WIND TUNNEL TESTING WITH A COMMON RESEARCH MODEL VERTICAL STABILIZER: WINTER 2022-23

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Prepared by:

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APS Aviation Inc.

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PREFACE

Under contract to the Transport Canada Programs Group 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 evaluate and develop the use of artificial snow machines for holdover time development;
- To conduct wind tunnel testing with a vertical stabilizer common research model to evaluate contaminated fluid flow-off before and after a simulated takeoff;
- To conduct comparative endurance time testing and evaluate endurance times in mixed conditions including snow and freezing fog;
- To conduct general and exploratory de/anti-icing research;
- To conduct analysis to support harmonization of the Transport Canada and the Federal Aviation Administration visibility table guidance;
- 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.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2022-23 are documented in five reports. The titles of the reports are as follows:

- TP 15557E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2022-23 Winter;
- TP 15558E Regression Coefficients and Equations Used to Develop the Winter 2023-24 Aircraft Ground Deicing Holdover Time Tables;
- TP 15559E Aircraft Ground Icing General Research Activities During the 2022-23 Winter;
- TP 15560E Wind Tunnel Testing with a Common Research Model Vertical Stabilizer: Winter 2022-23; and
- TP 15561E Testing and Evaluation of Mixed Phase Icing Conditions: Winter 2022-23.

In addition, the following interim report is being prepared:

- *Artificial Snow Research Activities for the 2022-23 Winter*.

This report, TP 15560E, has the following objective:

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

This objective was met by conducting a series of representative scaled 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 Programs Group 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, Steven D. Baker, David Beals, Benjamin Bernier, Chloë Bernier, Sarah Chadzak, Brandon Cheer, Devin Costain, John D'Avirro, Christopher D'Avirro, Peter Dawson, Sean Devine, Kyra Kinderman-McCormick, Peter Kitchener, Francine De Ladurantaye, Diana Lalla, Christian Mulligan, Shamim Nakhaei, Sumedha Raj Pilli, Dany Posteraro, Marco Ruggi, Javad Safari, James Smyth, Yi Tian, Jeffrey Wajsberg, Charles Wilson, and Ian Wittmeyer.

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

PROJECT ACKNOWLEDGEMENTS

APS Aviation Inc. would like to acknowledge the following:

- The team at the National Research Council Canada who operate the Icing Wind Tunnel, especially Catherine Clark, 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 and Mark Weiland 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 Programs Group 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 representative scaled tests in the National Research Council Canada (NRC) 3 m x 6 m Icing Wind Tunnel (IWT) evaluating contaminated fluid flow-off from a common research model (CRM) vertical stabilizer.

The model was painted light grey using aircraft-grade paint and load cells were installed into the four-point force balance to allow for the collection of aerodynamic data. In a dry and clean configuration, the model demonstrated a linear and symmetric trend in side force and yawing moment with rudder deflection at sideslip angles $\beta = 0°$ and $\beta = -10°$.Sandpaper roughness testing indicated that most of the side force was generated by the forward half of main element, and sealing the gap with speed tape was observed to offset the loss in side force generated by the sandpaper. The 40-grit sandpaper testing provided representative effects as compared to fluid and contamination tests. In general, fluid, fluid and contamination, and roughness testing all had comparable maximum side force losses, however, the worst-case conditions may not have been explored yet as testing was generally limited to warmer temperatures above -10ºC. Laser scanning of the model with ice contamination was possible once coated with titanium dioxide (TiO_2) mixture for both pre- and post-simulated takeoff surface conditions, however the laser scanning process was very long, and should be improved for efficiency.

The test campaign confirmed the desired performance of the new model equipped with load balances to evaluate aerodynamic forces and helped in understanding the effects of sideslip and rudder deflection on pristine and contaminated fluid flow-off. However, due to the unseasonably warm temperatures encountered during this test campaign, the effects of fluid and contamination at colder temperatures remains unknown and remains a gap in our understanding, therefore cold weather data collection is recommended to provide a better understanding of the sensitivity and context of the results.

Future testing should build upon the testing matrix described in this report. Testing should also focus on areas not extensively explored during this preliminary phase, including colder temperatures, different contamination types and levels, asymmetric contamination, and different fluids. Future research should focus on refining these observations through testing and industry discussion, with the aim of developing recommended operational practices.

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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 du groupe de programmes 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 à échelle représentative 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 d'un modèle consensuel de recherche (MCR).

Le modèle a été peint en gris pâle au moyen de peinture de qualité aéronautique et des capteurs de pression ont été installés dans le dispositif d'équilibrage des forces en quatre points pour permettre la collecte de données aérodynamiques. Dans une configuration sèche et propre, le modèle a démontré une tendance linéaire et symétrique de la force transversale et du moment de lacet avec un débattement de la direction aux angles de dérapage $\beta = 0°$ et $\beta = -10°$. Les essais de rugosité du papier abrasif ont démontré que la plus grande partie de la force transversale était générée par la moitié avant de l'élément principal, et on a observé que le scellage de l'espace au moyen d'une feuille d'aluminium autocollante permettait de compenser la perte de force transversale engendrée par le papier abrasif. L'essai avec papier abrasif à grain 40 a généré des effets représentatifs, comparativement aux essais sur les liquides et la contamination. En général, les essais sur les liquides, sur les liquides et la contamination et sur la rugosité ont tous produit des résultats comparables en matière de perte maximale de force transversale; toutefois, les conditions les plus défavorables n'ont peut-être pas encore été explorées, puisque les essais étaient généralement limités à des températures plus chaudes, supérieures à -10 °C. Le modèle avec contamination par la glace a pu être balayé par faisceau laser une fois recouvert d'un mélange de dioxyde de titane (TiO_2) pour les conditions de surface avant et après la simulation du décollage; le processus de balayage laser était toutefois très long et son efficacité devrait être améliorée.

La campagne d'essais a permis de confirmer le rendement souhaité du nouveau modèle équipé de dispositifs d'équilibrage des charges afin d'évaluer les forces aérodynamiques, et a aidé à comprendre les effets du dérapage et du débattement de la direction sur le ruissellement des liquides intacts et contaminés. Cependant, en raison des températures anormalement chaudes au cours de cette campagne d'essais, les effets de la contamination des liquides à des températures plus froides demeurent inconnus et constituent une lacune dans notre compréhension. Par conséquent, il est recommandé de recueillir des données par temps froid pour pouvoir mieux comprendre la sensibilité et le contexte des résultats.

Les futurs essais devraient s'appuyer sur la matrice décrite dans le présent rapport. Ils doivent également être axés sur les aspects n'ayant pas été explorés de façon approfondie au cours de cette phase préliminaire, par exemple, les températures plus froides, les divers types et degrés de contamination, la contamination asymétrique et les différents liquides. Les prochaines recherches devraient viser à parfaire ces observations au moyen d'essais et de discussions entre parties prenantes du secteur dans le but d'élaborer des pratiques d'exploitation recommandées.

17. Mots clés Stabilisateur vertical, modèle consensuel de recherche, rotation à vitesse élevée, rotation à faible vitesse, type II, type III, type IV, adhérence des liquides, ruissellement des liquides, soufflerie, soufflerie de givrage, comportement aérodynamique des ailes, défaillance d'un moteur, vent de travers	18. Diffusion Disponible auprès du Centre d'innovation du groupe de programmes de Transports Canada

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EXECUTIVE SUMMARY

Under contract to the Transport Canada (TC) Programs Group 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 2022-23 in support of the aircraft ground icing research program.

As part of a larger research program, APS conducted a series of representative scaled 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 2022-23 with the primary objective of continuing aerodynamic testing to document contaminated fluid flow-off using a custom-built common research model (CRM) vertical stabilizer.

Conclusions

Based on results from paint trials conducted using test plates, the model was painted light grey using aircraft-grade paint, the same colour as the NRC Convair underside. Load cells were installed into the four-point force balance to allow for the collection of aerodynamic data.

The CRM vertical stabilizer was tested in a dry and clean configuration and demonstrated a linear and symmetric trend in side force and yawing moment with rudder deflection (δ_r) at sideslip $\beta = 0°$ and $\beta = -10°$. This indicated that the model stall was not within the parameter ranges tested and that the data compares well to the computational fluid dynamics (CFD) predictions calculated by NRC and used during the model design.

Sandpaper roughness testing indicated that most of the side force was generated by the forward half of main element, and sealing the gap between the main element and the rudder with speed tape was observed to offset the loss in side force generated by the sandpaper. The 40-grit sandpaper testing provided representative effects as compared to fluid and contamination tests.

In general, fluid, fluid and contamination, and roughness testing all had comparable maximum side force losses, however, the worst-case conditions may not have been explored yet as testing was generally limited to warmer temperatures above -10°C.

In addition, the overall precipitation "catch factor" may vary based on precipitation types and wind speed, and these effects can impact fluid performance and flow-off, and this is an area of research that should be explored further.

Laser scanning of the model with ice contamination was possible once coated with titanium dioxide (TiO_2) mixture for both pre- and post-simulated takeoff surface conditions, however the laser scanning process was very long, and should be improved for efficiency.

In general, the test campaign confirmed the desired performance of the new model equipped with load balances to evaluate aerodynamic forces and helped in understanding the effects of sideslip and rudder deflection on pristine and contaminated fluid flow-off. However, due to the unseasonably warm temperatures encountered during this test campaign, the effects of fluid and contamination at colder temperatures remains unknown and remains a gap in our understanding.

Recommendations

Due to the unseasonably warm temperatures encountered during this test campaign, the effects of fluid and contamination at colder temperatures remains unknown and remains a gap in our understanding. Cold weather data collection is recommended to provide a better understanding of the sensitivity and context of the results.

Future testing should build upon the testing matrix described in this report, including calibration and validation of procedures, dry surface testing and tuft visualization, and fluid testing and flow-off characterization. Testing should also focus on areas not extensively explored during this preliminary phase, including colder temperatures, different contamination types and levels, asymmetric contamination, and different fluids.

Research conducted to date is still exploratory and has indicated benefits associated with specific fluid type applications (thickened or not) depending on the types of contamination and temperatures tested. Future research should focus on refining these observations through testing and industry discussion, with the aim of developing recommended operational practices.

SOMMAIRE

En vertu d'un contrat avec le groupe des programmes du 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 2022-2023 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 à échelle représentative 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 objectifs

On constate un manque de normalisation dans le traitement de surfaces verticales dans le cadre d'opérations de dégivrage. Un programme d'essais en soufflerie a été élaboré pour l'hiver 2022-2023 avec comme principal objectif de poursuivre des tests d'aérodynamisme visant à documenter les propriétés de ruissellement de liquides contaminés sur la surface d'un stabilisateur vertical d'un modèle consensuel de recherche (MCR) construit sur mesure.

Conclusions

À la lumière des résultats des essais de peinture réalisés sur des plaques, le modèle a été peint au moyen d'une peinture de qualité aéronautique gris pâle, soit la même couleur que la surface inférieure du Convair du CNRC. Des capteurs de pression ont été installés dans le dispositif d'équilibrage des forces en quatre points pour permettre la collecte de données aérodynamiques.

Le stabilisateur vertical du MCR a été testé dans une configuration sèche et propre, et a démontré une tendance linéaire et symétrique de la force transversale et du moment de lacet avec un débattement de la direction (δ_r) aux angles de dérapage $\beta = 0°$ et $\beta = -10°$. Ces constatations indiquent que le décrochage du modèle ne se situait pas dans les plages de paramètres testées et que les données pouvaient être comparées aux prévisions en matière de mécanique des fluides numérique calculées par le CNRC et utilisées lors de la conception du modèle.

Les essais de rugosité du papier abrasif ont démontré que la plus grande partie de la force transversale était générée par la moitié avant de l'élément principal, et on a observé que le scellage de l'espace entre l'élément principal et la gouverne de direction au moyen d'une feuille d'aluminium autocollante permettait de compenser la perte de force transversale engendrée par le papier abrasif. L'essai avec papier abrasif à grain 40 a généré des effets représentatifs, comparativement aux essais sur les liquides et la contamination.

En général, les essais sur les liquides, sur les liquides et la contamination et sur la rugosité ont tous produit des résultats comparables en matière de perte maximale de force transversale; toutefois, les conditions les plus défavorables n'ont peut-être pas encore été explorées, puisque les essais étaient généralement limités à des températures plus chaudes, supérieures à -10 °C. De plus, le « facteur d'accrétion » des précipitations global peut varier en fonction du type de précipitations et de la vitesse du vent, et ces effets peuvent avoir une incidence sur la performance et le ruissellement des liquides; il s'agit d'un domaine de recherche qui devrait être exploré davantage.

Le modèle avec contamination par la glace a pu être balayé par faisceau laser une fois recouvert d'un mélange de dioxyde de titane (TiO_2) pour les conditions de surface avant et après la simulation du décollage; le processus de balayage laser était toutefois très long et son efficacité devrait être améliorée.

En général, la campagne d'essais a permis de confirmer le rendement souhaité du nouveau modèle équipé de dispositifs d'équilibrage des charges afin d'évaluer les forces aérodynamiques, et a aidé à comprendre les effets du dérapage et du débattement de la direction sur le ruissellement des liquides intacts et contaminés. Cependant, en raison des températures anormalement chaudes au cours de cette campagne d'essais, les effets de la contamination des liquides à des températures plus froides demeurent inconnus et constituent une lacune dans notre compréhension.

Recommandations

En raison des températures anormalement chaudes au cours de cette campagne d'essais, les effets de la contamination des liquides à des températures plus froides demeurent inconnus et constituent une lacune dans notre compréhension. Il est recommandé de recueillir des données par temps froid pour pouvoir mieux comprendre la sensibilité et le contexte des résultats.

Les futurs essais devraient s'appuyer sur la matrice décrite dans le présent rapport, y compris l'étalonnage et la validation des procédures, les essais sur surface sèche et la visualisation à l'aide de fils, ainsi que les essais sur les liquides et la caractérisation du ruissellement. Ils doivent également être axés sur les aspects n'ayant pas été explorés de façon approfondie au cours de cette phase préliminaire, par exemple, les températures plus froides, les divers types et degrés de contamination, la contamination asymétrique et les différents liquides.

Les recherches effectuées à ce jour sont encore de nature exploratoire, et ont démontré des avantages associés à des applications spécifiques au type de liquides (épaissis ou non) selon les types de contamination et les températures évaluées. Les prochaines recherches devraient viser à parfaire ces observations au moyen d'essais et de discussions entre parties prenantes du secteur dans le but d'élaborer des pratiques d'exploitation recommandées.

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GLOSSARY

APS	APS Aviation Inc.
ARP	Aerospace Recommended Practice
AWG	Aerodynamics Working Group
C	Chord
C_Y	Side Force Coefficient
CCTV	Closed-Circuit Television
CFD	Computational Fluid Dynamics
CRM	Common Research Model
EG	Ethylene Glycol
FAA	Federal Aviation Administration
HOT	Holdover Time
HVLP	High-Volume Low-Pressure
IWT	3 m x 6 m Icing Wind Tunnel
LE	Leading Edge
LED	Light-Emitting Diode
NASA	National Aeronautics and Space Administration
NRC	National Research Council Canada
OAT	Outside Air Temperature
OEI	One Engine Inoperative
OEM	Original Equipment Manufacturer
PG	Propylene Glycol

RTD	Resistance Temperature Detector
SAE	SAE International
TC	Transport Canada
TE	Trailing Edge
TiO_2	Titanium Dioxide
V1	The maximum speed at which a rejected takeoff can be initiated in the event of an emergency
β	Effective Sideslip
δ_r	Rudder Deflection

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 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 freezing point depressant 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, enhance safety, and advance 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 Programs Group 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 2022-23 in support of the aircraft ground icing research program. Each major project completed as part of the 2022-23 research is documented in a separate individual report. This report documents the wind tunnel research performed to evaluate contaminated fluid flow-off from a common research model (CRM) 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 vertical stabilizer, while others only consider treatment during ongoing freezing precipitation. In some cases, the vertical stabilizer may only be deiced while the wings are being deiced and anti-iced. Some reports have also indicated that treatment of the vertical stabilizer may worsen takeoff performance as the anti-icing fluid on the vertical stabilizer 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 vertical stabilizer 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?

TC and the FAA, with the support of APS, the National Aeronautics and Space Administration (NASA), and the NRC, have been directing research to explore de/anti-icing of vertical surfaces. The discussion has also been brought to the SAE International (SAE) G-12 Aerodynamics Working Group (AWG) meetings to obtain additional expert feedback from the group's original equipment manufacturers (OEMs) and aerodynamicists.

1.2 Previous Related Research

Flat plate testing conducted in 2015-16 demonstrated the variability in both fluid protection times and characteristics of contamination on vertical surfaces (see the TC report, TP 15340E, *Aircraft Ground Icing General Research Activities During the 2015-16 Winter* [1]).

In 2019-20, aerodynamic testing to document contaminated fluid flow-off on a Piper PA-34-200T Seneca II vertical stabilizer demonstrated that fluid and contamination were always present at the end of each test run (see the TC report, TP 15454E, *Wind Tunnel Testing to Evaluate Contaminated Fluid Flow-Off from a Vertical Stabilizer* [2]). 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. The applicability of these results to commercial airliners was reviewed by the SAE G-12 AWG, and it was recommended that a new generic model be designed to allow for better, more relevant data to be collected.

In 2021-22, based on feedback and support from the AWG, a CRM was designed and built by the NRC based on an analysis of existing aircraft geometries. The size and shape of this model was better suited as compared to the previous Piper Seneca II model (see the TC report, TP 15538E, *Wind Tunnel Testing to Evaluate Contaminated Fluid Flow-Off from a Common Research Model Vertical Stabilizer* [3]).

Testing provided valuable insight into fluid and contamination flow-off and the effects of sideslip and rudder deflection on pristine and contaminated fluid flow-off. The installation of load cells for future testing was recommended to further support the interpretation of the acquired data through comparative aerodynamic load forces analysis.

1.3 Working Group Discussions

Regular discussions have been held with the SAE G-12 AWG to ensure the continued relevance of the methodologies and data collected. As it is anticipated that the test data collected could be used by aircraft manufacturers to better understand the expected impacts on their specific aircraft types, OEMs have been encouraged (via the forum of the AWG) to participate in the test plan preparation, observe the testing, and provide feedback on the analysis.

1.4 Project Objectives

A wind tunnel testing program was developed for the winter of 2022-23 with the primary objectives of conducting aerodynamic testing to document contaminated fluid flow-off on a CRM vertical stabilizer.

Table 1.1 reports the number of vertical stabilizer wind tunnel tests conducted during the winter of 2022-23, broken down by test objective. It should be noted that this research was conducted 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 2022-23 Vertical Stabilizer Tests by Objective

Objective #	Objective	# of Runs
1	Dry Wing Model Performance	29
2	Sandpaper Roughness Testing	32
3	Fluid Testing and Flow-Off Characterization	51
Total		**112**

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;
c) Section 4 describes the results from the calibration and validation of procedures;
d) Section 5 describes the results from the dry model, tuft visualization, boundary layer rake, and sandpaper roughness testing;
e) Section 6 describes the results from the fluid testing and flow-off characterization;
f) Section 7 describes the results of the laser scanning of fluid and contamination;
g) Section 8 provides a summary of the conclusions; and
h) Section 9 provides a summary of the recommendations.

2. METHODOLOGY

This section provides a brief description of the test methodology and equipment specific to the representative scaled aerodynamic tests conducted at the NRC 3 m x 6 m Icing Wind Tunnel (IWT).

2.1 Test Schedule

Ten days of overnight testing were organized between January 15 and January 26, 2023. 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 a summary of the total wind tunnel tests performed with the CRM vertical stabilizer. 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 as needed by TC, the FAA, and APS.

Table 2.1: 2022-23 Summary of Total Tests

Date (Start date of testing)	**# of Tests Run**
January 15, 2023	13
January 16, 2023	6
January 17, 2023	10
January 18, 2023	11
January 19, 2023	12
January 22, 2023	13
January 23, 2023	25
January 24, 2023	10
January 25, 2023	8
January 26, 2023	4
Total	**112**

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 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 application 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 simulated 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 Sandpaper Testing Procedure

In addition to the fluid testing, dry model performance tests and sandpaper roughness testing were performed to characterize the wing model. These were separate tests that did not require fluids and were conducted with a variety of different testing parameters specific to the individual objectives.

Testing was conducted with 40-grit sandpaper applied to various components of the CRM to simulate fluid/contamination effects and help understand model performance. The sandpaper represents a roughness to chord ratio (k/c) of 0.00025. The model was covered from leading edge (LE) to trailing edge (TE); sandpaper was then removed in segments loosely simulating shearing fluid/contamination during a takeoff. Testing was done with both sides covered in sandpaper, as well as the suction side only.

Additional tests were done to simulate fluid/contamination blocking the gap between the main element and the rudder on the pressure side by using speed tape to seal that gap in the model.

All tests were configured to $\beta = 0$, $\delta_r = -10$, and the data was analysed by evaluating the performance loss ($\%\Delta C_Y$) for each sandpaper and/or sealed gap test versus the clean $\beta = 0$, $\delta_r = -10$ baseline test run.

2.1.3 Test Sequence

The duration 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. A precipitation exposure time of 30 minutes was used for illustrative purposes; this time varied for each test depending on the objective.

It should be noted that the dry wing characterization and sandpaper roughness tests did not require application of fluid or precipitation.

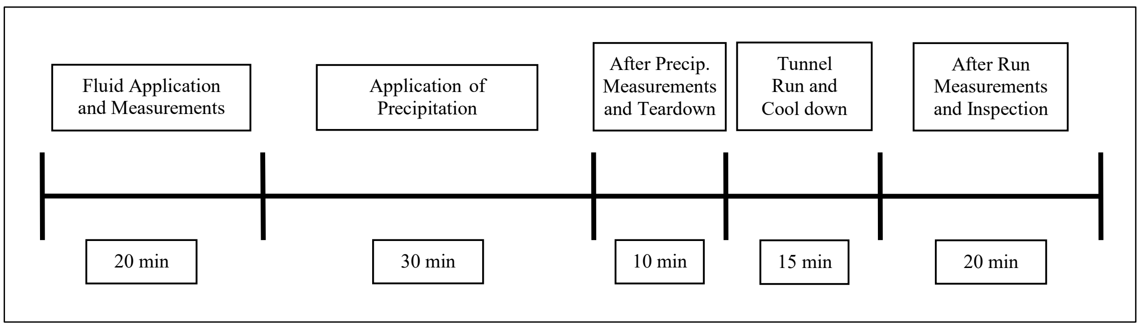


Figure 2.1: Typical Wind Tunnel Test Timeline

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 with the CRM installed. 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 with inserts is 3 m (10 ft.) wide by 5 m (16 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.

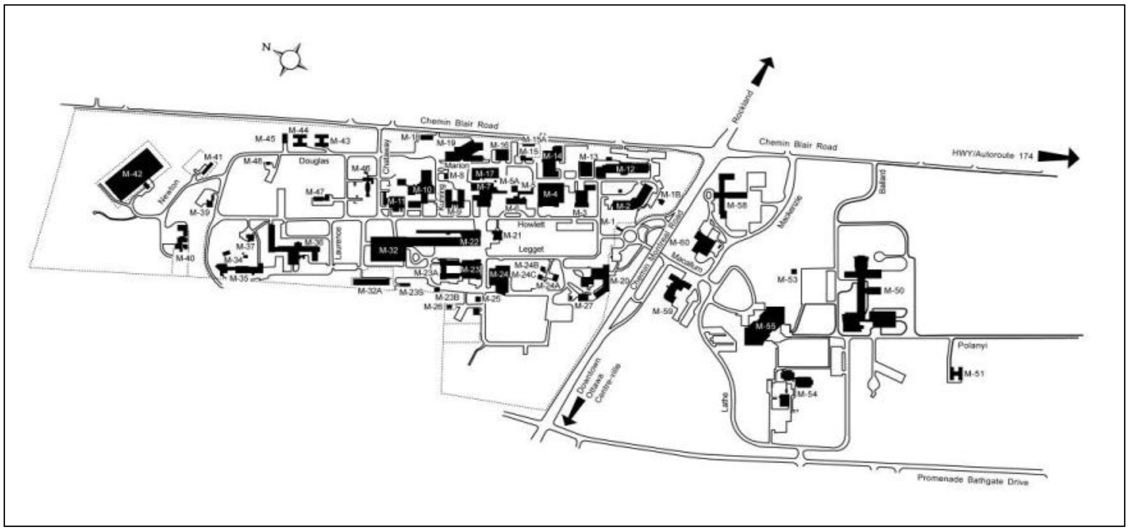


Figure 2.2: Schematic of the NRC Montreal Road Campus

2.2.2 Common Research Model Vertical Stabilizer

In consultation with the SAE G-12 AWG, a CRM was designed and built by the NRC (see Photo 2.3) in 2021-22. The geometry (see summary in Table 2.2) was based on an analysis of existing aircraft geometries and designed to be a best representation of commercial aviation aircraft while maintaining a size and span of the section small enough to test in the IWT. The model (see Figure 2.3) was initially installed and characterized for testing in the winter of 2021-22 (see Photo 2.4). The model was then painted and had load cells installed to be able to record aerodynamic load forces for the winter of 2022-23.

Table 2.2: Summary of CRM Geometry Parameters

Parameter	Value
Aspect Ratio	1.07
Taper Ratio (C_{tip}/C_{base})	0.50
¼ Chord Sweep	40°
C_{Rudder}/C_{VS}	0.38*
Height	1.83 m / 6 ft.
Mean Chord	1.71 m / 5.6 ft.

*Design specification for rudder chord ratio was 0.3, but the actual value was 0.38.

As shown in Photo 2.5, 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 (β) of the model ranged from -10 to +10 degrees. The rudder was servo-actuated and could also be changed dynamically prior to and during a test. The rudder deflection (δ_r) of the model ranged from -20 to +20 degrees. The sideslip and rudder limits were selected such that they provided adequate structural safety margins based on the load forces when in the tunnel. Crosswind effects were simulated by controlling the effective sideslip. Figure 2.4 and Figure 2.5 demonstrates the effective sideslip and rudder deflection angles that would occur during a crosswind takeoff roll and lift-off. Figure 2.6 demonstrates the simulated crosswind takeoff configuration used in the NRC IWT for the scenario shown in Figure 2.5. Figure 2.7 describes the sign conventions when referring to the CRM in the IWT.

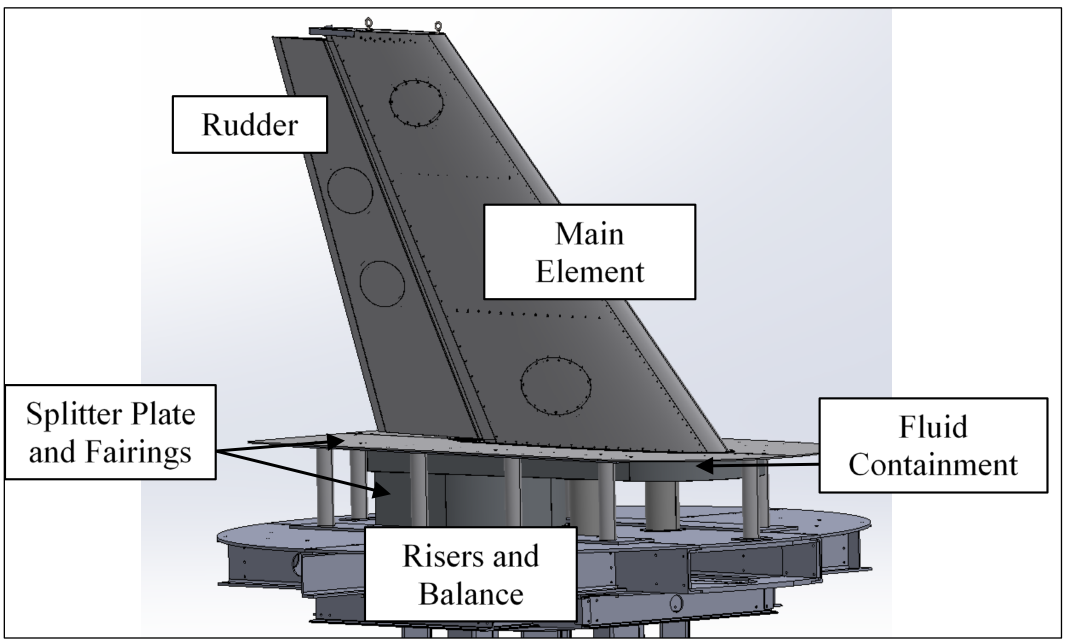


Figure 2.3: Common Research Model Vertical Stabilizer

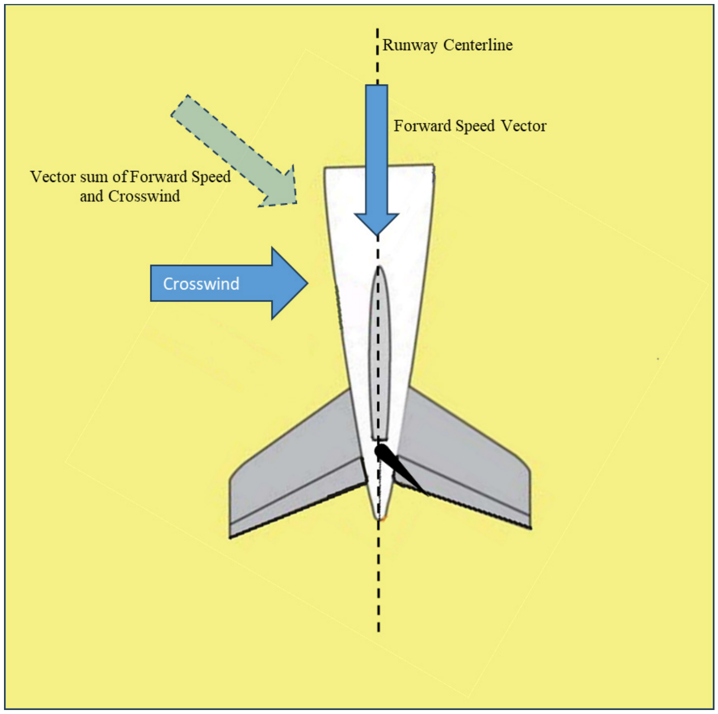


Figure 2.4: Effective Sideslip and Rudder Deflection Angles During a Crosswind Takeoff Roll (Prior to Rotation Holding Runway Centerline)

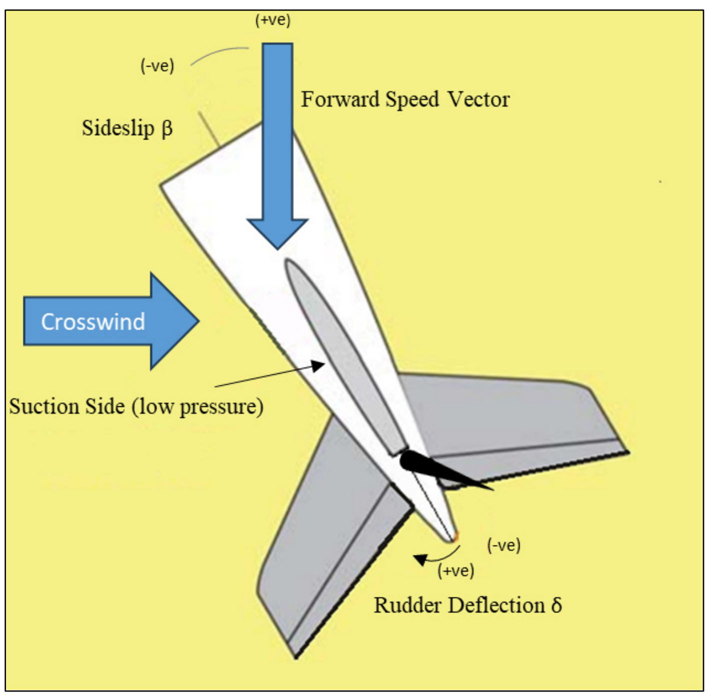


Figure 2.5: Effective Sideslip and Rudder Deflection Angles During a Crosswind Lift-off (After Rotation with Weather Vane Effect)

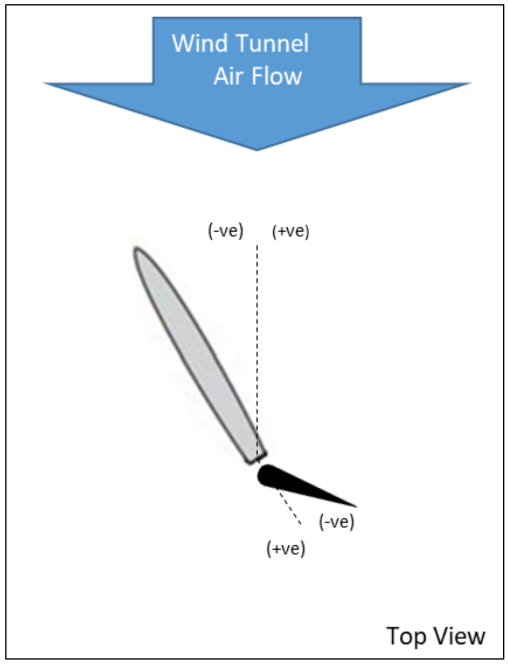


Figure 2.6: Simulated Crosswind Takeoff Configuration in the NRC IWT

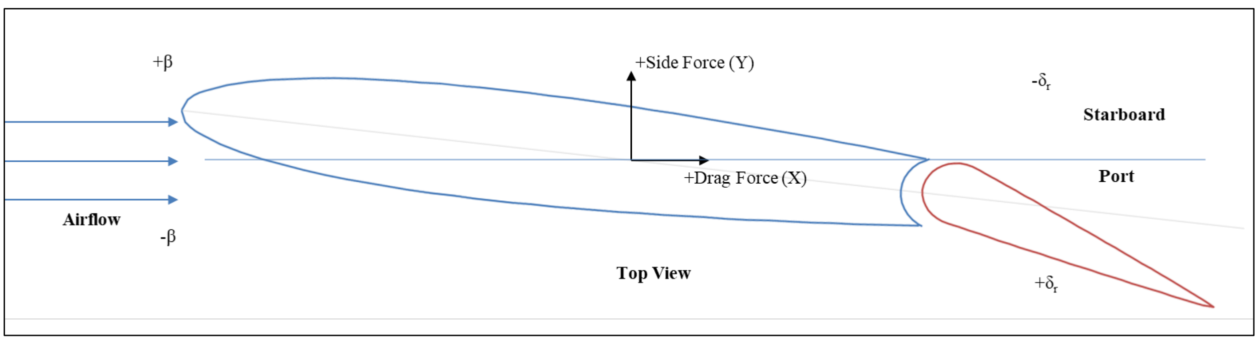


Figure 2.7: Sign Conventions for the CRM

2.2.3 Wind Tunnel Measurements

The vertical stabilizer was equipped with eight 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. The eight RTDs were positioned at approximately one- and two-thirds the span of the port and starboard sides of the main element and rudder. The RTDs were labeled Main Port Lower, Main Port Upper, Main Starboard Lower, Main Starboard Upper, Rudder Port Lower, Rudder Port Upper, Rudder Starboard Lower, and Rudder Starboard Upper, accordingly. Figure 2.8 shows the approximate location of the RTDs on the port side; the starboard side would be symmetric, but it is not shown in the figure.

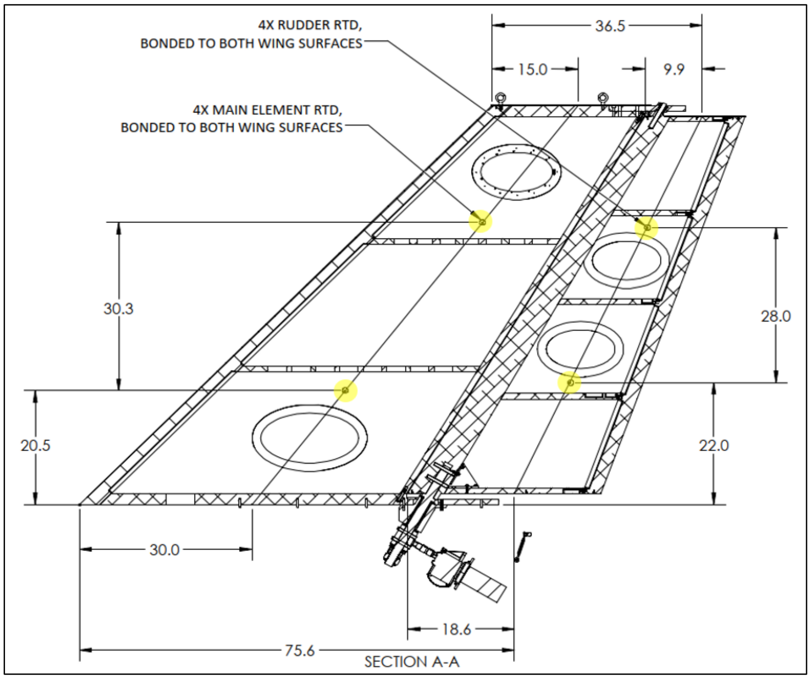


Figure 2.8: Location of RTDs on CRM

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.

The vertical stabilizer model was designed to include load cells for aerodynamic measurements; however, due to issues with procurement, dummy cells were used for Winter 2021-22 and the actual load cells were only installed for the winter of 2022-23. The load cells allowed for the measurement and calculation of side force, yaw, drag, lift, pitch, and roll, and they included corrections for solid blockage, wake blockage, and streamline curvature. Early data reviews during testing in 2022-23 indicated that side force, yaw, and drag were the most relevant to the research objectives; however, as testing progressed, analysis became focused on side force and evaluating the fluid and contamination tests against the clean baseline tests.

To evaluate the effect of fluid and contamination on rudder effectiveness, the delta difference in measured side force was calculated at the simulated time of rotation using Equation 2.1 and Equation 2.2.

$$C_Y = \frac{Side\ Force\ (Y)}{Dynamic\ Pressure\ \times Area}$$

Equation 2.1: Side Force Coefficient Calculation

$$\%\Delta C_Y = \frac{(C_{Y(Clean)} - C_{Y(Fluid\ or\ Cont.)})}{C_{Y(Clean)}} \times 100$$

Equation 2.2: Performance Loss Calculation

For a given run, $C_{Y-Clean}$ was the respective comparative run using the same β and δ_r, i.e., a fluid test with β = 0, δ_r = -20 was compared to a dry model test with β = 0, δ_r = -20. The delta side force was then reported in percentage as $\%\Delta C_Y$.

Many of the observations in this report are based upon the aerodynamic data obtained from the force balance, focusing mainly on the side force. As such, the force balance data has proven to be very useful in the interpretation of the fluid and contamination behaviour. It is important to keep in mind that the measurements are specific to this model configuration and may or may not be applicable to other configurations.

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 on-site inside a refrigerated truck (see Photo 2.6). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.7) to obtain the required ice pellet size range. Hand-held motorized dispensers (see Photo 2.8) 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. Historical 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 on-site inside a refrigerated truck (see Photo 2.6). Cubes of ice were crushed and passed through calibrated sieves (see Photo 2.7) 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 that is typically used for HOT testing and has been retrofitted to work in the wind tunnel for the RJ wing model 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 2.9). 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 representative scaled and plate testing, the rate limits defined in SAE Aerospace Recommended Practice (ARP) 5485, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type II, III, and IV* (4), and SAE ARP5945, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type I* (5), for standard HOT testing were referenced. Figure 2.9 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.

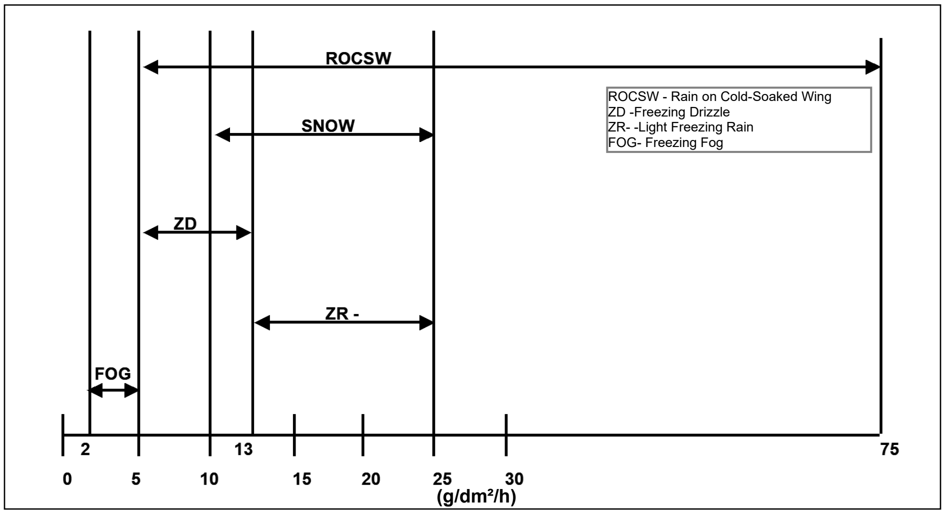


Figure 2.9: Precipitation Rate Breakdown

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, only limited simulated crosswind contamination tests (asymmetric contamination) were performed; most test runs performed featured symmetric contamination (equal mass of contamination applied to the model on both sides). The asymmetric contamination remains a parameter to investigate in future testing.

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 representative scaled 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.

For the purposes of this testing, 10 percent failure coverage of the vertical stabilizer was used as the standard fail call, and in some cases application of contamination was allowed to proceed beyond the standard failure (up to 100 percent failure coverage).

2.5 Test Equipment

A considerable amount of test equipment was used. 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. Due to facility occupancy and travel restrictions, a closed-circuit television (CCTV) system was installed by APS and allowed remote viewing of the tests by participants using iPad®-based software. The CCTV cameras were positioned to provide different angle views of the vertical stabilizer model. Additional light-emitting diode (LED) lighting was installed in the observation windows in the steel doors overlooking the test area to further enhance the videography. Photo 2.10 demonstrates the camera setup used for the testing period.

2.5.2 Refractometer/Brixometer

Fluid freezing points were measured using a hand-held Misco 10431VP refractometer with a Brix scale (shown in Figure 2.10). The freezing points of the various fluid samples were determined using the conversion curve or table provided to APS by the fluid manufacturer.

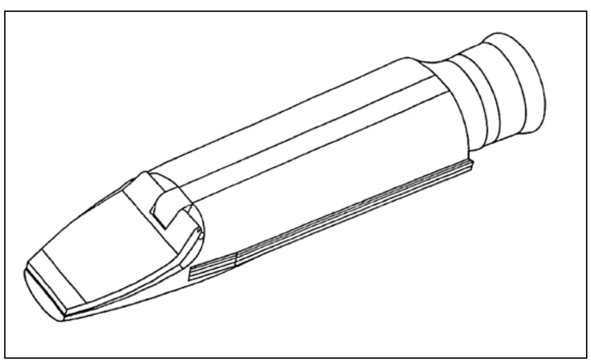


Figure 2.10: Hand-Held Refractometer/Brixometer

2.5.3 Wet Film Thickness Gauges

Wet film thickness gauges, shown in Figure 2.11, 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.

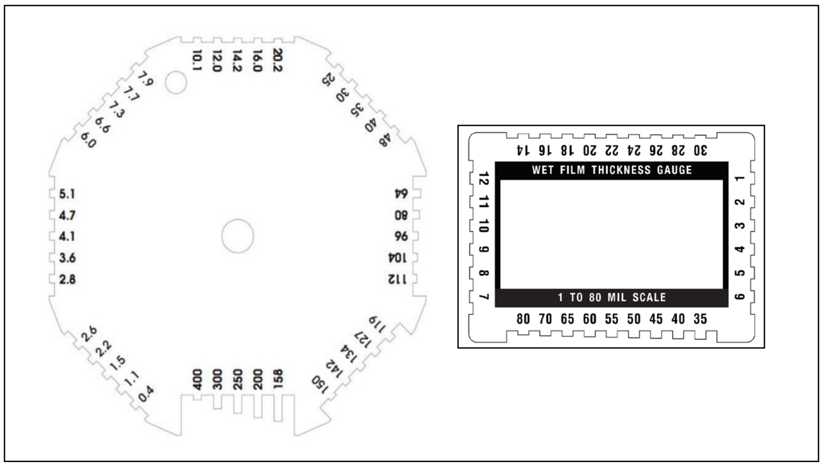


Figure 2.11: Wet Film Thickness Gauges

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 2-3 seconds read time. Figure 2.12 shows the schematic of the probes.

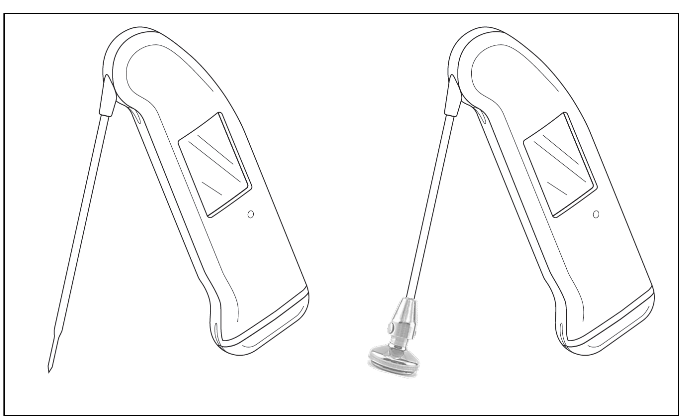


Figure 2.12: Hand-Held Immersion and Surface Temperature Probes

2.6 Personnel

During the fluid testing and exploratory research testing, three APS staff members were required to conduct the tests, and six additional personnel from Ottawa were tasked to manufacture and dispense precipitation 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. Three persons from the NRC were required to operate the tunnel. Representatives from TC and the FAA provided direction in testing and participated virtually as observers. Photo 2.11 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 vertical stabilizer 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 simulated 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 the high-resolution photos and video have been provided to TC in electronic format and can be made available upon request.

2.9 De/Anti-Icing Fluids and Application

Three fluids were used for the majority of the testing. Information about the fluids used as well as the viscosity measured by APS using the manufacturer recommended method is listed below.

- Dow Chemical Company UCAR™ propylene glycol (PG) aircraft deicing Concentrate Type I Fluid (measured viscosity n/a).
- Cryotech Deicing Technology Polar Guard® Advance Type IV Fluid (measured viscosity 13,660 cP).
- Dow Chemical Company UCAR™ Endurance EG106 De/Anti-Icing Type IV Fluid (measured viscosity 42,600 cP).

Additional limited testing was also conducted with the following:

- Clariant Produkte (Deutschland) GmbH Max Flight SNEG Type IV Fluid (measured viscosity 28,700 cP);
- Cryotech Deicing Technology Polar Guard® Xtend Type IV Fluid (measured viscosity 14,020 cP); and
- JSC RCP Nordix Defrost North 4 Type IV Fluid (measured viscosity 4,060 cP).

Due to the height and vertical orientation of the model, pouring fluid by hand was not possible; battery-operated garden sprayers were used to apply the fluid to the CRM. The atomizing nozzle was removed from the sprayer to prevent shearing of the fluid. The sprayer's hand-held wand attachment allowed personnel to apply fluid directly to the model with minimal waste. Due to the cold weather effects on the battery, additional care was taken to ensure batteries were fully charged and ready on standby for testing. The fluid application process was refined on the first day of testing and typically took about 10 minutes to complete for each test.

2.9.1 Viscometer

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

2.9.2 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 2.12). 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 simulated 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 with the CRM

Photo 2.3: Collage of Images During Manufacturing of the CRM

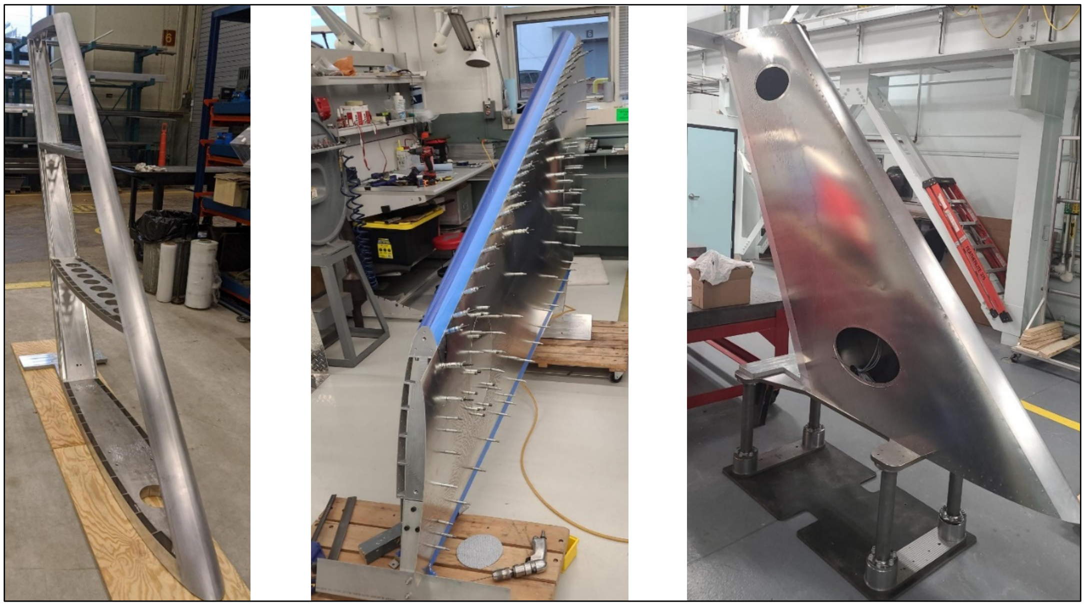


Photo 2.4: Vertical Stabilizer Mounted in the NRC IWT for Testing with Fluid Being Applied

Photo 2.5: View of Splitter Plate Used to Mount the CRM

Photo 2.6: Refrigerated Truck Used for Manufacturing Ice Pellets

Photo 2.7: Calibrated Sieves Used to Obtain Desired Size Distribution

Photo 2.8: Ice Pellet/Snow Dispenser Operated by APS Personnel

Photo 2.9: Simulating Freezing Rain with Garden Sprayer

Photo 2.10: Location of Osmo® and CCTV Video Camera Mounts

Photo 2.11: 2022-23 Research Team

Photo 2.12: Garden Sprayer Hand-Held Wand Applying Fluid

Photo 2.13: Brookfield Digital Viscometer

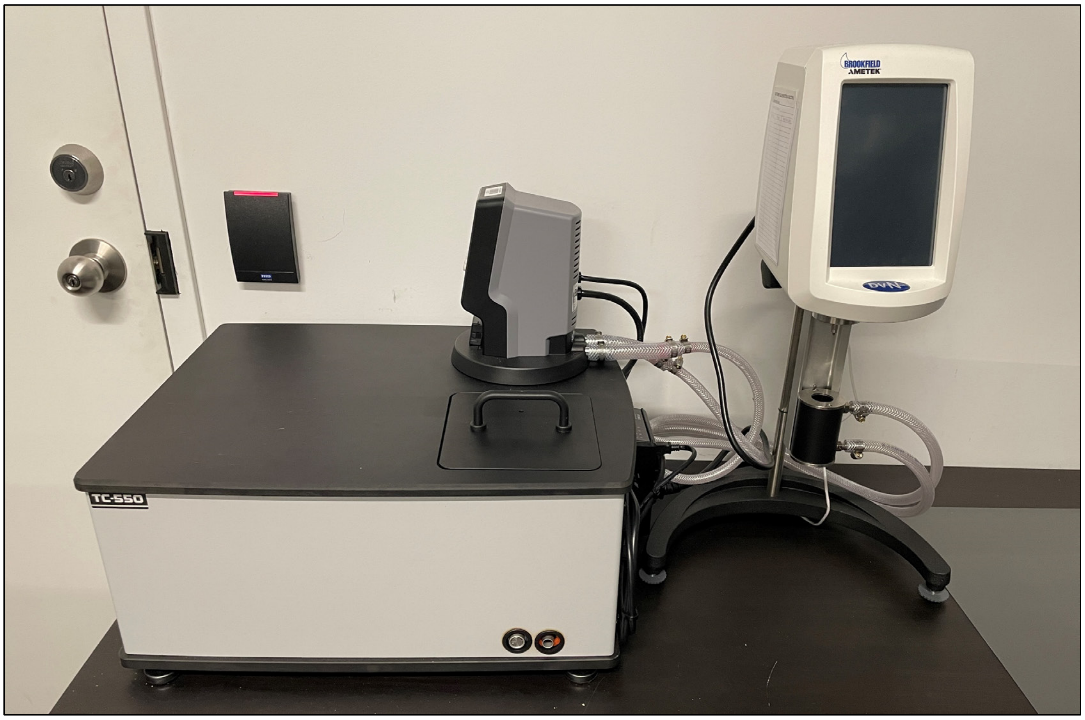
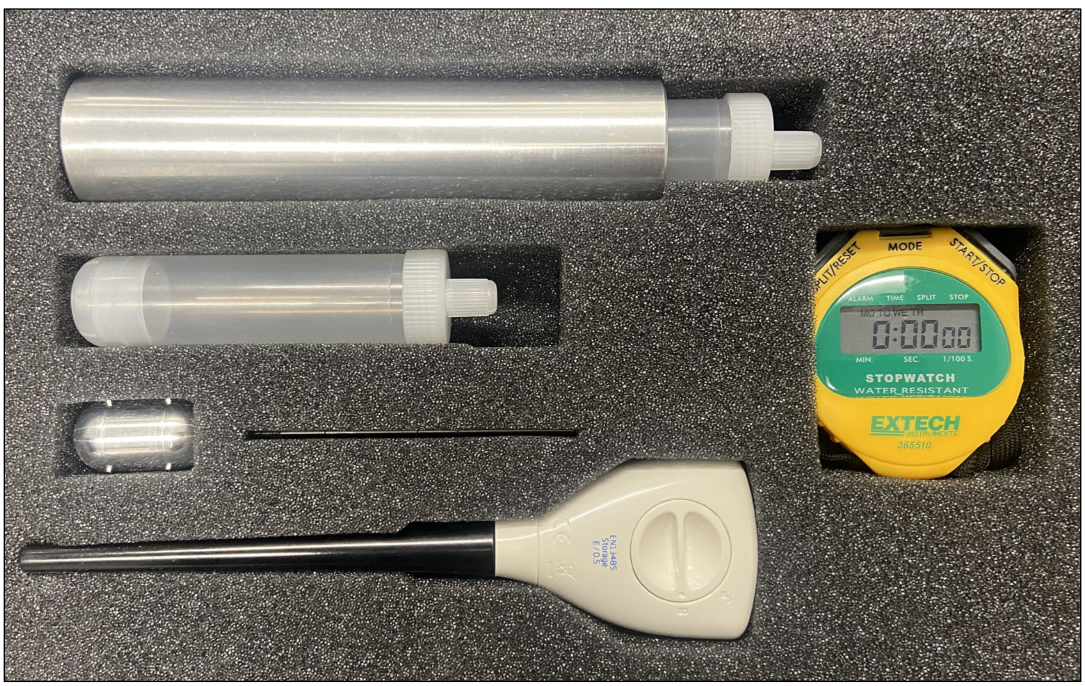


Photo 2.14: Stony Brook PDVdi-120 Falling Ball Viscometer



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3. REPRESENTATIVE SCALED DATA COLLECTED

3.1 Test Log

A detailed log of the tests conducted in the NRC IWT during the winter of 2022-23 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.
Test Objective:	Description of the test objective.
Fluid Name:	Aircraft anti-icing fluid used during the test.
Sideslip β*:*	The effective sideslip angle of the model during the test, ranging from +10° to -10°.
Rudder Deflection δ_r*:*	The rudder deflection angle during the test, ranging from +20° to -20°.
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.
Extra Comments:	Extra comments describing methodology changes or observations related to the test.

Table 3.1: Test Log

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
1	15-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	-7.9	n/a	-	-	
2	15-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	-7.9	n/a	-	-	
3	15-Jan-23	Dry Wing	None	β=0°	δ=0°	100	-7.57	n/a	-	-	
4	16-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	-8.2	n/a	-	-	
5	16-Jan-23	Dry Wing	None	β=0°	δ=-20°	100	-8.42	n/a	-	-	
6	16-Jan-23	Dry Wing	None	β=-10°	δ=-20°	100	-7.78	n/a	-	-	
7	16-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	-6.99	n/a	-	-	
8	16-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	-6.99	n/a	-	-	
9	16-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=0°	100	-9.21	-10.1	-	-	
10	16-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-9.96	-10.5	-	-	
11	16-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-20°	100	-9.35	-10.8	-	-	
12	16-Jan-23	Fluid Only	Polar Guard Advance	β=-10°	δ=-20°	100	-10.68	-11	-	-	
13	16-Jan-23	Fluid Only	EG106	β=0°	δ=-10°	100	-10.96	-10.9	-	-	

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
14	16-Jan-23	Dry Wing	None	β = 0°	δ = -10°	100	-1.5	-4.5	-	-	
15	16-Jan-23	Dry Wing	None	β = 0° and -10 when δ = -20	δ = 5 to -20 @5° incr.	100	-1.5	-4.5	-	-	
16	16-Jan-23	Fluid and Cont. (FZR)	Polar Guard Advance	β = 0°	δ = -10°	100	-5.7	-5.7	FZRA: 25	75	Exposure to HOT (Laser scan)
17	17-Jan-23	Dry Wing	None	β = 0°	δ = -10°	100	-5.53	n/a	-	-	
18	17-Jan-23	Fluid and Cont. (FZR)	Polar Guard Advance	β = 0°	δ = -10°	100	-3.8	-6.7	FZRA: 25	13.5	Exposure to V-Stab 10% fail (Laser scan)
19	17-Jan-23	Fluid and Cont. (FZR)	Polar Guard Advance	β = 0°	δ = -10°	100	-5	-6.7	FZRA: 25	19	Exposure to V-Stab 10% fail. Since contamination only on 1 side happened at 19 minutes rather than 13.5 minutes.
20	17-Jan-23	Dry Wing	None	β = 0°	δ = -10°	100	0.62	n/a	-	-	
21	17-Jan-23	Dry Wing	None	β = 0° and -10 when δ = -20	δ = 5 to -20 @5° incr.	100	0.62	n/a	-	-	
22	17-Jan-23	Fluid Only	EG106	β = 0°	δ = 0°	100	-0.51	-2.4	-	0	
23	17-Jan-23	Fluid Only	EG106	β = 0°	δ = -10°	100	0.2	-2.3	-	0	
24	18-Jan-23	Fluid Only	EG106	β = 0°	δ = -20°	100	0.17	-2.2	-	0	
25	18-Jan-23	Fluid Only	EG106	β = -10°	δ = -20°	100	0.5	-2.1	-	0	Post-run laser scan
26	18-Jan-23	Fluid Only	Polar Guard Xtend	β = 0°	δ = -10°	100	0.5	-1.7	-	0	Repeatability test (1 of 4)
27	18-Jan-23	Fluid Only	Polar Guard Xtend	β = 0°	δ = -10°	100	-0.2	-1.3	-	0	Repeatability test (2 of 4)

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
28	18-Jan-23	Fluid Only	Polar Guard Xtend	β=0°	δ=-10°	100	-0.7	-1.4	-	0	Repeatability test (3 of 4)
29	18-Jan-23	Fluid Only	Polar Guard Xtend	β=0°	δ=-10°	100	-1.2	-1.3	-	0	Repeatability test (4 of 4)
30	18-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	4.32	n/a	-	-	
31	18-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	4.32	n/a	-	-	
32	18-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	0.8	0.3	-	0	
33	18-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-20°	100	0.4	0.3	-	0	
34	18-Jan-23	OEI Simulations	Polar Guard Advance	β=0°	δ=0 to -20 @100kts	100	1.27	-0.2	-	0	OEI
35	19-Jan-23	OEI Simulations	Polar Guard Advance	β=+10° to 0 @100kts	δ=-20°	100	0	0	-	0	OEI + Xwind
36	19-Jan-23	OEI Simulations	Polar Guard Advance	β=+10° to -10 @100kts	δ=-20°	100	0.2	0	-	0	OEI + Xwind (2)
37	19-Jan-23	Fluid Only	Polar Guard Advance	β=-10°	δ=-20°	100	1.2	0.1	-	0	
38	19-Jan-23	Fluid Only	Dow Type I PG STD MIX 55/45	β=0°	δ=-10°	100	1	-0.1	-	0	STD MIX
39	19-Jan-23	Fluid Only	Dow Type I PG STD MIX 55/45	β=0°	δ=-20°	100	1.7	-0.3	-	0	STD MIX
40	19-Jan-23	Fluid Only	Dow Type I PG STD MIX 55/45	β=-10°	δ=-20°	100	1.6	-0.4	-	0	STD MIX
41	19-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	0.25	n/a	-	-	

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
42	19-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	0.25	n/a	-	-	
43	19-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-1.62	-3.1	-	0	
44	19-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-1.1	-3	-	0	Fluid Only Pressure Side
45	19-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-1.57	-2.9	-	0	Fluid Only Suction Side
46	20-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-0.79	-2.7	-	0	Fluid Only Rudder Both Sides
47	20-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-0.87	-2.5	-	0	Fluid Only Rudder Pressure Side
48	20-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-0.46	-2.2	-	0	Fluid Only Rudder Suction Side
49	20-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-0.57	-2.2	-	0	
50	20-Jan-23	Fluid Only	Polar Guard Advance	β=0°	δ=-10°	100	-0.51	-2.2	-	0	Fluid Only Pressure Side
51	20-Jan-23	Fluid Only	Max Flight SNEG	β=0°	δ=-10°	100	-0.76	-2.3	-	0	Fluid Variance v. PGA and others
52	20-Jan-23	Fluid Only	Defrost North 4	β=0°	δ=-10°	100	0.29	-2.1	-	0	Fluid Variance v. PGA and others
53	22-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	8.1	n/a	-	-	
54	22-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	8.1	n/a	-	-	
55	22-Jan-23	Dry Wing	None	β=-10°	δ=5 to -20 @5° incr.	100	8.1	n/a	-	-	

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
56	22-Jan-23	Roughness	None	β=0°	δ=-10°	100	9.37	-1.2	-	0	3M tape both sides, 40 Grit Port Rudder (Suction Side)
57	22-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	9.37	-1.2	-	0	3M tape both sides, 40 Grit Port Rudder (Suction Side)
58	22-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	9.37	-1.2	-	0	3M tape both sides, 40 Grit Port Rudder (Suction Side)
59	23-Jan-23	Roughness	None	β=0°	δ=-10°	100	9.17	-1.3	-	0	3M tape both sides, 40 Grit Both Rudder Sides
60	23-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	9.17	-1.3	-	0	3M tape both sides, 40 Grit Both Rudder Sides
61	23-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	9.17	-1.3	-	0	3M tape both sides, 40 Grit Both Rudder Sides
62	23-Jan-23	Roughness	None	β=0°	δ=-10°	100	10.38	-1.7	-	0	3M + 40 Grit Main and Rudder w/o LE
63	23-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	10.38	-1.7	-	0	3M + 40 Grit Main and Rudder w/o LE
64	23-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	10.38	-1.7	-	0	3M + 40 Grit Main and Rudder w/o LE
65	23-Jan-23	Roughness	None	β=0°	δ=-10°	100	6.76	-1.7	-	0	3M + 40 Grit Main and Rudder w/o LE, taped gap
66	23-Jan-23	Roughness	None	β=0°	δ=-10°	100	2.91	-0.1	-	0	3M + 40 Grit Main and Rudder w/o LE
67	23-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	2.91	-0.1	-	0	3M + 40 Grit Main and Rudder w/o LE
68	23-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	2.91	-0.1	-	0	3M + 40 Grit Main and Rudder w/o LE
69	23-Jan-23	Roughness	None	β=0°	δ=-10°	100	7.56	-0.1	-	0	3M + 40 Grit Main and Rudder + Leading Edge

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
70	23-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	7.56	-0.1	-	0	3M + 40 Grit Main and Rudder + Leading Edge
71	23-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	7.56	-0.1	-	0	3M + 40 Grit Main and Rudder + Leading Edge
72	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	9.98	-0.2	-	0	3M + 40 Grit LE + Main, and Rudder on Suction Side
73	24-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	9.98	-0.2	-	0	3M + 40 Grit LE + Main, and Rudder on Suction Side
74	24-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	9.98	-0.2	-	0	3M + 40 Grit LE + Main, and Rudder on Suction Side
75	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	6.34	0	-	0	3M + 40 Grit LE + Main/Rudder on Suction Side, Gap Sealed
76	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	6.08	0	-	0	3M + 40 Grit Main/Rudder on Suction Side. No LE
77	24-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	6.08	0	-	0	3M + 40 Grit Main/Rudder on Suction Side. No LE
78	24-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	6.08	0	-	0	3M + 40 Grit Main/Rudder on Suction Side. No LE
79	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	7.1	0.5	-	0	3M + 40 Grit 1/2 of Main + Full Rudder on Suction Side
80	24-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	7.1	0.5	-	0	3M + 40 Grit 1/2 of Main + Full Rudder on Suction Side
81	24-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	7.1	0.5	-	0	3M + 40 Grit 1/2 of Main + Full Rudder on Suction Side
82	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	1.51	0.6	-	0	3M + 40 Grit 1/2 of Main + Full Rudder on Suction Side. Sealed Gap
83	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	2.82	0.7	-	0	3M Tape, 40 Grit Port Rudder (Suction Side)

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
84	24-Jan-23	Roughness	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	2.82	0.7	-	0	3M Tape, 40 Grit Port Rudder (Suction Side)
85	24-Jan-23	Roughness	None	β=-10°	δ=5 to -20 @5° incr.	100	2.82	0.7	-	0	3M Tape, 40 Grit Port Rudder (Suction Side)
86	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	1.27	0.7	-	0	3M Tape, 40 Grit Port Rudder (Suction Side) + Sealed Gap
87	24-Jan-23	Roughness	None	β=0°	δ=-10°	100	1.13	0.8	-	0	Clean Wing, Sealed Gap
88	24-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	2.35	n/a	-	0	
89	24-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	2.35	n/a	-	0	
90	24-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	2.35	n/a	-	0	
91	24-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	-1.08	n/a	-	0	
92	24-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	-1.08	n/a	-	0	
93	24-Jan-23	Fluid and Cont. (PL)	Polar Guard Advance	β=0°	δ=-10°	100	-3.17	-5.4	PL: 75	15	Exposure to AT
94	25-Jan-23	Fluid and Cont. (PL)	EG106	β=0°	δ=-10°	100	-2.76	-6.6	PL: 75	35	Exposure to AT
95	25-Jan-23	Fluid and Cont. (SN)	EG106	β=0°	δ=-10°	100	-4.97	-7.4	SN: 25	40	Exposure to HOT
96	25-Jan-23	Fluid and Cont. (SN)	EG106	β=0°	δ=-10°	100	-4.98	-7.7	SN: 25	10	Exposure to V-Stab 10% fail

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
97	25-Jan-23	Fluid and Cont. (SN + FZRA)	EG106	β=0°	δ=-10°	100	-4.06	-9.1	SN: 18, FZRA: 21	11	Frankenstein Test: SN + FZRA applied freestyle over run 96 residual fluid. Total estimate SN 44+ FZRA 21 = 65 g/dm²/h for 11 minutes.
98	25-Jan-23	Adhered Contamination from Run 97	None	β=0°	δ=-10°	100	-1.67	-9.3	-	0	Repeat of #97 adhered contamination
99	25-Jan-23	Adhered Contamination from Run 97	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	-1.67	-9.3	-	0	Repeat of #97 adhered contamination
100	25-Jan-23	Adhered Contamination from Run 97	None	β=-10°	δ=5 to -20 @5° incr.	100	-1.67	-9.3	-	0	Repeat of #97 adhered contamination
101	25-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	-5	-6.6	-	0	Snow Ingestion during Baseline Test
102	25-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	-5	-6.6	-	0	Snow Ingestion during Baseline Test
103	25-Jan-23	Fluid and Cont. (SN)	Polar Guard Advance	β=0°	δ=-10°	100	-4.57	-6.3	SN: 25	65	Exposure to HOT Note: Snow ingestion during test
104	26-Jan-23	Fluid and Cont. (SN)	Polar Guard Advance	β=0°	δ=-10°	100	-4.08	-6	SN: 25	15	Exposure to V-Stab 10% fail Note: Snow ingestion during test
105	26-Jan-23	Fluid and Cont. (SN)	Dow Type I PG 10° Buffer (-5 / -15)	β=0°	δ=-10°	100	n/a	n/a	SN: 25	25	Exposure to Type IV HOT (25 min) ABORTED RUN AT 81 KTS DUE TO FOD IN TUNNEL
106	26-Jan-23	Fluid and Cont. (SN)	Dow Type I PG 10° Buffer (-5 / -15)	β=0°	δ=-10°	100	-3.92	-5.2	SN: 25	25	Repeat of residual fluid/contamination of run 105. Note: Snow ingestion during test.
107	26-Jan-23	Fluid and Cont. (SN)	Dow Type I PG 10° Buffer (-5 / -15)	β=0°	δ=-10°	100	-3.3	-4.8	SN: 25	5	Exposure to HOT Note: Snow ingestion during test.
108	26-Jan-23	Fluid and Cont. (SN + FZRA)	EG106	β=0°	δ=-10°	100	-2.67	-4.4	SN: 20, FZRA: 5	45	Exposure to FZRA HOT (45 min) - laser scan
109	26-Jan-23	Dry Wing	None	β=0°	δ=-10°	100	-2.28	-5.1	-	0	
110	26-Jan-23	Dry Wing	None	β=0° and -10 when δ=-20	δ=5 to -20 @5° incr.	100	-2.28	-5.1	-	0	

Table 3.1: Test Log (cont'd)

Test #	Date	Test Objective	Fluid Name	Sideslip (β)	Rudder Deflection (δr)	Speed (kts)	Tunnel Temp. Before Test (°C)	OAT Before Test (°C)	Precip. Rate (g/dm²/h)	Exposure Time (min)	Extra Comments
111	26-Jan-23	Fluid and Cont. (SN)	EG106	β = 0°	δ = -10°	100	-5.34	-5.9	SN: 25	40	Exposure to SN HOT (40 min) with 2x catch factor (Simulating higher wind speeds and increased catch factor) - laser scan
112	26-Jan-23	Cont. (FZRA)	None	β = 0°	δ = -10°	100	-5.72	-7.2	FZRA: 13	20	20 minutes no fluid - just FZRA on dry wing - laser scan Droplets not freezing, even with small fans - freezing occurred during takeoff.

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4. MODIFICATIONS TO TEST EQUIPMENT AND PROCEDURES

This section describes the modifications to test equipment and testing procedures.

4.1 Selection of Paint Colour for the Common Research Model

When the CRM was initially built for testing in the 2021-22 winter season, the model was left unpainted (bare aluminum). It was noted during the testing that year that this caused some challenges relating to the photography and videography, including surface reflectivity to light and flashes, fluids not being apparent after application (especially those with less dye), and snow and ice contamination not being apparent after application on a fluid-covered surface.

In addition to the above challenges, it was determined that the NASA laser scanning system that was being used in the 2022-23 tests would require a painted surface to minimize reflection for proper functionality. As a result, it was decided to paint the CRM in advance of the 2022-23 testing session.

To determine the most appropriate colour to paint the CRM, paint trials were conducted using test plates mounted on vertical stands. The test plates were painted various shades of colour from white to grey to black, including both glossy and flat finishes (see Figure 4.1). Fake snow (typically used for Christmas decorations) made from small pieces of reflective plastic film was used to evaluate the appearance of contamination on the painted surfaces. The use of fake snow was necessary as these trials were performed outdoors prior to the 2022-23 winter.

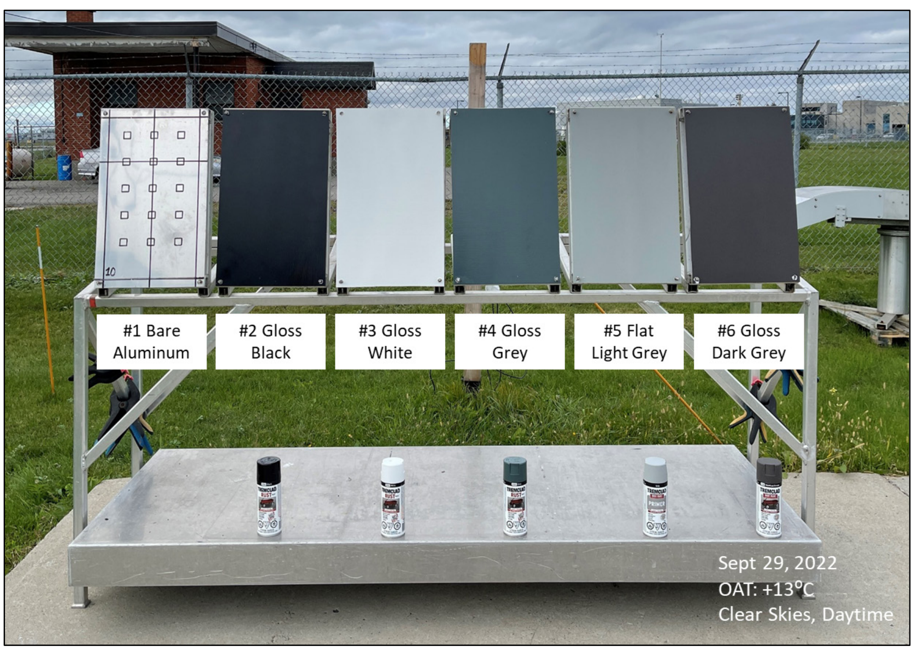

Figure 4.1: Setup with Different Colour Test Plates

The trials consisted of application of anti-icing fluid and fake snow to the painted surfaces, followed by photography and evaluation of the visibility of fluid/contamination on the different surfaces evaluated. Trials were conducted with both ethylene glycol (EG) and PG Type IV fluids (see Figure 4.2).

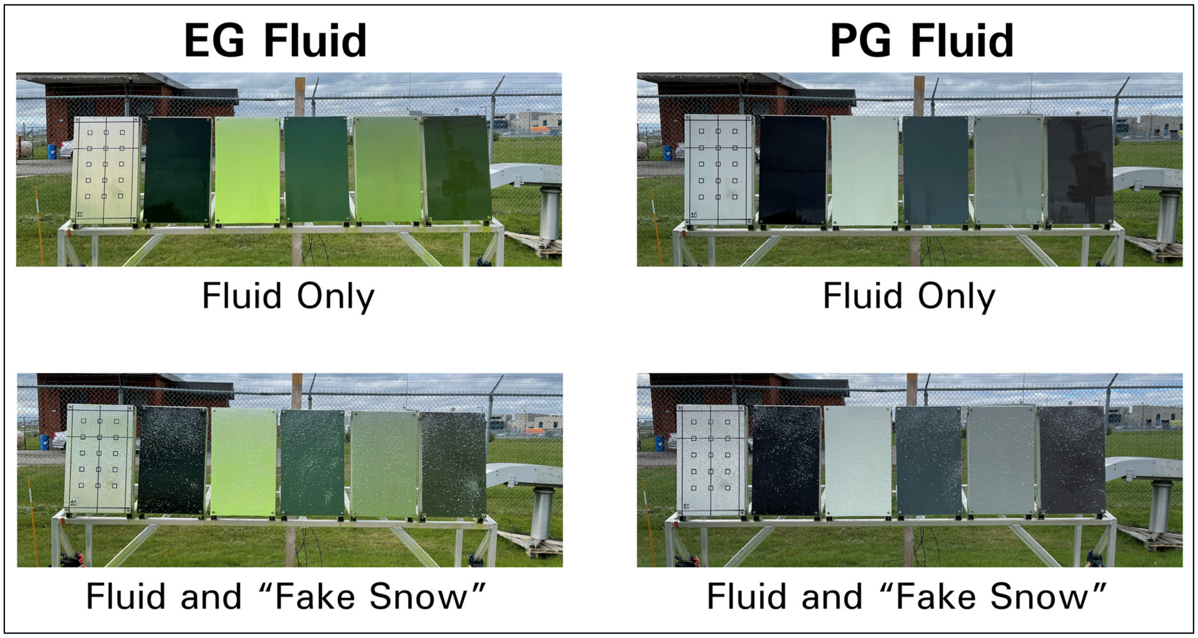

Figure 4.2: Results with EG and PG Fluids and Fake Snow

Review of the photography obtained during the trials indicated that white paint makes identifying snow and ice contamination more difficult (as seen with the Piper model), but it is best for seeing fluid. Black paint is best for seeing contamination (hence why representative surfaces are often black), but seeing fluid is more difficult. There were no significant differences noted when comparing glossy and flat finishes of the same paint colour. Type I fluid was not tested; however, it is expected that results would be similar to the Type IV PG fluid with faint dye. The colour of "#5 Flat Light Grey" paint seems to provide the best combination of fluid and contamination visibility, and based on discussions with the NRC, the model was painted light grey using aircraft-grade paint, the same colour as the NRC Convair underside (see Figure 4.3).

Figure 4.3: NRC Convair Aircraft Showing Grey Underside

4.2 Installation of Load Cells and Shakedown Runs

The CRM vertical stabilizer was mounted on a four-point balance with risers within the wind tunnel turntable floor. This configuration lifted the main element out of the floor boundary layer and provided space for the rudder motion system. The setup includes four six-component load cells, with thermal blankets to maintain a constant temperature. See Figure 4.4 for details.

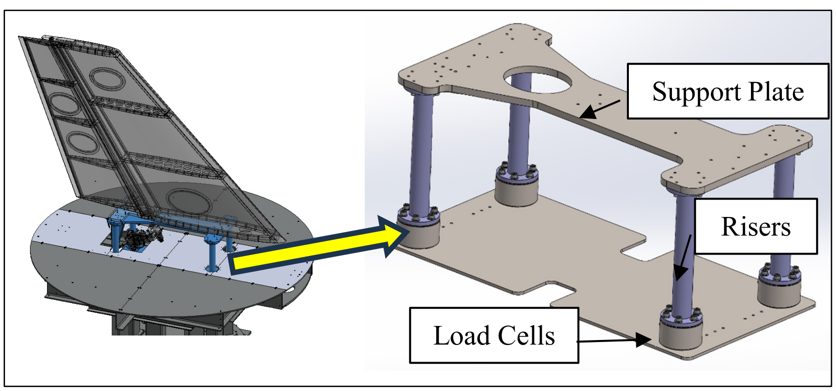

Figure 4.4: CRM Risers and Balance Configuration

As this was the first year of testing with the load cells installed in the CRM, several tests were done prior to the start of the testing program to verify proper functionality, and additional tests were done on the first day of testing.

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5. DRY MODEL, TUFT VISUALIZATION, BOUNDARY LAYER RAKE, AND SANDPAPER ROUGHNESS TESTING

This section describes activities related to the dry model testing, tuft visualization testing, boundary layer rake testing, and sandpaper roughness testing.

5.1 Dry Model Performance

The CRM vertical stabilizer was tested in a dry and clean configuration to document the baseline aerodynamic performance of the model. The aerodynamic data collected and analysed by the NRC (shown in Figure 5.1) demonstrated a linear trend in side force and yawing moment with rudder deflection at β = 0° and β = -10°, indicating that the model stall was not within the parameter ranges tested (otherwise the data plotted would not be linear). The model performance was generally symmetric with rudder deflection through 0° for side force and yawing moment and went through the 0-0 intercept (when looking at the -5º, 0º, and +5º rudder deflection data for side force and yaw). The data measured during the dry model runs compared well to the values predicted through computational fluid dynamics (CFD) modelling performed by the NRC and used during the model design.

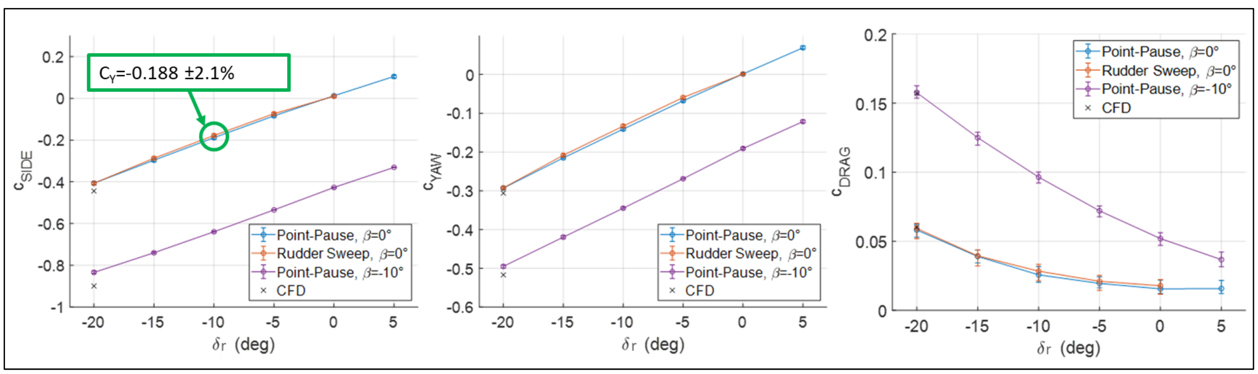


Figure 5.1: Dry Model Performance Data Provided by the NRC

The model uncertainty and the level of experimental variation were documented (see Figure 5.2). In addition, dry wing repeatability testing was conducted with three tests (#1, #4, and #7) configured to β = 0, δ_r = -10, and the standard deviation of the side force and yaw measured was 3 percent and 1 percent, respectively (see Figure 5.3).

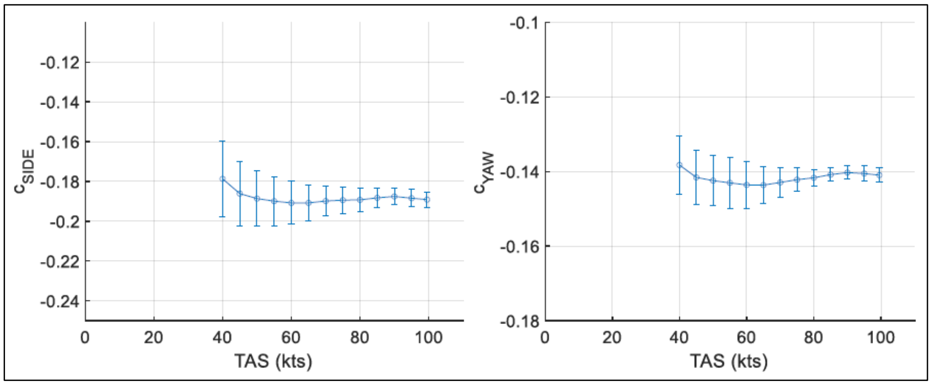


Figure 5.2: Side Force and Yaw Uncertainty Analysis by the NRC

Side Force

Profile		β=0º, δr=-10º
Average		**-0.187756667**
Runs	1	-0.19255
	4	-0.18199
	7	-0.18873
STDEV		**-3%**

Yawing Moment

Profile		β=0º, δr=-10º
Average		**-0.141646667**
Runs	1	-0.14254
	4	-0.14213
	7	-0.14027
STDEV		**-1%**

Figure 5.3: Dry Wing Repeatability Analysis

5.2 Tuft Visualization

Tuft testing was conducted with the unpainted CRM model in 2021-22. The historical results are presented in Table 5.1 for reference. The data from this testing was used to establish the standard research configuration (which could be modified based on objective), which included sideslip angle set to 0º and rudder deflection angle set to -10º. For the winter of 2022-23, this testing was not repeated as the results are expected to remain the same: the painting of the model should have little or no effect.

Table 5.1: Historical 2021-22 Summary of Aerodynamic Effects Visualized with Varying Configurations

Effective Sideslip β	**Rudder Deflection** δ_r	**Flow Characteristics**
0˚	0˚	Flow was attached with little turbulence.
-10˚	-20˚	Flow separated on the rudder on the suction side.
0˚	-12˚	Flow separation began (tip of the rudder on the suction side).
0˚	**-10˚**	**Selected as the limit of where flow remained attached.**

5.3 Boundary Layer Rake Testing

Boundary layer testing was conducted with the unpainted CRM model in 2021-22. The data collected in 2021-22 was analysed by the NRC and a separate report was prepared for TC and the FAA. The following provides a summary.

The test runs indicated uniform, attached flow and model symmetry with rudder deflection and sideslip. The results also indicated that the boundary layer was thicker at the bottom of the model and thinner at the top, a function of the greater chord length at the bottom. It was also observed that the boundary layer was thicker over the rudder compared to the main element. While the main element of the vertical stabilizer did not stall, the rudder stalled at 12° for the top boundary layer rake and at 16° for the middle and bottom boundary layer rakes. The boundary rake testing did not identify any anomalies in the flow characteristics.

For the winter of 2022-23, this testing was not repeated as the results are expected to remain the same: the painting of the model should have little or no effect.

5.4 Sandpaper Roughness Testing

Testing was conducted with 40-grit sandpaper applied to various components of the CRM to simulate fluid/contamination effects and help understand model performance. Figure 5.4 and Figure 5.5 provide the testing details showing the configuration tested, photos of both sides of the CRM, and the calculated delta loss in side force as compared to the clean baseline.

A selection of the data was plotted in Figure 5.6 and Figure 5.7 showing data from tests runs where sandpaper was applied to the suction side only, as well as from runs where sandpaper was applied to both sides.

The maximum $\%\Delta C_Y$ observed during the suction side only tests (Figure 5.6) was approximately 13 percent, with this result having been obtained when the entire suction side of the model was covered in sandpaper. Approximately 60 percent of the measured side force loss at $\beta = 0°$, $\delta_r = -10°$ was recovered when sandpaper was removed from the forward half of the main element, suggesting that most of the side force is generated by this section of the model (which is typical of most airfoil pressure distributions).

A similar trend in data was also observed when the sandpaper was applied to both sides (Figure 5.7); however, overall $\%\Delta C_Y$ was less as compared to the suction side only tests. The diagram in Figure 5.8 may provide some justification as to why the observed $\%\Delta C_Y$ was less when sandpaper was applied to the whole model as compared to the suction side only. The sandpaper applied to both sides serves to "re-centre the forces" and therefore nets a better $\%\Delta C_Y$ than the suction side only when compared to the baseline.

Sealing the gap between the main element and the rudder of the CRM with speed tape was observed to offset the loss in side force generated by applying sandpaper to the model. This needs to be further investigated in how it relates to aircraft configurations where the gap is sealed or not, and how the performance changes as a function of time during takeoff when the fluid is shearing off. Additional testing with fluids with the gap sealed was also conducted and is discussed in Section 6.

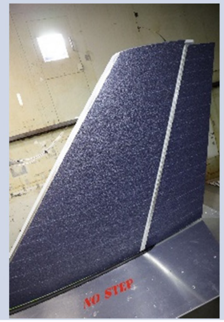
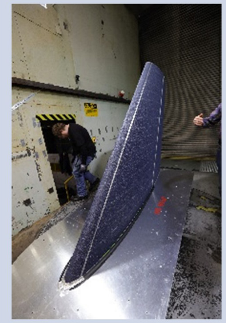
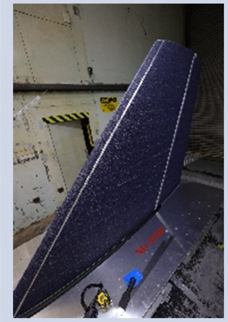
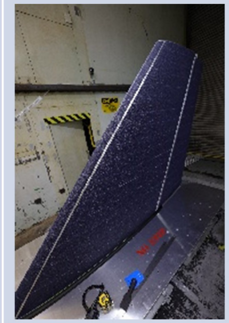
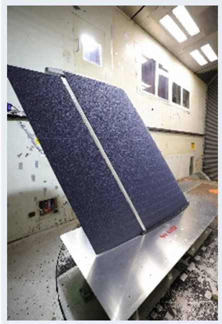
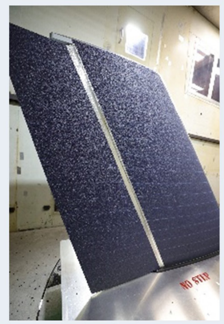
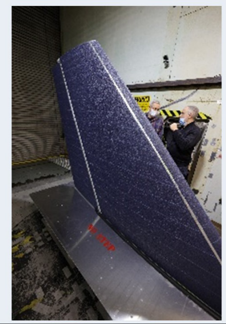
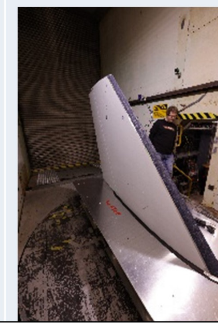
Rudder Suction Side ΔC_Y =-2.5% (#56)	Full Rudder ΔC_Y =-1.7% (#59)	Main w/o LE and Full Rudder ΔC_Y =-7.1% (#62),-9.4% (#66) AVG = -8.3%	Main w/o LE and Full Rudder, sealed gap ΔC_Y =-0.3% (#65)	Full Main and Rudder ΔC_Y =-11.3% (#69)	Main and Rudder Suction Side Only + LE ΔC_Y =-13%(#72)	Main and Rudder Suction Side Only + LE, sealed gap ΔC_Y =-6.3% (#75)
						
						

Figure 5.4: Sandpaper Grit Testing Details (Part 1 of 2)

Main w/o LE Suction Side and Rudder Suction Side ΔC_Y = -11% (#76)	1/2 of Main Suction Side + Rudder Suction Side ΔC_Y = -5.7% (#79)	1/2 of Main Suction Side + Rudder Suction Side, Sealed Gap ΔC_Y = +2.2% (#82)	Rudder Suction Side ΔC_Y = -2.6% (#83)	Rudder Suction Side Sealed Gap ΔC_Y = +5.1% (#86)	Clean wing, Sealed gap ΔC_Y = +8.1% (#87)
					
					

Figure 5.5: Sandpaper Grit Testing Details (Part 2 of 2)

Figure 5.6: Sandpaper Removal Effects When Applied to Suction Side Only

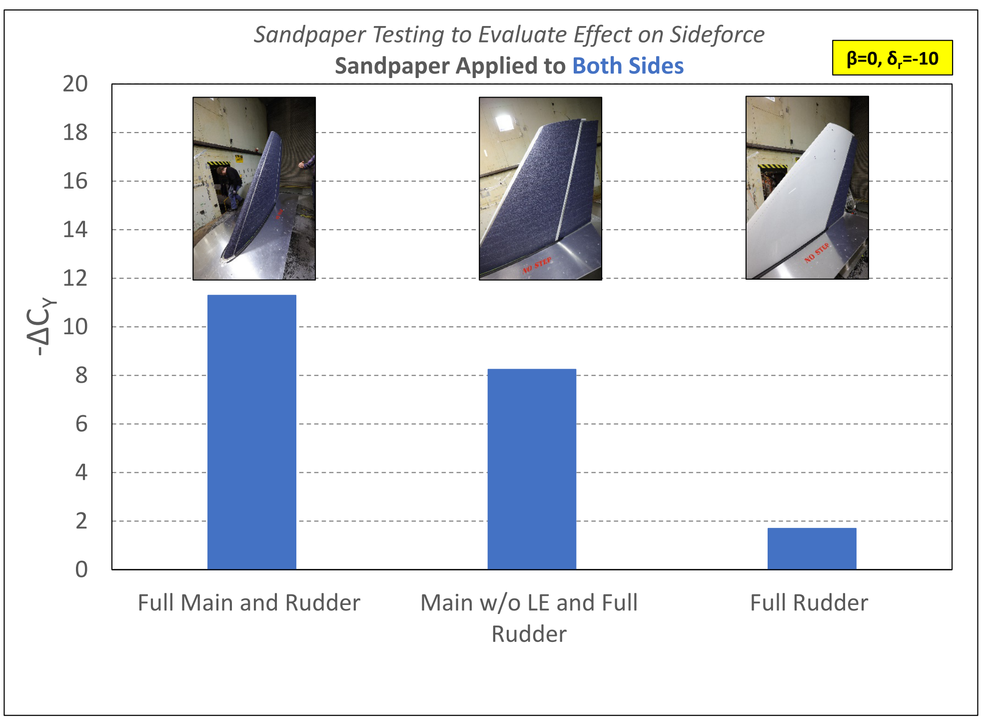


Figure 5.7: Sandpaper Removal Effects When Applied to Both Sides

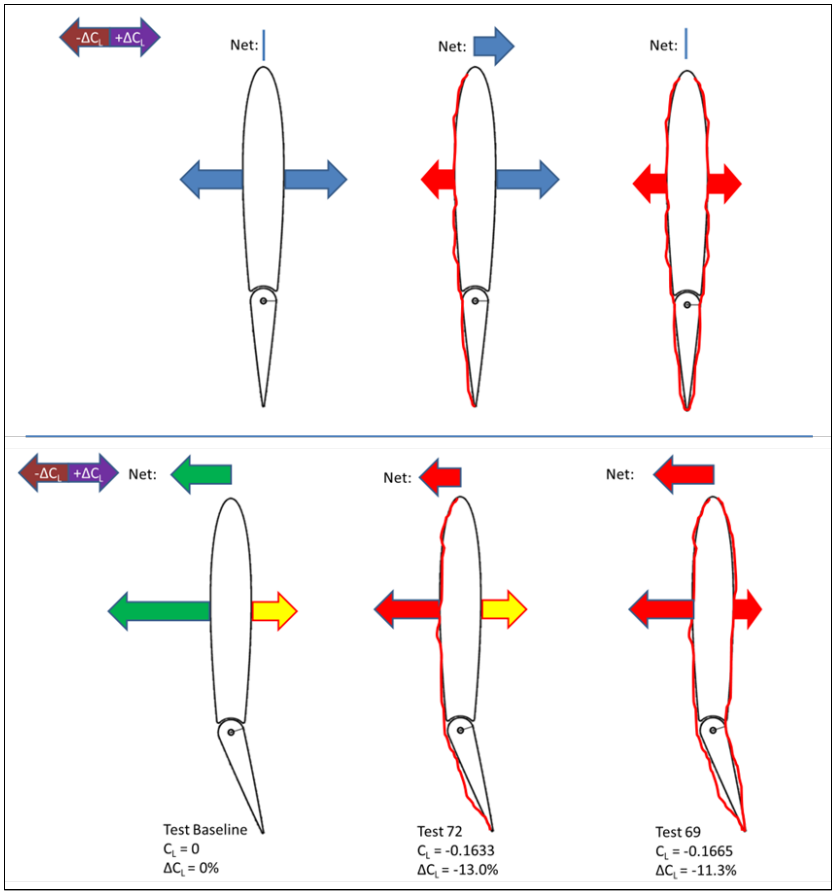


Figure 5.8: Depiction of Sandpaper Roughness Effects on Side Forces Generated

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

As the CRM vertical stabilizer testing was limited due to time and weather conditions, the tests performed were chosen based on their likeliness to provide the most informative data. This testing was conducted with Type IV EG- and PG-based fluids, as well as with PG-based Type I fluid.

The plan for the fluid testing and flow-off characterization can be inferred by the following major headings.

1. Fluid-Only Testing:
    a. Type IV PG Fluid Only (Cold and Warm);
    b. Type IV EG Fluid Only (Cold and Warm); and
    c. Type I PG Fluid Only (Warm).
2. Fluid and Contamination Testing:
    a. Type IV EG Fluid – Simulated Moderate Snow;
    b. Type IV PG Fluid – Simulated Moderate Snow;
    c. Type I PG Fluid – Simulated Moderate Snow;
    d. Type IV EG and PG Fluid – Ice Pellets;
    e. Type IV PG Fluid – Simulated Freezing Rain; and
    f. Type IV EG – Mixed Snow and Freezing Rain.
3. One Engine Inoperative (OEI) and Crosswind Simulations:
    a. Type IV PG Fluid – OEI;
    b. Type IV PG Fluid – OEI + Crosswind #1; and
    c. Type IV PG Fluid – OEI + Crosswind #2.
4. Repeatability and Variability Testing:
    a. Type IV PG Fluid Repeatability; and
    b. Type IV EG and PG Fluids Variability.

5. Non-Standard Fluid/Contamination Applications to Isolate Specific Aerodynamic Parameters:
   a. Asymmetric Simulated Freezing Rain with Type IV PG Fluid;
   b. Asymmetric Mixed Snow and Freezing Rain with Type IV EG Fluid;
   c. Simulated Freezing Rain on an Unprotected Wing;
   d. Adjusted Catch Factor on Vertical Surface with Type IV EG Fluid; and
   e. Sealed Gap Effect.

A photographic summary of each set of tests is included at the end of this section. In addition, a summary of the fluid thickness measurements for each set of tests is included in Appendix D. For ease of cross-referencing, the photo number in Section 6 refers to the corresponding figure number in Appendix D (e.g., Photo 6.3 refers to Figure 3).

6.2 Fluid-Only Testing

The following subsections provide a summary of the fluid-only testing.

6.2.1 Type IV PG Fluid Only

Four comparative Type IV PG fluid-only tests (#9, #10, #11, and #12) were conducted with an approximate tunnel temperature of -10˚C, where the only variables changed were the β and δ_r angles. Four different configurations of β and δ_r were tested:

- Test #9: $\beta = 0°$, $\delta_r = 0°$ (a zero crosswind scenario);
- Test #10: $\beta = 0°$, $\delta_r = -10°$ (the “basic” configuration);
- Test #11: $\beta = 0°$, $\delta_r = -20°$ (a full rudder configuration); and
- Test #12: $\beta = -10°$, $\delta_r = -20°$ (a maximum 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 pooled fluid remained on the rudder on the suction side. The observed residual fluid increased as the β and δ_r decreased. For Tests #10 and #11, the aerodynamic data showed performance degradation as δ_r increased at $\beta = 0°$ however, there was an improvement for Test #12 at $\beta = -10$, $\delta_r = -20$ (likely from the additional suction peak at a yaw angle helping to clear off the main element, which contributes significantly to the side force). For Test #9, the $\%\Delta C_Y$ was not calculated because with the side force being zero, any small deviation causes a large error. Photo 6.1 provides a photographic summary of these tests.

This testing was later repeated at a warmer temperature. Three comparative Type IV PG fluid-only tests (#32, #33, and #37) were conducted with an approximate tunnel temperature of +1°C, where the only variables changed were the β and δ_r angles. The three configurations of β and δ_r explored were the following:

- Test #32: β = 0°, δ_r = -10° (the "basic" configuration);
- Test #33: β = 0°, δ_r = -20° (a full rudder configuration); and
- Test #37: β = -10°, δ_r = -20° (a maximum crosswind scenario).

The test results demonstrated a trend similar to the Type IV PG colder temperature data; however, the decreases in side force recorded tended to be less severe than at the colder temperatures, likely a result of lower fluid viscosities at warmer temperatures. Photo 6.2 provides a photographic summary of these tests.

6.2.2 Type IV EG Fluid Only

Four comparative Type IV EG fluid-only tests (#22, #23, #24, and #25) were conducted with an approximate tunnel temperature of 0˚C, where the only variables changed were the β and δ_r angles. Four different configurations of β and δ_r were explored:

- Test #22: β = 0°, δ_r = 0° (a zero crosswind scenario);
- Test #23: β = 0°, δ_r = -10° (the "basic" configuration);
- Test #24: β = 0°, δ_r = -20° (a full rudder configuration); and
- Test #25: β = -10°, δ_r = -20° (a maximum crosswind scenario).

The test results demonstrated a trend similar to the Type IV PG cold and warm temperature data; however, the decreases in side force tended to be less severe than those recorded during the PG fluid tests, likely a result of the lower shear viscosity of EG versus PG fluids. The test results demonstrated that the fluid was generally well removed from the forward part (main element) of the vertical stabilizer; however, some pooled fluid remained on the rudder on the suction side. The observed residual fluid increased as the β and δ_r decreased. For Tests #23 and #24, the aerodynamic data showed performance degradation increasing as δ_r increased at β = 0; however, there was an improvement for Test #25 at β = -10, δ_r = -20 (likely from main element's contribution to the side force). For Test #22, the %ΔC_Y was not calculated because with the side force being zero, any small deviation causes a large error. Photo 6.3 provides a photographic summary of these tests.

Testing was repeated at a colder temperature. One Type IV EG fluid-only test (#13) was conducted with an approximate tunnel temperature of -11ºC in the following configuration:

- Test #13: β = 0°, δ_r = -20° (a full rudder configuration).

The test result demonstrated an overall increase in side force loss recorded as compared to the warmer temperature, Type IV EG fluid-only data, likely a result of the viscosity of the fluid increasing at colder temperatures. Photo 6.4 provides a photographic summary of these tests.

6.2.3 Type I PG Fluid Only

Three comparative Type I PG fluid-only tests (#38, #39, and #40) were conducted with an approximate tunnel temperature of +1˚C, where the only variables changed were the β and δ_r angles. Three different configurations of β and δ_r were explored:

- Test #38: β = 0°, δ_r = -10° (the "basic" configuration);
- Test #39: β = 0°, δ_r = -20° (a full rudder configuration); and
- Test #40: β = -10°, δ_r = -20° (a maximum crosswind scenario).

As compared to the Type IV EG and PG tests, the fluid layer was much thinner after application and barely present after the run, which made measuring fluid thickness very challenging. This was demonstrated in the aerodynamic data, which indicated the fluid had minimal effects on the measured side force. The residual fluid observed seemed to increase as the β and δ_r decreased; however, the fluid layer could not be measured using a thickness gauge as it was too thin. Photo 6.5 provides a photographic summary of these tests.

6.3 Fluid and Contamination Testing

The following subsections provide a summary of the fluid and contamination testing.

6.3.1 Type IV EG Fluid – Simulated Moderate Snow

Two comparative Type IV EG tests (#95 and #96) were conducted at an approximate tunnel temperature of -5°C with the model configured to β = 0° and δ_r = -10°. At -5°C, the HOT estimated from the Type IV HOT Guidelines was approximately 40 minutes.

In the first test (#95), the model was exposed to artificial snow precipitation for the full HOT of 40 minutes, resulting in a fluid that was 100 percent failed (the entire surface was covered in failed fluid) by the end of exposure. In the second test (#96), application of contamination was stopped after 10 minutes, at which point approximately 10 percent of the vertical stabilizer surface was failed.

The flow-off performance greatly varied in the two scenarios. In the first test, slushy contamination remained on various areas of the main element and rudder, especially in the areas where the fluid had thinned or dried out during the contamination application period. The contamination remaining after the test was not adhered (it could be easily moved around with a finger), but it was not removed by the shear forces during the test run. In the second test, the uncontaminated fluid was easily removed by the air stream, and the failed portions also sheared off.

The results were supported by the aerodynamic data collected whereby the second test (#96) demonstrated negligible difference in side force compared to the clean baseline, an improvement over Test #95, which demonstrated a 6.1 percent decrease in side force. Photo 6.6 provides a photographic summary of these tests.

6.3.2 Type IV PG Fluid – Simulated Moderate Snow

Two comparative Type IV PG tests (#103 and #104) were conducted at an approximate tunnel temperature of -4°C with the model configured to $\beta = 0°$ and $\delta_r = -10°$. At -4°C, the HOT estimated from the Type IV HOT Guidelines was approximately 65 minutes.

In the first test (#103), the model was exposed to artificial snow precipitation for the full HOT of 65 minutes, resulting in a fluid that was 100 percent failed by the end of exposure. In the second test (#104), application of contamination was stopped after 15 minutes, at which point approximately 10 percent of the vertical stabilizer surface was failed.

Like the Type IV EG results, the flow-off performance greatly varied in the two scenarios. In the first test, slushy contamination remained on various areas of the main element and rudder, especially in the areas where the fluid had thinned or dried out during the contamination application period. The contamination remaining after the test was not adhered (it could be easily moved around with a finger), but it was not removed by the shear forces during the test run. In the second test, the uncontaminated fluid was easily removed by the air stream, and the failed portions also sheared off.

The results were supported by the aerodynamic data collected whereby the second test (#104) demonstrated less loss in side force than in the first test (#103); however, the improvement was not as significant as observed with the EG fluid. This could be a function of the fluid properties, but may be due to snow having been ingested into the wind tunnel during the test (it was snowing outdoors) and sticking to the model during simulated takeoff. Photo 6.7 provides a photographic summary of these tests.

6.3.3 Type I PG Fluid – Simulated Moderate Snow

Two comparative Type I PG tests (#105 and duplicate test #106, and #107) were conducted at an approximate tunnel temperature of -4°C with the model configured to $\beta = 0°$ and $\delta_r = -10°$. At -4°C, the HOT estimated from the generic Type IV HOT Guidelines was approximately 25 minutes, and the Type I HOT was approximately 5 minutes.

In the first tests (#105 and duplicate test #106), the model was exposed to artificial snow precipitation for the full Type IV HOT of 25 minutes simulating a Type IV wings and Type I vertical stabilizer deicing procedure request. This resulted in a fluid that was 100 percent failed by the end of exposure with significant adhered contamination.

In the second test (#107), the model was exposed to artificial snow precipitation for the full Type I HOT of 5 minutes simulating a Type I full body deicing procedure request. This also resulted in a fluid that was 100 percent failed by the end of exposure, but with less accumulated contamination by comparison.

The results were supported by the aerodynamic data collected whereby both tests demonstrated a loss in side force, with a marginally better performance in the second test conducted. Losses were comparable to the results observed with Type IV fluid when the wing was completely failed prior to simulated takeoff. Note that it was snowing outdoors during the runs, which may have resulted in snow being ingested into the wind tunnel and sticking to the model during simulated takeoff. Photo 6.8 provides a photographic summary of these tests.

6.3.4 Type IV PG and EG Fluid – Simulated Moderate Ice Pellets

Two tests (#93 and #94) were conducted with PG and EG Type IV fluid at an approximate tunnel temperature of -3°C with the model configured to $\beta = 0°$ and $\delta_r = -10°$. At -3°C, the allowance time in moderate ice pellet conditions was 15 minutes for PG Type IV fluid and 35 minutes for EG Type IV fluid.

In both tests, 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. This resulted in a generally clean fluid that was thinned out by the application of contamination.

The results were supported by the aerodynamic data collected whereby both tests demonstrated minimal losses in side force, indicative of the generally clean fluid present with minimal contamination at the time of simulated takeoff. Photo 6.9 provides a photographic summary of these tests.

6.3.5 Type IV PG Fluid – Simulated Freezing Rain

Two comparative Type IV PG tests (#16 and #18) were conducted at an approximate tunnel temperature of -5°C with the model configured to $\beta = 0°$ and $\delta_r = -10°$. At -5°C, the HOT estimated from the generic Type IV HOT Guidelines was approximately 75 minutes.

In the first test (#16), the model was exposed to simulated freezing rain for the full HOT of 75 minutes and resulted in a fluid that was 100 percent failed by the end of exposure with adhered contamination. In the second test (#18), application of contamination was stopped after 13.5 minutes, at which point approximately 10 percent of the vertical stabilizer surface was failed.

In the first test, residual slushy and adhered contamination remained on various areas of the main element and rudder after the simulated takeoff. In the second test, the residual slushy and adhered contamination fluid was less significant by comparison.

The results were supported by the aerodynamic data collected whereby the second test (#18) demonstrated no loss in side force, a significant improvement compared to the 9.6 percent loss observed in the first test (#16). Photo 6.10 provides a photographic summary of these tests.

6.3.6 Type IV EG Fluid – Mixed Snow and Freezing Rain

One Type IV EG fluid test (#108) was conducted at an approximate tunnel temperature of -3°C with the model configured to $\beta = 0°$ and $\delta_r = -10°$. No HOTs currently exist for the mixed condition of snow and freezing rain, so the light freezing rain HOT of 45 minutes was used for this test. The ratio of snow (20 $g/dm^2/h$) to freezing rain (5 $g/dm^2/h$) was chosen specifically to try and generate a rough contamination whereby the lower rate of freezing rain would serve to solidify the contamination rather than wash it off.

The test demonstrated a slushy and adhered rough contamination that was particularly adhered on the LE where the fluid layer was thinner. At the time of rotation, most of the contamination was still present on the LE, with slushy residual present on the TE of the main element and on the rudder.

The results were supported by the aerodynamic data indicating a 9.5 percent loss in side force due to the residual contamination present. A laser scan of the contamination present after the run was also performed. Photo 6.11 provides a photographic summary of the test.

6.4 One Engine Inoperative and Crosswind Simulations

For the purposes of simulating OEI and crosswind scenarios in the wind tunnel, a NASA representative (with the support of the research team) developed operational scenarios that could be simulated by modifying the controllable testing parameters.

The OEI scenario simulated an engine failure (assuming the port-side engine) with no crosswind occurring at V1 (the maximum speed at which a rejected takeoff can be initiated in the event of an emergency) during the takeoff. Failure of the port engine will cause a counterclockwise yaw moment around the centre of gravity. For any velocity greater than V1, rudder deflection would be needed to maintain the runway heading (see Figure 6.1). Therefore, with no crosswind, we would assume that the sideslip and rudder angles would be $\beta = 0°$ and $\delta_r = 0°$ up to engine failure at 100 knots (V1 in this simulation), and then the model would transition to $\beta = 0°$ and $\delta_r = -20°$ (at 4°/sec), simulating the rudder deflection required to compensate for the counterclockwise yaw moment of the failed engine.

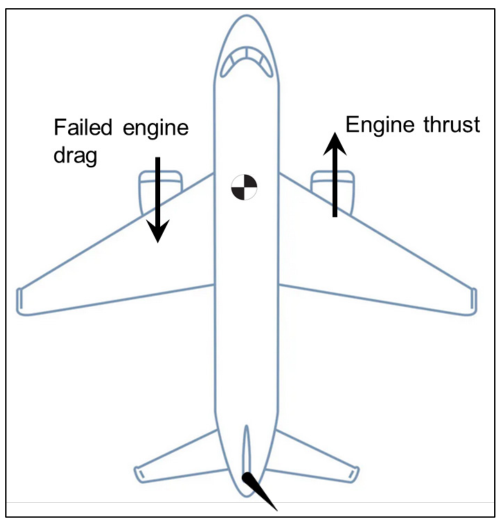


Figure 6.1: Schematic Representation of OEI Scenario

To simulate an OEI plus crosswind scenario, we would assume that in the initial takeoff roll prior to engine loss, nosewheel steering and rudder deflection are sufficient to maintain runway heading and prevent the aircraft from "weathervaning" into the wind. Rudder deflection would be maintained for the OEI and crosswind condition. At the point of rotation, the nosewheel steering would no longer hold runway heading, allowing the aircraft to "weathervane" into the wind, and the resulting angle would be added at the point of rotation (see Figure 6.2).

Assuming a crosswind condition from the port side, with port engine failure at V1 = 100 knots, this would be simulated with a starting configuration of β = +10º and δ_r = -20º while accelerating to 100 knots and then transition to β = -10º (at 2.5º/sec) and δ_r = -20º (at 4º/sec), or β = 0º and δ_r = -20º at the simulated time of rotation.

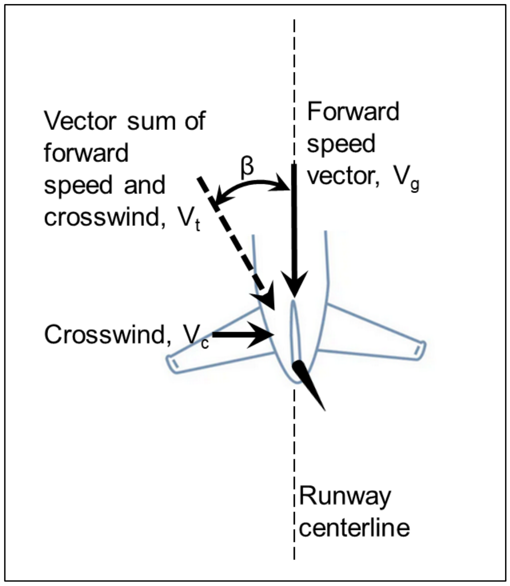


Figure 6.2: Schematic Representation of OEI + Crosswind Scenario

Based on these two scenarios, OEI and OEI plus crosswind, additional scenarios were run while further modifying specific parameters of the simulated takeoff profile. The following subsections will provide a summary of the different scenarios explored.

6.4.1 Type IV PG Fluid – OEI

Two comparative Type IV PG fluid-only tests (#34 and #33) were conducted with an approximate tunnel temperature of +1ºC. Test #34 simulated the OEI by dynamically transitioning from β = 0º/δ_r = 0º to β = 0º/δ_r = -20º at a rate of 4º/s once a speed of 100 knots was achieved. The results were compared to Test #33, run with a static configuration of β = 0º/δ_r = -20º. The results in the Test #34 OEI scenario demonstrated a generally improved flow-off as compared to the static scenario, as the ramp-up time spent at the β = 0º/δ_r = 0º configuration would have helped the fluid shear off prior to the transition. In addition, the extra ramp time required to perform the maneuver (approximately 5 seconds) may also have contributed to the improved flow-off. The results were supported by the aerodynamic data, which indicated a slight improvement in side forces from the OEI scenario at time of rotation but comparable results 10 seconds after time of rotation. Photo 6.12 provides a photographic summary of these tests.

6.4.2 Type IV PG Fluid – OEI + Crosswind #1

Two comparative Type IV PG fluid-only tests (#35 and #33) were conducted with an approximate tunnel temperature of 0ºC. Test #35 simulated the OEI plus crosswind scenario by dynamically transitioning from $\beta = +10^{\circ}/\delta_r = -20^{\circ}$ to $\beta = 0^{\circ}/\delta_r = -20^{\circ}$ at a rate of 2.5°/s once a speed of 100 knots was achieved. The results were compared to Test #33, run with a static configuration of $\beta = 0^{\circ}/\delta_r = -20^{\circ}$. The results demonstrated a generally improved flow-off from the OEI plus crosswind scenario as compared to the static scenario, as the ramp-up time spent at the $\beta = 0^{\circ}/\delta_r = 0^{\circ}$ configuration would have helped the fluid shear off prior to the transition. In addition, the extra ramp time required to perform the maneuver (approximately 4 seconds) may also have contributed to the improved flow-off. The results were supported by the aerodynamic data, which indicated a slight improvement in side forces from the OEI plus crosswind scenario at time of rotation but comparable results 10 seconds after time of rotation. Photo 6.13 provides a photographic summary of these tests.

6.4.3 Type IV PG Fluid – OEI + Crosswind #2

Two comparative Type IV PG fluid-only tests (#36 and #37) were conducted with an approximate tunnel temperature of 0ºC. Test #36 simulated a variation of the OEI plus crosswind scenario by dynamically transitioning from $\beta = +10^{\circ}/\delta_r = -20^{\circ}$ to $\beta = -10^{\circ}/\delta_r = -20^{\circ}$ (instead of $\beta = 0^{\circ}/\delta_r = -20^{\circ}$) once a speed of 100 knots was achieved. The results were compared to Test #37, run with a static configuration of $\beta = -10^{\circ}/\delta_r = -20^{\circ}$. The results demonstrated a generally improved flow-off from the OEI plus crosswind scenario as compared to the static scenario, as the ramp-up time spent at the $\beta = 0^{\circ}/\delta_r = 0^{\circ}$ configuration would have helped the fluid shear off prior to the transition. In addition, the extra ramp time required to perform the maneuver may also have contributed to the improved flow-off. The results were supported by the aerodynamic data, which indicated a slight improvement in side forces from the OEI plus crosswind scenario at time of rotation but comparable results 10 seconds after time of rotation. Photo 6.14 provides a photographic summary of these tests.

6.5 Repeatability and Variability Testing

The following subsections provide a summary of the tests conducted to investigate the repeatability and variability in the fluid testing results.

6.5.1 Type IV PG Fluid – Repeatability

To understand the repeatability of fluid testing, four comparative Type IV PG fluid-only tests (#26, #27, #28, and #29) were conducted with an approximate tunnel temperature of 0ºC with the model configured to $\beta = 0^{\circ}$ and $\delta_r = -10^{\circ}$.

The tests demonstrated good repeatability both visually and aerodynamically. The average loss in side force was 4.7 percent with individual test values of 5.4 percent, 4.7 percent, 3.6 percent, and 5.0 percent. These results provide confidence in the ability of the testing setup to provide repeatable results. Photo 6.15 provides a photographic summary of these tests.

6.5.2 Type IV EG and PG Fluid – Variability

To understand the variability between different brands and types of Type I fluids, five comparative Type IV EG and PG fluid-only tests (#23, #26, #32, #51, and #52) were conducted with an approximate tunnel temperature of 0ºC with the model configured to $\beta = 0°$ and $\delta_r = -10°$.

As expected, the tests demonstrated variability in the visual and aerodynamic performance of the fluids tested. The loss in side force ranged from 2.5 percent to 7.6 percent for the same conditions with different fluids. This type of variance has been observed and well reported as part of the allowance time research with the thin high-performance wing and is being observed with the CRM as well. These results indicate that fluid-specific performance is an important consideration in testing. Photo 6.16 provides a photographic summary of these tests.

6.6 Non-Standard Fluid/Contamination Applications to Isolate Specific Aerodynamic Parameters

The following subsections provide a summary of the results from the non-standard fluid and contamination tests conducted with the purpose of isolating specific aerodynamic parameters for analysis.

6.6.1 Asymmetric Simulated Freezing Rain with Type IV PG Fluid

One Type IV PG fluid test (#19) was conducted with fluid applied to both sides of the wing; however, contamination was only applied to the suction side, simulating a high-crosswind taxi scenario resulting in an asymmetric level of contamination. The test was conducted with an approximate tunnel temperature of -5ºC with the model configured to $\beta = 0°$ and $\delta_r = -10°$. At -5°C, the HOT estimated from the generic Type IV HOT Guidelines was approximately 75 minutes; however, the application of contamination was stopped after 19 minutes, at which point approximately 10 percent of the vertical stabilizer surface was failed. The exposure time was longer as compared to Test #18 (described in Subsection 6.3.5) since a larger surface area needed to be failed on the port side of the model to meet the 10 percent failure criteria for the entire surface area of the CRM.

For Test #19, the residual slushy and adhered contamination fluid was well removed by the shear forces during simulated takeoff, and the aerodynamic results supported these results. Photo 6.17 provides a photographic summary of these tests. The results were comparable to Test #18 (described in Subsection 6.3.5), in which contamination was applied to both sides. Further testing should evaluate the asymmetric contamination with a more severe level of adhered contamination to determine if the outcome would change.

6.6.2 Asymmetric Mixed Snow and Freezing Rain with Type IV EG Fluid

One Type IV EG fluid test (#97) was conducted with mixed snow (44 g/dm²/h) and freezing rain (21 g/dm²/h) for a total of 65 g/dm²/h. For this test, residual fluid and contamination remaining on the wing from previous symmetric snow-only Test #96 (see details in Subsection 6.3.1) was further contaminated with “freestyle” snow and freezing rain to create a worst-case roughness on the LE and suction side only. The primary objective was to support the laser scanning activity (to generate a notably rough surface for scanning purposes).

The residual slushy and adhered contamination remained on various areas of the main element and rudder after the simulated takeoff, supported by the aerodynamic data indicating a 14 percent decrease in side force. Photo 6.18 provides a photographic summary of the test. Of interest is that this was one of the more severely contaminated tests, and yet the delta in side force was still comparable to the worst-case fluid-only test, which indicated that the model may not be very sensitive to contamination and roughness.

6.6.3 Simulated Freezing Rain on an Unprotected Surface

One test (#112) was conducted with an unprotected vertical surface, where no de/anti-icing fluid was applied, and the model was exposed to simulated freezing rain. This scenario represented an operation whereby a pilot would request only wings de/anti-iced but not the vertical stabilizer.

The approximate tunnel temperature during the test was -6ºC. The freezing rain did not immediately freeze, so the contaminated model was allowed to sit in the cold prior to simulated takeoff. Only small areas of adhered ice were present on the model before the run, and these areas nucleated and grew during the simulated takeoff run. The adhered areas were not removed, and the rest of the water turned slushy and was not removed during simulated takeoff, though the contamination was generally smooth. The contamination caused a loss in side force of 6.1 percent. Photo 6.19 provides a photographic summary of the test.

6.6.4 Adjusted Catch Factor on Vertical Surface with Type IV EG Fluid

One test (#111) was conducted with Type IV EG fluid to simulate the effect of the "catch factor" on the vertical surface, where increased wind speed will increase the amount of precipitation impacting a surface dependent on the angle of the surface to the wind vector and terminal velocity of the precipitate.

An analysis was completed to determine the effective catch factor using the parameters of a standard 30 cm x 50 cm test plate oriented at 10º into the wind (the standard for HOT testing) or 90º into the wind simulating a vertical stabilizer (see Figure 6.3 for an example of the catch factor on a vertical plate in snow with 3-knot wind speed). The results for different wind speeds are summarized in Table 6.1, which indicated that the effective rate on the 90º versus 10º vertical surface is equal at 3-knot wind speed, doubles at 7.7 knots, and more than quadruples at 36.5 knots. A full detailed analysis on how the catch factor was calculated for snow, freezing rain, and freezing drizzle is found in Appendix E. One consideration is that the vertical stabilizer may not always be oriented sideways into the wind as the aircraft taxis; therefore, the rate could be halved if the aircraft were continually rotating (for simulation purposes). In addition, taxi speeds could add or negate the catch factor.

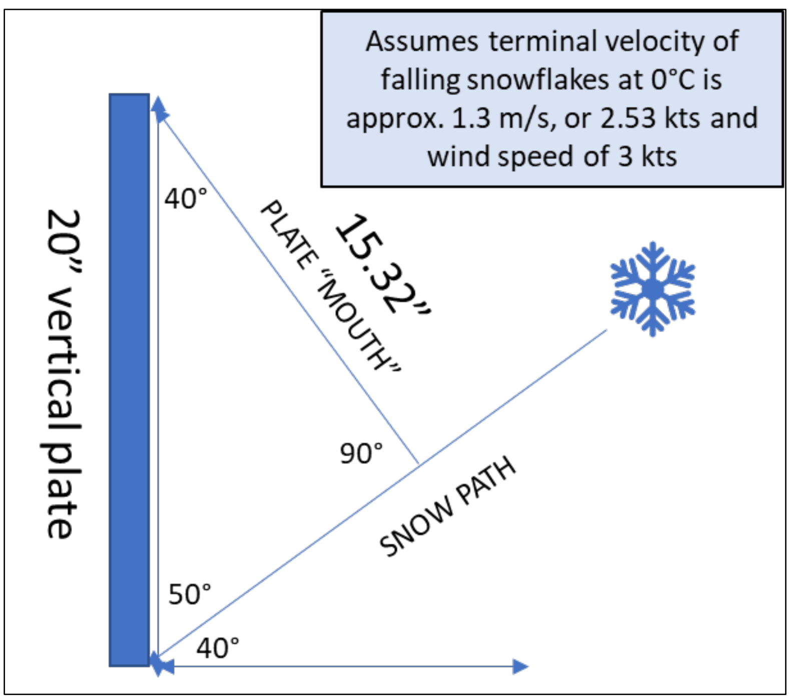


Figure 6.3: Example Catch Factor Analysis for a Vertical Plate in Snow

Table 6.1: Summary of Catch Factor Calculations

Effective Precipitation Rate on Surfaces as Function of Wind Speed and Surface Angle				
Wind Speed (kts)	Snowfall Angle (°)	10° Pan Rate (g/dm²/h)	Static Vertical Surface Rate – Static Asymmetric (g/dm²/h)	Rotating Vertical Surface Rate – Dynamic Symmetric (g/dm²/h)
0	90	25	0	0
3.0	40	25	25	12.5
7.7	18.3	25	50	25
36.2	4	25	103	51.5

For this test, the simulated 10º plate (or wing) rate of precipitation was moderate snow (at 25 g/dm²/h), but the vertical stabilizer was exposed to twice the rate to simulate an increased catch factor. The approximate tunnel temperature during the test was -4ºC. The vertical stabilizer was exposed for a total precipitation time of 40 minutes, which is the holdover time for this condition.

Because of the warmer temperatures, the fluid drained out and only small patches of slush were present; however, these patches were removed during simulated takeoff. The loss in side force was less as compared to the moderate snow test conducted with the same fluid (Test #95 described in Subsection 6.3.1). A laser scan was also performed during this test to try and document the surface topography after the run. Photo 6.20 provides a photographic summary of these tests. It was observed that the overall precipitation "catch factor" may vary based on precipitation type and wind speed, and these effects can impact fluid performance and flow-off. This is an area of research that should be explored further.

6.6.5 Sealed Gap Effect

One test (#47) was conducted with fluid to investigate the effect of the sealed gap. A Type IV PG fluid was applied to the pressure side of the model only. During flow-off, the fluid partially sealed the gap, and the test resulted in an improved side force (less performance degradation). The results were similar to those observed during sealed gap Test #87 (see Subsection 5.4), in that an increase in side force was observed (not a loss) but to a lesser degree since the gap was only partially sealed from the fluid and was draining during simulated takeoff. Photo 6.21 provides a photographic summary of these tests.

6.7 Summary of Fluid Thickness Measurements

For all tests conducted with fluid, thickness measurements were taken at seven locations on the port side of the model (typically the pressure side) and at seven locations on the starboard side of the model (typically the suction side [see the procedure in Appendix B for more details]). The data collected was summarized graphically per test set in Appendix D.

The fluid thickness data collected is summarized in Table 6.2 to provide minimum and maximum fluid thickness records for the port and starboard sides of the vertical stabilizer at the three different stages of the test – after fluid application, after precipitation application, and after simulated takeoff – using available data (some tests have partial or incomplete data sets). The summary includes only Type IV EG and PG data and does not include the limited data with Type I fluid.

As expected, the “after fluid application” measurements were similar for all four test objectives. The results for “after precipitation application” were generally less than the ”after fluid application”, which is likely a result of the warmer testing temperatures allowing the fluid to drip down better as compared to colder temperatures where the fluid thickens and generates a thicker slush (the previous year’s testing showed the contrary in colder temperature testing). After simulated takeoff, the results were comparable with the exception of freezing rain, which had some adhered patches.

Table 6.2: Summary of Fluid Thicknesses for Type IV Tests

Condition	Fluid Thickness (mm)											
	After Fluid Application				After Precip. Application				After Takeoff Run			
	Port		STBD		Port		STBD		Port		STBD	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Snow Contamination	0.3	1.1	0.4	1.0	0.0	0.8	0.0	0.8	0.0	0.4	0.0	0.4
Freezing Rain Contamination	0.2	0.6	0.3	0.6	0.1	0.3	0.1	0.4	0.0	1.6	0.1	0.2
Ice Pellet Contamination	0.4	1.0	0.3	0.7	0.0	0.2	0.0	0.2	0.2	0.7	0.1	0.3
Other Icing Contamination	0.6	0.7	0.5	0.8	0.0	0.1	0.0	0.2	0.0	0.0	0.0	0.1
Fluid Only	0.3	0.8	0.2	0.8	-	-	-	-	0.1	0.8	0.1	0.5
OEI + Crosswind	0.3	0.6	0.3	0.6	-	-	-	-	0.1	0.4	0.1	0.2

6.8 Summary of Fluid, Contamination, and Roughness Tests

In general, the fluid, fluid and contamination, and sandpaper roughness testing all had comparable maximum side force losses (see Table 6.3). There were two notable exceptions. First, fluid and ice pellets had the least effect on side force, likely due to the pellets not sticking in the fluid and dragging down the fluid, resulting in a thinner fluid layer that was less contaminated and easier to flow off. Second, freezing rain alone generated a somewhat smooth surface; therefore, although contaminated with ice, the smooth surface did not significantly impact side force.

Table 6.3: Summary of Maximum Percentage Loss in Side Force by Test Type

Test Type (Only $\beta = 0$, $\delta_r = -10$)	**# of Tests**	**Max % Loss in Side Force**
Fluid and Cont. (PL)	2	-3%
Cont. (FZRA)	1	-6%
Fluid and Cont. (FZR)	4	-10%
Fluid and Cont. (SN)	12	-10%
Fluid Only (Including Partial Application)	26	-13%
Roughness	14	-13%
Fluid and Cont. (SN + FZRA)	2	-14%

The testing results also showed a trend of greater side force losses at lower temperatures, indicating that the higher viscosity of fluid and resultant thicker fluid layers on the model may not be as effectively removed as in warmer temperatures. There was good repeatability observed amongst the tests conducted with the same fluid. There was expected variation amongst different fluid brands and types as indicated by the aerodynamic impacts with PG fluids compared to EG fluids, a phenomenon also observed with the ice pellet allowance time testing wing model. A negligible change in model performance was seen with clean Type I fluids. Finally, during contamination tests, the worst-case loss in side force was no more extreme than the worst fluid-only case.

Photo 6.1: Type IV PG Fluid Only (Cold)

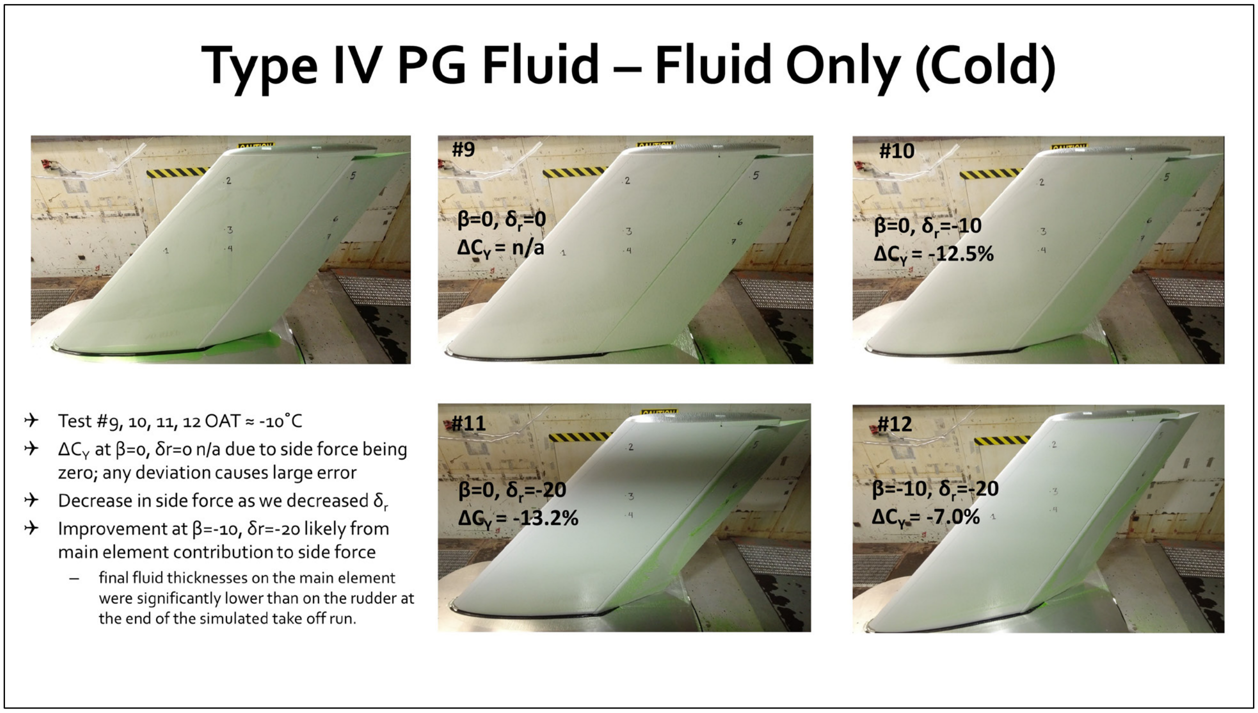


Photo 6.2: Type IV PG Fluid Only (Warm)

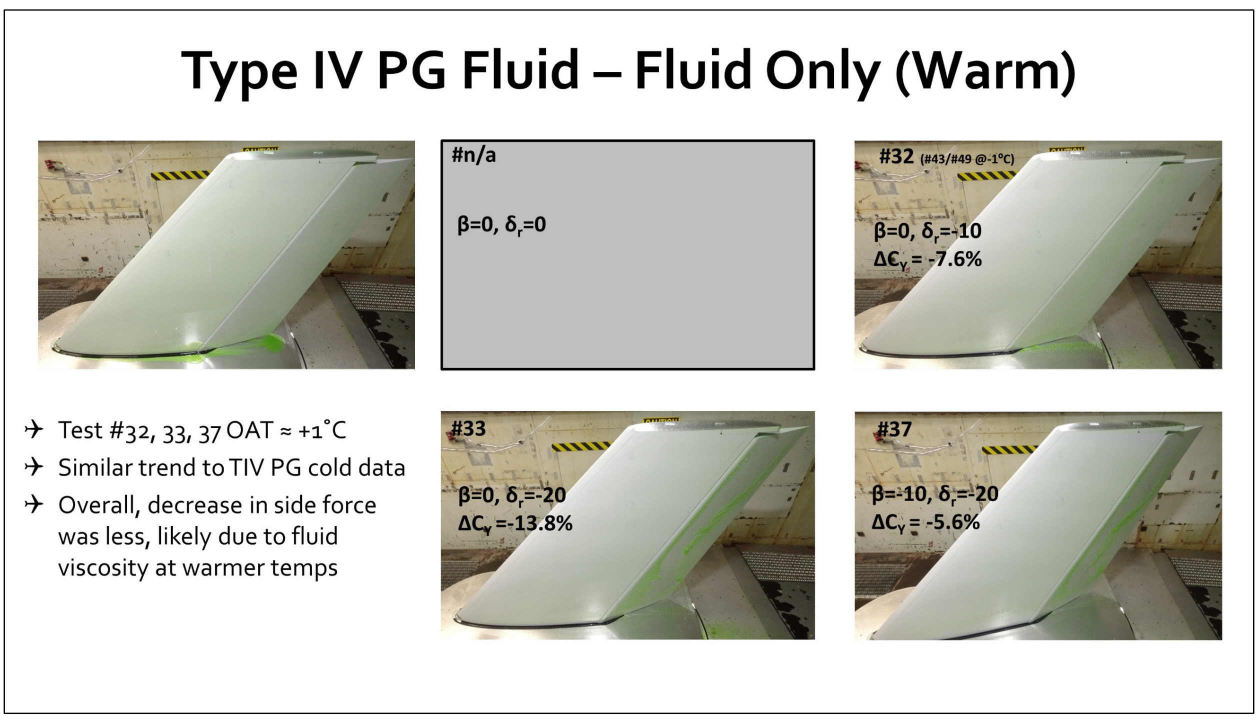


Photo 6.3: Type IV EG Fluid Only (Warm)

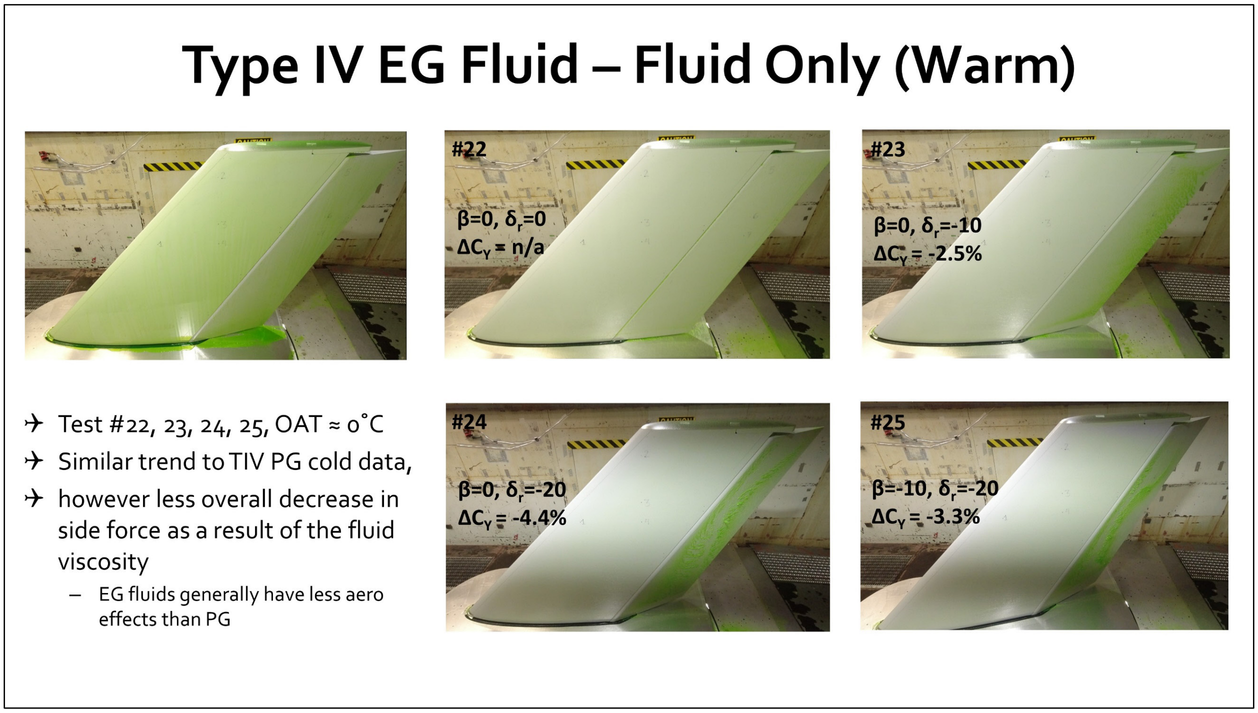


Photo 6.4: Type IV EG Fluid Only (Cold)

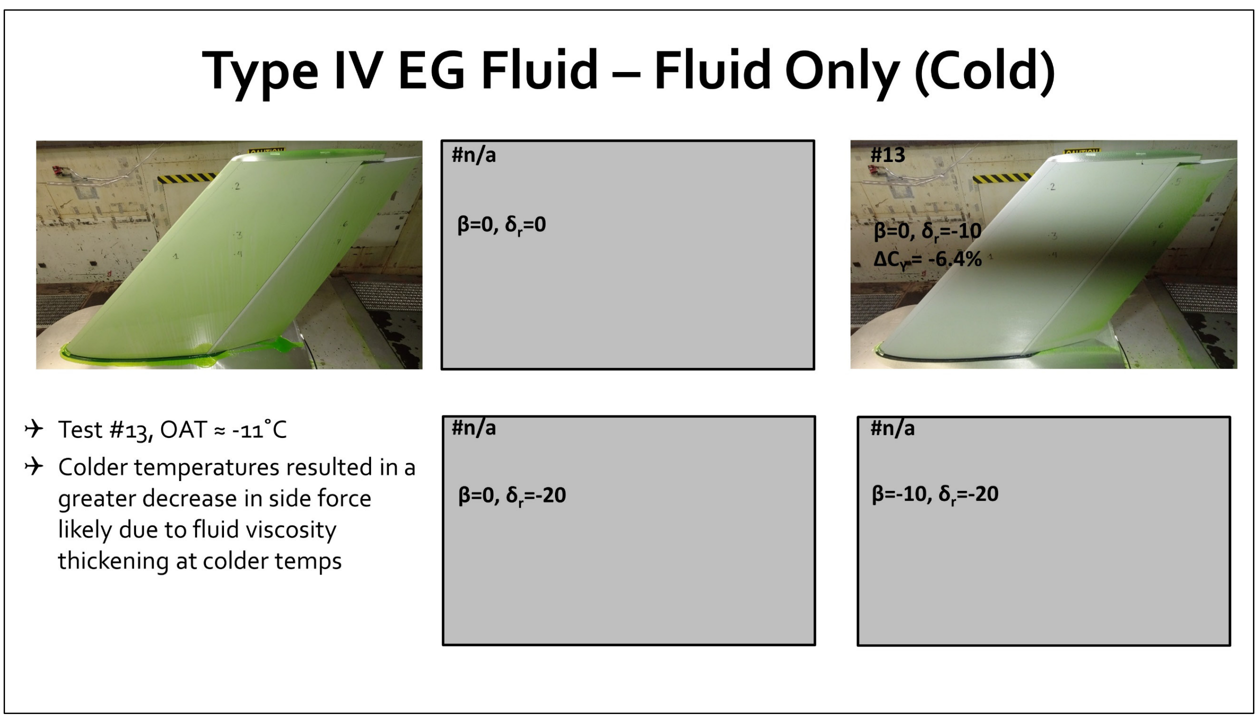


Photo 6.5: Type I PG Fluid Only (Warm)

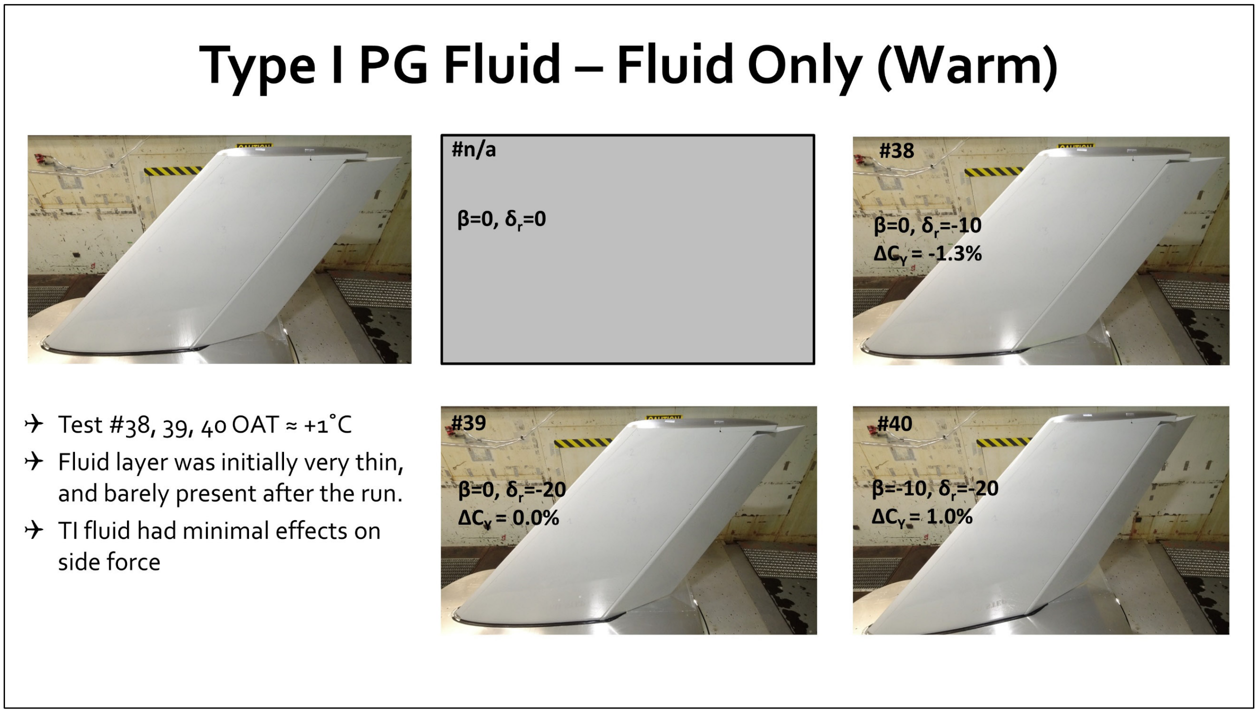


Photo 6.6: Type IV EG Fluid – Simulated Moderate Snow

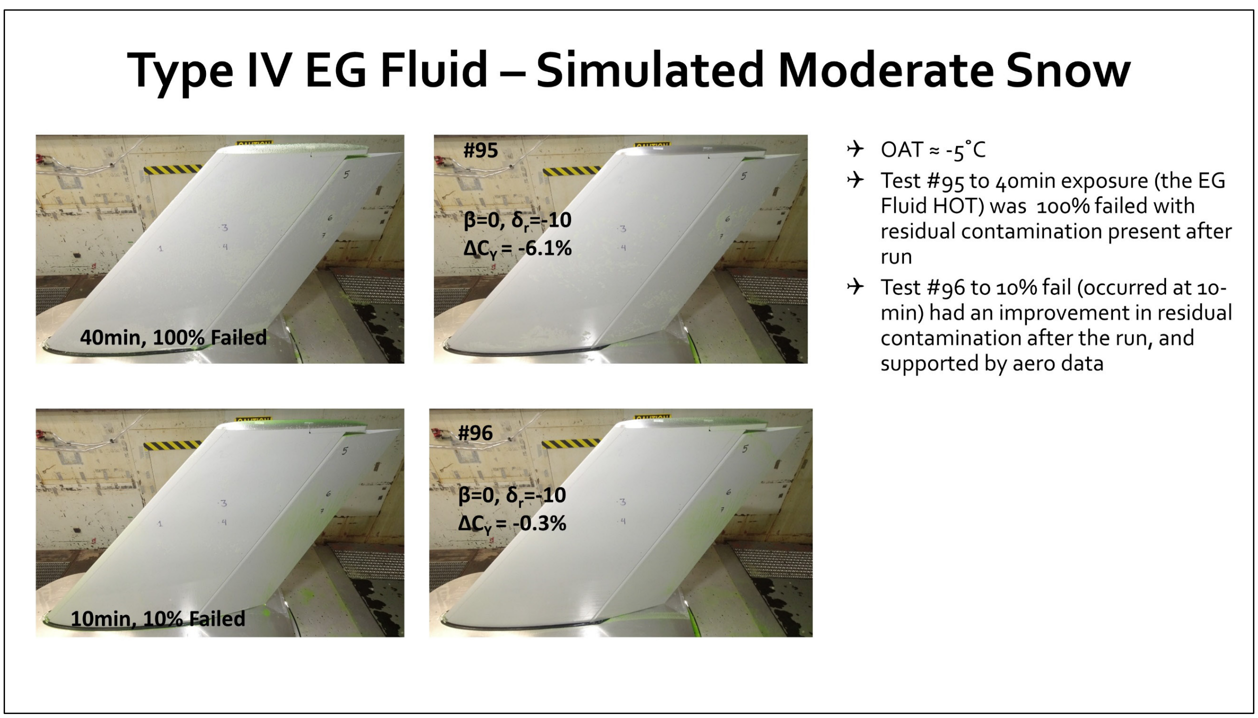


Photo 6.7: Type IV PG Fluid – Simulated Moderate Snow

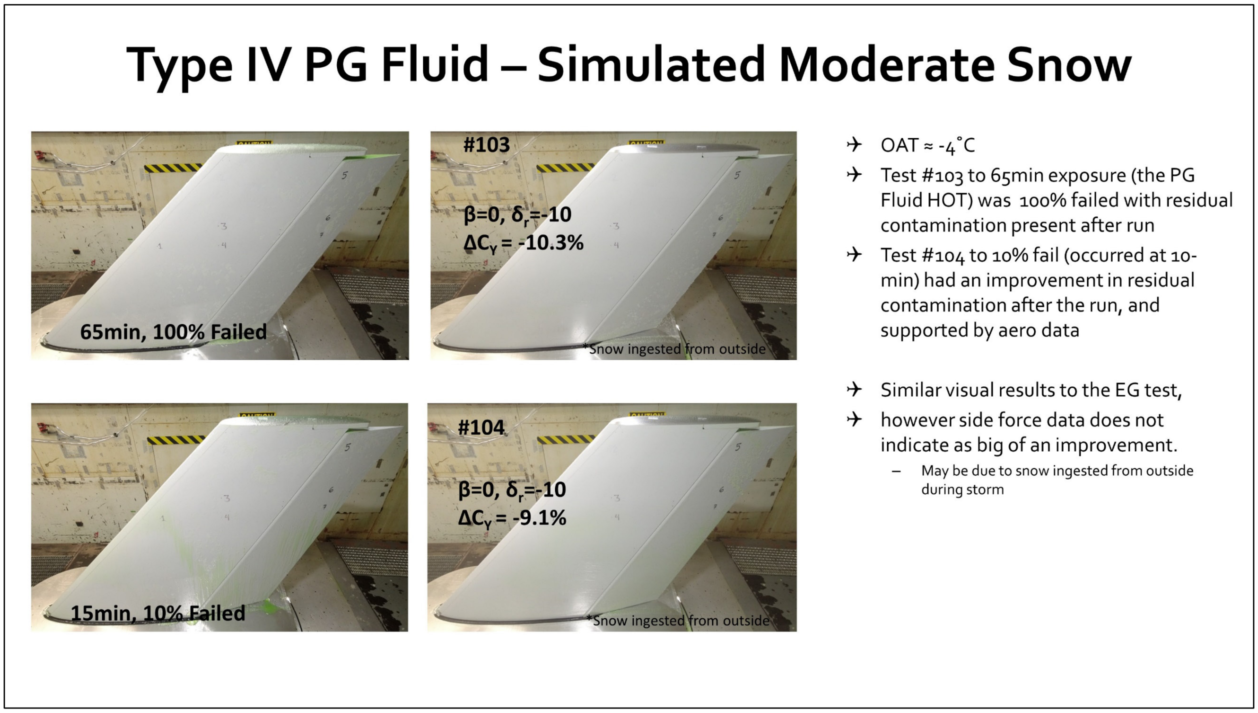


Photo 6.8: Type I PG Fluid – Simulated Moderate Snow

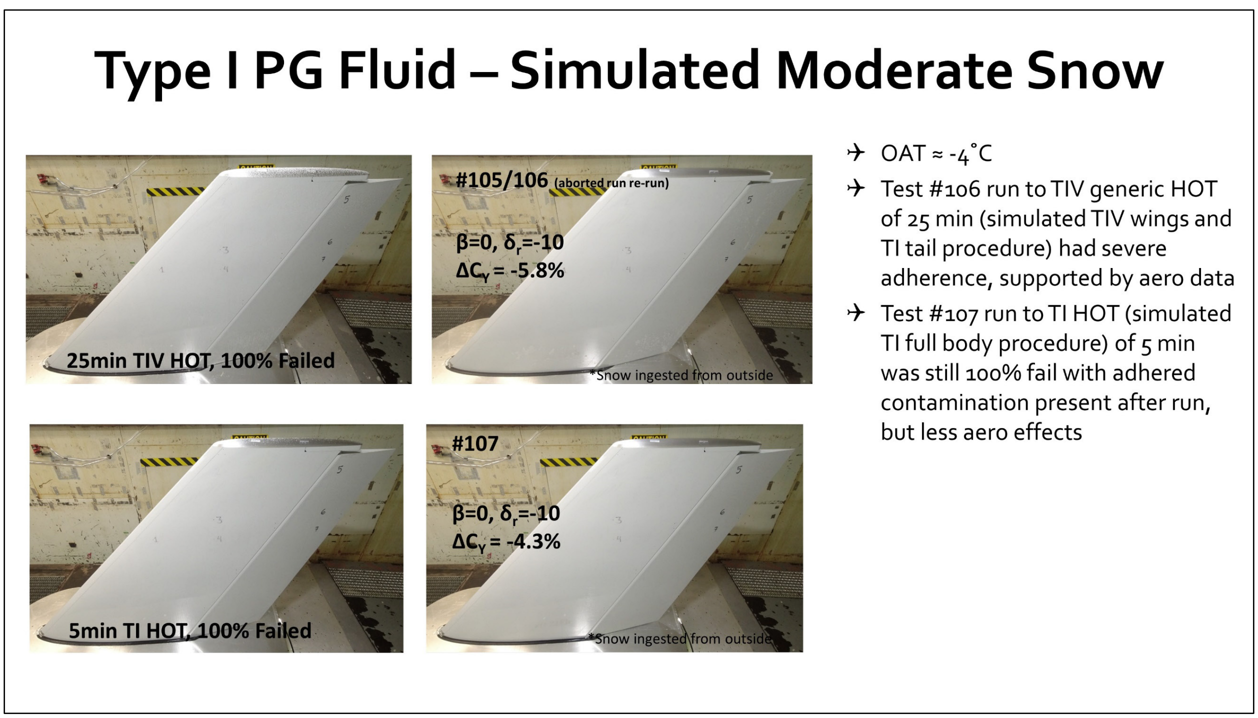
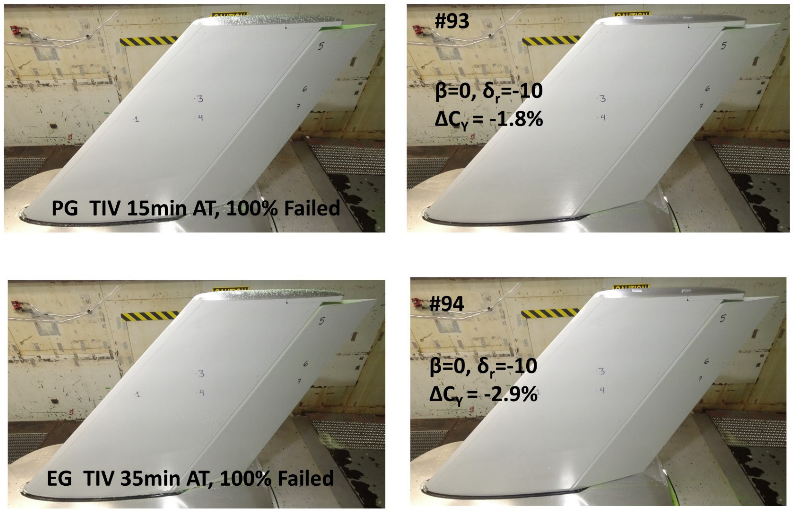


Photo 6.9: Type IV PG and EG Fluid – Simulated Moderate Ice Pellets

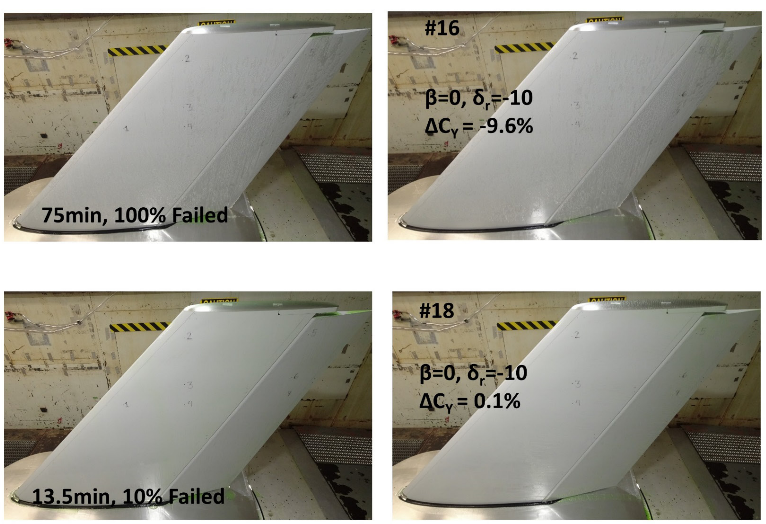
Simulated Moderate Ice Pellets



- OAT ≈ -3˚C
- Ice pellets bounced of the surface resulting in very little contamination present in the fluid at end of AT
- Both PG and EG had little decrease in side force, supporting the generally clean fluid condition

Photo 6.10: Type IV PG – Simulated Freezing Rain

Type IV PG Fluid – Simulated Freezing Rain



- OAT ≈ -5˚C
- Test #16 to 75 min HOT was 100% failed with residual adhered contamination present after run
- Test #18 to 10% fail only had a significant improvement in residual contamination after the run, and supported by aero data

Photo 6.11: Type IV EG Fluid – Mixed Snow and Freezing Rain

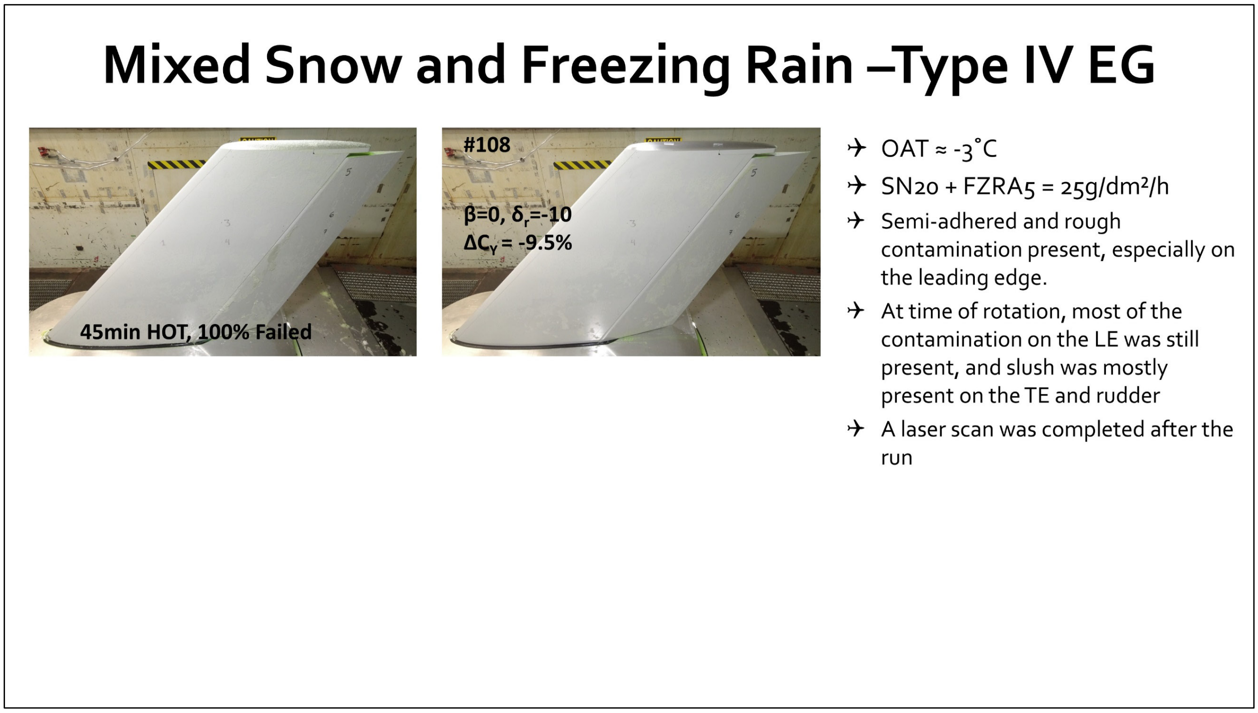


Photo 6.12: Type IV PG Fluid – OEI

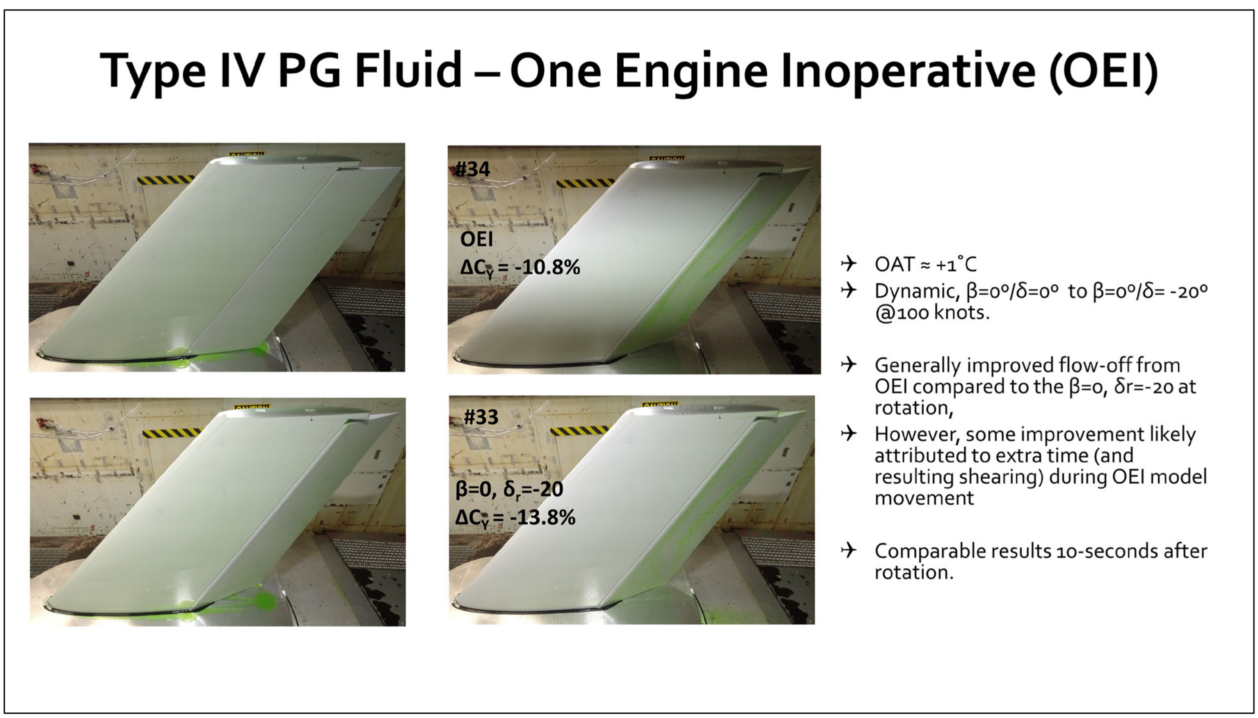
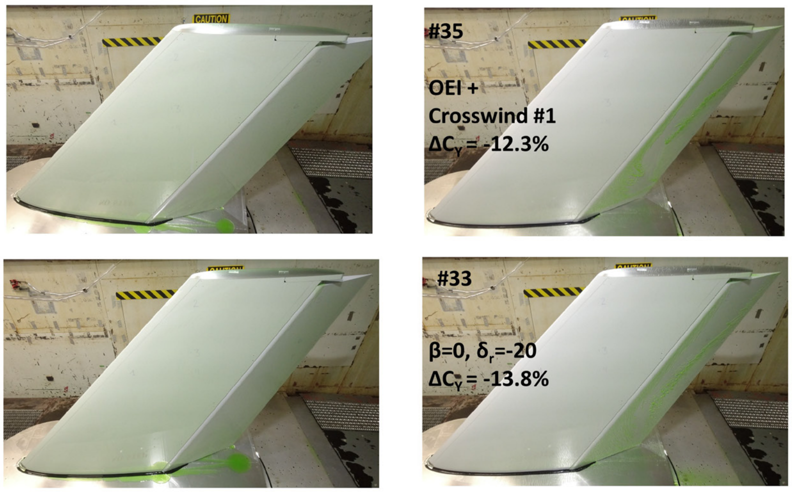


Photo 6.13: Type IV PG Fluid – OEI + Crosswind #1

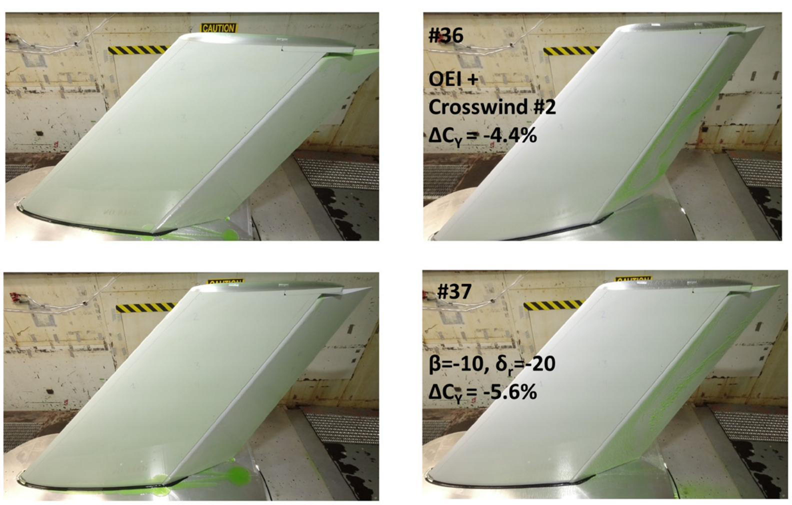
Type IV PG Fluid – OEI + Crosswind #1



- OAT ≈ 0˚C
- Dynamic, β=+10º/δ=-20º to β=0º/δ=-20º @100 knots.
- Generally improved flow-off from OEI compared to the β=0, δr=-20 and supported by aero data
- However, some improvement likely attributed to extra time (and resulting shearing) during OEI model movement
- Comparable results 10-seconds after rotation.

Photo 6.14: Type IV PG Fluid – OEI + Crosswind #2

Type IV PG Fluid – OEI + Crosswind #2



- OAT ≈ 0˚C
- Dynamic, β=+10º/δ=-20º to β=-10º/δ=-20º @100 knots.
- Generally improved flow-off from OEI compared to the β=0, δr=-20 and supported by aero data
- However, some improvement likely attributed to extra time (and resulting shearing) during OEI model movement
- Comparable results 10-seconds after rotation.

Photo 6.15: Type IV PG Fluid – Fluid Testing Repeatability

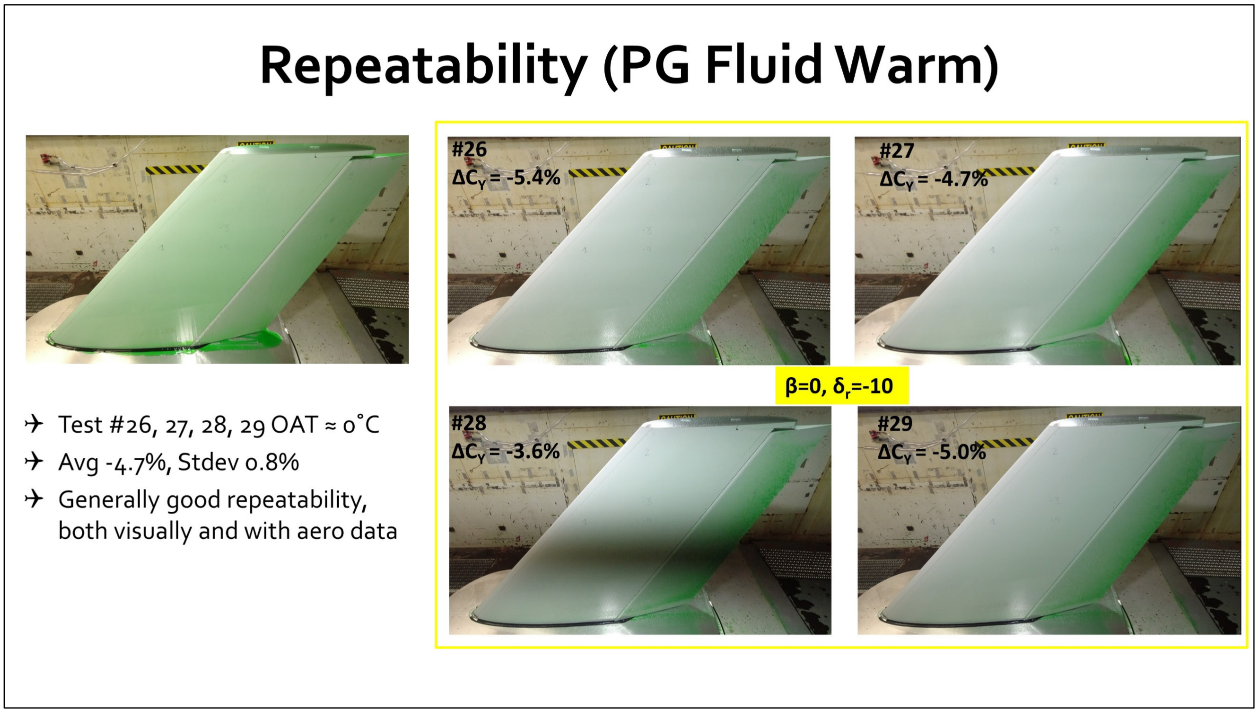


Photo 6.16: Type IV EG and PG Fluids – Variability

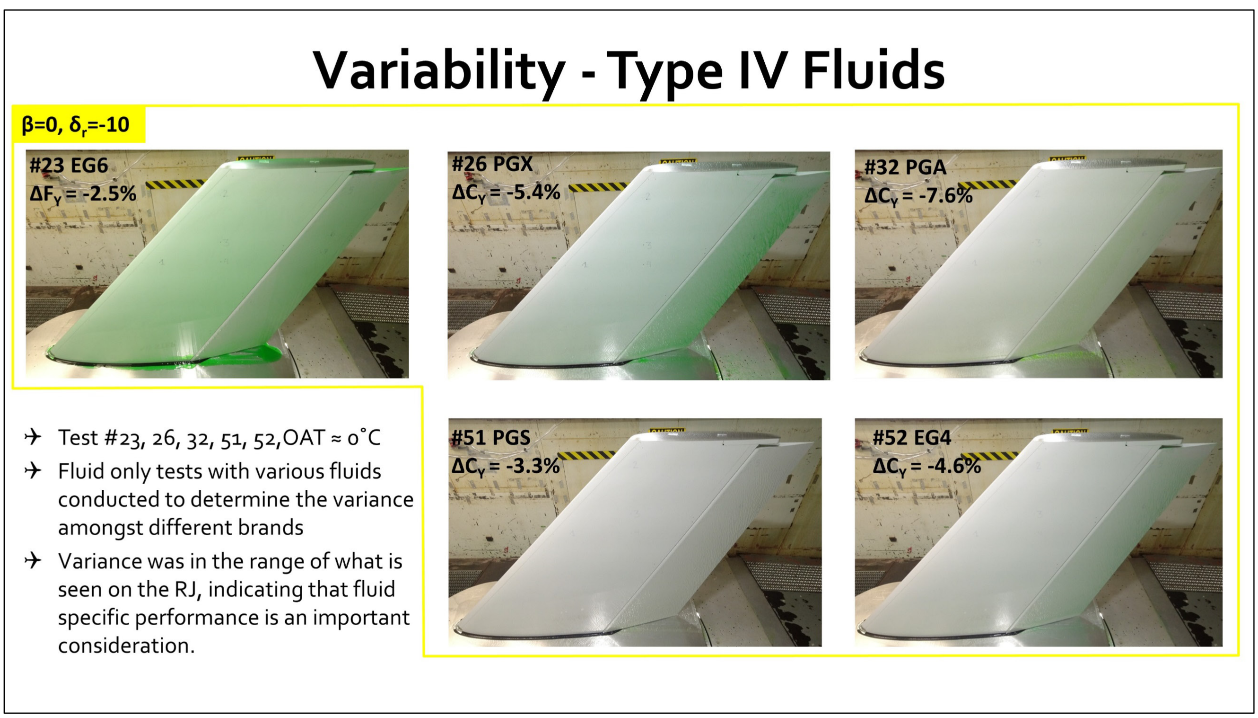
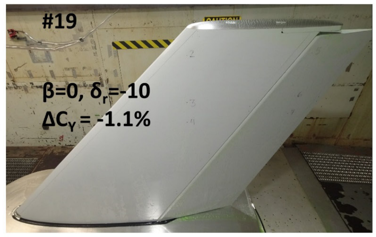


Photo 6.17: Type IV PG Fluid – Asymmetric Simulated Freezing Rain

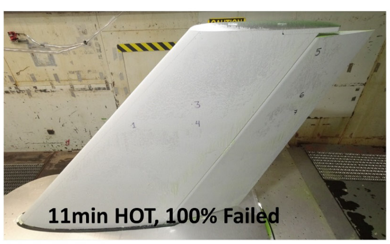
Asymmetric Simulated Freezing Rain (PG TIV)

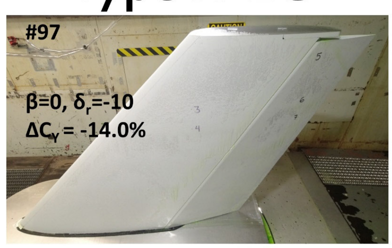


- OAT ≈ -5˚C
- Asymmetric contamination on suction side only to simulate high crosswind contamination during taxi
- 10% failure occurred around 19 minutes
  - longer than #18 since only one side
- Fluid cleaned off well and supported by aero data

Photo 6.18: Type IV EG Fluid – Asymmetric Mixed Snow and Freezing Rain

Asymmetric Mixed Snow and Freezing Rain – Type IV EG

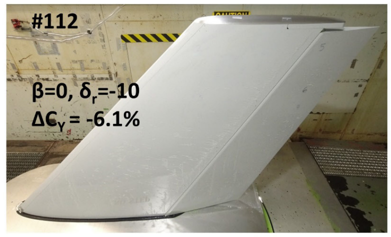




- OAT ≈ -4˚C
- SN 44+ FZRA 21 = 65 g/dm²/h, "freestyle" application to support laser scanning
- Residual fluid remaining on the wing from previous snow only test was further contaminated with a "freestyle" snow and freezing rain in order to create a worse case roughness on the LE and suction side only
- Contamination resulted in a -14% decrease in side force, which was still comparable to the worst fluid only case tested.
- This further indicated that the model was not very sensitive to contamination and roughness.

Photo 6.19: No Fluid – Simulated Freezing Rain on Unprotected Surface

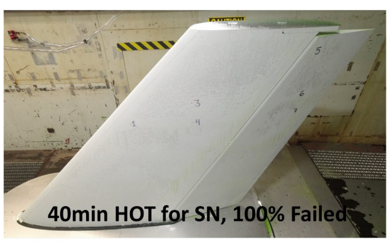
Simulated Freezing Rain on Unprotected Surface

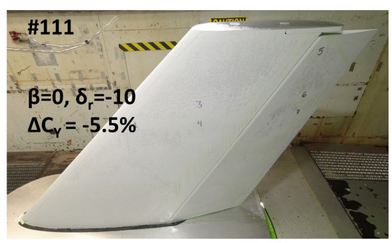


- OAT ≈ -6˚C
- Freezing rain only applied to a dry model simulating a deicing scenario when the pilot would request only wings de/anti-iced, but not the tail.
- Freezing rain did not immediately freeze, so was allowed to sit in the cold prior to takeoff
- Only small areas of adhesion were present before the run, and they nucleated and grew during takeoff.
- Poor flow off from adhered contamination supported by aero data

Photo 6.20: Type IV EG Fluid – Adjusted Catch Factor

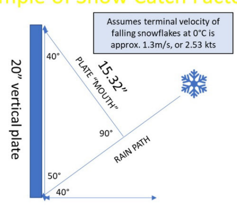
Adjusted Catch Factor –Type IV EG





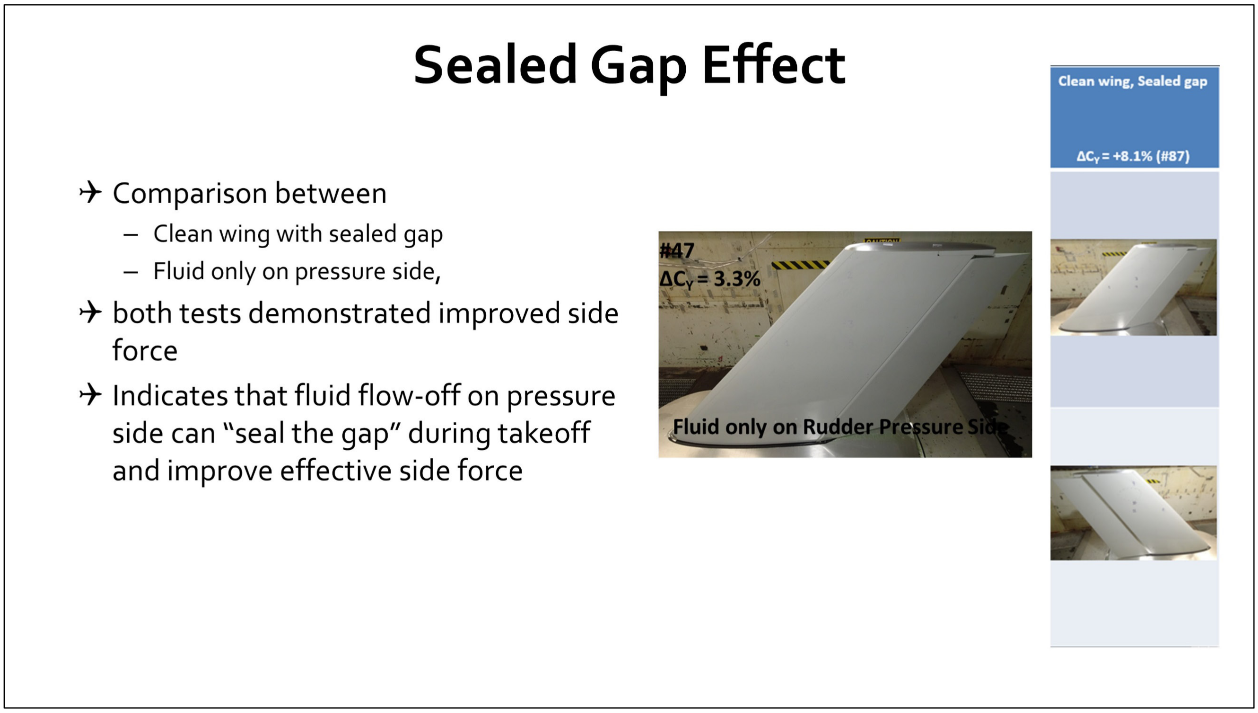
- OAT ≈ -4˚C
- Test conducted in moderate snow but with twice the rate simulating an increased catch factor on the v-stab.
- Therefore the rate was 2x25g/dm2/h for a total of 50g/dm2/h, so in the heavy snow range.
- Because of the warmer temperatures, the fluid drained out and only small patches of slush were present which was not removed during takeoff .
- The decrease in side force was -6%.
- A laser scan was done before and after takeoff.

Sample of Snow Catch Factor Analysis



Effective Precipitation Rate on Surfaces as Function of Wind Speed and Surface Angle				
Wind Speed (kts)	Snowfall Angle (°)	10° Rate Pan Rate (g/dm²/h)	Static Vertical Surface Rate - Static Asymmetric (g/dm²/h)	Rotating Vertical Surface Rate – Dynamic Symmetric (g/dm²/h)
0	90	25	0	0
3.0	40	25	25	12.5
7.7	18.3	25	50	25
36.2	4	25	103	51.5

Photo 6.21: Type IV PG Fluid – Sealed Gap Effect



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7. LASER SCANNING OF FLUID AND CONTAMINATION

This section describes the activities related to the laser scanning of the fluid and contamination on the CRM vertical stabilizer.

7.1 NASA Laser Scanning Technique

For the winter of 2022-23, NASA was scheduled to participate in the CRM tests by conducting laser scanning to collect three-dimensional imagery of the fluid and contamination present on the model. NASA has been using a laser scanning technique for several years that is designed to work with frozen in-flight icing shapes that are painted with a custom paint formula (mixture of titanium dioxide [TiO_2] pigment, poly binder, and tetrahydrofuran solvent) to improve the reflectiveness of the ice. The purpose of these tests was to demonstrate the feasibility of using this technology to document fluid and contaminated fluid for ground icing research purposes.

7.2 Painting of Fluid and Contamination for Scanning

The NASA custom paint formulation required sourcing of specific chemicals which required special handling precautions and the use of an ultrasonic mixer to fully suspend the solids in solution. Therefore, sixteen alternative products, including aerosol and power-based, were evaluated to determine if a more practical solution could be identified. TiO_2 was determined to have produced the best surface for laser scanning. With some trial and error, APS developed a formulation of food-grade TiO_2 powder with 99% isopropyl alcohol mixed to a 1:4 ratio by weight, respectively, that could be sprayed using a high-volume low-pressure (HVLP) spray gun paint applicator (see Photo 7.1). This formula was much easier to mix and readily sourced from numerous potential suppliers.

Due to concerns with airborne TiO_2 powder in the wind tunnel, the NRC and APS developed a mitigation plan for application of the TiO_2 mixture during testing, which included personal protective equipment, large fans to improve airflow in the test section, and personnel limitations in the test area during application (see Photo 7.2).

7.3 Sample of Laser Scanning Results

The scanning of the model and analysis of the data were the responsibility of NASA, and a separate report will be compiled by NASA for TC and the FAA. Three tests were attempted and included scans before and after simulated takeoff (Photo 7.3 demonstrates a laser scan in progress). Due to the amount of time required to install equipment, spray the surface, and scan the area (which could be approximately 1-2 hours per test), scanning was limited to smaller sections of interest to accelerate the process and minimize impact on the testing schedule. Photo 7.4 provides a sample of the laser data collected from NASA in comparison to the test photos captured by APS at the same time.

7.4 Summary of Laser Scanning

The testing indicated that laser scanning of the model with fluid and ice contamination was possible once the surface was coated with the TiO_2 mixture for both pre- and post-simulated takeoff scenarios. However, clean fluid or wet slushy contamination was not feasible as it was sliding off and not static enough to allow the laser scanning process to occur without distortion. One test was conducted with spraying the TiO_2 mixture pre-simulated takeoff, and it was observed that this did impact the fluid flow-off and also interacted with the fluid layer.

An important finding was that the ice thicknesses derived from the scan data compared well to manual point measurements, supporting the future use of this technology. The laser scanning process was long; therefore, it should be improved for efficiency for future testing. Photogrammetry should also be explored to evaluate the feasibility of an instantaneous point-and-shoot process.

Photo 7.1: APS Mixture of 99% Isopropyl Alcohol and TiO_2

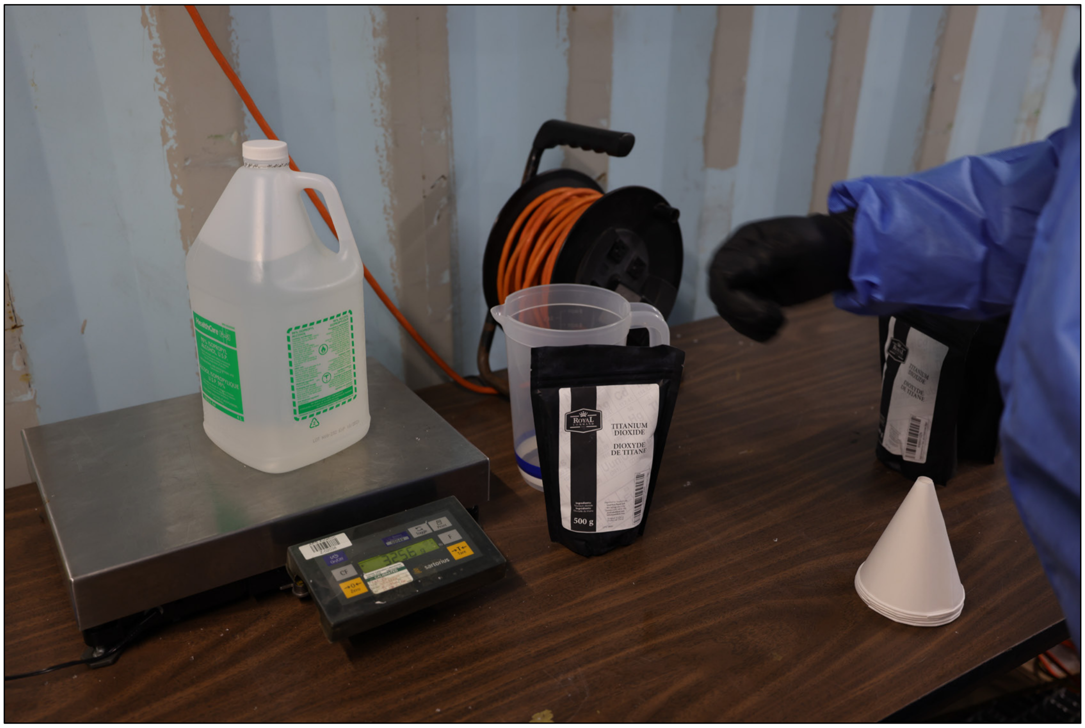
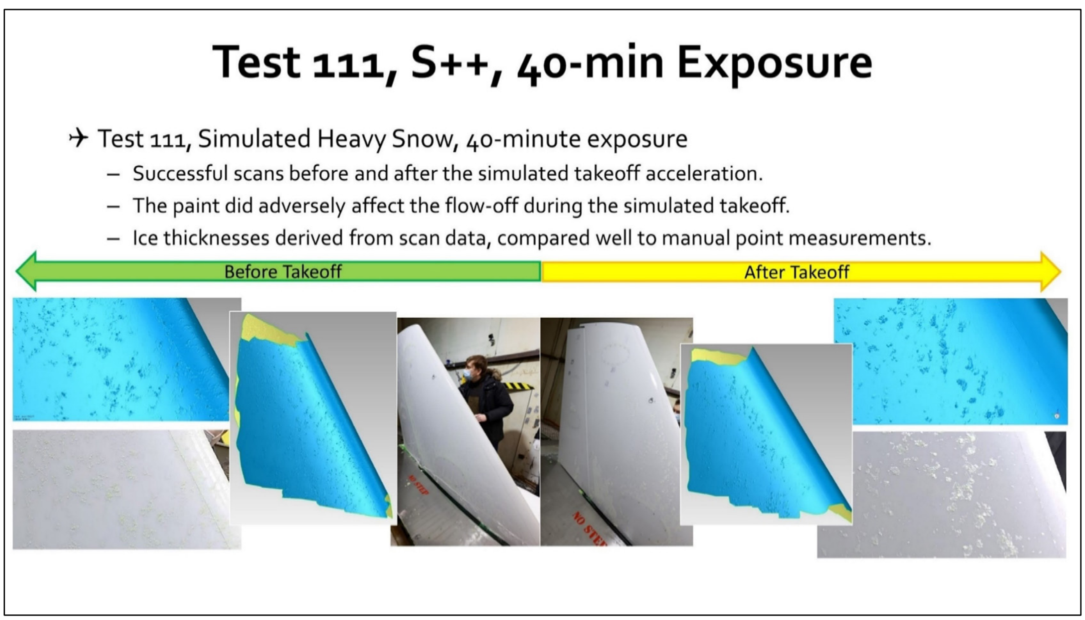


Photo 7.2: NASA Applying TiO_2 Mixture to Contaminated CRM

Photo 7.3: NASA Personnel Performing Laser Scan

Photo 7.4: Sample of NASA Laser Scanning Data in Comparison to Test Photos



8. CONCLUSIONS

These conclusions were derived from the testing conducted during the winter of 2022-23.

8.1 Modifications to Test Equipment and Procedures

To determine the most appropriate colour to paint the CRM, paint trials were conducted using test plates mounted on vertical stands painted various shades of colour from white to grey to black, including gloss and flat finishes. Light grey paint provided the best fluid and contamination visibility, and based on discussions with the NRC, the model was painted light grey using aircraft-grade paint, the same colour as the NRC Convair underside.

The CRM vertical stabilizer was mounted on a four-point balance with risers within the wind tunnel turntable floor. As this was the first year testing with load cells installed in the CRM, several tests were done prior to the start of the testing program to verify proper functionality, and additional tests were done on the first day of testing.

Many of these observations are based upon the aerodynamic data obtained from the force balance, focusing mainly on the side force. As such, the additional force balance data has proven to be very useful in the interpretation of the fluid and contamination behaviour. It is important to keep in mind that the measurements are specific to this model configuration and may or may not be applicable to other configurations.

8.2 Dry Model, Tuft Visualization, Boundary Layer Rake, and Sandpaper Roughness Testing

The CRM vertical stabilizer was tested in a dry and clean configuration to document the baseline performance of the model. The aerodynamic data collected demonstrated a linear trend in side force and yawing moment with rudder deflection at $\beta = 0°$ and $\beta = -10°$, indicating that the model stall was not within the parameter ranges tested. The model performance was generally symmetric, and the data compares well to the CFD predictions calculated by the NRC and used during the model design. The model uncertainty was documented and provided an acceptable level of experimental variation.

For the winter of 2022-23, testing with tufts and the boundary layer rake was not repeated as the results were expected to remain the same: the painting of the model should have little or no effect.

Sandpaper roughness testing was conducted with 40-grit sandpaper (k/c = 0.00025) applied to various components of the CRM to simulate fluid/contamination effects and help understand model performance. Data indicated that most of the side force was generated by the forward half of main element, and a sealed gap versus unsealed gap does not change the net effect of contamination on side force loss. The 40-grit sandpaper testing provided representative effects as compared to fluid and contamination tests.

8.3 Fluid Testing and Flow-Off Characterization

As the CRM vertical stabilizer testing was limited due to time and weather conditions, the tests performed were chosen based on their likeliness to provide the most informative data. This testing was conducted with Type IV EG- and PG-based fluids, as well as with PG-based Type I fluid.

Repeatability testing with fluids demonstrated that results were consistent, providing confidence in the data obtained. The calculated percentage decrease in side force was effective as an aerodynamic measure for comparative evaluation.

Exploratory fluid-only testing allowed the documentation of aerodynamic forces with different simulated takeoff profiles, as well as with non-standard fluid applications.

In general, fluid, fluid and contamination, and roughness testing all had comparable maximum side force losses; however, the worst-case conditions may not have been explored yet as testing was generally limited to warmer temperatures above -10ºC. In addition, the overall precipitation “catch factor” may vary based on precipitation types and wind speed, and these effects can impact fluid performance and flow-off. This is an area of research that should be explored further.

8.4 General Observations

In general, the test campaign confirmed the desired performance of the new model equipped with load balances to evaluate aerodynamic forces and helped in understanding the effects of sideslip and rudder deflection on pristine and contaminated fluid flow-off. However, due to the unseasonably warm temperatures encountered during this test campaign, the effects of fluid and contamination at colder temperatures remains unknown and remains a gap in our understanding.

9. RECOMMENDATIONS

These recommendations were derived from the testing conducted during the winter of 2022-23.

9.1 Cold Weather Data

Due to the unseasonably warm temperatures encountered during this test campaign, the effects of fluid and contamination at colder temperatures remains unknown and remains a gap in our understanding. Cold weather data collection is recommended to provide a better understanding of the sensitivity and context of the results. Options for scheduling accommodations should be explored with the NRC to optimize the chances of being able to test in colder weather conditions.

9.2 Better Lighting in the Wind Tunnel

The location of the CRM when installed in the M-46 wind tunnel makes lighting a challenge. The model sits on the floor of the tunnel, downwind of the overhead lighting. A temporary LED lighting installation was used by APS in 2022-23, which proved useful. Consideration should be given to this or better permanent lighting installations.

9.3 Laser Scanning Photogrammetry

Laser scanning of the model with ice contamination was possible once coated with a TiO_2 mixture for both pre- and post-simulated takeoff; however, the laser scanning process was very long and should be improved for efficiency. Photogrammetry should also be explored to evaluate the feasibility of an instantaneous point-and-shoot process. Development of these technologies could help support interpretation of results and potential implications for aerodynamic effects.

9.4 Future Testing with the Common Research Model Vertical Stabilizer

Future testing should build upon the testing matrix described in this report, including calibration and validation of procedures, dry surface testing and tuft visualization, and fluid testing and flow-off characterization. Testing should also focus on areas not extensively explored during this preliminary phase, including colder temperatures, different contamination types and levels, asymmetric contamination, and different fluids.

9.5 Development of Recommended Operational Practices

Research conducted to date is still exploratory and has indicated benefits associated with specific fluid type applications (thickened or not) depending on the types of contamination and temperatures tested. Future research should focus on refining these observations through testing and industry discussion, with the aim of developing recommended operational practices.

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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).

2. Ruggi, M., *Wind Tunnel Testing to Evaluate Contaminated Fluid Flow-Off from a Vertical Stabilizer*, APS Aviation Inc., Transport Canada, Montreal, December 2020, TP 15454E, 64.

3. Ruggi, M., *Wind Tunnel Testing to Evaluate Contaminated Fluid Flow-Off from a Common Research Model Vertical Stabilizer*, APS Aviation Inc., Transport Canada, Montreal, November 2022, TP 15538E, 76.

4. Society of Automotive Engineers Aerospace Recommended Practice 5485, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type II, III, and IV*, July 2004.

5. SAE International Aerospace Recommended Practice 5945, *Endurance Time Tests for Aircraft Deicing/Anti-Icing Fluids: SAE Type I*, July 2007.

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APPENDIX A

TRANSPORT CANADA
STATEMENT OF WORK EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2022-23

TRANSPORT CANADA
STATEMENT OF WORK EXCERPT –
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2022-23

12. Wind Tunnel Testing – Planning and Setup Activities – Priority 1

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.

14. Wind Tunnel Testing – CRM V-Stab Testing – Priority 1

Note: The NRC facility costs associated with manufacturing test models 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.

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 ten days of wind tunnel tests with the vertical stabilizer common research model. Testing objectives should be focused on further evaluation of contaminated fluid flow-off from a vertical stabilizer.

   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 takeoff runs. 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. 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 use of photogrammetry technology should be considered for integration, if resources are sufficient. 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) Analyse data.

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

APPENDIX B

PROCEDURE:
WIND TUNNEL TESTING TO EVALUATE CONTAMINATED FLUID FLOW-OFF FROM A VERTICAL STABILIZER
WINTER 2022-2023

0300293

PROCEDURE:

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

Winter 2022-23

Prepared for:

Transport Canada
Programs Group 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

APS Aviation Inc.

December 20, 2022
Final Version 1.0

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

Winter 2022-23

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 behavior 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?

Flat plate testing conducted in 2015-16 demonstrated the variability in both fluid protection times and characteristics of contamination on vertical surfaces. In 2019-20, aerodynamic testing to document contaminated fluid flow-off on a Piper PA-34-200T Seneca II vertical stabilizer 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. The applicability of these results to commercial airliners was reviewed by the G-12 Aerodynamics Working Group (AWG), and it was recommended that a new generic model be designed to allow for better, more relevant data to be collected.

Through discussions with the SAE International G-12 AWG, a "Common Research Model" (CRM) was designed based on an analysis of existing aircraft geometries and built by the National Research Council Canada (NRC) for testing in the winter of 2021-22. In general, the testing results supported the observations from prior testing, and in addition, however showed that the V-Stab CRM was a better more representative model for continued evaluation of ground icing situations. Unfortunately, there was limited cold weather days during the planned winter

2021-22 test program, therefore testing consisted of a large number of fluids only tests due to the warm temperature. As such, many of the objectives related to icing remained outstanding. In addition, load cells that were ordered for the model were not acquired in time, therefore aerodynamic data could not be collected.

It was recommended that testing continue during the winter of 2022-23 with the V-Stab CRM to include the newly acquired load cells, to continue the research focusing on icing conditions, and to include more detailed photography and laser scanning to characterize the fluid and contamination present on the wing. The model would be painted gloss light grey in preparation for the 2022-23 testing plan to support better visualization of fluids and contamination, and to aid the laser scanning technology.

2. OBJECTIVES AND TIMING

Ten days of wind tunnel testing are being planned based on TC/FAA funding resources. The following sections describe the objectives.

2.1 Documentation of Contaminated Fluid Flow-Off on a Vertical Stabilizer

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

To satisfy this objective, a CRM vertical stabilizer (see Figure 2.1) will be subjected to a series of tests in the NRC Icing Wind Tunnel (IWT).

Ten days of testing are required for conducting of these tests.

As part of an exploratory initiative led by NASA, this testing will incorporate a laser scanning system to evaluate ice and fluid thickness for a limited select number of tests.

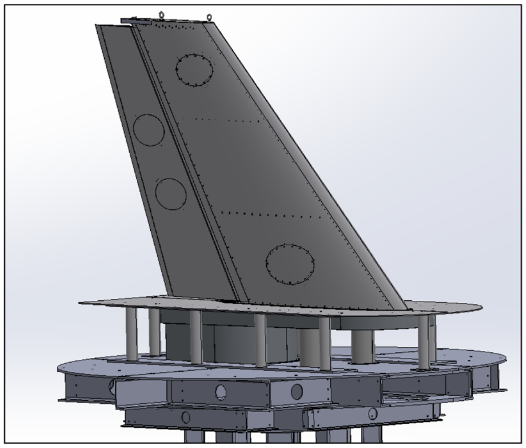

Figure 2.1: Vertical Stabilizer Mounted on Turntable

2.2 Ice Pellet Allowance Time Testing

Ice pellet is typically conducted yearly or bi-yearly as part of the wind tunnel testing program. Due to limited TC/FAA funding resources and priority focused on V-Stab CRM research, ice pellet allowance time testing was not possible for the winter of 2022-23 and will be deferred to the winter of 2023-24 at the earliest.

2.3 Timing

Ten days of testing will be conducted with the V-Stab CRM based on the available TC/FAA funding resources.

At the time of writing this procedure, it is expected that several activities will occur in advance of the official start of the testing program on January 15, 2023. NRC will conduct shakedown and calibration runs and begin analysis of the aerodynamic data collected up to January 11, 2023. Starting January 12, 2023 for a period of up to two days National Aeronautics and Space Administration (NASA) will setup and test the laser scanning technology, and APS Aviation Inc (APS) will setup equipment and cameras and begin training and precipitation calibration.

Testing with the V-Stab CRM will start on the evening of January 15, 2023. See Table 2.1 for details. Testing will be conducted during overnight periods (9:30 pm to 5:30 am). The weekends will be considered only if deemed necessary.

Table 2.1: Test Calendar

Week of	Sun	Mon	Tue	Wed	Thurs	Fri	Sat
18-Dec-22							
25-Dec-22							
01-Jan-23							
08-Jan-23		NRC CRM Shakedown and Calibration - Dry Runs	NRC CRM Shakedown and Calibration - Dry Runs	NRC CRM Shakedown and Calibration - Dry Runs	NASA Laser Scanning Setup and Pre-Tests	NASA Laser Scanning Setup and Pre-Tests	
					APS Setup, Training, and Precip. Calibration	APS Setup, Training, and Precip. Calibration	
15-Jan-23	APS CRM Fluid Tests	APS CRM Fluid Tests	APS CRM Fluid Tests	APS CRM Fluid Tests	APS CRM Fluid Tests		
22-Jan-23	APS CRM Fluid Tests	APS CRM Fluid Tests	APS CRM Fluid Tests	APS CRM Fluid Tests	APS CRM Fluid Tests		
29-Jan-23							

Legend

APS Setup, Training, and Precip. Calibration	APS to setup equipment, setup remote vieweing cameras, conduct training for new staff, and (if possible) conduct calibration of precipitation dispensing.
NASA Laser Scanning Setup and Pre-Tests	NASA to setup and prepare the laser scanning system in anticipation of the folloiwing weeks testing.
NRC CRM Shakedown and Calibration	NRC lead activity to deliver a working and repeatable CRM model. APS to support. Shakedown and dry run repeatability. May consider Boundary Layer Rake Tests and Tuft tests as required.
APS CRM Fluid Tests	Fluid only, and fluid with contamination tests (SN, FZRA, PL). Up to 5 days

3. TEST PLAN

The NRC IWT 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 glycol and ethylene glycol-based fluids in the 100/0 dilution (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 items #1, #2, and #3 (CRM testing) is shown in Table 3.2. It is expected that the shakedown runs and dry wing tests be conducted during the first week of testing, and the fluid testing will begin the week of January 9, 2023. Testing with tuft tests and boundary layer rake tests are included in the test plan but are not likely to be conducted as results are expected to be the same as what was achieved during the 2021-22 testing with the CRM. 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. Daily planning meetings will be held at the start of each day with stakeholders and the daily set of target tests will be identified based on weather conditions and testing priorities.

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

Table 3.1: Preliminary List of Testing Objectives for Winter 2022-23 Wind Tunnel Testing

Item #	Objective	Priority	Description	# of Days
0	Setup, Training, and Precipitation Calibration	1	Setup of equipment and calibration of the rain sprayer and the ice pellet and snow dispensers	Pre-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	Shakedown and Calibration Testing	1	Shakedown and dry run repeatability, boundary layer rake tests, and tuft tests. Sandpaper and boundary-layer trip tests may be considered.	1
3	Fluid Testing	1	Fluid only, and fluid with contamination tests (SN, FZRA, PL).	9
4	Other R&D Activities	-	Any potential suggestions from industry	-
			Total # of Days for Priority 1 Tests	**10**

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
1	1	Shakedown Runs	None	β=TBD°, δ=TBD°	Any	None	N/A	Parameters TBD as required
2	1	Dry Wing	None	β=TBD°, δ=TBD° (dynamic)	Any	None	N/A	To be done at start of each day
3	1	Dry Wing	None	β=TBD°, δ=TBD° (static)	Any	None	N/A	To be done at start of each day
4	2	Tufts	None	β= 0, δ = 0 to -20 @2° incr.	Any	None	N/A	Tufts on both sides
5	2	Tufts	None	β= 0, δ = 0 to +20 @2° incr.	Any	None	N/A	Tufts on both sides
6	2	Tufts	None	β= -5, δ = 0 to -20 @2° incr.	Any	None	N/A	Tufts on both sides
7	2	Tufts	None	β= -5, δ = 0 to +20 @2° incr.	Any	None	N/A	Tufts on both sides
8	2	Tufts	None	β= -10, δ = 0 to -20 @2° incr.	Any	None	N/A	Tufts on both sides
9	2	Tufts	None	β= -10, δ = 0 to +20 @2° incr.	Any	None	N/A	Tufts on both sides
10	2	Tufts	None	β=TBD°, δ=TBD°	Any	None	N/A	Tufts on both sides
11	2	Boundary Layer Rake	None	β= 0 δ= 0 to -20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
12	2	Boundary Layer Rake	None	β= 0 δ= 0 to +20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
13	2	Boundary Layer Rake	None	β= -5 δ= 0 to -20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
14	2	Boundary Layer Rake	None	β= -5 δ= 0 to +20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
15	2	Boundary Layer Rake	None	β= -10 δ= 0 to -20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
16	2	Boundary Layer Rake	None	β= -10 δ= 0 to +20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
17	2	Boundary Layer Rake	None	β= +10 δ= 0 to -20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
18	2	Boundary Layer Rake	None	β= +10 δ= 0 to +20 @2° incr.	Any	None	N/A	#1 BLR Location (main port)
19	2	Boundary Layer Rake	None	β= 0 δ= 0 to -20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)
20	2	Boundary Layer Rake	None	β= 0 δ= 0 to +20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)
21	2	Boundary Layer Rake	None	β= -5 δ= 0 to -20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)
22	2	Boundary Layer Rake	None	β= -5 δ= 0 to +20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
23	2	Boundary Layer Rake	None	β = -10 δ = 0 to -20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)
24	2	Boundary Layer Rake	None	β = -10 δ = 0 to +20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)
25	2	Boundary Layer Rake	None	β = +10 δ = 0 to -20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)
26	2	Boundary Layer Rake	None	β = +10 δ = 0 to +20 @2° incr.	Any	None	N/A	#2 BLR Location (rudder port)
27	2	Boundary Layer Rake	None	β = 0 δ = 0 to -20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
28	2	Boundary Layer Rake	None	β = 0 δ = 0 to +20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
29	2	Boundary Layer Rake	None	β = -5 δ = 0 to -20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
30	2	Boundary Layer Rake	None	β = -5 δ = 0 to +20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
31	2	Boundary Layer Rake	None	β = -10 δ = 0 to -20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
32	2	Boundary Layer Rake	None	β = -10 δ = 0 to +20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
33	2	Boundary Layer Rake	None	β = +10 δ = 0 to -20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
34	2	Boundary Layer Rake	None	β = +10 δ = 0 to +20 @2° incr.	Any	None	N/A	#3 BLR Location (main stbd)
35	2	Boundary Layer Rake	None	β = 0 δ = 0 to -20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
36	2	Boundary Layer Rake	None	β = 0 δ = 0 to +20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
37	2	Boundary Layer Rake	None	β = -5 δ = 0 to -20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
38	2	Boundary Layer Rake	None	β = -5 δ = 0 to +20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
39	2	Boundary Layer Rake	None	β = -10 δ = 0 to -20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
40	2	Boundary Layer Rake	None	β = -10 δ = 0 to +20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
41	2	Boundary Layer Rake	None	β = +10 δ = 0 to -20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
42	2	Boundary Layer Rake	None	β = +10 δ = 0 to +20 @2° incr.	Any	None	N/A	#4 BLR Location (rudder stbd)
43	1	Fluid Only	None	β=0°, δ=0°	Cold	PG TIV	N/A	-
44	1	Fluid Only	None	β=0°, δ=0°	Warm	PG TIV	N/A	-
45	1	Fluid Only	None	β=TBD°, δ=TBD°	Cold	PG TIV	N/A	-

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
46	1	Fluid Only	None	β = TBD°, δ = TBD°	Warm	PG TIV	N/A	-
47	1	Fluid Only	None	β = -10°, δ = -20°	Cold	PG TIV	N/A	-
48	1	Fluid Only	None	β = -10°, δ = -20°	Warm	PG TIV	N/A	-
49	1	Fluid Only	None	β = 0°, δ = 0°	Cold	TI	N/A	-
50	1	Fluid Only	None	β = 0°, δ = 0°	Warm	TI	N/A	-
51	1	Fluid Only	None	β = TBD°, δ = TBD°	Cold	TI	N/A	-
52	1	Fluid Only	None	β = TBD°, δ = TBD°	Warm	TI	N/A	-
53	1	Fluid Only	None	β = -10°, δ = -20°	Cold	TI	N/A	-
54	1	Fluid Only	None	β = -10°, δ = -20°	Warm	TI	N/A	-
55	1	Fluid Only	None	β = 0°, δ = 0°	Cold	EG TIV	N/A	-
56	1	Fluid Only	None	β = 0°, δ = 0°	Warm	EG TIV	N/A	-
57	1	Fluid Only	None	β = TBD°, δ = TBD°	Cold	EG TIV	N/A	-
58	1	Fluid Only	None	β = TBD°, δ = TBD°	Warm	EG TIV	N/A	-
59	1	Fluid Only	None	β = -10°, δ = -20°	Cold	EG TIV	N/A	-
60	1	Fluid Only	None	β = -10°, δ = -20°	Warm	EG TIV	N/A	-
61	2	OEI Simulations	TBD	TBD	Cold	PG TIV	TBD	Simulation parameters tbd
62	2	OEI Simulations	TBD	TBD	Warm	PG TIV	TBD	Simulation parameters tbd
63	2	OEI Simulations	TBD	TBD	Cold	TI	TBD	Simulation parameters tbd
64	2	OEI Simulations	TBD	TBD	Warm	TI	TBD	Simulation parameters tbd
65	2	OEI Simulations	TBD	TBD	Cold	EG TIV	TBD	Simulation parameters tbd
66	2	OEI Simulations	TBD	TBD	Warm	EG TIV	TBD	Simulation parameters tbd
67	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
68	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	PG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
69	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
70	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Warm	PG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
71	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
72	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
73	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
74	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
75	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
76	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
77	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
78	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
79	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
80	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
81	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
82	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
83	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
84	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Cold	TI	Asymmetric (either side)	Exposure to V-Stab 10% fail
85	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
86	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Warm	TI	Asymmetric (either side)	Exposure to V-Stab 10% fail
87	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
88	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
89	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
90	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
91	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	**Precipitation** *Snow, Freezing Rain, Other, None*	**Sideslip (β) and Rudder Deflection (δ)** *β = -10° to +10°, δ = -20° to +20°*	**Temperature** *Cold, Warm, Any*	Fluid	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
92	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
93	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
94	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
95	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
96	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
97	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
98	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
99	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
100	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	EG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
101	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
102	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	EG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
103	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
104	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
105	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
106	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
107	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
108	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
109	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
110	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
111	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
112	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
113	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
114	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
115	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
116	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	None	Asymmetric (either side)	Exposure to V-Stab 10% fail
117	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
118	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	None	Asymmetric (either side)	Exposure to V-Stab 10% fail
119	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
120	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
121	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
122	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
123	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
124	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
125	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
126	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
127	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
128	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
129	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
130	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
131	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
132	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	PG TIV	Asymmetric (either side)	Exposure to HOT
133	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
134	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	PG TIV	Asymmetric (either side)	Exposure to HOT
135	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
136	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
137	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
138	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
139	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
140	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
141	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
142	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
143	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
144	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
145	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
146	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
147	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Cold	TI	Symmetric (both sides)	Exposure to HOT
148	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Cold	TI	Asymmetric (either side)	Exposure to HOT
149	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Warm	TI	Symmetric (both sides)	Exposure to HOT
150	1	Fluid and Cont. (SN)	Snow	β=0°, δ=0°	Warm	TI	Asymmetric (either side)	Exposure to HOT
151	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	TI	Symmetric (both sides)	Exposure to HOT
152	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
153	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
154	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	TI	Symmetric (both sides)	Exposure to HOT
155	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
156	1	Fluid and Cont. (SN)	Snow	β=TBD°, δ=TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
157	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	TI	Symmetric (both sides)	Exposure to HOT
158	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
159	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
160	1	Fluid and Cont. (SN)	Snow	β= -10°, δ= -20°	Warm	TI	Symmetric (both sides)	Exposure to HOT

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
161	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
162	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
163	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
164	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	EG TIV	Asymmetric (either side)	Exposure to HOT
165	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
166	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	EG TIV	Asymmetric (either side)	Exposure to HOT
167	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
168	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
169	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
170	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
171	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
172	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
173	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
174	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
175	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
176	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
177	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
178	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
179	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	None	Symmetric (both sides)	Exposure to HOT
180	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Cold	None	Asymmetric (either side)	Exposure to HOT
181	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	None	Symmetric (both sides)	Exposure to HOT
182	1	Fluid and Cont. (SN)	Snow	β = 0°, δ = 0°	Warm	None	Asymmetric (either side)	Exposure to HOT
183	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	None	Symmetric (both sides)	Exposure to HOT

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
184	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
185	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
186	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	None	Symmetric (both sides)	Exposure to HOT
187	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
188	1	Fluid and Cont. (SN)	Snow	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
189	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	None	Symmetric (both sides)	Exposure to HOT
190	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
191	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
192	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	None	Symmetric (both sides)	Exposure to HOT
193	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
194	1	Fluid and Cont. (SN)	Snow	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
195	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
196	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	EG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
197	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
198	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	PG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
199	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
200	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	EG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
201	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
202	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	PG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
203	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
204	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
205	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
206	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
207	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
208	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
209	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
210	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
211	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
212	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
213	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
214	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
215	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
216	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
217	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
218	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
219	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
220	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
221	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
222	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
223	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
224	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
225	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
226	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
227	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
228	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Cold	TI	Asymmetric (either side)	Exposure to V-Stab 10% fail
229	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	**Precipitation** *Snow, Freezing Rain, Other, None*	**Sideslip (β) and Rudder Deflection (δ)** *β = -10° to +10°, δ = -20° to +20°*	**Temperature** *Cold, Warm, Any*	Fluid	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
230	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Warm	TI	Asymmetric (either side)	Exposure to V-Stab 10% fail
231	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
232	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
233	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
234	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
235	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
236	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
237	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
238	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
239	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
240	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
241	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
242	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
243	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
244	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Cold	None	Asymmetric (either side)	Exposure to V-Stab 10% fail
245	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
246	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Warm	None	Asymmetric (either side)	Exposure to V-Stab 10% fail
247	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
248	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
249	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
250	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
251	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
252	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	**Precipitation** *Snow, Freezing Rain, Other, None*	**Sideslip (β) and Rudder Deflection (δ)** *β = -10° to +10°, δ = -20° to +20°*	**Temperature** *Cold, Warm, Any*	Fluid	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
253	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
254	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
255	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
256	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
257	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
258	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
259	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
260	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	EG TIV	Asymmetric (either side)	Exposure to HOT
261	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
262	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	PG TIV	Asymmetric (either side)	Exposure to HOT
263	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
264	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	EG TIV	Asymmetric (either side)	Exposure to HOT
265	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
266	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	PG TIV	Asymmetric (either side)	Exposure to HOT
267	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
268	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
269	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
270	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
271	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
272	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
273	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
274	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
275	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT

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

Test #	Priority	Objective	**Precipitation** *Snow, Freezing Rain, Other, None*	**Sideslip (β) and Rudder Deflection (δ)** *β = -10° to +10°, δ = -20° to +20°*	**Temperature** *Cold, Warm, Any*	Fluid	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
276	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
277	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
278	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
279	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
280	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
281	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
282	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
283	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
284	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
285	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
286	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
287	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
288	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
289	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
290	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
291	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	TI	Symmetric (both sides)	Exposure to HOT
292	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Cold	TI	Asymmetric (either side)	Exposure to HOT
293	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	TI	Symmetric (both sides)	Exposure to HOT
294	1	Fluid and Cont. (FZR)	Freezing Rain	β = 0°, δ = 0°	Warm	TI	Asymmetric (either side)	Exposure to HOT
295	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	TI	Symmetric (both sides)	Exposure to HOT
296	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
297	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
298	1	Fluid and Cont. (FZR)	Freezing Rain	β = TBD°, δ = TBD°	Warm	TI	Symmetric (both sides)	Exposure to HOT

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

Test #	**Priority**	**Objective**	**Precipitation** *Snow, Freezing Rain, Other, None*	**Sideslip (β) and Rudder Deflection (δ)** *β = -10° to +10°, δ = -20° to +20°*	**Temperature** *Cold, Warm, Any*	**Fluid**	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	**Comments**
299	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
300	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
301	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	TI	Symmetric (both sides)	Exposure to HOT
302	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
303	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
304	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	TI	Symmetric (both sides)	Exposure to HOT
305	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
306	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
307	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Cold	None	Symmetric (both sides)	Exposure to HOT
308	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Cold	None	Asymmetric (either side)	Exposure to HOT
309	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Warm	None	Symmetric (both sides)	Exposure to HOT
310	1	Fluid and Cont. (FZR)	Freezing Rain	β=0°, δ=0°	Warm	None	Asymmetric (either side)	Exposure to HOT
311	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	None	Symmetric (both sides)	Exposure to HOT
312	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
313	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
314	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	None	Symmetric (both sides)	Exposure to HOT
315	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
316	1	Fluid and Cont. (FZR)	Freezing Rain	β=TBD°, δ=TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
317	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	None	Symmetric (both sides)	Exposure to HOT
318	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
319	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
320	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	None	Symmetric (both sides)	Exposure to HOT
321	1	Fluid and Cont. (FZR)	Freezing Rain	β= -10°, δ= -20°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to HOT

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

Test #	Priority	Objective	**Precipitation** *Snow, Freezing Rain, Other, None*	**Sideslip (β) and Rudder Deflection (δ)** *β = -10° to +10°, δ = -20° to +20°*	**Temperature** *Cold, Warm, Any*	Fluid	**Contamination Application** *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
322	1	Fluid and Cont. (FZR)	Freezing Rain	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
323	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
324	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Cold	EG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
325	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
326	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Cold	PG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
327	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
328	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	EG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
329	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
330	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	PG TIV	Asymmetric (either side)	Exposure to V-Stab 10% fail
331	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
332	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
333	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
334	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
335	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
336	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
337	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
338	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
339	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
340	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
341	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
342	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
343	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
344	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
345	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
346	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
347	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
348	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
349	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	EG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
350	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
351	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
352	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	PG TIV	Symmetric (both sides)	Exposure to V-Stab 10% fail
353	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
354	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
355	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
356	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	TI	Asymmetric (either side)	Exposure to V-Stab 10% fail
357	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
358	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	TI	Asymmetric (either side)	Exposure to V-Stab 10% fail
359	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
360	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
361	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
362	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
363	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
364	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
365	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
366	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
367	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
368	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	TI	Symmetric (both sides)	Exposure to V-Stab 10% fail
369	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
370	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
371	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
372	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	None	Asymmetric (either side)	Exposure to V-Stab 10% fail
373	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
374	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	None	Asymmetric (either side)	Exposure to V-Stab 10% fail
375	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
376	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
377	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
378	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
379	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
380	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
381	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
382	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
383	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
384	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	None	Symmetric (both sides)	Exposure to V-Stab 10% fail
385	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to V-Stab 10% fail
386	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to V-Stab 10% fail
387	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
388	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	EG TIV	Asymmetric (either side)	Exposure to HOT
389	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
390	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	PG TIV	Asymmetric (either side)	Exposure to HOT

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Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
391	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
392	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	EG TIV	Asymmetric (either side)	Exposure to HOT
393	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
394	2	Fluid and Cont. (Other)	Other	β=0°, δ=0°	Warm	PG TIV	Asymmetric (either side)	Exposure to HOT
395	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
396	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
397	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
398	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
399	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
400	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
401	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT
402	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
403	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
404	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
405	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
406	2	Fluid and Cont. (Other)	Other	β=TBD°, δ=TBD°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
407	2	Fluid and Cont. (Other)	Other	β= -10°, δ= -20°	Cold	EG TIV	Symmetric (both sides)	Exposure to HOT
408	2	Fluid and Cont. (Other)	Other	β= -10°, δ= -20°	Cold	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
409	2	Fluid and Cont. (Other)	Other	β= -10°, δ= -20°	Cold	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
410	2	Fluid and Cont. (Other)	Other	β= -10°, δ= -20°	Cold	PG TIV	Symmetric (both sides)	Exposure to HOT
411	2	Fluid and Cont. (Other)	Other	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
412	2	Fluid and Cont. (Other)	Other	β= -10°, δ= -20°	Cold	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
413	2	Fluid and Cont. (Other)	Other	β= -10°, δ= -20°	Warm	EG TIV	Symmetric (both sides)	Exposure to HOT

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind), Asymmetric (Cont. Into Wind), Tufts*	Comments
414	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
415	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	EG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
416	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	PG TIV	Symmetric (both sides)	Exposure to HOT
417	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	PG TIV	Asymmetric (Cont. Into Wind)	Exposure to HOT
418	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	PG TIV	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
419	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	TI	Symmetric (both sides)	Exposure to HOT
420	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	TI	Asymmetric (either side)	Exposure to HOT
421	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	TI	Symmetric (both sides)	Exposure to HOT
422	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	TI	Asymmetric (either side)	Exposure to HOT
423	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	TI	Symmetric (both sides)	Exposure to HOT
424	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
425	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
426	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	TI	Symmetric (both sides)	Exposure to HOT
427	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
428	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
429	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	TI	Symmetric (both sides)	Exposure to HOT
430	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
431	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
432	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	TI	Symmetric (both sides)	Exposure to HOT
433	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Into Wind)	Exposure to HOT
434	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	TI	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
435	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	None	Symmetric (both sides)	Exposure to HOT
436	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Cold	None	Asymmetric (either side)	Exposure to HOT

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

Test #	Priority	Objective	Precipitation *Snow, Freezing Rain, Other, None*	Sideslip (β) and Rudder Deflection (δ) *β = -10° to +10°, δ = -20° to +20°*	Temperature *Cold, Warm, Any*	Fluid	Contamination Application *Symmetric, Asymmetric (Either side), Asymmetric (Cont. Not Into Wind) , Asymmetric (Cont. Into Wind), Tufts*	Comments
437	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	None	Symmetric (both sides)	Exposure to HOT
438	2	Fluid and Cont. (Other)	Other	β = 0°, δ = 0°	Warm	None	Asymmetric (either side)	Exposure to HOT
439	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	None	Symmetric (both sides)	Exposure to HOT
440	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
441	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
442	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	None	Symmetric (both sides)	Exposure to HOT
443	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
444	2	Fluid and Cont. (Other)	Other	β = TBD°, δ = TBD°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
445	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	None	Symmetric (both sides)	Exposure to HOT
446	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
447	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Cold	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT
448	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	None	Symmetric (both sides)	Exposure to HOT
449	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Into Wind)	Exposure to HOT
450	2	Fluid and Cont. (Other)	Other	β = -10°, δ = -20°	Warm	None	Asymmetric (Cont. Not Into Wind)	Exposure to HOT

4. PRE-TESTING SETUP ACTIVITIES

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

5. DATA FORMS

The following data forms are required for the 2022-23 wind tunnel tests:

- Attachment 2: General Form;
- Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form;
- Attachment 4: Example Snow Dispensing Form;
- Attachment 5: Example Ice Pellet Dispensing Form;
- Attachment 6: Example Manual Freezing Rain/Rain Dispensing Form;
- Attachment 7: Visual Evaluation Rating Form;
- Attachment 8: General Form for Calibration Test;
- Attachment 9: Fluid Receipt Form (Electronic Form); and
- Attachment 10: Log of Fluid Sample Bottles.

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

6. PROCEDURE

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

A rating system based on aerodynamic and visual observation data 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 adequately shed the contaminated fluid at time of rotation) shall be determined by the on-site experts based on residual contamination.

6.1 Initial Test Conditions Survey

- Record ambient conditions of the test (Attachment 2: General Form).

- Record wing temperature (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).

6.2 Fluid Application (Pour)

- Apply a minimum of 7.5 L of anti-icing fluid over the test area (3.75 L per side). This accounts for the minimum of 1 L/m² and includes a 20 percent buffer for loss. Ideally fluid is sprayed using a motorized backpack sprayer as pouring on the vertical surface is not efficient.
- Record fluid application times and quantities (Attachment 2: General Form).
- Let fluid settle for 5 minutes.
- Measure fluid thickness at pre-determined locations on the wing (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Record wing temperature (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Measure fluid Brix value (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Photograph and videotape the appearance of the fluid on the wing.
- Begin the time-lapse camera to gather photos of the precipitation application phase.

6.3 Application of Contamination

The precipitation systems used for typical ice pellet allowance time testing cannot be directly adapted to the CRM V-Stab. Instead, the following are available:

- Snow using the ice pellet dispensers and calibration data specific to the CRM (Attachment 4: Example Snow Dispensing Form);
- Ice pellets using the ice pellet dispensers and calibration data specific to the CRM (Attachment 5: Example Ice Pellet Dispensing Form); and
- Rain or Freezing Rain using a garden sprayer and an 80 percent efficiency spray (20 percent overspray) based on the surface area of 3.1 m² per side (Attachment 6: Example Manual Freezing Rain/Rain Dispensing Form).

6.3.1 Snow and Ice Pellet Dispenser Calibration and Setup

Calibration work was performed during the winter of 2021-22 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 336 collection pans in a vertical area 7 x 12 feet with effective openings measuring 6 in. x 6 in. Pre-measured amounts of snow were dispersed over this area and the amount collected by each pan will be recorded. A distribution footprint of the dispenser was attained and efficiency for the dispenser computed.

6.3.2 Rain and Freezing Rain with a Motorized Garden Sprayer Setup

Rain or freezing rain will be applied using a garden sprayer. A mix of ice and water will be used to supply the freezing rain, and cold water will be used for rain. The amount of water dispensed will be calculated using an estimated 80 percent efficiency of the spray (20 percent overspray) based on the surface area of 3.1 m^2 per side. Based on the desired exposure time, the total amount of water required for the test can be determined. The total amount is then divided per 5 minutes and per side and tracked using a graduated sprayer container and validated by weighing before and after weights of the sprayer system full and empty. The application is done using an "S" pattern to provide adequate and even coverage.

6.4 Prior to Engines-On Wind Tunnel Test

- Measure fluid thickness at the pre-determined locations on the wing (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Measure fluid Brix value (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Record wing temperatures (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Record start time of test (Attachment 2: General Form).
- Fill out visual evaluation rating form (Attachment 7: Visual Evaluation Rating Form).

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

6.5 During Wind Tunnel Test

- Take still pictures and video the behaviour of the fluid on the wing during the takeoff run, capturing any movement of fluid/contamination.
- Fill out visual evaluation rating form at the time of rotation (Attachment 7: Visual Evaluation Rating Form).
- Record wind tunnel operation start and stop times.

6.6 After the Wind Tunnel Test

- Measure fluid thickness at the pre-determined locations on the wing (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Measure fluid Brix value (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Record wing temperatures (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Observe and record the status of the fluid/contamination (Attachment 3: Wing Temperature, Fluid Thickness and Fluid Brix Form).
- Fill out visual evaluation rating form (Attachment 7: Visual Evaluation Rating Form).
- Obtain aerodynamic data (excel file) from NRC.
- Update APS test log with pertinent information.

6.7 Fluid Sample Collection for Viscosity Testing

Two liters of each fluid for testing are to be collected on the first day of testing. The fluid receipt form [Attachment 9: Fluid Receipt Form (Electronic Form)] 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 9: Fluid Receipt Form (Electronic Form)]; however, an additional form (Attachment 10: Log of Fluid Sample Bottles) is available if required. A falling ball viscosity test should be performed on site to confirm that fluid viscosity is appropriate before testing.

6.8 At the End of Each Test Session

If required, APS personnel will collect the waste solution. At the end of the testing period, NRC will organize for a glycol recovery service provider to safely dispose of the waste glycol fluid.

6.9 Camera Setup

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 Osmo cameras with viewing capabilities through a paired iPad® along with DSLR cameras to document fluid condition up close. The final positioning of the cameras and lighting should be documented.

In addition, a closed-circuit television (CCTV) camera system will be used to allow participants to view the tests remotely. The data from the CCTV system will be saved and used as a backup.

6.10 Demonstration of a Typical Wind Tunnel Test Sequence

Table 6.1 demonstrates a typical Wind Tunnel test sequence of activities, assuming the test starts at 08:30:00. Figure 6.1 demonstrates a typical wind tunnel run timeline.

Table 6.1: Typical Wind Tunnel Test

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

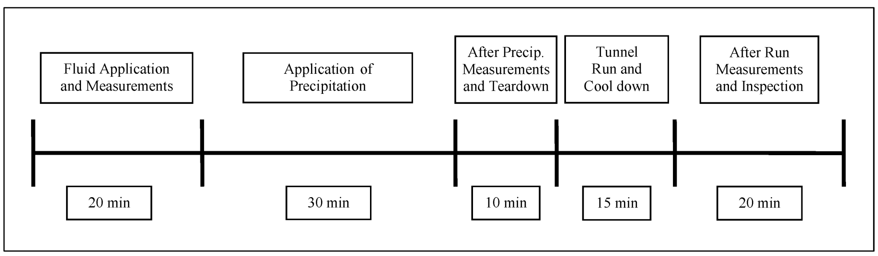

Figure 6.1: Typical Wind Tunnel Run Timeline

6.11 Procedures for Testing Objectives

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

- Attachment 11: Procedure – Calibration and Validation of Procedures;
- Attachment 12: Procedure – Vertical Surface Test Plan – Suggestions for Tuft Flow Visualization;
- Attachment 13: Procedure – Vertical Surface Test Plan – Suggestions for Boundary Layer Rake Tests;
- Attachment 14: Procedure – Fluid Flow-Off Characterization; and
- Attachment 15: Procedure – Laser Scanning of Ice Contamination.

7. EQUIPMENT

Equipment to be employed is shown in Table 7.1. As this testing is exploratory, additional equipment may be required and will be identified and acquired as necessary.

Table 7.1: Equipment List

EQUIPMENT	STATUS		EQUIPMENT	STATUS
General Support and Testing Equipment			**Camera Equipment**	
~~20L clean containers (if expecting totes)~~			DSLR cameras x3 + lenses etc. (2 suitcases)	
~~Barrel Opener (if expecting barrels)~~			Godox flashes x2	
~~Black Shelving Unit for rate pans (or plastic)~~			Manfroto arms and mounts suitcase	
Blow Horns x 2			Osmo/GoPro Cameras + accessories	
Blue Protective Face Masks x 2 boxes			Ipad®s x 2 for remote viewing Osmos	
Brixometer x 3			Remote camera system (See SM for details)	
Electrical tape x 2			Photography laptop with mouse/charger	
Exacto Knives x 2				
Extension cords 2x steel reel, 4x flat reel, 6x 25ft extension cords, 6 power bars,			**Ice Pellets Fabrication Equipment**	
Eye protection x 10			Adherence Probes Kit	
Falling Ball Viscometer			Blenders x 12 in good condition	
~~Fluid pouring pitchers x148~~			Folding tables (2 large, 1 small)	
~~Fluids (ORDER and SHIP to Ottawa)~~			Ice bags	
~~Fridge for personnel x1~~			Ice bags storage freezer x 3	
Funnels (1 big + 1 small)			Ice pellet box supports for railing x4	
Gloves - black and yellow			Ice Pellet control wires and boxes	
Gloves - cotton (a lot)			Ice pellets dispersers x 12	
Gloves - latex (a lot)			Sieves (solid base, 1.4 mm, 4 mm) x 2 each	
Grid Section + Location docs			Stands for ice pellets dispensing devices x 6	
~~Hard water chemicals x 3 premixes~~			Ice pellets Styrofoam containers x40	
~~Hand Sanitizer (x3 larger jugs/dispensers)~~			Measuring cups (1L + 1cup/smaller)	
~~Horse and tap for fluid barrel x all~~			Sartorius 35KG scale	
Pots and Sous Vide for Type I x 2			Refrigerated Truck	
Inclinometer (yellow level) x 2			Rubber Mats x 4	
Isopropyl x 12			Wooden Spoons	
Large and small tape measure				
Large Sharpies for Grid Section			**Freezing Rain Equipment**	
~~Long Ruler for marking wing x 2~~			~~Rates laptop (use BB's or bring an extra one)~~	
Marker for waste x 2			~~NRC Freezing rain sprayer (NRC provided)~~	
Paper towel (blue shop towel) x 48			~~Rubber suction feet for wooden boards x8~~	
Protective yellow rubber clothing (all)			~~White plastic rate pans (4 sets)~~	
Personal Clothing for APS YUL team			~~Wooden boards for rate pans (x4)~~	
~~Red Thermoses for Type III Transport~~				
Sample bottles for viscosity (x6)			**Office Equipment**	
Sartorius Weigh Scale x 2			Laptops (MR, MR2, BB, CB) with accessories	
Scrapers x 5			APS tuques x 10	
~~Shop Vac~~			Calculators x 3	
Speed tape x 1 small			Clip boards x 8	
Squeegees (5 small + 3 large floor)			Data Forms	
Stop Watches x 4			Dry eraser markers	
Temperature probes: immersion x 3			Envelopes (9x12) x box	
Temperature probes: surface x 3			File box x 2	
Test Plate x 1			Hard drive with all WT Photos	
Thermometer for Reefer Truck			New blank SSD Hard Drives x 2	
Thickness Gauges (5 small, 5 big)			Pencils + sharpies/markers	
Vise grip + rubber opener for containers			~~Projector for laptop~~	
Walkie Talkies x 12 (8+4)			Scissors	
~~Water (2 x 18L) for hard water~~			~~Small 90° aluminum ruler for wing~~	
~~Whatmans Paper and conversion charts~~			Test Procedures x 4, printer paper	
			YOW employee contracts	
			V-Stab Gear	
			Motorized backpack sprayer for Fluids/ZR x5	
			~~Calibration pans and stand (if needed)~~	
			Little Giant Step ladders x2 (4 available)	
			Folding horse work table x2	

8. FLUIDS

Mid-viscosity samples of both ethylene glycol and propylene glycol based Type IV fluids will be used in the wind tunnel tests as well as a propylene glycol based Type I fluid. Although the number of tests conducted will be determined based on the results obtained, the fluid quantities available are shown in Table 8.1. Additional fluids are available and in inventory on site in the event that more fluid or different fluid is required. Fluid application will be performed using a motorized backpack sprayer (without the shearing nozzle) to reduce the quantity of fluid required during application.

Table 8.1: Fluid Available for CRM Wind Tunnel Tests

Company Name	Fluid Name	Type	Quantity (L)
Cryotech Deicing Technology	Polar Guard® Advance	PG - IV	240
Dow Chemical Company	UCAR™ Endurance EG106 De/Anti-Icing Fluid	EG - IV	240
Dow Chemical Company	UCAR™ PG ADF Concentrate	PG - I	160

9. PERSONNEL

Four APS staff members are required for the tests at the NRC IWT. Five additional persons will be required from Ottawa to assist with the preparation and application of fluids and contamination. One additional person from Ottawa will be required to coordinate the photography and videography.

Table 9.1 demonstrates the personnel required and their associated tasks.

Fluid and contamination applications will be performed by APS/YOW personnel at the NRC IWT. NRC personnel will operate the NRC wind tunnel.

Table 9.1: Personnel List

Wind Tunnel Personnel List	
Person	**Responsibility**
John D'Avirro (JD)	Director (participating mostly remotely)
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	
Photo 1	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

- Catherine Clark: (613) 990-6796.
- Cory Bates: (613) 913-9720.

10. SAFETY

- A safety briefing will be done on the first day of testing.
- COVID-19 mitigation procedures will be in place.
- 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.
- Canadian Standards Association (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.
- If fluid comes into contact with eyes, flush with the portable eye wash station.
- Personnel must ensure they follow the protocols for working extended hours.

Separate guidelines related to COVID-19 mitigation strategies will be communicated to staff prior to the start of any activities.

Personnel must operate in accordance with the “Testing Safety Recommendations” and must follow the protocols for “Extended Work Hours Protocol for APS Personnel.” These documents are included in the “APS Office Policies & Procedures,” which is made available to all APS staff.

Attachment 1: Task List for Setup and Actual Tests

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

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

Attachment 2: General Form

GENERAL FORM (EVERY TEST)

DATE: ____________ FLUID APPLIED: ____________ RUN # (Plan #): ____________

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

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

WIND TUNNEL START TIME: ____________ PROJECTED SPEED (S/KTS): ____________

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/dm²/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/dm²/h): ____________ Droplet Size (mm): ____________

Exposure Time: ____________ Needle: ____________

Flow: ____________

Pressure ____________

SNOW APPLICATION (if applicable)

Actual start time: ____________ Actual End Time: ____________

Rate of Snow Applied (g/dm²/h): ____________ Snow Size (mm): <1.4 mm

Exposure Time: ____________ Method: ☐ Dispenser ☐ Sieve

Total SN Required per Dispenser: ____________

COMMENTS ____________

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

APS/Library/Projects/300293 (TC Deicing 2022-23)/Procedures/Wind Tunnel/V-Stab Procedure/Final Version 1.0/V-Stab Wind Tunnel 2022-23 Final Version 1.0.docx
Final Version 1.0, December 22

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

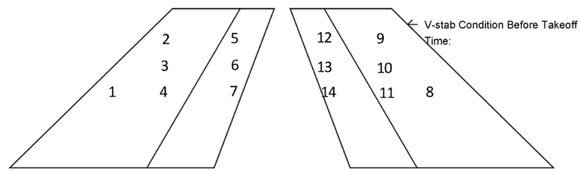
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

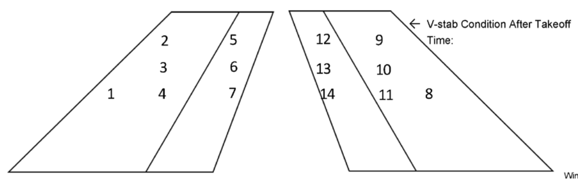
Date: ______________________ Run: ______________

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:			





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 4: Example Snow Dispensing Form

Snow Order Data Form for Dispensing on Vertical Stabilizer

Date: ____________________

Precipitation Type: Snow

Target Rate:	25	g/dm²/h
Duration:	15	minutes

Indicates fields to be manipulated

Snow needed per 5 minutes		
In each position	417	g
In each Dispensor	2501	g
Snow needed for entire test		
In each Dispensor (or if only doing 1 side)	7503	g
Total Amount for Entire Test (both sides)	15005	g

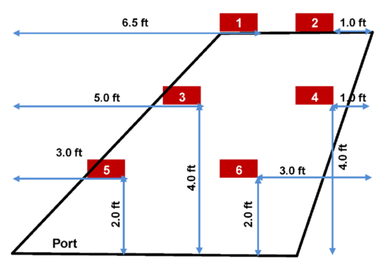
Original Avg Rate	10	g/dm²/h
Original Rate Duration	5	minutes
Original Snow Per Position	167	g/dm²/h

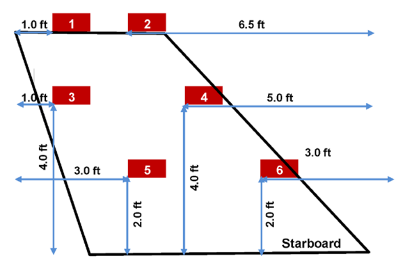
Expected Footprint of Snow

		1ft		2ft		3ft		4ft		5ft		6ft		7ft		8ft		9ft		10ft
8ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7ft	0	0	0	0	0	0	0	0	0	1	2	5	7	6	5	6	7	6	3	1
	0	0	0	0	0	0	0	0	2	11	14	17	20	28	27	20	20	18	13	4
6ft	0	0	0	0	0	0	0	2	6	11	8	9	12	18	15	11	10	8	8	5
	0	0	0	0	0	0	1	3	7	10	5	7	10	14	8	7	6	4	5	4
5ft	0	0	0	0	0	0	1	5	11	14	9	7	8	10	7	9	10	9	5	3
	0	0	0	0	0	2	11	15	19	23	20	16	10	19	18	19	20	19	15	5
4ft	0	0	0	0	2	6	11	9	9	11	9	12	13	18	11	9	8	8	9	5
	0	0	0	1	3	7	11	5	5	5	5	8	11	15	7	6	4	4	4	4
3ft	0	0	1	3	8	12	13	6	3	3	6	11	14	15	7	3	2	2	2	2
	0	2	11	14	18	21	22	15	8	15	16	20	23	23	16	6	4	2	2	1
2ft	2	6	11	8	8	9	11	11	11	15	10	10	11	12	10	6	4	2	2	1
	3	7	10	4	4	4	5	8	10	13	6	6	5	5	5	4	3	2	2	0
1ft	3	5	7	3	2	3	3	5	7	9	4	3	3	3	3	2	2	1	1	0
	2	3	5	2	2	1	2	4	4	5	3	2	2	2	2	1	1	1	1	0

		1ft		2ft		3ft		4ft		5ft		6ft		7ft		8ft		9ft		10ft
8ft	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7ft	0	1	2	5	7	6	5	6	7	6	3	1	0	0	0	0	0	0	0	0
	2	11	14	17	20	28	27	20	20	18	13	4	3	1	0	0	0	0	0	0
6ft	6	11	8	9	12	18	15	11	10	8	8	5	3	1	0	0	0	0	0	0
	7	10	5	7	10	14	8	7	6	4	5	4	2	1	1	0	0	0	0	0
5ft	5	8	6	10	14	15	7	4	4	5	8	9	7	4	1	0	0	0	0	0
	5	15	16	19	22	23	17	8	15	16	18	19	18	14	5	3	1	0	0	0
4ft	8	14	9	9	10	12	12	11	15	10	9	8	8	8	5	3	1	0	0	0
	8	12	5	5	5	6	8	11	14	6	5	4	3	4	3	2	1	1	0	0
3ft	6	8	3	2	4	6	11	13	15	7	3	3	4	8	8	7	4	1	0	0
	4	5	3	4	12	16	20	22	23	16	8	14	16	18	19	18	14	5	3	1
2ft	3	5	4	7	12	9	10	10	12	12	12	15	9	8	8	8	8	5	3	1
	1	2	4	7	11	5	5	5	6	8	11	13	6	5	4	3	4	3	2	1
1ft	1	2	3	5	8	3	2	3	4	5	7	9	4	3	2	2	2	2	1	1
	1	1	2	3	5	2	2	2	3	4	4	5	3	2	1	1	2	1	1	1

Dispenser Locations





Attachment 5: Example Ice Pellet Dispensing Form

Ice Pellet Order Data Form for Dispensing on Vertical Stabilizer

Date: ____________________

Precipitation Type: Ice Pellets

Target Rate:	25	g/dm²/h
Duration:	190	minutes

Indicates fields to be manipulated

Ice Pellets needed per 5 minutes

In each position	265	g
In each Dispensor	1590	g

IP needed for entire test

In each Dispensor (or if only doing 1 side)	60420	g
Total Amount for Entire Test (both sides)	120840	g

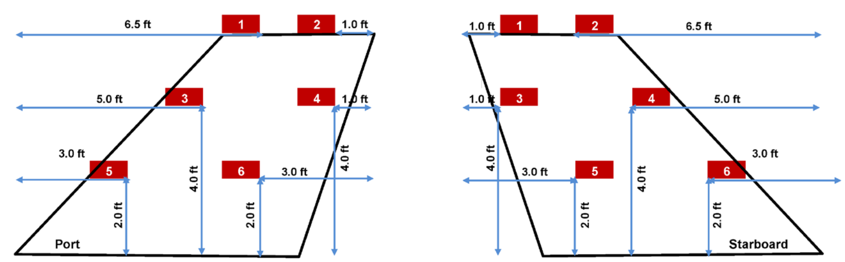
Original Avg Rate	25	g/dm²/h
Original Rate Duration	5	minutes
Original IP Per Position	265	g/dm²/h

Expected Footprint of Ice Pellets

8ft		1ft		2ft		3ft		4ft		5ft		6ft		7ft		8ft		9ft		10ft
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7ft	0	0	0	0	0	0	0	0	0	2	6	11	9	7	7	11	9	5	1	-1
	0	0	0	0	0	0	0	2	10	32	35	36	44	63	56	37	35	30	21	4
6ft	0	0	0	0	0	0	2	14	30	24	16	22	38	31	25	17	13	9	12	9
	0	0	0	0	0	0	9	27	41	17	15	30	44	20	11	9	9	8	6	7
5ft	0	0	0	0	0	0	12	34	56	23	20	30	47	17	12	15	14	10	5	4
	0	0	0	0	2	10	40	56	69	43	40	47	50	44	39	36	37	33	24	6
4ft	0	0	0	2	14	30	30	31	33	17	19	44	67	41	19	10	10	11	14	11
	0	0	0	9	27	41	19	13	14	7	17	40	57	27	13	7	4	5	7	7
3ft	0	0	2	17	39	54	21	9	8	6	21	45	63	25	9	4	3	2	3	3
	2	10	32	42	55	69	41	30	19	38	47	60	74	44	27	8	3	3	2	2
2ft	14	30	24	20	25	32	22	32	44	33	26	31	36	21	17	13	8	4	2	1
	27	41	17	9	11	14	17	33	47	23	14	14	14	8	7	7	6	5	2	0
1ft	28	45	14	6	7	8	15	30	47	18	9	9	8	5	3	2	4	3	3	0
	21	35	9	4	5	6	12	24	36	11	6	7	7	5	3	2	1	2	2	1

8ft		1ft		2ft		3ft		4ft		5ft		6ft		7ft		8ft		9ft		10ft
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7ft	0	2	6	11	9	7	7	11	9	5	1	-1	0	0	0	0	0	0	0	0
	10	32	35	36	44	63	56	37	35	30	21	4	1	0	0	0	0	0	0	0
6ft	30	24	16	22	38	31	25	17	13	9	12	9	5	1	0	0	0	0	0	0
	41	17	15	30	44	20	11	9	9	8	6	7	5	4	1	0	0	0	0	0
5ft	45	15	20	41	56	21	6	4	7	11	15	13	9	4	2	0	0	0	0	0
	45	42	45	57	71	41	28	16	36	38	37	36	32	23	5	1	0	0	0	0
4ft	56	34	22	27	34	22	29	42	33	18	10	9	9	13	10	5	1	0	0	0
	51	21	10	12	14	18	34	48	23	12	7	4	4	5	6	5	4	1	0	0
3ft	51	16	6	7	10	21	42	56	24	8	5	4	8	13	12	9	4	2	0	0
	39	12	8	15	39	47	58	71	41	29	18	36	37	35	35	32	23	5	1	0
2ft	28	14	19	36	29	24	27	34	22	30	43	32	17	9	8	9	13	10	5	1
	10	13	28	42	17	10	12	14	17	33	48	23	12	6	4	4	5	6	5	4
1ft	6	13	29	45	14	6	7	8	15	31	48	18	7	5	2	2	2	2	3	3
	4	10	23	35	9	5	5	7	12	24	37	11	4	4	3	2	2	1	1	1

Dispenser Locations



Attachment 6: Example Manual Freezing Rain/Rain Dispensing Form

Precipitation Type	Manual ZR/R

Date	

Run #	

* *Field to be manipulated*

Target Rate	**25**	**g/dm²/h**
Duration	**20**	**minutes**

Surface Area x2 sides	620	dm²
Efficiency of Spray	80%	%

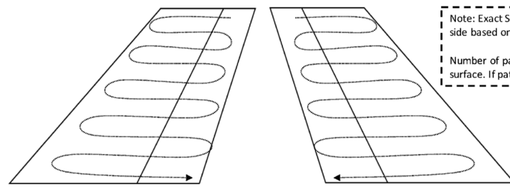
Water needed per 5 minutes

Sprayed per 5 -min (L)	1.6

Water needed for entire test

Total Water (L)	6.5

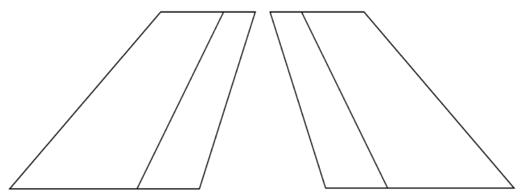
1. Enter "Run #".
2. Manipulate desired "Target Rate" for test event.
3. Manipulate desired "Duration" for test event.
4. Prepare "Total Amount of Water Needed for Entire Test" in Litres in the backpack sprayer (use ice bath if needing freezing rain)
5. Spray in a continual "S" pattern on the port side of the wing, and then continue onto the starboard side. Stop once the required amount per 5-min is reached.
6. Repeat step 5 for the desired duration of the test.



Note: Exact S-pattern to be determined on site. Expect 10 passes per side based on what was done for Piper model.

Number of passes should be enough to evenly cover the wing surface. If patter is different, it should be documented on this form.

Diagram to be filled out if spray patter is different than above.



Attachment 7: 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 8: General Form 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 (°): ________

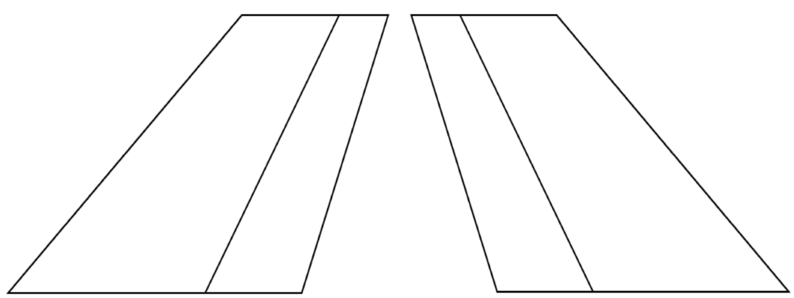
WIND TUNNEL END TIME: ________ RUDDER DEFLECTION ANGLE (°): ________

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

Attachment 9: 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 10: 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 11: Procedure – Calibration and Validation of Procedures

Background

As the work with the vertical stabilizer is exploratory, and the V-Stab CRM model has been painted and updated with new load cells, 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;
  - Equipment reliability during "wind on" tests;
  - Repeatability of data collected;
  - Physical evaluation of model to ensure robustness of installation; and
  - Other procedural elements identified on site.

Test Plan

One day of testing is planned.

Attachment 12: Procedure – Vertical Surface Test Plan – Suggestions for Tuft Flow Visualization

Section originally written by: Andy Broeren for Piper Seneca II model in 2019 and modified by APS in 2021 for the CRM model

Background

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

Tuft Layout

The exact layout of the tufts will be determined on site with the direction of the test team, however the following are general guidelines:

- Target 3 rows of tufts on rudder, and 3 rows of tufts on the main element. (see below photo);
- Add partial strips if appropriate; and
- 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 δ_r = 0 deg. and β = 0 deg.
2. Set tunnel to desired speed (e.g. 100 knots).
3. Photograph tufts.
4. Set rudder to δ_r = 0 deg. Set side slip β = -10 deg and increase to β = +10 deg in 2 deg increments.
5. Repeat step 4 decreasing rudder angle by 5 deg increments up to δ_r = -20 deg.
6. Repeat step 4 with rudder δ_r = +10 deg to verify symmetry.
7. Check for highly 3D and/or separated flow.

Additional testing may be considered using boundary layer trips in conjunction with the tufts to evaluate the separation of flow.

Test Plan

No day of testing is planned. Limited testing may be considered as part of the calibration and shakedown portion of the testing program.

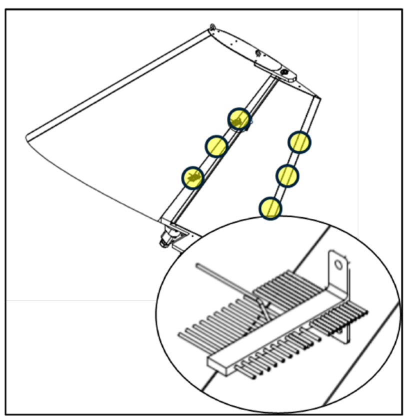
Attachment 13: Procedure – Vertical Surface Test Plan – Suggestions for Boundary Layer Rake Tests

Objective

To conduct testing with the objective of collecting pressure data with a boundary layer rake that will characterize boundary layer separations.

Boundary Layer Rake Layout

- 3 boundary layer rakes available for aerodynamic characterization work.
- Pre-drilled mounting points exist on CRM.
  - 3 mounting points on trailing edge of main element.
  - 3 mounting points on trailing edge of rudder.
  - Approx. 1/4, 1/2 and 3/4 span.
  - Note: boundary layer rakes are not permanently installed and will be removed for fluid tests.



Methodology

Suggested Procedure

1. Set δ_r = 0 deg. and β = 0 deg.
2. Set tunnel to desired speed (e.g. 100 knots).
3. Set rudder to δ_r = 0 deg. Set side slip β = -10 deg and increase to β = +10 deg in 2 deg increments.
4. Repeat step 4 decreasing rudder angle by 5 deg increments up to δ_r = -20 deg.
5. Repeat step 4 with rudder δ_r = +10 deg to verify symmetry.
6. Check for highly 3D and/or separated flow.

Additional testing may be considered using boundary layer trips and/or sandpaper roughness in conjunction with the boundary layer rake equipment to evaluate the separation of flow.

Test Plan

No days of testing are planned. Limited testing may be considered as part of the calibration and shakedown portion of the testing program.

Attachment 14: 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 clean and 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.
- Adjust testing plan accordingly based on results obtained.

Test Plan

Nine days of testing are planned.

Attachment 15: Procedure – Laser Scanning of Ice Contamination

NOTE: This procedure is in development and may change prior to the start of the test. Check with the APS test lead for the latest information prior to testing.

Background

The 2022-23 CRM V-Stab testing will incorporate a laser scanning system to evaluate frozen adhered contamination. There are challenges related to the laser scanner picking up reflections off fluids and ice, as well as the non-static nature of fluids while scanning. To mitigate this, a procedure for coating the ice and fluids using a sprayed mixture of titanium dioxide (TiO2) and isopropyl alcohol has been developed to provide better capture of the topography of the surface by the laser scanner.

Objective

The objective of this testing is to perform laser scanning of the CRM V-Stab with frozen adhered contamination and document the topography of the surface.

Special Safety Considerations

Due to inhalation concerns with the mixture of TiO2 and isopropyl, special safety considerations are required.

- The use of 3M half-mask 7000 series respirator with a 3M™ Multi Gas/Vapor Cartridge/Filter 60926 P100 combination cartridge masks will be required by any personnel in the wind tunnel at the time of application, during the laser scanning, and during removal and cleanup of the TiO2 and isopropyl mixture. In addition, the wearing of disposable coveralls will be required to eliminate the potential for TiO2 to deposit on clothing.
- The number of personnel in the test section during application and removal of the mixture are to be kept to the minimum required.
- A fan providing the required flow rate must be in the test section prior to application; NRC has located one 14,400 CFM fan (48″ diameter) that will be placed upstream of the model and a 7,200 CFM fan (24″ diameter) that will be placed downstream of the model to push the air further into the diffuser. NRC has deemed this sufficient to provide the ventilation required. The fans

must remain on during the application of the mixture, during the laser scanning, and during removal and cleanup of the mixture.

- Both roll-up doors to the test section must be open to increase ventilation.
- Mixing of TiO2 and isopropyl alcohol mixture must be done in a contained environment (no splashing) in an outdoor well-ventilated area with personnel wearing P100 cartridge masks.

Preparation of the TiO2 and Isopropyl Mixture

- Mixing of TiO2 and isopropyl alcohol must be done in a contained environment (no splashing) in an outdoor well-ventilated area with personnel wearing P100 cartridge masks and personal protective equipment (gloves, safety glasses, disposable coveralls, etc).
- Mix the titanium dioxide (TiO2) and 99% concentration isopropyl alcohol in a 1:4 by weight ratio, respectively. This ratio may be revised to optimize and minimize the use of the mixture.
- It is estimated that approximately 1.5Litres of the mixture are required to cover the entire V-Stab (both sides).
- The mixture should be prepared in advance and kept outdoors to cool to ambient temperature.
- Ensure the spray gun is kept outdoors to remain at ambient temperature.
- Transfer the mixture to a spray gun.
- Use a compressed air line and regulator to engage the spray gun for application.

Post-run Procedure for Laser Scanning

- Ensure the tunnel fan is stopped or not running.
- Ensure APS has performed all measurements (thickness and brix) and photography of the model, if required.
- Both tunnel roll-up doors remain open.
- North side door remains locked to ensure people without sufficient PPE don't enter the test section accidentally.

- NRC personnel enter test section and place fans upstream and downstream of the model and turn on the fans.
- NRC personnel will assist NASA personnel with attaching steel plate to the splitter plate in pre-determined location.
- NRC personnel leave test section, only NASA personnel with P100 cartridge masks and PPE remain in test section and close door behind them.
- NASA personnel spray a minimum amount of the mixture required to coat the ice for laser scanning visibility.
- NASA move laser/small table/computer into test section
- NASA personnel will place scanner onto steel plate.
- NRC personnel will dim lights in test section
- NASA performs the laser scanning.
- When completed, NASA inform APS personnel who will clean and prepare the wing for the next tests. APS personnel must wear P100 cartridge masks and PPE to clean the wing. APS personnel will clean spray gun in an approved designated location.
- When completed, NASA personnel will remove the scanner equipment.
- NRC and NASA personnel will remove the small table and steel plate.
- When the model is clean, fans can be turned off and preparation for the next tests can resume.

General Testing Methodology

- Perform a clean wing laser scan to determine the baseline topography.
  - The clean model surface must be scanned, ideally when “cold”.
  - Timing of the clean scan can be coordinated at the start or end of day to have least impact on program.
  - Scanning the clean model will likely not need spraying the mixture.
  - Whenever possible, a clean scan should be performed after a contamination scan to provide the best baseline reference.

- Conduct testing with fluid or with fluid contaminated with simulated snow or freezing rain in accordance with the typical wind tunnel testing protocol.
- Perform a post-fluid and/or post-contamination laser scan to determine the topography prior to takeoff, if required.
- Run the wind tunnel. Record visual observations, video, photography, and manually collected data, as applicable.
- Perform a post-takeoff laser scan to determine the topography following the wind tunnel test run.
- Adjust testing plan accordingly based on results obtained.

Test Plan

This testing is exploratory. The number of tests will be determined based on the ease of use of the technology and overall impact on the testing schedule. A minimum of 3 tests are expected, however this could be increased based on the success rate and ease of use.

APPENDIX C

CRM TESTING 2022-23 FLUID THICKNESS, TEMPERATURE, AND BRIX DATA FORMS

No Data Available

Figure C1: Runs #1-8

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

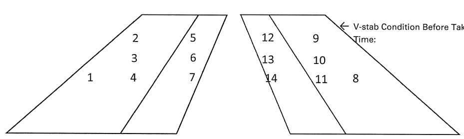
Date: January 16, 2023

Run: 9 (F043)

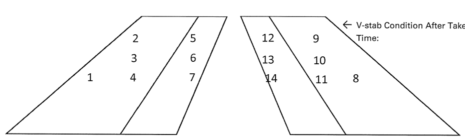
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-4.9	-4.5		-5.5
10	-4.5	-4.3		-5.6
Time:	1:31	1:55		2:04

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		37.25
10	37.0		37.25
Time:	1:51		2:03

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	16		5
3	20		8
4	22		9
5			
6			
7			
8			
9	16		6
10	18		9
11	22		8
12			
13			
14			
Time:	1:52		2:02



← 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

OBSERVER: BB / CS

General Comments:

Figure C2: Run #9

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

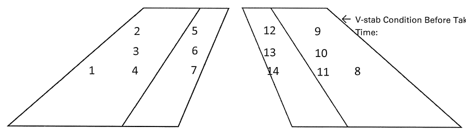
Date: January 16, 2023

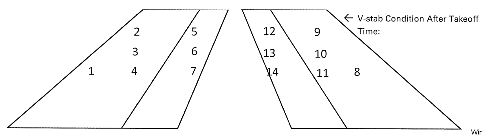
Run: 10 (P045)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-5.0	-5.0	/	-6.8
10	-4.9	-5.1	/	-6.8
Time:	2:17	2:35	/	2:44

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.25	/	37.25
10	37.25	/	37.25
Time:	2:37	/	2:46

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	16		6
3	18		8
4	24		10
5			
6			
7			
8			
9	18		5
10	22		8
11	22		8
12			
13			
14			
Time:	2:37		2:46





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

OBSERVER: BB / CB

General Comments:

Figure C3: Run #10

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

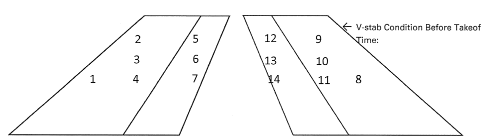
Date: January 16 2023

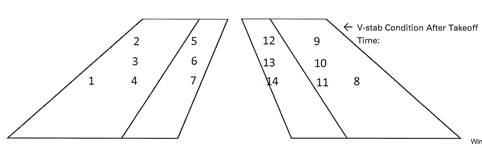
Run: 11 (P045)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-5.1	-5.1	/	-6.7
10	-5.3	-5.3	/	-7.0
Time:	3:02	3:20	/	3:30

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.25	/	37.25
10	37.25	/	37.25
Time:	3:20	/	3:30

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	16		5
3	20		7
4	22		7
5			
6			
7			
8			
9	18		5
10	22		9
11	22		8
12			
13			
14			
Time:	3:20		3:30





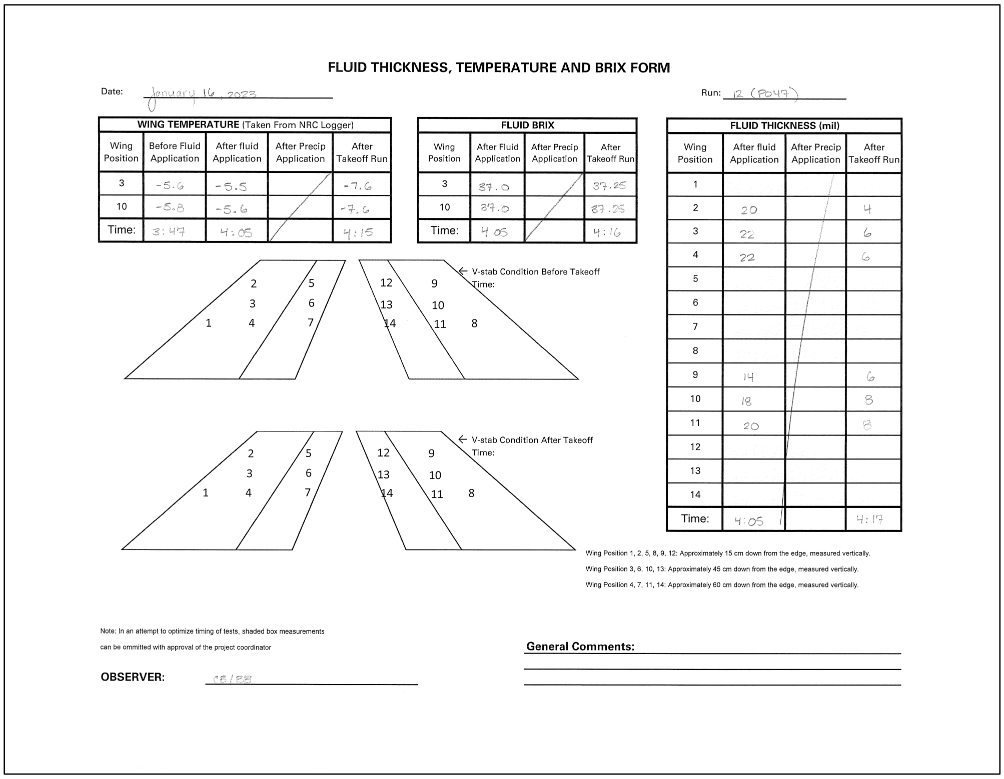
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

OBSERVER: BB / CB

General Comments:

Figure C4: Run #11



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 16, 2023

Run: 12 (P047)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-5.6	-5.5		-7.6
10	-5.8	-5.6		-7.6
Time:	3:47	4:05		4:15

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		37.25
10	37.0		37.25
Time:	4.05		4:16

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	20		4
3	22		6
4	22		6
5			
6			
7			
8			
9	14		6
10	18		8
11	20		8
12			
13			
14			
Time:	4:05		4:17

← V-stab Condition Before Takeoff
Time:

← V-stab Condition After Takeoff
Time:

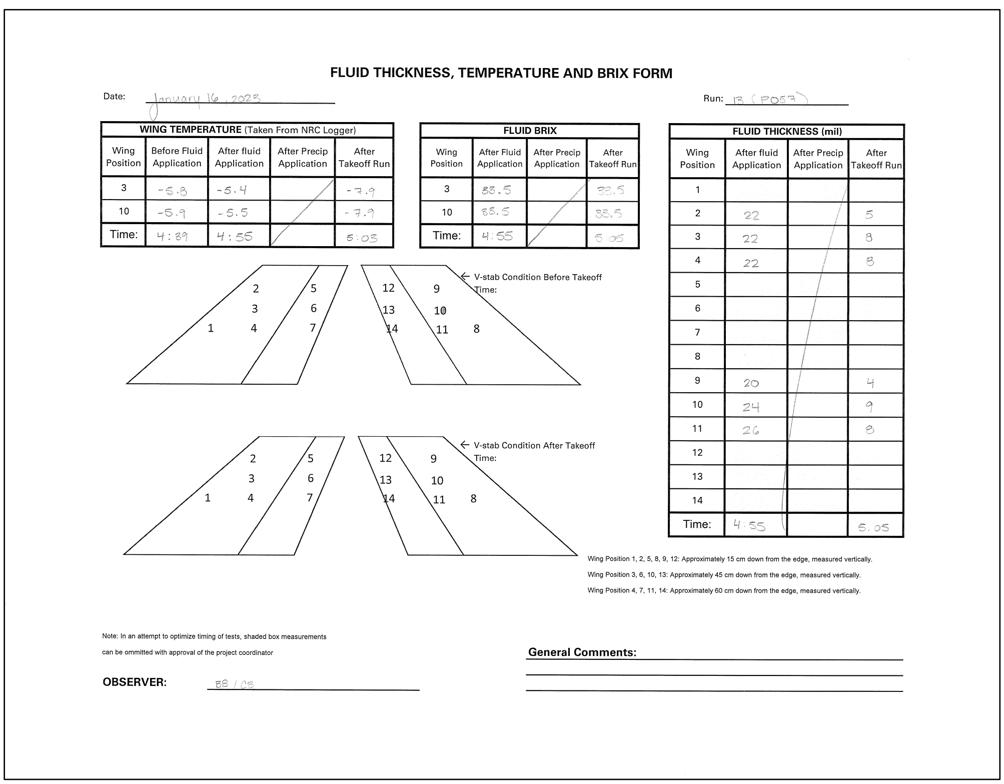
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

OBSERVER: CE / BB

General Comments:

Figure C5: Run #12



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 16, 2023

Run: 13 (P057)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-5.8	-5.4		-7.9
10	-5.9	-5.5		-7.9
Time:	4:39	4:55		5:03

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.5		33.5
10	33.5		33.5
Time:	4:55		5:05

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	22		5
3	22		8
4	22		8
5			
6			
7			
8			
9	20		4
10	24		9
11	26		8
12			
13			
14			
Time:	4:55		5.05

← 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

OBSERVER: BB / CE

General Comments:

Figure C6: Run #13

No Data Available

Figure C7: Run #14

No Data Available

Figure C8: Run #15

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 16 2023

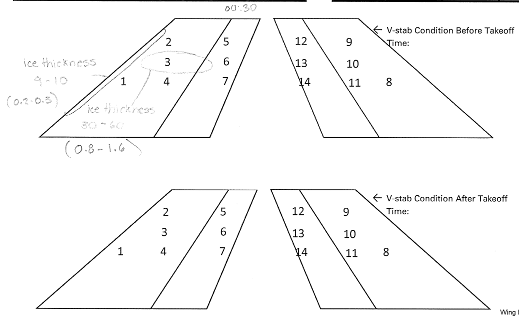
Run: 16 (P261)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	1.8	1.4	2.4 1.3	-3.7
10	1.7	1.2	2.4 0.6	-3.4
Time:	2:29	22:52	00:13	00:35

00:30

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0	ice	ice
10	37.0	ice	ice
Time:	22:50	00:14	00:35

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	20 0.5	ice	ice
3	18 0.5	ice	ice
4	22 0.6	ice	ice
5			
6			
7			
8			
9	16 0.4	ice	ice
10	18 0.5	ice	ice
11	20 0.5	ice	ice
12			
13			
14			
Time:	22:50	00 15	00 35



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

75 minutes : 24.2L
35 minutes : 11.3 L
1.6L / 5 minutes

Figure C9: Run #16

No Data Available

Figure C10 Run #17

4.41

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

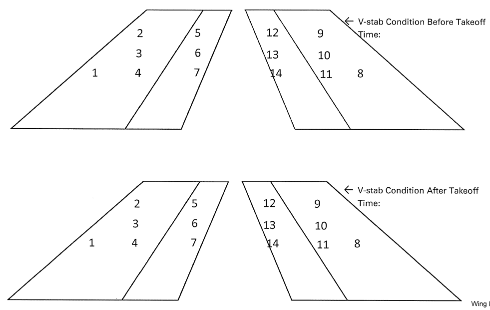
Date: January 17, 2023

Run: 18 (P206)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-1.0	-0.7	-0.3	-3.0
10	-1.0	-0.9	-0.5	-3.0
Time:	2:19	2:41	3:02	3:15

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0	11.75	20.5
10	37.0	12.5	17.0
Time:	2:41	3:02	3:16

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	18	3	7
2	14	6	3
3	16	7	3
4	18	7	2
5	7	3	11
6	14	10	6
7	14	9	7
8	12	4	4
9	11	6	3
10	20	6	2
11	22	6	2
12	11	7	4
13	14	11	2
14	18	10	2
Time:	2:41	3:02	3:17



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

Figure C11 Run #18

3.15

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

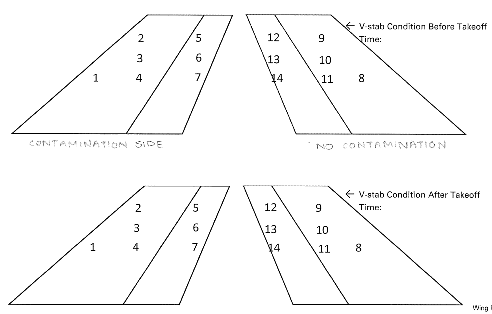
Date: January 17, 2023

Run: 19 (P207)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-1.0	-0.9	0.0	-3.2
10	-1.2	-1.0	-0.4	-2.5
Time:	3:48	4:09	4:31	4:41

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.5	8.25	13.25
10	37.5	37.25	37.25
Time:	4:09	4:30	4:44

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	16	6	5
2	14	12	4
3	14	5	2
4	16	4	4
5	7	ice	9
6	12	7	11
7	14	5	1
8	14	10	5
9	16	10	3
10	22	11	8
11	22	14	7
12	11	9	5
13	14	14	6
14	14	10	6
Time:	4:09	4:30	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

Figure C12 Run #19

No Data Available

Figure C13 Run #20

No Data Available

Figure C14: Run #21

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

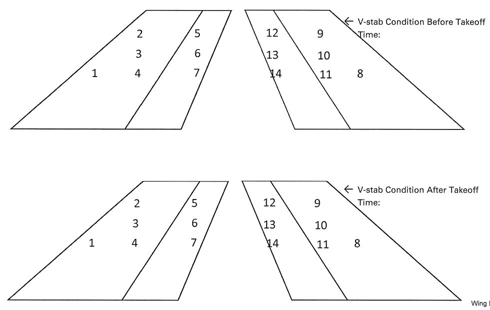
Date: January 17, 2023

Run: 22 (P056)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	2.4	2.8		2.3
10	2.3	2.5		2.1
Time:	22:09	22:38		22:49

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.25		32.75
10	33.25		32.75
Time:	22:36		22:48

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	26		7
2	26		7
3	26		8
4	28		8
5	18		12
6	22		10
7	20		12
8	18		5
9	22		6
10	24		9
11	24		7
12	14		18
13	18		14
14	18		12
Time:	22:37		22:47



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

Figure C15: Run #22

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

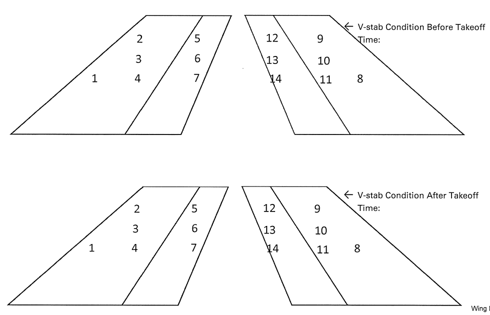
Date: January 17, 2023

Run: 23 (P058)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	2.9	2.9		2.0
10	2.7	2.7		1.8
Time:	22:59	23:16		23:24

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.25		32.75
10	33.25		32.75
Time:	23:15		23:24

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	24		7
2	24		6
3	28		8
4	30		9
5	16		12
6	20		26
7	22		22
8	16		6
9	18		4
10	24		8
11	30		7
12	22		10
13	18		10
14	20		11
Time:	23:14		23:24



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

Figure C16: Run #23

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

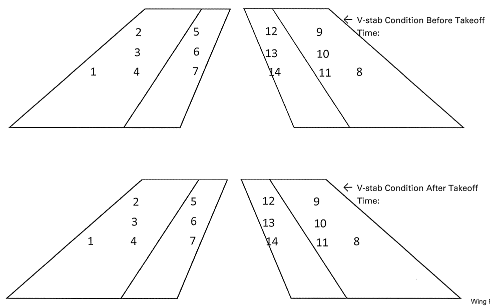
Date: January 18 2023

Run: 24 (P058)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	4.1	3.3		2.2
10	4.0	3.1		2.2
Time:	23:51	00:09		00:20

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.0		32.75
10	33.0		32.75
Time:	00:10		00:22

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	22		6
2	24		5
3	18		8
4	22		6
5	14		16
6	22		18
7	22		28
8	16		5
9	14		6
10	24		8
11	28		8
12	20		11
13	22		10
14	18		9
Time:	00:11		00:22



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

Figure C17: Run #24

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

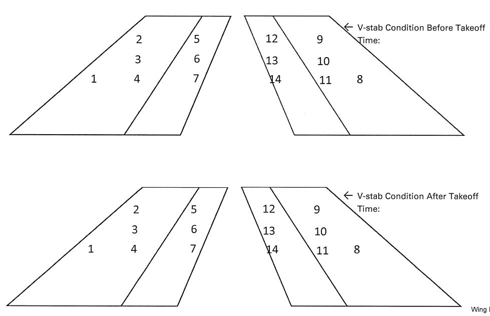
Date: January 18, 2023

Run: 25 (P060)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	3.6	3.2		2.3
10	3.4	3.0		2.2
Time:	00:40	00:57		1:09

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.5		32.75
10	33.5		32.75
Time:	00:58		1.09

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	18		12
2	18		5
3	18		7
4	20		8
5	12		26
6	22		30
7	20		26
8	14		6
9	12		7
10	20		7
11	24		8
12	12		6
13	18		6
14	20		5
Time:	00:59		1:09



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

Figure C18: Run #25

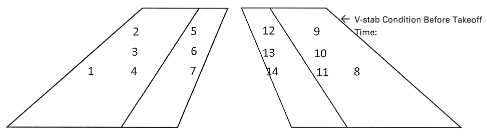
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

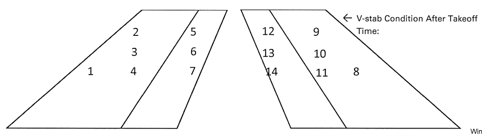
Date: January 18, 2023 Run: 26 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	3.9	3.5		2.5
10	3.7	3.3		2.5
Time:	1:54	2:14		2:24

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		36.75
10	37.0		36.75
Time:	2:15		2:25

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	24		7
2	24		5
3	28		9
4	30		8
5	26		18
6	26		26
7	28		26
8	24		3
9	18		3
10	26		8
11	26		11
12	20		9
13	24		10
14	28		8
Time:	2:16		2:26





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

Figure C19: Run #26

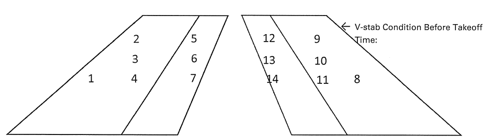
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

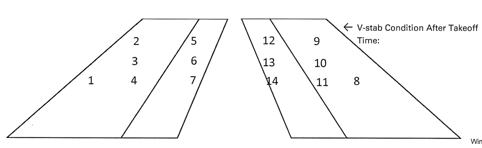
Date: January 18, 2023 Run: 27 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	3.7	3.5		2.3
10	3.7	3.3		2.3
Time:	2:51	3:12		3:21

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.75		36.75
10	36.75		36.75
Time:	3:12		3:22

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	26		5
2	20		5
3	28		6
4	28		6
5	22		24
6	28		22
7	28		22
8	24		4
9	20		5
10	24		6
11	26		8
12	22		9
13	26		9
14	28		6
Time:	3:13		3:23





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

Figure C20 Run #27

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

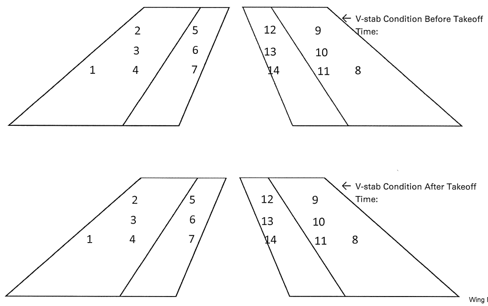
Date: January 18, 2023

Run: 28 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	3.0	2.9		2.9
10	3.2	2.7		2.6
Time:	3:34	3:54		4:07

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.75		36.75
10	36.75		36.75
Time:	3:55		4:07

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	26		6
2	22		6
3	28		7
4	30		7
5	26		18
6	30		26
7	26		26
8	24		6
9	18		5
10	26		7
11	28		7
12	22		7
13	24		9
14	26		10
Time:	3:56		4:07



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

OBSERVER: BB/CB

General Comments:

Figure C21 Run #28

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

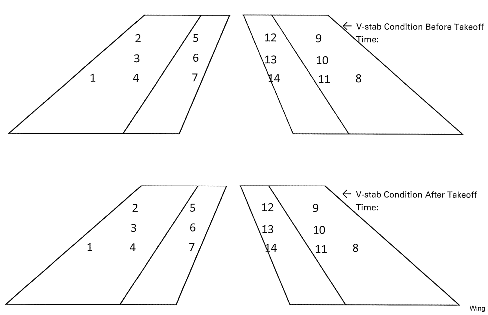
Date: January 18, 2023

Run: 29 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	3.1	3.0		2.7
10	3.1	3.1		2.6
Time:	4:19	4:40		4:47

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.75		36.75
10	36.75		36.75
Time:	4:40		4:48

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	26		7
2	22		4
3	28		7
4	28		10
5	14		18
6	26		26
7	24		20
8	18		4
9	20		5
10	22		8
11	24		9
12	22		11
13	24		11
14	26		7
Time:	4:40		4:49



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

OBSERVER: BB/CB

General Comments:

Figure C22 Run #29

No Data Available

Figure C23 Run #30

No Data Available

Figure C24: Run #31

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

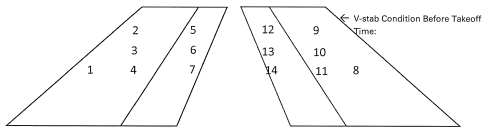
Date: January 18, 2023

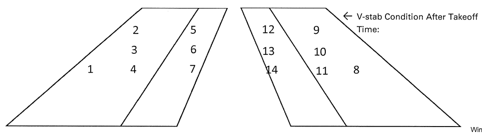
Run: 32 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	7.1	6.2	/	4.0
10	7.0	6.0	/	4.0
Time:	21:50	22:08	/	22:17

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.25	/	37.5
10	37.25	/	37.5
Time:	22:06	/	22:18

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	20	/	4
2	14	/	2
3	18	/	5
4	22	/	5
5	10	/	10
6	20	/	14
7	20	/	16
8	12	/	2
9	10	/	2
10	22	/	7
11	22	/	5
12	11	/	5
13	18	/	3
14	22	/	7
Time:	22:07	/	22:19





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

OBSERVER: BB / CB

General Comments:

Figure C25: Run #32

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

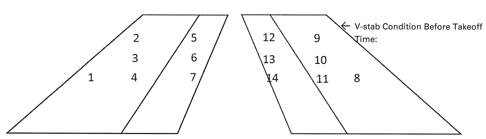
Date: January 18, 2023

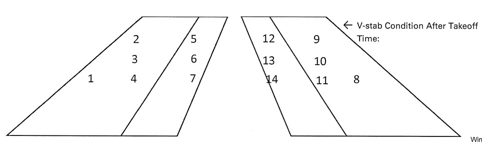
Run: 33 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	5.3	4.7	/	3.2
10	5.2	4.7	/	3.3
Time:	22:29	22:46	/	23:00

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0	/	38.0
10	37.0	/	38.0
Time:	22:47	/	23:00

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	14	/	4
2	12	/	2
3	16	/	3
4	18	/	5
5	12	/	12
6	18	/	12
7	16	/	14
8	11	/	2
9	12	/	2
10	16	/	5
11	18	/	9
12	12	/	5
13	16	/	3
14	18	/	4
Time:	22:48	/	23:00





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

OBSERVER: BB / CB

General Comments:

Figure C26: Run #33

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

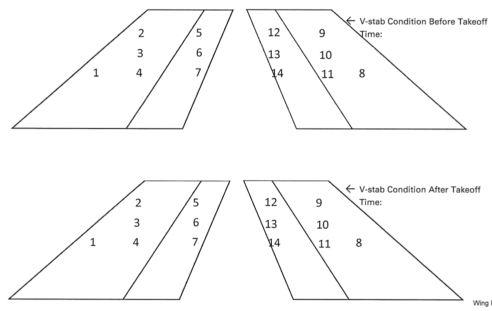
Date: January 18, 2023

Run: 34 (P062)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	4.3	4.3		3.2
10	4.2	4.1		3.2
Time:	23:12	2 :29		23:38

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		37.5
10	37.0		37.5
Time:	23:27		23:39

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	20		3
2	14		2
3	18		5
4	24		5
5	12		6
6	18		12
7	18		12
8	12		2
9	14		3
10	18		5
11	20		6
12	12		8
13	16		4
14	16		5
Time:	23:28		23:40



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

Figure C27: Run #34

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

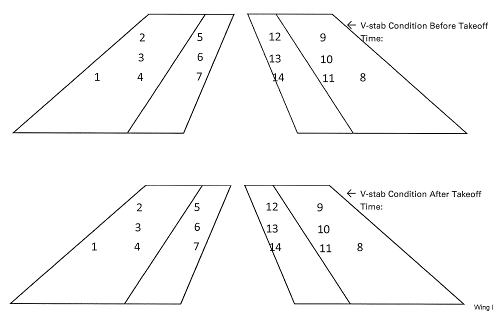
Date: January 19, 2023

Run: 35 (P062)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	5.7	4.7		3.5
10	5.6	4.6		3.5
Time:	00:12	00:29		00:43

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		38.25
10	37.0		38.25
Time:	00:30		00:44

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	20		4
2	18		6
3	20		4
4	24		4
5	12		7
6	22		14
7	18		14
8	16		2
9	10		2
10	22		6
11	24		6
12	11		5
13	18		3
14	22		5
Time:	00:31		00:45



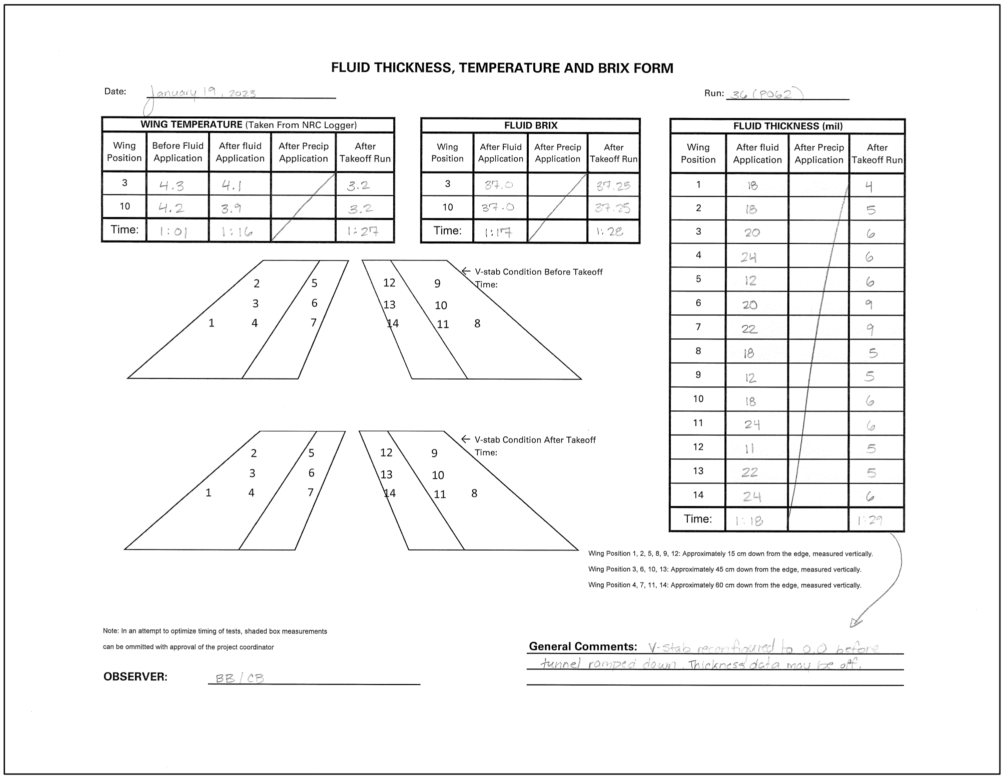
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

Figure C28: Run #35



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 19, 2023

Run: 36 (P062)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	4.3	4.1		3.2
10	4.2	3.9		3.2
Time:	1:01	1:16		1:27

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		37.25
10	37.0		37.25
Time:	1:17		1:28

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	18		4
2	18		5
3	20		6
4	24		6
5	12		6
6	20		9
7	22		9
8	18		5
9	12		5
10	18		6
11	24		6
12	11		5
13	22		5
14	24		6
Time:	1:18		1:29

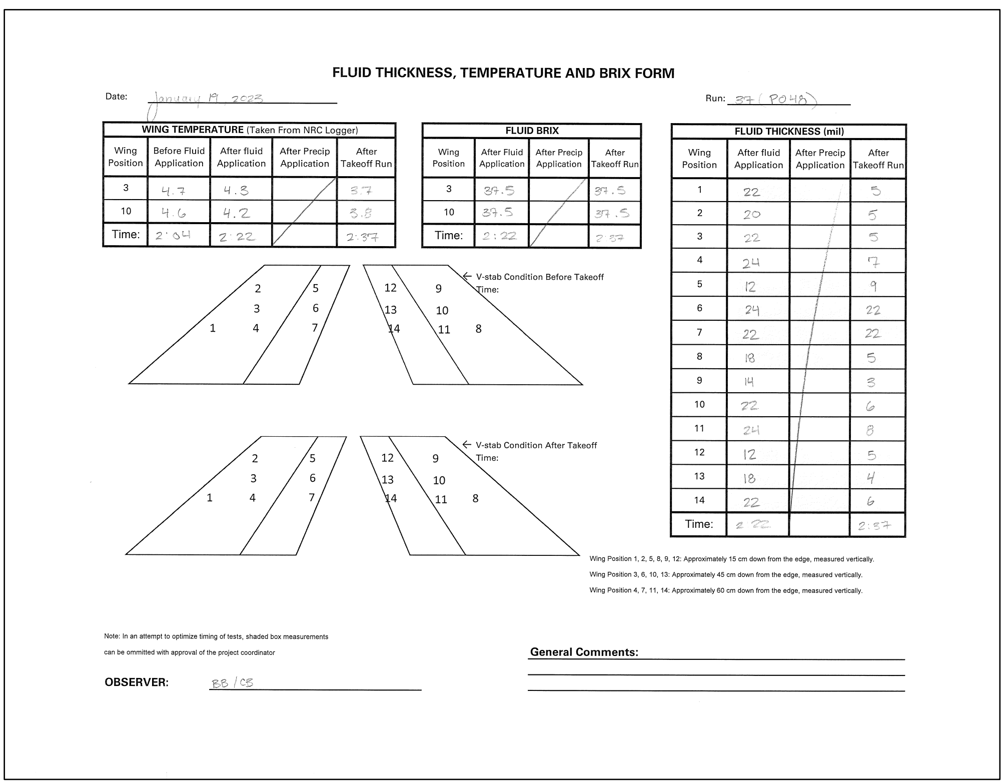
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments: V-stab reconfigured to 0.0 before tunnel ramped down. Thickness data may be off.

OBSERVER: BB / CB

Figure C29: Run #36



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 19, 2023

Run: 37 (P048)

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		3.7
10	4.6	4.2		3.8
Time:	2:04	2:22		2:37

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.5		37.5
10	37.5		37.5
Time:	2:22		2:37

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	22		5
2	20		5
3	22		5
4	24		7
5	12		9
6	24		22
7	22		22
8	18		5
9	14		3
10	22		6
11	24		8
12	12		5
13	18		4
14	22		6
Time:	2:22		2:37

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

Figure C30: Run #37

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

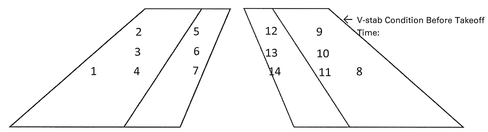
Date: January 19, 2023

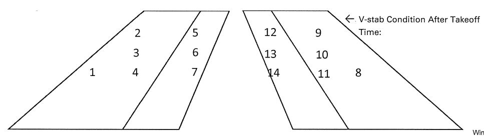
Run: 38 (P052)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	4.7	7.2	/	4.8
10	4.5	7.0	/	4.7
Time:	2:57	3:13	/	3:25

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.75	/	37.75 ☆ dry
10	37.75	/	37.75 dry
Time:	3:14	/	3:26

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	2	/	0
2	1	/	0
3	1	/	0
4	1	/	0
5	1	/	0
6	1	/	0
7	1	/	0
8	1	/	0
9	1	/	0
10	<1	/	0
11	<1	/	0
12	<1	/	0
13	2	/	0
14	<1	/	0
Time:	3:15	/	3:27 (dry with droplets)





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

OBSERVER: BB/CB

General Comments:

Figure C31: Run #38

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

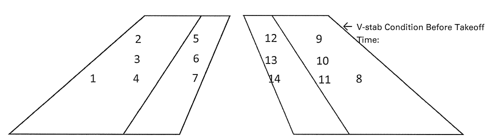
Date: January 19, 2023

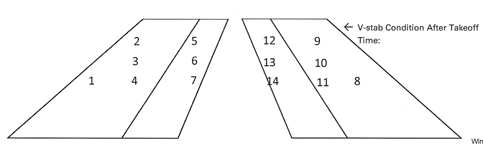
Run: 39 (P052)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	5.4	7.8	/	4.3
10	5.3	7.9	/	4.0
Time:	3:40	3:53	/	4:02

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0	/	37.0 dry
10	37.0	/	37.0 dry
Time:	3:53	/	4:02

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	<1	/	0
2	<1	/	0
3	1	/	0
4	1	/	0
5	<1	/	0
6	<1	/	0
7	<1	/	0
8	<1	/	0
9	<1	/	0
10	1	/	0
11	<1	/	0
12	1	/	0
13	<1	/	0
14	<1	/	0
Time:	3:53	/	4:02 (dry with droplets)





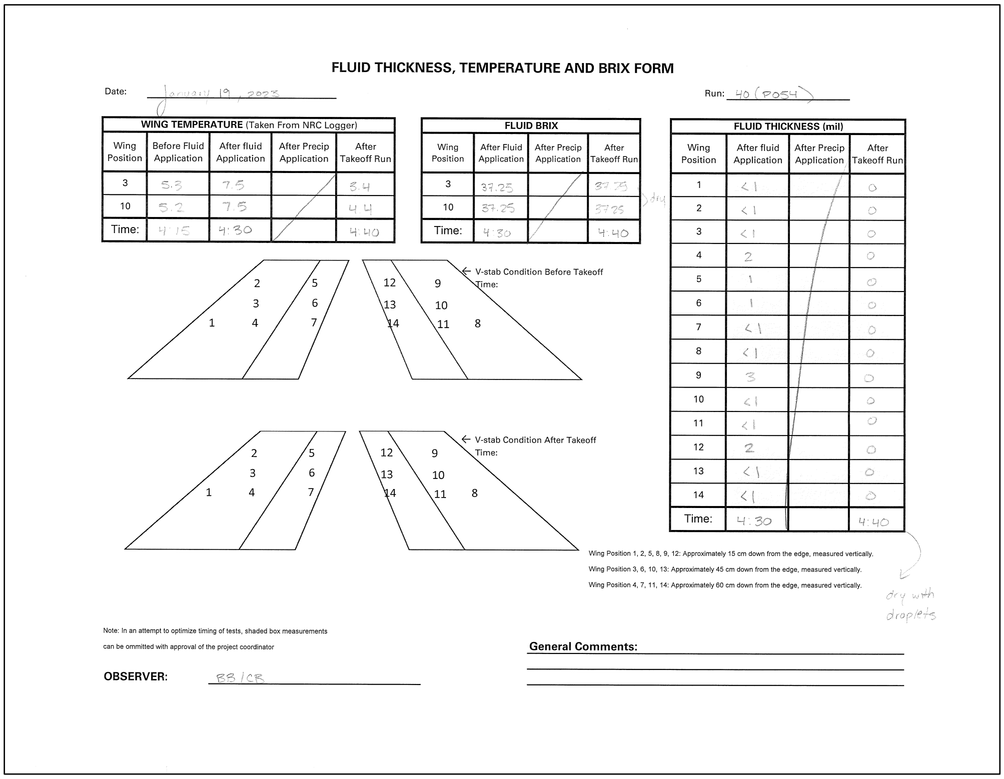
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

OBSERVER: BB/CB

General Comments:

Figure C32: Run #39



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 19, 2023 Run: 40 (P054)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	5.3	7.5		3.4
10	5.2	7.5		4.4
Time:	4:15	4:30		4:40

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.25		37.25
10	37.25		37.25
Time:	4:30		4:40

dry

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	<1		0
2	<1		0
3	<1		0
4	2		0
5	1		0
6	1		0
7	<1		0
8	<1		0
9	3		0
10	<1		0
11	<1		0
12	2		0
13	<1		0
14	<1		0
Time:	4:30		4:40

dry with droplets

← 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

OBSERVER: BB/CR

General Comments:

Figure C33: Run #40

No Data Available

Figure C34: Run #41

No Data Available

Figure C35: Run #42

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

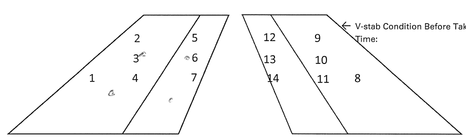
Date: January 19, 2023

Run: 43 (P046)

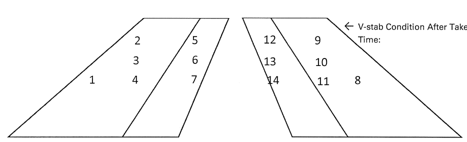
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	2.20	2.18	/	0.9
10	2.33	2.44	/	0.9
Time:	22:00	22:20	/	22:33

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0	/	33.0
10	-	/	
Time:	22:20	/	22:33

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	22	/	4
2	20	/	4
3	22	/	7
4	26	/	9
5	11	/	11
6	22	/	20
7	24	/	22
8	18	/	4
9	16	/	4
10	22	/	8
11	24	/	8
12	12	/	5
13	22	/	7
14	22	/	6
Time:	22:20	/	22:33



← 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

OBSERVER: BB/PK

General Comments: Snow sucked in from outside - no visible contamination

Figure C36: Run #43

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 19, 2023

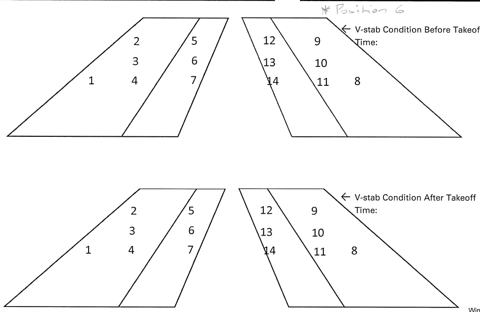
Run: 44 (E5)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3				
10	2.06	2.14		1.04
Time:	22:50	23:01		23:14

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3			36.5*
10	36.75		36.75
Time:	23:01		23:15

* Position 6

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5			
6			
7			
8	20		5
9	18		4
10	24		8
11	24		9
12	22		5
13	22		4
14	22		7
Time:	23:01		23:15



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

OBSERVER: BB/PK

General Comments: Test Type → Fluid Only Pressure Side

Figure C37: Run #44

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

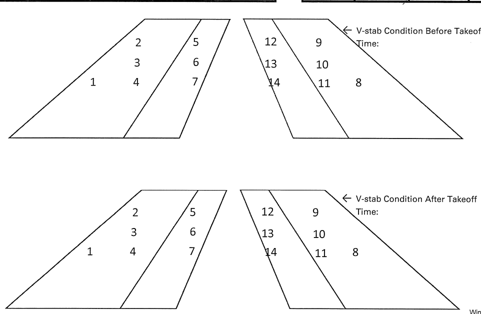
Date: January 19, 2023

Run: 45 (E6)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	2.02	1.95		1.41
10				
Time:	23:28	23:38		23:48

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		36.75
10			
Time:	23:38		23:48

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	22		5
2	22		5
3	24		5
4	24		8
5	11		10
6	24		22
7	24		22
8			
9			
10			
11			
12			
13			
14			
Time:	23:48		23:48



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

OBSERVER: BB/PK

General Comments: Test type → Fluid Only Suction side

Figure C38: Run #45

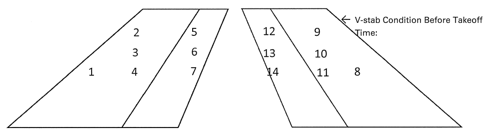
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 20, 2023 Run: 46 (E7)

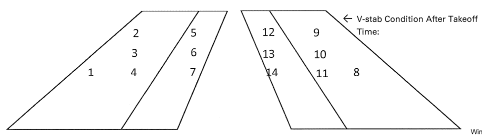
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3 6	3.54	3.78		3.29
10 13	3.83	3.81		3.33
Time:	0:02	0:12		0:21

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3 6	37.0		37.0
10 13	37.0		37.0
Time:	0:12		0:21

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5	22		7
6	22		11
7	24		18
8			
9			
10			
11			
12	22		5
13	22		5
14	22		6
Time:	0:12		0:21



← 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/PK

Figure C39: Run #46

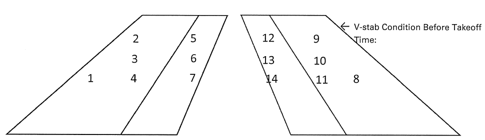
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 20, 2023 Run: 47 (E8)

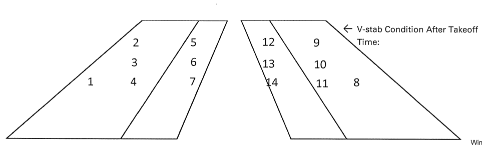
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3 6				
10 13	4.2	4.03		3.5
Time:	0:34	0:40		0:53

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3 6			
10 13	37.25		37.5
Time:	0:40		0:53

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	16		5
13	18		5
14	22		6
Time:	0:40		0:53



← 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/PK

Figure C40: Run #47

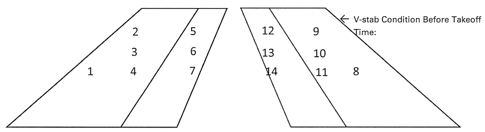
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

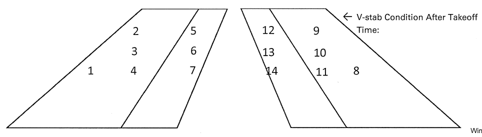
Date: January 20, 2023 Run: 48 (E9)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
~~3~~ 6	3.93	4.25		3.90
10				
Time:	01:13	01:21		01:33

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
~~3~~ 6	37.5		37.25
10 13			
Time:	01:21		01:33

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5	20		7
6	24		14
7	26		16
8			
9			
10			
11			
12			
13			
14			
Time:	01:21		01:33





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

OBSERVER: BB/PK

General Comments:

Figure C41: Run #48

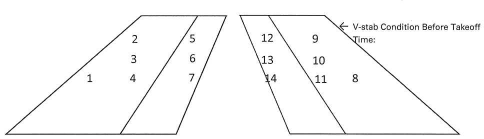
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

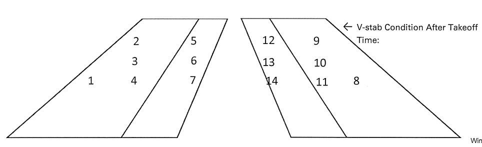
Date: January 20, 2023 Run: 49 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	2.41	2.67		2.36
10	2.57	2.51		2.17
Time:	01:44	02:00		02:12

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0		37.25
10			
Time:	02:00		02:12

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	24		5
2	22		5
3	24		7
4	26		7
5	11		9
6	22		22
7	22		24
8	18		2
9	14		3
10	22		6
11	24		7
12	14		5
13	20		6
14	22		6
Time:	02:00		02:12





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

OBSERVER: BB/PK

General Comments:

Figure C42: Run #49

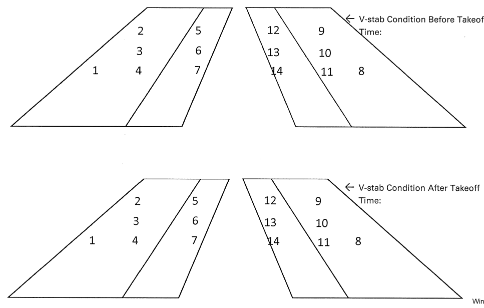
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 20, 2023 Run: 50 (E5)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3				
10	2.50	2.60		2.37
Time:	02:23	02:43		02:55

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
36			37.25
10	37.0		36.75
Time:	02:43		02:55

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2			
3			
4			
5			
6			
7			
8	16		4
9	9		3
10	22		7
11	24		7
12	18		5
13	20		6
14	24		7
Time:	02:43		02:55



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: Fluid leaked through to other side of the rudder.

OBSERVER: BB/PK

Figure C43: Run #50

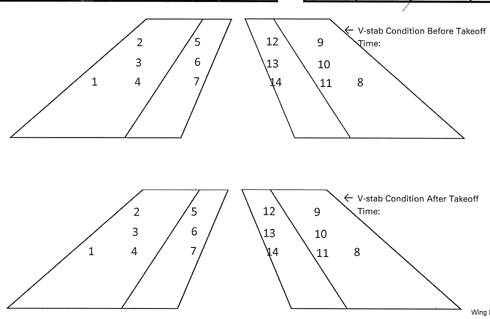
FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 20, 2023 Run: 51 (P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	2.89	2.63		1.77
10	2.74	2.57		1.78
Time:	03:10	03:25		03:34

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	36.75		36.0
10			
Time:	03:25		03:34

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	18		5
2	20		6
3	24		5
4	26		6
5	14		10
6	24		14
7	24		20
8	14		4
9	10		11
10	22		6
11	24		7
12	11		6
13	22		6
14	20		6
Time:	03:25		03:34



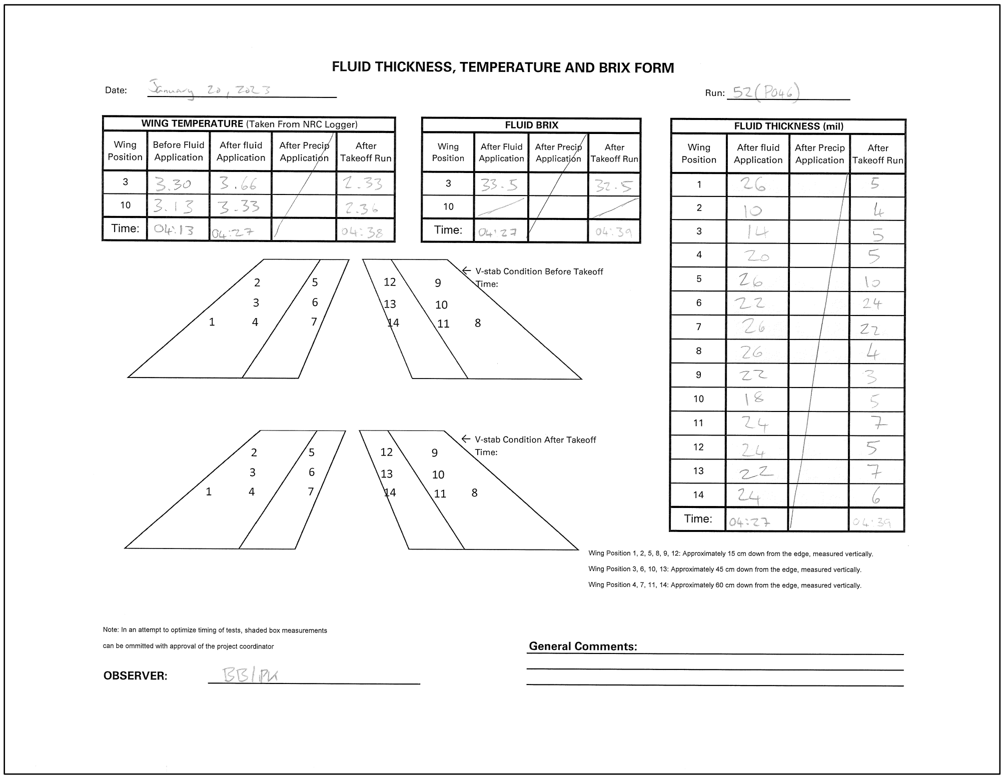
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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/PK

Figure C44: Run #51



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 20, 2023

Run: 52(P046)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	3.30	3.66		2.33
10	3.13	3.33		2.36
Time:	04:13	04:27		04:38

FLUID BRIX				
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.5		32.5
10			
Time:	04:27		04:39

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	26		5
2	10		4
3	14		5
4	20		5
5	26		10
6	22		24
7	26		22
8	26		4
9	22		3
10	18		5
11	24		7
12	24		5
13	22		7
14	24		6
Time:	04:27		04:39

← 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

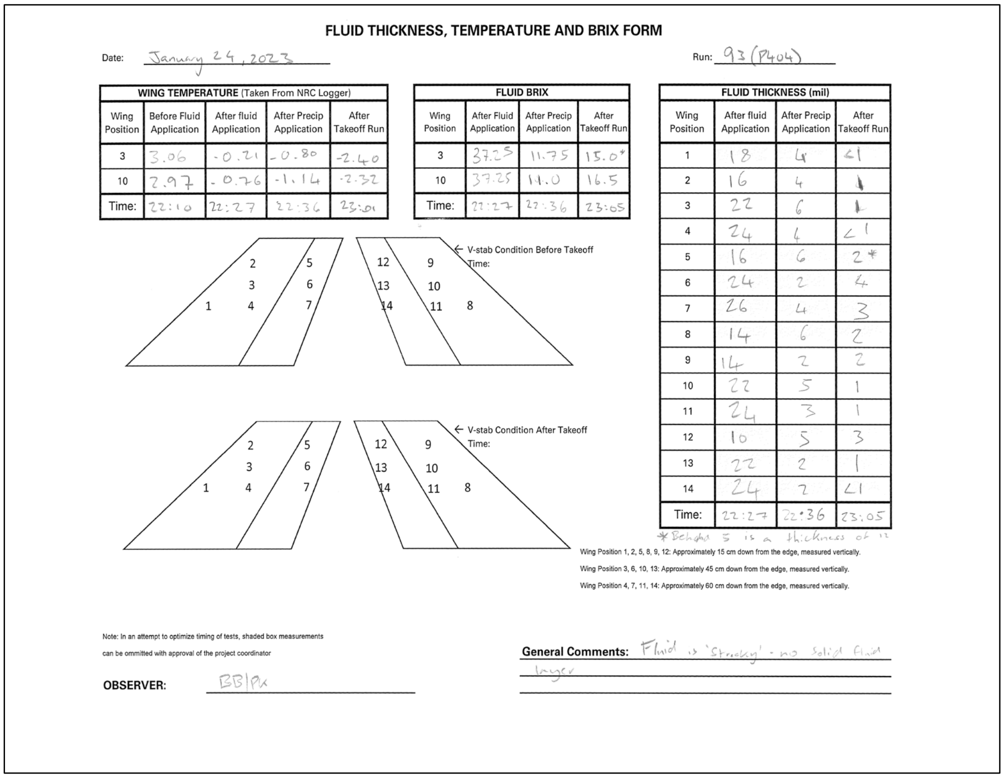
OBSERVER: BB/PK

General Comments:

Figure C45: Run #52

No Data Available

Figure C46: Runs #53-92



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 24, 2023 Run: 93 (P404)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	3.06	-0.21	-0.80	-2.40
10	2.97	-0.76	-1.14	-2.32
Time:	22:10	22:27	22:36	23:01

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.25	11.75	15.0*
10	37.25	11.0	16.5
Time:	22:27	22:36	23:05

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	18	4	<1
2	16	4	1
3	22	6	1
4	24	4	<1
5	16	6	2*
6	24	2	4
7	26	4	3
8	14	6	2
9	14	2	2
10	22	5	1
11	24	3	1
12	10	5	3
13	22	2	1
14	24	2	<1
Time:	22:27	22:36	23:05

*Behind 5 is a thickness of 12

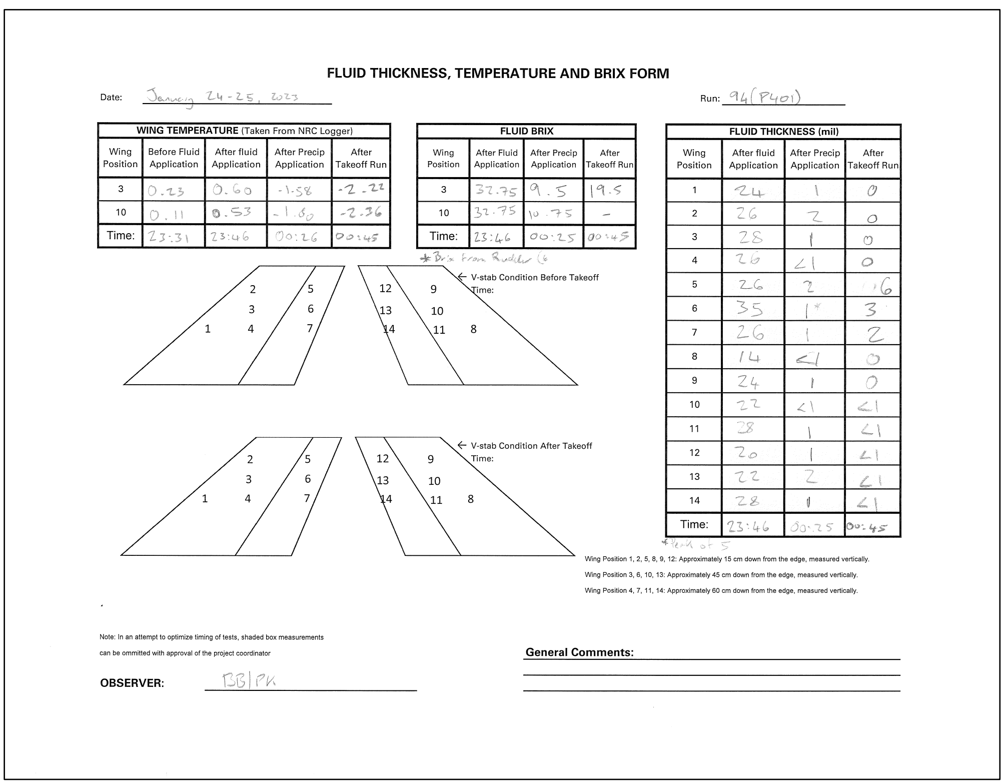
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

General Comments: Fluid is 'Streaky' - no solid fluid layer

OBSERVER: BB/PK

Figure C47: Run #93



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 24-25, 2023 Run: 94 (P401)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	0.23	0.60	-1.58	-2.22
10	0.11	0.53	-1.80	-2.36
Time:	23:31	23:46	00:26	00:45

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	32.75	9.5	19.5
10	32.75	10.75	–
Time:	23:46	00:25	00:45

*Brix from Rudder (6

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	24	1	0
2	26	2	0
3	28	1	0
4	26	<1	0
5	26	2	6
6	35	1*	3
7	26	1	2
8	14	<1	0
9	24	1	0
10	22	<1	<1
11	28	1	<1
12	20	1	<1
13	22	2	<1
14	28	1	<1
Time:	23:46	00:25	00:45

*Peak of 5

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/PK

Figure C48: Run #94

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 25, 2023

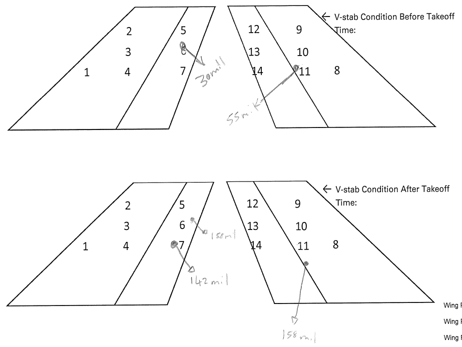
Run: 95 (P170)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-1.55	-0.69	-2.06	-2.70
10	-1.70	-0.82	-2.31	-3.24
Time:	00:54	01:09	01:55	02:08

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	32.5	15.75	6.0
10	32.5	7.0	6.5
Time:	01:09	01:55	02:08

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	22	1	0
2	26	<1	0
3	28	2	0
4	25	1	0
5	22	1	2
6	40	<1	3
7	35	3	1
8	24	<1	0
9	24	6	0
10	28	1	0
11	30	<1	0
12	26	4	1
13	35	<1	0
14	28	<1	0
Time:	01:09	01:55	02:08

*On contamination



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

OBSERVER: BB/PK

General Comments:

Figure C49: Run #95

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 25, 2023

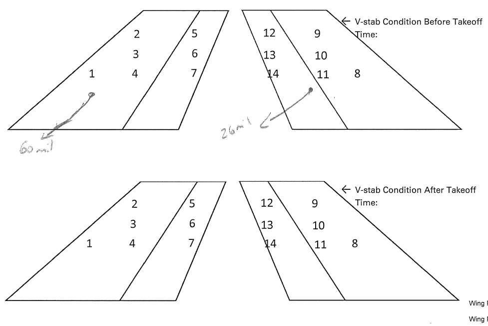
Run: 96 (P106)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-2.20	-1.20	-3.76	-5.38
10	-2.39	-1.42	-4.02	-5.41
Time:	02:24	02:39	02:55	03:06

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.0	13.6	17.5
10	33.0	15.25	18.5
Time:	02:39	02:55	03:06

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	26	1	2
2	22	4	<1
3	24	2	1
4	26	2	2
5	22	2	7
6	33	6	6
7	33	14	14*
8	24	8	4
9	24	7	4
10	28	4	3
11	30	3	1
12	24	8	5
13	30	4	1
14	28	5	2
Time:	02:39	02:55	03:06

*Peak of 20



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.

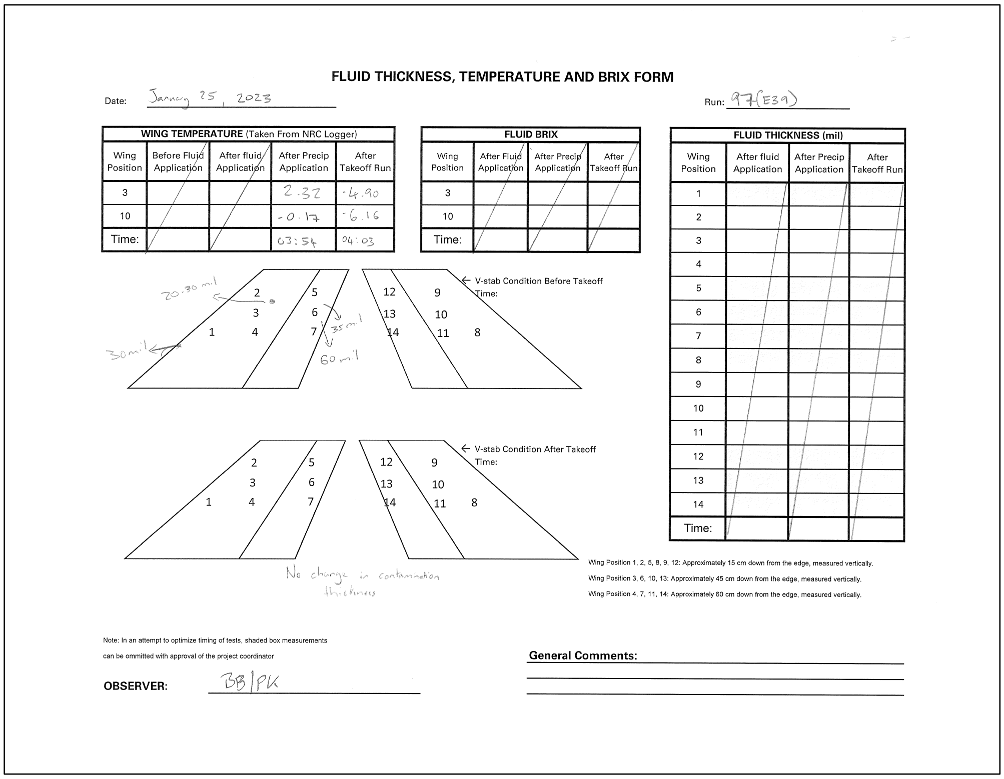
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

OBSERVER: BB/PK

General Comments:

Figure C50: Run #96



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 25, 2023

Run: 97(E39)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3			2.32	-4.90
10			-0.17	-6.16
Time:			03:54	04:03

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

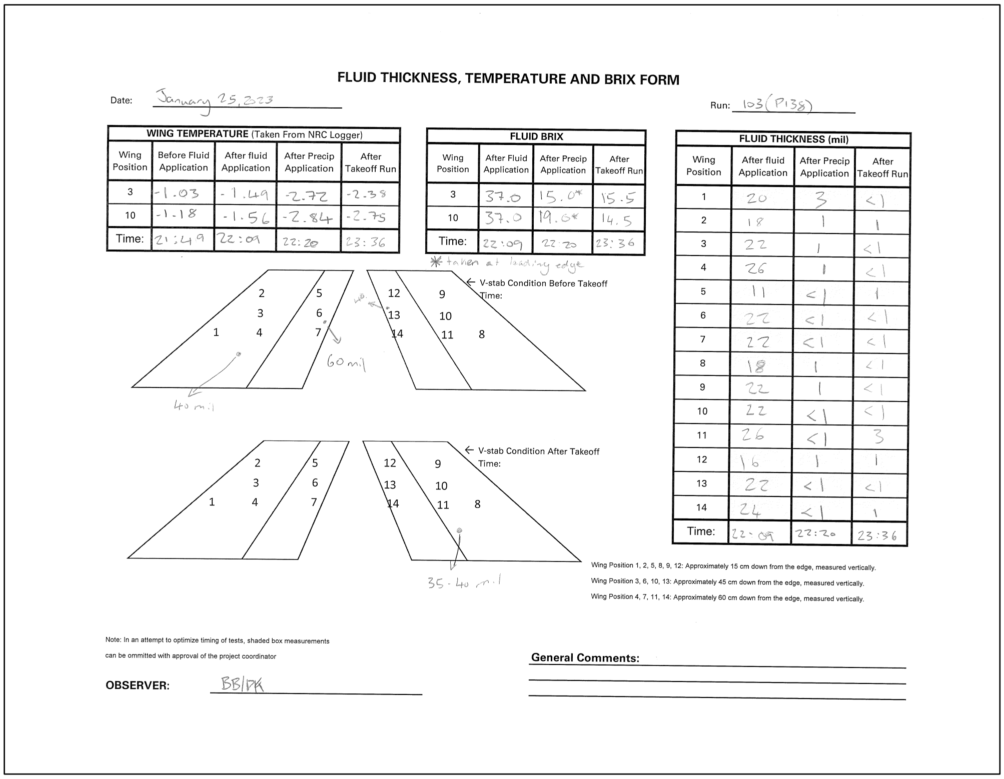
OBSERVER: BB/PK

General Comments:

Figure C51: Run #97

No Data Available

Figure C52: Runs #98-102



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 25, 2023   Run: 103 (P138)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-1.03	-1.49	-2.72	-2.38
10	-1.18	-1.56	-2.84	-2.75
Time:	21:49	22:09	22:20	23:36

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.0	15.0*	15.5
10	37.0	19.0*	14.5
Time:	22:09	22:20	23:36

* taken at leading edge

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	20	3	<1
2	18	1	1
3	22	1	<1
4	26	1	<1
5	11	<1	1
6	22	<1	<1
7	22	<1	<1
8	18	1	<1
9	22	1	<1
10	22	<1	<1
11	26	<1	3
12	16	1	1
13	22	<1	<1
14	24	<1	1
Time:	22:09	22:20	23:36

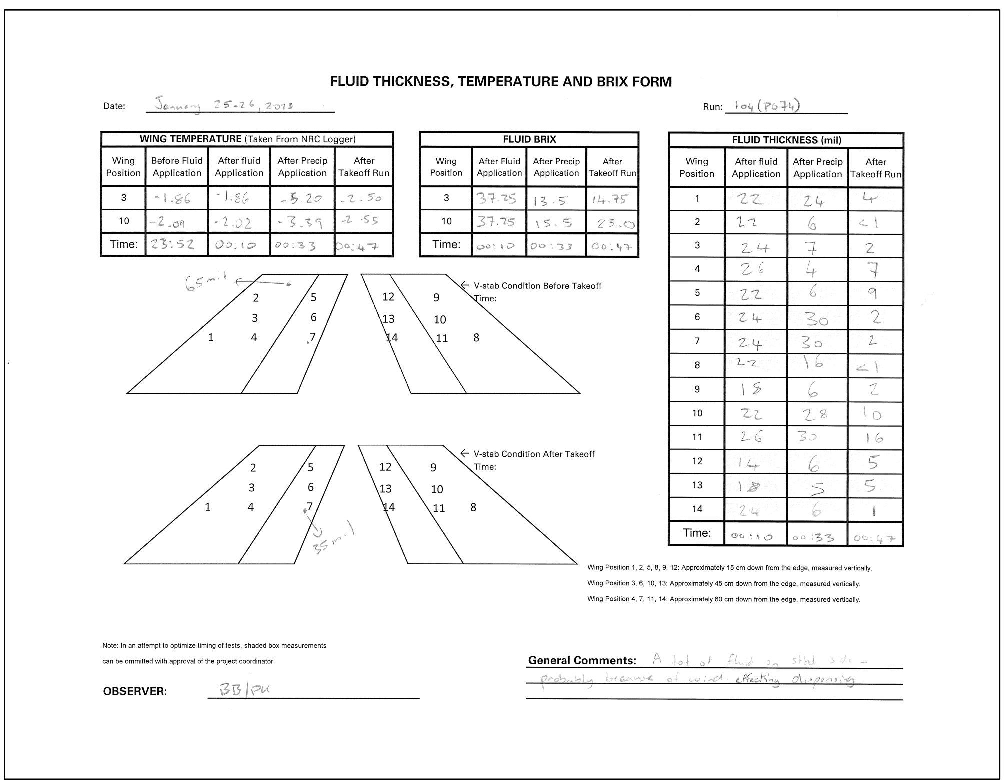
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

OBSERVER: BB/PK

General Comments:

Figure C53: Run #103



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 25-26, 2023   Run: 104 (P074)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-1.86	-1.86	-5.20	-2.50
10	-2.09	-2.02	-3.39	-2.55
Time:	23:52	00:10	00:33	00:47

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	37.25	13.5	14.75
10	37.25	15.5	23.0
Time:	00:10	00:33	00:47

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	22	24	4
2	22	6	<1
3	24	7	2
4	26	4	7
5	22	6	9
6	24	30	2
7	24	30	2
8	22	16	<1
9	18	6	2
10	22	28	10
11	26	30	16
12	14	6	5
13	18	5	5
14	24	6	1
Time:	00:10	00:33	00:47

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

OBSERVER: BB/PK

General Comments: A lot of fluid on stbd side – probably because of wind effecting dispensing

Figure C54: Run #104

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

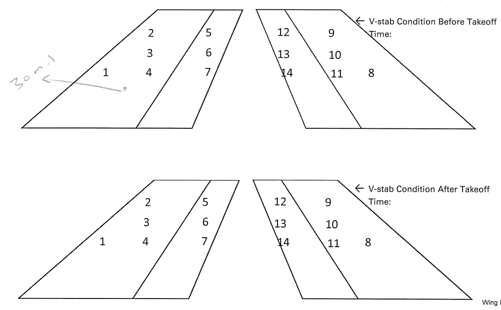
Date: January 26, 2023

Run: 105 (E43), 106 (E43

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-1.59	2.42	-0.60	-1.40
10	-1.70	3.24	-0.91	-1.45
Time:	01:06	01:23	01:49	02:14

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3		5.5	–
10		6.75	–
Time:		01:49	02:14

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1		<1	0
2		<1	0
3		<1	0
4		<1	0
5		5	1
6		<1	0
7		<1	0
8		<1	0
9		0	0
10		<1	0
11		<1	0
12		<1	0
13		<1	0
14		<1	0
Time:		01:49	02:14



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: Begin precipitation straight after fluid application.

OBSERVER: BB/PK

Figure C55: Runs #105 and #106

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

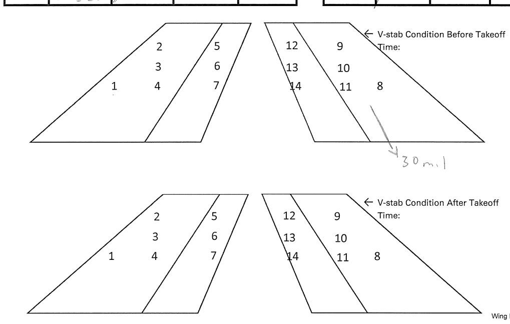
Date: January 26, 2023

Run: 107 (P154)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	-0.68		0.33	0.06
10	-0.88		0.40	-0.30
Time:	02:26		02:51	03:06

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3		6.0	–
10		7.5	–
Time:		02:51	03:06

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1		1	0
2		3	0
3		2	0
4		<1	0
5		<1	0
6		<1	0
7		<1	0
8		<1	0
9		1	0
10		<1	0
11		<1	0
12		1	0
13		<1	0
14		<1	0
Time:		02:51	03:06



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/PK

Figure C56: Run #107

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 26, 2023

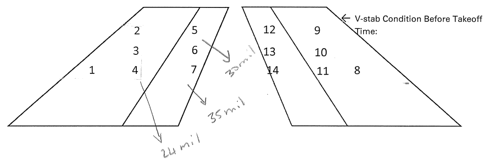
Run: 108(E44)

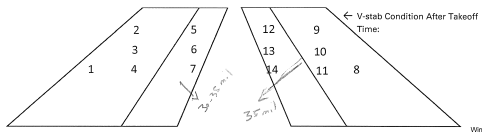
WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	0.08	-0.04	0.46	-0.51
10	-0.14	-0.19	0.01	-0.74
Time:	03:13	03:27	04:16	04:32

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.25	—	—
10	33.25	—	—
Time:	03:27	04:16	04:32

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	28	0	0
2	28	0	0
3	28	0	0
4	26	0	0
5	24	1	1
6	26	4*	0
7	28	2	0
8	26	8*	3
9	24	0	0
10	20	3	0
11	26	1	4
12	24	4	0
13	26	<1	0
14	30	2	0
Time:	03:27	04:16	04:32

*mostly water.





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|PK

Figure C57: Run #108

No Data Available

Figure C58: Run #109

No Data Available

Figure C59: Run #110

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

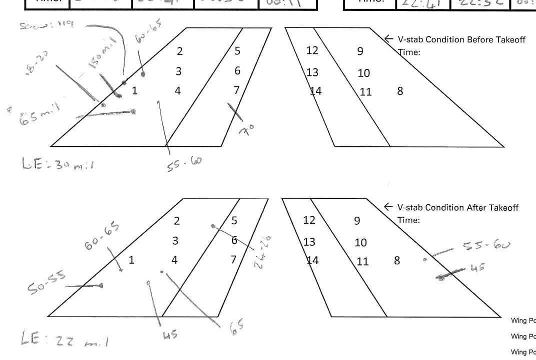
Date: January 26, 2023

Run: 111 (E45)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
3	0.25	-0.30	-2.68	-3.43
10	0.00	-0.51	-2.76	-3.46
Time:	22:25	22:41	22:32	00:11

FLUID BRIX			
Wing Position	After Fluid Application	After Precip Application	After Takeoff Run
3	33.25	-	-
10	33.25	-	-
Time:	22:41	22:32	00:14

FLUID THICKNESS (mil)			
Wing Position	After fluid Application	After Precip Application	After Takeoff Run
1	24	<1	0
2	24	0	0
3	26	0	0
4	28	0	0
5	26	2	0
6	28	<1	0
7	28	<1	0
8	24	<1	0
9	24	1	0
10	22	<1	0
11	24	<1	0
12	22	<1	0
13	22	<1	0
14	26	<1	0
Time:	22:41	22:32	00:14



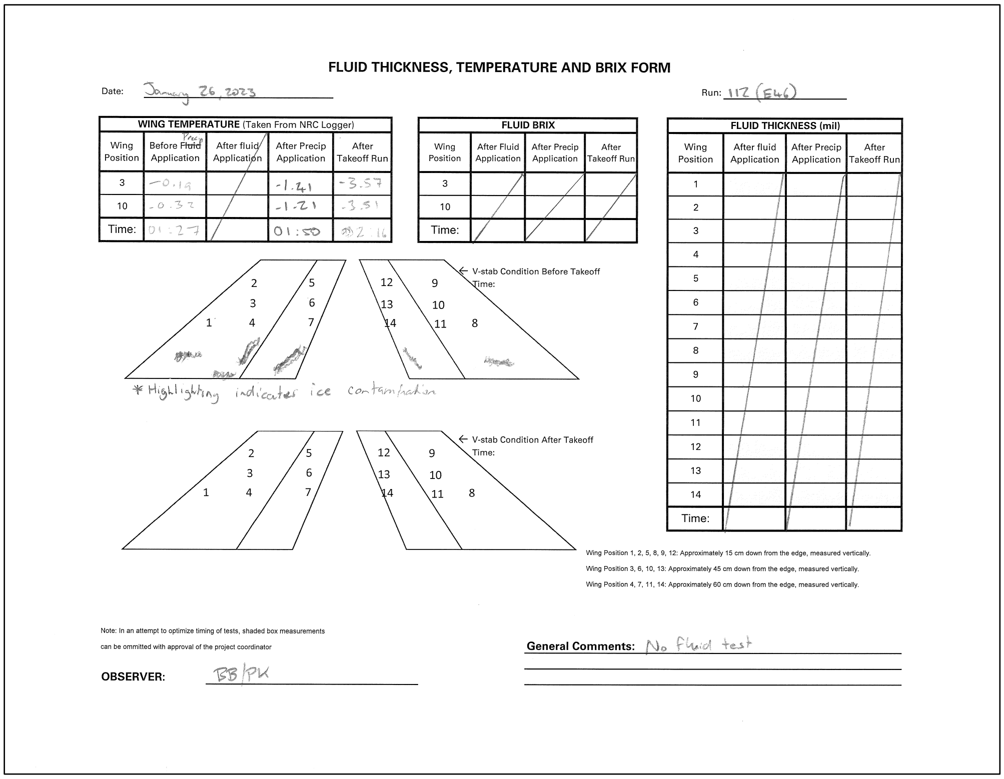
Wing Position 1, 2, 5, 8, 9, 12: Approximately 15 cm down from the edge, measured vertically.
Wing Position 3, 6, 10, 13: Approximately 45 cm down from the edge, measured vertically.
Wing Position 4, 7, 11, 14: Approximately 60 cm down from the edge, measured vertically.

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

OBSERVER: BB/PK

General Comments:

Figure C60: Run #111



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: January 26, 2023

Run: 112 (E46)

WING TEMPERATURE (Taken From NRC Logger)				
Wing Position	Before ~~Fluid~~ Precip Application	After fluid Application	After Precip Application	After Takeoff Run
3	-0.19		-1.41	-3.57
10	-0.32		-1.21	-3.51
Time:	01:27		01:50	02:16

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:

* Highlighting indicates ice contamination

← 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

OBSERVER: BB/PK

General Comments: No fluid test

Figure C61: Run #112

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APPENDIX D

SUMMARY OF FLUID THICKNESS DATA

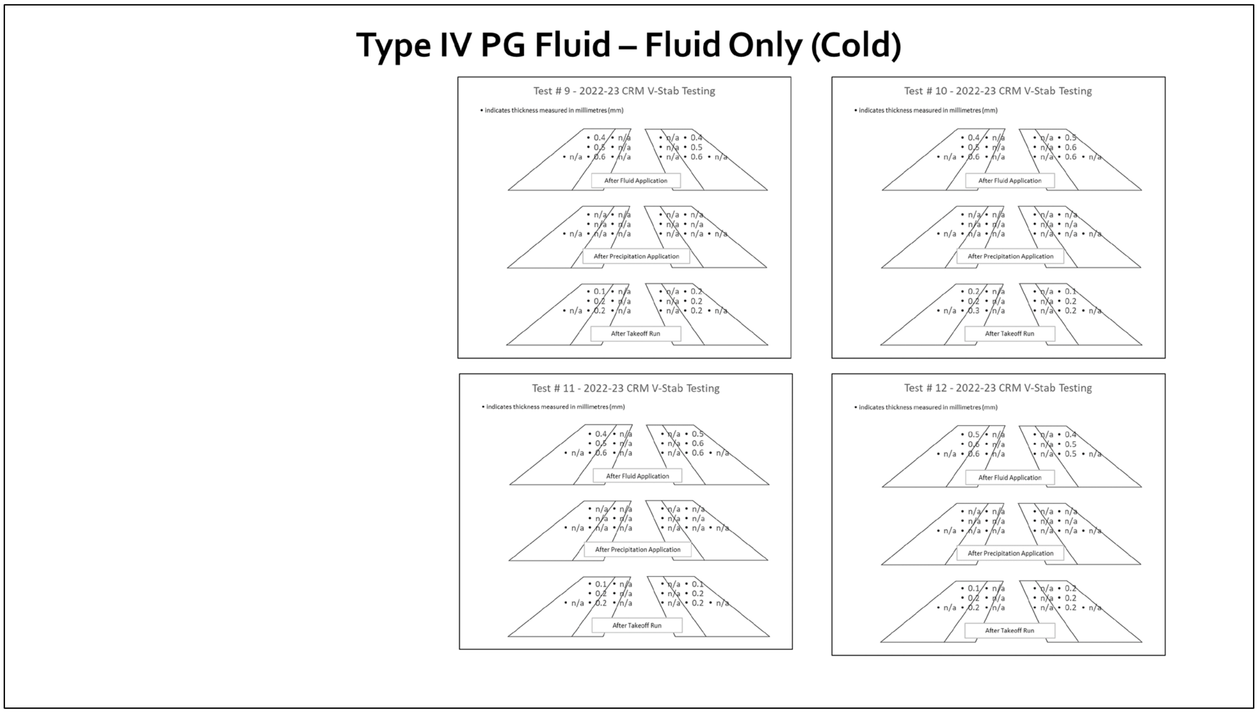

Figure 1: Thickness Data: Type IV PG Fluid Only (Cold)

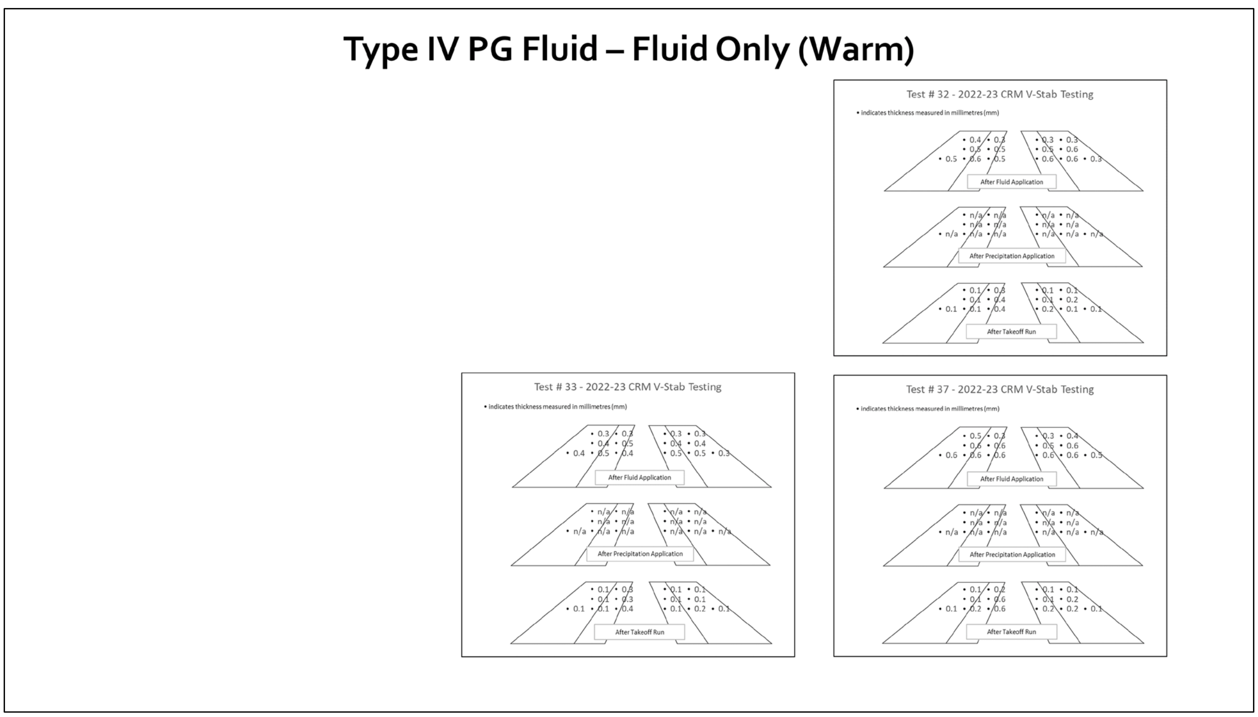

Figure 2: Thickness Data: Type IV PG Fluid Only (Warm)

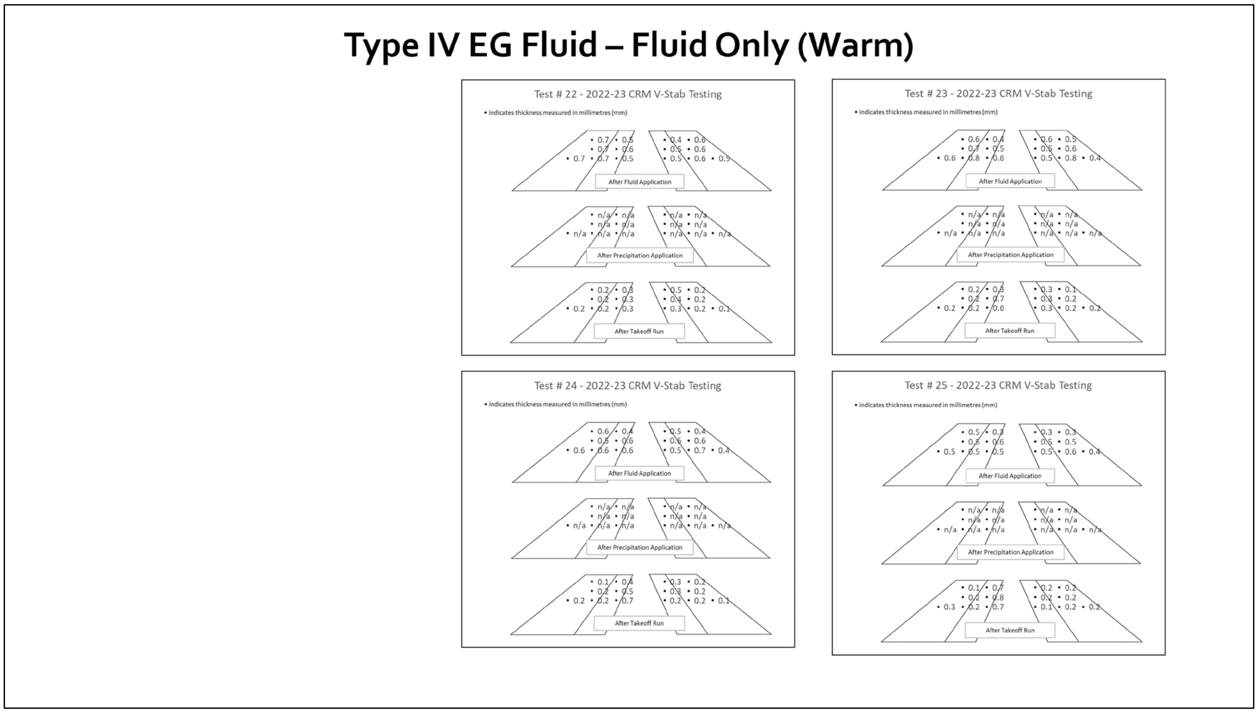

Figure 3: Thickness Data: Type IV EG Fluid Only (Warm)

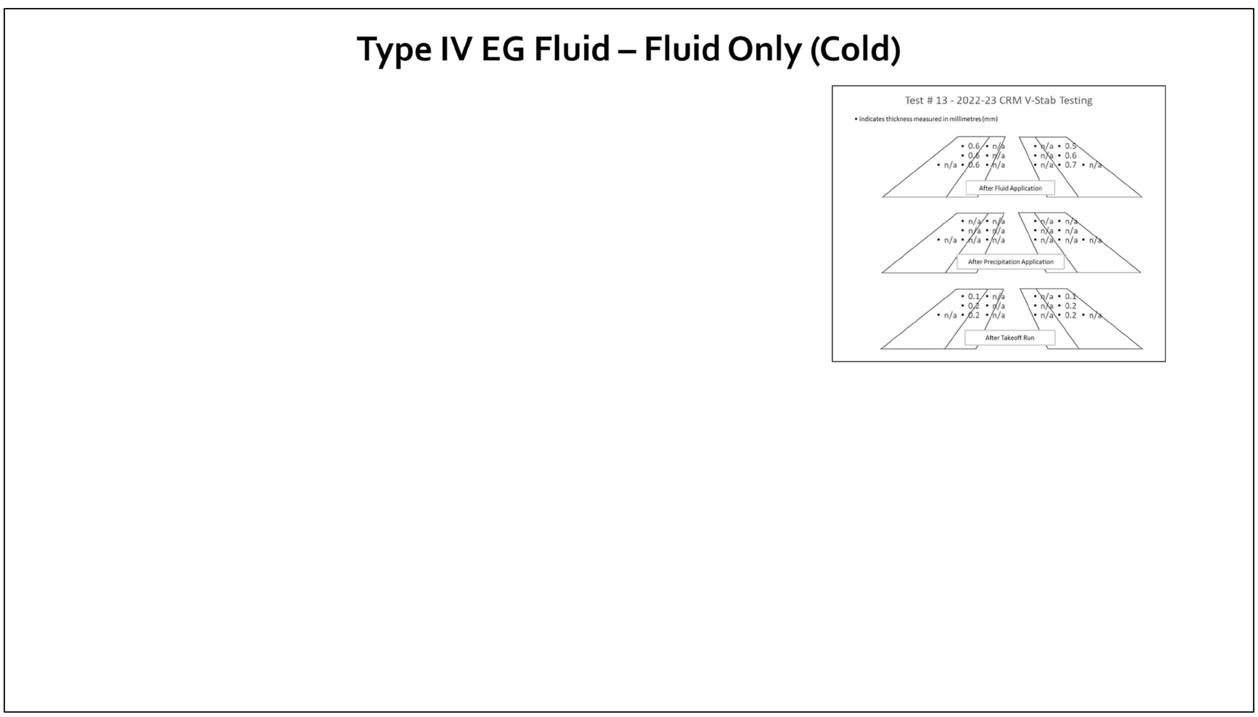

Figure 4: Thickness Data: Type IV EG Fluid Only (Cold)

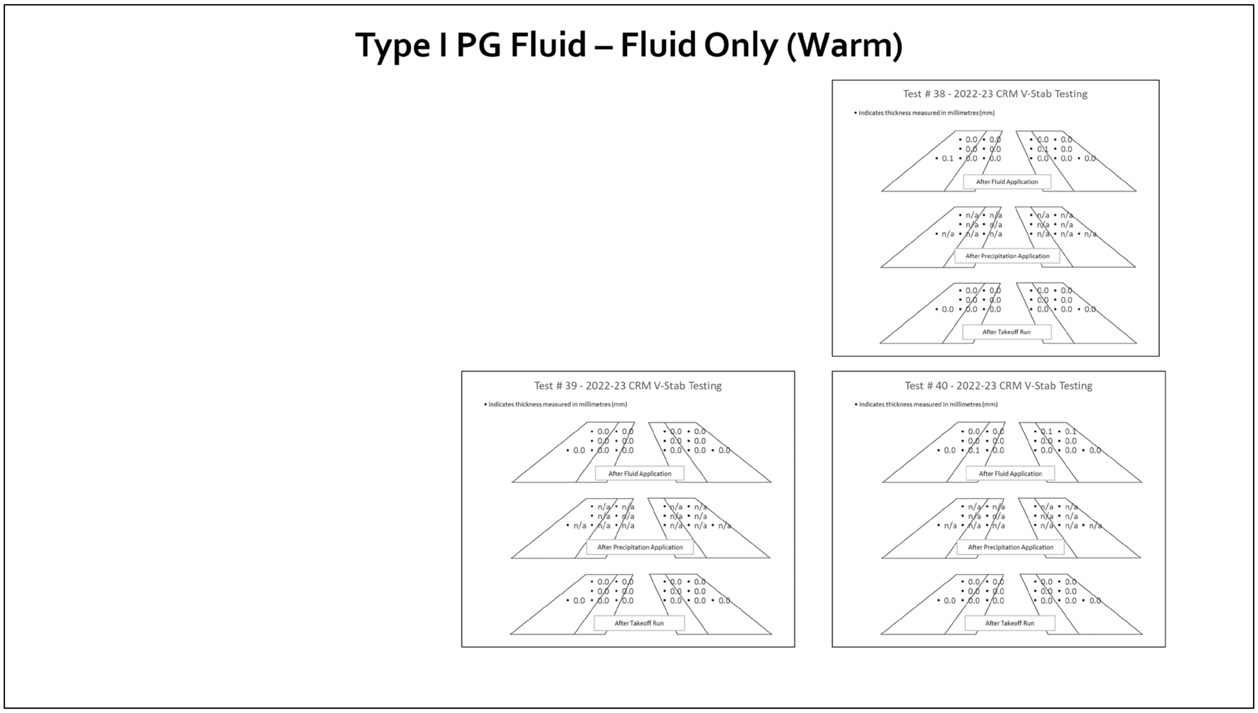

Figure 5: Thickness Data: Type I PG Fluid Only (Warm)

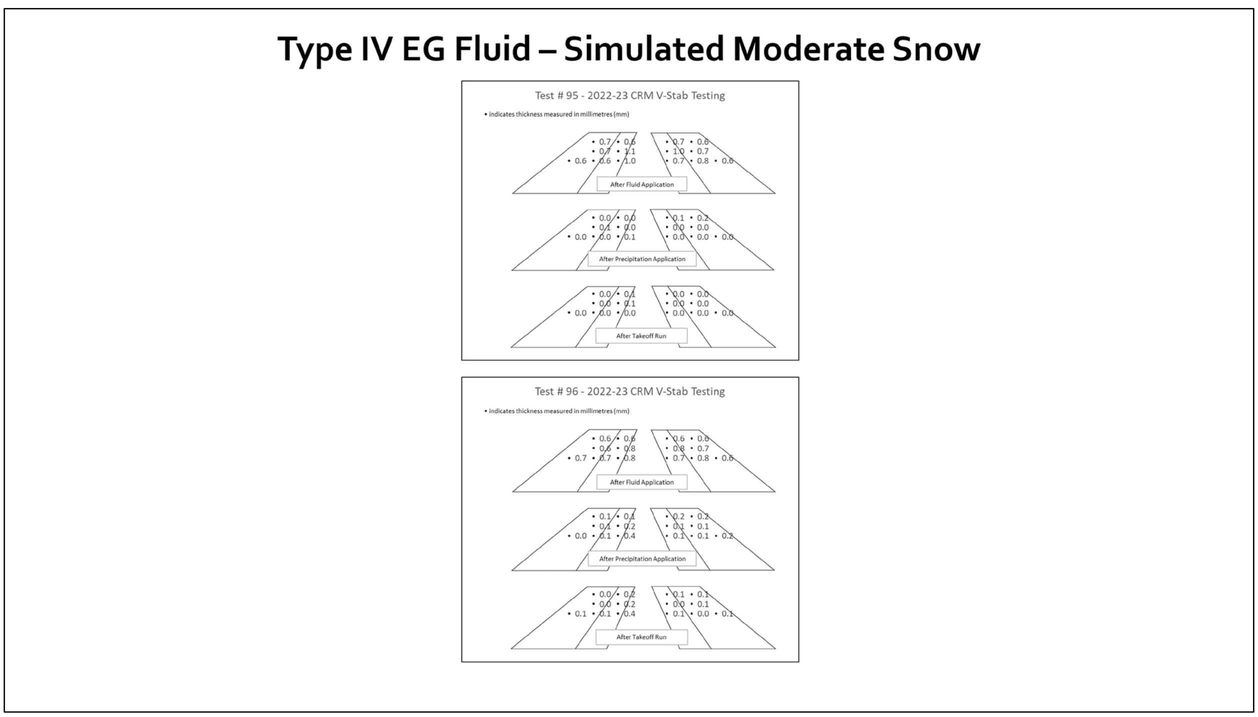

Figure 6: Thickness Data: Type IV EG Fluid – Simulated Moderate Snow

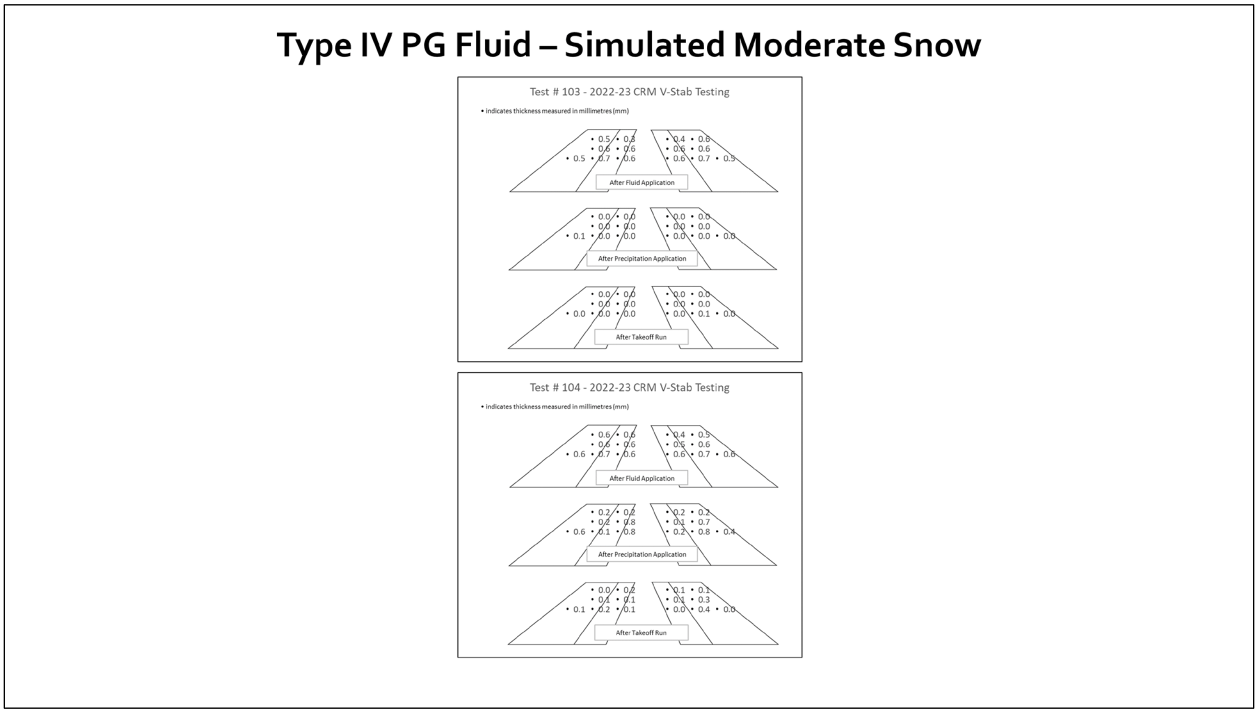

Figure 7: Thickness Data: Type IV PG Fluid – Simulated Moderate Snow

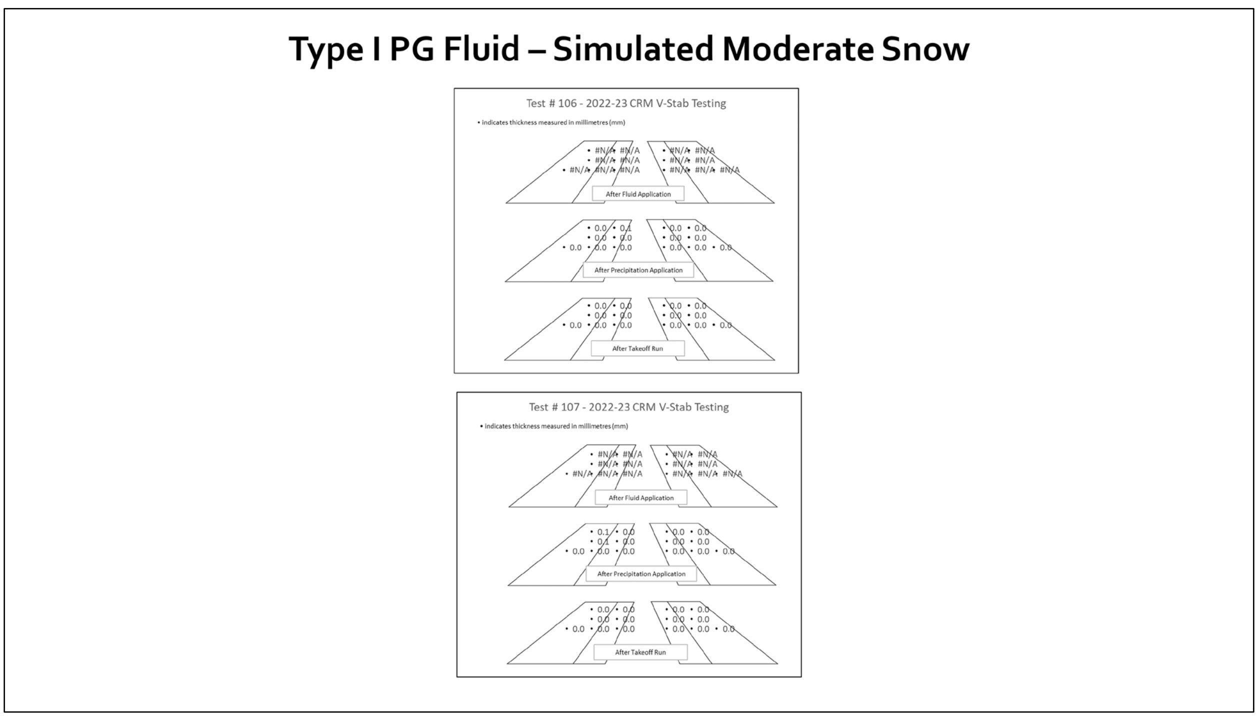

Figure 8: Thickness Data: Type I PG Fluid – Simulated Moderate Snow

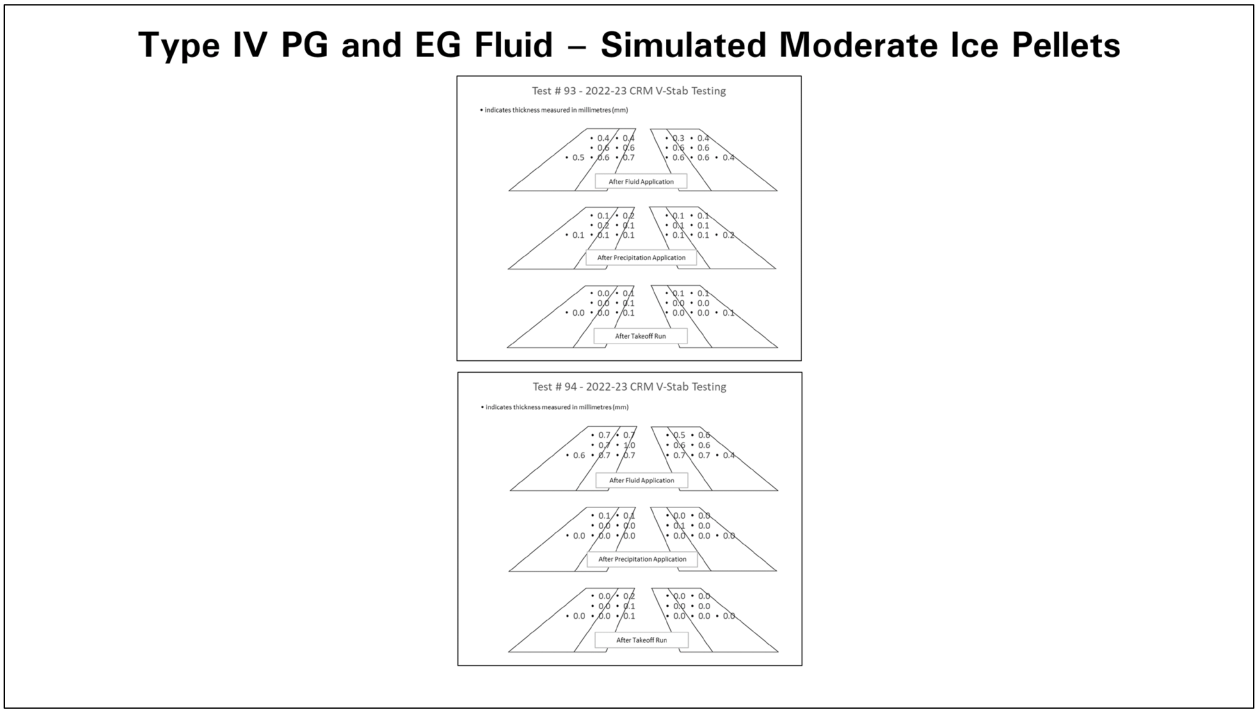

Figure 9: Thickness Data: Type IV PG and EG Fluid – Simulated Moderate Ice Pellets

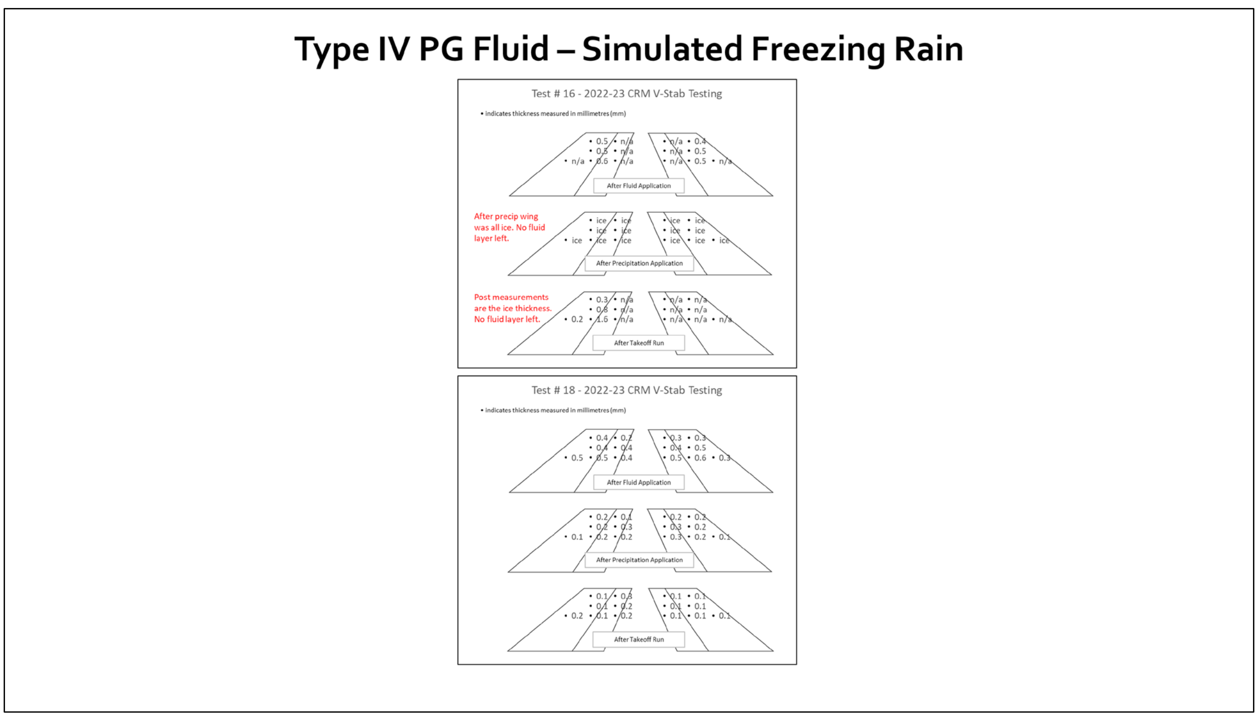

Figure 10: Thickness Data: Type IV PG – Simulated Freezing Rain

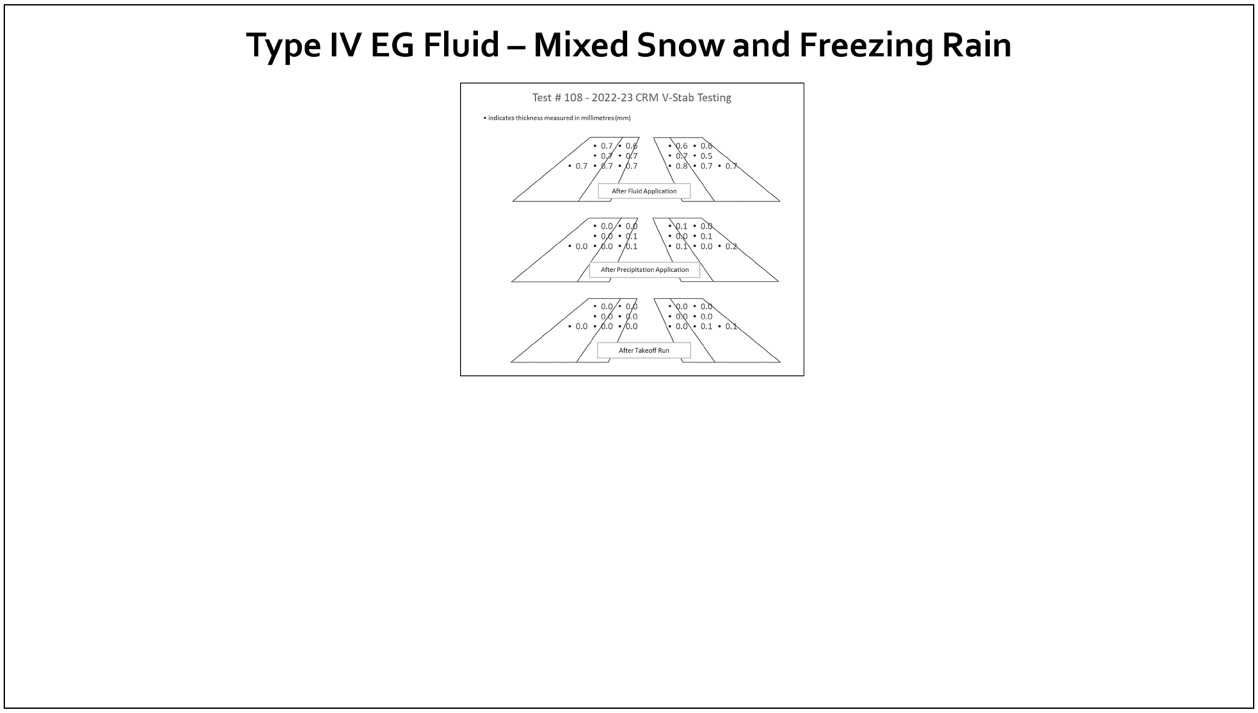

Figure 11: Thickness Data: Type IV EG Fluid – Mixed Snow and Freezing Rain

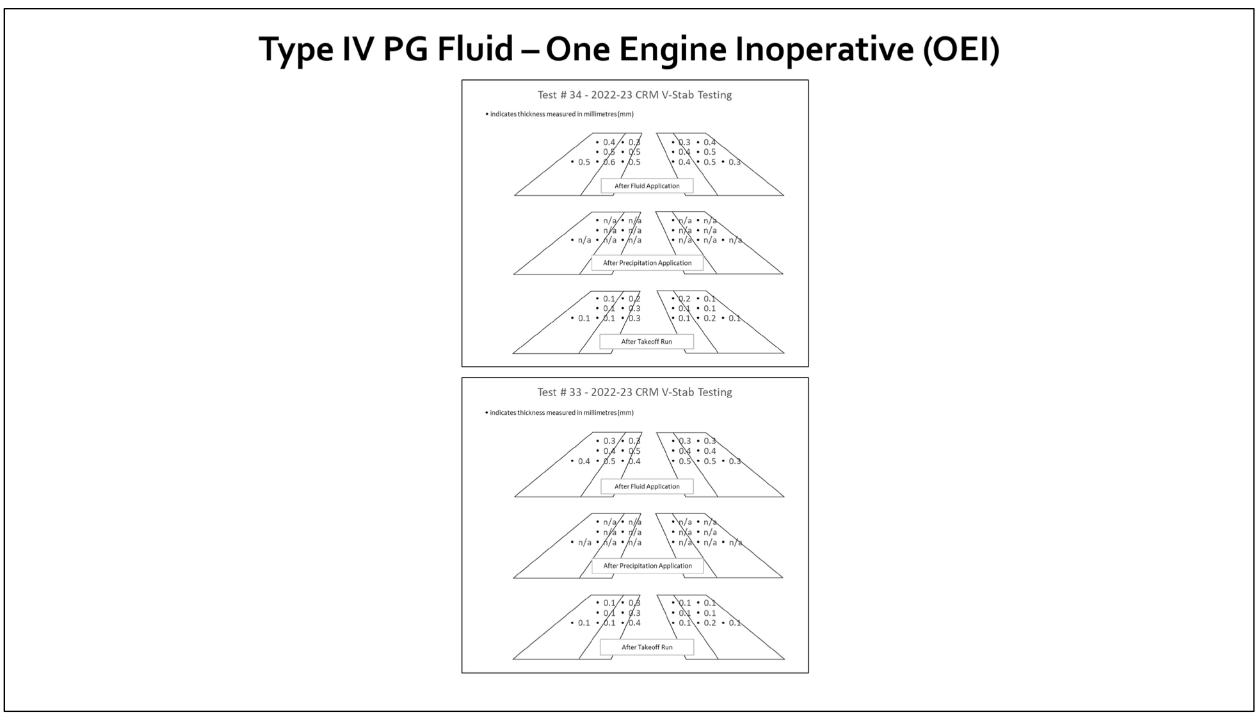

Figure 12: Thickness Data: Type IV PG Fluid – OEI

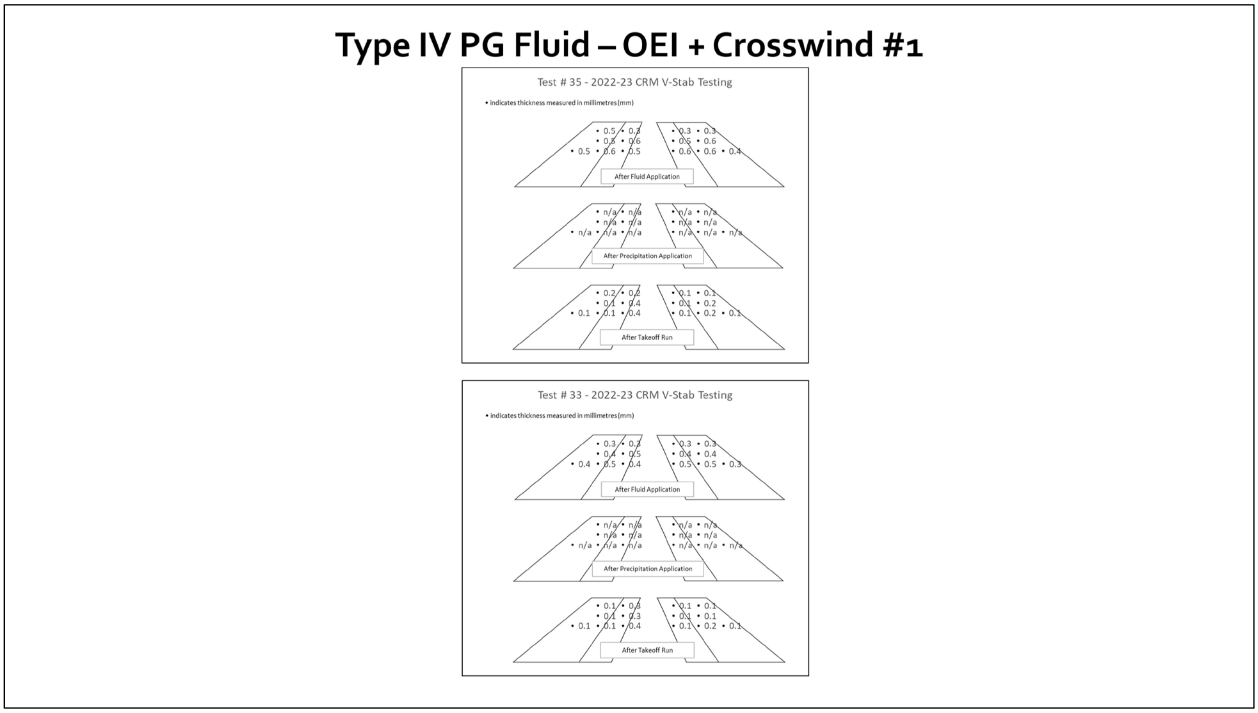

Figure 13: Thickness Data: Type IV PG Fluid – OEI + Crosswind #1

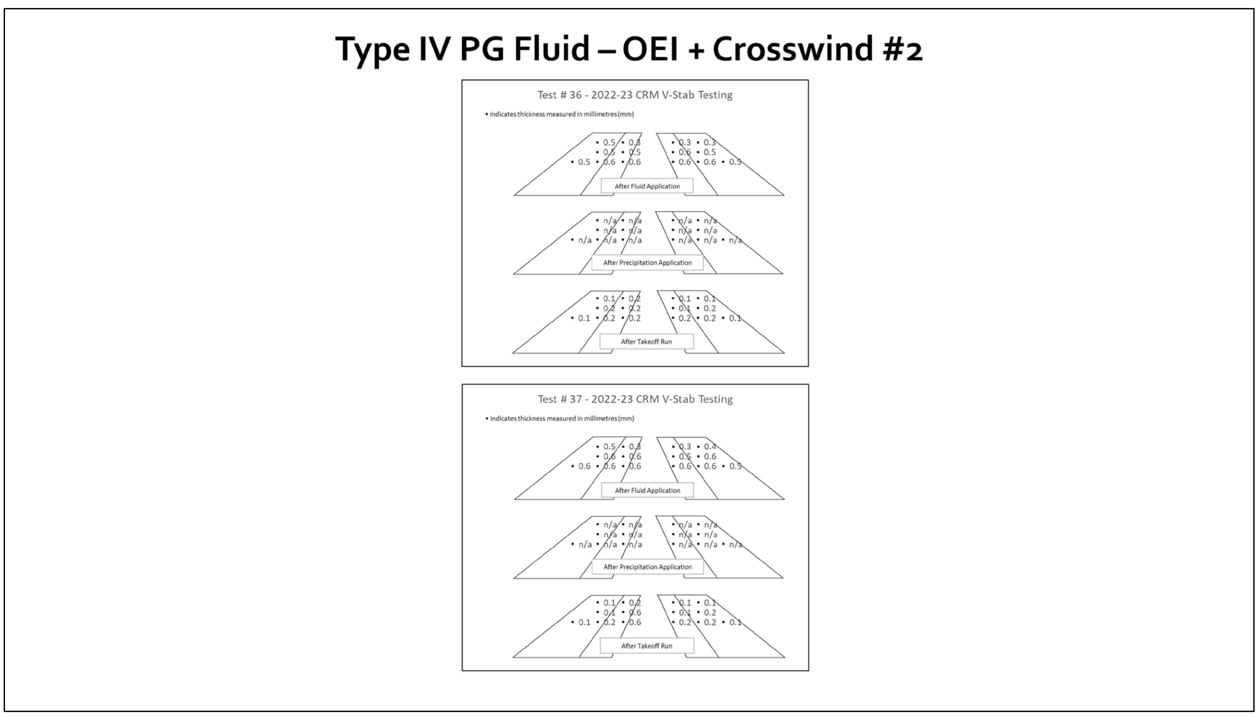

Figure 14: Thickness Data: Type IV PG Fluid – OEI + Crosswind #2

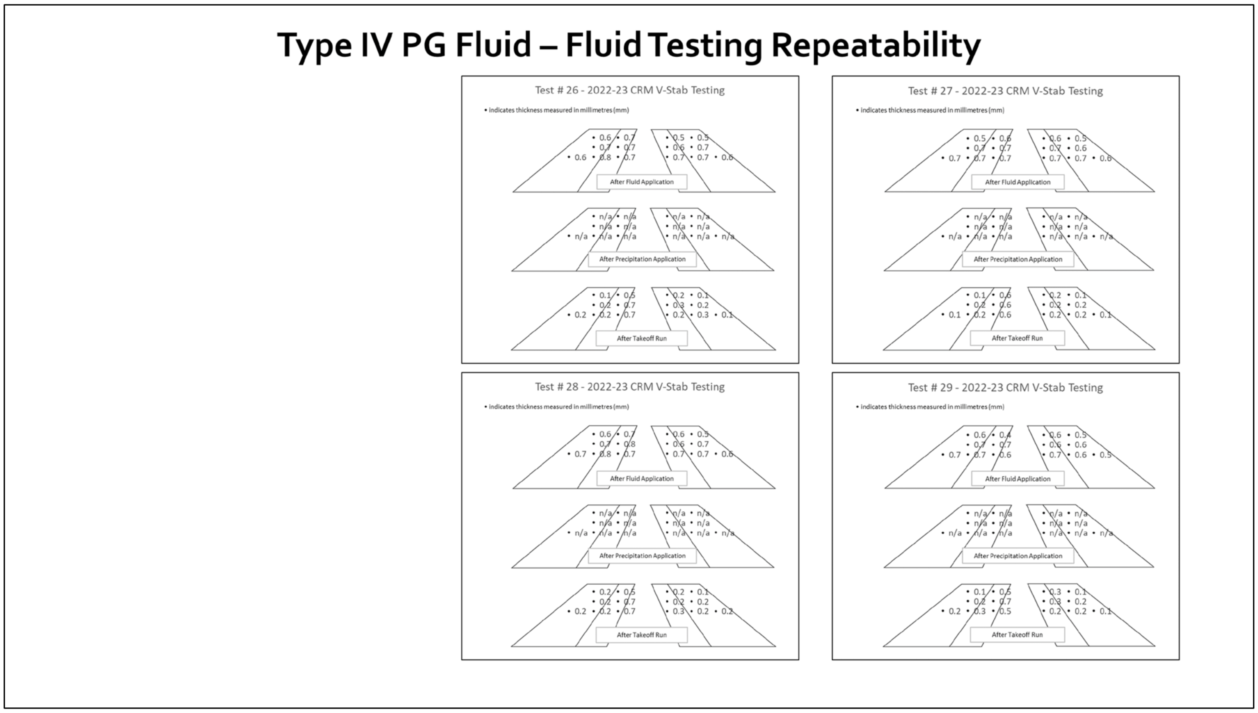

Figure 15: Thickness Data: Type IV PG Fluid – Fluid Testing Repeatability

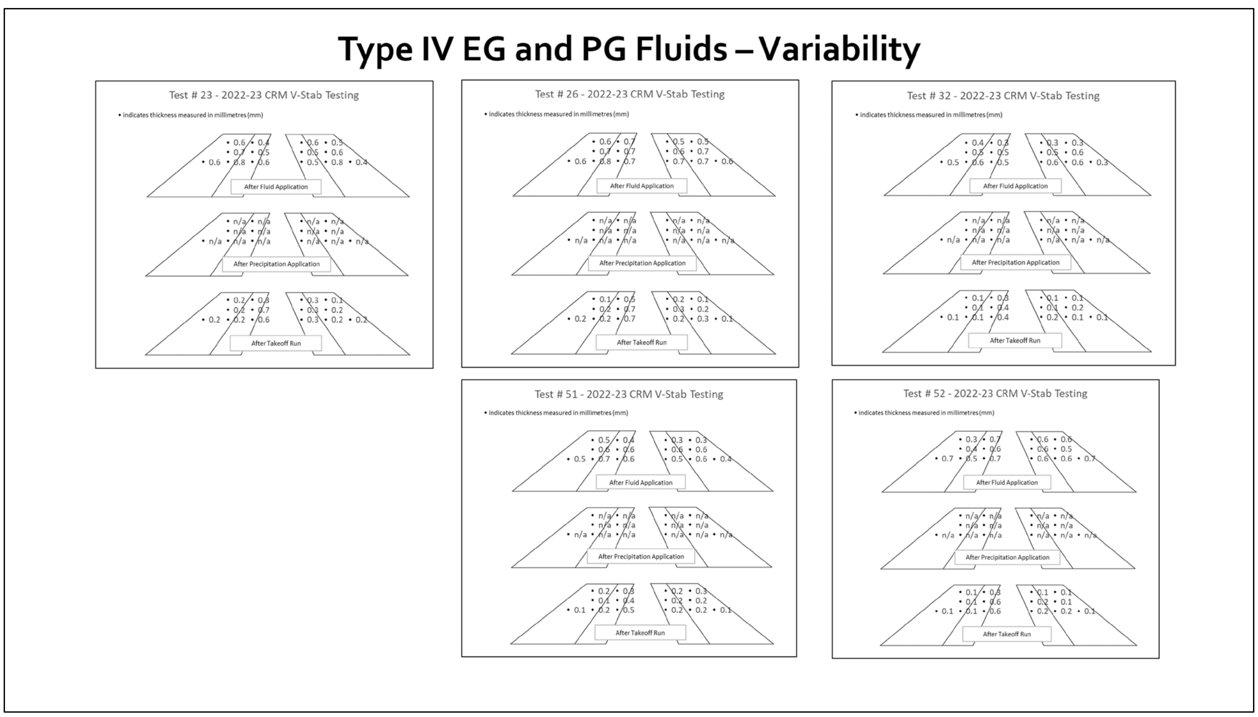

Figure 16: Thickness Data: Type IV EG and PG Fluids – Variability

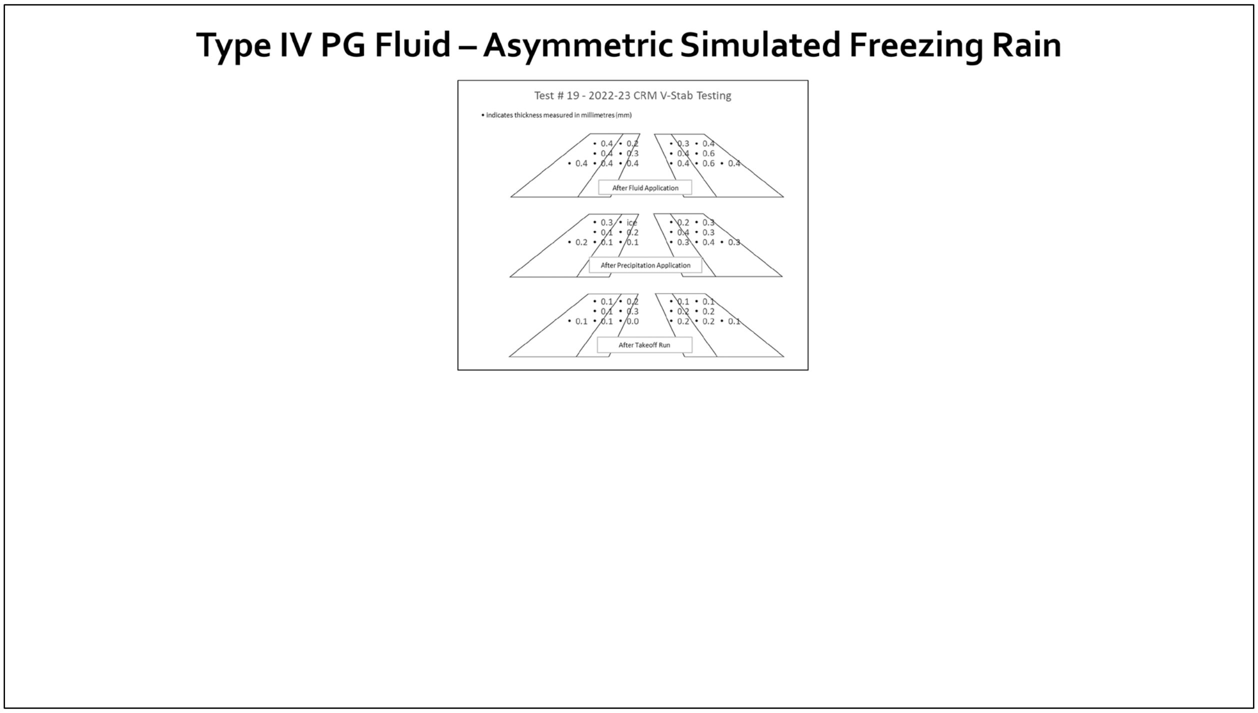

Figure 17: Thickness Data: Type IV PG Fluid – Asymmetric Simulated Freezing Rain

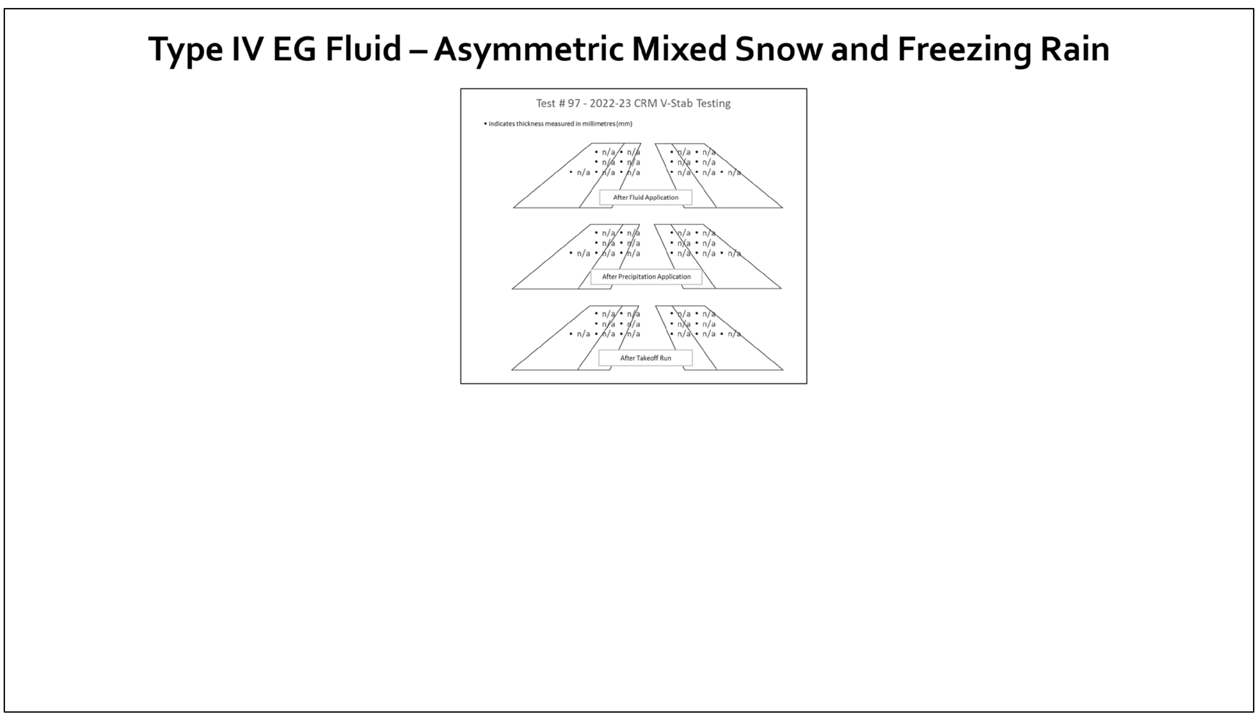

Figure 18: Thickness Data: Type IV EG Fluid – Asymmetric Mixed Snow and Freezing Rain

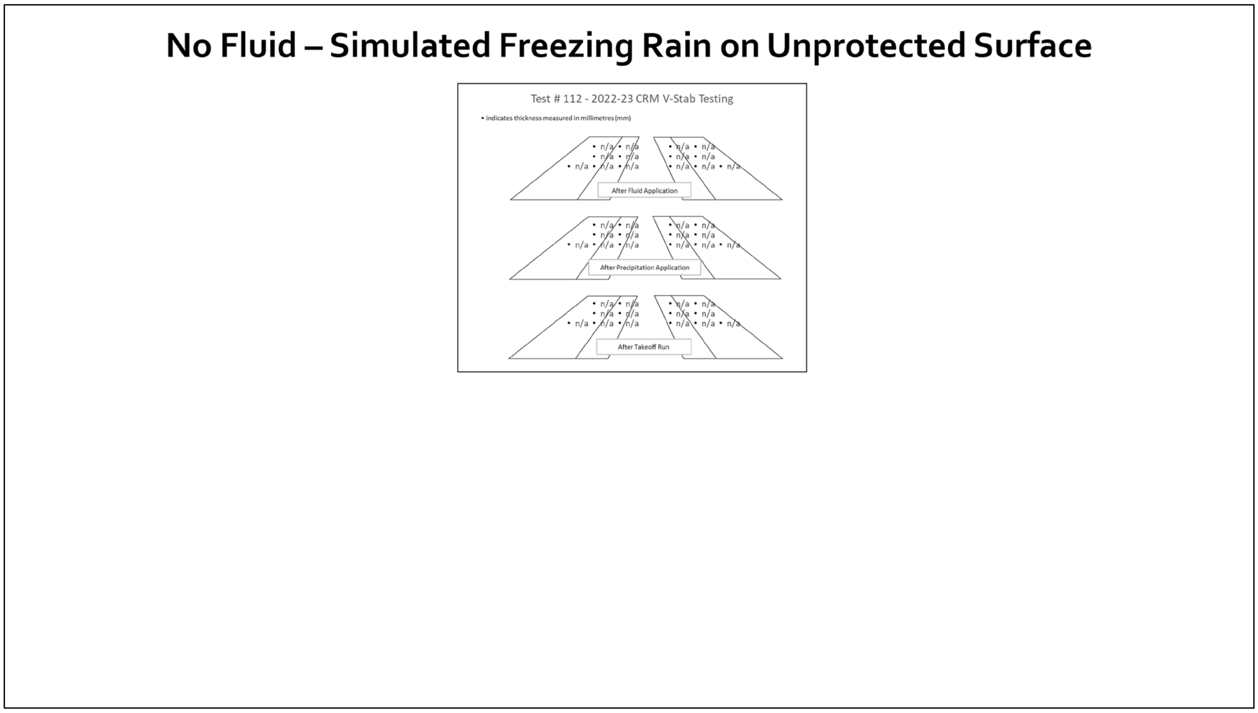

Figure 19: Thickness Data: No Fluid – Simulated Freezing Rain on Unprotected Surface

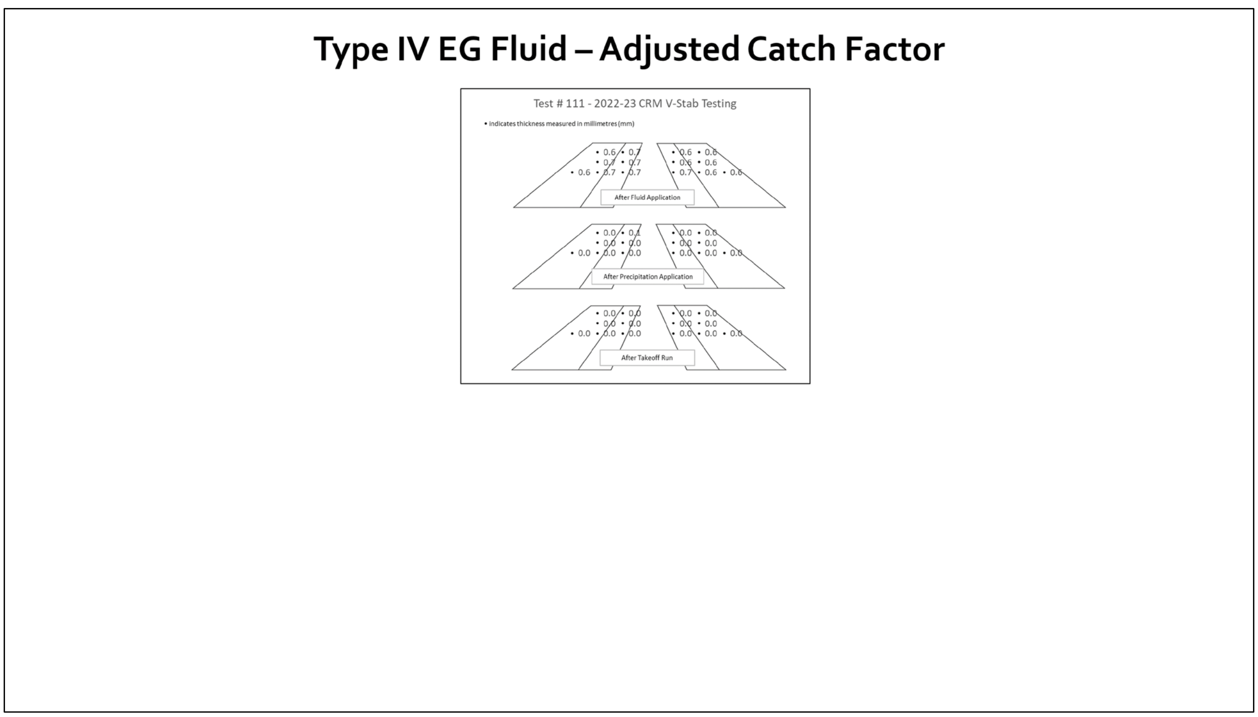

Figure 20: Thickness Data: Type IV EG Fluid – Adjusted Catch Factor

Type IV PG Fluid – Sealed Gap Effect

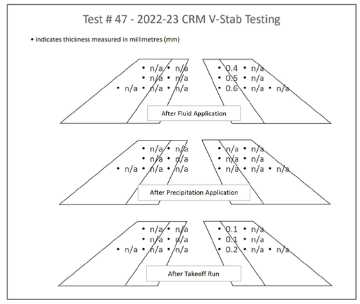

Figure 21: Thickness Data: Type IV PG Fluid – Sealed Gap Effect

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APPENDIX E

CATCH FACTOR ANALYSIS IN SNOW, FREEZING RAIN, AND FREEZING DRIZZLE

0301351

CATCH FACTOR ANALYSIS IN SNOW, FREEZING RAIN, AND FREEZING DRIZZLE

Winter 2022-23

Prepared for:

Transport Canada
Programs Group 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: Benjamin Bernier

Reviewed by: Marco Ruggi

APS Aviation Inc.

November 16, 2023
Final Version 1.0

CATCH FACTOR ANALYSIS IN SNOW, FREEZING RAIN, AND FREEZING DRIZZLE

Introduction and Data Sources

The angle at which precipitation falls is dependent on both the terminal velocity of the falling particle as well as the wind speed at the time of precipitation. As wind speeds change, the precipitation rate experienced by a surface will change depending on the angle of the surface to the wind vector and terminal velocity of the precipitate.

Precipitation rate limits (as used in HOT development) are based on a standard 12″x20″ test plate oriented at 10° into the wind. The vertical stabilizer testing conducted in 2022-23 utilizes a model where the critical surface is oriented at near 90°and does not incorporate wind speed.

The precipitation rates used for most of the vertical stabilizer test runs to date were based upon the standard rates used in HOT development (which were developed for a 10° plate). It was recognized during the testing session that consideration should be given to high wind conditions, where a static vertical surface may experience a greater effective precipitation rate due to the higher angle of the surface as compared to a 10° plate.

This analysis was completed to determine the potential impacts of different wind speeds on the effective catch factor of a 90° vertical surface. This information is intended to determine whether the precipitation rate limits used in the vertical stabilizer testing are sufficiently conservative, or if different rate limits should be considered for future evaluation. Separate analyses were performed for snow, freezing rain, and freezing drizzle (as the terminal velocity for each precipitation type differs).

The terminal velocity value used in the calculations for snow was obtained from the following source:

- https://www.jstor.org/stable/26172765

The terminal velocity values used in the calculations for freezing rain and freezing drizzle were obtained from the following source:

- http://www.atmosedu.com/meteor/TerminalVelocity.htm

Vertical Surface Catch Factor for Snow

The effective rate experienced by a vertical surface (90°) vs. a standard test surface (10°) at a specific angle of precipitation can be determined by calculating and comparing the surface "mouth" – the length of the span within which all falling precipitation will impact the surface.

Examples of this calculation at a snowfall angle of 40° are shown below in Figure 1 and Figure 2 for a 10° surface and a 90° surface, respectively.

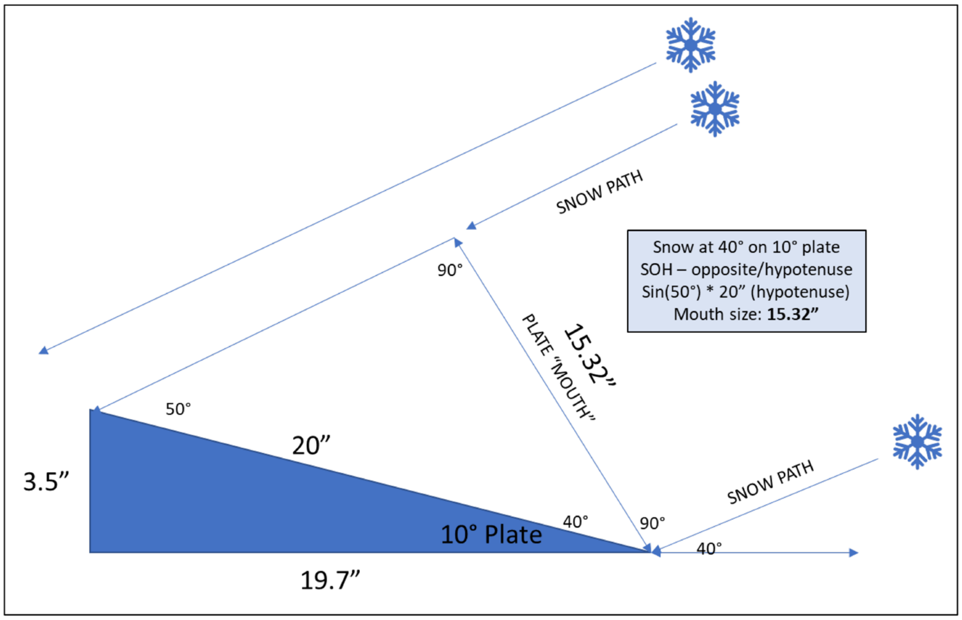

Figure 1: 10° Plate Mouth Size Calculation at Snowfall Angle of 40°

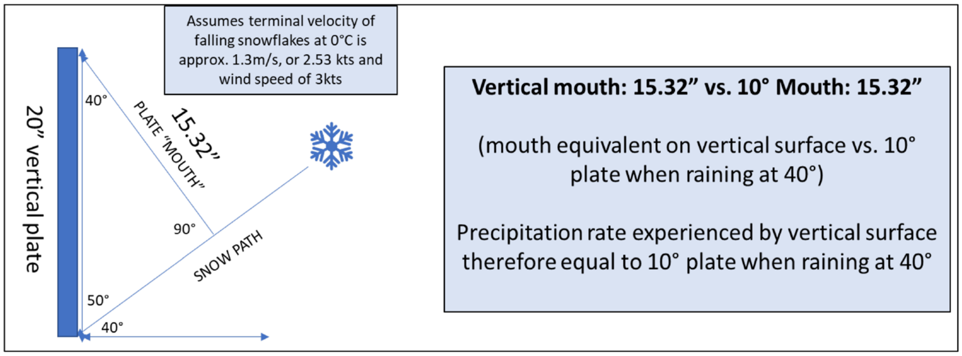

Figure 2: 90° Plate Mouth Size Calculation at Snowfall Angle of 40°

For this snowfall angle, the "mouth" size is the same for the vertical and 10° surface, therefore the effective precipitation rate experienced is also equivalent. At any other snowfall angle, the mouth sizes will not be equivalent and one surface will experience a greater rate than the other (equivalent to the ratio between their determined mouth sizes).

The calculation to determine the wind speed required to produce a specific angle of precipitation in snow is as follows:

$$\text{Wind Speed Needed to Produce Desired Angle} = \frac{\text{Terminal Velocity of Snowfall}}{\text{Tan(Angle of Precipitation)}}$$

The terminal velocity of snowfall at 0°C is approximately 1.3 m/s (or 2.53 knots). To produce a snowfall angle of 40°, the necessary wind speed is therefore:

$$2.53 \text{ knots} / \tan(40°) = 3.0 \text{ knots}$$

At wind speeds less than 3.0 knots (and snowfall angles of greater than 40°), the 10° plate would experience a greater effective precipitation rate than the 90° plate. At wind speeds greater than 3.0 knots (and snowfall angles of less than 40°), the 90° plate would experience a greater effective precipitation rate than the 10° plate.

Table 1 demonstrates the snowfall angle and effective precipitation rates experienced by various surfaces (10° rate pan, static 90° surface, and rotating 90° surface) in snow conditions at several different wind speeds. The precipitation rate for the rotating 90° surface was determined by halving the rate of the static 90° surface (assuming that the surface would spend half the time oriented into the wind, and half the time shielded from the wind).

Table 1: Effective Snow Precipitation Rate on Surfaces as a Function of Wind Speed and Surface Angle

Wind Speed (kts)	Snowfall Angle (°)	10° Rate Pan Rate (g/dm²/h)	Static Vertical Surface Rate – Static Asymmetric (g/dm²/h)	Rotating Vertical Surface Rate – Dynamic Symmetric (g/dm²/h)
0	90	25	0	0
3.0	40	25	25	12.5
7.7	18.3	25	50	25
32.9	4.4	25	100	50

Wind speeds of 32.9 knots (which is in the range of maximum crosswind typically allowed for takeoff for a commercial jet) would theoretically be sufficient to produce a snowfall angle of 4.4° to the ground, which would result in a static vertical surface experiencing an effective precipitation rate more four times greater than that experienced by a 10° surface in the same conditions.

Vertical Surface Catch Factor for Freezing Rain

The calculations for freezing rain differ from those in snow only in the fact that the terminal velocity of a rain droplet differs from that of a snow particle.

The terminal velocity of falling rain is approximately 3.92 m/s (or 7.6 knots). To produce a rainfall angle of 40° (equivalent effective rates for 10°/90° surfaces), the necessary wind speed is therefore:

$$7.6 \text{ knots} / \tan(40°) = 9.1 \text{ knots}$$

At wind speeds less than 9.1 knots (and rainfall angles of greater than 40°), the 10° plate would experience a greater effective precipitation rate than the 90° plate. At wind speeds greater than 9.1 knots (and rainfall angles of less than 40°), the 90° plate would experience a greater effective precipitation rate than the 10° plate.

Table 2 demonstrates the rainfall angle and effective precipitation rates experienced by various surfaces (10° rate pan, static 90° surface, and rotating 90° surface) in freezing rain conditions at several different wind speeds. The precipitation rate for the rotating 90° surface was determined by halving the rate of the static 90° surface (assuming that the surface would spend half the time oriented into the wind, and half the time shielded from the wind).

Table 2: Effective Rain Precipitation Rate on Surfaces as a Function of Wind Speed and Surface Angle

Wind Speed (kts)	Rainfall Angle (°)	10° Rate Pan Rate (g/dm²/h)	Static Vertical Surface Rate – Static Asymmetric (g/dm²/h)	Rotating Vertical Surface Rate – Dynamic Symmetric (g/dm²/h)
0	90	25	0	0
9.1	40	25	25	12.5
23.0	18.3	25	50	25
98.8	4.4	25	100	50

Wind speeds of 23.0 knots or greater (well within typical operational range for a commercial jet) would be theoretically sufficient to produce a rainfall angle of 18° to the ground, which would result in a static vertical surface experiencing an effective precipitation rate that is twice as great as that experienced by a 10° surface in the same conditions.

Vertical Surface Catch Factor for Freezing Drizzle

The calculations for freezing drizzle differ from the other conditions only in the different terminal velocity value for falling drizzle.

The terminal velocity of falling drizzle is approximately 1.22 m/s (or 2.36 knots). To produce a precipitation angle of 40° (equivalent effective rates for 10°/90° surfaces), the necessary wind speed is therefore:

$$2.36 \text{ knots} / \tan(40°) = 2.8 \text{ knots}$$

At wind speeds less than 2.8 knots (and precipitation angles of greater than 40°), the 10° plate would experience a greater effective precipitation rate than the 90° plate. At wind speeds greater than 2.8 knots (and precipitation angles of less than 40°), the 90° plate would experience a greater effective precipitation rate than the 10° plate.

Table 3 demonstrates the precipitation angle and effective precipitation rates experienced by various surfaces (10° rate pan, static 90° surface, and rotating 90° surface) in drizzle conditions at several different wind speeds. The precipitation rate for the rotating 90° surface was determined by halving the rate of the static 90° surface (assuming that the surface would spend half the time oriented into the wind, and half the time shielded from the wind).

Table 3: Effective Drizzle Precipitation Rate on Surfaces as a Function of Wind Speed and Surface Angle

Wind Speed (kts)	Precipitation Angle (°)	10° Rate Pan Rate (g/dm²/h)	Static Vertical Surface Rate – Static Asymmetric (g/dm²/h)	Rotating Vertical Surface Rate – Dynamic Symmetric (g/dm²/h)
0	90	25	0	0
2.8	40	25	25	12.5
7.1	18.3	25	50	25
30.7	4.4	25	103	51.5

Wind speeds of 30.7 knots (which are near the maximum crosswind typically experienced during takeoff for a commercial jet) would theoretically be sufficient to produce a snowfall angle of 4.4° to the ground, which would result in a static vertical surface experiencing an effective precipitation rate more four times greater than that experienced by a 10° surface in the same conditions.

Conclusions as Relating to the Test Methodology

The precipitation types used in the V-Stab testing in 2022-23 were freezing rain and snow. For the standard test runs, snow or rain was applied at a rate of 25 g/dm²/h on each side of the model. This equates to an effective precipitation rate of 50 g/dm²/h on the model, and incorporates the assumption that the aircraft would be rotating during taxi and that each side of the v-stab would see an equivalent amount of precipitation, and therefore the effective rate is halved for each side of the model.

The 10° plate holdover times used to set the exposure time (duration of precipitation) were based on rates of 25 g/dm²/h.

Based on the analysis calculations, if a 10° plate is seeing a snow rate of 25 g/dm²/h, a vertical surface in the same storm would see an overall rate greater than 50 g/dm²/h at wind speeds exceeding 7.7 knots if static, or an equivalent 25 g/dm²/h if constantly rotating. This suggests that the precipitation rates used for the snow test would be insufficiently conservative if the wind speed exceeds this limit.

If a 10° plate is seeing a freezing rain rate of 25 g/dm²/h, a vertical surface in the same storm would see an overall rate greater than 50 g/dm²/h at wind speeds exceeding 23 knots if static, or an equivalent 25 g/dm²/h if constantly rotating. This suggests that the precipitation rates used for the freezing rain test would be insufficiently conservative if the wind speed exceeds this limit.

With these figures in mind, consideration should be given to conducting future tests at higher rate limits (particularly important for future snow or drizzle tests).