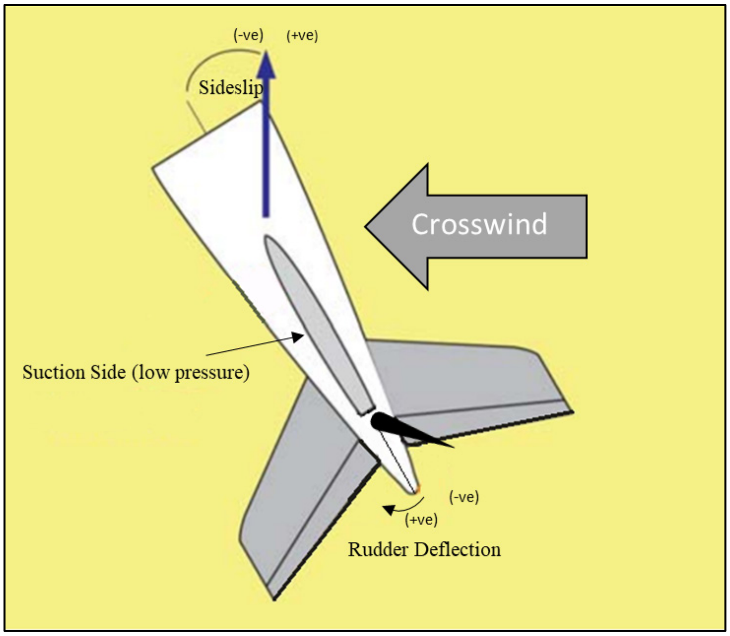

Figure 2.4: Schematic Demonstrating the Effective Sideslip and Rudder Deflection Angles During a Crosswind Takeoff

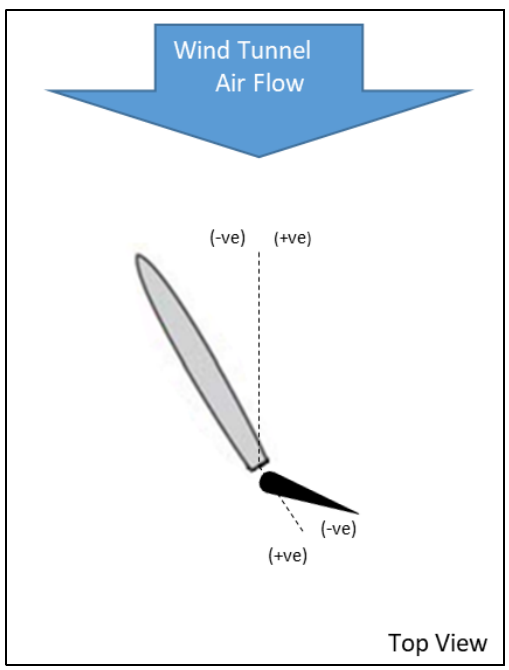

Figure 2.5: Schematic Demonstrating the Simulated Crosswind Takeoff Configuration in the NRC IWT

2.2.3 Wind Tunnel Measurements

The vertical stabilizer was equipped with four resistance temperature detectors (RTDs); these were installed by NRC personnel to record the skin temperature on both the port and starboard sides on the model. In pairs on the port and starboard sides, the RTDs were placed just above the access panel at the bottom of the vertical stabilizer and, as high as possible within arms reach from the access panel at the bottom of the vertical stabilizer. The RTDs were labeled Port Lower, Port Upper, Starboard Lower, and Starboard Upper accordingly. Figure 2.6 shows the approximate location of the RTDs on the starboard side; the port side would be symmetric, but it is not shown in the figure.

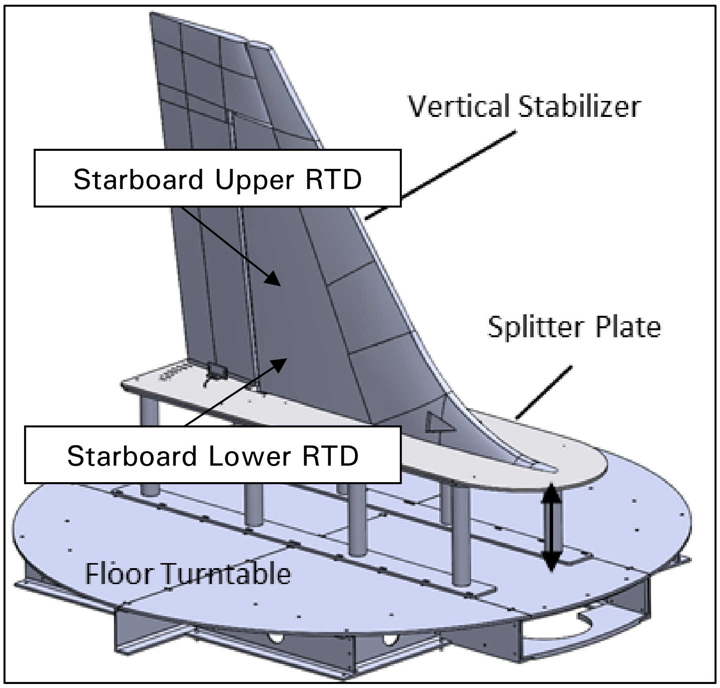

Figure 2.6: Starboard Side Locations of RTDs (Port Side Not Shown)

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.

It should be noted that aerodynamic forces on the model were not measured.

2.3 Simulated Precipitation

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

- Ice Pellets;
- Snow;
- Freezing Rain/Rain; and
- Other conditions related to holdover times (HOTs).

2.3.1 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 2.7). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.8) to obtain the required ice pellet size range. Hand-held motorized dispensers (see Photo 2.9) were used to dispense the ice pellets. The ice pellets were applied to the port and starboard sides of the vertical stabilizer at the same time.

2.3.2 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 port and starboard sides of the vertical stabilizer at the same time.

2.3.3 Freezing Rain/Rain

The NRC sprayer head and scanner could not be used due to the location of the equipment versus the location of the vertical stabilizer. Instead, a mix of water and ice in a garden sprayer was used to dispense simulated freezing rain (see Photo 2.10). A constant “S” shape spray pattern was produced manually, and the quantity of water being sprayed was measured before, after, and at several increments during the contamination period to ensure even distribution and a proper rate of precipitation.

2.3.4 Definition of Precipitation Rates

For the simulation of precipitation rates for full-scale and plate testing, the rate limits defined for standard HOT testing were referenced. Figure 2.7 demonstrates the HOT testing rate precipitation breakdown as follows:

- Light Ice Pellets: 13-25 g/dm²/h;
- Moderate Ice Pellets: 25-75 g/dm²/h;
- Light Freezing Rain: 13-25 g/dm²/h;
- Freezing Drizzle (Heavy): 5-13 g/dm²/h;
- Light Rain: 13-25 g/dm²/h;
- Moderate Rain: 25-75 g/dm²/h;
- Light Snow: 4-10 g/dm²/h; and
- Moderate Snow: 10-25 g/dm²/h.

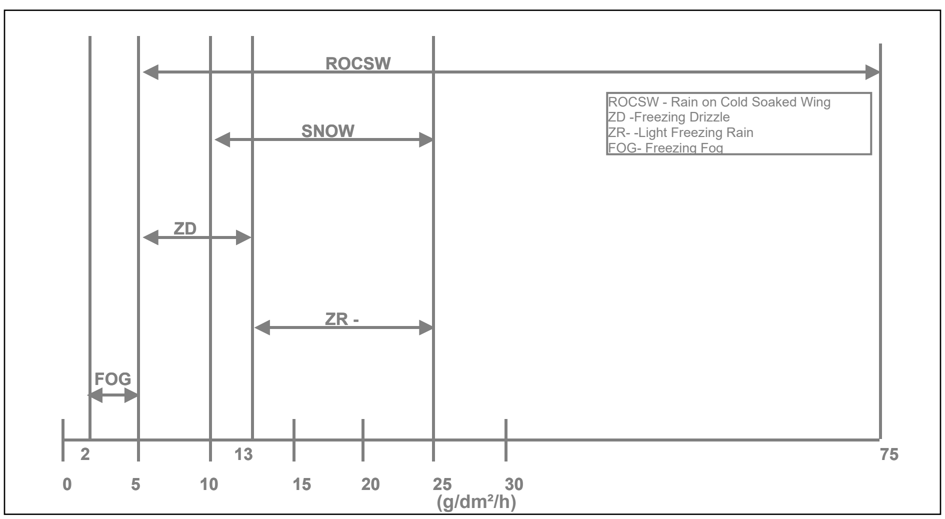

Figure 2.7: Precipitation Rate Breakdown

2.3.5 Simulated Crosswind Contamination

The test plan originally included a test parameter that was set to simulate the effect of high crosswinds. This high crosswind scenario would result in an asymmetric contamination to one side of the vertical stabilizer versus the other. This would be simulated by applying contamination to only one side.

It should be noted that due to changing priorities during the test campaign, the simulated crosswind contamination tests (asymmetric contamination) were not performed. All contamination applied to the model was symmetric on both sides.

2.4 Fluid Failure on the Vertical Stabilizer Model

The time of visual failure was observed for each fluid test. The fluid was determined to have failed visually when the snow or precipitation was no longer absorbed by the fluid and began to accumulate on the fluid surface. A 10 percent failure coverage was historically used during TC/FAA full-scale aircraft fluid testing in the 1990s and was determined to correlate with the 33 percent failure coverage on the standard aluminum 10º angled test plates that have since been used to develop the HOTs. A fluid is expected to have visual failure at the end of the HOT.

2.5 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.

2.5.1 Video and Photo Equipment

Osmo® and GoPro® cameras were used for wide-angle filming of fluid flow-off during the test runs. Cameras were positioned on both sides of the vertical stabilizer, and live feeds were provided to observers to allow both sides of the vertical stabilizer to be observed during the test runs. In addition, Canon® EOS XTi DSLR cameras and Profoto® Compact 600 flashes capable of second-by-second photography with an intervalometer were used for still photography.

Photo 2.11, Photo 2.12, Photo 2.13, and Photo 2.14 demonstrate the camera setup used for the testing period.

2.5.2 Refractometer/Brixometer

FFPs were measured using a hand-held Misco 10431VP refractometer with a Brix scale (shown in Figure 2.8). The freezing points of the various fluid samples were determined using the conversion curve or table provided to APS by the fluid manufacturer.

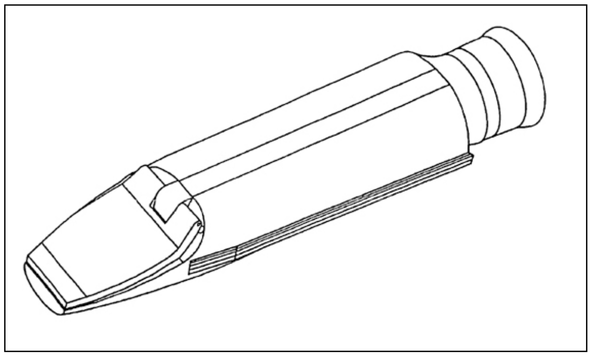

Figure 2.8: Hand-Held Refractometer/Brixometer

2.5.3 Wet Film Thickness Gauges

Wet film thickness gauges, shown in Figure 2.9, 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.

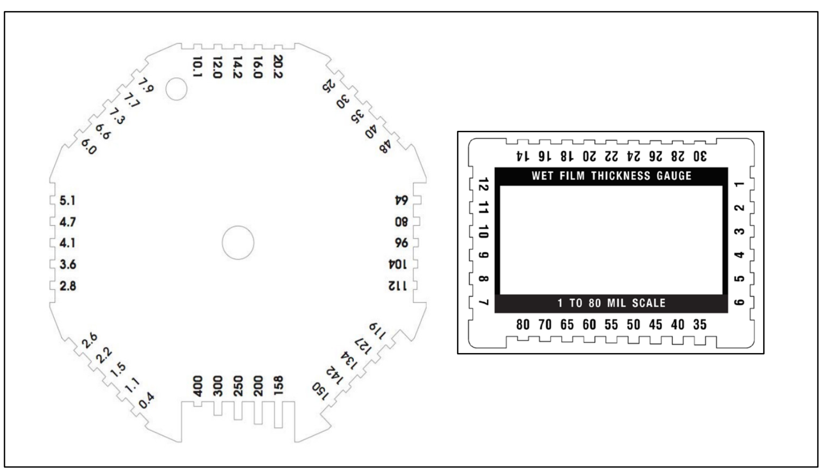

Figure 2.9: Wet Film Thickness Gauges

2.5.4 Hand-Held Immersion and Surface Temperature Probes

Hand-held immersion and surface temperature probes were used to provide instantaneous spot measurements during testing. These devices have an accuracy of ±0.4°C with a 2-3 second read time. Figure 2.10 shows the schematic of the probes.

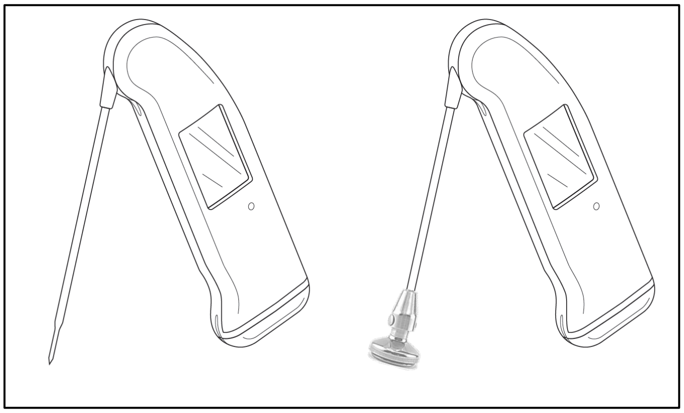

Figure 2.10: Hand-Held Immersion and Surface Temperature Probes

2.6 Personnel

During the fluid testing and exploratory research testing, four APS staff members were required to conduct the tests, and five 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 2.16 shows a portion of the research team (due to scheduling, not all participants were available for the photo).

2.7 Data Forms

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

2.8 Data Collection

Fluid thickness, fluid Brix, and skin temperature measurements were collected by APS personnel. The measurements, along with other pertinent data parameters, were collected before and after fluid application, after the application of contamination, and at the end of the test. Visual evaluations of the model were also documented before, during, and after the takeoff runs. The completed data forms have been scanned and included in Appendix C for referencing purposes.

Video and photography were also taken during 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 and video available in electronic format have been provided to TC and can be made available upon request.

2.9 De/Anti-Icing Fluids

Three fluids were used for testing:

- Dow Chemical Company UCAR™ propylene glycol (PG) aircraft deicing fluid Concentrate Type I Fluid (measured viscosity n/a);
- Cryotech Deicing Technology Polar Guard® Advance Type IV Fluid (measured viscosity 14,820 cP); and
- Dow Chemical Company UCAR™ Endurance EG106 De/Anti-Icing Fluid Type IV Fluid (measured viscosity 39,500 cP).

2.9.1 Viscometer

Historically, viscosity measurements have been carried out using a Brookfield viscometer (Model DV-1+, shown in Photo 2.17) 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 2.18) 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.

2.9.2 Fluid Application Equipment

The Type II/III/IV fluids were stored outside the wind tunnel and were kept at ambient temperature.

Type II, III, and IV fluids are generally received in 20 L containers; however, some fluids are received in large 200 L barrels or larger 1000 L totes. The fluid was applied to the model by using a garden sprayer with the atomizing nozzle removed to minimize fluid shearing (Photo 2.15).

Type I fluid was diluted with hard water and heated in large pots using hot plates. The Type I fluid heated to 60°C was applied to the vertical stabilizer using a garden sprayer.

2.9.3 Waste Fluid Collection

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.

Photo 2.1: Outside View of the NRC Wind Tunnel Facility

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

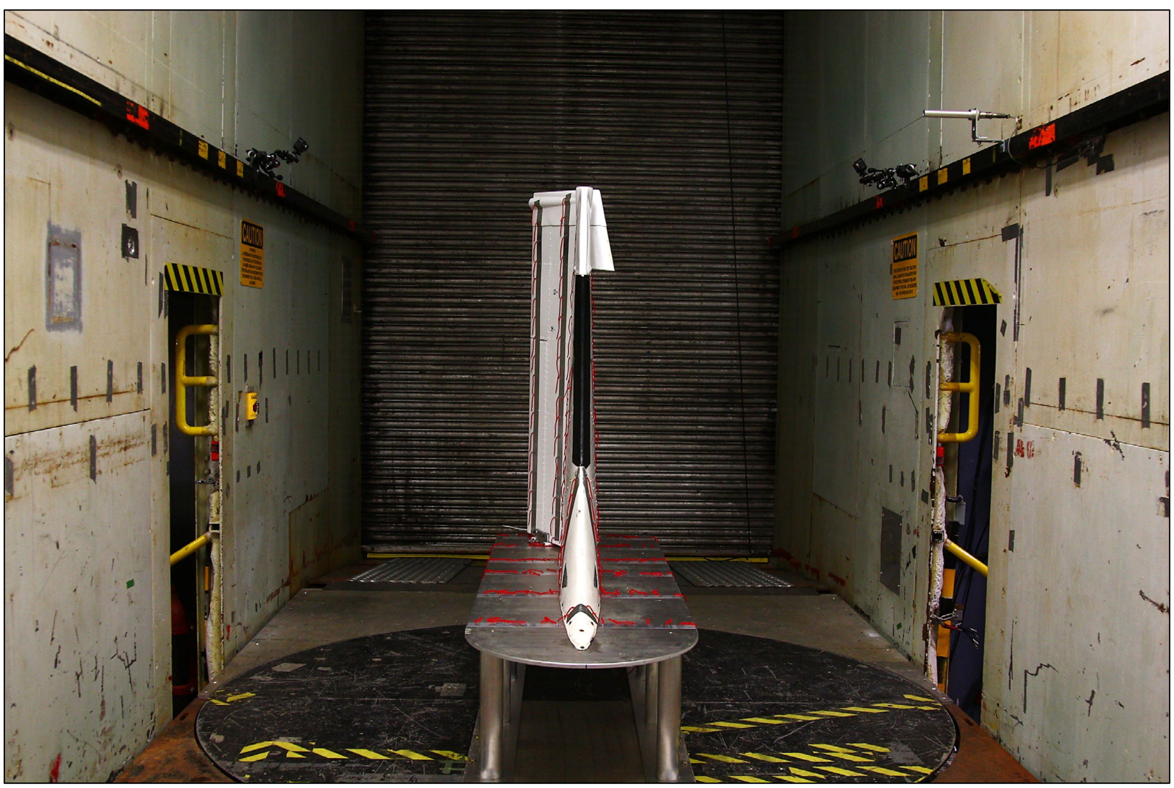

Photo 2.3: Piper PA-34-200T Seneca II Aircraft (Photo from Airliners.net)

Photo 2.4: Salvaged Piper PA-34-200T Seneca II Vertical Stabilizer

Photo 2.5: Vertical Stabilizer Mounted for Endurance Time Testing Outdoors

Photo 2.6: Vertical Stabilizer Mounted in the NRC IWT for Testing

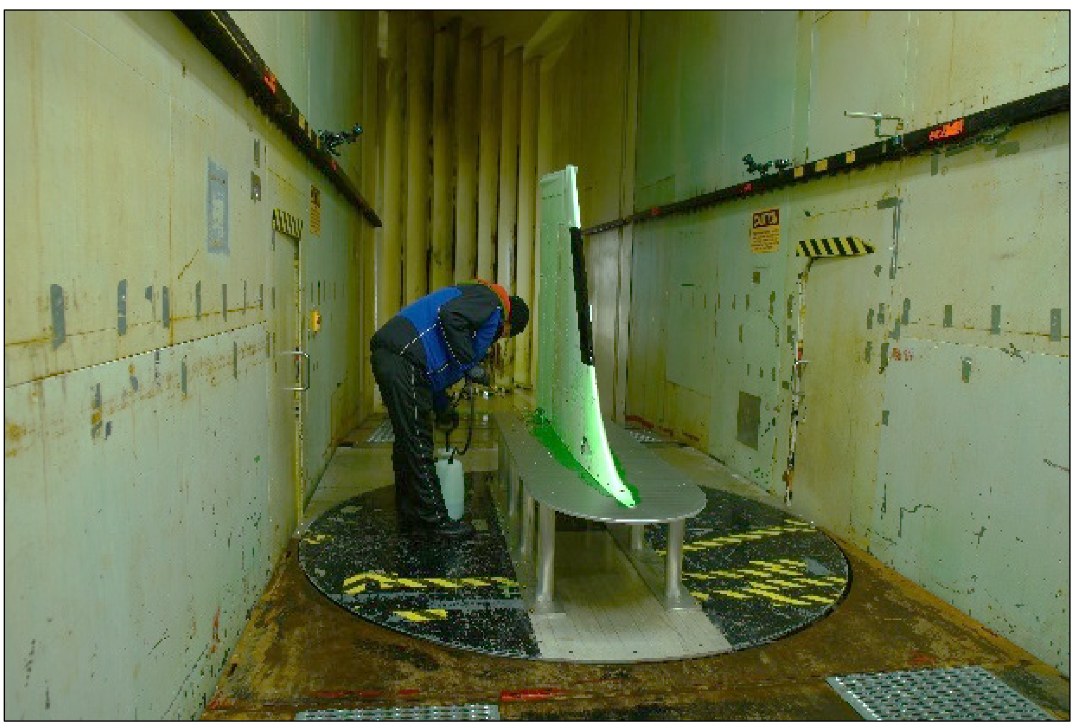

Photo 2.7: Refrigerated Truck Used for Manufacturing Ice Pellets

Photo 2.8: Calibrated Sieves Used to Obtain Desired Size Distribution

Photo 2.9: Ice Pellet/Snow Dispenser Operated by APS Personnel

Photo 2.10: Simulating Freezing Rain with Garden Sprayer

Photo 2.11: Wind Tunnel Setup for Flashes

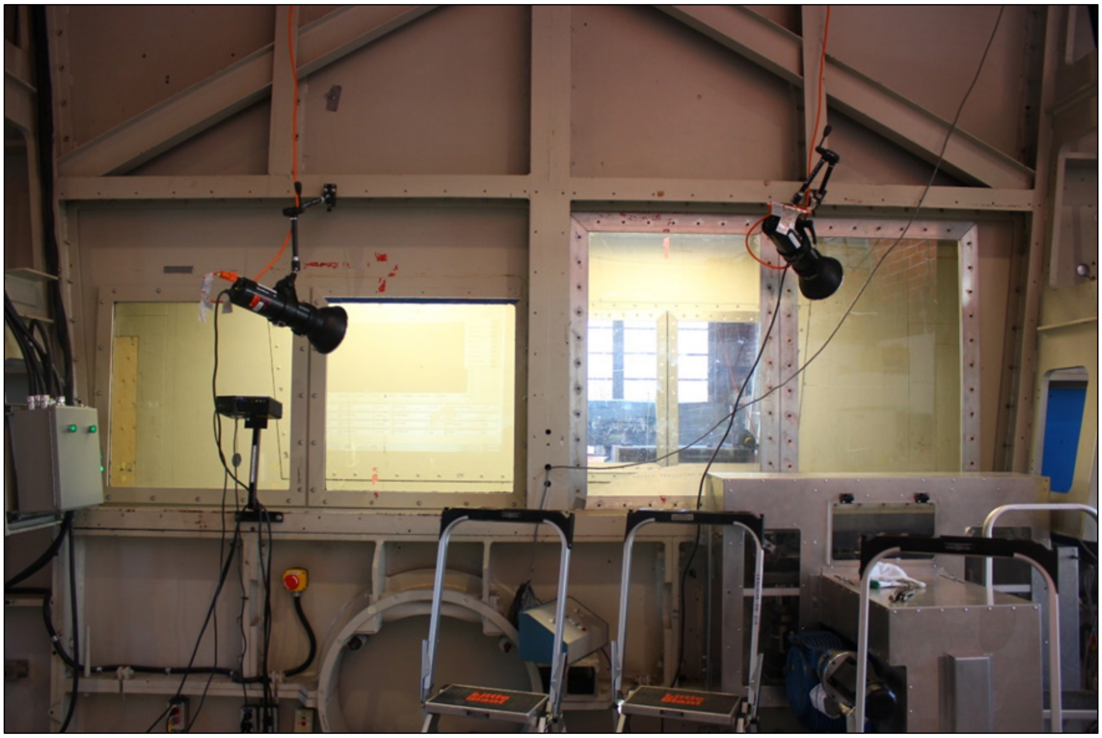

Photo 2.12: Wind Tunnel Setup for Digital Cameras

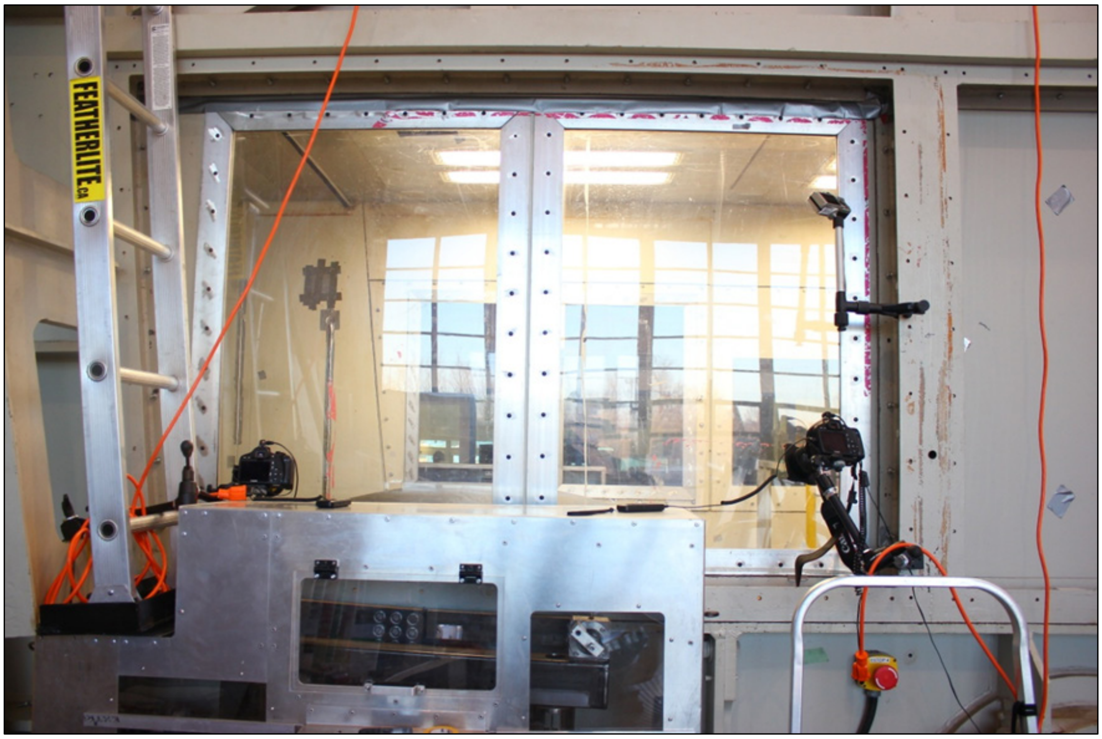

Photo 2.13: Osmo® Video Camera Installed on Wall of Wind Tunnel

Photo 2.14: Location of Osmo® Video Camera Mounts

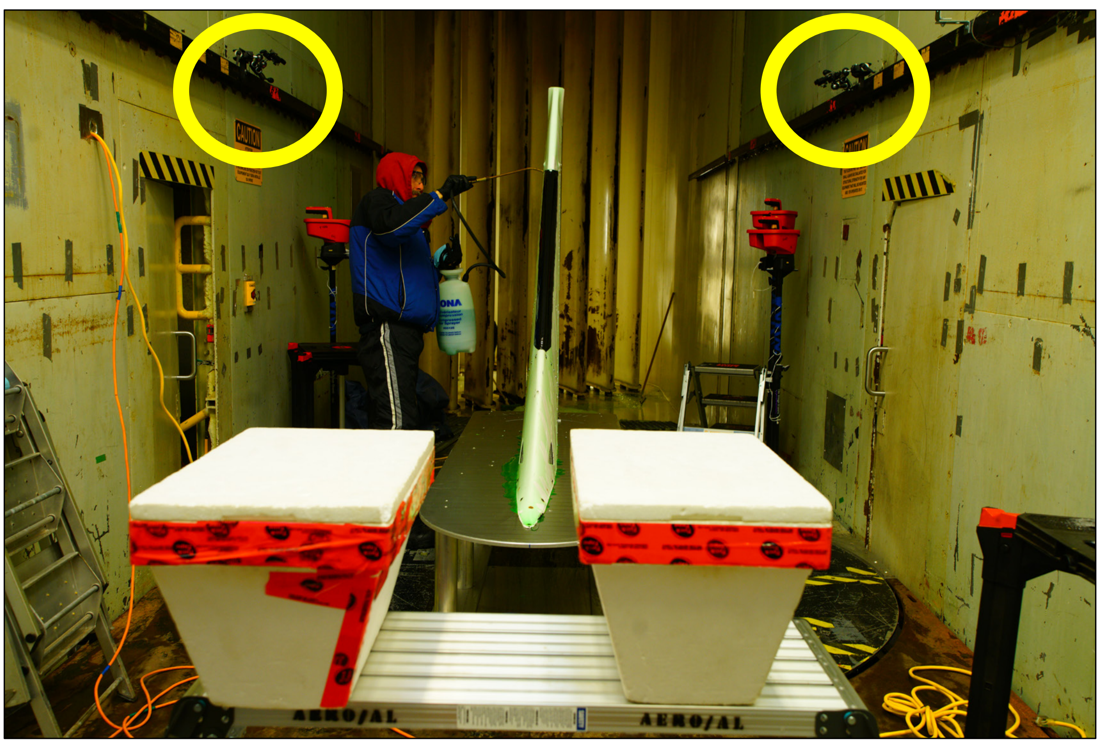

Photo 2.15: Garden Sprayer Hand-Held Wand Applying Fluid

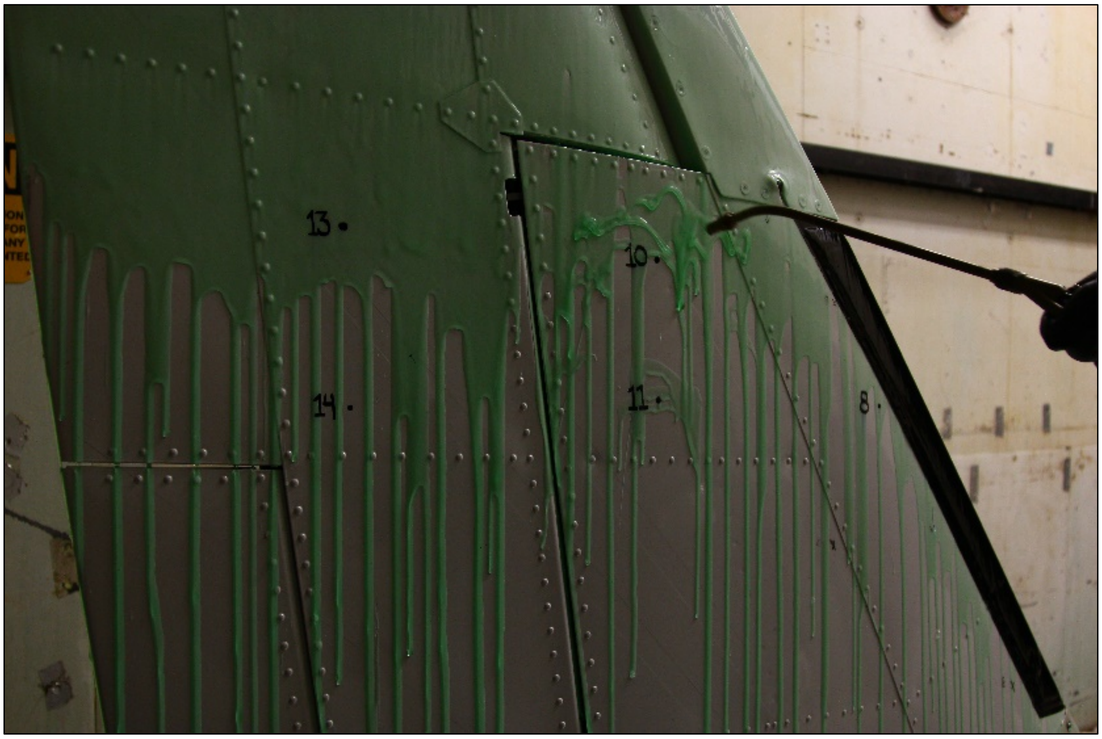

Photo 2.16: 2019-20 Research Team

Photo 2.17: Brookfield Digital Viscometer Model DV-1+

Photo 2.18: Stony Brook PDVdi-120 Falling Ball Viscometer

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3. FULL-SCALE DATA COLLECTED

3.1 Test Log

A detailed log of the tests conducted in the NRC IWT during the winter of 2019-20 is included in Table 3.1. 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 Table 3.1.

Test #:	Exclusive number identifying each test run.
Date:	Date when the test was conducted.
Fluid Name:	Aircraft anti-icing fluid used during the test.
Sideslip Β:	The effective sideslip angle of the model during the test, ranging from +7.5° to -7.5°.
Rudder Deflection δ_r:	The rudder deflection angle during the test, ranging from +30° to -30°.
Speed (kts):	Maximum speed obtained during simulated takeoff run, recorded in knots.
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.*
OAT Before Test (°C):	OAT recorded just before the start of the simulated takeoff test, measured in degrees Celsius. *Note: This is not an important parameter as "Tunnel Temp. Before Test" was used as the actual test temperature for analysis.*
Precipitation Rate (Type: [g/dm²/h]):	Simulated freezing precipitation rate (or combination of different precipitation rates); "-" indicates that no precipitation was applied.

Exposure Time:	Simulated precipitation period, recorded in minutes.

Visual contamination ratings were typically reported as the average of the three observer ratings and rounded to the nearest decimal. The visual contamination rating system used a scale from 1 to 5 to evaluate the level of contamination present.

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.

The visual contamination ratings are described below.

Port Visual Contamination Rating Before Takeoff (LE, TE, Rudder):	Visual contamination rating determined before the start of the simulated takeoff.
STBD Visual Contamination Rating Before Takeoff (LE, TE, Rudder):	Visual contamination rating determined before the start of the simulated takeoff.
Port Visual Contamination Rating at Rotation (LE, TE, Rudder):	Visual contamination rating determined at the time of rotation.
STBD Visual Contamination Rating at Rotation (LE, TE, Rudder):	Visual contamination rating determined at the time of rotation.
Port Visual Contamination Rating After Takeoff (LE, TE, Rudder):	Visual contamination rating determined at the end of the test.
STBD Visual Contamination Rating After Takeoff (LE, TE, Rudder):	Visual contamination rating determined at the end of the test.

Table 3.1: Test Log

Test (#)	Date	Fluid Name	Sideslip B (°)	Rudder Deflection δ_r (°)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Port Visual Rating Before Takeoff	Port Visual Rating at Rotation	Port Visual Rating After Takeoff	STBD Visual Rating Before Takeoff	STBD Visual Rating at Rotation	STBD Visual Rating After Takeoff
1	3-Feb-20	None	0, -2.5, -5, -7.5, +7.5	0	100	6.3	-3.5	-	-	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
2	3-Feb-20	None	0, -2.5, -5, -7.5, +7.5	-30	100	-3.7	-3.5	-	-	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
3	3-Feb-20	None	0, -2.5, -5, -7.5, +7.5	-20	100	3.15	-3.3	-	-	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
4	3-Feb-20	None	0, -2.5, -5, -7.5, +7.5	-10	100	1.93	0.8	-	-	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
5	3-Feb-20	None	0, -2.5, -5, -7.5, +7.5	-15	100	0.3	0.5	-	-	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
6	3-Feb-20	None	0, -2.5, -5, -7.5, +7.5	-12.5	100	0.3	1.0	-	-	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
7	3-Feb-20	Polar Guard Advance	0	0	100	0.96	-0.6	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
8	4-Feb-20	Polar Guard Advance	0	-10	100	0.13	-1.2	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
9	4-Feb-20	Polar Guard Advance	0	-30	100	-0.54	-1.5	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
10	4-Feb-20	Polar Guard Advance	-7.5	-30	100	-0.69	-1.6	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
11	4-Feb-20	Polar Guard Advance	0	-10	100	-1.07	-2.1	SN: 25	20	4, 4, 4	1, 1, 1	1, 1, 1	4, 4, 4	1, 1, 1	1, 1, 1

Table 3.1: Test Log (cont'd)

Test #	Date	Fluid Name	Sideslip Β (°)	Rudder Deflection δ_r (°)	Speed Kts	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Port Visual Rating Before Takeoff	Port Visual Rating at Rotation	Port Visual Rating After Takeoff	STBD Visual Rating Before Takeoff	STBD Visual Rating at Rotation	STBD Visual Rating After Takeoff
12	4-Feb-20	Polar Guard Advance	0	-10	100	-1.52	-3.1	SN: 25	75	4, 4, 4	1.3, 2.7, 2.7	1, 2.7, 2.7	4, 4, 4	1.3, 2.7, 2.7	1, 2.7, 2.7
13	4-Feb-20	None	0	-10	100	-1.64	0.5	SN: 25	10	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
14	4-Feb-20	Dow Type I PG	0	-10	100	-1.3	0	SN: 25	10	3.5, 3.5, 3.5	1.5, 1.5, 1.5	3, 3, 3	3.5, 3.5, 3.5	1.5, 1.5, 1.5	3, 3, 3
15	4-Feb-20	Dow Type I PG	0	-10	100	-2.19	-0.4	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
16	5-Feb-20	Dow Type I PG	0	-10	100	-2.82	-1.8	SN: 25	40	4.3, 4.3, 4.3	4.5, 4.5, 4.5	4.5, 4.5, 4.5	4.3, 4.3, 4.3	4.5, 4.5, 4.5	4.5, 4.5, 4.5
17	5-Feb-20	Dow Type I PG	0, -2.5, -5, -7.5, +7.5	-30	100	-3.61	-2.1	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
18	5-Feb-20	EG106	0	-10	100	-6.61	-8	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
19	5-Feb-20	EG106	0	-10	100	-6.84	-8.7	SN: 25	35	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4
20	5-Feb-20	Polar Guard Advance	0	-10	100	-7.65	-9	-	0	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a
21	6-Feb-20	Polar Guard Advance	0	-10	100	-7.35	-9	SN: 25	45	3.5, 3.5, 3.5	3, 3.5, 3.5	2.5, 3.5, 3.5	3.5, 3.5, 3.5	3, 3.5, 3.5	2.5, 3.5, 3.5
22	6-Feb-20	Polar Guard Advance	0	-10	100	-7.61	-9.1	ZR: 25	35	5, 5, 5	5, 5, 5	5, 5, 5	5, 5, 5	5, 5, 5	5, 5, 5

Table 3.1: Test Log (cont'd)

Test #	Date	Fluid Name	Sideslip β (°)	Rudder Deflection δ_r (°)	Speed Kts	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Port Visual Rating Before Takeoff	Port Visual Rating at Rotation	Port Visual Rating After Takeoff	STBD Visual Rating Before Takeoff	STBD Visual Rating at Rotation	STBD Visual Rating After Takeoff
23	6-Feb-20	Polar Guard Advance	0	-10	100	-8.22	-9.5	ZR: 25	20	4, 4, 4	4.5, 4.5, 4.5	4.5, 4.5, 4.5	4, 4, 4	4.5, 4.5, 4.5	4.5, 4.5, 4.5
24	6-Feb-20	Polar Guard Advance	0	-10	100	-8.43	-9.5	ZR: 25	15	1.5, 2.5, 2	1.5, 3, 1.5	1.5, 3, 1.5	1.5, 3, 2.5	1.5, 3, 1.5	1.5, 3, 1.5
25	6-Feb-20	Dow Type I PG	0	-10	100	-8.18	-9.4	SN: 25	5	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4	4, 4, 4
26	6-Feb-20	None	0	-10	100	n/a	-9.4	SN: 25	10	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a, n/a	n/a, n/a,
27	6-Feb-20	EG106	0	-10	100	-3.44	-4.4	SN: 25	40	4, 4, 4	2.5, 2.5, 3	2.5, 2.5, 3	4, 4, 4	2.5, 2.5, 3	2.5, 2.5, 3
28	6-Feb-20	Polar Guard Advance	0	0	100	-3.14	-4.4	SN: 25	60	4, 4, 4	2, 3.5, 3.5	2.5, 3.5, 3.5	4, 4, 4	2.5, 3.5, 3.5	2.5, 3.5, 3.5
29	7-Feb-20	Polar Guard Advance	-7.5	-30	100	-4.1	-4.7	SN: 25	60	4, 3.5, 4	1.5, 3, 3	1.5, 3, 3	4, 3.5, 4	2.5, 2.5, 2.5	2.5, 2.5, 2.5
30	7-Feb-20	Polar Guard Advance	0	-10	100	-4.66	-4.8	IP: 75	15	2, 2, 2	1, 1, 1	1, 1, 1	2, 2, 2	1, 1, 1	1, 1, 1

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4. CALIBRATION AND VALIDATION OF PROCEDURES

The following subsections describe the activities related to the calibration and validation of the testing procedures.

4.1 Safety Checks and Shakedown Runs

The vertical stabilizer model was taken from a salvaged aircraft. It needed to be verified that the model would safely withstand the air speeds in the wind tunnel. Several tests were done prior to the start of the testing program for this purpose, and additional tests were done on the first day of testing.

It was observed during the first day of testing that the mounting system used to attach the model to the splitter plate was slipping. This was observed while performing max sideslip and max rudder deflection tests. As a result, testing was stopped to allow for the machine shop to make modifications to the setup to reinforce the mount. Once the modifications were made, the model was stable throughout the testing.

4.2 Fluid Application Procedures

The vertical orientation of the model posed a challenge to fluid application. During typical wind tunnel testing, the fluid can be poured onto the wing model using 2 L pouring jugs. For the vertical stabilizer model, pouring fluid generated a significant amount of waste as most of the fluid would immediately drip down to the ground. Fluid spreaders were also ineffective at properly applying fluid to the vertical surfaces.

A garden sprayer was ultimately used to apply the fluid. The atomizing nozzle was removed to prevent shearing of the fluid. The hand-held wand allowed personnel to apply fluid to the model with minimal waste. The fluid application procedures were refined on the first day of testing.

4.3 Precipitation Application Procedures

Those dispensers used for the ice pellet allowance time research were also used for this vertical stabilizer research. A separate calibration procedure was performed with the dispensers to determine the vertical footprint of the dispensers when dispersing snow, the details of which can be found in the procedure included in Appendix B.

The vertical stabilizer was mounted on a splitter plate that elevated the model off the ground. As such, the team needed to devise a ladder system to allow the staff to safely and properly dispense snow to the top of the model. Several different ladders and configurations were tested before proceeding to ensure a safe and efficient setup that could be easily mounted and torn down. The setup was finalized on the first day of testing.

4.4 Viewing Platforms and Live Video Feeds

Viewing windows are located on both sides of the wind tunnel. Typically, the test team observers would set up on the port side of the vertical stabilizer model due to the location of the viewing platforms. To obtain a view of both sides of the model, WiFi Osmo video cameras were utilized with iPads® to allow for live viewing of both sides of the model during each test. In addition, the effective sideslip and rudder deflection angles were configured (whenever possible) to allow the best viewing angle from the port side with the viewing platform. The setup was finalized on the first day of testing.

4.5 General Observation

The IWT provided an effective setting to carry out the anticipated research, accommodating the installation of an appropriate size model and allowing the application of fluids.

5. DRY WING TESTING AND TUFT VISUALIZATION

The following subsections describe activities related to the calibration and validation of the testing procedures.

5.1 Dry Wing Testing

The vertical stabilizer model was not equipped with any sensors measuring loads or aerodynamic forces. As such, the dry wing testing was limited to the shakedown runs done as part of the initial calibration and validation tests. If, in the future, this model (or another model) is equipped with such load sensors, more extensive dry wing testing would be recommended to explore the effect of sideslip and rudder deflection angles on the aerodynamic forces recorded.

5.2 Tuft Visualization

The tuft testing aimed to evaluate the aerodynamic flow over the surface of the vertical stabilizer model. The objective was to identify the different patterns of airflow that would present themselves with different configurations while changing the effective sideslip angle (Β) and rudder deflection (δ_r) angles of the model. The tufts, which were pieces of red yarn attached to the model using speed tape, were used for flow visualization (see Photo 5.1). The motion of the tufts would help identify the flow patterns (boundary layer separation, reattachment, et cetera) on areas of the tailfin. For the purpose of this testing, the definitions below were used.

1. <u>Laminar flow:</u> All tufts are perfectly straight with no movement indicating that the airflow is perfectly attached. Note: This is not a realistic scenario; aerodynamicists strive for this perfection, but it is not feasible in operations.
2. <u>Attached/turbulent:</u> Most of the tufts are straight, but you have areas where some tufts will "shimmy" indicating slight separation.
3. <u>Separated:</u> The tufts move around erratically indicating a separation of flow and significant turbulent flow.

During testing, the rudder deflection was fixed for each run; however, the effective sideslip could be changed dynamically by rotating the mechanical turntable that supported the model. The tuft visualization testing targeted the following rudder deflection configurations during six different test runs: 0°, -10°, -12.5°, -15°, -20°, and -30°. During those same test runs, the effective sideslip was changed dynamically once the tunnel reached the 100-knot speed, and therefore the model was moved through 0°, -2.5°, -5°, -7.5°, and +7.5° effective sideslip angles during each of those test runs. It should be noted that the aerodynamic effects were assumed to be symmetric; consequently, the angle selection was biased towards the port side, which allowed the best visual observations from the viewing platform.

The limits of the model configuration were $B=0°$, $\delta_r=0°$ (the neutral configuration) and $B=-7.5°$, $\delta_r=30°$ (full sideslip and full rudder deflection). Photo 5.2 and Photo 5.3 represent both configurations during the test run. The photos, respectively, demonstrate examples of attached/turbulent airflow on the main element and the rudder, as well as attached/turbulent airflow on the main element and separated flow on the rudder. The objective of the tuft visualization test matrix was to determine at which point the flow began to separate. Through the testing performed, the $B=0°$, $\delta_r=-12.5°$ configuration was found to be the point at which separation began on the rudder. Table 5.1 provides a summary of the results observed.

Through discussions with TC, the FAA, NASA, Boeing, and APS, it was decided that $B=0°$, $\delta_r=-10°$ (see Photo 5.4) would be selected as the "basic" or "standard" configuration for testing to "bound" the ideal flow conditions. Through this configuration, any separation or excessively turbulent airflow could be attributed to any externalities from test variables such as fluid and contamination. The effective sideslip remained 0° intentionally to reduce the variables and because, in basic principles, modifying it would only amplify or reduce the effect of the rudder deflection, so there was no need at this early stage in research to further complicate the protocol.

Table 5.1: Summary of Aerodynamic Effects Visualized with Varying Configurations

Effective Sideslip B	Rudder Deflection δ_r	Flow Characteristics
0°	0°	Flow was attached with little "shimmy."
-7.5°	-30°	Flow completely separated on the rudder on the suction side.
0°	-12.5°	Flow separation begins on the rudder on the suction side.
0°	***-10°***	***Selected as the limit of where flow remains attached.***

Based on the configuration selected, the basic research protocol (which could be modified based on objective) was the following:

- Configure effective sideslip angle to 0º;
- Configure rudder deflection angle to -10º;
- Apply fluid and contamination;
- Accelerate to 100 knots; and
- Evaluate flow-off and compare to dry or baseline tests.

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Photo 5.1: Tufts Attached to the Vertical Stabilizer Model Using Speed Tape

Photo 5.2: Attached/Turbulent Airflow

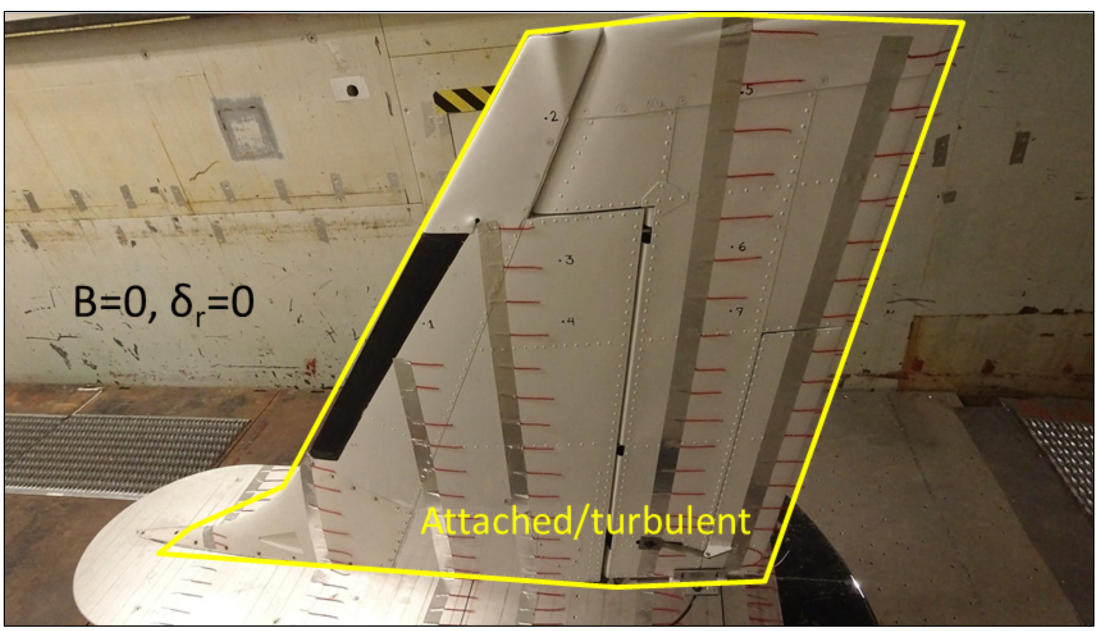

Photo 5.3: Attached/Turbulent Airflow on the Main Element and Separated Flow on the Rudder

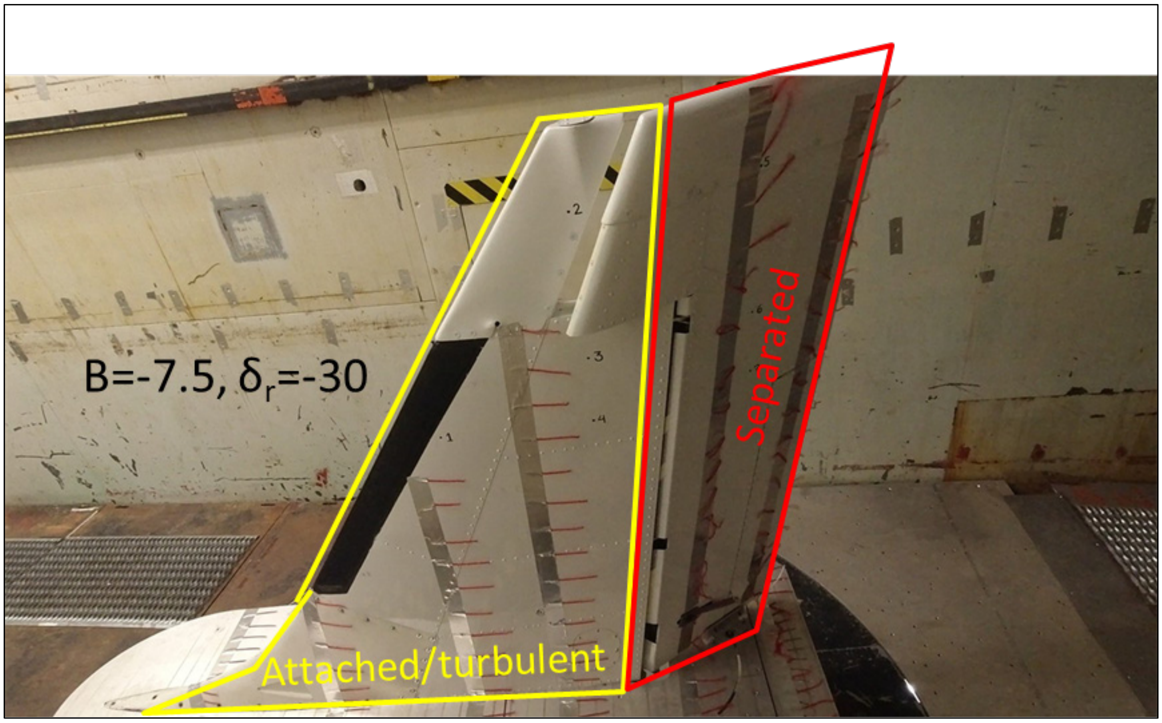

Photo 5.4: Limit of Attached/Turbulent Airflow

6. FLUID TESTING AND FLOW-OFF CHARACTERIZATION

This section describes the activities related to the fluid testing and flow-off characterization.

6.1 Overview of Testing Strategy

The vertical stabilizer testing was preliminary and limited; therefore, tests to be performed were strategically chosen based on their likeliness to provide the most informative data. This testing was primarily conducted with Type IV PG based fluid to get a more wholistic view of the expected performance in varying conditions. Complementary testing was then conducted with Type IV ethylene glycol (EG) fluid and Type I PG fluid in specific conditions to evaluate the similarities or differences of the fluid types.

The testing plan for the fluid testing and flow-off characterization could be summarized by the following major categories, the titles of which correspond to the subsections of this chapter.

1. Type IV PG Fluid Testing
   a) Effects of B and δ_r on Fluid Only Flow-Off
   b) Artificial Snow
   c) Simulated Freezing Rain
   d) Simulated Ice Pellets
   e) Effects of B and δ_r in Artificial Snow
2. Type I PG Fluid Testing
   a) Fluid Only
   b) Artificial Snow
3. Type IV EG Fluid Testing
   a) Fluid Only
   b) Artificial Snow
4. Snow on a Dry Wing Testing
   a) Warmer Temperatures
   b) Colder Temperatures

6.2 Type IV PG Fluid Testing

The following subsections provide a summary of the Type IV PG fluid testing.

6.2.1 Effects of ß and δ_r on Fluid Only Flow-Off

Four comparative Type IV PG fluid only tests (#7, #8, #9, and #10) were conducted with an approximate tunnel temperature of -1˚C, whereby the only variables changed were the ß and δ_r. Four different configurations of ß and δ_r were explored:

1. Test #7: ß=0°, δ_r=0° (a zero crosswind scenario);
2. Test #8: ß=0°, δ_r=-10° (selected as the "basic" configuration for most tests);
3. Test #9: ß=0°, δ_r=-30° (a full rudder configuration); and
4. Test #10: ß=-7.5°, δ_r=-30° (a max crosswind scenario).

The test results demonstrated that the fluid was generally well removed from the forward part (main element) of the vertical stabilizer; however, some fluid remained on the rudder on the suction side. The residual fluid observed increased as the ß and δ_r increased from a zero crosswind scenario to a max crosswind scenario. The locations of the residual fluid were consistent with the results observed during the tuft tests that demonstrated turbulent flow or flow separation in those same areas. Photo 6.1 provides a photographic summary of these tests.

6.2.2 Artificial Snow

Two comparative Type IV PG tests (#11 and #12) were conducted at an approximate tunnel temperature of -1°C with the model configured to ß=0° and δ_r=-10°. At the -1°C temperature, the HOT estimated from the Type IV HOT Guidelines was approximately 75 minutes.

In the first test (#11), the model was exposed to artificial snow precipitation until approximately 10 percent of the vertical stabilizer surface was failed; this occurred at the 20-minute mark, at which point the exposure was stopped. In the second test (#12), the precipitation continued to the full 75-minute Type IV HOT, and the model was 100 percent failed by the end of exposure.

The flow-off performance was much different in both scenarios. In the first test, the fluid was easily removed, and the failed portions also sheared off. Overall, the flow-off may have improved compared to fluid only test #8 (see Subsection 6.2.1), as there was less residual fluid remaining on the model afterwards. In the second test, slushy contamination remained on various areas of the tailfin, especially in the areas where the fluid had thinned out or dried out during the contamination period. The contamination was not adhered (could be easily moved around with a finger), but neither was it removed by the shear forces. Photo 6.2 provides a photographic summary of these tests.

A repeat of the warmer temperature tests was done at colder temperatures. One Type IV PG test (#21) was conducted at an approximate tunnel temperature of -7˚C with the model configured to $B=0°$ and $\delta_r=-10°$. At the -7°C temperature, the Type IV HOT from the HOT Guidelines was estimated to be approximately 45 minutes. A fluid only test (#20) was also conducted to get a baseline for the expected flow-off performance of the fluid at this temperature.

In test #21, precipitation continued to the full 45-minute Type IV HOT and the model was 100 percent failed by the end of exposure. Following the wind tunnel run, slushy contamination remained on various areas of the tailfin, especially in the areas where the fluid had thinned out or dried out during the contamination period. The remaining slushy contamination was thicker than what was observed at the warmer temperatures in test #12. A similar result was seen with fluid only test #20, which demonstrated a thicker residual fluid layer remaining after the test compared to warmer temperature test #8 (see Subsection 6.2.1). Photo 6.3 provides a photographic summary of these tests.

6.2.3 Simulated Freezing Rain

Three comparative Type IV PG tests (#22, #23, and #24) were conducted at an approximate tunnel temperature of -8°C with the model configured to $B=0°$ and $\delta_r=-10°$. At the -8°C temperature, the Type IV HOT from the HOT Guidelines was estimated to be approximately 35 minutes.

During test #24, the model was exposed to simulated freezing rain until approximately 10 percent of the vertical stabilizer surface was failed with adhered contamination; this occurred at the 15-minute mark, at which point the exposure was stopped. During test #22, precipitation continued to the full 35-minute Type IV HOT, and the model was 100 percent failed by the end of exposure with adhered contamination present.

The flow-off performance was much different in both scenarios. In the first test, the fluid was generally well removed (even the adhered contamination) with few spots of contamination remaining on the wing after the test. In the second test, adhered contamination remained on various areas of the tailfin. Photo 6.4 provides a photographic summary of these tests.

A third test (#23) was also conducted with a 20-minute exposure time, and the results were slightly worse than test #24 with a 15-minute exposure time.

6.2.4 Simulated Ice Pellets

One Type IV PG test (#30) was conducted at an approximate tunnel temperature of -5°C with the model configured to $B=0°$ and $\delta_r=-10°$. At the -5°C temperature, the moderate ice pellet allowance time for Type IV PG fluids was estimated to be 15 minutes.

During test #30, the model was exposed to moderate ice pellet conditions for the full 15-minute allowance time. Contamination was present at the end of the exposure time, but the majority of the ice pellets slid down or bounced off the surface during application.

During the wind tunnel run, the fluid and contamination were generally well removed, and the condition of the model at the end of the test looked marginally better compared to the snow conditions, as there was less slushy residual left over. Photo 6.5 provides a photographic summary of this test.

6.2.5 Effects of B and δ_r in Artificial Snow

To evaluate the effects of B and δ_r on fluid flow-off, two comparative tests (#28 and #29) were conducted in artificial snow. The two tests were conducted at approximately -4°C and both exposed the model to 60 minutes of artificial moderate snow, which is the estimated Type IV HOT at this temperature. In both cases, the wing was 100 percent failed by the end of the exposure time to snow.

In the first test (#28), the model was configured to $B=0°$ and $\delta_r=0°$ and simulated a zero crosswind takeoff. In the second test (#29), the model was configured to $B=-7.5°$ and $\delta_r=-30°$ and simulated a max crosswind takeoff.

Due to the high level of contamination and thick slush at the start of the test, the flow-off was poor in both tests. As a result, the difference in flow-off due to the B and δ_r configuration was not apparent. Based on the tuft testing and fluid only testing, it would be expected that the flow-off would be worse for $B=-7.5°$, $\delta_r=-30°$ based on fluid and tuft tests, but because slush was so thick and difficult to flow-off, no noticeable differences were observed. If future testing is planned, this test should be repeated at a lower level of contamination to better understand the effect. Photo 6.6 provides a photographic summary of these tests.

6.3 Type I PG Fluid Testing

The following subsections provide a summary of the Type I PG fluid testing.

6.3.1 Fluid Only Testing

One fluid only test (#15) was conducted with the Type I PG fluid, and the results were compared to the Type IV PG result (test #8). Test #15 was conducted with a tunnel temperature of approximately -2°C with the model configured to ß=0° and δ_r=-10°. The test results demonstrated a thin residual fluid layer at the end of the run, which was generally clean. At the end of the test, more Type I fluid was present on the rudder compared to the main element, a result similar to the Type IV test and consistent with the observations from the tuft tests. Photo 6.7 provides a photographic summary of this test.

6.3.2 Artificial Snow

Two comparative Type I PG tests (#14 and #16) were conducted in moderate snow at an approximate tunnel temperature of -2°C with the model configured to ß=0° and δ_r=-10°. At the -2°C temperature, the Type I HOT from the HOT Guidelines was estimated to be approximately 10 minutes, and the Type IV HOT was estimated to be approximately 40 minutes.

In the first test (#14), the model was exposed to artificial snow precipitation for 10 minutes, based on the Type I HOT. At the end of the 10-minute period, the model had failed fluid on about 50 percent of the surface. In the second test (#16), the model was run to the Type IV 40-minute HOT (simulating a Type I tail, Type IV wing de/anti-icing operation), and the model was 100 percent failed by the end of the 40-minute exposure. For both tests, the contamination on the model was mostly slush and was not adhered to the surface (could be easily moved around with a finger).

The flow-off performance was much different in both scenarios. In the first test (#14), the fluid was generally removed, and most of the failed portions also sheared off; however, some contamination was still present on the model at the end of the test. In the second test (#16), significant slushy contamination remained on various areas of the wing, including the leading edge, which is especially important from an aerodynamics perspective. Wind tunnel test #16 was re-run as test #17, leaving the tailfin untouched with δ_r=-30° and incrementally changing ß from 0° to -7.5° and +7.5° to see if the flow-off would change based on the different configurations.

However, very little contamination was moved at all. Photo 6.8 provides a photographic summary of these tests.

A repeat of the warmer temperature test was done at colder temperatures. One Type I PG test (#25) was conducted at an approximate tunnel temperature of -8°C with the model configured to $B=0°$ and $\delta_r=-10°$. At the -8°C temperature, the Type I HOT from the HOT Guidelines was estimated to be approximately 5 minutes. The test results were similar and slightly worse compared to test #14, as expected due to the colder temperature.

6.4 Type IV EG Fluid

The following subsections provide a summary of the Type IV EG fluid testing.

6.4.1 Fluid Only Testing

One fluid only test (#18) was conducted with the Type IV EG fluid. Test #18 was conducted with a tunnel temperature of approximately -7°C with the model configured to $B=0°$ and $\delta_r=-10°$. Similar to what was observed with the Type IV PG fluid, the test results demonstrated that the fluid was generally well removed from the forward part (main element) of the vertical stabilizer; however, some fluid remained on the rudder on the suction side. The residual fluid was prominent, likely due to the colder temperature tested.

6.4.2 Artificial Snow

One Type IV EG test (#19) was conducted at an approximate tunnel temperature of -7°C with the model configured to $B=0°$ and $\delta_r=-10°$. At the -7°C temperature, the Type IV HOT from the HOT Guidelines was estimated to be approximately 35 minutes. At the end of the 35-minute period, the model was 100 percent failed with slushy contamination. After the wind tunnel test, slushy contamination remained on various areas of the wing, especially in the areas where the fluid had thinned out or dried out during the contamination period. The contamination was not adhered (could be easily moved around with a finger), but neither was it removed by the shear forces.

A second test (#27) was conducted at a warmer temperature of -3°C with the model configured to $B=0°$ and $\delta_r=-10°$. At the -3°C temperature, the Type IV HOT from the HOT Guidelines was estimated to be approximately 40 minutes. At the end of the 40-minute period, the model was again 100 percent failed with slushy contamination. After the wind tunnel test, slushy contamination remained on various areas of the wing, especially in the areas where the fluid had thinned out or dried out during the contamination period. The results were marginally better than the colder test (#19) results. Again, the contamination was not adhered (could be easily moved around with a finger), but neither was it removed by the shear forces.

Both the colder and warmer Type IV EG test results were consistent with the observations made with the Type IV PG fluid.

6.5 Snow on a Dry Wing Testing

Two tests were conducted at a warmer and a colder temperature. The warmer test (#13) was conducted at an approximate tunnel temperature of -2°C with the model configured to $\beta=0°$ and $\delta_r=-10°$. The colder test (#26) was conducted at an approximate tunnel temperature of -9°C with the model configured to $\beta=0°$ and $\delta_r=-10°$.

During the warmer test, the tailfin surface was slightly above 1°C. The snow turned to slush and stuck to the model. When the wind tunnel was run, the slush quickly froze and was not removed from the model.

During the colder test, the snow remained cold and dry during the application phase. The cold dry snow did not stick to the surface of the model, and at the end of the contamination period, the model was as clean as when it started. Since the model was completely clean, the tunnel was not run.

6.6 Analysis of Peak Contamination Thickness Post-Run

A selection of the tests conducted was further analysed and included in Appendix D. The objective was to determine the max levels of contamination that could be present on the vertical stabilizer, and as such, a selection of the worse case tests was reviewed. The results demonstrated that the thicknesses post-run ranged from 0.8 mm to 5.0 mm. It was observed that the shear forces during the wind tunnel run could cause fluid and contamination to “pile up” increasing the peak thickness.

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Photo 6.1: Type IV PG Fluid – Fluid Only

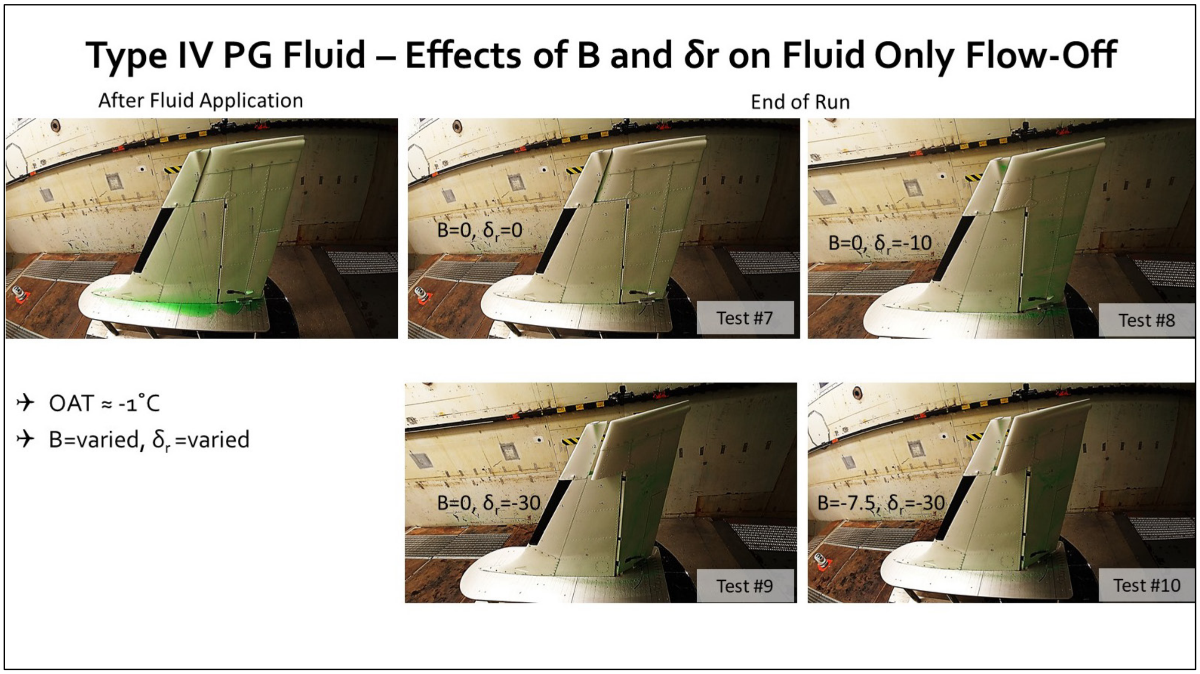

Photo 6.2: Type IV PG Fluid – Artificial Snow at Warmer Temperatures

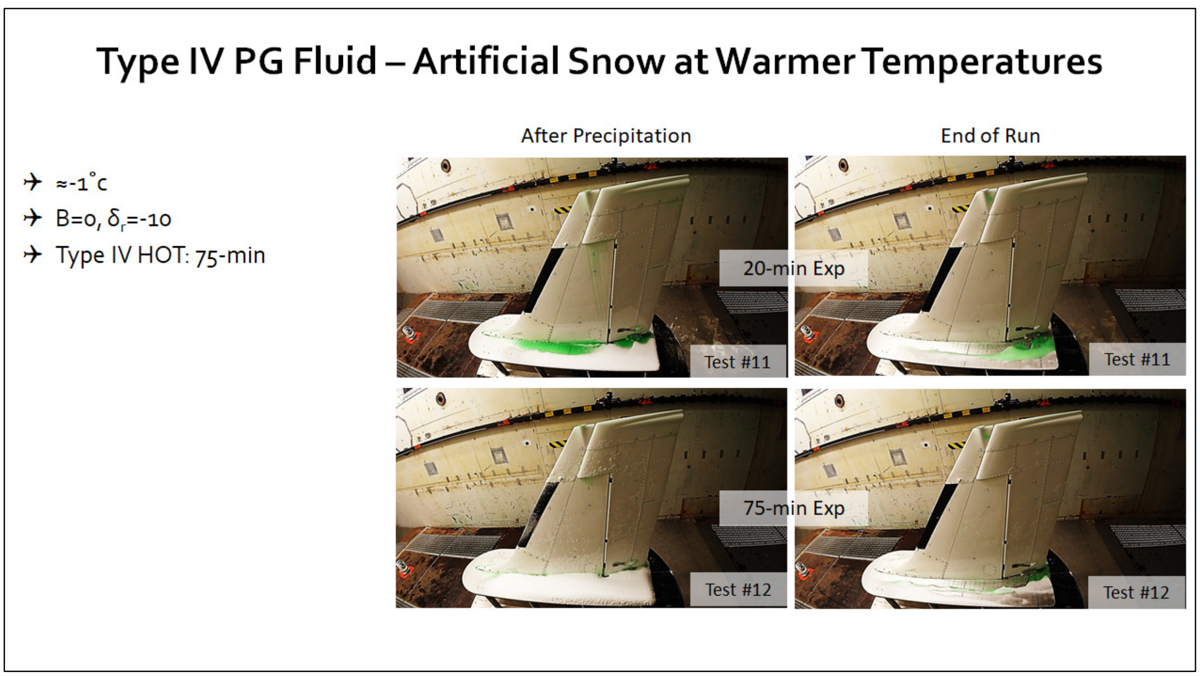

Photo 6.3: Type IV PG Fluid – Fluid Only and Artificial Snow at Colder Temperatures

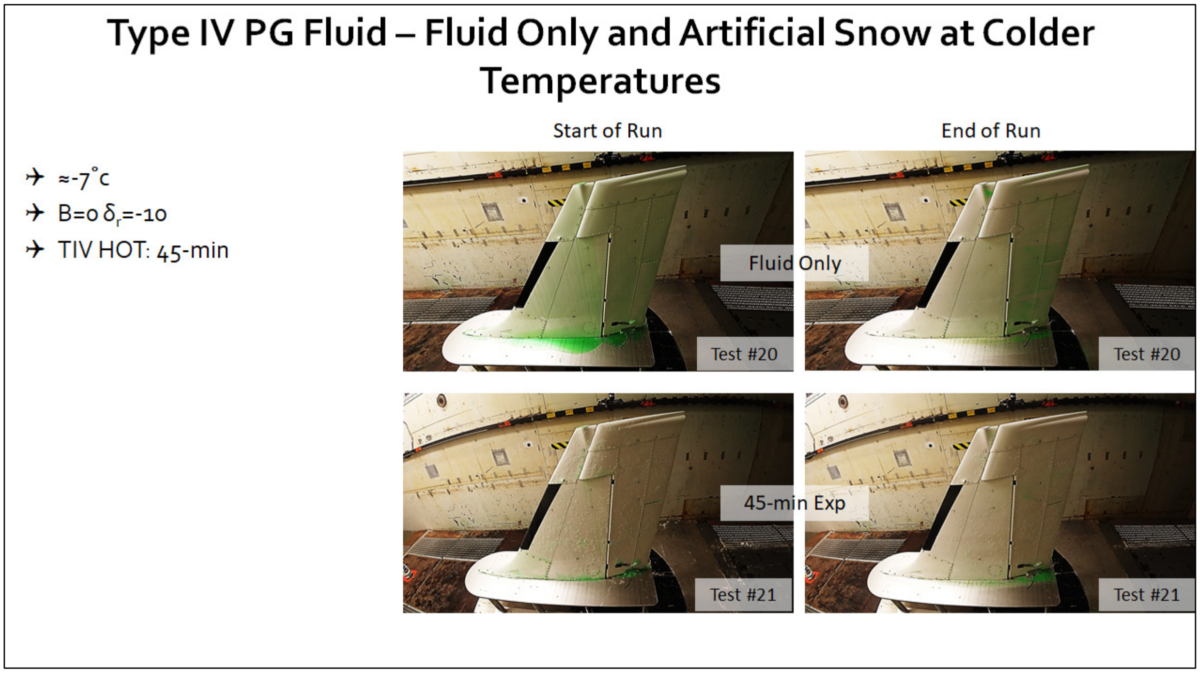

Photo 6.4: Type IV PG Fluid – Simulated Freezing Rain

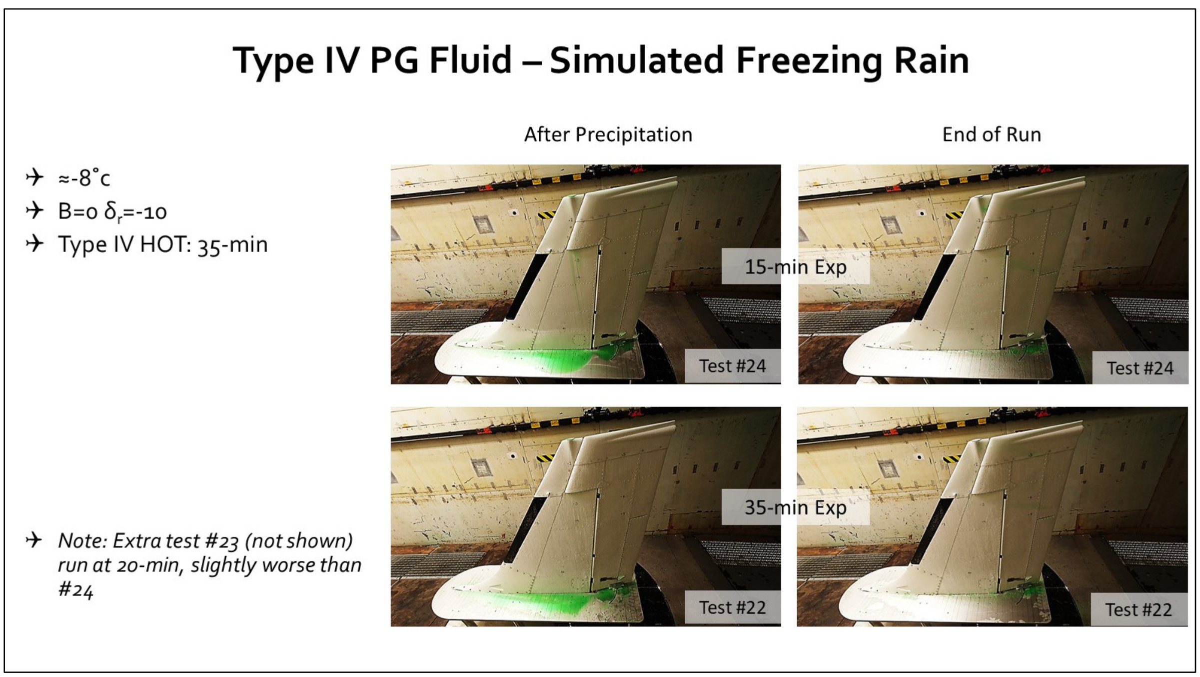

Photo 6.5: Type IV PG Fluid – Ice Pellets

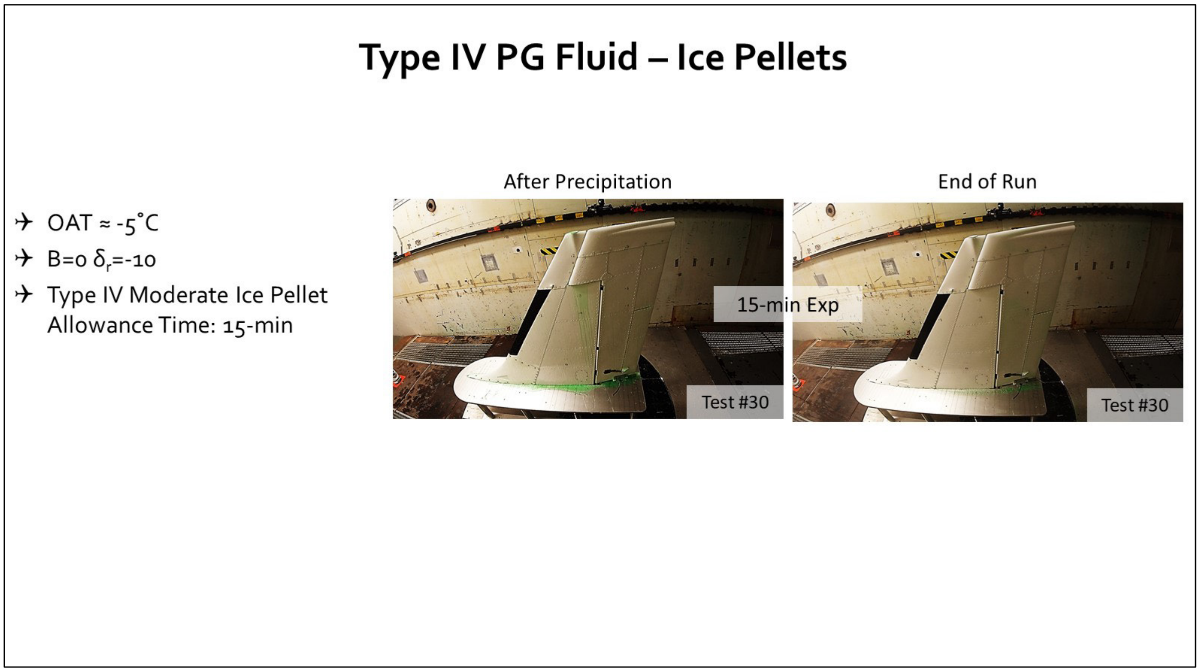

Photo 6.6: Type IV PG Fluid – Artificial Snow and the Effect of B and δ_r

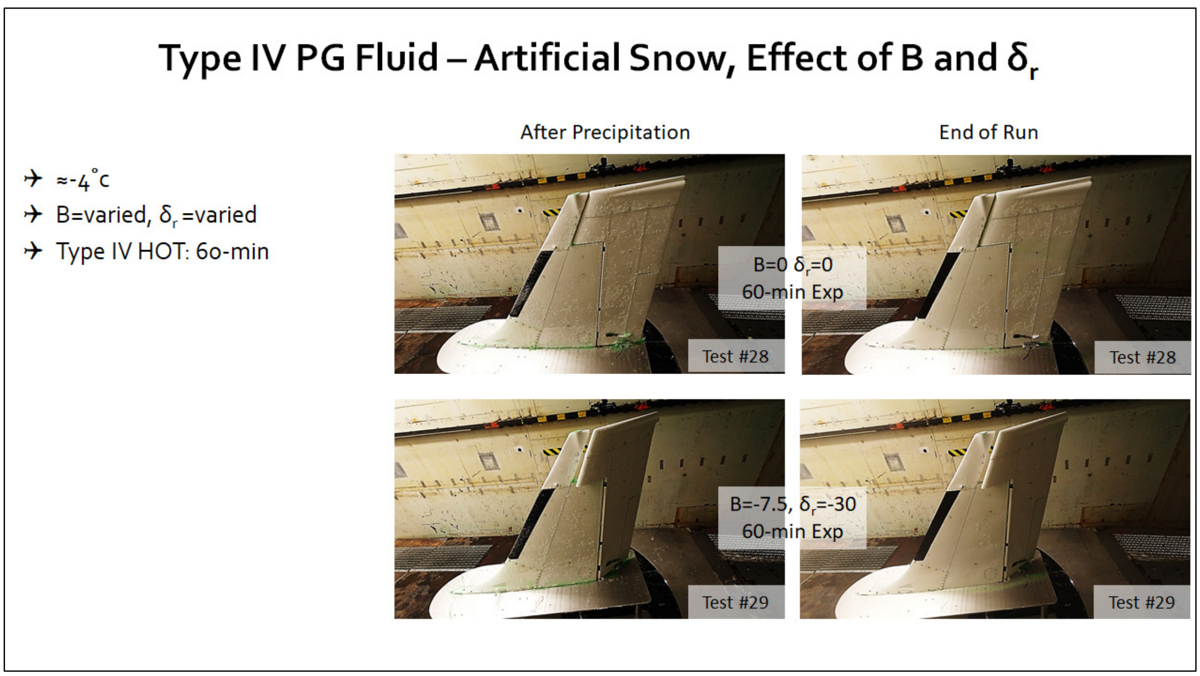

Photo 6.7: Type I PG Fluid – Fluid Only

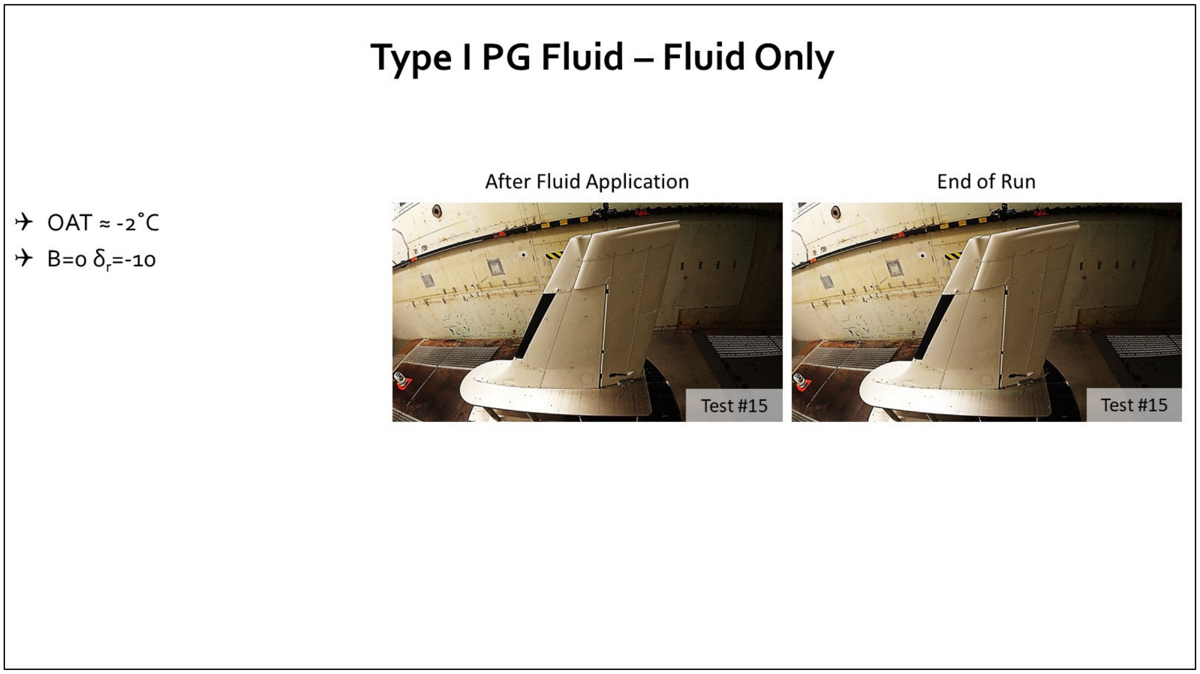

Photo 6.8: Type I PG Fluid – Artificial Snow

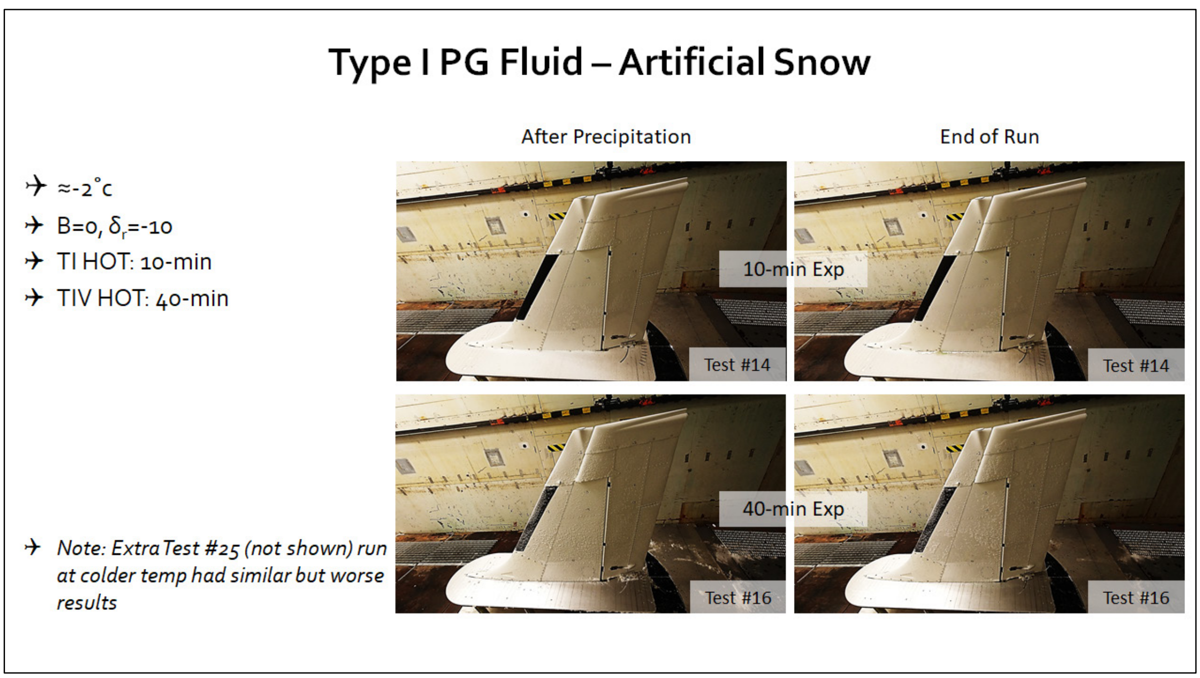

Photo 6.9: Type IV EG Fluid – Fluid Only and Artificial Snow

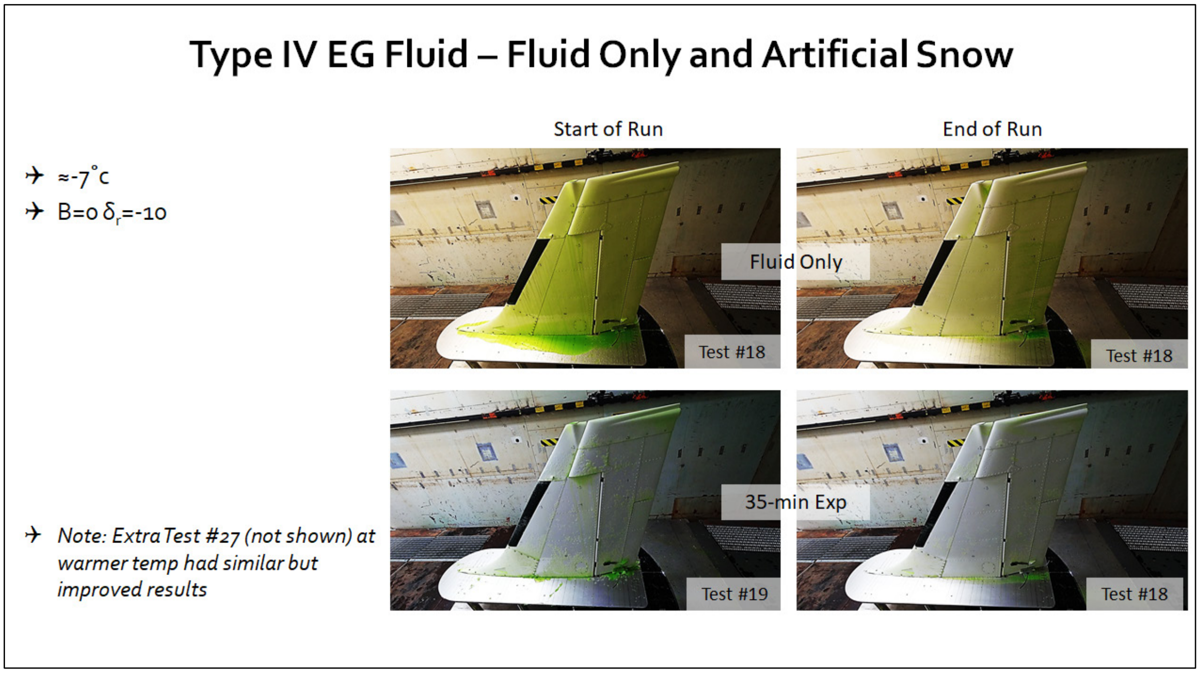

Photo 6.10: Artificial Snow on a Dry Wing

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7. DISCUSSIONS ABOUT A CRM WITH THE G-12 AWG

This section describes the ongoing discussions with the SAE International (SAE) G-12 Aerodynamics Working Group (AWG) in relation to the development of a vertical stabilizer common research model (CRM).

7.1 Industry Participation in Testing

TC and the FAA have encouraged industry participation in the planning and execution of the vertical stabilizer research. The goal has been to ensure relevance and applicability of the testing results obtained. The participation of Boeing in the 2019-20 planning and testing is an example of this, which in turn provided useful industry feedback for the testing program from an airframe manufacturer.

7.2 Ongoing Discussion

The testing results were presented at the SAE G-12 AWG and HOT meeting in May 2020, which was planned for Portland, Oregon, but was held on Webex due to the COVID-19 pandemic. The feedback received from the group was that the testing provided valuable insight into fluid and contamination flow-off from a vertical stabilizer. When discussing future plans for testing, the AWG provided feedback that led to a discussion on and collaborative initiative for developing a vertical stabilizer CRM that would allow for a better extrapolation of results compared to the current Piper Seneca II model. The CRM design would take into consideration commercial aircraft design and test facility limitations.

The AWG is currently hosting ongoing discussions in line with the bi-annual meeting with the goal of obtaining agreement on the design of the CRM. The objective is to reach agreement on a CRM by the end of 2020, so that APS and the NRC, under contract to TC and the FAA, can begin construction in 2021 and conduct testing in the winter of 2021-22.

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8. CONCLUSIONS

These conclusions were derived from the testing conducted during the winter of 2019-20.

8.1 Calibration and Validation of Procedures

The calibration and validation of procedures ensured safety in and repeatability of the testing protocols. The fluid and precipitation application procedures were refined, and the videography and live streaming setup was finalized. The safety checks and shakedown runs quickly identified deficiencies that were rectified, ensuring a safe and successful test campaign. The IWT provided an effective means to carry out the anticipated research accommodating the installation of an appropriately sized model and allowing the application of fluids.

8.2 Dry Wing Testing and Tuft Visualization

The dry wing testing and tuft visualization testing allowed the researchers to gain insight into the aerodynamic behaviour of the vertical stabilizer model in advance of testing with fluids and contamination.

Through the testing performed, the $B=0°$, $\delta_r=-12.5°$ configuration was found to be the point at which separation began on the rudder. Through discussions with TC, the FAA, NASA, Boeing, and APS, $B=0°$, $\delta_r=-10°$ was selected as the basic configuration for testing to “bound” the ideal flow conditions. Through this configuration, any separation or excessively turbulent airflow could be attributed to any externalities from test variables such as fluid and contamination.

8.3 Fluid Testing and Flow-Off Characterization

The vertical stabilizer testing was preliminary and limited; therefore, tests to be performed were strategically chosen based on their likeliness to provide the most informative data. This testing was primarily conducted with Type IV PG based fluid to get a more wholistic view of the expected performance in varying conditions. Complementary testing was conducted with Type IV EG fluid and Type I PG fluid in specific conditions to evaluate the similarities or difference of the fluid types.

The testing demonstrated that fluid and contamination were always present at the end of each test run. The amount of residual increased or decreased based on the severity of the condition tested and was affected by the sideslip and rudder deflection, the level of contamination, the temperature at which the test was run, the type of fluid used, and other factors.

Testing conducted in snow conditions demonstrated that failed fluid, which had a slushy consistency, generally had poor flow-off. In contrast, fluid that was not failed, because it was either clean or limited amounts of contamination were applied, demonstrated adequate flow-off. Freezing rain tests demonstrated similar results as the snow tests but had the added complexity of adherence to the surface, making flow-off more difficult in some conditions. However, ice pellet tests cleaned off well compared to snow, mainly because the pellets may have been bouncing off or sliding down the model, leaving behind a cleaner fluid at takeoff compared to snow.

9. RECOMMENDATIONS

These recommendations were derived from the testing conducted during the winter of 2019-20.

9.1 Development of a Vertical Stabilizer Common Research Model

Discussions should continue with the AWG to agree on the design of the CRM. The objective is to reach agreement on a CRM by the end of 2020 so that APS and the NRC, under contract to TC and the FAA, can begin construction in 2021 and conduct testing in the winter of 2021-22.

9.2 Construction of a New Vertical Stabilizer Model

Construction of a new vertical stabilizer model is expected to begin in 2021, once agreement on a CRM has been reached. It is recommended to begin the planning and construction phases as early in 2021 as possible to ensure completion well in advance of the 2021-22 testing season. Delays due to manufacturing or the COVID-19 pandemic could impact the delivery of the new model, in turn impacting the 2021-22 testing schedule; an early start, therefore, would mitigate this.

9.3 Future Testing with a New Vertical Stabilizer Model

It is recommended that testing in 2021-22 be conducted with a new vertical stabilizer model, ideally based on an agreed-upon CRM. The testing plan should build upon the testing matrix developed for this testing and described in this report, including calibration and validation of procedures, dry wing testing and tuft visualization, and fluid testing and flow-off characterization. Testing should also focus on areas not extensively explored during this preliminary phase of testing, including asymmetric contamination and different fluids.

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REFERENCES

1. APS Aviation Inc., *Aircraft Ground Icing General Research Activities During the 2015-16 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, January 2017, TP 15340E, XX (to be published).

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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.

8. Wind Tunnel Testing – Seneca V-Stab Testing in the Wind Tunnel to Characterize Contaminated Fluid Flow off (5 Days)

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 c), d), e), and f). Tasks a) and b) 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.

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APPENDIX B

PROCEDURE:
WIND TUNNEL TESTING TO EVALUATE CONTAMINATED FLUID FLOW-OFF FROM A VERTICAL STABILIZER WINTER 2019-20

300293

PROCEDURE:

WIND TUNNEL TESTING TO EVALUATE CONTAMINATIED FLUID FLOW-OFF FROM A VERTICAL STABLIZER

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

WIND TUNNEL TESTING TO EVALUATE CONTAMINATIED FLUID FLOW-OFF FROM A VERTICAL STABLIZER

Winter 2019-20

1. BACKGROUND

There is a lack of standardization in the treatment of vertical surfaces. Some operators in the United States and Canada exclude the treatment of vertical surfaces, including the tail, while others only consider treatment in ongoing freezing precipitation. Some reports have also indicated that treatment of the tail may worsen takeoff performance as the anti-icing fluid on the tail may lead to increased accumulation of contamination in active precipitation conditions.

Current Transport Canada (TC) and Federal Aviation Administration (FAA) rules and regulations require that critical surfaces be free of contamination prior to takeoff. The vertical stabilizer is defined as a critical surface by both TC and the FAA. However, from a regulatory implementation and enforcement standpoint, there is currently no standardized guidance that offers inspectors a means to determine if an air operator is complying with operational rules. If current operational rules aim to achieve the clean aircraft concept – which requires the tail to have zero adhering frozen contamination – the question remains: How can this be adequately achieved, or appropriately mitigated by operators, to ensure a satisfactory level of safety?

The research conducted to date has demonstrated the variability in the fluid protection times and characteristics of contamination that can be present on vertical surfaces. Additional research would provide a better understanding of the influence of the different variables including the rate and type of precipitation, along with wind conditions and other meteorological conditions.

The overall aerodynamic impact of the contamination on vertical surfaces has yet to be fully understood. A working group was started in June 2019 which included FAA/TC/NASA/Boeing/APS with the objective to determine the best plan forward for testing in 2019-20 to quantify the aerodynamic impacts of contamination on vertical surfaces. A preliminary plan has been developed to use the TC owned Piper Seneca II tail model and conduct testing at the National Research Council Canada (NRC) Icing Tunnel in Ottawa to qualify the contaminated fluid flow-off characteristics. This data will then be used by aircraft manufacturers to better understand the expected impacts on their specific aircraft types.

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, five days of which are reserved for testing with the vertical stabilizer. The sequence of testing is fixed due to availability of the wind tunnel and NRC personnel required to swap out the aerodynamic models (wing vs. vertical stabilizer).

2.1 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 2.1) will be subjected to a series of tests in the NRC Propulsion Icing Wind Tunnel (PIWT).

Five days of testing are required for the conduct of these tests.

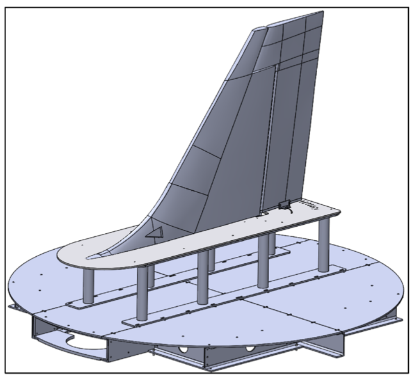


Figure 2.1: Vertical Stabilizer Mounted on Turntable

2.2 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 2.2) 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.

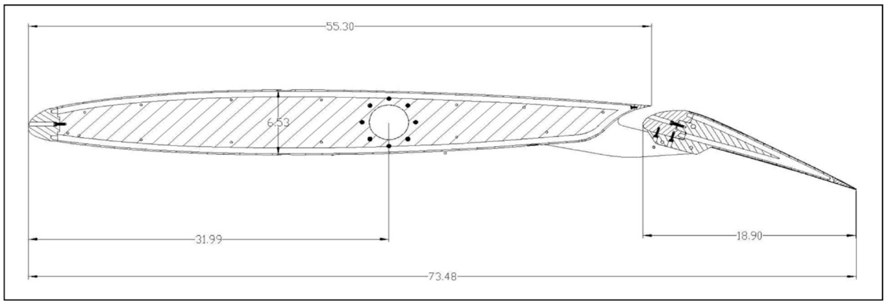


Figure 2.2: Thin High Performance Wing Section

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

2.3 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 objective, a thin high performance wing section (described in Subsection 2.2 and shown in Figure 2.2) 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. The details of these tests will be described in a separate procedure.

2.4 Timing

Five days are required for the "Documentation of Contaminated Fluid Flow-Off on a Vertical Stabilizer " (Subsection 2.1), one and a half days are required for the "Type IV Allowance Time Validation Testing" (Subsection 2.2), and one and a half days are required for the "Type IV Allowance Time Expansion for EG Fluids" (Subsection 2.3), and. This totals to 8 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 21st. Changing over of the aerodynamic models will require some down-time which will occur during the week of January 27th. Testing will resume with the vertical stabilizer model (details described in a separate procedure) for an additional five days of testing starting February 3rd (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/dm²/h;
- R – 25g/dm²/h;
- R – 75g/dm²/h;
- ZD – 5g/dm²/h;
- ZD – 13g/dm²/h;
- SN – 10g/dm²/h;
- SN – 25g/dm²/h;
- IP – 25g/dm²/h; and
- IP – 75g/dm²/h.

WIND TUNNEL TESTING TO EVALUATE CONTAMINATIED FLUID FLOW-OFF FROM A VERTICAL STABLIZER

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

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

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 #4 (V-Stab Testing) is shown in Table 3.2. As 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.

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	1	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 @ LOUT	-	Effect of contamination on fluid performance at LOUT 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**

Table 3.2: Proposed Test Plan for Testing with the V-Stab

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	**Comments**
1	1	None	β=0, 2.5, 5, 7.5, 10°, δ=0°	Any	None	N/A	Use Tufts on both sides for calibration
2	1	None	β=TBD°, δ=TBD°	Any	None	N/A	Use Tufts on both sides for calibration
3	1	None	β=0, 2.5, 5, 7.5, 10°, δ=30°	Any	None	N/A	Use Tufts on both sides for calibration
4	2	None	β=0°, δ=0°	Cold	PG	N/A	Fluid Only
5	2	None	β=0°, δ=0°	Warm	PG	N/A	Fluid Only
6	2	Snow	β=0°, δ=0°	Cold	PG	Symmetric (both sides)	
7	2	Snow	β=0°, δ=0°	Cold	PG	Asymmetric (either side)	
8	2	Snow	β=0°, δ=0°	Warm	PG	Symmetric (both sides)	
9	2	Snow	β=0°, δ=0°	Warm	PG	Asymmetric (either side)	
10	2	None	β=TBD°, δ=TBD°	Cold	PG	N/A	Fluid Only
11	2	None	β=TBD°, δ=TBD°	Warm	PG	N/A	Fluid Only
12	2	Snow	β=TBD°, δ=TBD°	Cold	PG	Symmetric (both sides)	
13	2	Snow	β=TBD°, δ=TBD°	Cold	PG	Asymmetric (Cont. Into Wind)	
14	2	Snow	β=TBD°, δ=TBD°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
15	2	Snow	β=TBD°, δ=TBD°	Warm	PG	Symmetric (both sides)	
16	2	Snow	β=TBD°, δ=TBD°	Warm	PG	Asymmetric (Cont. Into Wind)	
17	2	Snow	β=TBD°, δ=TBD°	Warm	PG	Asymmetric (Cont. Not Into Wind)	
18	2	None	β=7.5°, δ=30°	Cold	PG	N/A	Fluid Only
19	2	None	β=7.5°, δ=30°	Warm	PG	N/A	Fluid Only
20	2	Snow	β=7.5°, δ=30°	Cold	PG	Symmetric (both sides)	
21	2	Snow	β=7.5°, δ=30°	Cold	PG	Asymmetric (Cont. Into Wind)	
22	2	Snow	β=7.5°, δ=30°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
23	2	Snow	β=7.5°, δ=30°	Warm	PG	Symmetric (both sides)	
24	2	Snow	β=7.5°, δ=30°	Warm	PG	Asymmetric (Cont. Into Wind)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
1	1	None	β = 0, 2.5, 5, 7.5, 10°, δ = 0°	Any	None	N/A	Use Tufts on both sides for calibration
2	1	None	β = TBD°, δ = TBD°	Any	None	N/A	Use Tufts on both sides for calibration
3	1	None	β = 0, 2.5, 5, 7.5, 10°, δ = 30°	Any	None	N/A	Use Tufts on both sides for calibration
4	2	None	β = 0°, δ = 0°	Cold	PG	N/A	Fluid Only
5	2	None	β = 0°, δ = 0°	Warm	PG	N/A	Fluid Only
6	2	Snow	β = 0°, δ = 0°	Cold	PG	Symmetric (both sides)	
7	2	Snow	β = 0°, δ = 0°	Cold	PG	Asymmetric (either side)	
8	2	Snow	β = 0°, δ = 0°	Warm	PG	Symmetric (both sides)	
9	2	Snow	β = 0°, δ = 0°	Warm	PG	Asymmetric (either side)	
10	2	None	β = TBD°, δ = TBD°	Cold	PG	N/A	Fluid Only
11	2	None	β = TBD°, δ = TBD°	Warm	PG	N/A	Fluid Only
12	2	Snow	β = TBD°, δ = TBD°	Cold	PG	Symmetric (both sides)	
13	2	Snow	β = TBD°, δ = TBD°	Cold	PG	Asymmetric (Cont. Into Wind)	
14	2	Snow	β = TBD°, δ = TBD°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
15	2	Snow	β = TBD°, δ = TBD°	Warm	PG	Symmetric (both sides)	
16	2	Snow	β = TBD°, δ = TBD°	Warm	PG	Asymmetric (Cont. Into Wind)	
17	2	Snow	β = TBD°, δ = TBD°	Warm	PG	Asymmetric (Cont. Not Into Wind)	
18	2	None	β = 7.5°, δ = 30°	Cold	PG	N/A	Fluid Only
19	2	None	β = 7.5°, δ = 30°	Warm	PG	N/A	Fluid Only
20	2	Snow	β = 7.5°, δ = 30°	Cold	PG	Symmetric (both sides)	
21	2	Snow	β = 7.5°, δ = 30°	Cold	PG	Asymmetric (Cont. Into Wind)	
22	2	Snow	β = 7.5°, δ = 30°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
23	2	Snow	β = 7.5°, δ = 30°	Warm	PG	Symmetric (both sides)	
24	2	Snow	β = 7.5°, δ = 30°	Warm	PG	Asymmetric (Cont. Into Wind)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
25	2	Snow	β = 7.5°, δ = 30°	Warm	PG	Asymmetric (Cont. Not Into Wind)	
26	3	None	β = 0°, δ = 0°	Cold	TI	N/A	Fluid Only
27	3	None	β = 0°, δ = 0°	Warm	TI	N/A	Fluid Only
28	3	Snow	β = 0°, δ = 0°	Cold	TI	Symmetric (both sides)	
29	3	Snow	β = 0°, δ = 0°	Cold	TI	Asymmetric (either side)	
30	3	Snow	β = 0°, δ = 0°	Warm	TI	Symmetric (both sides)	
31	3	Snow	β = 0°, δ = 0°	Warm	TI	Asymmetric (either side)	
32	3	None	β = TBD°, δ = TBD°	Cold	TI	N/A	Fluid Only
33	3	None	β = TBD°, δ = TBD°	Warm	TI	N/A	Fluid Only
34	3	Snow	β = TBD°, δ = TBD°	Cold	TI	Symmetric (both sides)	
35	3	Snow	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	
36	3	Snow	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	
37	3	Snow	β = TBD°, δ = TBD°	Warm	TI	Symmetric (both sides)	
38	3	Snow	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	
39	3	Snow	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	
40	3	None	β = 7.5°, δ = 30°	Cold	TI	N/A	Fluid Only
41	3	None	β = 7.5°, δ = 30°	Warm	TI	N/A	Fluid Only
42	3	Snow	β = 7.5°, δ = 30°	Cold	TI	Symmetric (both sides)	
43	3	Snow	β = 7.5°, δ = 30°	Cold	TI	Asymmetric (Cont. Into Wind)	
44	3	Snow	β = 7.5°, δ = 30°	Cold	TI	Asymmetric (Cont. Not Into Wind)	
45	3	Snow	β = 7.5°, δ = 30°	Warm	TI	Symmetric (both sides)	
46	3	Snow	β = 7.5°, δ = 30°	Warm	TI	Asymmetric (Cont. Into Wind)	
47	3	Snow	β = 7.5°, δ = 30°	Warm	TI	Asymmetric (Cont. Not Into Wind)	
48	4	None	β = 0°, δ = 0°	Cold	EG	N/A	Fluid Only

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	**Comments**
49	4	None	β= 0°, δ= 0°	Warm	EG	N/A	Fluid Only
50	4	Snow	β= 0°, δ= 0°	Cold	EG	Symmetric (both sides)	
51	4	Snow	β= 0°, δ= 0°	Cold	EG	Asymmetric (either side)	
52	4	Snow	β= 0°, δ= 0°	Warm	EG	Symmetric (both sides)	
53	4	Snow	β= 0°, δ= 0°	Warm	EG	Asymmetric (either side)	
54	4	None	β= TBD°, δ= TBD°	Cold	EG	N/A	Fluid Only
55	4	None	β= TBD°, δ= TBD°	Warm	EG	N/A	Fluid Only
56	4	Snow	β= TBD°, δ= TBD°	Cold	EG	Symmetric (both sides)	
57	4	Snow	β= TBD°, δ= TBD°	Cold	EG	Asymmetric (Cont. Into Wind)	
58	4	Snow	β= TBD°, δ= TBD°	Cold	EG	Asymmetric (Cont. Not Into Wind)	
59	4	Snow	β= TBD°, δ= TBD°	Warm	EG	Symmetric (both sides)	
60	4	Snow	β= TBD°, δ= TBD°	Warm	EG	Asymmetric (Cont. Into Wind)	
61	4	Snow	β= TBD°, δ= TBD°	Warm	EG	Asymmetric (Cont. Not Into Wind)	
62	4	None	β= 7.5°, δ= 30°	Cold	EG	N/A	Fluid Only
63	4	None	β= 7.5°, δ= 30°	Warm	EG	N/A	Fluid Only
64	4	Snow	β= 7.5°, δ= 30°	Cold	EG	Symmetric (both sides)	
65	4	Snow	β= 7.5°, δ= 30°	Cold	EG	Asymmetric (Cont. Into Wind)	
66	4	Snow	β= 7.5°, δ= 30°	Cold	EG	Asymmetric (Cont. Not Into Wind)	
67	4	Snow	β= 7.5°, δ= 30°	Warm	EG	Symmetric (both sides)	
68	4	Snow	β= 7.5°, δ= 30°	Warm	EG	Asymmetric (Cont. Into Wind)	
69	4	Snow	β= 7.5°, δ= 30°	Warm	EG	Asymmetric (Cont. Not Into Wind)	
70	5	Snow	β= 0°, δ= 0°	Cold	None	Symmetric (both sides)	
71	5	Snow	β= 0°, δ= 0°	Cold	None	Asymmetric (either side)	
72	5	Snow	β= 0°, δ= 0°	Warm	None	Symmetric (both sides)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
73	5	Snow	β = 0°, δ = 0°	Warm	None	Asymmetric (either side)	
74	5	Snow	β = TBD°, δ = TBD°	Cold	None	Symmetric (both sides)	
75	5	Snow	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Into Wind)	
76	5	Snow	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	
77	5	Snow	β = TBD°, δ = TBD°	Warm	None	Symmetric (both sides)	
78	5	Snow	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Into Wind)	
79	5	Snow	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	
80	5	Snow	β = 7.5°, δ = 30°	Cold	None	Symmetric (both sides)	
81	5	Snow	β = 7.5°, δ = 30°	Cold	None	Asymmetric (Cont. Into Wind)	
82	5	Snow	β = 7.5°, δ = 30°	Cold	None	Asymmetric (Cont. Not Into Wind)	
83	5	Snow	β = 7.5°, δ = 30°	Warm	None	Symmetric (both sides)	
84	5	Snow	β = 7.5°, δ = 30°	Warm	None	Asymmetric (Cont. Into Wind)	
85	5	Snow	β = 7.5°, δ = 30°	Warm	None	Asymmetric (Cont. Not Into Wind)	
86	6	Freezing Rain	β = 0°, δ = 0°	Cold	EG	Symmetric (both sides)	
87	6	Freezing Rain	β = 0°, δ = 0°	Cold	EG	Asymmetric (either side)	
88	6	Freezing Rain	β = 0°, δ = 0°	Cold	PG	Symmetric (both sides)	
89	6	Freezing Rain	β = 0°, δ = 0°	Cold	PG	Asymmetric (either side)	
90	6	Freezing Rain	β = 0°, δ = 0°	Warm	EG	Symmetric (both sides)	
91	6	Freezing Rain	β = 0°, δ = 0°	Warm	EG	Asymmetric (either side)	
92	6	Freezing Rain	β = 0°, δ = 0°	Warm	PG	Symmetric (both sides)	
93	6	Freezing Rain	β = 0°, δ = 0°	Warm	PG	Asymmetric (either side)	
94	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG	Symmetric (both sides)	
95	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG	Asymmetric (Cont. Into Wind)	
96	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG	Asymmetric (Cont. Not Into Wind)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	**Comments**
97	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	PG	Symmetric (both sides)	
98	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	PG	Asymmetric (Cont. Into Wind)	
99	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
100	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	EG	Symmetric (both sides)	
101	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	EG	Asymmetric (Cont. Into Wind)	
102	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	EG	Asymmetric (Cont. Not Into Wind)	
103	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	PG	Symmetric (both sides)	
104	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	PG	Asymmetric (Cont. Into Wind)	
105	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	PG	Asymmetric (Cont. Not Into Wind)	
106	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	EG	Symmetric (both sides)	
107	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	EG	Asymmetric (Cont. Into Wind)	
108	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	EG	Asymmetric (Cont. Not Into Wind)	
109	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	PG	Symmetric (both sides)	
110	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	PG	Asymmetric (Cont. Into Wind)	
111	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
112	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	EG	Symmetric (both sides)	
113	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	EG	Asymmetric (Cont. Into Wind)	
114	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	EG	Asymmetric (Cont. Not Into Wind)	
115	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	PG	Symmetric (both sides)	
116	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	PG	Asymmetric (Cont. Into Wind)	
117	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	PG	Asymmetric (Cont. Not Into Wind)	
118	6	Freezing Rain	β = 0°, δ = 0°	Cold	TI	Symmetric (both sides)	
119	6	Freezing Rain	β = 0°, δ = 0°	Cold	TI	Asymmetric (either side)	
120	6	Freezing Rain	β = 0°, δ = 0°	Warm	TI	Symmetric (both sides)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
121	6	Freezing Rain	β = 0°, δ = 0°	Warm	TI	Asymmetric (either side)	
122	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	TI	Symmetric (both sides)	
123	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	
124	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	
125	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	TI	Symmetric (both sides)	
126	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	
127	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	
128	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	TI	Symmetric (both sides)	
129	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	TI	Asymmetric (Cont. Into Wind)	
130	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	TI	Asymmetric (Cont. Not Into Wind)	
131	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	TI	Symmetric (both sides)	
132	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	TI	Asymmetric (Cont. Into Wind)	
133	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	TI	Asymmetric (Cont. Not Into Wind)	
134	6	Freezing Rain	β = 0°, δ = 0°	Cold	None	Symmetric (both sides)	
135	6	Freezing Rain	β = 0°, δ = 0°	Cold	None	Asymmetric (either side)	
136	6	Freezing Rain	β = 0°, δ = 0°	Warm	None	Symmetric (both sides)	
137	6	Freezing Rain	β = 0°, δ = 0°	Warm	None	Asymmetric (either side)	
138	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	None	Symmetric (both sides)	
139	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Into Wind)	
140	6	Freezing Rain	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	
141	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	None	Symmetric (both sides)	
142	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Into Wind)	
143	6	Freezing Rain	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	
144	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	None	Symmetric (both sides)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	**Comments**
145	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	None	Asymmetric (Cont. Into Wind)	
146	6	Freezing Rain	β = 7.5°, δ = 30°	Cold	None	Asymmetric (Cont. Not Into Wind)	
147	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	None	Symmetric (both sides)	
148	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	None	Asymmetric (Cont. Into Wind)	
149	6	Freezing Rain	β = 7.5°, δ = 30°	Warm	None	Asymmetric (Cont. Not Into Wind)	
150	7	Other	β = 0°, δ = 0°	Cold	EG	Symmetric (both sides)	
151	7	Other	β = 0°, δ = 0°	Cold	EG	Asymmetric (either side)	
152	7	Other	β = 0°, δ = 0°	Cold	PG	Symmetric (both sides)	
153	7	Other	β = 0°, δ = 0°	Cold	PG	Asymmetric (either side)	
154	7	Other	β = 0°, δ = 0°	Warm	EG	Symmetric (both sides)	
155	7	Other	β = 0°, δ = 0°	Warm	EG	Asymmetric (either side)	
156	7	Other	β = 0°, δ = 0°	Warm	PG	Symmetric (both sides)	
157	7	Other	β = 0°, δ = 0°	Warm	PG	Asymmetric (either side)	
158	7	Other	β = TBD°, δ = TBD°	Cold	EG	Symmetric (both sides)	
159	7	Other	β = TBD°, δ = TBD°	Cold	EG	Asymmetric (Cont. Into Wind)	
160	7	Other	β = TBD°, δ = TBD°	Cold	EG	Asymmetric (Cont. Not Into Wind)	
161	7	Other	β = TBD°, δ = TBD°	Cold	PG	Symmetric (both sides)	
162	7	Other	β = TBD°, δ = TBD°	Cold	PG	Asymmetric (Cont. Into Wind)	
163	7	Other	β = TBD°, δ = TBD°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
164	7	Other	β = TBD°, δ = TBD°	Warm	EG	Symmetric (both sides)	
165	7	Other	β = TBD°, δ = TBD°	Warm	EG	Asymmetric (Cont. Into Wind)	
166	7	Other	β = TBD°, δ = TBD°	Warm	EG	Asymmetric (Cont. Not Into Wind)	
167	7	Other	β = TBD°, δ = TBD°	Warm	PG	Symmetric (both sides)	
168	7	Other	β = TBD°, δ = TBD°	Warm	PG	Asymmetric (Cont. Into Wind)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	**Priority**	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	**Comments**
169	7	Other	β = TBD°, δ = TBD°	Warm	PG	Asymmetric (Cont. Not Into Wind)	
170	7	Other	β = 7.5°, δ = 30°	Cold	EG	Symmetric (both sides)	
171	7	Other	β = 7.5°, δ = 30°	Cold	EG	Asymmetric (Cont. Into Wind)	
172	7	Other	β = 7.5°, δ = 30°	Cold	EG	Asymmetric (Cont. Not Into Wind)	
173	7	Other	β = 7.5°, δ = 30°	Cold	PG	Symmetric (both sides)	
174	7	Other	β = 7.5°, δ = 30°	Cold	PG	Asymmetric (Cont. Into Wind)	
175	7	Other	β = 7.5°, δ = 30°	Cold	PG	Asymmetric (Cont. Not Into Wind)	
176	7	Other	β = 7.5°, δ = 30°	Warm	EG	Symmetric (both sides)	
177	7	Other	β = 7.5°, δ = 30°	Warm	EG	Asymmetric (Cont. Into Wind)	
178	7	Other	β = 7.5°, δ = 30°	Warm	EG	Asymmetric (Cont. Not Into Wind)	
179	7	Other	β = 7.5°, δ = 30°	Warm	PG	Symmetric (both sides)	
180	7	Other	β = 7.5°, δ = 30°	Warm	PG	Asymmetric (Cont. Into Wind)	
181	7	Other	β = 7.5°, δ = 30°	Warm	PG	Asymmetric (Cont. Not Into Wind)	
182	7	Other	β = 0°, δ = 0°	Cold	TI	Symmetric (both sides)	
183	7	Other	β = 0°, δ = 0°	Cold	TI	Asymmetric (either side)	
184	7	Other	β = 0°, δ = 0°	Warm	TI	Symmetric (both sides)	
185	7	Other	β = 0°, δ = 0°	Warm	TI	Asymmetric (either side)	
186	7	Other	β = TBD°, δ = TBD°	Cold	TI	Symmetric (both sides)	
187	7	Other	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	
188	7	Other	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	
189	7	Other	β = TBD°, δ = TBD°	Warm	TI	Symmetric (both sides)	
190	7	Other	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	
191	7	Other	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	
192	7	Other	β = 7.5°, δ = 30°	Cold	TI	Symmetric (both sides)	

Table 3.2: Proposed Test Plan for Testing with the V-Stab (cont'd)

Test #	Priority	**Precipitation*** *In Order of Priority: None, Snow, Freezing Rain, Other*	**Sideslip (β) and Rudder Deflection (δ) **** In order of Priority: *None (0°, 0°), Max (7.5°, 30°: based on B757 report), TBD*	**Temperature** *Cold, Warm, Any*	**Fluid** *In order of Priority: PG, TI, EG, None*	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
193	7	Other	β = 7.5°, δ = 30°	Cold	TI	Asymmetric (Cont. Into Wind)	
194	7	Other	β = 7.5°, δ = 30°	Cold	TI	Asymmetric (Cont. Not Into Wind)	
195	7	Other	β = 7.5°, δ = 30°	Warm	TI	Symmetric (both sides)	
196	7	Other	β = 7.5°, δ = 30°	Warm	TI	Asymmetric (Cont. Into Wind)	
197	7	Other	β = 7.5°, δ = 30°	Warm	TI	Asymmetric (Cont. Not Into Wind)	
198	7	Other	β = 0°, δ = 0°	Cold	None	Symmetric (both sides)	
199	7	Other	β = 0°, δ = 0°	Cold	None	Asymmetric (either side)	
200	7	Other	β = 0°, δ = 0°	Warm	None	Symmetric (both sides)	
201	7	Other	β = 0°, δ = 0°	Warm	None	Asymmetric (either side)	
202	7	Other	β = TBD°, δ = TBD°	Cold	None	Symmetric (both sides)	
203	7	Other	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Into Wind)	
204	7	Other	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	
205	7	Other	β = TBD°, δ = TBD°	Warm	None	Symmetric (both sides)	
206	7	Other	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Into Wind)	
207	7	Other	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	
208	7	Other	β = 7.5°, δ = 30°	Cold	None	Symmetric (both sides)	
209	7	Other	β = 7.5°, δ = 30°	Cold	None	Asymmetric (Cont. Into Wind)	
210	7	Other	β = 7.5°, δ = 30°	Cold	None	Asymmetric (Cont. Not Into Wind)	
211	7	Other	β = 7.5°, δ = 30°	Warm	None	Symmetric (both sides)	
212	7	Other	β = 7.5°, δ = 30°	Warm	None	Asymmetric (Cont. Into Wind)	
213	7	Other	β = 7.5°, δ = 30°	Warm	None	Asymmetric (Cont. Not Into Wind)	

4. DATA FORMS

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

- Attachment 1: General Form;
- Attachment 2: Wing Temperature, Fluid Thickness and Fluid Brix Form;
- Attachment 3: Example Snow Dispensing Form;
- Attachment 4: Visual Evaluation Rating Form;
- Attachment 5: General From for Calibration Test;
- Attachment 6: Fluid Receipt Form (Electronic Form); and
- Attachment 7: Log of Fluid Sample Bottles.

When and how the data forms will be used is described throughout Section 5.

5. 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.

5.1 Initial Test Conditions Survey

- Record ambient conditions of the test (Attachment 1); and
- Record wing temperature (Attachment 2).

5.2 Fluid Application (Pour)

- Apply a minimum of 4L of anti-icing fluid over the test area (2L per side). This accounts for the minimum of 1L/m² and includes a 20 percent buffer for loss. Ideally fluid is sprayed using a garden sprayer as pouring on the vertical surface is not efficient;
- Record fluid application times and quantities (Attachment 1);
- Let fluid settle for 5-minutes;
- Measure fluid thickness at pre-determined locations on the wing (Attachment 2);

- Record wing temperature (Attachment 2);
- Measure fluid Brix value (Attachment 2);
- 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.

5.3 Application of Contamination

5.3.1 Snow Dispenser Calibration and Set-Up

Calibration work is being performed during the winter of 2019-20 with the purpose of obtaining the dispenser's distribution footprint for snow on a vertical surface. A series of tests were performed in low wind conditions. These tests were conducted using 120 collection pans in a vertical area 5 x 6 feet with effective openings measuring 6" x 6". Pre-measured amounts of 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.

As this work is still ongoing at the time of writing this procedure, the exact location of the dispenser's vis-a-vis the wing model have yet to be finalized and therefore cannot be included. Upon completion of the calibration work, detailed instructions for dispensing the snow on the vertical stabilizer will be developed and provided to the team for training and execution.

5.4 Prior to Engines-On Wind Tunnel Test

- Measure fluid thickness at the pre-determined locations on the wing (Attachment 2);
- Measure fluid Brix value (Attachment 2);
- Record wing temperatures (Attachment 2);
- Record start time of test (Attachment 1); and
- Fill out visual evaluation rating form (Attachment 4).

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).

5.5 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 4); and
- Record wind tunnel operation start and stop times.

5.6 After the Wind Tunnel Test

- Measure fluid thickness at the pre-determined locations on the wing (Attachment 2);
- Measure fluid Brix value (Attachment 2);
- Record wing temperatures (Attachment 2);
- Observe and record the status of the fluid/contamination (Attachment 2);
- Fill out visual evaluation rating form (Attachment 4);
- Obtain lift data (excel file) from NRC; and
- Update APS test log with pertinent information.

5.7 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 6) 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 6), however an additional form (Attachment 7) is available if required. A falling ball viscosity test should be performed on site to confirm that fluid viscosity is appropriate before testing.

5.8 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.

5.9 Camera Setup

The camera setup will be investigated in advance of the testing in order to determine the best locations to position video or still cameras with the restrictions of space, lighting, and access windows. The setup will likely use a combination of GoPro and DSLR cameras. The final positioning of the cameras and lighting should be documented.

5.10 Demonstration of a Typical Wind Tunnel Test Sequence

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

Table 5.1: 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.

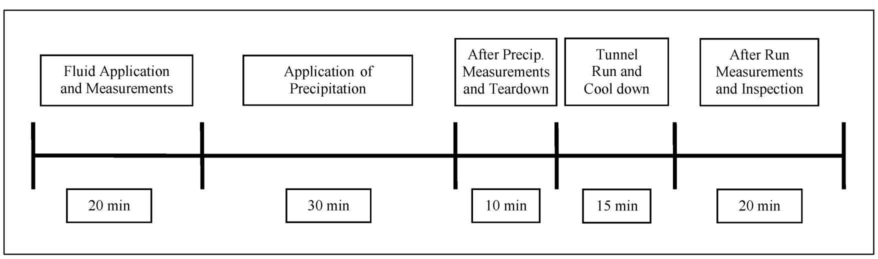


Figure 5.1: Typical Wind Tunnel Run Timeline

5.11 Procedures for Testing Objectives

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

- Attachment 8: Procedure – Calibration and Validation of Procedures;
- Attachment 9: Procedure – Vertical Surface Test Plan – Suggestions for Tuft Flow Visualization; and
- Attachment 10: Procedure – Fluid Flow-Off Characterization.

6. EQUIPMENT

Equipment to be employed is shown in Table 6.1. As this testing is exploratory, additional equipment may be required and will be identified and acquired as necessary.

Table 6.1: Equipment List

EQUIPMENT	STATUS		EQUIPMENT	STATUS
General Support and Testing Equipment			**Camera Equipment**	
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			**Ice Pellets Fabrication Equipment**	
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			**Freezing Rain Equipment**	
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			**Office Equipment**	
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				

7. 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 7.1 (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 7.1: 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)

8. 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 8.1 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).

Table 8.1: Personnel List

Wind Tunnel 2015-16 - Tentative	
Person	**Responsibility**
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
YOW Personnel	
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.

9. 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;

- Caution should be taken when walking in the test section due to slippery floors, and dripping fluid from the wing section;
- If fluid comes into contact with skin, rinse hands under running water; and
- If fluid comes into contact with eyes, flush with the portable eye wash station.

Attachment 1: 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): ____________

EFFECTIVE SIDE SLIP ANGLE (°) ____________ EXTRA RUN INFO: ____________

RUDDER DEFLECTION ANGLE (°) ____________

☐ Check if additional notes provided on a separate sheet

FLUID APPLICATION

Actual start time: ____________ Actual End Time: ____________

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

Fluid Temperature (°C): ____________ Fluid Application Method: POUR

ICE PELLETS APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Ice Pellets Applied (g/dm^2/h): ____________ Ice Pellets Size (mm): 1.4 - 4.0 mm

Exposure Time: ____________

Total IP Required per Dispenser: ____________

FREEZING RAIN/DRIZZLE APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Precipitation Applied (g/dm^2/h): ____________ Droplet Size (mm): ____________

Exposure Time: ____________ Needle: ____________

Flow: ____________

Pressure ____________

SNOW APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Snow Applied (g/dm^2/h): ____________ Snow Size (mm): <1.4 mm

Exposure Time: ____________ Method: ☐ Dispenser ☐ Sieve

Total SN Required per Dispenser: ____________

COMMENTS

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

Attachment 2: Wing Temperature, Fluid Thickness and Fluid Brix Form

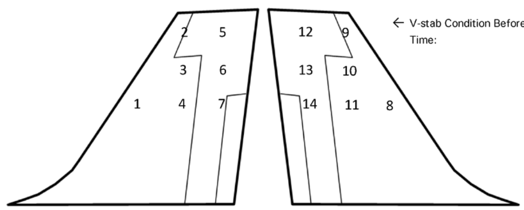
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: ____________________ Run: ____________________

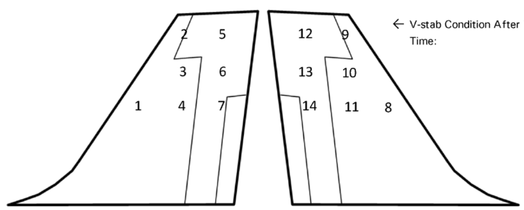
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3				
10				
Time:				

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3			
10			
Time:			

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
Time:			



← V-stab Condition Before Takeoff
Time:



← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.

Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.

Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments: ____________________

OBSERVER: ____________________

Attachment 3: Example Snow Dispensing Form

Snow Order Data Form for Dispensing on Vertical Stabilizer

Date: ____________________

Precipitation Type: Snow

Fields to be manipulated

Target Rate: 10 g/dm²/h

Duration: 10 minutes

Snow needed per 5 minutes

In each position 216 g

Snow needed for entire test

In each Dispensor (or if only doing 1 side) 1726 g

Total Amount Snow Needed for Entire Test (both sides) 3452 g

Expected Footprint of Snow

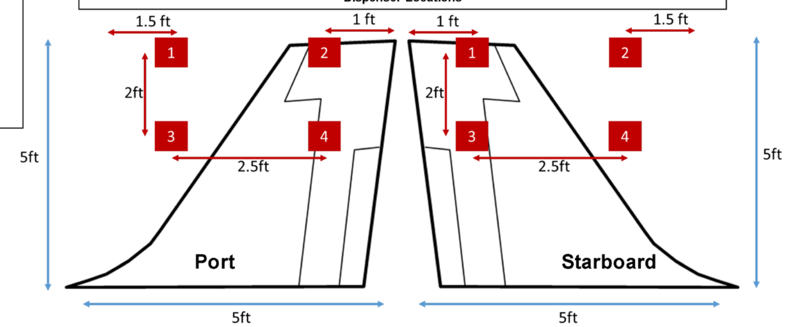
← 5ft → (↑ 5ft ↓)

4	18	21	21	17	16	18	16	10	9
17	25	13	14	15	24	29	21	15	13
9	19	7	5	14	24	15	12	9	6
4	5	3	4	12	20	9	3	3	2
4	4	3	3	10	13	9	14	17	7
4	7	11	12	8	12	14	16	15	12
5	9	10	9	11	21	12	10	9	8
7	10	8	10	13	13	8	8	3	5
12	9	6	5	6	12	5	3	1	2
8	6	5	3	4	5	4	1	1	2

← 5ft → (↑ 5ft ↓)

4	18	21	21	17	16	18	16	10	9
17	25	13	14	15	24	29	21	15	13
9	19	7	5	14	24	15	12	9	6
4	5	3	4	12	20	9	3	3	2
4	4	3	3	10	13	9	14	17	7
4	7	11	12	8	12	14	16	15	12
5	9	10	9	11	21	12	10	9	8
7	10	8	10	13	13	8	8	3	5
12	9	6	5	6	12	5	3	1	2
8	6	5	3	4	5	4	1	1	2

Dispenser Locations



Attachment 4: Visual Evaluation Rating Form

VISUAL EVALUATION RATING OF CONDITION OF WING

Date: ______________________ Run Number: _______

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

Note: Ratings can include decimals i.e. 1.4 or 3.5

Before Take-off Run

Area	Visual Severity Rating (1-5)		
	Port	Stbd	
Leading Edge			*>3 = Review, >3.5=Bad*
Trailing Edge			*>3 = Review, >3.5=Bad*
Rudder			*>4 = Review, >4.5=Bad*

At Rotation

Area	Visual Severity Rating (1-5)		
	Port	Stbd	
Leading Edge			*>1= Review >1.5 = Bad*
Trailing Edge			
Rudder			

Expected Lift Loss (%) *>5.4 = Review* *>9.2 = Bad*

After Take-off Run

Area	Visual Severity Rating (1-5)	
	Port	Stbd
Leading Edge		
Trailing Edge		
Rudder		

Additional Observations: ____

____

____

OBSERVER:________________________

Attachment 5: General From for Calibration Test

GENERAL FORM (EVERY CALIBRATION TEST)

DATE: ____________________ RUN # (Plan #): ____________________

OJECTIVE: ☐ Tuft Tests ☐ Boundary Layer Rake

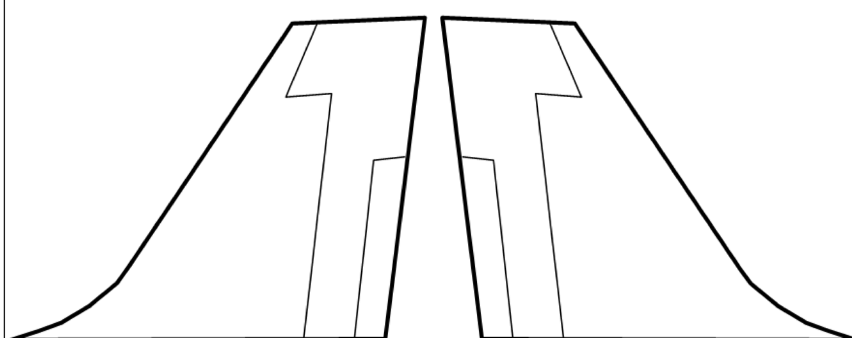
AIR TEMPERATURE (°C) BEFORE TEST:	________	AIR TEMPERATURE (°C) AFTER TEST:	________
TUNNEL TEMPERATURE (°C) BEFORE TEST:	________	TUNNEL TEMPERATURE (°C) AFTER TEST:	________
WIND TUNNEL START TIME:	________	EFFECTIVE SIDE SLIP ANGLE (°):	________
WIND TUNNEL END TIME:	________	RUDDER DEFLECTION ANGLE (°):	________
PROJECTED SPEED (S/KTS):	________		

TUFTS APPLIED: Y / N TUFT DETAILS: ____________________

☐ Full Wing ☐ Partial Wing (describe) ____________________

BOUNDARY LAYER RAKE: Y / N RAKE DETAILS: ____________________

____



COMMENTS :

____

____

____

HANDWRITTEN BY:

☐ Check if further details are available behind this sheet

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Final Version 1.0, January 20

32

Attachment 6: Fluid Receipt Form (Electronic Form)

FORM 1

GENERAL FORM FOR RECEIVING FLUID

Receiving Location: ☐ APS Site ☐ Other: ______________ **Date of Receipt:** ____________________

Fluid Characteristics: Type: Colour: **Date of Production:** ____________________

Manufacturer: ____________________________________ **Batch #:** ____________________

Fluid Name: ____________________________________ **Project Task:**

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 _____

Sample Collection:

HOT Fluids:	Extract 4 L 100 / 75 / 50 and 2 L Type I
Other Fluids:	Extract 3 L 100 / 75 / 50 / Type I

Sample Distribution:

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

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)

Attachment 7: Log of Fluid Sample Bottles

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

Attachment 8: Procedure – Calibration and Validation of Procedures

Background

As the work with the vertical stabilizer is exploratory, and have never been done before on a vertical test model, it is important to validate the testing procedures to ensure safety, reliability, and repeatability.

Objective

Validate the testing procedures to ensure safety, reliability, and repeatability.

Methodology

- Simulate and validate testing procedures related to:
  - Safety measures when operating around the model and at heights if necessary;
  - Application of fluids;
  - Application of contamination, and calibration as required; and
  - Other procedural elements identified on site.

Test Plan

One day of testing is planned.

Attachment 9: Procedure – Vertical Surface Test Plan – Suggestions for Tuft Flow Visualization

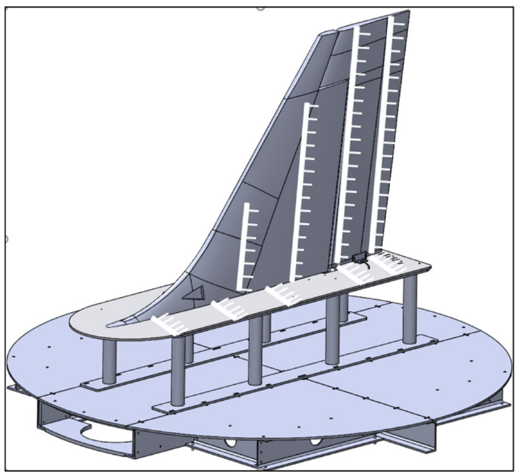
Section written by: Andy Broeren
December 3, 2019

Background

Here are some suggestions for conducting flow visualization on the Piper Seneca vertical tail model in the NRC 3m x 6m wind tunnel.

Tuft Layout

- Two rows of tufts on rudder (if possible)
- Use same layout on each side (suction and pressure surfaces)



Objective

Objective for Tuft Flow Visualization

- The objective for these tests is to check for highly three-dimensional and/or separated flow over the vertical tail including the rudder and on the splitter plate. Highly 3D and/or separated flow will be indicated by tufts that are not nicely aligned with the flow stream direction.
- It is important to apply tufts to both the suction and pressure surfaces as this will provide a nice comparison or contrast in the flow visualization images. For example, one would assume that the flow on the pressure

surface should be free of highly 3D and/or separated flow. These tuft images can then be easily compared or contrasted to the suction side which might show some evidence of highly 3D or separated flow.

Methodology

Suggested Procedure

1. Set β = 0 deg. and δ_r = 0 deg.
2. Set tunnel to desired speed (e.g. 100 knots).
3. Photograph tufts.
4. Assuming β can be changed while tunnel is running, increase β to 2.5, 5.0, 7.5 and 10 deg. and photograph tufts.
5. Stop tunnel.
6. Set rudder to δ_r = 30 deg.
7. Repeat steps 2, 3, and 3. May need to limit β to 7.5 deg. at δ_r = 30 deg. due to design loads.
8. Check for highly 3D and/or separated flow. If this exists, consider reducing δ_r to 25 or 20 deg.

Test Plan

One day of testing is planned.

Attachment 10: Procedure – Fluid Flow-Off Characterization

Background

The overall aerodynamic impact of contaminated fluid on vertical surfaces has yet to be fully understood. This data will then be used by aircraft manufacturers to better understand the expected impacts on their specific aircraft types.

Objective

The objective of this testing is to conduct aerodynamic testing with a vertical stabilizer to document contaminated fluid flow-off on a vertical stabilizer.

Methodology

- Conduct testing with clean fluids to understand the baseline fluid flow-off performance;
- Conduct testing with fluid contaminated with simulated snow and compare the fluid flow-off performance to the clean fluid performance;
- Record visual observations, video, photography, and manually collected data; and
- Adjust testing plan accordingly based on results obtained.

Test Plan

Three days of testing are planned.

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APPENDIX C

VERTICAL STABILIZER TESTING 2019-20 FLUID THICKNESS, TEMPERATURE, AND BRIX DATA FORMS

No Data Available

Figure C1: Run # 1 to Run # 6

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

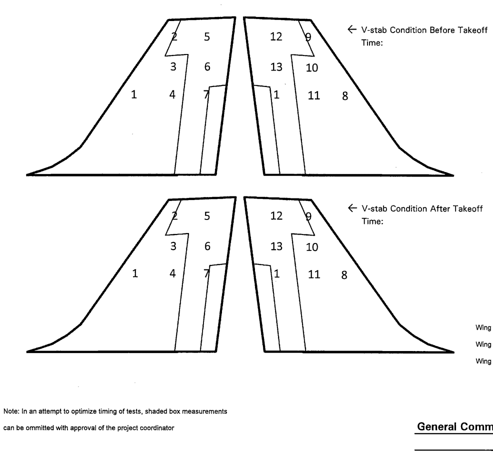
Date: February 3, 2020

Run: 7 (5)

WING TEMPERATURE (Taken From NRC Logger)					
	Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
P	3	3.2	2.5		1.2
S	10	2.6	2.0		0.6
	Time:	23:00	23:34		23:49

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.75		37.25
10	36.75		37.5
Time:	23:34		23:49

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			5
2	12		4
3	11		6
4	12		9
5			5
6			5
7			9
8			5
9	11		4
10	11		8
11	12		7
12			4
13			5
14			5
Time:	23:34		23:49



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

M:\Projects\300293 (TC Deicing 2019-20)\Procedures\V-Stab (see also Wind Tunnel)\Supporting Docs\Data Forms\V-stab Tests\Fluid Thickness, Temperature and Brix Form Version 1.0 V-stab

Figure C2: Run # 7

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

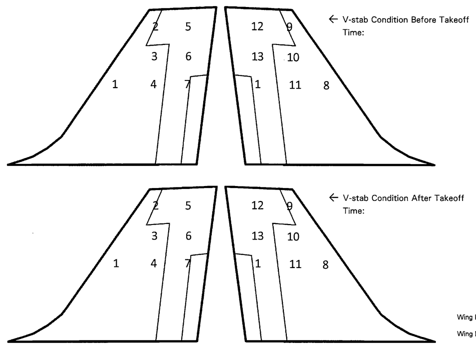
Date: February 4, 2020

Run: 8(11)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	2.3	1.9		-0.7
10	1.6	1.5		-1.2
Time:	23:57	00:16		00:28

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.5		37.0
10	36.5		37.0
Time:	00:16		00:28

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			5
2	22		4
3	11		7
4	14		9
5			10
6			8
7			12
8			5
9	14		3
10	16		9
11	20		9
12			8
13			5
14			6
Time:	00:17		00:30



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB, CB

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Figure C3: Run # 8

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

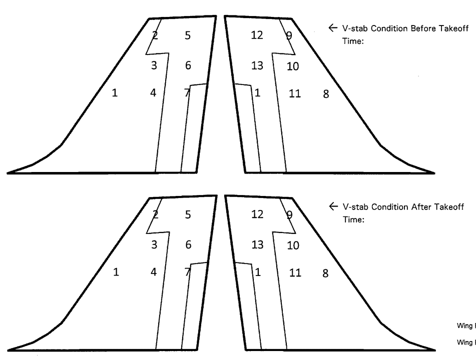
Date: February 4, 2020

Run: 9(19)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	1.7		1.1	-0.8
10	1.1		0.6	-1.3
Time:	00:41		1:00	1:09

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.5		37.25
10	36.75		37.0
Time:	1:01		1:10

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			4
2	26		2
3	24		10
4	22		10
5			8
6			10
7			16
8			4
9	24		2
10	22		9
11	22		11
12			5
13			4
14			5
Time:	1:02		1:11



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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Figure C4: Run # 9

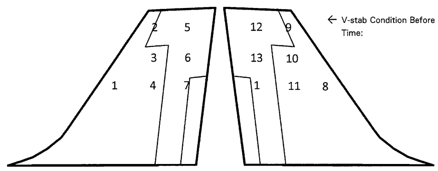
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 4, 2020 Run: 10 (19)

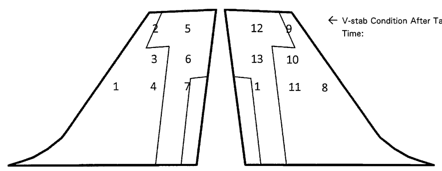
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	1.4	0.9		-0.7
10	1.0	0.5		-1.4
Time:	01:21	1:38		1:51

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.5		36.75
10	36.75		37.0
Time:	1:39		1:52

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			5
2	28		6
3	24		10
4	18		10
5			11
6			10
7			12
8			10
9	16		4
10	18		11
11	18		10
12			5
13			6
14			5
Time:	1:40		1:53



← V-stab Condition Before Takeoff
Time:



← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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Figure C5: Run # 10

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

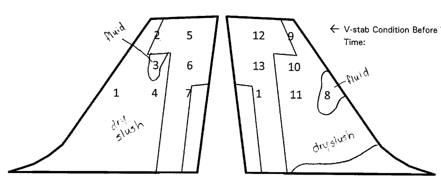
Date: February 4, 2020 Run: 11 (15)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	1.3	1.0	-3.8	-2.2
10	0.7	0.4	-5.1	-2.6
Time:	2:04	2:19	2:50	3:00

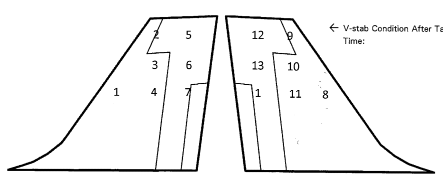
FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.5	29.5	16.25
10	36.75	11.0	15.5
Time:	2:23	2:50	3:01

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			<1
2	12	9	<1
3	22	3	2
4	18	5	<1
5			10
6			2
7			6
8			<1
9	10	5	5
10	24	4	2
11	20	6	2
12			4
13			1
14			<1
Time:	2:23	2:50	3:02

~~1 2 3 4 5~~
~~1 2 3 4 10~~
~~1 2 3 4~~ 15
~~1 2 3 4~~ 20
~~1 2 3 4 25~~
~~1 2 3 4 30~~



← V-stab Condition Before Takeoff
Time:



← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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Figure C6: Run # 11

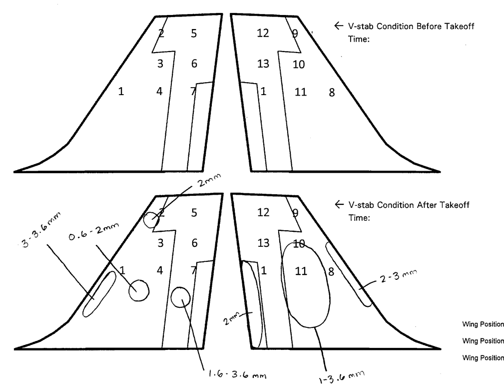
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 4, 2020 Run: 12 (15)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-0.2	-0.3	-1.9	-3.2
10	-0.6	-0.3	-2.6	-3.7
Time:	3:15	3:26	4:56	5:06

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.5	11.5	no brix.
10	36.5	3.75	10.0
Time:	3:31	4:57	5:10

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			<1
2	12	5	<1
3	22	4	5
4	20	5	2
5			4
6			<1
7			6
8			<1
9	9	5	2
10	26	4	4
11	22	2	2
12			2
13			<1
14			<1
Time:	3:33	4:58	5:12



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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Figure C7: Run # 12

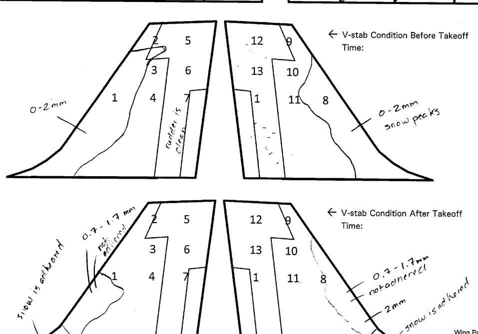
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 4, 2020 Run: 13 (77)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before ~~Fluid~~ Precip. Application	After fluid Application	After Precip Application	After Takeoff Run
3	1.7		0.0	0.0
10	1.3		-0.7	-0.7
Time:	21:37		21:52	22:11

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3			
10			
Time:			

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
Time:			



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments: Snow is adhered on the composite section of the v-stab, not on the aluminum

OBSERVER: BB/CB

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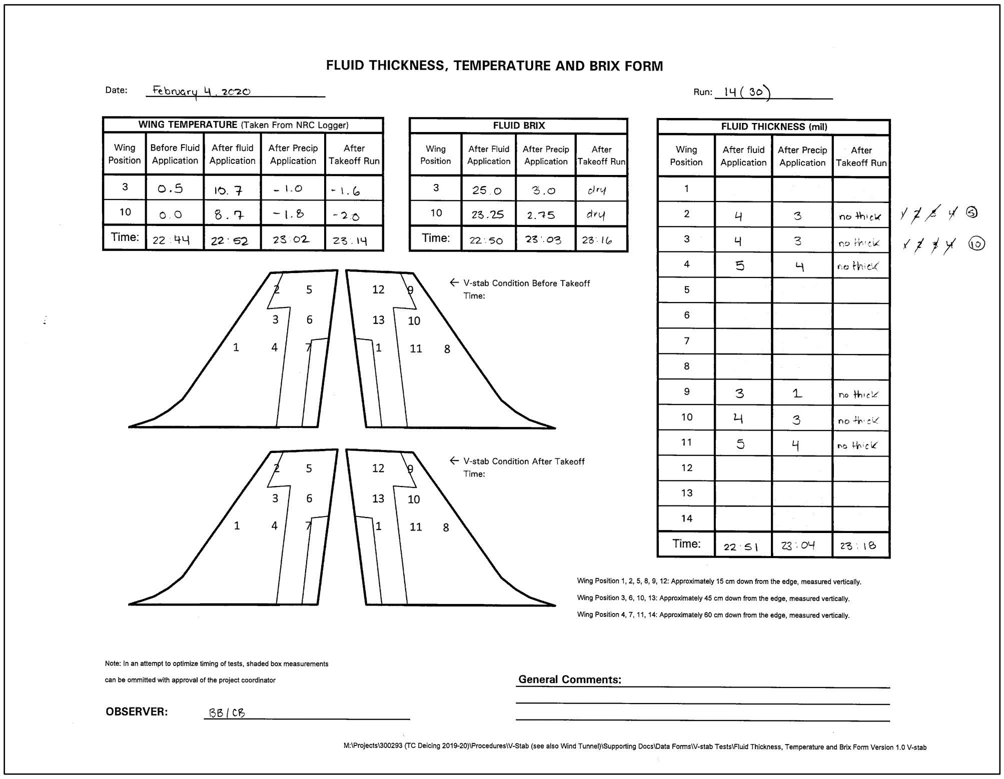
Figure C8: Run # 13



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 4, 2020 Run: 14 (30)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	0.5	10.7	-1.0	-1.6
10	0.0	8.7	-1.8	-2.0
Time:	22:44	22:52	23:02	23:14

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	25.0	3.0	dry
10	23.25	2.75	dry
Time:	22:50	23:03	23:16

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	4	3	no thick
3	4	3	no thick
4	5	4	no thick
5			
6			
7			
8			
9	3	1	no thick
10	4	3	no thick
11	5	4	no thick
12			
13			
14			
Time:	22:51	23:04	23:18

(5) (10)

← V-stab Condition Before Takeoff
Time:

← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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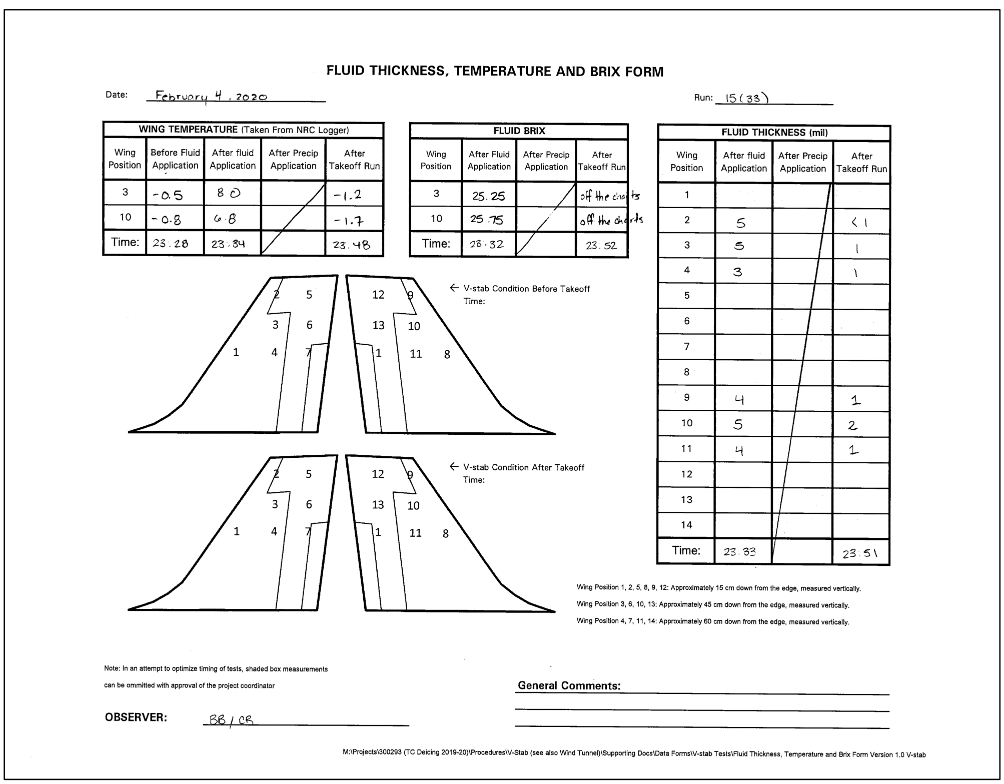
Figure C9: Run # 14



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 4, 2020 Run: 15 (33)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-0.5	8.0		-1.2
10	-0.8	6.8		-1.7
Time:	23:28	23:34		23:48

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	25.25		off the charts
10	25.75		off the charts
Time:	23:32		23:52

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	5		< 1
3	5		1
4	3		1
5			
6			
7			
8			
9	4		1
10	5		2
11	4		1
12			
13			
14			
Time:	23:33		23:51

← V-stab Condition Before Takeoff
Time:

← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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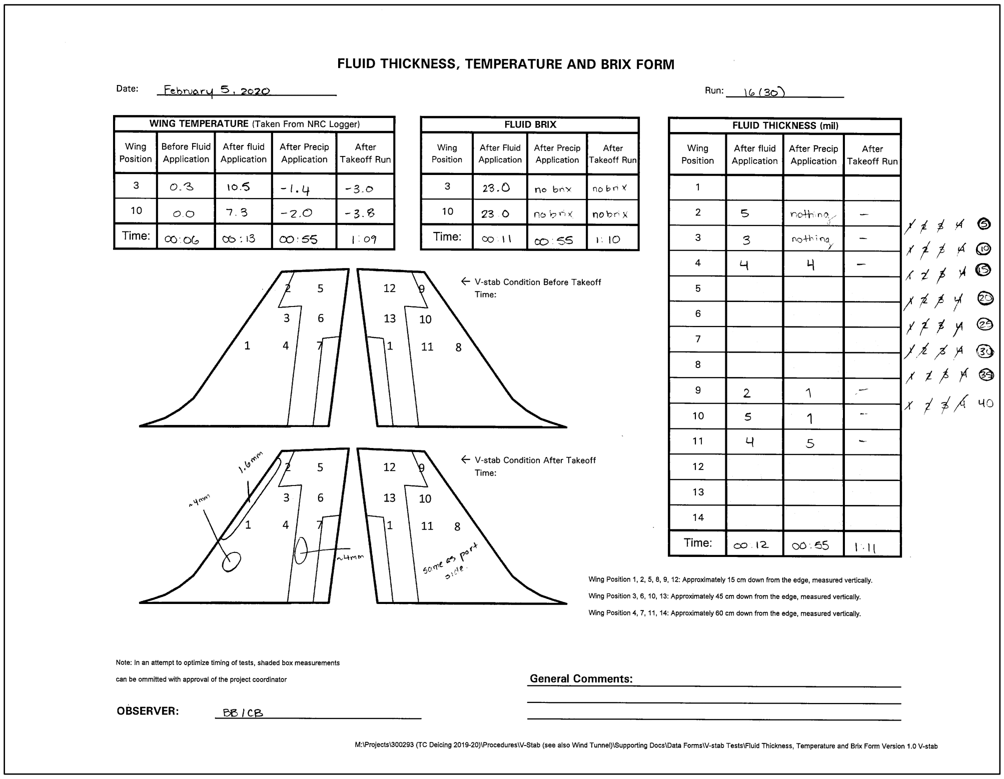
Figure C10: Run # 15



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 5, 2020   Run: 16 (30)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	0.3	10.5	-1.4	-3.0
10	0.0	7.3	-2.0	-3.8
Time:	00:06	00:13	00:55	1:09

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	23.0	no brix	no brix
10	23.0	no brix	no brix
Time:	00:11	00:55	1:10

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	5	nothing	–
3	3	nothing	–
4	4	4	–
5			
6			
7			
8			
9	2	1	–
10	5	1	–
11	4	5	–
12			
13			
14			
Time:	00:12	00:55	1:11

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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Figure C11: Run # 16

No Data Available

Figure C12: Run # 17

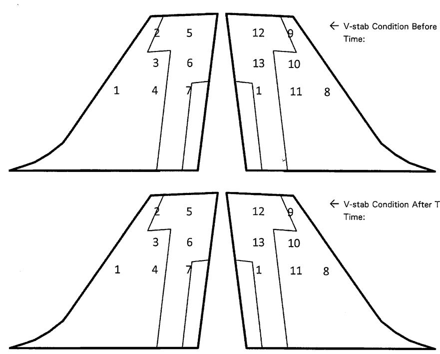
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 5, 2020 Run: 18 (54)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-3.8	-4.0		-8.0
10	-4.3	-4.5		-8.5
Time:	19:58	20:20		20:31

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.25		35.0
10	33.25		34.5
Time:	20:20		20:31

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			9
2	18		6
3	22		10
4	26		11
5			18
6			9
7			20
8			11
9	26		2
10	20		20
11	24		22
12			8
13			10
14			9
Time:	20:20		20:32



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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Figure C13: Run # 18

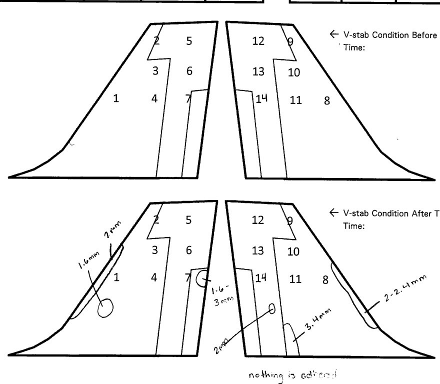
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 5, 2020 Run: 19 (56)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-4.7	-4.3	-7.6	-9.4
10	-5.3	-5.0	-8.2	-10.0
Time:	20:43	21:02	21:40	21:56

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.25	16.25	23.0
10	33.5	8.75	21.5
Time:	21:02	21:41	21:57

FLUID THICKNESS (mil)				
Wing Position	After fluid Application	After Precip Application	After Takeoff Run	
1				
2	22	3	nothing	1 2 3 4 (5)
3	30	12 - dry to the left	1	1 2 3 4 (10)
4	26	9 - dry to the left	nothing	1 2 3 4 (15)
5				1 2 3 4 (20)
6				1 2 3 4 (25)
7				1 2 3 4 (30)
8				1 2 3 4 35
9	22	5	nothing	
10	28	nothing	2	
11	28	nothing	nothing	
12				
13				
14				
Time:	21:02	21:42	21:58	



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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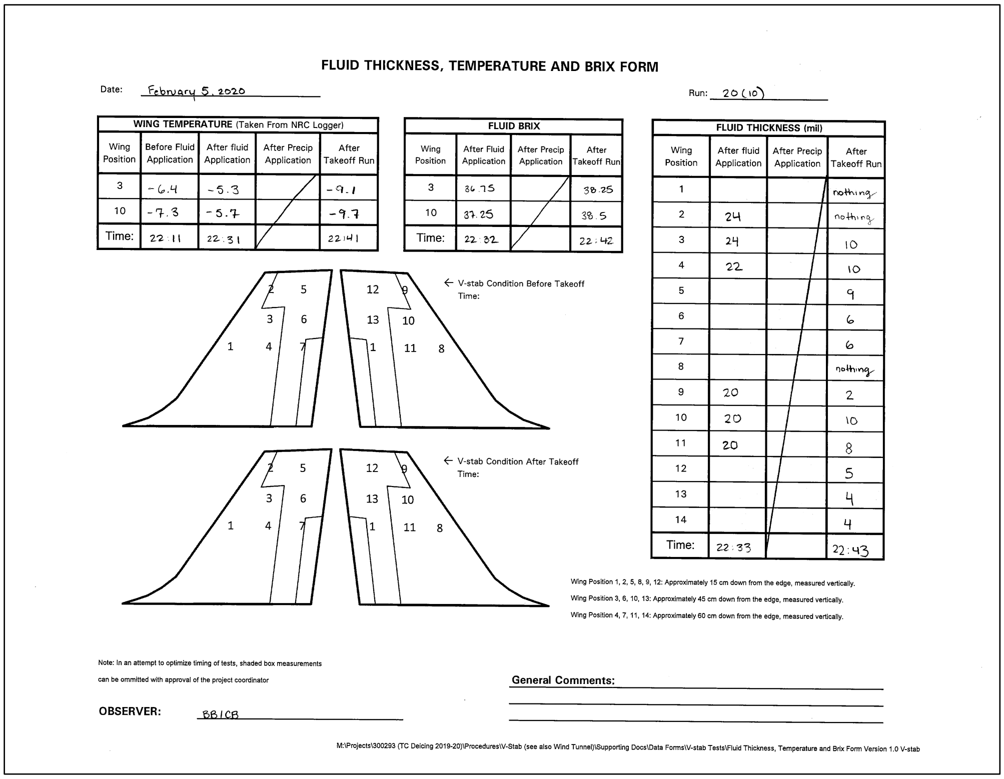
Figure C14: Run # 19



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 5, 2020 Run: 20 (10)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-6.4	-5.3		-9.1
10	-7.3	-5.7		-9.7
Time:	22:11	22:31		22:41

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.75		38.25
10	37.25		38.5
Time:	22:32		22:42

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			nothing
2	24		nothing
3	24		10
4	22		10
5			9
6			6
7			6
8			nothing
9	20		2
10	20		10
11	20		8
12			5
13			4
14			4
Time:	22:33		22:43

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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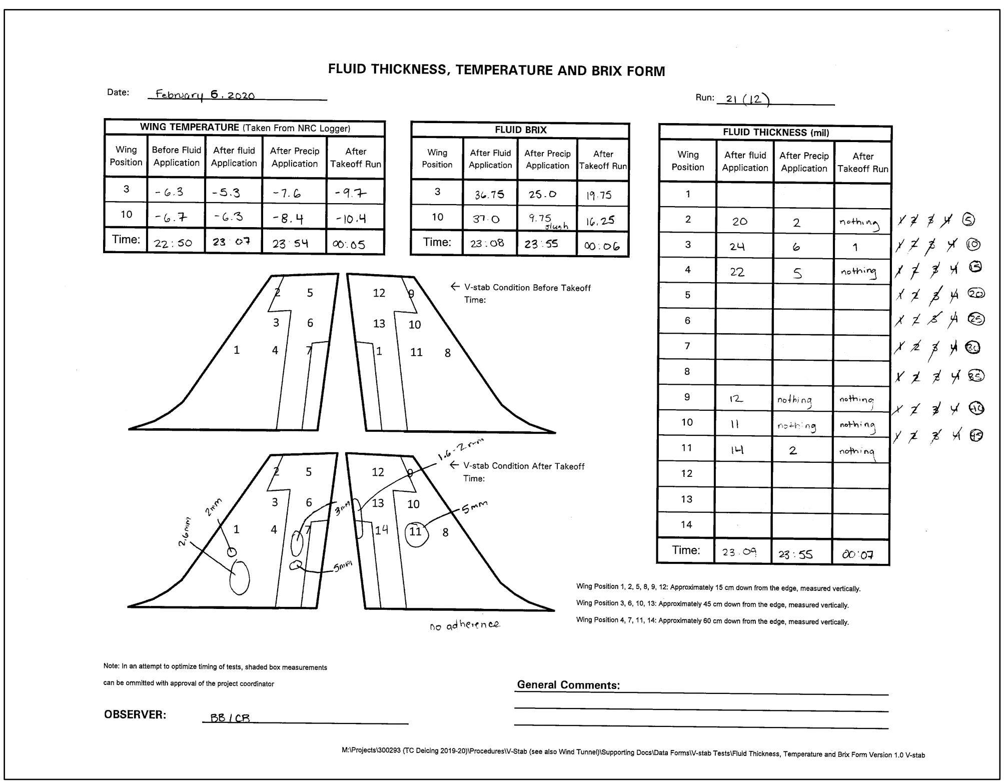
Figure C15: Run # 20



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 6, 2020 Run: 21 (12)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-6.3	-5.3	-7.6	-9.7
10	-6.7	-6.3	-8.4	-10.4
Time:	22:50	23:07	23:54	00:05

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.75	25.0	19.75
10	37.0	9.75 slush	16.25
Time:	23:08	23:55	00:06

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	20	2	nothing
3	24	6	1
4	22	5	nothing
5			
6			
7			
8			
9	12	nothing	nothing
10	11	nothing	nothing
11	14	2	nothing
12			
13			
14			
Time:	23:09	23:55	00:07

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CR

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Figure C16: Run # 21

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

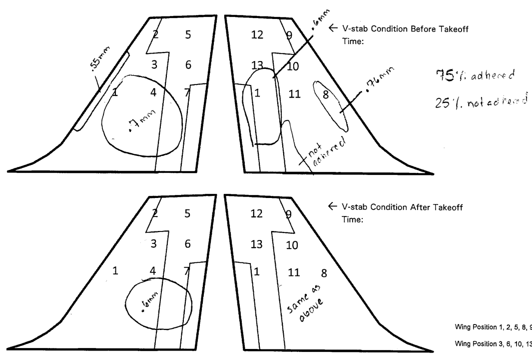
Date: February 6, 2020

Run: 22 (138)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-6.6	-5.5	-0.5	-8.9
10	-7.3	-6.3	-1.0	-9.7
Time:	00:27	00:44	1:22	1:39

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.5	ice	ice
10	37.0	ice	ice
Time:	00:45	1:23	

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	24	ice	ice
3	18	ice	ice
4	14	ice	ice
5			
6			
7			12
8			
9	16	ice	ice
10	18	ice	ice
11	18	ice	ice
12			
13			
14			
Time:	00:46	1:24	



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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Figure C17: Run # 22

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

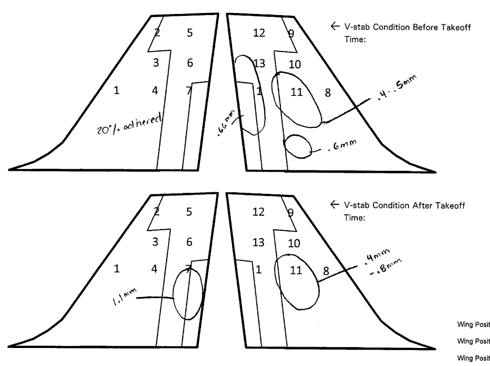
Date: February 6, 2020

Run: 23 (138)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-5.5	-5.2	-3.6	-9.5
10	-6.1	-6.0	-3.9	-10.1
Time:	2:00	2:16	2:44	2:54

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0	25.0 [illegible]	26.25
10	37.0	ice	20.5
Time:	2:20	2:45	2:57

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	22	ice	ice
3	24	ice	6
4	22	ice	3
5			
6			
7			
8			
9	18	ice	6
10	16	ice	ice
11	18	ice	ice
12			
13			
14			
Time:	2:21	2:46	2:58



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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Figure C18: Run # 23

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

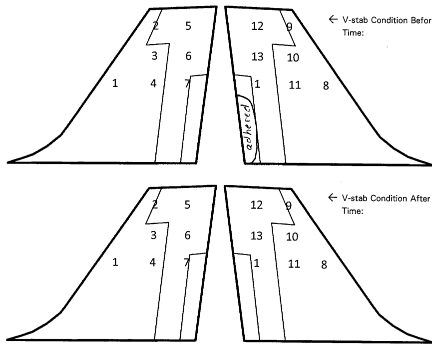
Date: February 6, 2020 Run: 24 (138)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-7.1	-5.8	-4.6	-9.5
10	-7.6	-6.5	-4.9	-10.1
Time:	3:11	3:28	3:44	3:59

brixometer broken

FLUID BRIX				
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3			
10			
Time:			

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	24	12	4
3	24	22 fluid streak	10
4	24	8	6
5			
6			
7			
8			
9	16	11	5
10	11	ice	10
11	22	ice	1
12			
13			
14			
Time:	3:29	3:45	3:59



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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Figure C19: Run # 24

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

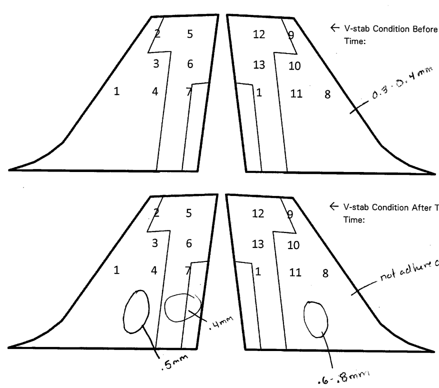
Date: February 6, 2020 Run: 25 (34)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-6.2	2.7	-4.0	-9.5
10	-6.8	2.7	-5.2	-10.0
Time:	4:16	4:25	4:31	4:40

brixometer is broken

FLUID BRIX				
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3			
10			
Time:			

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	5	1	dry
3	4	1	dry
4	6	10	dry
5			
6			
7			
8			
9	2	8	dry
10	5	7	dry
11	5	5	dry
12			
13			
14			
Time:	4:26	4:32	4:42



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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Figure C20: Run # 25

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

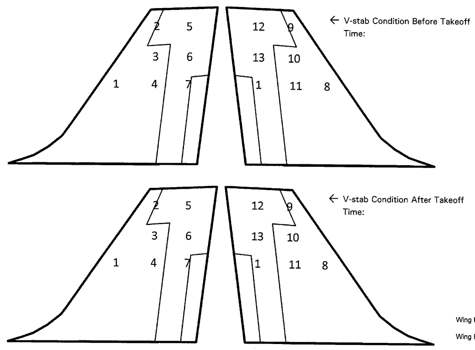
Date: February 6, 2020

Run: 26 (74)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-6.6		-6.9	
10	-7.3		-7.8	
Time:	4:55		5:04	

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3			
10			
Time:			

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
Time:			



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: CB

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Figure C21: Run # 26

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

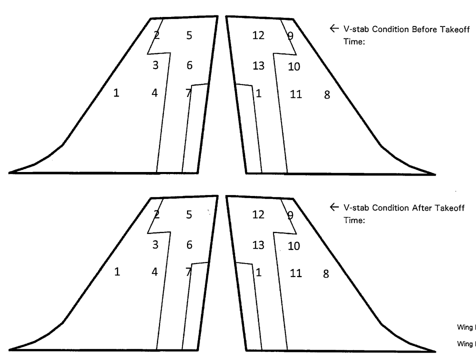
Date: February 6, 2020

Run: 27 (59)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-1.9	-1.6	-3.8	-4.7
10	-2.4	-2.3	-4.6	-5.4
Time:	20:11	20:29	21:12	21:27

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	32.25	23.5	15.5
10	32.75	6.0 slush	16.0
Time:	20:30	21:12	21:27

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	18	3	nothing
3	28	6	1
4	28	2	nothing
5			
6			
7			
8			
9	16	2	nothing
10	44	2	nothing
11	46	dry	1
12			
13			
14			
Time:	20:31	21:12	21:27



Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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Figure C22: Run # 27

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

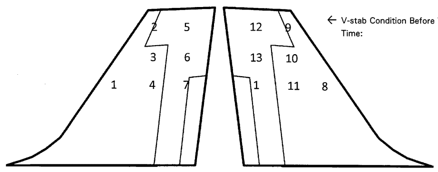
Date: February 6, 2020

Run: 28 (8)

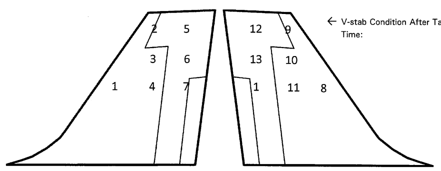
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-3.4	-2.9	-3.0	-4.8
10	-4.1	-3.3	-3.5	-5.4
Time:	21:40	21:53	23:00	23:12

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	35.75	5.0	11.0
10	35.75	4.0	11.75
Time:	21:57	23:01	23:13

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	20	dry	dry
3	18	dry	6
4	16	2	1
5			
6			
7			
8			
9	18	2	dry
10	18	3	2
11	18	1	nothing
12			
13			
14			
Time:	21:58	23:02	23:14



← V-stab Condition Before Takeoff
Time:



← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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Figure C23: Run # 28

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

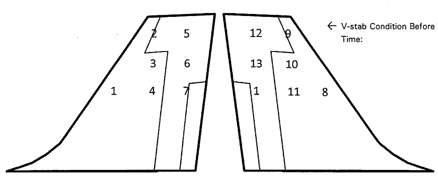
Date: February 7, 2020

Run: 29 (23)

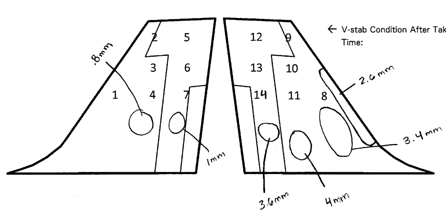
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-2.5	-2.1	-3.5	-4.6
10	-3.3	-3.0	-4.1	-5.2
Time:	00:02	00:23	1:24	1:42

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.0	6.0	11.0
10	36.0	4.5	11.75
Time:	00:23	1:25	1:43

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	22	1	dry
3	18	2	3
4	22	1	2
5			
6			
7			
8			
9	18	1	dry
10	18	1	3
11	22	dry	1
12			
13			
14			
Time:	00:23	1:26	1:44



← V-stab Condition Before Takeoff
Time:



← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB / CB

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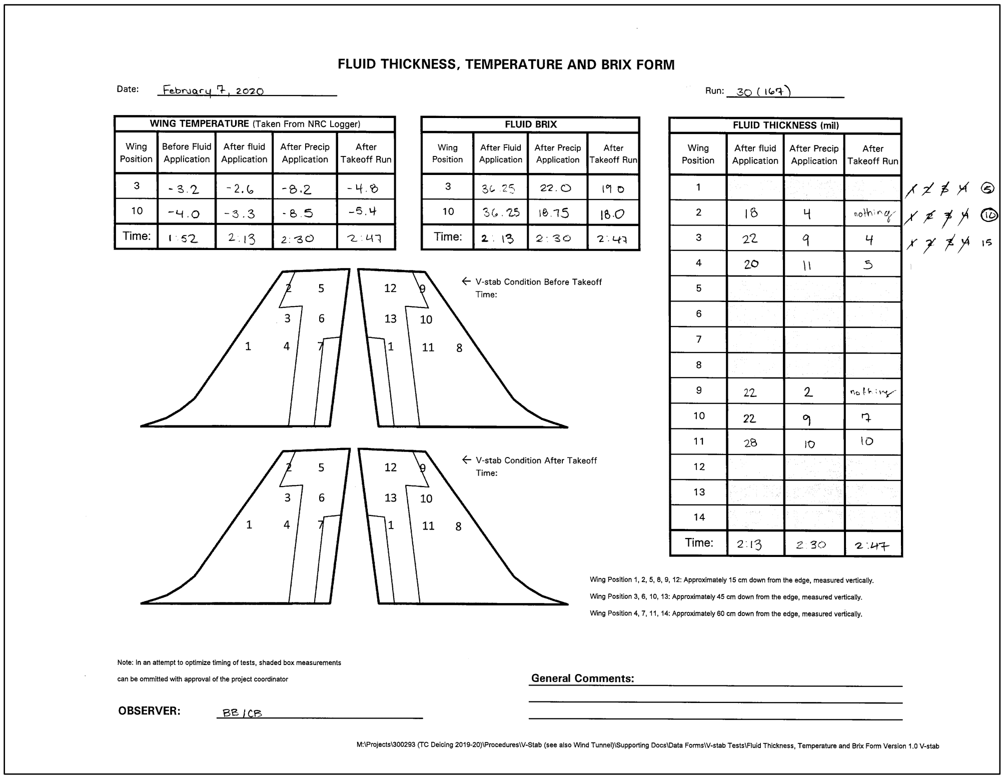
Figure C24: Run # 29



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: February 7, 2020

Run: 30 (167)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-3.2	-2.6	-8.2	-4.8
10	-4.0	-3.3	-8.5	-5.4
Time:	1:52	2:13	2:30	2:47

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.25	22.0	19.0
10	36.25	18.75	18.0
Time:	2:13	2:30	2:47

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	18	4	nothing
3	22	9	4
4	20	11	5
5			
6			
7			
8			
9	22	2	nothing
10	22	9	7
11	28	10	10
12			
13			
14			
Time:	2:13	2:30	2:47

← V-stab Condition Before Takeoff
Time:

← V-stab Condition After Takeoff
Time:

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments:

OBSERVER: BB/CB

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Figure C25: Run # 30

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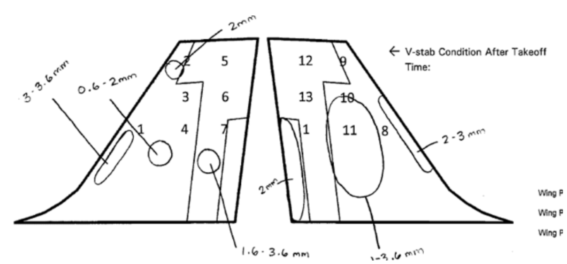
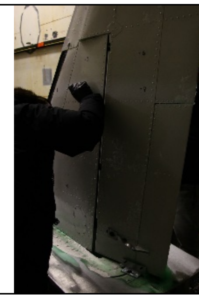
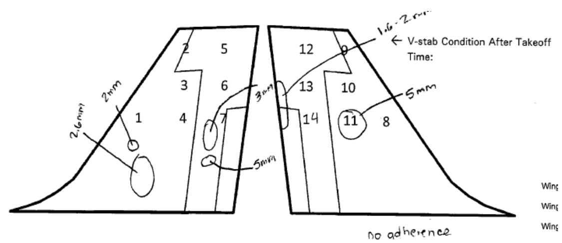
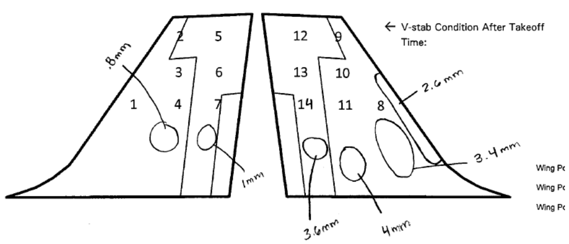
APPENDIX D

ANALYSIS OF PEAK CONTAMINATION THICKNESS POST-RUN

Run #	Fluid	Tunnel Temp Before Test (°C)	Precipitation Type	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Effective Side Slip Angle (°)	Rudder Deflection Angle (°)	Run Comments	Peak Contamination Thickness (from post-run diagram)
12	Polar Guard Advance (Type IV PG)	-1.5	Snow	25	75	0	-10	Longest snow exposure for Type IV-PG snow runs	3.6mm
21	Polar Guard Advance (Type IV PG)	-7.4	Snow	25	45	0	-10	Coldest temperature for Type IV-PG snow runs	5mm
29	Polar Guard Advance (Type IV PG)	-4.0	Snow	25	60	-7.5	-30	Less intense/cold run for comparative reference (note variation in sideslip and rudder deflection)	4mm

Run #	Post-Run Contamination Documentation Diagram	Post-Run Photo - Port Side	Post-Run Photo - Starboard Side
12			
21			
29			

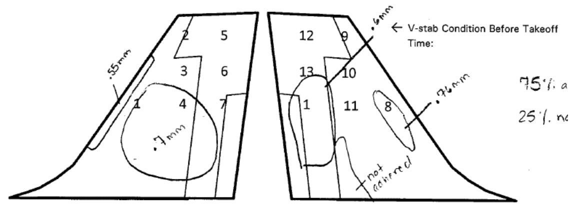
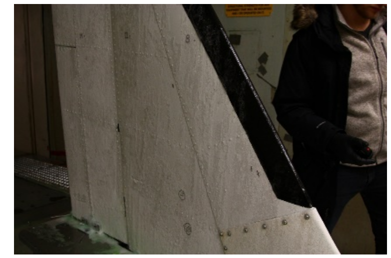
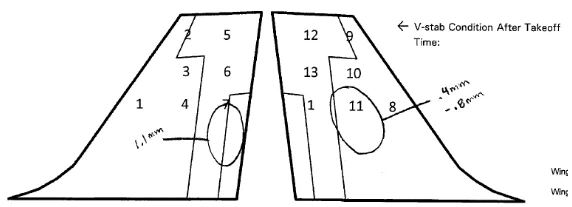
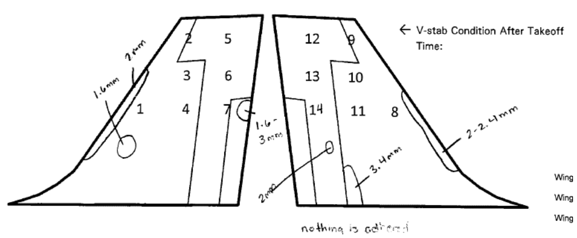
Wing Position Reference Guide

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.

Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.

Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

Run #	Fluid	Tunnel Temp Before Test (°C)	Precipitation Type	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Effective Side Slip Angle (°)	Rudder Deflection Angle (°)	Run Comments	Peak Contamination Thickness (from post-run diagram)
22	Polar Guard Advance (Type IV PG)	-7.6	Freezing Rain	25	35	0	-10	Longest exposure for Type IV-PG freezing rain runs. Note: Before takeoff run diagram shown in column L, as post takeoff run diagram simply notes "same as above" Diagram notes contamination is "75% adhered, 25% not adhered"	0.76mm
23	Polar Guard Advance (Type IV PG)	-8.2	Freezing Rain	25	20	0	-10	Shorter exposure for Type IV-PG freezing rain runs for comparative reference	1.1mm
19	Dow EG-106 (Type IV EG)	-6.8	Snow	25	35	0	-10	Cold temperature Type IV EG run for comparison	3.4mm

Run #	Post-Run Contamination Documentation Diagram	Post-Run Photo - Port Side	Post-Run Photo - Starboard Side
22			
23			
19			

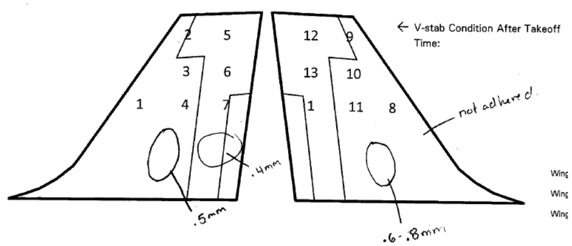
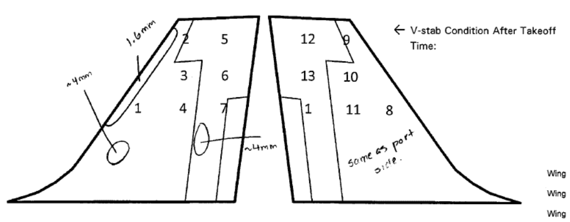
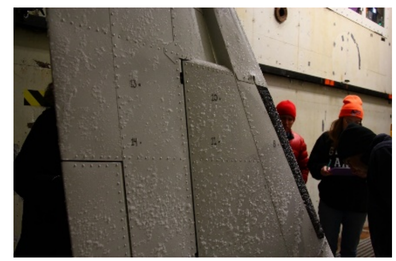
Wing Position Reference Guide

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.

Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.

Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

Run #	Fluid	Tunnel Temp Before Test (°C)	Precipitation Type	Precipitation Rate (g/dm²/h)	Exposure Time (min)	Effective Side Slip Angle (°)	Rudder Deflection Angle (°)	Run Comments	Peak Contamination Thickness (from post-run diagram)
25	Dow Type I PG	-8.2	Snow	25	5	0	-10	Cold temperature Type I PG run for comparison (short exposure)	0.8mm
16	Dow Type I PG	-2.8	Snow	25	40	0	-10	Warm temperature Type I PG run for comparison (longer exposure)	1.6mm

Run #	Post-Run Contamination Documentation Diagram	Post-Run Photo - Port Side	Post-Run Photo - Starboard Side
25			
16			

Wing Position Reference Guide

Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.

Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.

Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.