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European Aviation Safety Agency

Report EASA.2013.2

Research Project:

DIFT

De-icing fluid wind tunnel testing

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AERODYNAMICS LABORATORY

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Final Report

Volume 1

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LTR-AL-2014-0122

09/03/2015

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

ABSTRACT

The European Aviation Safety Agency (EASA) contracted the National Research Council Canada (NRC) in November 2013 to perform de/anti-icing fluid wind tunnel testing on a full-scale 2D horizontal stabilizer model. The primary objective of the research program is to understand the effects of anti-icing fluids on the horizontal stabilizer performance and elevator hinge moments during take-off rotation. A secondary research objective involved adding ice to the leading edge and lower surface of the model to examine the impact of that ice on the horizontal stabilizer performance. The NRC subcontracted APS Aviation Inc. to help with the fluid selection, application, and data analysis. Transport Canada's Transportation Development Center (TDC) supported the design and construction of the model by contributing a model that belongs to TDC and matches the EASA model specifications.

The contract work (EASA.2013.C22) included the design and construction of a horizontal stabilizer model, the test plan development, execution of a 1-week research program at the NRC Propulsion and Icing Wind Tunnel (PIWT), and analysis and presentation of the results. This final report provides details on the project as broken down into the following tasks:

Task 1 – Literature review and analysis
Task 2 – Model design, construction and instrumentation
Task 3 – Test program development
Task 4 – Testing phase
Task 5 – Data reduction, analysis and reporting

The baseline dry model aerodynamic performance was established for hinge gap sizes of 2 mm, 4 mm and 8 mm. The runs with fluids were then compared to this baseline data to see if at least a 50% increase in hinge moment coefficient or 10% reduction in lift coefficient could be obtained. The test plan included multiple fluid types, dilutions and viscosities and tested multiple elevator deflection profiles.

The results of the test program show that the fluid viscosity is the main factor determining the impact of the fluid on the model aerodynamics. It was found that over the range of temperatures tested that the air and fluid temperatures had minimal influence on the results. Methods to rectify the rotation difficulties, including simulating downwash angles, adjusting the trim tab, using a two-step de-icing process, and varying the fluid application method, were found to produce minimal changes in the results. Suggestions for future research include the addition of freezing precipitation in the fluid (snow, freezing rain, ice pellets), testing at lower temperatures closer to the operating limits of the fluids, dry model flow characterization work and additional fluid viscosity testing.

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

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Symbols

A	Model planform surface area [m^2]
C_l	Lift Coefficient
C_d	Drag Coefficient
C_m	Pitching Moment Coefficient
C_h	Hinge Moment Coefficient
c	Chord [m]
D	Drag [N]
h	Test Section Height [m]
H	Hinge Moment [Nm]
L	Lift [N]
M	Mach Number
q	Dynamic Pressure [Pa]
P_S	Static Pressure [Pa]
P_T	Total Pressure [Pa]
ΔP_c	Contraction pressure differential [Pa]
PM	Pitching Moment [Nm]
t	Time [s]
T	Temperature [K]
V	True Airspeed [kts]
V_R	Rotation Speed [kts]
V_1	Take-off Decision Speed [kts]
V_{max}	Maximum Speed during Take-off Run [kts]

Subscripts

HS	Horizontal Stabilizer
E	Elevator
TT	Trim Tab
TS	Test Section
u	Uncorrected
c	Corrected for Aerodynamic Blockage

Greek Letters

α	Angle of Attack (degrees)
δ	Deflection Angle (degrees)
ε_{WB}	Wake Blockage Correction
ε_{SB}	Solid Blockage Correction
ρ	Air Density [g/m^3]
σ	Streamline Curvature Correction

Acronyms

AIR	Aerospace Information Report
CADORS	Civil Aviation Daily Occurrence Reporting System
DFS	Design and Fabrication Services
DIFT	De-Icing Fluid Tests
DPT	Dew Point Temperature
FDR	Flight Data Recorder
EASA	European Aviation Safety Agency
IAS	Indicated Air Speed
N/A	Not Available
NRC	National Research Council Canada
OAT	Outdoor Air Temperature
PIWT	Propulsion and Icing Wind Tunnel
RTD	Resistance Temperature Detectors
SAE	Society of Automotive Engineers
SHK	Swedish Accident Investigation Board
TAS	True Airspeed
TC	Transport Canada
TDC	Transportation Development Centre
TSB	Transportation Safety Board
UK AAIB	United Kingdom Air Accidents Investigation Branch
WAT	Wing Area Temperature

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

1.0 Introduction

In the summer of 2013, the European Aviation Safety Agency (EASA) requested proposals for a research project investigating the contributing factors in incidents where aircraft have had difficulty rotating during take-off after the application of de/anti-icing fluids on the horizontal stabilizer.

The National Research Council Canada (NRC) Aerodynamics Laboratory was awarded the contract (EASA.2013.C22) and led the project, with the research program performed at the NRC Propulsion and Icing Wind Tunnel (PIWT). The NRC sub-contracted APS Aviation Inc. to provide their expertise in the development and execution of the research program. Transport Canada's Transportation Development Centre (TDC) provided a horizontal stabilizer model that matched the EASA model specifications, and the EASA program budget allowed for one (1) week of testing at the NRC PIWT. (NRC, 2013)

The main objective of this research program is to understand the effects of anti-icing fluids on the horizontal stabilizer during take-off and rotation in icing conditions. This objective is achieved by conducting a series of tests with a model of a horizontal stabilizer section. The model is anti-iced with Type II or IV fluid, and the fluid flow-off effects are observed and evaluated quantitatively using the elevator hinge moment and horizontal stabilizer downward lift force. A secondary objective is to assess the effects of ice accumulation underneath the horizontal stabilizer, downstream and in the vicinity of the stagnation point.

APS Aviation provided a separate report to the NRC detailing their work on this project including details on the fluid measurement methods, quantities of fluids used, and the fluid thickness and brix measurements for each run (Ruggi, 2015). The data from the APS report is summarized where applicable in this document.

2.0 Project Overview

2.1 Participants

National Research Council Canada

The NRC is leading the EASA DIFT project as the main contractor and is responsible for the project. The NRC has been working with TDC on ground de-icing research since 2006 on a NACA 23012 airfoil section, and during each of the last five (5) winters on the aerodynamic evaluation of de-icing and anti-icing fluid flow-off from a wing section representative of modern commercial aircraft. The results from these studies have been presented to the SAE G12 Aerodynamic Working Group and Holdover Time Committee on multiple occasions; further details can be found in conference papers AIAA-2011-1101 (Clark & McMaster, 2011), AIAA-2012-2799 (Clark & McMaster, 2012) and AIAA 2013-2933 (Broeren, Lee, & Clark, 2013).

Project Manager:	Catherine Clark, M.A.Sc., P.Eng.
Position:	Research Officer, Aviation Aerodynamics Group
Relevant Experience:	Project manager for 2010/11-2013/14 TDC icing research program Test engineer for 2009/10 TDC icing research program

APS Aviation Inc.

APS Aviation was sub-contracted by the NRC to provide their expertise in the development and execution of the research program. Their responsibilities include helping the NRC develop the test plan, selection and acquisition of appropriate de/anti-icing fluids, application and measurement of the fluids during the test, and post-test analysis of the data. APS has been a leader in de-icing research and development since the early 1990s in this area in association with Transport Canada and the Federal Aviation Administration.

Project Manager:	Marco Ruggi, Eng. M.B.A.
Position:	Project Manager
Relevant Experience:	Project manager for 2006-2014 TDC icing research program

Transport Canada, Transportation Development Center

The Transportation Development Center (TDC) of Transport Canada contributed to the project by providing the horizontal stabilizer model.

Project Managers:	Yvan Chabot / Antoine Lacroix
Position:	Research Development Officer

2.2 Tasks and Milestones

The main tasks for this project are outlined in Table 1 and the body of this report follows these tasks.

Table 1 Task Breakdown and Schedule

Task	Start Date	End Date
T1. Literature review and analysis	November 2013	January 2014
T2. Model design, construction and instrumentation	December 2013	October 2014
T3. Development of test program and procedure	May 2014	November 2014
T4. Testing phase	15 Dec. 2014	20 Dec. 2014
T5. Data reduction, analysis and reporting	January 2015	February 2015

The project progress can also be tracked in terms of milestones, as shown in Table 2. The dates the milestones were completed indicate the project closely followed the original schedule.

Table 2 Milestone Breakdown and Schedule

Milestone	Target Date	Completed
M1. Contract signed	T_o	21 Nov. 2013
M2. General project meeting	T_o + 1 month (Dec. 2013)	28 Nov. 2013
M3. First progress review meeting	T_o + 2 months (Jan. 2014)	23 Jan. 2014
M4. Model geometry approval	T_o + 2 months (Jan. 2014)	10 Feb. 2014
M5. Delivery of interim report	T_o + 10 months (Sept. 2014)	17 Oct. 2014
M6. Second progress review meeting	T_o + 12 months (Nov. 2014)	5 Nov. 2014
M7. Presentation of project to SAE G12 AWG	Oct. 2013, April 2014, Oct. 2014	Oct. 2013, April 2014, Oct. 2014
M8. Completion of research program	T_o + 13 months (Dec. 2014)	20 Dec. 2014
M9. Delivery of final report	T_o + 15 months (Feb. 2015)	February 2015
M10. Presentation of results to EASA	-	23 March 2015

3.0 Task 1 – Literature Review and Analysis

This literature review includes a summary of the Swedish Accident Investigation Board (SHK) study that prompted the current research program, a summary of similar incidents that have occurred, the type of aircraft that seem to be susceptible to these incidents, and what preliminary investigations into these incidents revealed as contributing factors. The information in this literature review is used to select the appropriate model geometry and develop test plans that are intended to reproduce the rotation difficulties in the wind tunnel.

3.1 Swedish Accident Investigation Board RL 2011:16e Report Summary

On 11 January 2010 at Helsinki/Vantaa Airport in Finland, a BAe ATP cargo aircraft (SE-MAP) was scheduled to fly from Helsinki to Copenhagen. Due to prevailing snowfall and an outdoor air temperature of -12°C, the aircraft underwent a two-step de-icing/anti-icing process to remove existing ice, frost and snow and prevent ice from re-forming on critical aircraft surfaces. Once the de-icing/anti-icing process was completed, the aircraft taxied to position on the runway and the flight crew verified full response of all flight controls. The first part of the take-off roll was normal, but when the rotation speed (V_R) was reached the pilot noticed excessive forces were required to pull back the control column. The pilot continued to pull the control column as far back as possible with no aircraft response, at which point the take-off was aborted and the aircraft taxied back to the hanger. (Swedish Accident Investigation Board, 2011)

The SHK report also identifies a serious incident of a similar nature that occurred on 30 November 2009 with an ATP aircraft (SE-LLO) at Arvidsjaur Airport in Sweden. The aircraft in this incident was de-iced with Type I and anti-iced with Type IV fluids prior to departure in heavy snow conditions. During taxi all flight controls checked out as operating normally. During take-off the aircraft did not respond when the co-pilot pulled back on the control column. The captain took control and pulled back the throttles to abort take-off while the aircraft speed was estimated to be 10-15 kts above take-off decision speed (V_1). At this point the ‘standby controls’ warning indicator was activated and the aircraft lifted off the runway. The captain set full power again to keep airborne, reviewed their emergency checklist once a safe altitude was reached, and continued the flight to its destination without incident.

Further incidents involving the BAe ATP aircraft were identified that were similar in nature to the SE-MAP and SE-LLO incidents described above, but not serious enough to warrant their own investigation. These incidents are listed in Table 3. All de-icing/anti-icing fluids in these incidents were neat fluids (not diluted with water).

Table 3 BAe ATP Incident List

Date	Aircraft	Airport	Fluid Type	Known or Assumed Fluid	OAT/DPT
25 Jan 2007	SE-LPV	BGO (Bergen)	I + II	N/A	N/A
30 Nov 2009	SE-LLO	AJR (Arvidsjaurt)	I + II	Clariant Safewing MP II Flight*	N/A
10 Dec 2009	SE-MAP	CPH (Copenhagen)	I + IV	N/A	N/A
22 Dec 2009	SE-MAP	HEL (Helsinki)	I + IV	Clariant Safewing MP IV Launch** (assumed)	N/A
23 Dec 2009	SE-LLO	AJR (Arvidsjaurt)	I + II	Clariant Safewing MP II Flight*	-16°C/-18°C
11 Jan 2010	SE-MAP	HEL (Helsinki)	I + IV	Clariant Safewing MP IV Launch**	-2°C/-4°C
18 Mar 2010	SE-LLO	HMV (Hemavan)	I + II	Kilfrost ABC-2000***	-6°C/-7°C
20 Oct 2010	SE-MAL	AJR (Arvidsjaurt)	N/A	N/A	N/A

*Lowest on-wing viscosity using AIR 9968 Rev. A method from 2009/2010 winter HOT tables was 3,340 mPa-s.
** Lowest on-wing viscosity using AIR 9968 Rev. A method from 2009/2010 winter HOT tables was 7,550 mPa-s.
***Lowest on-wing viscosity using AIR 9968 Rev. A method from 2009/2010 winter HOT tables was 2,350 mPa-s.

3.2 Incidents of Elevator Control Restriction at Take-off

A review of databases from North American and European regulatory agencies revealed other reported incidents where the pilot experienced similar difficulty rotating the aircraft during take-off. The examples summarized below relate specifically to incidents that may have been caused by the de/anti-icing fluid interacting with the elevator. Many other reports regarding rotation difficulties were found, but often the reports did not provide enough information to determine if the incident was caused by anti-icing fluid that was applied prior to take-off. As well, examples of frozen spring-tabs and re-hydrated fluid causing problems have been found, but are not within the scope of the current research program.

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EXAMPLE #1
Date: 30 December 2004
Aircraft: de Havilland DHC-8-202, N345PH
Location: Kelowna, British Columbia, Canada
Source: CADORS report 2005P0001
Fluid: Type I+IV, type unknown
OAT/DPT: -2°C, N/A

The aircraft was de-iced with Type I and anti-iced with Type IV fluids prior to departure with an outdoor air temperature of -2ºC and unknown precipitation. During take-off rotation there was no response to back pressure on the controls and the flight crew aborted take-off at 115kts IAS. Upon returning to the gate for inspection it was noted that Type IV fluid had accumulated along the leading edge and at various locations on the elevator surface. The operator reported that they had experienced this occurrence on similar aircraft.

EXAMPLE #2
Date: 28 November 2005
Aircraft: Dornier 328-110, D-CPRW
Location: Isle of Man (Ronaldsway) Airport, United Kingdom
Source: UK AAIB Bulletin: 10/2006
Fluid: Type II (75/25), type unknown (assume Kilfrost ABC-II Plus*)
*Lowest on-wing viscosity using AIR 9968 from 2005/2006 winter HOT tables was 3,600 mPa-s.
OAT/DPT: 4°C, -4°C

The aircraft was de-iced and anti-iced using a heated mixture of Type II fluid and water. All pre-start and taxi checks of the control systems performed normally prior to take-off. At the calculated rotation speed, the commander pulled back on the control column; when the aircraft did not appear to rotate in response to the control input, the commander abandoned the takeoff and brought the aircraft to a stop. The rotation speed used by the crew was 109 kts, while the recommended speed in icing conditions was 128 kts. As well, the aircraft elevator was de-iced from trailing edge towards leading edge, instead of from leading edge to trailing edge as recommended.

EXAMPLE #3
Date: 17 January 2005
Aircraft: de Havilland DHC-8-202, N353PH
Location: Pasco, Washington, U.S.A.
Source: FAA Service Difficulty Report QXEA200500109
Fluid: Type III, 100/0 dilution, type unknown (assume Clariant 2031)
OAT/DPT: N/A, N/A

The aircraft was anti-iced with Type III fluid prior to take-off. During initial rotation, the first officer noted higher than normal back pressure on the control column and slower than normal rotation time. Functional checks of the elevator system, elevator trim, and elevator control system post-flight all passed and the aircraft was returned to service.

3.3 Commonalities between Incidents of Elevator Control Restriction at Take-off

As identified in the SHK report, the following elements were found to be common to all incidents: (Swedish Accident Investigation Board, 2011)

- All aircraft had been de-iced in preparation for flight using anti-icing fluid
- All incidents took place during winter conditions
- Aircraft weight and balance were within acceptable limits
- No technical/mechanical faults could be identified in the aircraft
- Full elevator travel had been confirmed in rudder checks before and after incidents
- Problems arose at speeds around V_R
- Elevator movement was restricted and/or felt very stiff to maneuver in connection with takeoff rotation
- Incidents were often accompanied by 'Standby Controls' and/or 'Split' warnings

The aircraft identified in the SHK report and in Section 3.2 are turboprop aircraft with unpowered flight controls. It is believed that the low-rotation speed associated with turboprop aircraft may have contributed to the rotation difficulties reported. Unpowered flight controls allow the pilots to feel the elevator motion restriction and therefore report the event. Aircraft with powered flight controls may or may not suffer from similar elevator restrictions or reductions in elevator performance, but these effects would not necessarily be observed by the pilots.

3.4 Preliminary Research into Contributing Factors

As outlined in report RL 2011:16, the SHK in cooperation with West Air Sweden completed a series of tests designed to recreate and document the rotation difficulties under controlled conditions. After completing detailed checks on the horizontal stabilizer and elevator construction of an ATP aircraft involved in an incident (SE-MAP), they found that the average gap between the horizontal stabilizer main element and the elevator was 2.0 mm for the left elevator and 2.0 mm for the right elevator. For another aircraft which had experience a similar incident (SE-LLO), the average clearance was 2.4 mm for the left elevator and 3.9 mm for the right elevator. The BAe ATP tolerance for the elevator hinge gap is between 2.5 mm (minimum) and 5.0 mm (maximum). In light of these results, SHK completed high-speed taxi tests aiming to reproduce the event in a documented and controlled fashion. The results of these tests are shown in Table 4.

Table 4 Full-Scale High-Speed Taxi Test Results

Test Series	Aircraft	Average Elevator Gap Clearance		Fluid Type	Elevator Controls
		Left	Right		
1	SE-MAP	2.0 mm	2.0 mm	IV	Heavy
1	SE-MAP	2.0 mm	2.0 mm	I	Normal
2	SE-MAP	2.0 mm	2.0 mm	I + II	Heavy
2	SE-LPU	3.5 mm	3.6 mm	IV	Normal
3	SE-MAP (elevators replaced)	3.4 mm	2.4 mm	IV	Normal

The results suggest a connection between too small an elevator hinge gap and elevator restrictions at rotation, in situations where de-icing had been carried out using fluids containing thickening agents (typically Type II, III and IV fluids).

In addition to the SHK research program, BAe conducted their own series of aircraft checks and hired a de-icing expert to investigate this problem (BAe Systems, 2010). They came to the conclusion that the problem was likely caused by some property of the de-icing fluids used, especially if the viscosity of the fluid is higher than usual. In response, SHK collected and analyzed fluids from two airports in Sweden found that the samples did not deviate from the fluid specifications.

The SHK study concluded that the following factors may have contributed to the elevator restriction incidents on take-off:

- Residual de-icing fluid of Type II or IV
- Average elevator clearance below permitted minimum for aircraft type
- Unknown impact of propeller slipstream
- Remnant of fluid in the hinge gap, where the polymers probably have not been fully affected by the airflow's shear forces
- Altered or restricted flow of air through the gap
- Altered aerodynamic pressure conditions around horizontal stabilizer

The research program conducted by the NRC attempts to evaluate the effects of the above factors on the performance of the horizontal stabilizer in the week allocated for testing, with the exception of the propeller slipstream.

4.0 Task 2 – Horizontal Stabilizer Model Design and Manufacturing

4.1 Geometries of Aircraft Experiencing Elevator Control Restriction at Take-off

The aircraft identified in the previous section are the BAe ATP, the deHavilland DHC-8, and the Dornier 328-110. The characteristics of these aircraft are outlined in Table 5.

Table 5 Aircraft Geometries

	BAe ATP	**deHavilland DHC-8 100/200 series**	**Dornier 328-110**
Engines	Twin-engine, turboprop	Twin-engine, turboprop	Twin-engine, turboprop
Size	72 passengers or 8 tonnes of cargo	37-39 passengers	30-33 passengers
Horizontal Stabilizer	Fuselage mounted, in line with engines	T-tail	T-tail
Horz. Stab. Chord	48 in. (1.22 m) at tip 106 in. (2.69m) at root	62 in. (1.57 m) at tip 86 in. (2.18 m) at root	Not available
Elevator to horizontal stabilizer chord ratio	0.414 (mean)	0.47 (mean)	Not available
Trim tab to horizontal stabilizer chord ratio	0.15 (mean)	0.12 (mean)	Not available

These aircraft have all been approved for winter operations using de/anti-icing fluids. The BAe ATP maintenance manual states that operators should be aware that when using Type II or Type IV ground de/anti-icing fluid no performance adjustments are necessary, although higher stick forces than normal may be expected at rotation.

4.2 Horizontal Stabilizer Profile

The geometry of the model for this research program was selected based on the information from the literature review, the proposed criteria in the EASA tender specification (EASA, 2013), and the generous co-operation of Bombardier and BAe in supplying information on the tail geometries of their aircraft. This model does not match any existing aircraft tail geometry exactly, but it is similar to those mentioned in the previous section in terms of size, profile and non-dimensional parameters.

The model profile was presented to EASA during the first progress review meeting in January 2014 and the geometry was frozen with EASA approval in February 2014. The agreed-upon model geometry has the following characteristics, as shown in Figure 1.

- NACA 0015 profile
- c_{HS} = 1.82 m (6 ft), c_E/c_{HS} = 0.4, c_{TT}/c_{HS} = 0.05
- Elevator pivot point at 0.3 c_E measured from the elevator leading edge
- Circular profiles on main element trailing edge, elevator trailing edge, and trim tab leading edge
- Elliptical leading edge profile on elevator (a = 0.100, b = 0.045)

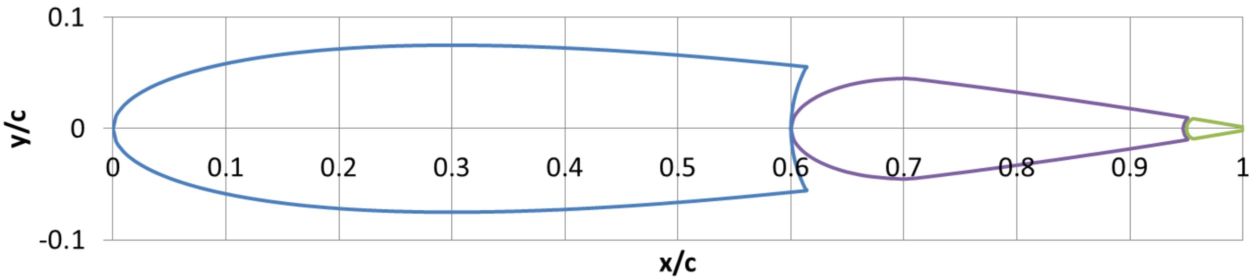


Figure 1 Horizontal Stabilizer Model NACA 0015 Profile

4.3 Horizontal Stabilizer Detailed Design

The model was designed by the NRC project engineer and NRC Design and Fabrication Services (DFS) staff. Located in Building M-4 at the NRC Montreal Road Campus in Ottawa, DFS provides design, engineering, fabrication and advisory services that support research and innovation across the NRC. Based on the information provided by the NRC project engineer, DFS staff created the detailed design of the model in ProE and performed a stress analysis to ensure it could support the estimated aerodynamic loads, including a safety factor. A screenshot of the complete ProE model with endplates is shown in Figure 2.

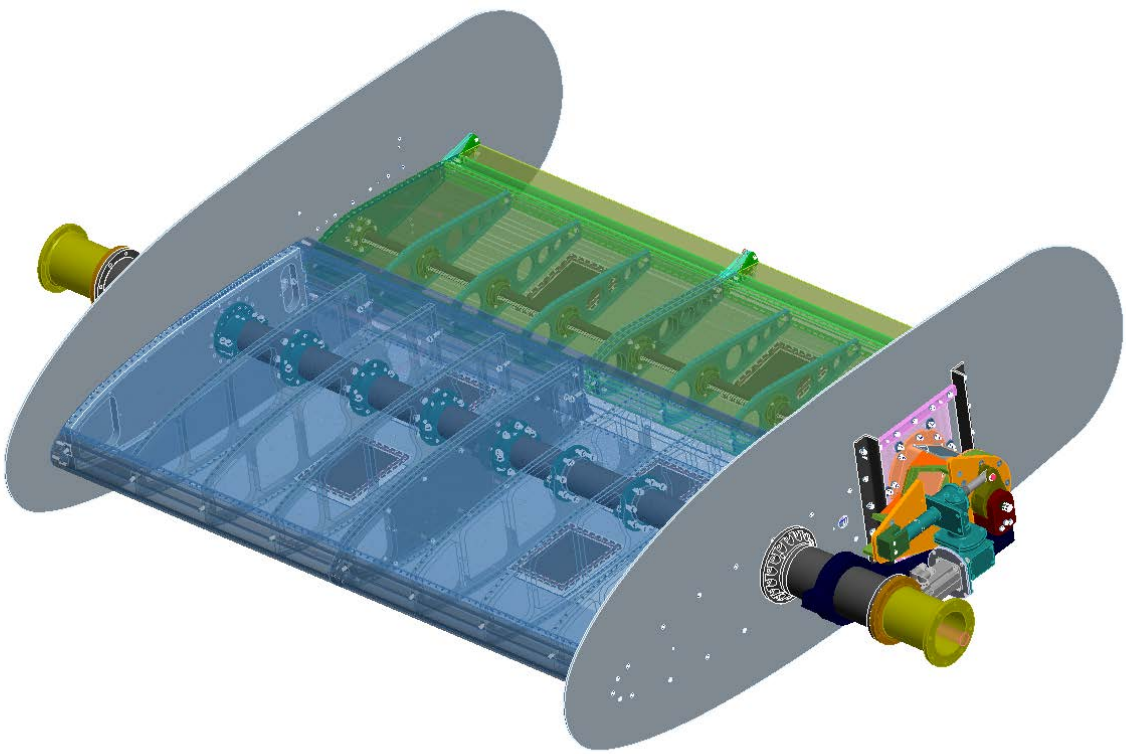


Figure 2 Horizontal Stabilizer Model in ProE

4.3.1 Main Element

The main element consists of a solid leading edge, aluminum ribs, and 2024 aluminum skin. The cut-outs in the ribs are used to minimize the overall weight. The skin is made from a single piece of aluminum on the upper and lower surfaces spanning the width of the model and is attached to the ribs using blind, flush-head 8740 alloy steel stem CherryMax aerospace rivets. The main element is designed to be mounted on the existing external wall-balances at the PIWT in order to measure the aerodynamic loads as well as rotate the model. A circular aluminum shaft runs along the span of the model, connecting the two balances. The main element pitch angle is $\alpha = 0°$ unless otherwise indicated in the test plan.

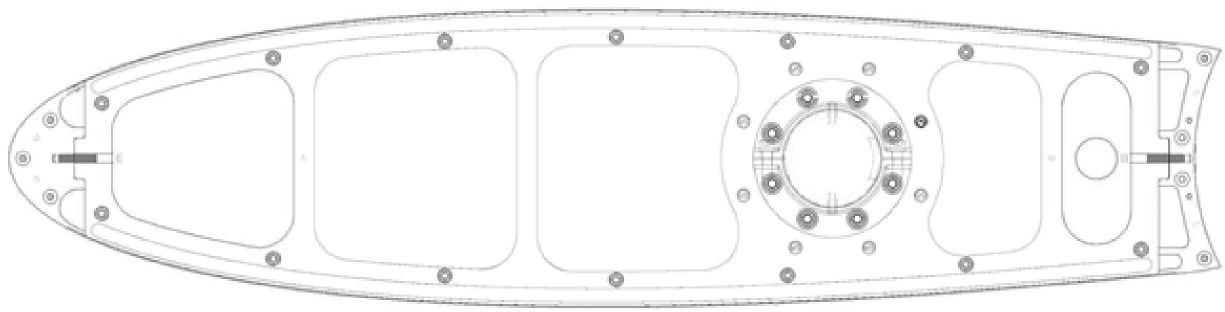


Figure 3 Main Element Cross-Section

4.3.2 Elevator

Similar to the main element in overall design, the elevator has a solid leading edge, aluminum ribs and aluminum skin attached using blind, flush-head rivets. The circular cut-outs in the elevator ribs are designed to minimize the weight of the model. The elevator is mounted on a traverse system that allows it to move laterally along the model chord relative to the main element in order to adjust the hinge gap between the two elements from 0.5 mm to 10 mm. The elevator can rotate ±25° independently of the model through the use of a separate servo motor and screw jack system on the port side of the model. The elevator deflection is measured relative to the chord line of the main element, with a positive deflection in the downwards direction. The starboard side is supported and allowed to rotate freely on a bearing. The lateral traverse and elevator rotation systems are described in more detail in Section 4.4.

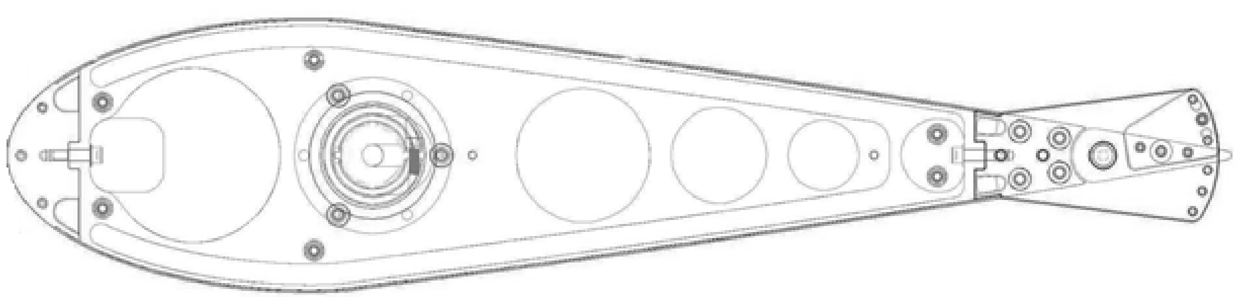


Figure 4 Elevator Cross-Section

4.3.3 Trim Tab

A trim tab was not originally intended to be part of the model based on the original proposal to EASA. However, feedback from the SAE G-12 Aerodynamic Working Group indicated the addition of a trim tab would make the model more versatile and helps with 'buy-in' for the results, so a tab was added to the trailing edge of the elevator. In order to keep the additional costs and complexity to a minimum, the trim tab was designed so that it is manually set to a desired position and stays in that position for the entirety of a run. The trim tab deflection is measured relative to the chord line of the elevator, with a positive deflection in the downwards direction, and can be manually set to 0°, ±4°, ±8° or ±12°. Unless otherwise mentioned, the trim tab deflection was set to 0° for the test program.

4.3.4 Endplates

The endplates are designed to keep the airflow over the model as two-dimensional as possible and keep the fluid contained on the model surface. Originally designed to follow the NACA 0015 profile of the model, the endplate upper and lower surfaces were extended in order to maximize their performance. The vertical size of the endplates is restricted, as the gantry system that allows access to the front of the model must be able to slide on rails under the model and observers in the building need visual access to the top surface of the model during runs. The endplates with the cross-section of the horizontal stabilizer model are shown in Figure 5.

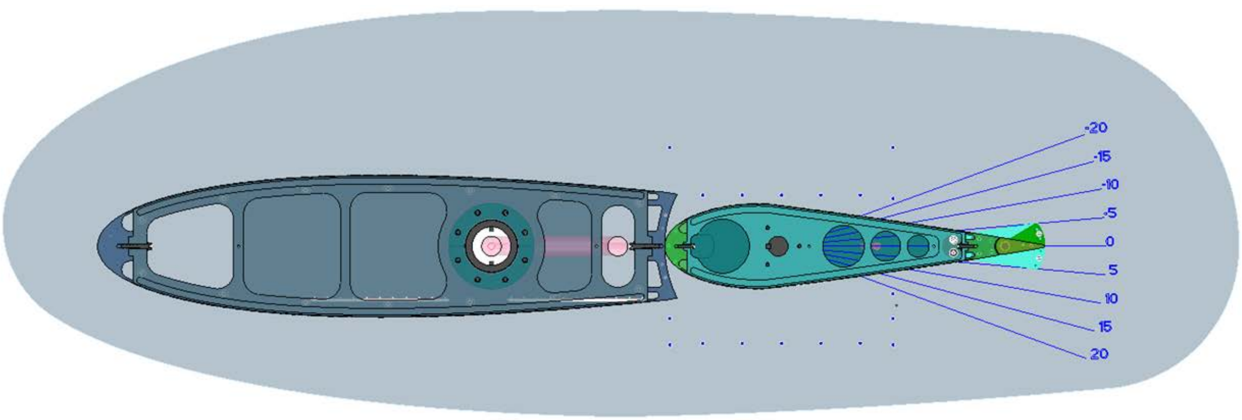


Figure 5 End Plate Design

4.3.5 Fairings

Two identical and symmetric fairings are attached to the wind tunnel side walls on the port and starboard sides and span the distance to the endplates without touching them, covering the elevator traverse assembly, the elevator rotation system assembly, and the shaft that connects the model to the external balances. All of these surfaces are on-balance, so the fairings are designed to remove as much of the aerodynamic load from them as possible while maintaining access to the traverse assembly. Figure 6 shows the locations of the fairing (in orange) around the elevator rotation and traverse systems. The large circular piece is a flat plate mounted against the test section wall to reinforce the shape of the fairings and the ends of the fairings are supported by triangular brackets also attached to the wall.

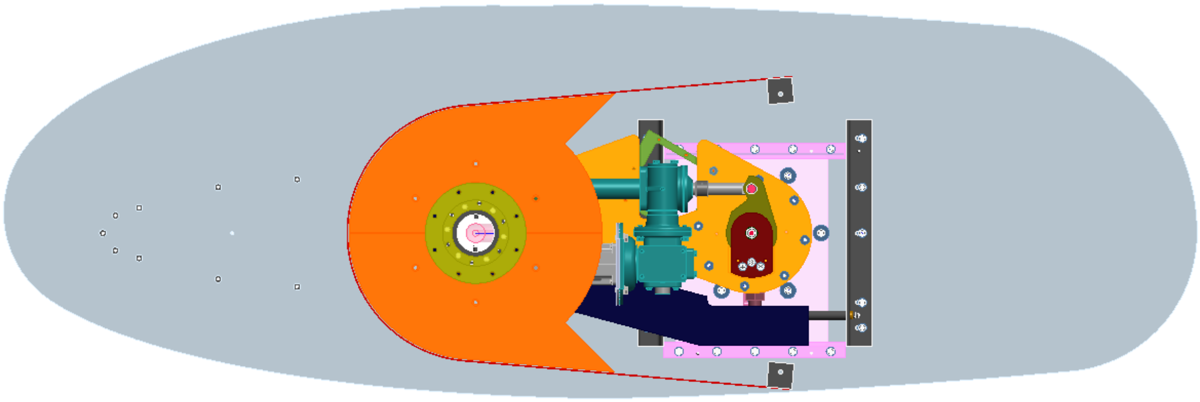


Figure 6 Fairing Location Relative to Model

4.3.6 Position in Wind Tunnel

The horizontal stabilizer model is positioned so that its spanwise centerline matches the centerline of the test section. The original model design had the centerline of the model shifted 15 cm (6 inches) off-centre in order to accommodate a gearbox and motor design for the elevator motion system while keeping the model span as large as possible. After some discussions between NRC, EASA and TDC, it was decided that this was not acceptable to EASA or TDC as they were concerned the different distances between the walls and the endplates would result in non-uniform flow over the model. The NRC modified the design by replacing the gearbox with the current screwjack and lever arm assembly, allowing the model to be shifted over to the centerline while maintaining the full span. The NRC accepted the responsibility and costs for changing the design at this stage, and the resulting delays did not impact the overall project schedule.

4.4 Mechanics and Instrumentation

4.4.1 Side-Wall External Balances with Motor/Gearbox

The overall aerodynamic loads on the model (lift, drag and pitching moment) are measured using two side-wall balances mounted outside the wind tunnel on each side of the test section. Each balance consists of two load cells in the normal direction and one load cell in the chord-wise direction. All of the load cells in the normal direction have ranges of 8,896 N (2,000 lb), while the load cells in the chord-wise direction on the port and starboard sides have ranges of 2,224 N (500 lb) and 4,448 N (1,000 lb) respectively. The port balance is connected to a motor and gear box that controls the model geometric pitch angle, while the starboard balance rotates freely. The gearbox is a right-angle high-precision gearbox designed for highly dynamic and cyclic applications and it is driven by a brushless servomotor. Although the balances are capable of rotating from -10° to +24° relative to the tunnel centerline, the fairings for this test restrict the motion to approximately ±3°. Protective covers prevent observers looking through the test section windows from touching the balance and fouling the load measurements. The balance calibrations were verified prior to the start of the test.

4.4.2 Elevator Rotation System

The elevator is rotated independently of the rest of the model with an independent motion system mounted on the outside of the port-side endplate, shown in Figure 7. A servomotor drives a screw jack connected to a lever arm, which rotates the elevator to the desired position at the set angular rotation rate. This system is automated to provide repeatable elevator deflections during the simulated take-off runs.

The servomotor is a Kollmorgen AKM42G model with a continuous torque to stall of 3.51 Nm (2.59 ft-lb), a rated speed of 3500 rpm, and an accuracy of 1 arc-min. The gearbox limits the speed to 1500 rpm, which corresponds to a maximum deflection rate of 5.5°/s for the elevator. Based on the accuracy of the servomotor and the expected tolerances in the assembly, the angular precision of the elevator is ±0.25°. The holding of the elevator position is accomplished using the servomotor brake.

The screw jack is a worm gear machine type manufactured by Joyce/Dayton with a 5:1 ratio gearset, a screw pitch of 6.35 mm (0.25 inch), a screw diameter of 25.4 mm (1 inch), and a 704.85 mm/min (27.75 inch/min) travel speed. The 101.6 mm (4 inch) rise of the screw jack provides the ability to rotate the elevator ±25°.

The elevator hinge moment is one of the key measurements for this research program, and is measured using a Futek reaction torque sensor mounted between two flex couplings between the elevator main shaft and the rotation system lever arm. With a maximum capacity of 1129.85 Nm (833.33 ft-lb), the torque sensor non-repeatability, non-linearity, and hysteresis are all 2.26 Nm (1.67 ft-lb).

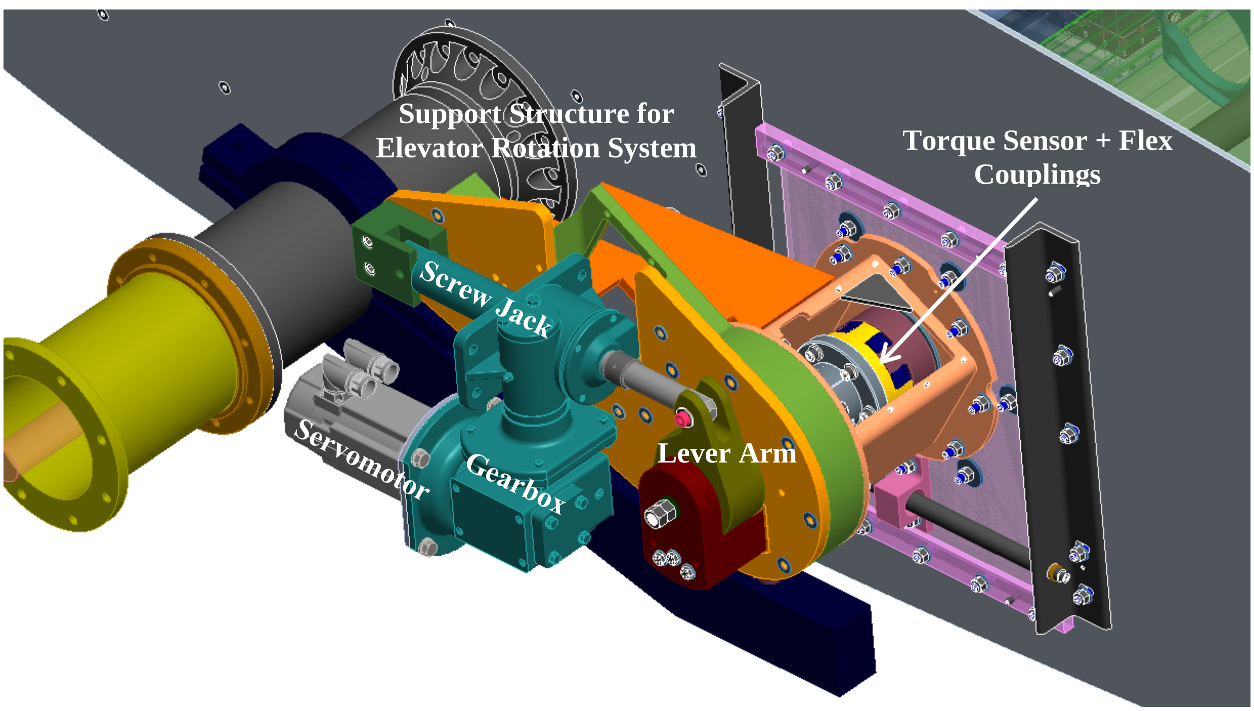


Figure 7 Elevator Rotation System

4.4.3 Elevator Traverse System

The hinge gap is the gap between the trailing edge of the main element of the horizontal stabilizer and the leading edge of the elevator. The hinge gap was identified in Section 3.4 where the elevator clearance is mentioned as a potential contributor to the incidents under investigation. The elevator traverse system is designed to allow for lateral movement to adjust this hinge gap in between runs while supporting the weight of the elevator, trim tab, and elevator rotation system. The traverse mechanisms are mounted on each side of the model to the outside of the endplates and use a threaded rod to manually translate the elevator assembly. The position of the elevator relative to the zero-gap position is set using spacer blocks; six bolts mounted in slotted holes are tightened to secure the assembly in place when the desired lateral position is reached. The port side of the main elevator shaft connects to the torque sensor and elevator rotation system. The starboard side of the shaft is supported by a roller bearing and rotates freely. Two people are required to operate the elevator traverse system, one on each side of the model working synchronously.

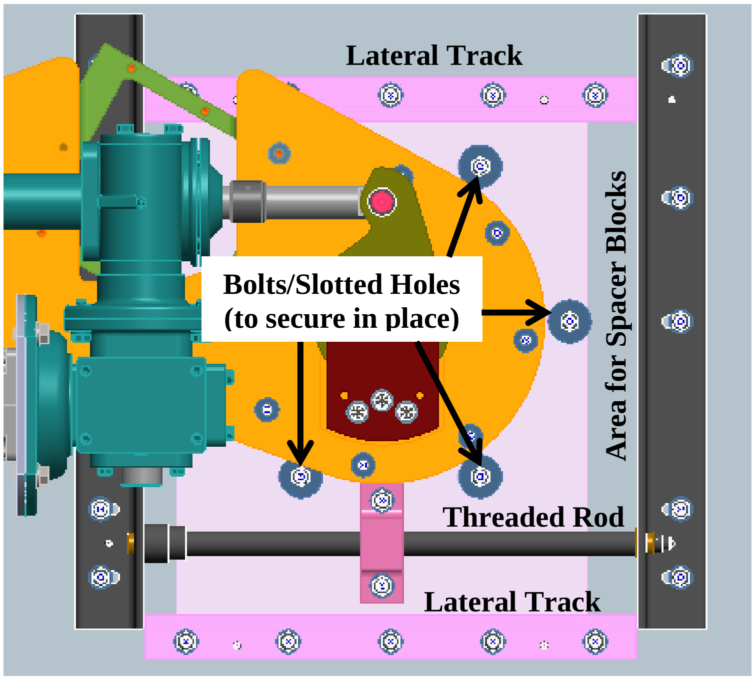


Figure 8 Elevator Lateral Traverse Assembly

4.4.4 Temperature Measurements

Ten (10) resistance temperature detectors (RTDs) were installed beneath the skin of the main element and elevator to monitor the skin temperatures throughout the test. Access panels on the underside of the model allow access to these RTDs for maintenance and repair. Figure 9 shows the approximate positions of the RTDs on the upper and lower surfaces of the model. The RTDs have an accuracy of ±1ºC. Other temperature measurements for the test include the outdoor air temperature, test section inlet temperature, and model area temperature just above the upper surface of the model.

4.4.5 Wiring

The torque sensor and servomotor wiring on the port side of the model is routed through a hole in the endplate into the main element, through the cylindrical center spar in the main element and out the port side of the test section.

The wiring from the thermocouples in the main element is routed directly into the center spar and out the port side of the test section. The wiring from the thermocouples in the elevator is routed out the starboard side of the elevator and along the endplate to re-enter the main element through a hole in the endplate. The wiring then enters the main spar and exits through the port side of the model with the rest of the thermocouple wiring.

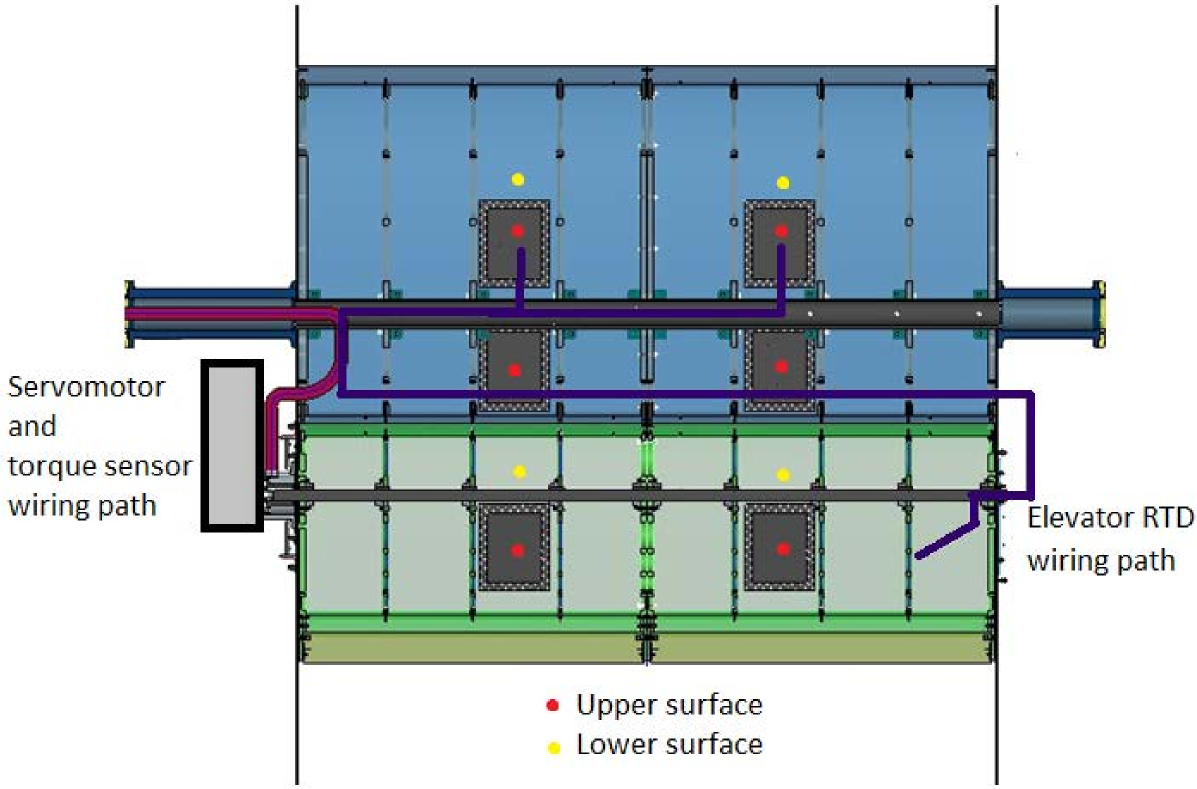
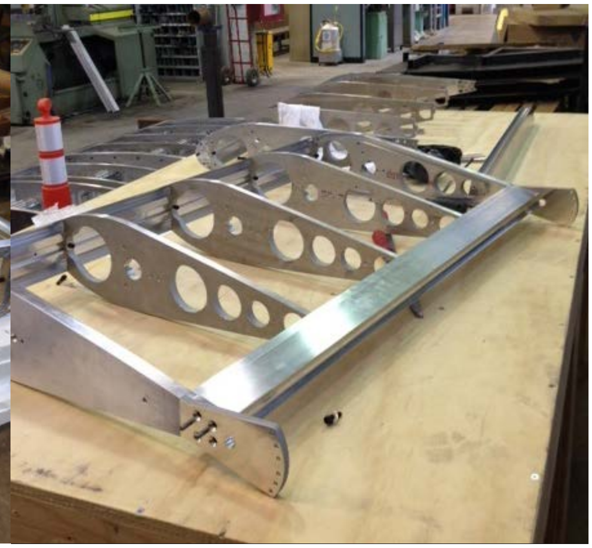


Figure 9 RTD Positions and Wiring Routes

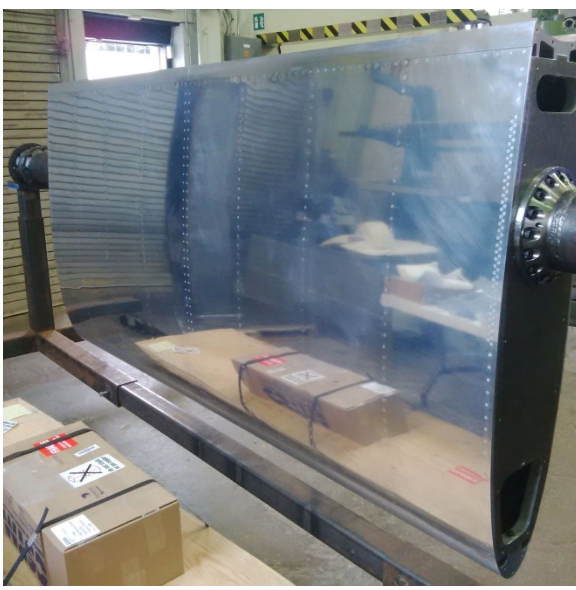
4.5 Manufacturing

The horizontal stabilizer model was manufactured in-house at the NRC-DFS fabrication shop. Photos of the model construction and assembly are shown below.

a) Main element rib assembly



b) Elevator rib assembly



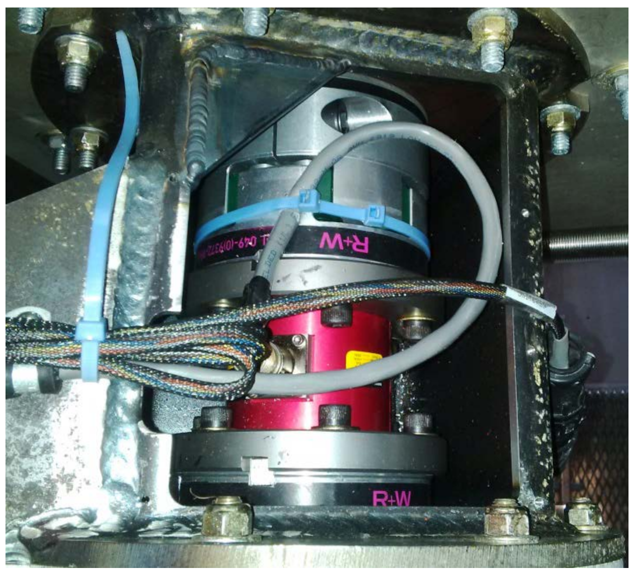
c) Main element skinned

d) Elevator skinned

Figure 10 Pictures of Horizontal Stabilizer Model Assembly

a) Starboard elevator traverse system

b) Port elevator traverse and rotation system



c) Torque sensor and flex couplings

Figure 11 Pictures of Elevator Traverse and Rotation System

The request from Transport Canada TDC that the skins on the lower and upper surfaces of the model be made out of a single piece in order to avoid a seam along the center of the model required the NRC to contract with an external shop to roll the skins into the correct shape. The NRC shop has the capability to roll the larger sheets of metal required for a single-piece skin, but not at the small diameters required for this model. TDC covered the extra costs associated with this contract as it was not a requirement for the original model design.

APS personnel marked a grid on the model upper and lower surfaces prior to the start of the test. Each grid cell measured 5.1 cm × 5.1 cm (2 in. × 2 in.). The grid spanned a width of 1.8 m (6 ft), starting approximately 10.1 cm (4 in.) aft of the leading edge of the main element and ending at the trailing edge of the model (including the trim tab). This grid was used to facilitate observations of the fluid shearing off the model surface during the tests. A photo of the complete model installed in the test section is shown in Figure 12, with the key model components labelled.

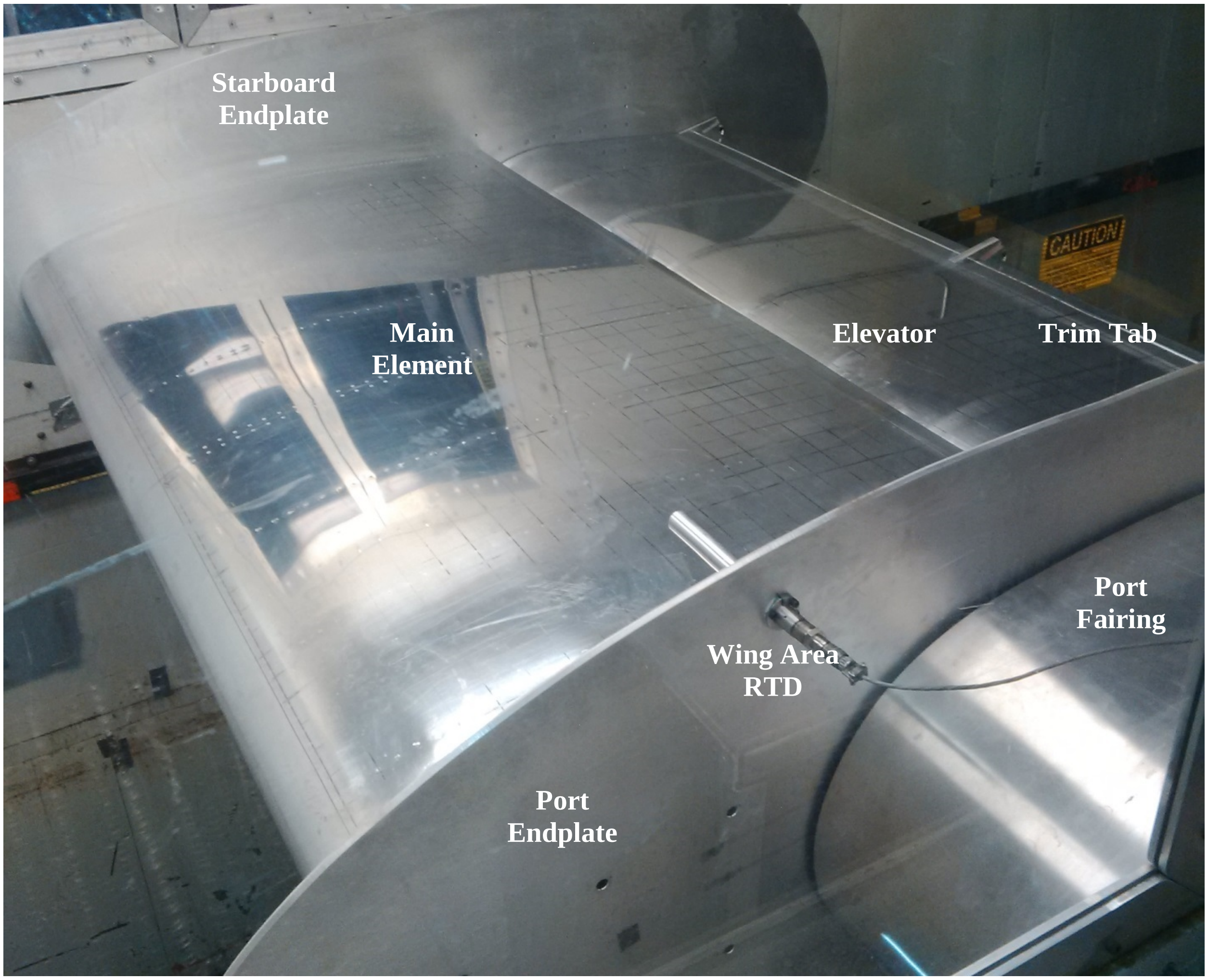


Figure 12 Model Installed in Test Section

5.0 Task 3 – Development of Test Program and Procedures

5.1 Take-Off Elevator Deflection Profiles

Multiple elevator deflection profiles were considered and tested in order to determine the conditions where the fluids may have the most adverse influence on the aircraft rotation. EASA was able to obtain the flight data recorder (FDR) data from aircraft manufacturers on particular take-off profiles for regional turboprop aircraft and this information was used to define Scenarios 1 to 3 for this research program. Scenarios 4 and 5 were developed during the research program, and are based at least in part on Scenarios 1 and 2. All of the elevator deflection profiles are described in the scenarios below, with the elevator deflection positive for trailing-edge down. For Scenarios 1 to 3, the elevator deflections from the FDR were mirrored up to the 'end of main rotation' point. After the 'end of main rotation' for all five deflection profiles, the elevator deflection was maintained at a constant value for 10 seconds at the maximum speed for the run in order to see improvement of the aerodynamic performance over time due to fluid shearing off the model. Scenarios 1 and 2 were the main profiles of interest during the test campaign, with 3 to 5 only used to assess particular situations.

The timing for each take-off profile is triggered at V = 40 kts and data below this speed is discarded. This is because the wind tunnel acceleration profile is not linear at the lower speeds and there is minimal movement of the fluid due to shear forces at those speeds.

Scenario 1: Heavy aircraft at maximum take-off weight with a center of gravity forward of its maximum permitted position. In this case the horizontal stabilizer needs to generate a high value of negative lift in order to rotate the aircraft.

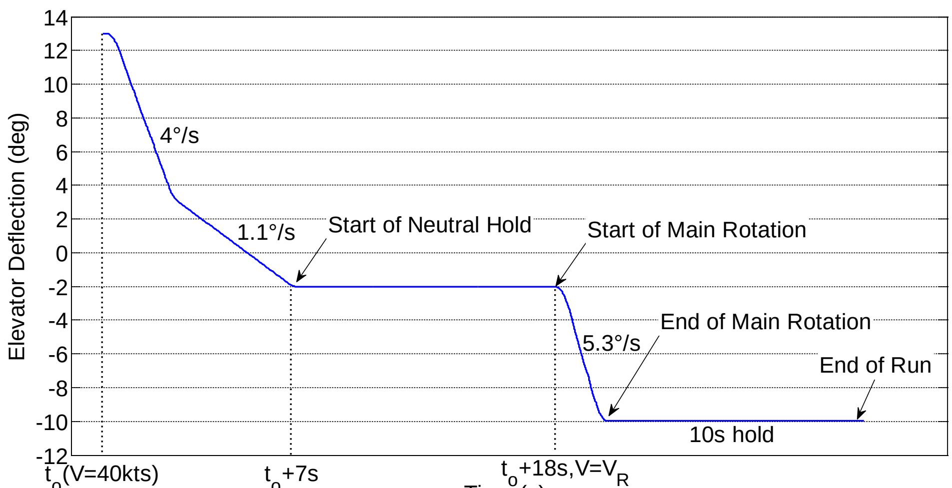


Figure 13 Scenario 1 (Heavy Aircraft) Rotation Profile

Scenario 2: Light aircraft with a center of gravity towards the back, within permitted limits. In this case the aircraft accelerates quickly and there is minimal time for the anti-icing fluids to shear off the horizontal stabilizer, so excessive fluid could exist on the critical surfaces at the time of rotation. The lift required on the horizontal stabilizer to rotate the aircraft is minimal due to the center of gravity position.

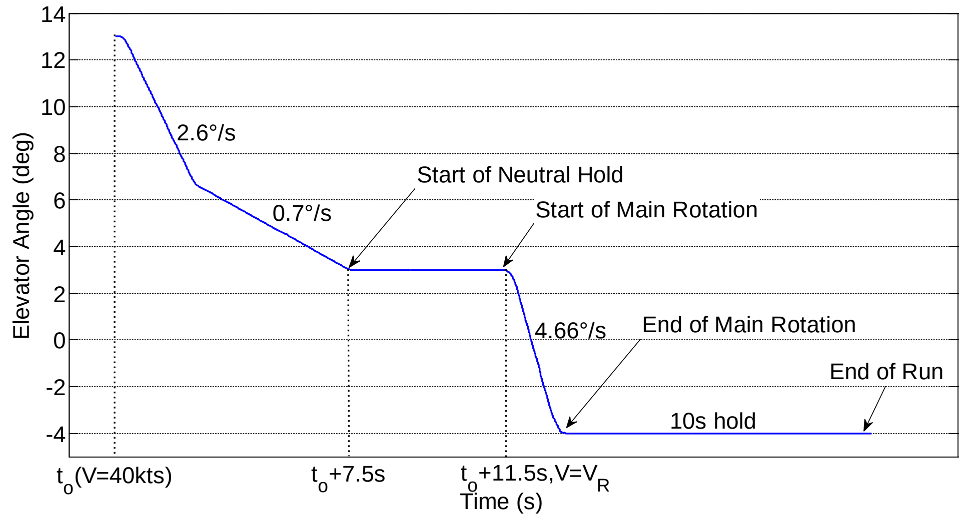


Figure 14 Scenario 2 (Light Aircraft) Rotation Profile

Scenario 3: Typical aircraft weight and center of gravity position. This profile attempts to replicate a normal take-off in winter conditions without intending to abuse any variable.

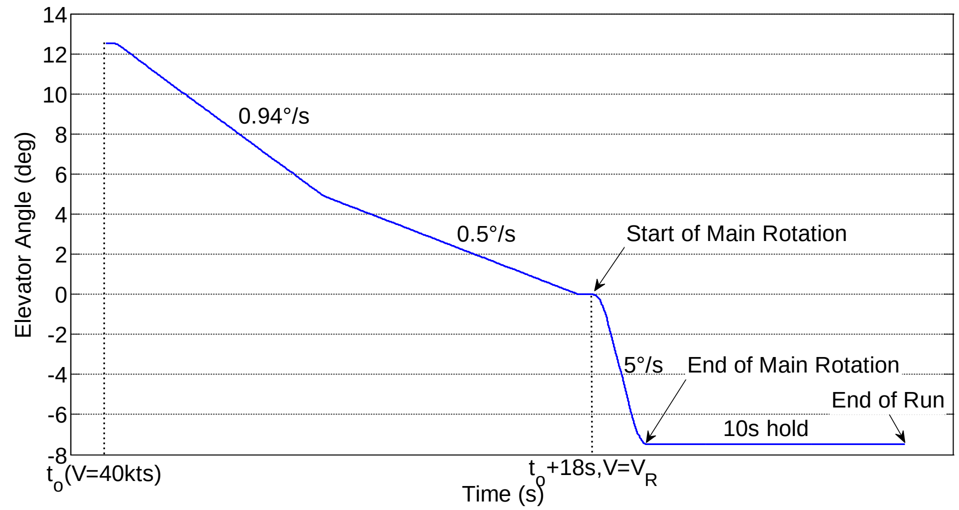


Figure 15 Scenario 3 (Moderate) Rotation Profile

Scenario 4: Modified heavy aircraft profile from Scenario 1, at maximum take-off weight with a center of gravity forward of its maximum permitted position. In this case the elevator deflection rates are slower, so there is no hold period before the main rotation.

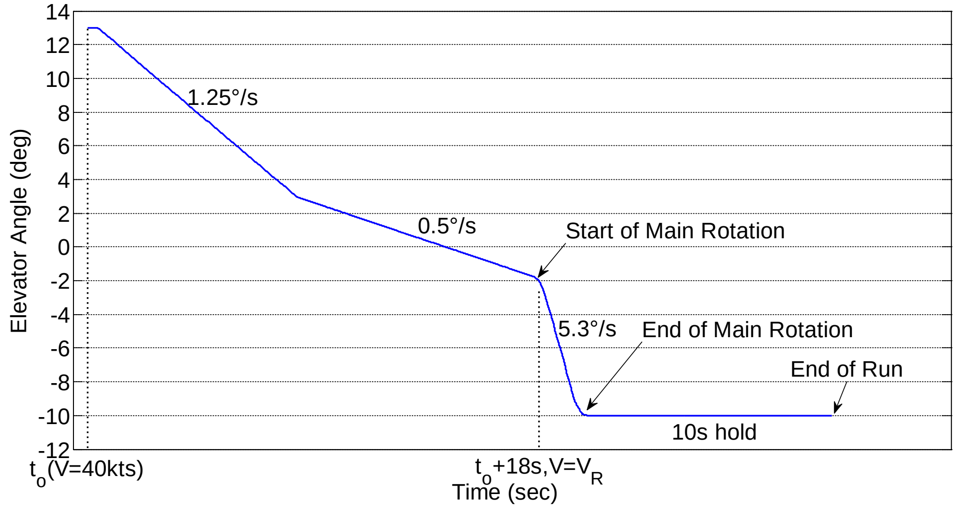


Figure 16 Scenario 4 (Modified Heavy) Rotation Profile

Scenario 5: Modified light aircraft profile from Scenario 2, with a center of gravity towards the back, within permitted limits. In this case, the pilot continues to pull back on the controls after the end of the main rotation, simulating a scenario where the pilot has completed normal rotation procedures but still has not lifted off the runway and continues to deflect the elevator until δ_E = -10°.

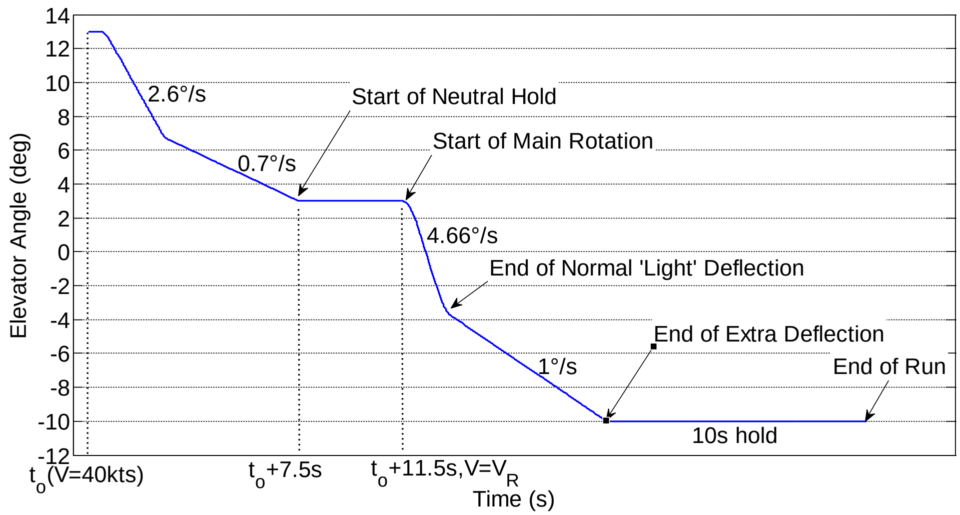


Figure 17 Scenario 5 (Modified Light) Rotation Profile

5.2 Wind Tunnel Acceleration Profiles

Two different tunnel acceleration profiles were tested using the above elevator deflection scenarios. The first acceleration profile targeted a rotation speed of 115 kts and was used with Scenarios 1, 3, 4 and 5. These acceleration profiles were also based on the FDR data that lead to the definition of Scenarios 1 to 3. In order to obtain the 18 s target time from 40 kts to rotation in a repeatable manner, the logic in the wind tunnel control systems triggered the main rotation of the elevator when 115 kts was reached or when the 18 s timer expired provided the speed was above 112 kts. Since this is the maximum speed of the wind tunnel, if the elevator rotation triggered solely on the velocity requirement there could be large variations in the time from 40 kts to rotation as the velocity asymptotically approaches 115 kts. A typical 115 kts acceleration profile compared to the targeted acceleration profile in the test plan is shown in Figure 18.

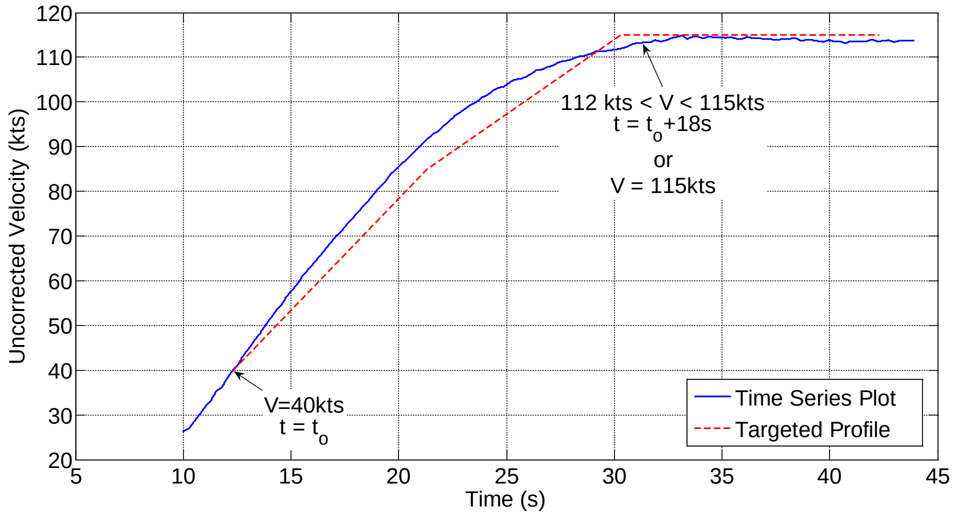


Figure 18 115 kts Acceleration Profile

The second acceleration profile targeted a rotation speed of 105 kts and was used with the elevator deflection profile defined in Scenario 2. This scenario uses similar logic to the 115 kts rotation profile, triggering the main elevator rotation when the target speed of 105 kts was reached or when the 11.5s timer expired provided the speed was above 102 kts. In order to match the targeted acceleration profile, the operator of the wind tunnel set the automatic ramp to a target of 115 kts and then manually reduced the tunnel speed once 105 kts was reached. This allowed for a nearly linear acceleration profile with a small overshoot in speed after rotation. A typical 105 kts acceleration profile compared to the targeted acceleration profile in the test plan is shown in Figure 19.

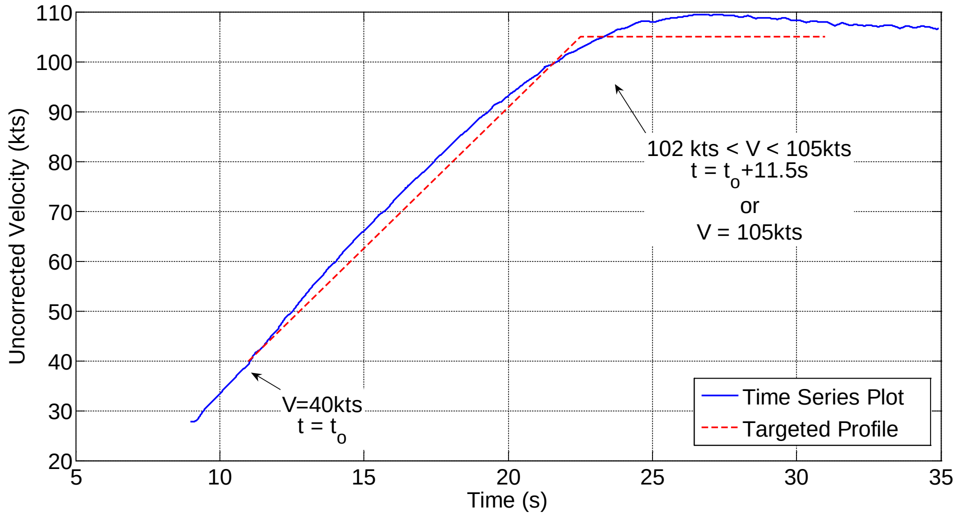


Figure 19 105 kts Acceleration Profile

5.3 Evaluation Criteria

Based on the elevator rotation scenarios provided in Section 5.1, four main points of interest were identified to use for evaluation of the horizontal stabilizer performance. A 'positive' case is defined as a test run where the difficulties experienced by pilots during take-off rotation have been reproduced.

Although the overall drag and pitching moment on the model are also measured by the side-wall balances for all runs and are included in the data provided to EASA, only the dry model values are presented in this paper. The drag on a horizontal stabilizer is small compared to the overall drag on an aircraft and the incremental effects of fluid on the horizontal stabilizer drag would likely not be noticed by the pilot so it is not an effective measure of the fluid performance. A similar argument can be made for the pitching moment on the horizontal stabilizer. Therefore the evaluation criteria for the model only apply to the elevator hinge moment and the horizontal stabilizer lift coefficients.

Control Law Evaluation Points

Point 1 - Start of neutral hold (if applicable for run profile)
Point 2 - Start of main rotation
Point 3 - End of main rotation
Point 4 - End of run

Column Force Evaluation Procedure

1. Establish the elevator hinge moment (C_h) generated by the dry horizontal stabilizer during a wind tunnel run.
2. For the wet horizontal stabilizer cases outlined in the test plan, perform runs using the same velocity profile, acceleration profile and elevator deflection law as the dry case.

3. Compare C_h for the wet and dry cases at the identified evaluation points. A 50% increase in C_h for high speeds ($V > 0.7V_{max}$) is considered a positive case, fulfilling the control force evaluation criteria.

Elevator Effectiveness Evaluation Criteria

1. Establish the downwards force (C_l) generated by the dry horizontal stabilizer during a wind tunnel run.
2. For the wet horizontal stabilizer cases outlined in the test plan, perform runs using the same velocity profile, acceleration profile and elevator deflection law as the dry case.
3. Compare C_l for the wet and dry cases at the identified evaluation points. A 10% decrease in C_l for high speeds ($V > 0.7V_{max}$) is considered a positive case, fulfilling the elevator effectiveness evaluation criteria.

The 50% increase in C_h and 10% reduction in C_l criterion were best-guess estimates on the actual increase in elevator hinge moment and horizontal stabilizer lift reduction experienced by pilots and were agreed upon by EASA with support from the NRC, APS, TC and NASA. The test runs where these criterion are met or exceeded are defined as ‘positive’ cases in this research program. As well, the column force evaluation criteria has been established as being the more important criteria, with the corresponding decrease in C_l more of an outcome of the test than an evaluation parameter.

5.4 Test Program Methodology

A summary of the test program phases is provided below, and are referred to in the test plan provided in Appendix A – Run Log.

Phase 1: Establish Evaluation Criteria

Perform dry horizontal stabilizer runs to measure the baseline aerodynamic performance of the model that will be used to calculate the column force and elevator effectiveness evaluation criteria.

Phase 2: Identify Contributing Variables

Attempt to reproduce rotation difficulties based on conditions identified in the literature survey with thickened anti-icing fluid. Systematically vary stabilizer-elevator gap, outdoor air temperature, fluid type, take-off law and control column applied-force law to identify variables that contribute to rotation difficulties.

Phase 3: Attempt to Rectify Rotation Difficulties

Repeat conditions that led to rotation difficulties with variations to parameters that may help rectify the issues.

Phase 4: Ice Under Horizontal Stabilizer

Test the effects of small amounts of ice underneath the horizontal stabilizer with respect to the generated negative lift. Phase 4 is to address a separate research objective and is not linked to the results from Phase 2 or Phase 3.

5.5 Test Procedures

The following section describes the tasks performed during each test run. The NRC test engineer kept a detailed log recording the configuration for each run, including information such as the target speed, rotation profile, stabilizer-elevator gap, and fluid type. The APS staff recorded data on multiple forms for each run, including data such as the fluid thickness and fluid brix, in addition to the data automatically collected by the NRC data acquisition system. The timeline for a typical wind tunnel run is shown in Figure 20.

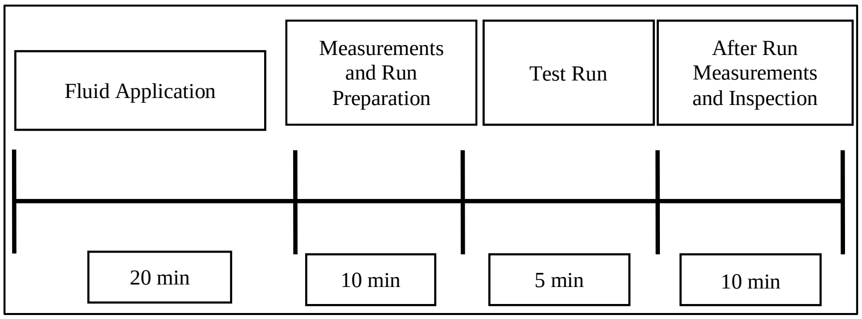


Figure 20 Typical Wind Tunnel Run Timeline

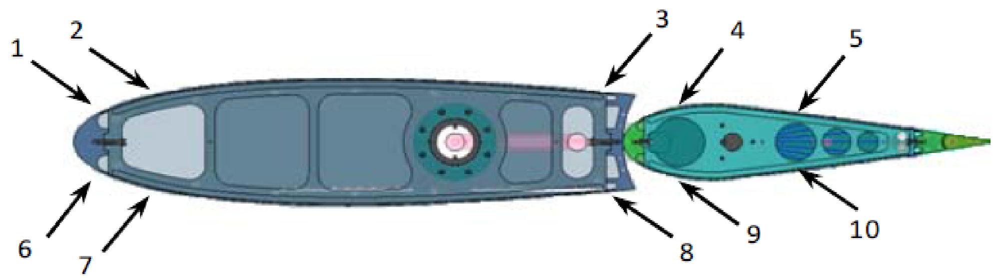
Pre-Test Configuration
- If required, rinse the model with fluid from the upcoming run and clean the horizontal stabilizer using squeegees to remove any fluids from previous runs.
- NRC staff manually configures the model with the appropriate gap setting.

Initial Test Conditions Survey
- Record ambient conditions of the test.
- Record horizontal stabilizer temperature.

Fluid Application
- Measure and record fluid temperature prior to pour.
- Pour 16-20L of anti-icing fluid over the test area.
- Record fluid application time and quantity.
- Let fluid settle for 5 minutes.
- Tilt the model forward to $\alpha = -3°$ for a 1-minute period to help the fluid spread out evenly.
- Return model to $\alpha = 0°$.
- Cycle the elevator to $\delta_E = -20°$ and $\delta_E = +20°$ then back to neutral to simulate pilot checks.
- Measure and record fluid thickness, brix, and skin temperature at the required locations.
- Photograph and videotape the appearance of the fluid on the wing.

The fluids were poured, rather than sprayed, on the model so that the application process would not apply a shear stress to the fluid and potentially change its viscosity. This methodology was appropriate given the relatively small surface area of the model and the goal of minimizing the amount of fluid flowing off it.

Wet film thickness gauges were used by APS staff to measure the fluid film thickness. These gauges were selected because they provide an adequate range of thickness measurements (from 0.1 mm to 10.2 mm) for all fluid types. A rectangular gauge with a finer scale was used in some cases when the fluid film was thinner; after a run for example. The locations of the fluid thickness, brix, and skin temperature measurements on the model surface are shown in Figure 21.



Position 1 – 10 cm downstream of the leading edge stagnation point
Position 2 – 15 cm downstream of position 1
Position 3 – 10 cm from the trailing edge of the main element
Position 4 – 15 cm downstream of the elevator stagnation point
Position 5 – Mid-chord of the elevator
Positions 6, 7, 8, 9, 10: Same positions as 1, 2, 3, 4, 5 respectively, on lower surface of model

Figure 21 Location of APS Fluid Property Measurements

<u>Prior to Engines-On Wind Tunnel Test</u>

- Record start time of test.
- NRC staff update the data acquisition and control system with the appropriate acceleration and elevator rotation profile

<u>During Wind Tunnel Test</u>

- Take still pictures and video the behavior of the fluid on the horizontal stabilizer during the takeoff run, capturing any movement of fluid/contamination.
- Record wind tunnel operation stop time.

<u>After the Wind Tunnel Test</u>

- Measure and record fluid thickness, brix (refraction index), and skin temperature at pre-determined locations on the horizontal stabilizer.
- Observe and record the status of the fluid/contamination.
- NRC process data to obtain hinge moment coefficients and lift coefficients.

5.6 Fluid Selection

Fluid selection was based upon a review of relevant information available from incident reports and holdover time guidelines. A range of viscosities was desired in order to evaluate the effect of viscosity on the fluid flow-off and the resulting aerodynamic effects. From the thirteen (13) incident reports obtained, nine (9) had fluid information described within which included the fluid type (I, II, III, and IV) as well as dilutions. The fluids identified in these incidents are no longer commercially available, but newer generations of the same or similar fluids have been identified. (Ruggi, 2015)

The lowest on-wing viscosities from Table 9 of the TC holdover time guidelines (Transport Canada, 2014) were analyzed. The published viscosities for currently available and relevant Type II and Type IV 100/0 and 75/25 fluids were compiled and sorted according to AIR 9968 method measured viscosity. The 50/50 dilution fluids considered were also included in this list. Based on the information found and the commercial availability, the fluids presented in Table 6 were selected and were approved by EASA in emails dated 5 September 2014 and 18 September 2014. A Type IV fluid is used as a substitute for the Type III fluid identified from accident reports, as it has the appropriate low viscosity when diluted. During the research program a Type I fluid was added to the test plan and the fluid obtained from AéroMag, a company that provides de-icing services at the Ottawa International Airport. (Ruggi, 2015)

Table 6 Recommended Fluids for Research Program

Fluid	Dilution	Viscosity Range (mPa-s)
IV-L	100/0	5,000-10,000
IV-L	75/25	15,000-20,000
II-F	100/0	< 5,000
II-F	75/25	10,000-15,000
IV-A75	75/25	30,000-35,000
III-P50	50/50	<1,000
I	60/40	n/a

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

6.0 Task 4 – Testing Phase

6.1 Facility Description

The program was completed at the NRC Propulsion and Icing Wind Tunnel (PIWT) in Ottawa, Ontario, Canada. This is an open-circuit wind tunnel facility that allows for naturally-cold test section conditions during the winter months in Ottawa. The wind tunnel fan is exposed to the atmosphere and has a high solidity ratio to reduce unsteadiness in the test section due to outdoor wind conditions. A screen across the front of the wind tunnel inlet blocks debris and birds. For this research program the PIWT test section is configured with the upper and lower inserts deployed and the fan driven by a gas-turbine engine. The 0.5 m high inserts reduce the test section height from 6 m to 5 m to allow for a maximum speed of 115 kts. Flow angularity over most of the working section is within 1° of the longitudinal axis. The NRC Aerodynamics Laboratory and its wind tunnels are ISO 9001:2008 certified.

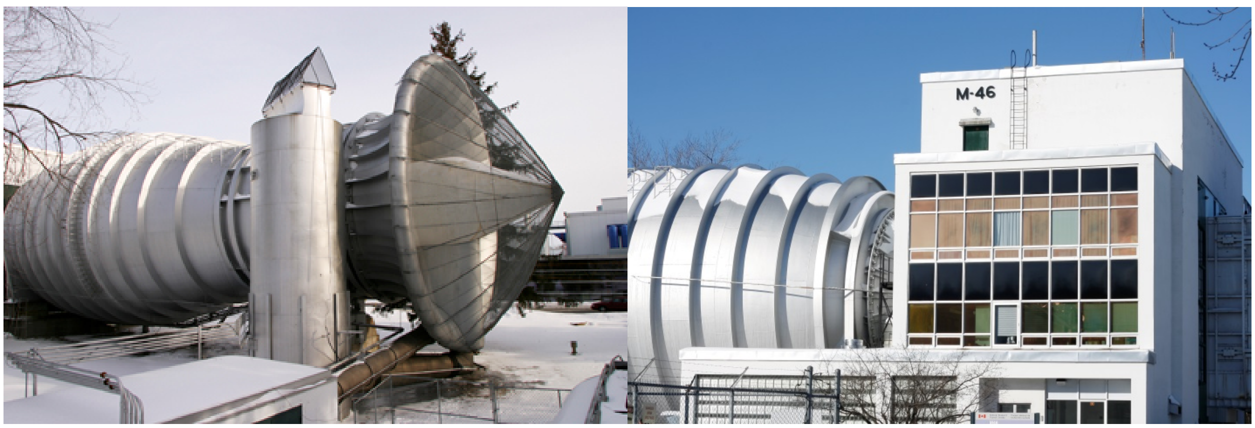


Figure 22 Exterior View of PIWT

6.2 Wind Tunnel Features

6.2.1 <u>Gantry System</u>

In order to access the model in the test section there is a gantry system that slides on rails below the model. The upstream gantry is accessed using a ladder and the downstream gantry can be accessed using either a ladder or the third-floor access doors. The grated surface, yellow non-slip coatings, and rails with access gates provide a safe environment when working from the height of the model. When the wind tunnel is running, the gantry system is stored at the downstream end of the diffuser so it does not impact the aerodynamics of the flow around the model. A picture of the gantry system from downstream of the model is shown in Figure 23.

Figure 23 Gantry System

Staff and clients who enter the test section between runs must remain on the grating applied to the test section floor as much as possible to reduce the probability of a slip-and-fall due to leftover anti-icing fluids. There is grip-tape on the stairways in the PIWT and mats on the floor areas around the test section entrances to wipe shoes on.

6.2.2 Glycol Containment System

A glycol containment system collects the fluids that are shed from the model throughout the tests. The system was designed to speed up cleaning of the fluid from the wind tunnel floor while providing containment in accordance with NRC environmental policies. The system requires that the fluid be squeegeed into a trough in the floor of the diffuser. The fluid then drains through a 0.152 m (6 in.) diameter downspout to a standard 55-gallon collection barrel outside the wind tunnel. This barrel has a pop-up gauge on it to let the staff know when it is almost full and needs to be switched out with an empty barrel. The trough is recessed from the floor level by 6.35 mm (0.25 in.) to allow a cover plate to be installed when not in use.

6.2.3 Viewing Platform

A viewing platform, whose construction was funded by Transport Canada in 2014, allows the client to see the model surface during the test runs and replaces short step-ladders used in previous years. Visual observations are important for understanding the fluid behaviour and this platform provides a stable area to make those observations from. A picture of the viewing platform outside the test section is shown in Figure 24.

Figure 24 Viewing Platform

6.2.4 Roof and Floor Cameras

The roof insert of the test section has two 360° rotation video cameras that are used to record the fluid flow-off the upper surface of the model for each run. A floor-mounted video camera with pan, tilt and zoom capability and a built-in light records the fluid flow-off the lower surface of the model. Examples of the views from one of the roof cameras and the floor camera are shown in Figure 25.

Figure 25 Example of NRC Roof and Floor Camera Views

6.3 Calibrations and Tares

6.3.1 Empty Test Section Calibration

The test section was calibrated by placing a pitot-static probe in the centre of the empty test section and measuring the probe and wind tunnel pressures at a number of different fan speeds. The relationships between the test section uncorrected total pressure (P_T), the test section static pressure (P_S) and the pressure differential in the contraction (ΔP_C) are shown below. This method to calibrate the empty test section of a wind tunnel is a standard method, and is described in Section 3.11 of 'Low-Speed Wind Tunnel Testing" (Rae & Pope, 1984). This information was entered as part of the data reduction code.

$$P_T = P_{baro} + (-5.7939 \cdot 10^{-6})\,\Delta {P_C}^2 + 1.0212\,\Delta P_C \qquad \text{Equation 1}$$

$$P_S = P_{baro} + (-2.8338 \cdot 10^{-5})\,\Delta {P_C}^2 - 0.2738\,\Delta P_C \qquad \text{Equation 2}$$

The data from the pitot-static probe mounted in the centre of the empty test section were measured using 10-inch H_2O sensors with accuracies of ±0.05% of reading.

6.3.2 Side-Wall External Balance Calibrations

The external side-wall balances were calibrated in-place using a balance calibration rig in the test section loaded with dead weights. The calibration rig has a torque arm assembly that allows dead-weights to be applied at three different streamwise positions in the upwards and downwards directions. The load schedule shown in Table 7 was used to verify the load cell calibrations prior to the test start.

Table 7 Balance Calibration Load Schedule

Load Range	Load Direction	x (inches)	α (º)
1000 lbs	Up	0	0
1000 lbs	Down	0	0
1000 lbs	Down	+20	0
1000 lbs	Down	-20	0
1000 lbs	Down	0	-10
1000 lbs	Down	0	+10
500 lbs	Downstream	0	0

6.3.3 Torque Sensor Calibration

The torque sensor was calibrated by the manufacturer (Futek Advanced Sensor Technology Inc.) prior to shipping it to the NRC. The calibration was performed on 17 April 2014 and is valid until for one (1) year. The maximum non-linear error in the calibration certificate was less than 0.045% of the reading. The torque sensor is installed with flexible couplings on either side to account for any misalignments in the manufacturing and assembly of the model. These flexible couplings each have a static torsional stiffness of 18,000 Nm/rad.

6.3.4 Torque Sensor Corrections

Since the center of gravity of the elevator is not the same as the pivot point of the elevator, which is where the torque sensor takes its readings, as the elevator moves up and down the torque sensor readings change. To remove the elevator weight from the torque sensor data, the elevator was pitched from -20° to +20° in 2° increments. A 2nd-order polynomial was fit to the resulting data and this tare was applied in the data reduction code.

When there is no flow through the test section, the torque sensor measures only the torque created by the weight of the elevator. As the tunnel speed increases, aerodynamic forces act on the model due to small misalignments relative to the zero-degree aerodynamic angle of attack. This aerodynamic effect was measured by taking torque sensor readings through a range of speeds, with the elevator at $\delta = 0°$. A linear fit was applied to obtain the torque sensor reading as a function of the pressure differential in the contraction, and this offset was removed in the data reduction code.

6.4 Research Program

6.4.1 Shakedown Runs

The model was brought to the PIWT in mid-October 2014 for instrumentation assembly and testing. After bench tests showed the model to be functioning with the wind tunnel control systems, it was mounted in the test section and run through a variety of simulated take-off runs to ensure functionality under load. Some modifications to the model had to be done at this point to improve the measured backlash and account for some misalignments. None of these runs involved the application of anti-icing fluids.

When the model was first installed in the test section, it was installed such that the chord-line of the model was 0° as measured by a digital inclinometer. To account for offsets due to manufacturing tolerances, effects of endplates and flow angularity, the model was pitched up and down with the wind on at 100 kts to find the aerodynamic zero degree angle of attack. Based on this information, the model was pitched nose-down 1.3° in order to provide zero-lift at $\alpha = 0°$. The elevator remained geometrically at 0° relative to the chord of the main element.

The angle of the elevator deflection was verified using an external digital inclinometer mounted on the flat surface of the trim tab supports. This inclinometer was used to verify the motion system commands, and marks were made on the endplates to allow easy visual confirmation of the angle.

6.4.2 Camera Position

APS used the observation windows on the sides of the test section to install Canon DSLR cameras and Profoto Compact 600 flashes capable of second-by-second photography with an intervalometer. In addition, two cameras were used for wide-angle filming of the fluid flow-off during the test runs. The first was a Canon EOS XTi DSLR camera operated in video mode which was positioned in the first observation window. The second was a GoPro video camera which had a similar vantage point but was installed inside the test section looking at the bottom of the model. The positions of the flashes and cameras are shown in Figure 26. Due to the large amount of photos collected, a small sample is included in this report and the remaining photos were provided to the client on a hard drive at the end of the research program. (Ruggi, 2015)

Figure 26 Positions of APS Cameras

6.4.3 Fluid Sampling

Prior to the start of the testing, APS Aviation visited the NRC to collect samples of the fluids that were to be used for the research program. A viscosity test was performed on-site using the Stony Brook PDVdi-120 Falling Ball Viscometer to confirm that fluid viscosity was within the specifications. A Brookfield Digital Viscometer Model DV-1+ was also used to measure the fluid, and the results from both tests are presented in Table 8. The measurements indicated that the fluids selected for this research program represent a wide range of viscosities as desired, and the measured viscosities are all higher than the lowest on-wing viscosities specified by the manufacturer. (Ruggi, 2015)

At the request of EASA on 26 January 2015, viscosity testing of the fluid samples at higher shear forces was performed. The fluids were all tested according to the same method using a 9.4 mL sample and spindle SC4-34 at 30 rpm for 5 minutes and 0°C in order to test at conditions representative of the wind tunnel. The results are presented in the last column of Table 8. The results showed similar trends to what was observed using the manufacturer's method, with the exception of IV-A75. Since viscosity is a function of many variables, it is not uncommon for the relative relationship amongst fluids to change once the viscosity testing variables are modified as each fluid is designed for specific operating markets and applications. (Ruggi, 2015)

Table 8 Fluid Viscosity Test Results

Fluid	Dilution	Measured Viscosity (mPa-s)	Falling Ball (s)	Viscosity Re-Test with Method (x) (mPa-s)
IV-L	100/0	15,760	31	1,328
IV-L	75/25	21,800	13	1,794
II-F	100/0	13,600	26	1,230
II-F	75/25	20,300	14	1,832
IV-A75	75/25	36,000	48	1,286
III-P50	50/50	5,320	3	868
I	60/40	n/a	n/a	n/a

6.4.4 Fluid Storage

During the tests, the fluids were stored outside of the wind tunnel building in a separate storage container to maintain them at the outside ambient temperature. The fluids were received in individual 18 L to 25 L pails, and then applied to the model using smaller 2 L containers. Approximately 16 L to 20 L of fluid were applied for each test, with less fluid required for the III-P50 fluid applications. Fluid remaining at the end of the tests is stored in that container for future use. (Ruggi, 2015)

6.4.5 Main Research Program

The main research program was conducted over a period of six (6) days from December 15-20 to allow for the range of desired temperatures in the test section. The run log is provided in Appendix A – Run Log at the end of this report. Two EASA representatives were present for the entire test program, and representatives from Transport Canada visited throughout the week. Figure 27 shows a photo of the staff present during one of the test days (due to scheduling not all participants were available for this photo).

The PIWT and related equipment (including the model and elevator rotation and instrumentation) were operated by NRC personnel. Two NRC facility staff members were required to operate the wind tunnel, the model equipment and instrumentation, and provide general support to the client. An NRC engineer was also present to manage the research program, process the data and interpret the results.

Activities with respect to de-icing fluid acquisition, collection, application, and contamination were performed by APS staff. Three APS staff members were required to conduct the research program and additional APS support staff were tasked with fluid application and general support. An APS photographer was on-site to record the digital images and videos of the tests. APS records of the fluid thickness, brix and temperature are provided in Appendix B – Complete Test Results.

Upon delivery of the final report, the NRC provided EASA with the full set of processed data on DVD. The videos from the NRC cameras, as well as the APS videos and still photos, are provided on Blu-ray discs.

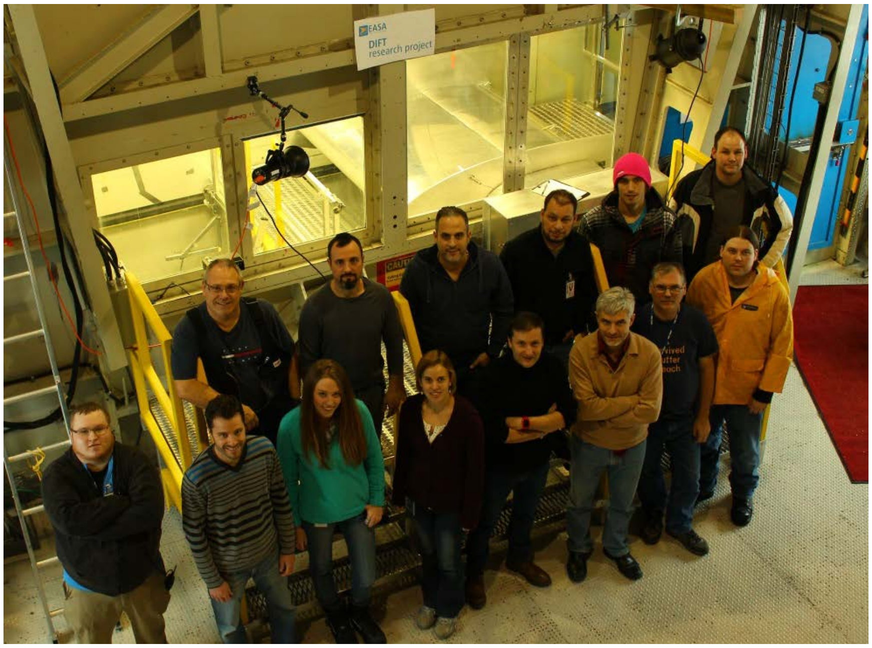


Figure 27 EASA, NRC and APS Staff Photo

7.0 Task 5 – Data Reduction, Analysis and Reporting

7.1 Calculation of Aerodynamic Parameters

7.1.1 Dynamic Pressure and Velocity

The total and static pressure in the test section is calculated based on the established empty-tunnel calibration presented in Section 6.3.1. These values are then used to calculate the test section velocity using the following equations.

The Mach number is calculated using the uncorrected test section pressures.

$$M = \sqrt{5\left(\frac{P_T}{P_S}\right)^{\frac{2}{7}} - 1} \qquad \text{Equation 3}$$

The dynamic pressure in the test section is corrected for compressibility effects.

$$q = 0.7 P_S \, M^2 * 1000 \qquad \text{Equation 4}$$

The air density in the test section is calculated based on the test section static pressure and the static air temperature in the test section.

$$\rho = 1.225\left(\frac{P_S}{101325}\right)\left(\frac{288.15}{T}\right) \qquad \text{Equation 5}$$

The uncorrected airspeed in the test section is calculated using the calculated dynamic pressure and air density.

$$V = \sqrt{\frac{2q}{\rho}} \qquad \text{Equation 6}$$

7.1.2 Lift, Drag Pitching Moment and Elevator Hinge Moment Coefficients

The lift, drag and pitching moment coefficients are calculated using standard equations for these non-dimensional aerodynamic parameters.

$$C_l = \frac{L}{\frac{1}{2}\rho V^2 A_{HS}} \qquad \text{Equation 7}$$

$$C_d = \frac{D}{\frac{1}{2}\rho V^2 A_{HS}} \qquad \text{Equation 8}$$

$$C_m = \frac{PM}{\frac{1}{2}\rho V^2 A_{HS}\, c_{HS}} \qquad \text{Equation 9}$$

To rotate an aerodynamic control surface about its hinge, it is necessary to apply a torque to it to overcome the aerodynamic pressures that resist the motion, with the torque due to the elevator mass distribution already taken into account – see tares in Section 6.3. The aerodynamic forces produce a moment about the hinge. The coefficient of elevator hinge moment is defined as:

$$C_h = \frac{H}{\frac{1}{2}\rho V^2 A_E c_E} \qquad \text{Equation 10}$$

The aerodynamic forces and moments are defined using the conventions shown in Figure 28.

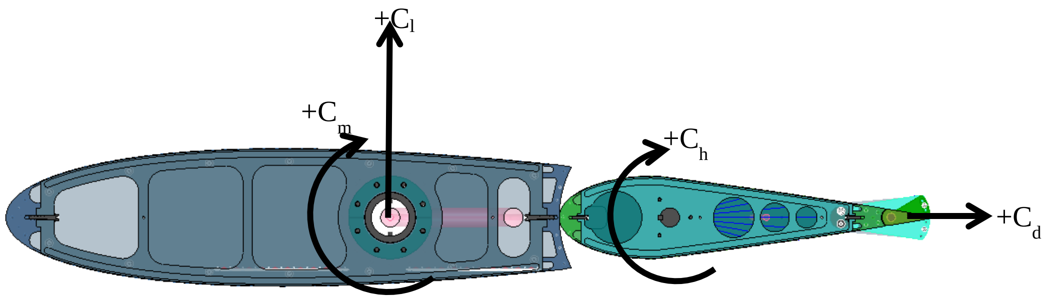


Figure 28 Aerodynamic Sign Conventions

7.2 Blockage Corrections

The raw data from the wind tunnel data acquisition system is acquired using TestSLATE and processed by the NRC using a Matlab program developed in-house. This program converts the data to engineering units, and includes standard corrections for wind tunnel blockage effects. The data from the model instrumentation (lift, drag, pitching moment, temperatures, elevator deflection, elevator hinge moment) are synchronized with the data from the wind tunnel and the external balances. All assumptions and possible limitations of the data collected are identified below.

The wall corrections used in the data reduction code are based on standard two-dimensional testing corrections (Rae & Pope, 1984). Although the model is not wall-to-wall and therefore not completely two-dimensional, the endplates significantly limit the amount of three-dimensional flow across the model and it was decided that the two-dimensional corrections would be more representative of flow conditions than the three-dimensional corrections. As the research program is looking at comparative differences in aerodynamic coefficients, the absolute values aren't as critical as they might be for a different type of test.

7.2.1 Solid Blockage Correction

The presence of a model in the test section reduces the area through which the air must flow. Using continuity and Bernoulli's equation, this increases the velocity of the air as it flows over the model. This increase in velocity, which is considered constant over the model, is called "solid blockage". The solid-blockage velocity increment at the model is much less than the increment obtained from direct area reduction, since the streamlines far away from the model are the most displaced (Rae & Pope, 1984).
The two-dimensional correction for solid blockage is shown in Equation 11, where K_1 = 0.74 for a model spanning the tunnel width and A_{TS} is the cross-sectional area of the test section (15.2 m^2). A good approximation for airfoil model volume is 0.7 × model thickness × model chord × model span, which equals 0.576 m^3 for the EASA horizontal stabilizer.

$$\epsilon_{SB} = \frac{K_1 * (model\ volume)}{A_{TS}^{\frac{3}{2}}} \qquad \text{Equation 11}$$

7.2.2 Wake Blockage Correction

Most models will have a wake behind them, and this wake will have a mean velocity lower than the freestream velocity. By Bernoulli's principle, the higher velocity in the mainstream has a lowered pressure and this lowered pressure puts the model in a pressure gradient, resulting in a velocity increment at the model. The two-dimensional correction for wake blockage is:

$$\epsilon_{WB} = \frac{1}{2}\frac{c}{h}C_d \qquad \text{Equation 12}$$

7.2.3 Streamline Curvature

The effect of the floor and ceiling of the test section is to restrain the naturally free air curvature of the flow so that the model acts like one with extra camber. This results in too much lift and moment about the quarter-chord point. Making the assumption that $(0.25c)^2$ is small compared to h^2, which it is for this model, the two-dimensional correction for streamline curvature is described below and is equal to 0.0284 for the EASA horizontal stabilizer model.

$$\sigma = \frac{\pi^2}{48}\left(\frac{c_{HS}}{h}\right)^2 \quad \text{Equation 13}$$

7.2.4 Application of Corrections

The above factors are applied to correct for blockage effects using the following equations:

$$\epsilon = \epsilon_{SB} + \epsilon_{WB} \quad \text{Equation 14}$$

$$V_c = V(1+\epsilon) \quad \text{Equation 15}$$

$$q_c = q(1+2\epsilon) \quad \text{Equation 16}$$

$$\alpha_c = \alpha + \frac{57.3\sigma}{2\pi}(C_l + 4C_m) \quad \text{Equation 17}$$

$$C_{lc} = C_l(1-\sigma-2\epsilon) \quad \text{Equation 18}$$

$$C_{dc} = C_d(1-3\epsilon_{SB}-2\epsilon_{WB}) \quad \text{Equation 19}$$

$$C_{mc} = C_m(1-2\epsilon) + \frac{1}{4}\sigma C_{lc} \quad \text{Equation 20}$$

7.3 Uncertainty Analysis

7.3.1 Dynamic Pressure and Velocity

The uncertainty in the calculated dynamic pressure and velocity in the test section can be calculated from the measurement accuracies of the pressure transducers used to measure the pressure differential in the contraction and the barometric pressure.

The pressure differential in the contraction was measured using a 12-inch H_2O sensor with an accuracy of ±0.01% of the full-scale range (±0.299 Pa). The barometric pressure was measured using an absolute pressure transducer with an accuracy of ±0.1% of reading (±101.325 Pa at standard atmosphere). From the operations in Equations 1 and 2, the uncertainties in both the uncorrected dynamic pressure and static pressure are calculated to be ±0.04% of reading at a tunnel speed of 100kts.

Propagating the uncertainty analysis through Equations 3 to 6, the resulting uncertainty in dynamic pressure corrected for Mach number effects is ±0.11% of reading. The uncertainty in the air density is a function of the uncertainty in absolute static pressure and temperature in Kelvin, and is ±0.1% of reading.

The uncertainty in the calculated airspeed is a function of the uncertainty in air density and in dynamic pressure corrected for compressibility effects, and is equal to ±0.074% of reading.

7.3.2 Lift, Drag and Pitching Moment

The uncertainty associated with each of the 2,000 lbs normal load cells is ±9.96 N (±2.24 lbs), the uncertainty of the 500 lbs chord-wise port load cell is ±2.49 N (±0.56 lbs) and the uncertainty of the 1,000 lbs chord-wise starboard load cell is ±4.98 N (±1.12 lbs). The results from the balance calibration load checks indicate an accuracy of ±3.11 N (±0.70 lbs) in the normal direction and ±4.40 N (±0.99 lbs) in the axial direction, or ±0.0011 C_l and ±0.0016 C_d at 100 kts.

7.3.3 Elevator Hinge Moment

As mentioned in Section 0, the torque sensor used to measure the elevator hinge moment has an uncertainty of ±2.26 Nm (1.67 ft-lb). When the hinge moment coefficient is calculated using the test section dynamic pressure at 100 kts, the resulting uncertainty in the coefficient at rotation is ±0.0008 C_h.

7.3.4 Elevator Deflection Angle

Due to backlash in the system, there is an estimated uncertainty in the elevator of ±0.45°.

7.4 Analysis and Interpretation of Time Series Data and Photographs

As previously mentioned in Section 5.3, for each run the main points of interest are at the start of the neutral hold (1), the start of the main rotation (2), the end of the main rotation (3) and the end of the run (4) as labelled in Figure 29. This section presents an example of the time series data and photography at these points of interest. For the fluid run presented in Figure 29 the hinge gap was set to a 4 mm hinge gap, using Scenario 1 deflections with a 115 kts acceleration profile after the application of IV-L fluid. The data presented is from NRC Run #55 (EASA Run #42).

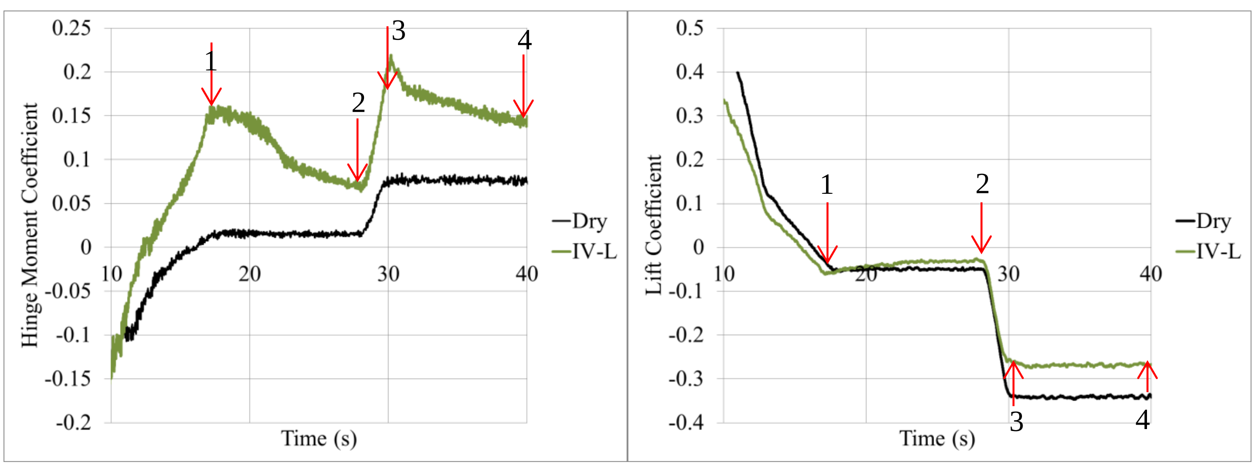


Figure 29 Hinge Moment and Lift Coefficients vs. Time

As the speed of the wind tunnel increases, the fluid moves downstream due to the shear forces of the air acting on the model. Since the runs start with a positive elevator deflection, the horizontal stabilizer acts like a conventional wing in that the low pressure side is on the upper surface. The fluid that has entered the gap area, due to gravity and the elevator cycle prior to the start of the run, remains trapped in that area and starts to move against gravity towards the upper surface of the model due to the pressure difference between the upper and lower surfaces. Once the elevator reaches the neutral position that pressure difference is minimized, or changes direction so that the low pressure side is on the lower surface of the model, and the fluid that was contained in the gap is flushed through to the slower surface of the elevator, as shown in Figure 30. This contaminates the lower surface of the elevator prior to the start of the main rotation sequence.

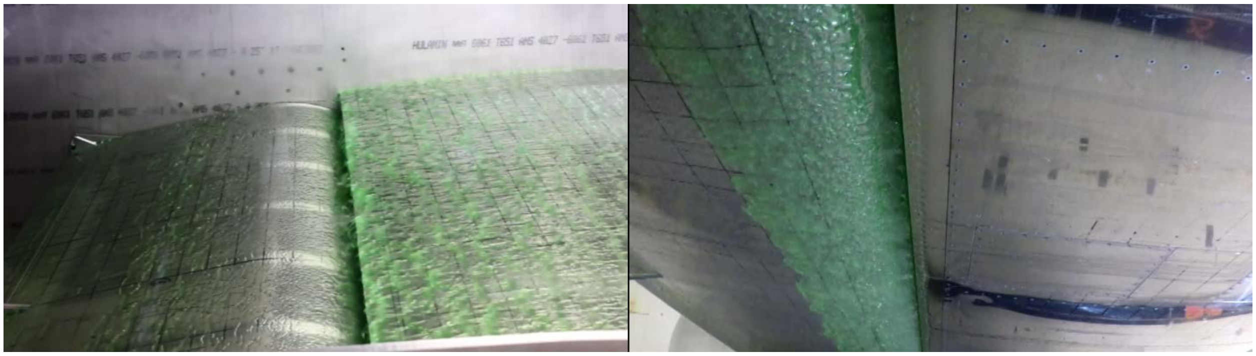
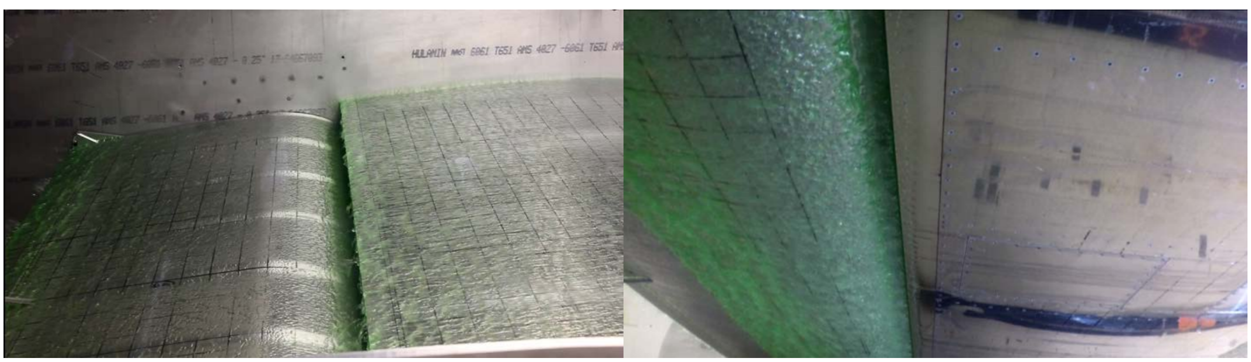


Figure 30 APS Photos Prior to Start of Neutral Hold

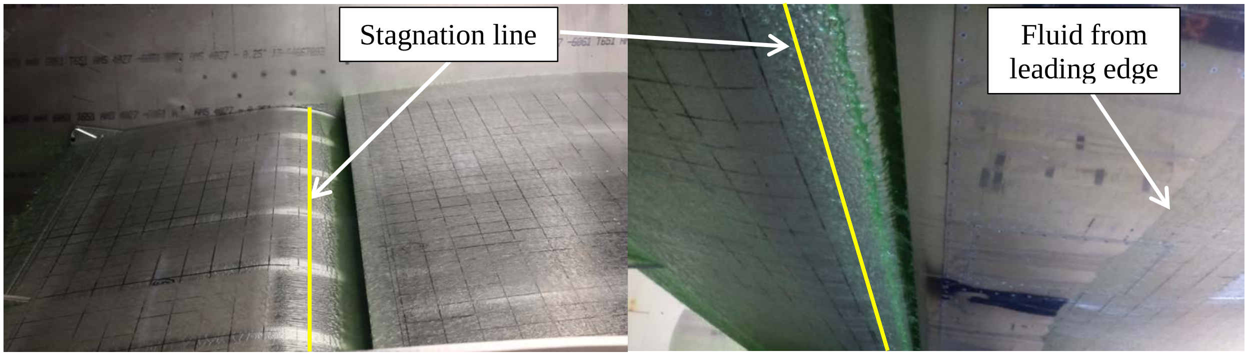
The state of the model and fluid at the start of the neutral hold (Point 1) is shown in Figure 31, when δ_E = -2°. At this point the upper surface of the main element contains a significant amount of fluid that has not sheared off and the lower surface of the main element has no fluid contamination. There is a significant amount of fluid on both the upper and lower surfaces of the elevator, with all of the fluid on the lower surface of the elevator pulled from the upper surface through the hinge gap.



(a) Upper surface (b) Lower Surface

Figure 31 APS Photos at Start of Neutral Hold (Point 1)

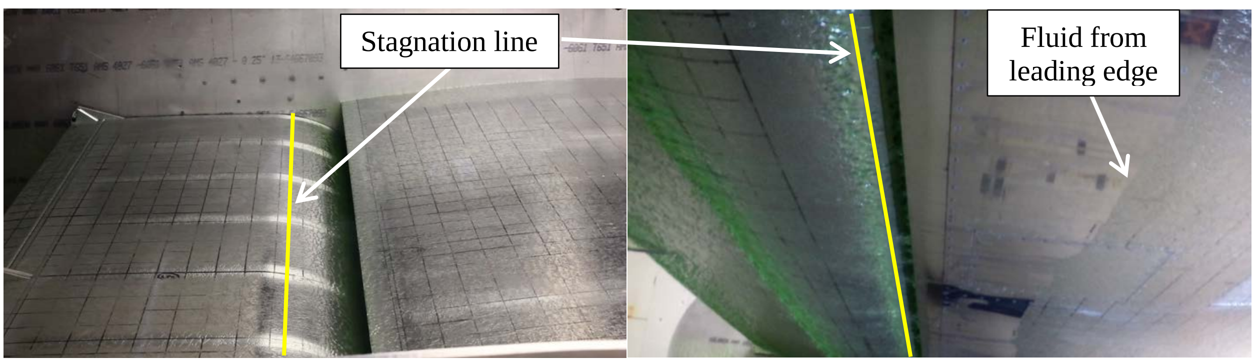
The state of the model and fluid at the start of the main rotation (Point 2) is shown in Figure 32, and the elevator angle has not changed from δ_E = -2°. During the hold period, a large amount of fluid has sheared off the upper surface of the main element and the upper and lower surfaces of the elevator. The stagnation line of the elevator upper and lower surfaces is at the approximate location indicated in yellow on the figure, with all the fluid downstream of this location continuing to shear off the model and all the fluid upstream of this location staying in the gap between the elevator and the main element. The ridge of fluid on the lower surface of the elevator is caused by the fluid in the gap detaching from the downstream edge of the main element and reattaching to the elevator upstream of the stagnation line. On the lower surface of the main element a thin wave of fluid originating from the leading edge is slowly moving downstream.



(a) Upper surface (b) Lower Surface

Figure 32 APS Photos at Start of Main Rotation (Point 2)

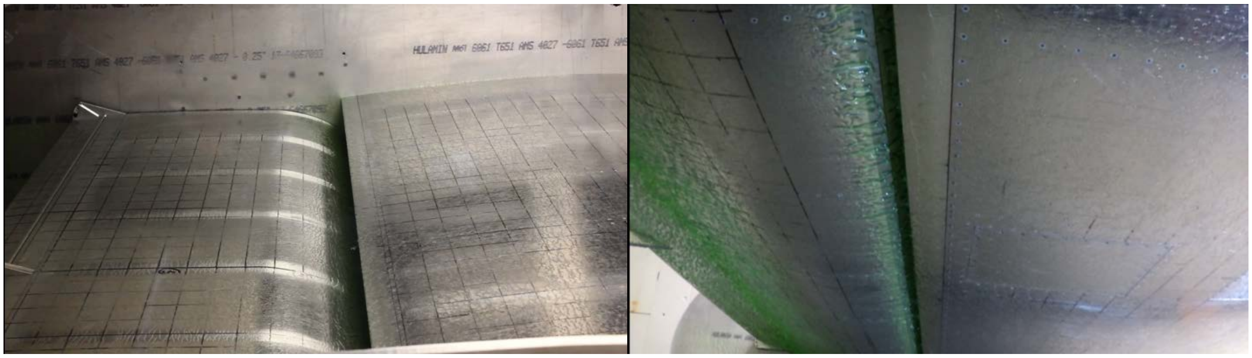
The state of the model and fluid at the end of the main rotation (Point 3) is shown in Figure 33, when δ_E = -10°. The change in elevator deflection angle means an increase in the pressure differential between the upper and lower surface and a change in the stagnation point on the elevator, as shown by the yellow lines in the figure below. The fluid that was trapped in the gap during the hold period is flushed through to the lower surface of the elevator. The thin wave of fluid on the lower surface of the main element continues its downstream progression. The upper surfaces of the main element and the elevator have minimal fluid remaining on them at this point.



(a) Upper surface (b) Lower Surface

Figure 33 APS Photos at End of Main Rotation (Point 3)

The state of the model and fluid at the end of the run (Point 4) is shown in Figure 34, and the elevator angle has not changed from δ_E = -10°. The shear forces continue to clean the fluid off the lower surface of the elevator. The fluid near the downstream end of the elevator is slow to clean off, which may be due to flow separation in that area. The fluid that was progressing downstream on the lower surface of the main element has now completely covered the lower surface and that fluid is flowing onto the lower surface of the elevator. The upper surfaces of the main element and the elevator continue to have minimal fluid on them at this point.



(a) Upper surface (b) Lower Surface

Figure 34 APS Photos at End of Run (Point 4)

7.5 Phase 1: Establish Evaluation Criteria

The effect of the hinge gap spacing on the dry elevator performance was evaluated in order to provide baseline performance characteristics against which to compare the fluid runs. Three different hinge gap sizes were tested: 2 mm, 4 mm and 8 mm. Based on the model chord of 1.82 m (6 ft), these values correspond to hinge gaps of 0.11%, 0.22% and 0.44% c_{HS} respectively.

Being used as baselines, the dry cases were performed multiple times in order to evaluate the repeatability of the data. The results shown in Figure 35 are an average of all the dry runs performed for each hinge gap setting. The repeatability of the dry model performance is on average ±0.002 C_h, ±0.004 C_l, ±0.0007 C_d and ±0.001 C_m. There is slightly more variation at the lower tunnel speeds (V < 50 kts) that aren't considered for these tests and data are only included for points above that speed.

The lift coefficient plot shows that at $\delta_E = 0°$ there is a 0.025 offset in lift coefficient due to a misalignment of the model relative to the zero-lift angle of attack. This offset is small and should not affect the overall results of the research program. The elevator hinge moment is not completely symmetric about $\delta_E = 0°$; this is due to Reynolds number effects as the speed is between 40 kts (Re ~2.75×10^6) at the most positive deflections and 115 kts (Re ~8×10^6) at the most negative deflections.

The results show that the hinge gap has an influence on the dry model performance, with the larger hinge gap decreasing the hinge moment coefficient and lift coefficient for a given elevator deflection angle. Compared to the 2 mm and 4 mm gap cases, the large 8 mm creates distinct changes in the aerodynamic performance of the dry model. Therefore the fluid runs must be individually compared against the appropriate dry baseline values measured with the same hinge gap.

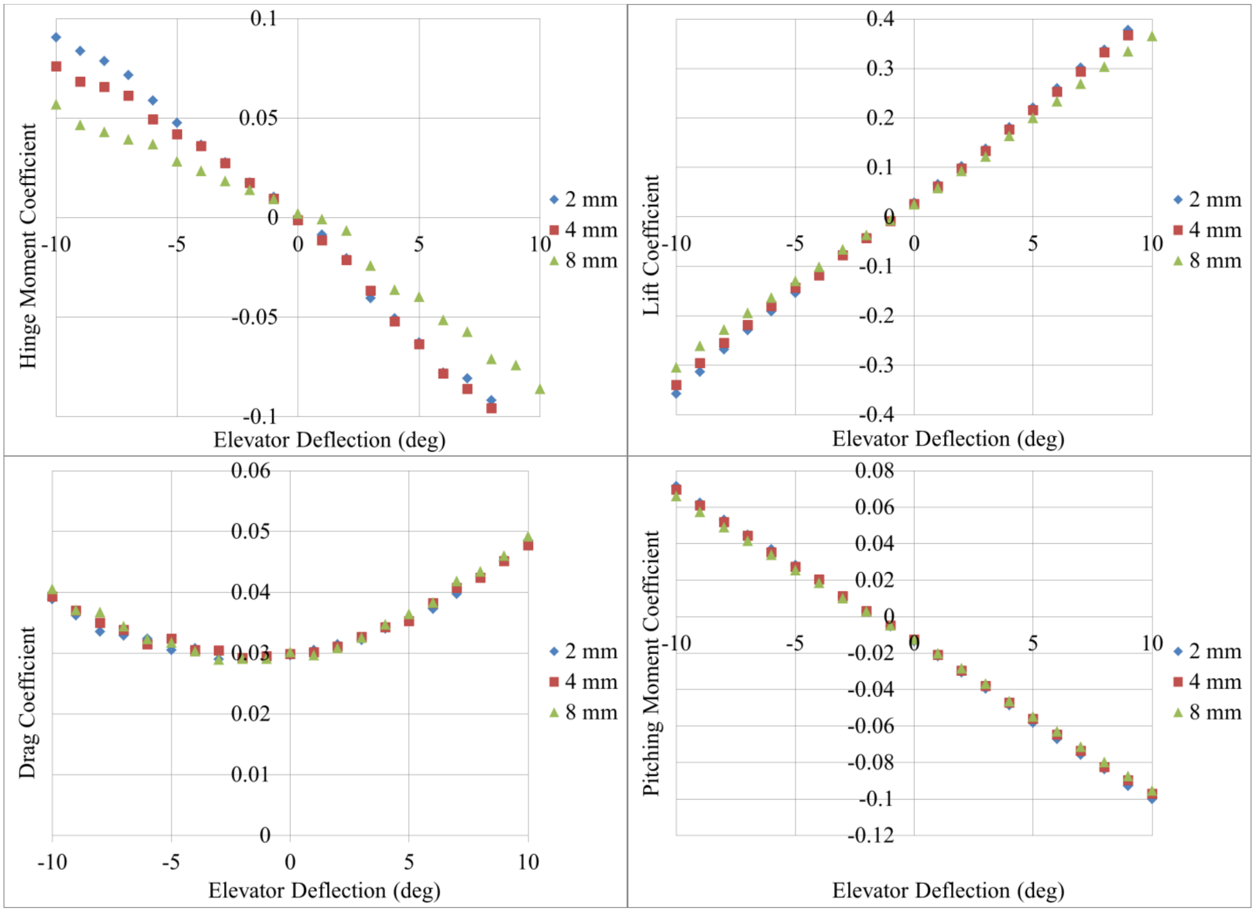


Figure 35 Dry Horizontal Stabilizer Performance for Varying Hinge Gap

7.6 Phase 2: Identify Contributing Variables

To understand the factors contributing to the problem with the horizontal stabilizer performance on take-off, a number of factors including the take-off profile, fluid type, air temperature and horizontal stabilizer hinge gap were varied systematically. The take-off scenarios were defined in Section 5.1 and control law evaluation points were identified in Section 5.3. All of the data provided in this section are from individual test cases; repeatability runs to establish the effects of experimental variations on lift and hinge moment were not possible due to time constraints. To ensure the individual run results were reasonable and correct without repeating each case, the results were assessed individually for the effects of the different inputs and compared with similar cases.

7.6.1 Scenario 1 – Effect of Fluid Type and Gap Size

The effects of the fluids on the horizontal stabilizer performance using take-off Scenario 1 and a 115 kts acceleration profile are shown in Figure 36. The data shown are from individual runs, not averages of runs, and a list of the corresponding run numbers are provided in Table 9.

Table 9 Scenario 1 Run Log Information

Hinge Gap (mm)	NRC Run #	EASA Run #	Fluid
2	27	18	IV-A75
	31	21	IV-L
	33	23	II-F
	37	27	III-P50
4	52	40	II-F
	55	42	IV-L
	61	46	IV-A75
	63	48	III-P50
8	42	31	IV-L
	43	32	II-F
	44	33	IV-A75
	46	35	III-P50

At the start of the neutral position, all of the fluids show larger hinge moments than the established +50% C_h criteria and the lift coefficient shows both positive and negative variations about the baseline dry value depending on the fluid. At the start of the neutral position the velocity is between 80 and 90 kts, but the pilot isn't trying to pull back on the controls to rotate the aircraft at this point. During the hold period a significant amount of fluid is removed from the model due to shear forces. Although the results at the start of the neutral hold are presented, there will be minimal discussion on the aerodynamic impact of the fluids at this point as they are not critical to the rotation sequence.

At the start of rotation both the IV-L and II-F fluids show hinge moments on the order of double to triple the baseline, although the lift coefficients are comparable to the baseline. To a pilot this means that the force required to pull back on the control column would feel high, but that the aircraft would likely start to rotate normally or with some delay until the speed increased sufficiently to generate the required lift. The IV-A75 and III-P50 fluids show hinge moments within the established limits, indicating that a significant amount of fluid has sheared off the model surface and the pilot would experience typical control column forces.

At the end of the rotation, the elevator has changed from a neutral position to a highly deflected position and any fluid that was trapped in the gap between the elevator and the horizontal stabilizer gets flushed through onto the lower surface of the elevator due to the pressure differential. At this point the IV-L, II-F and IV-A75 fluids all show increases in the hinge moment greater than the +50% C_h criteria for all gap sizes, with the hinge moment further increasing for larger hinge gaps. The III-P50 fluid results are near or under the +50% C_h criteria for gap sizes of 2 mm and 4 mm, but increase above this criterion for an 8 mm gap. For the lift coefficients at the end of rotation, all of the fluids fail the -10% C_l criteria, except for the III-P50 case at a 2 mm gap size.

At the end of the run the fluid has had an extra 10 s to shear off the model surface, and this cleaning action brings the hinge moment and lift coefficients within the established limits for the 2 mm gap. The 4 mm and 8 mm gaps see less improvement, so it appears that a larger hinge gap corresponds overall to worse performance of the horizontal stabilizer.

Fluids IV-L and II-F have very similar aerodynamic performance at all four evaluation points for all the hinge gap sizes. Based on these results, subsequent testing may use only one fluid or the other in order to use the research program time more effectively.

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

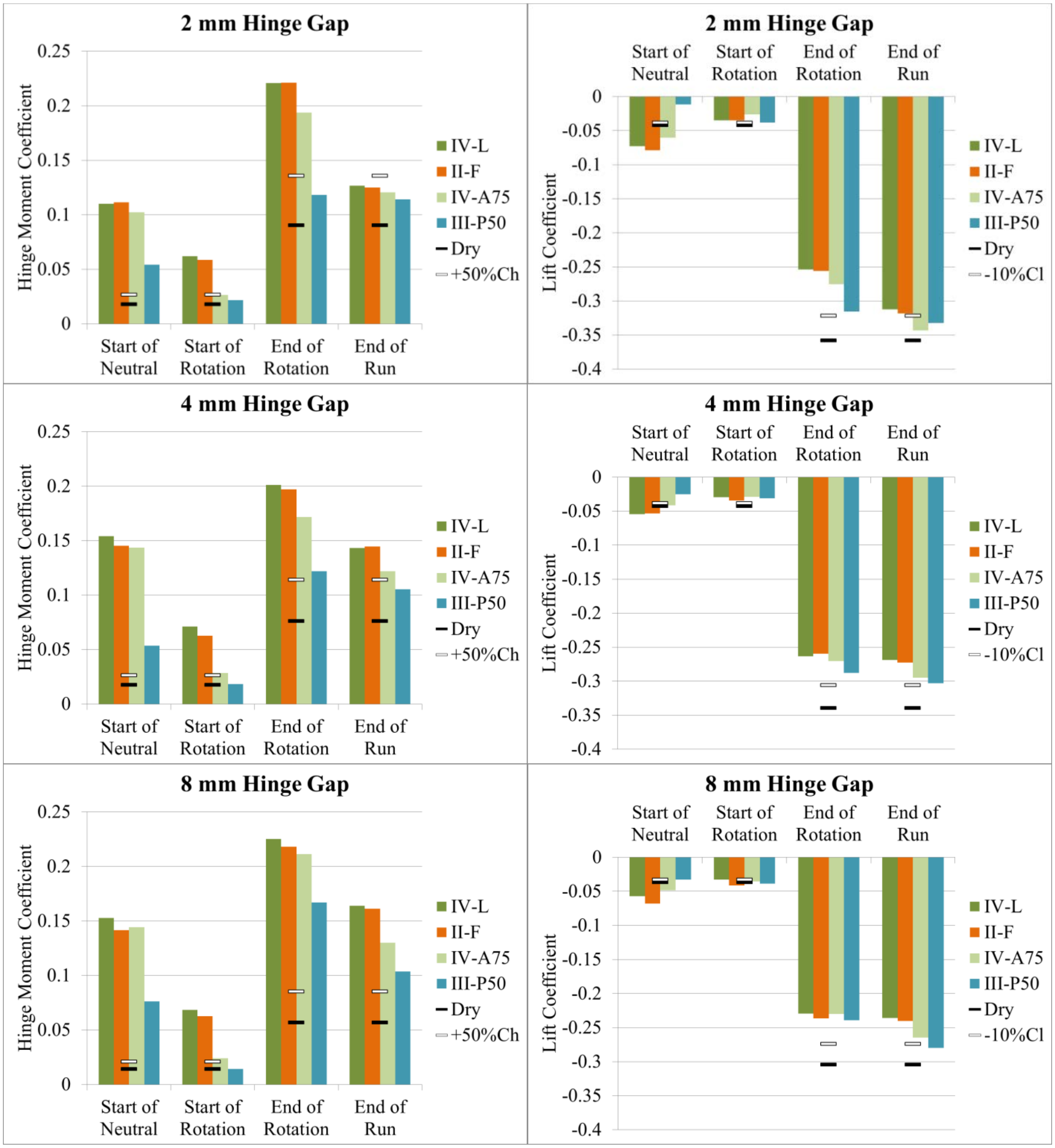


Figure 36 Effects of Fluids and Hinge Gap on Scenario 1 Performance

7.6.2 Scenario 2 – Effect of Fluid Type and Gap Size

The effects of the fluids on the horizontal stabilizer performance using take-off Scenario 2 and a 105 kts acceleration profile are shown in Figure 37. A more limited set of data was collected for this scenario, and due to an error in the run profile the ‘end of run’ data point is not available for the 4 mm hinge gap case. The data shown are from individual runs, not averages of runs, and a list of the corresponding run numbers are provided in Table 10.

Table 10 Scenario 2 Run Log Information

Hinge Gap (mm)	NRC Run #	EASA Run #	Fluid
2	25	17	IV-A75
	30	20	IV-L
	34	24	II-F
	36	26	III-P50
4	68	52	II-F
8	45	34	IV-A75
	48	37	III-P50

At the start of the neutral position and the start of rotation the hinge coefficients have an opposite sign compared to the baseline values. This shows the significant impact the fluid can have on the aerodynamic properties of the model. The magnitude of the hinge coefficient at the start of rotation is still less than the baseline value and the lift coefficient is comparable to the baseline case, so a pilot may not notice any change in elevator performance during this portion of take-off. Also note that the hold period for Scenario 2 is much shorter than for Scenario 1 (4 s instead of 11 s.) so there is less time for the fluid to shear off the model and improve the aerodynamic performance of the model. This can be seen in the figures below, where for Scenario 1 runs there was a noticeable difference between the start of the neutral hold and the start of rotation, there is minimal differences for most runs between those points for Scenario 2.

As with Scenario 1, as the elevator moves from the neutral position at the start of rotation to the higher deflection angle at the end of rotation, the fluid trapped in the gap between the horizontal stabilizer and the elevator gets sucked through onto the lower surface of the elevator due to the pressure differential. This results in larger hinge moments exceeding the +50% C_h criteria at all gap sizes, and the magnitude of the hinge moment coefficient again increases with gap size.

Despite the increase in hinge moment, the lift coefficients at both the start and end of the rotation are close to or greater than the baseline values. Therefore even if a pilot experienced heavier than normal forces on the control column, the aircraft would likely rotate through its take-off profile without any problems. By the end of the run, the majority of the values are back within the hinge moment coefficient limits. This may be because at the smaller elevator deflections the pressure gradient through the hinge gap isn’t as large and less fluid is pulled through to contaminate the lower surface of the elevator.

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure 37 Effects of Fluids and Hinge Gap on Scenario 2 Performance

7.6.3 Scenario 3 – Effect of Fluid Type

A single run was performed using take-off Scenario 3 and a 115 kts acceleration profile, with the results shown in Figure 38. The hinge gap was set to 2 mm for this test and there is no 'hold' period before rotation so only three evaluation points are used. The data corresponds to NRC Run #39 (EASA Run #29).

At the start of rotation, the elevator deflection is 0° so the hinge moment coefficient for the baseline case is equal to zero. There is a small amount of lift at this elevator deflection for the baseline case due to the model offsets previously mentioned. Looking at the results with fluid at the start of rotation, there is a positive increase in hinge moment on the elevator due to the effects of the fluid moving over the elevator surface, while the lift stays essentially the same as the baseline case.

At the end of the rotation, the hinge moment and lift coefficients both exceed the established limits, but not by the large magnitude seen in Scenarios 1 and 2. By the end of the run the hinge moment is close to the +50% C_h limit, but the overall lift is still lower than the -10% C_l limit.

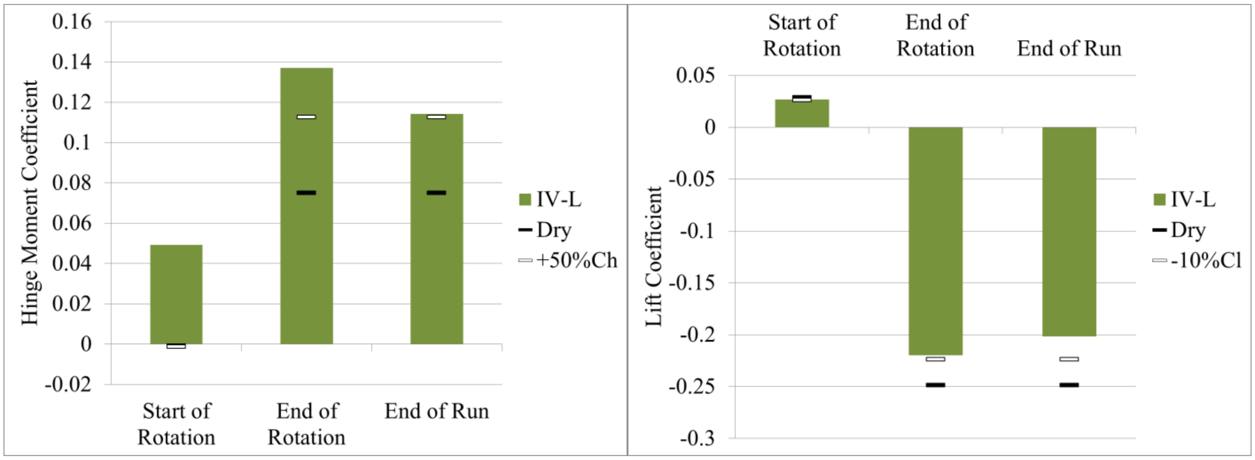


Figure 38 Effects of Fluid on Scenario 3 Performance

7.6.4 Scenario 4 – Effect of Fluid Type

A single run was performed using take-off Scenario 4 and a 115 kts acceleration profile, with the results shown in Figure 39. The hinge gap was set to 4 mm for this test and the same elevator deflection angles and speeds as Scenario 1 are used but there is no 'hold' period before rotation, so only three evaluation points are used. The Scenario 4 data corresponds to NRC Run #58 (EASA Run #44) and the Scenario 1 data used for comparison purposes corresponds to NRC Run 55 (EASA Run #42).

The results show that, for this case, the 'hold' period before the start of rotation does not have a significant impact on the aerodynamic performance of the horizontal stabilizer during or after the rotation. As the pilot accelerates the aircraft down the runway, it makes no difference to the performance at rotation whether the pilot holds the elevator at one angle for a period of time or gradually approaches that angle over the same period of time.

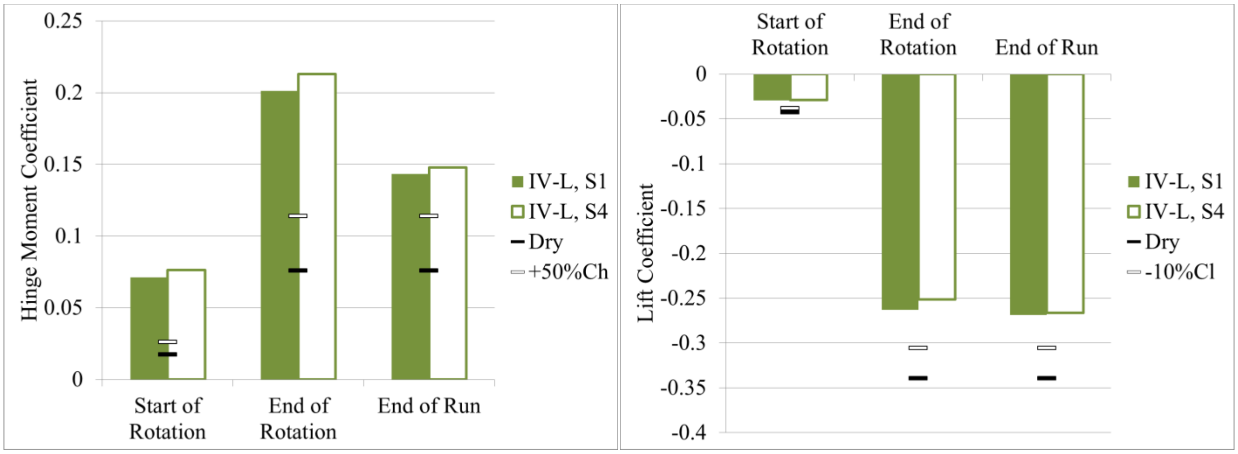


Figure 39 Effects of Fluid on Scenario 4 Performance

7.6.5 Scenario 5 – Effect of Fluid Type

A single run was performed using take-off Scenario 5 and a 115 kts acceleration profile, with the results shown in Figure 40. This scenario is meant to simulate a pilot that has completed normal rotation procedures following the same profile as Scenario 2 but still has not lifted off the runway, so the pilot continues to pull back on the control column as the aircraft accelerates. The Scenario 5 data corresponds to NRC Run #57 (EASA Run #43) and the Scenario 2 data used for comparison purposes corresponds to NRC Run #30 (EASA Run #20). The hinge gap was set to 4 mm for this test and the dry values for hinge moment coefficient and lift coefficient at the end of extra rotation and the end of run correspond to data from Scenario 1.

The results show that the performance at the start of rotation and the end of normal rotation are similar, as expected. The slightly smaller values of C_h for Scenario 5 may be due to differences in the acceleration profile of the wind tunnel as it is targeting 115 kts instead of 105 kts. After the end of normal rotation, as the pilot continues to pull back and the elevator deflection increases, the increase in hinge moment relative to the baseline value does not change. This indicates that fluid is continuing flow through the hinge gap due to the increasing pressure differential and contaminating the lower surface of the elevator.

At the end of the run after the 10 s hold period, there is some cleaning action of the fluid due to shear forces and the hinge moment and lift coefficients start to approach the baseline values.

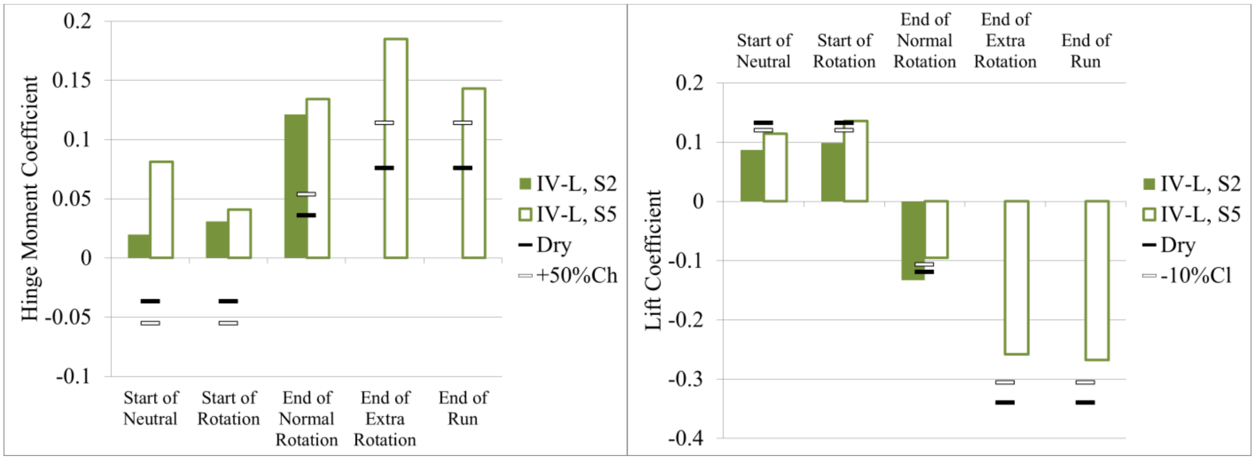


Figure 40 Effects of Fluid on Scenario 5 Performance

7.6.6 Effect of Temperature on Horizontal Stabilizer Performance

The effect of temperature on the horizontal stabilizer performance was evaluated for all four fluids over the range of temperatures that were available during the research program. The hinge gap was set to 4 mm for these tests and Scenario 1 deflections with 115 kts acceleration profiles were used. A list of the corresponding run numbers are provided in Table 11.

Table 11 Temperature Variation Run Log Information

NRC Run #	EASA Run #	Fluid	OAT (ºC)	WAT (ºC)
55	42	IV-L	-0.1	0.2
66	50	IV-L	-7.6	-5.9
81	64	IV-L	-10.7	-7.8
52	40	II-F	1.0	3.7
67	51	II-F	-7.7	-6.1
61	46	IV-A75	-0.1	0.0
71	54	IV-A75	-6.4	-5.4
63	48	III-P50	-0.6	-0.2
72	55	III-P50	-4.8	-5.5

Although a minimum 10°C temperature difference target was set in the test plan, the maximum temperature difference obtained in the air temperature around the model was 8°C for the IV-L fluid, 9.8°C for the II-F fluid, 5.4°C for the IV-A75 fluid and 5.3°C for the III-P50 fluid. This is due to the weather conditions in Ottawa and is not a factor that can be controlled. Looking at the results in Figure 41 through Figure 44, there does not appear to be any significant differences in hinge moment or lift coefficients due to temperature changes. It is unknown if the same would be seen with larger temperature differences.

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

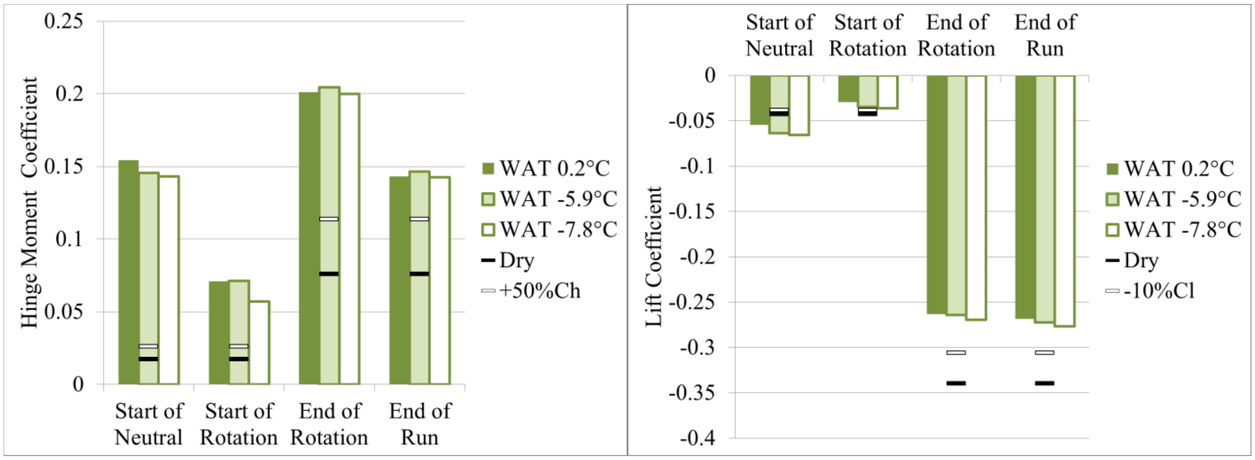


Figure 41 Effects of Wing Area Temperature on IV-L Fluid Performance

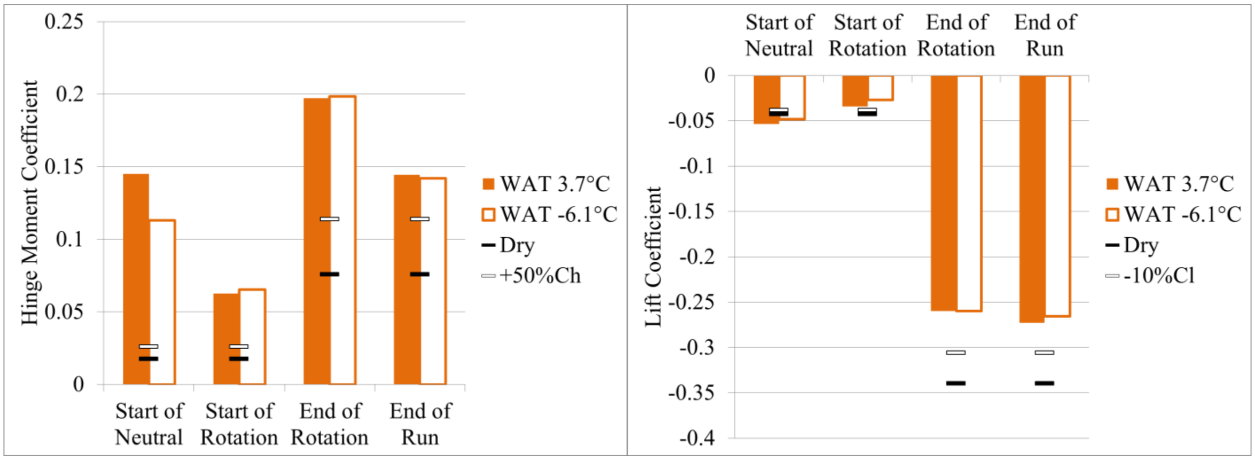


Figure 42 Effects of Wing Area Temperature on II-F Performance

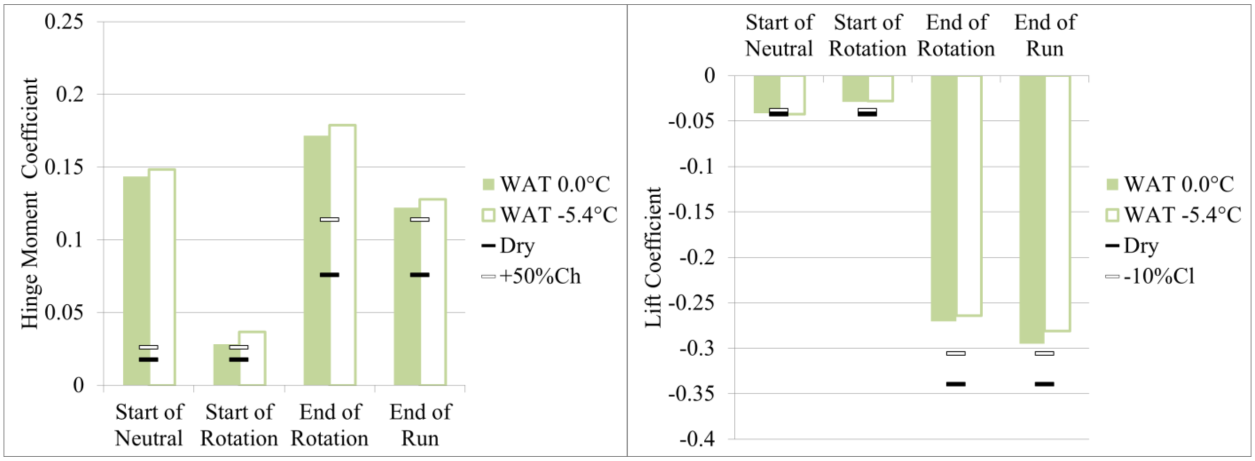


Figure 43 Effects of Wing Area Temperature on IV-A75 Performance

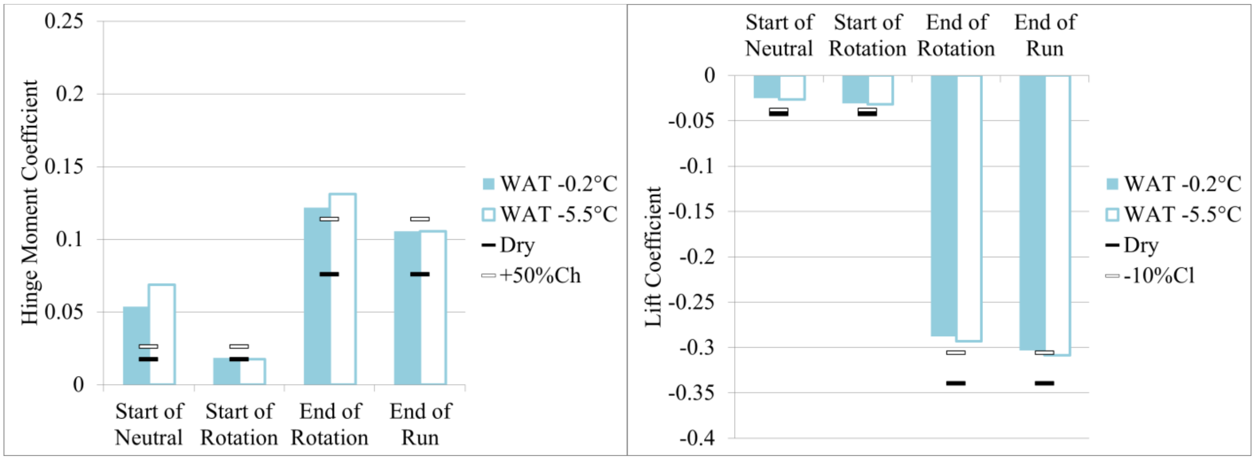


Figure 44 Effects of Wing Area Temperature on III-P50 Performance

7.6.7 Effect of Downwash on Horizontal Stabilizer Performance

The effect of main wing downwash on the horizontal stabilizer performance was simulated by pitching the model down such that α = -3.5°. A baseline run was performed to establish the dry performance of the model in this configuration. A fluid run was then performed to see if the additional aerodynamic forces introduced by the downwards angle of attack change the effects of the fluid on the hinge moment and lift coefficients. The hinge gap was set to 4 mm for this test and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 45. The downwash data corresponds to NRC Run #82 (EASA Run #65) and the data at α = 0° used for comparison purposes corresponds to NRC Run #81 (EASA Run #64).

The results show that at all evaluation points, the differences in hinge moment between the fluid run and the baseline were larger when α = -3.5°. This is likely because at α = -3.5° there is a pressure differential between the upper and lower surfaces of the horizontal stabilizer, with the low pressure side on the lower surface. This increase in pressure differential compared to the baseline case where α = 0° and encourages more fluid to flow in the elevator gap, further contaminating the lower surface of the elevator and increasing the hinge moment coefficient.

The differences in hinge moment between the fluid run and the baseline are approximately the same for both α = -3.5° and α = 0°, indicating that although there is a significant increase in hinge moment, the overall lift generated by the horizontal stabilizer doesn't change.

Note that the results from this test case are given in order to provide a complete description of the test program completed. However, the results are not considered conclusive nor do they represent a real aircraft configuration.

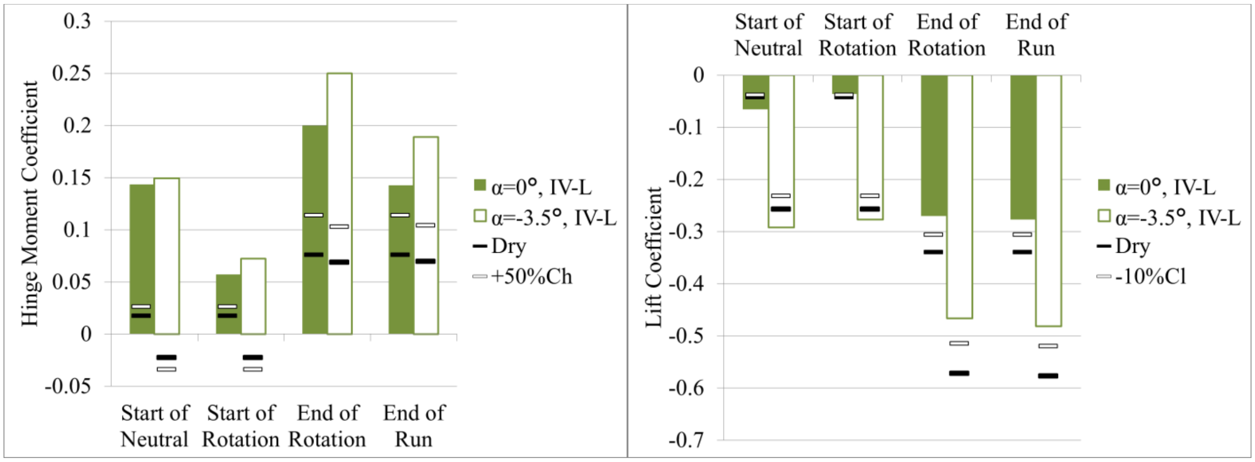


Figure 45 Effects of Downwash on Horizontal Stabilizer Performance

7.6.8 Effect of Trim Tab on Horizontal Stabilizer Performance

The effect of the trim tab setting on the horizontal stabilizer performance was evaluated by manually setting the trim tab to δ_{TT} = 4°. The trim tab deflections follow the same sign conventions as the elevator deflections, with positive angles being a downwards deflection. Settings of δ_{TT} = 8° and δ_{TT} = 12° were also tested without fluid but were determined to be unrealistic settings for this model since they created excessive changes in the hinge moment, and deflection settings smaller than 4° were not available, although they could be added for future testing. The hinge gap was set to 4 mm for this test and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 46. The trim tab data corresponds to NRC Run #83 (EASA Run #66) and the data at δ_{TT} = 0° used for comparison purposes corresponds to NRC Run #81 (EASA Run #64).

The results show that the trim tab has a significant impact on the baseline performance of the horizontal stabilizer, inducing a negative hinge moment coefficient and reducing the lift for the same elevator deflection angles. The differences in hinge moment between the fluid run and the baseline were larger for the case with the trim tab deflected, but the absolute magnitude of the hinge moment with δ_{TT} = 4° fell within the established limits from δ_{TT} = 0° baseline. There is a reduction in lift, so although the trim tab may compensate for the hinge moment increases the pilot would still need to either increase speed or increase total elevator deflection to get the required amount of lift on the horizontal stabilizer to rotate the aircraft.

Note that the results from this test case are given in order to provide a complete description of the test program completed. However, the results are not considered conclusive nor do they represent a real aircraft configuration.

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

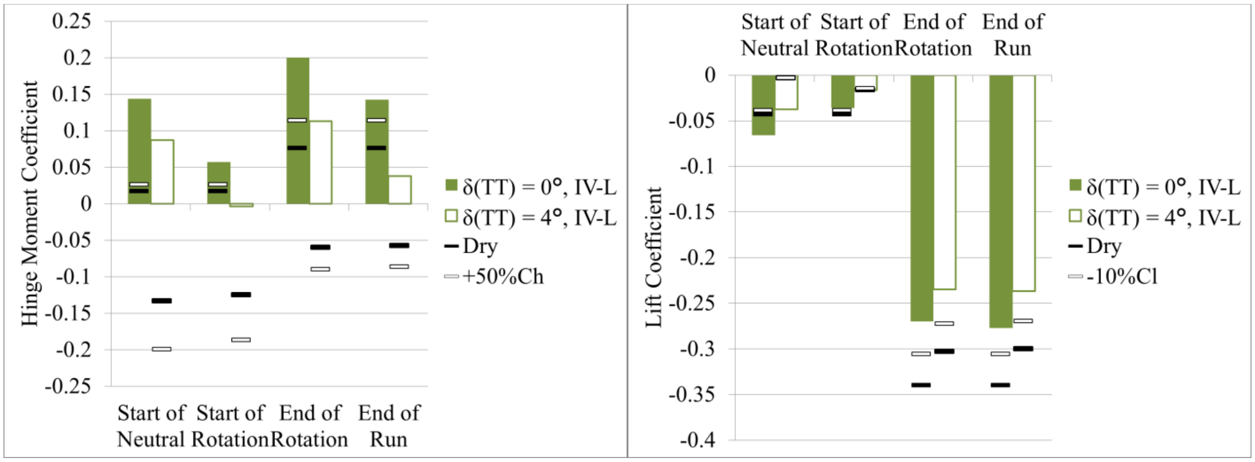


Figure 46 Effects of Trim Tab on Horizontal Stabilizer Performance

7.6.9 Effect of Leftover Fluid on Horizontal Stabilizer Performance

After take-off, there is still some fluid left on the wings and horizontal stabilizer that has not cleaned off due to shear forces, either because there was not enough time for it to clean off or because the fluid is located in an area of low shear (such as in the elevator hinge gap). There was some interest to see if this leftover fluid would have a significant effect on the model performance, simulating a case where a pilot would abort a takeoff because they couldn't rotate the aircraft, then taxi back and try again. This situation was simulated by performing a typical take-off run with a normal amount of fluid, and then repeating the run without cleaning off any of the fluid from the model surface. The hinge gap was set to 2 mm for these tests and both Scenario 1 deflections with a 115 kts acceleration profile and Scenario 2 deflections with a 105 kts acceleration profile were used, with the results shown in Figure 47 and Figure 48 respectively. The leftover fluid data corresponds to NRC Run #32 (EASA Run #22) for the IV-L fluid and NRC Run #35 (EASA Run #25) for the II-F fluid. The data used for comparison purposes corresponds to NRC Run #31 (EASA Run #21) for the IV-L fluid and NRC Run #34 (EASA Run #24) for the II-F fluid.

For both take-off scenarios, each using a different type of fluid, the results show that there is leftover fluid on the model that creates an increase in hinge moment coefficient and a decrease in lift. The overall impact of this leftover fluid is small, and the aerodynamic performance of the horizontal stabilizer stays within the established +50% C_h and -10% C_l criteria. These results show that the rotation difficulties are cause by the fluid applied to the aircraft during the anti-icing process and are not caused by the thin residue that remains for longer periods of time after take-off.

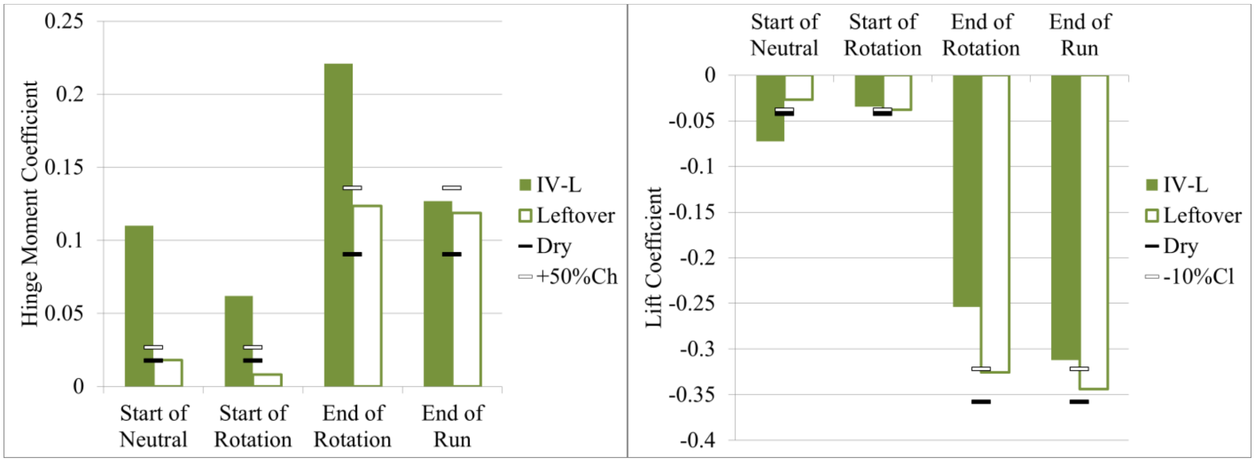


Figure 47 Effects of Leftover IV-L Fluid on Scenario 1 Performance

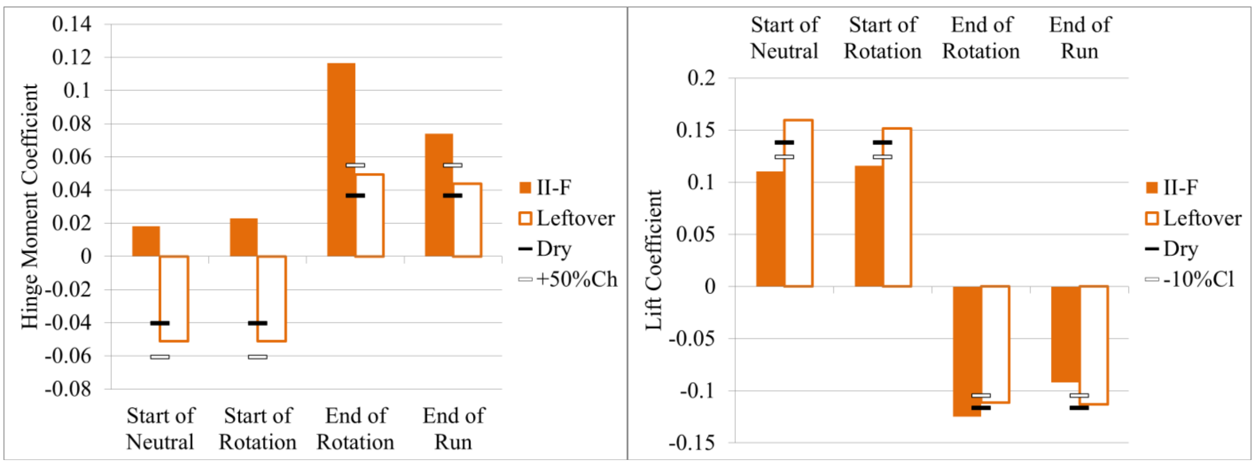


Figure 48 Effects of Leftover II-F Fluid on Scenario 2 Performance

7.6.10 Effect of Lower Surface Fluid on Horizontal Stabilizer Performance

During the test program it was observed that there was a significant amount of fluid on the lower surface of the elevator during the take-off run prior to the start of the rotation sequence (see Section 7.4). In an effort to isolate the effects of this fluid on the lower surface on the aerodynamic performance of the model, the following test case was performed:

1) The wind tunnel was run up to approximately 60 kts with the elevator at δ_E = 13° to distribute the fluid in a similar manner to the typical runs
2) The wind tunnel was stopped
3) The fluid remaining on the upper surface of the model was cleaned off
4) The wind tunnel was completed using the normal acceleration and elevator deflection profiles

The hinge gap was set to 4 mm for this test and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 49. The lower-surface fluid data corresponds to NRC Run #64 (EASA Run #49) and the data used for comparison purposes corresponds to NRC Run #55 (EASA Run #42).

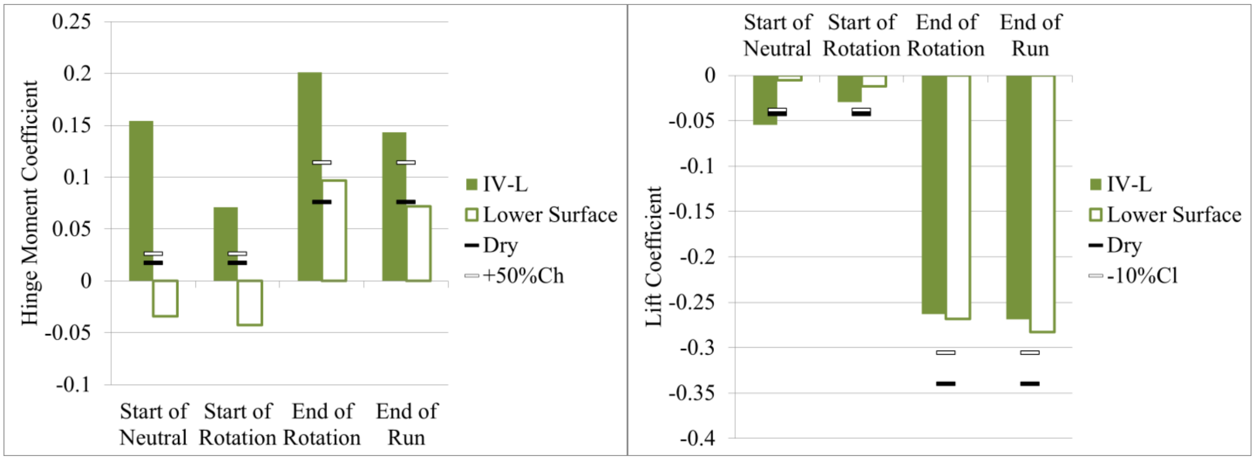


Figure 49 Effects of Lower Surface IV-L Fluid on Horizontal Stabilizer Performance

The results show that the fluid remaining on the lower surface of the elevator has the effect of shifting the elevator hinge moment coefficient in the negative direction compared to when the entire elevator is covered with fluid. With the contamination on the lower surface of the elevator disrupting the flow, the elevator is not as effective at generating lift on the horizontal stabilizer, so there is an overall reduction in lift and hinge moment. Further investigation into the flow characteristics of this model would be useful to help interpret these results.

7.6.11 Effect of 10 mm Hinge Gap with Fluid on Horizontal Stabilizer Performance

The effect of a very large hinge gap was tested by setting the gap to the maximum value of 10 mm and comparing the results to the aerodynamic performance with the same fluids and an 8 mm hinge gap. Unfortunately there is no dry baseline case with 10 mm to compare the results against. The hinge gap was set to 10 mm for these tests and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 50. The 10 mm gap data corresponds to NRC Run #49 (EASA Run #38) for the IV-L fluid and NRC Run #50 (EASA Run #39) for the II-F fluid. The 8 mm gap data used for comparison purposes corresponds to NRC Run #42 (EASA Run #31) for the IV-L fluid and NRC Run #43 (EASA Run #32) for the II-F fluid.

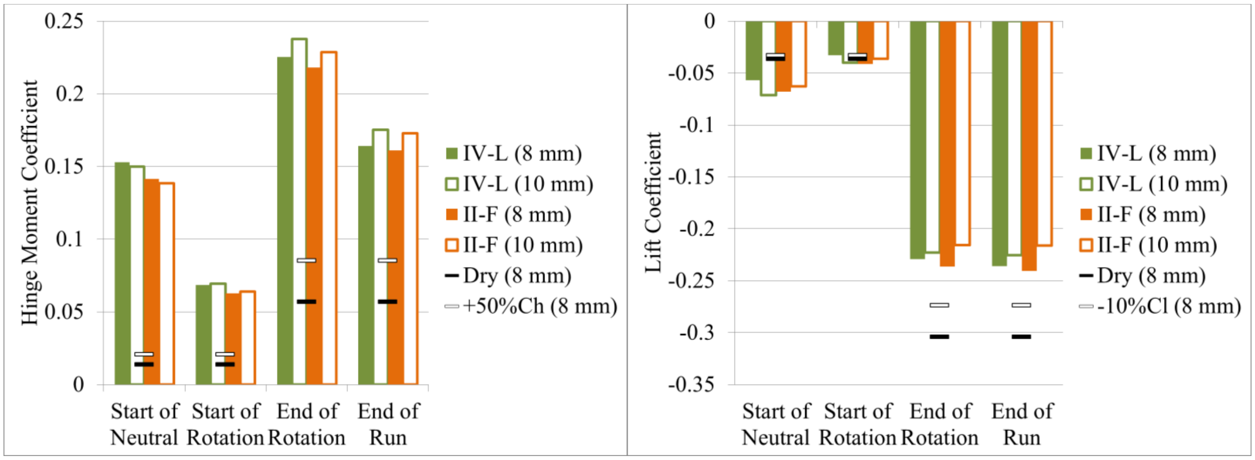


Figure 50 Effects of 10 mm Hinge Gap with Fluids on Horizontal Stabilizer Performance

The results show minimal difference between the 10 mm and 8 mm hinge gap performance with the same fluids. Since there are no baseline measurements with the 10 mm gap size it is not possible to comment on the effects of the fluid relative to the dry case.

7.7 Phase 3: Attempt to Rectify Rotation Difficulties

In Phase 3, modifications to the fluids and fluid application procedures were tested in an attempt to rectify the rotation difficulties seen in the Phase 2 results. These modifications include the addition of a Type I fluid, spraying fluid on the underside of the model, and diluting the fluids with water.

7.7.1 Type I Fluid Application

At the request of EASA staff on-site during the research program, a Type I fluid was obtained from AeroMag 2000, a company that provides de-icing services at the Ottawa International Airport. Type I fluids are used as de-icing agents, have lower viscosities than the anti-icing fluids, and are applied heated. A Type I standard mix fluid was applied at room temperature in a similar manner to the other fluids applied for this research program to examine if its low viscosity would still have an impact on the aerodynamic performance of the horizontal stabilizer. The hinge gap was set to 4 mm for this test and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 51. The data corresponds to NRC Run #73 (EASA Run #56).

The results show that the Type I fluid has minimal effect on the hinge moment and lift coefficients, with the performance at the start of rotation, end of rotation and end of the run well within the +50% C_h and -10% C_l criteria.

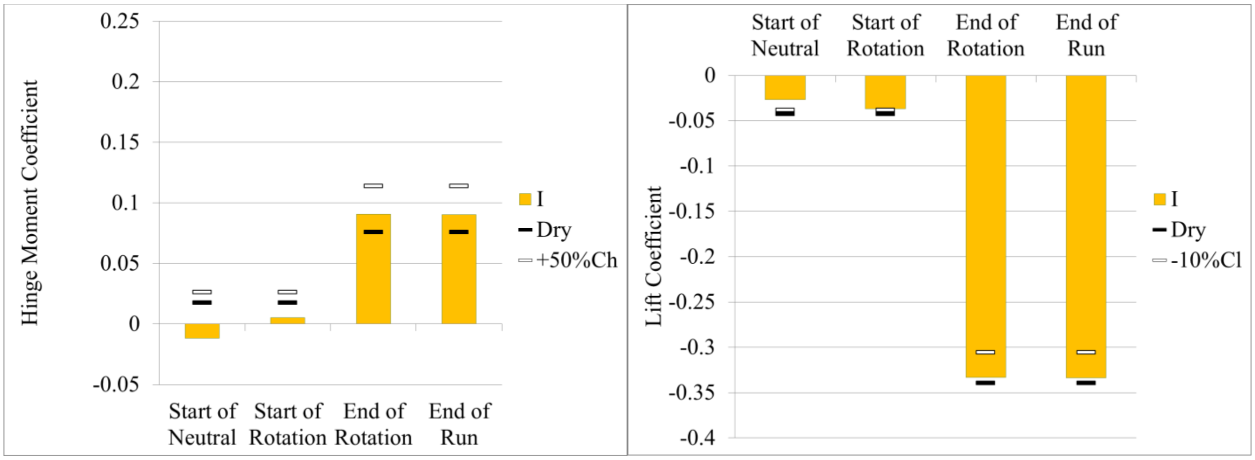


Figure 51 Effects of Type I Fluid on Horizontal Stabilizer Performance

7.7.2 Two-Step De-Icing Process

A two-step de-icing process is used at most airports; a Type I fluid is applied to de-ice the aircraft and then a thickened anti-icing fluid is applied to protect the aircraft from further ice accumulation. It was thought that if a residue from the Type I fluid remains on the horizontal stabilizer underneath the layer of anti-icing fluid this might help the thickened fluids shear off the model and improve horizontal stabilizer performance. A two-step process was tested for two different types of anti-icing fluids, IV-A75 and II-F, using the same type of Type I fluid for both processes. The hinge gap was set to 4 mm for these tests and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 52 and Figure 53.

The two-step data corresponds to NRC Run #62 (EASA Run #47) for the IV-A75 fluid and NRC Run #74 (EASA Run #57) for the II-F fluid. The data used for comparison purposes corresponds to NRC Run #61 (EASA Run #46) for the IV-L fluid and NRC Run #52 (EASA Run #40) for the II-F fluid.

The results show that the addition of a de-icing step with a Type I fluid has no significant impact on the aerodynamic performance of the horizontal stabilizer with anti-icing fluids applied.

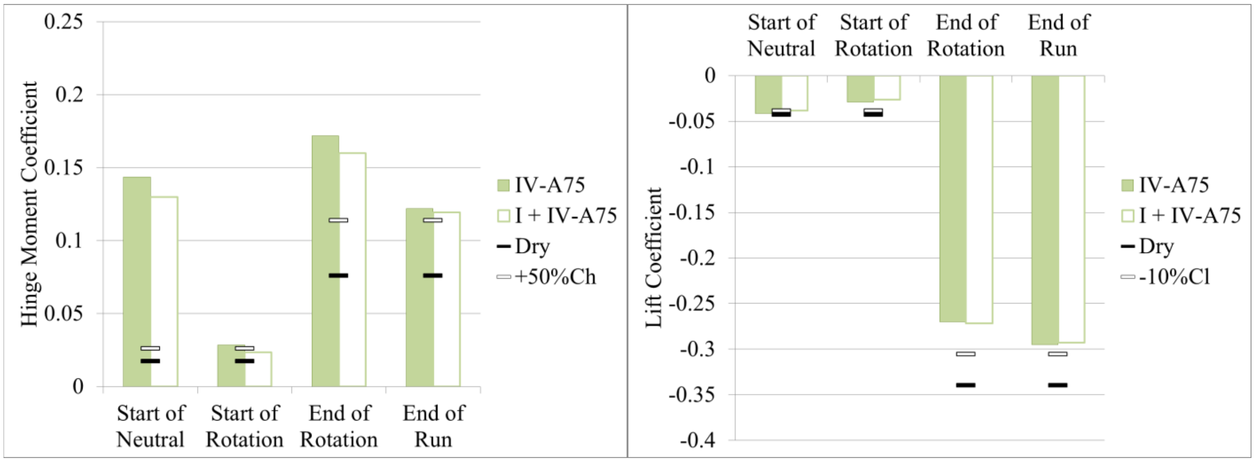


Figure 52 Effect of Two-Step De-Icing Process (I + IV-A75) on Horizontal Stabilizer Performance

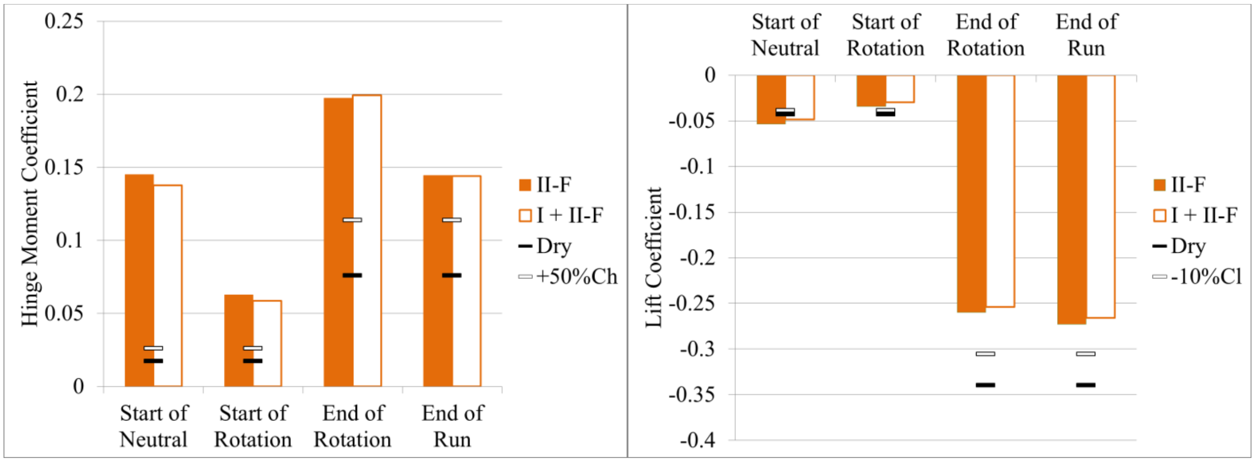


Figure 53 Effects of Two-Step De-Icing Process (I + II-F) on Horizontal Stabilizer Performance

7.7.3 Spraying vs. Pouring Fluid

The effect of spraying the fluids instead of pouring them on the model was evaluated to see if a thinner layer of the fluid would impact the aerodynamic performance of the model. The sprayed fluid was simulated by using a brush to evenly apply a thin coating of fluid to the model surface; this was more consistent than using a garden sprayer as originally planned. For the 'sprayed' fluid runs only 4 L of fluid were applied, compared to the 16 L typically applied for the poured fluid runs. The hinge gap was set to 4 mm for this test and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 54. The 'sprayed' data corresponds to NRC Run #38 (EASA Run #28) and the 'poured' data used for comparison purposes corresponds to NRC Run #31 (EASA Run #21).

The results show minor changes in the hinge moment coefficients for the simulated sprayed fluid, with the values about equal to or greater than the poured fluid case. For the lift coefficient we see that there is an increase in lift coefficient with the sprayed fluid, bringing it closer to the dry baseline values than the poured fluid case.

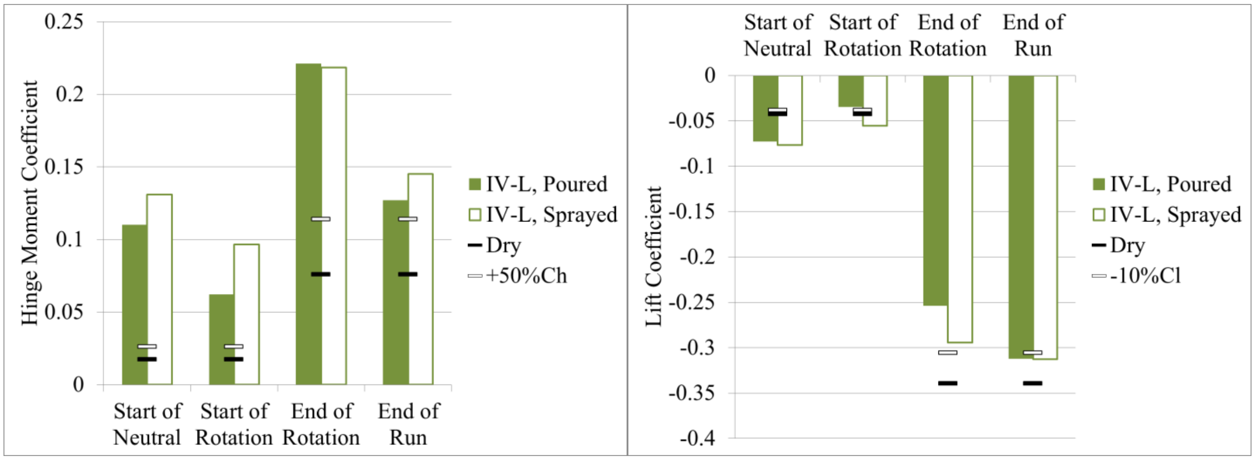


Figure 54 Effects of Spraying vs. Pouring Fluid

7.7.4 Fluid Sprayed on Underside of Model

It has been reported by some operators that spraying anti-icing fluids on the underside of the elevator may balance out the effects of the fluids and achieve hinge moments and lift coefficients closer to the baseline values. This process was tested by spraying fluid on the underside of the horizontal stabilizer model using a garden sprayer and examining the change in aerodynamic performance compared to a run with fluid applied only to the upper surface. The hinge gap was set to 4 mm for this test and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 55. The 'sprayed' data corresponds to NRC Run #75 (EASA Run #58) and the data used for comparison purposes corresponds to NRC Run #31 (EASA Run #21).

The results show that spraying the underside of the model with fluid does not improve the overall aerodynamics of the model, and can worsen the performance during rotation. It is believed that the increase in the hinge moment coefficient is caused at least in part by the fluid flowing on the underside of the elevator, so adding more fluid to this side of the model only makes the problem worse. Although there is a pressure differential at the start of the run that would move the fluid from the lower surface to the upper surface of the elevator through the hinge gap, this occurs at low speeds so the pressure difference isn't as large as when the elevator deflects in the opposite direction at higher speeds.

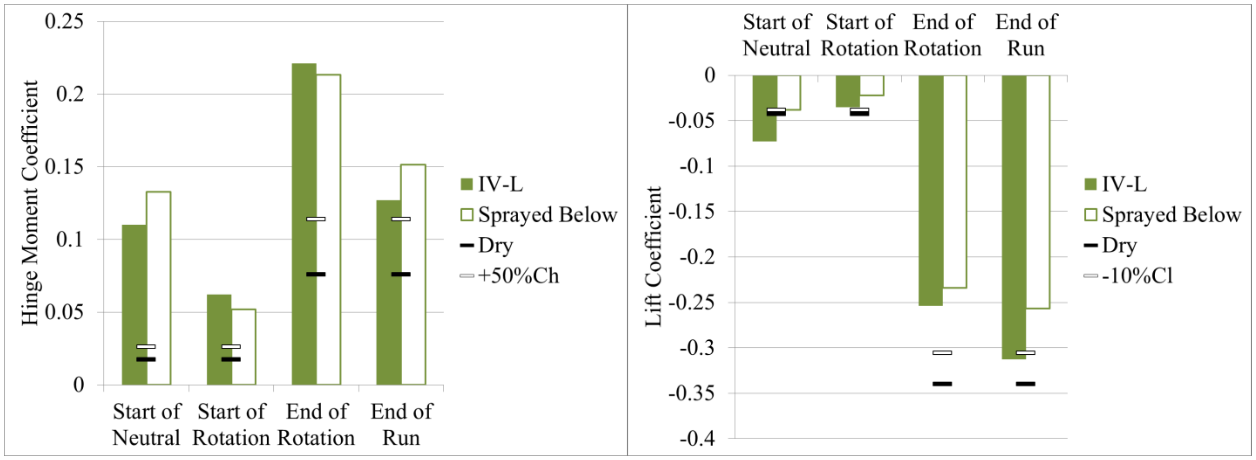


Figure 55 Effects of Additional Fluid Sprayed on Underside of Model

7.7.5 Fluid Dilution

The viscosity of a fluid can be changed through dilution; in this case a 75/25 dilution with hard water was used with the IV-L and II-F fluids. Due to the properties of the propylene glycol fluids, the dilution with water has the effect of increasing the viscosity of the fluid for the dilutions tested here. The run numbers and the corresponding fluids and dilution are provided in Table 12. The corresponding viscosities for these fluids can be found in Table 8. The hinge gap was set to 4 mm for these tests and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 56.

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Table 12 Fluid Dilution Run Log Information

NRC Run #	EASA Run #	Fluid	Dilution
60	45	IV-L75	75/25
70	53	II-F75	75/25
55	42	IV-L	100/0
52	40	II-F	100/0

The results show that the diluted fluids improve the hinge moment coefficients, despite having a higher viscosity than the neat cases. This is consistent with the previous results that show better performance with the IV-A75 fluid than the IV-L and II-F neat fluids despite the IV-A75 fluid having the highest viscosity. However the lift coefficient shows no measurable difference at the start and end of rotation between the neat and diluted fluids, and only minor improvements at the end of the run with the diluted fluids.

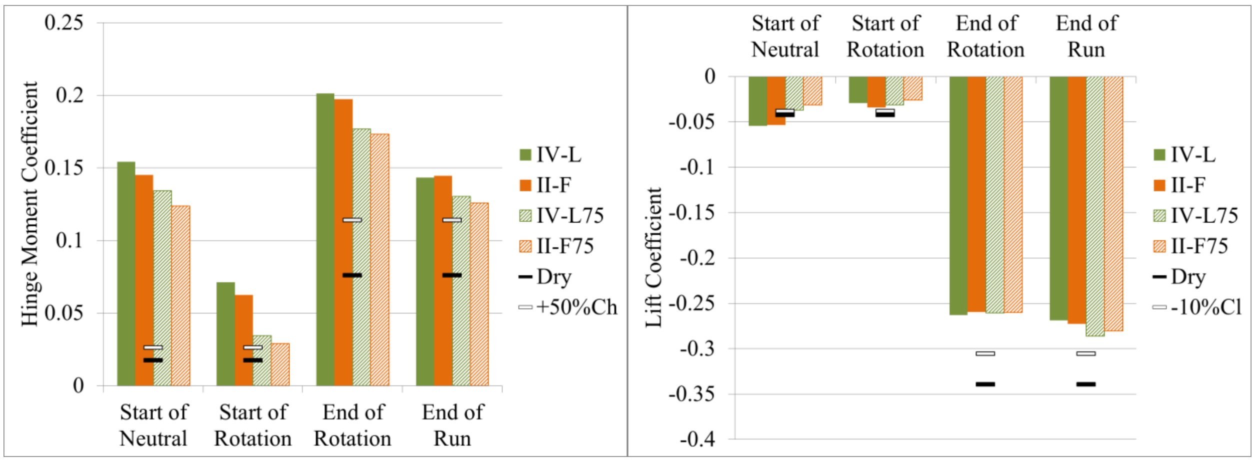


Figure 56 Effects of Fluid Dilution on Horizontal Stabilizer Performance

7.8 Phase 4: Ice Under Horizontal Stabilizer

An objective of the research program, separate from Phases 1 through 3, was to evaluate the effect of a small amount of ice near the stagnation point and underneath the horizontal stabilizer. Cold, near freezing, water was applied to the leading edge of the model in freezing temperature conditions until a substantial layer of ice had built up, as shown in Figure 57. The water ran downstream from the leading edge along the lower surface on the main element. The hinge gap was set to 4 mm for this test and Scenario 1 deflections with a 115 kts acceleration profile were used, with the results shown in Figure 58. The data corresponds to NRC Run #80 (EASA Run #63).

This test case was performed in order to rule out the hypothesis that minor ice contamination underneath the horizontal stabilizer that may be caused by only de-icing the upper surface could create enough lift degradation to affect the aircraft rotation. The method to generate the ice, its coverage and its roughness may not represent operational conditions.

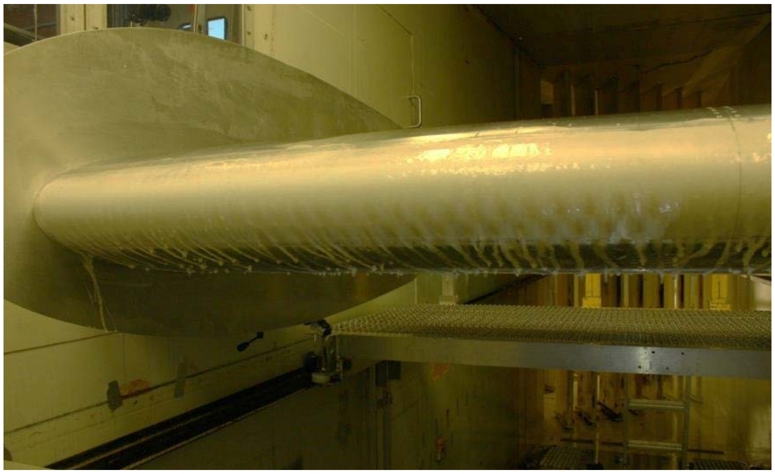


Figure 57 Ice Applied to Model Surface

The results show that the ice had the effect of reducing the hinge moment coefficient at the points of interest, with minor reductions in the lift coefficient. The effect of the ice on the leading edge shape was minimal, but the run-back on the lower surface of the main element would introduce extra turbulence that could create the effects seen on the hinge moment and lift coefficients. Note that these results are with a smooth layer of ice applied only to the leading edge of the model, and are not representative of a case where an entire tail section is exposed to freezing precipitation without anti-icing protection. Also the results presented are from a single test run and single form of ice shape, so conclusions should not be generalized without further data.

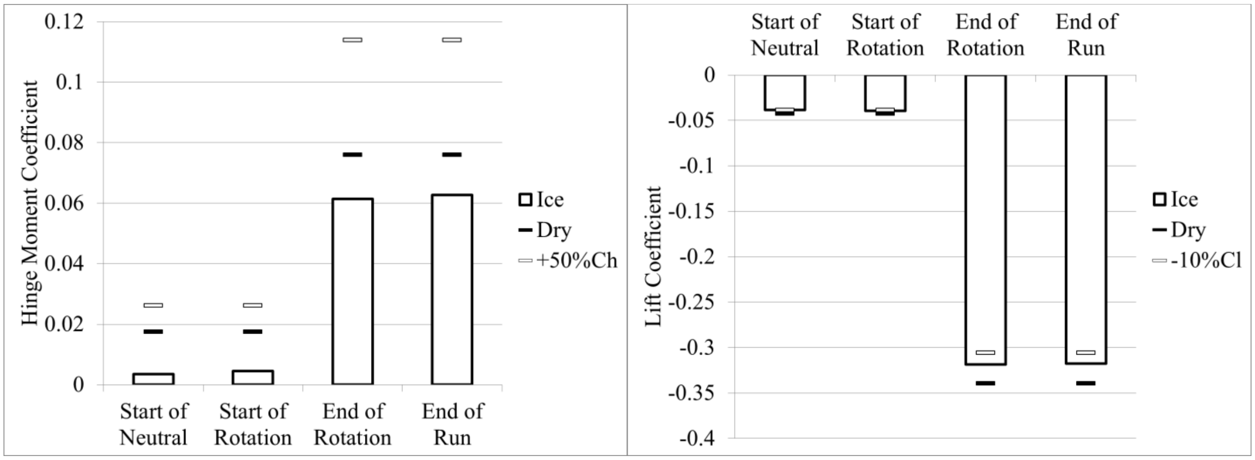


Figure 58 Effects of Ice on Horizontal Stabilizer Performance

7.9 Reporting and Presentation

Over the course of the project teleconferences and in-person meetings were used to update the client (EASA) and interested agencies (TDC, FAA, NASA) on the project progress. A list of these meetings and presentations are listed below. Progress reports were delivered to EASA detailing the progress on a monthly basis from December 2013 to February 2015.

List of Reports, Meetings and Presentations

28 Nov. 2013	General project meeting (Teleconference/WebEx)
23 Jan. 2013	First progress review meeting (Teleconference/WebEx)
9 May 2014	SAE G12 AWG Presentation
30 May 2014	Model geometry review (Teleconference/WebEx)
4 June 2014	Model geometry discussions continued (Teleconference/WebEx)
26 June 2014	Model geometry and test plans (Teleconference/WebEx)
27 Aug. 2014	Test plan and fluid selection (Teleconference/WebEx)
23 Sept. 2014	Interim report delivered to EASA
30 Oct. 2014	SAE G12 AWG Presentation in Montreal, Quebec
5 Nov. 2014	Second progress review meeting (Teleconference/WebEx)
1 Dec. 2014	Research program schedule discussion (Teleconference/WebEx)
15-20 Dec. 2014	Research program at NRC PIWT
23 March 2015	Final project presentation in Cologne, Germany

8.0 Summary and Future Work

A research program was successfully completed at the NRC PIWT in December 2014 with the goal of reproducing and investigating the causes of the increases in hinge moment and decreases in lift coefficient reported by pilots after the application of thickened anti-icing fluids for certain aircraft types.

The baseline dry model aerodynamic performance was established for hinge gap sizes of 2 mm, 4 mm and 8 mm. Multiple fluids, take-off scenarios and elevator rotation profiles were then tested in order to identify variables that may contribute to the change in the model aerodynamic performance. The results of these runs are summarized below.

- The dry baseline runs were repeatable, with the best repeatability at the higher speeds. The few fluid runs that were repeated to check for variations in the results due to the fluid application process also showed good repeatability.

- Fluid type and fluid viscosity have a significant impact on the hinge moment and lift coefficients. The IV-L and II-F fluids (mid-range viscosity) had the most impact, followed by the IV-A75 fluid (highest viscosity) and then the III-P50 fluid (lowest viscosity).

- A larger gap size resulted in increased hinge moments on the elevator and reductions in lift on the horizontal stabilizer model compared to the dry baseline case. It was observed that with the larger gap sizes there is more space for the fluid from the upper surface to flow between the elevator and the main element and therefore there is more fluid contaminating the lower surface of the elevator.

- At the smallest gap size, there seemed to be a fluid puddle contained in the area between the elevator and the hinge moment prior to the start of rotation. This ‘puddle’ decreased as the gap size increased and there was more space for the fluid to drain onto the lower surface.

- At the largest negative deflection angles there may be flow separation at the trailing edge of the elevator on the low-pressure side.

- Modifying the take-off profile to simulate light, normal and heavy aircraft, and modifying those profiles to remove the ‘hold’ periods did not change the overall trends in the results.

- The air and fluid temperatures had minimal influence on the hinge moment and lift coefficients over the range of temperatures examined during this research program.

Attempts were made to rectify the rotation difficulties by changing the model angle of attack, the trim tab angle, the fluid type and dilution, and the application method. These results are summarized below.

- Simulating main-wing downwash did not improve the overall performance of the model with fluids compared to the appropriate dry baseline performance.

- The fixed-position trim tab was used to counteract the additional hinge moment on the elevator caused by the presence of fluids, and was nominally investigated in this research program. However, a moving trim tab on an aircraft introduces more complex interactions and the results presented here may only be valid for the fixed-tab geometry. The modification of the existing fixed-position trim tab into a spring tab may be of interest for future testing.

- The leftover fluid from a simulated aborted take-off run (when re-run as a subsequent test) had little impact on the aerodynamic performance of the model and the resulting hinge moment and lift coefficients were within the established criteria (negative case).

- The application of a Type I fluid had minimal effect of the hinge moment and lift coefficients compared to the dry baseline (negative case).

- A two-step process with a Type I and then a Type IV fluid produced similar results to a one-step Type IV fluid application.

- Using a simulated spraying application method for the fluid application produced minimal changes compared to when the fluids are poured.

- Spraying fluid on the underside of the model in addition to the normal amount of fluid on the upper surface produced minimal improvements in the hinge moment and decreased the lift coefficient, so it does not help rectify the rotation difficulties.

- Diluting the IV-L and II-F fluids has the effect of increasing their viscosity. Testing these diluted fluids there was improvement in the hinge moment and lift coefficients compared to the neat fluids. This shows that the relationship between viscosity and the model aerodynamic performance is not linear and that the highest and lowest viscosity fluids in this test program performed best.

As part of a separate research objective, ice was added to the leading edge and lower surface of the model to examine the impact of that ice on the horizontal stabilizer performance. This resulted in a reduction in the hinge moment coefficient and minimal reductions in lift. It is important to note that the ice profile tested is not necessarily representative of real-world icing conditions, so the results should not be taken as an indication that anti-icing protection is not required.

Dilution of the anti-icing fluids has been shown in this research program to have a significant impact on the aerodynamic performance of the horizontal stabilizer. Testing that evaluates the effects of contamination such as snow, freezing rain, and other holdover time related conditions should be considered to provide additional insight, as the precipitation acts to dilute the fluids. Testing at colder temperatures, ideally closer to the LOUT of the fluids, should be conducted as much of the work completed during this research program was at temperatures above -10°C. Considering that these fluids have non-Newtonian properties that change with temperature and shear stress, additional viscosity profiling on the fluids used in this test program could be performed to better understand the correlation between viscosity, shear forces, and aerodynamic performance.

Dry model flow characterization tests using tools such as flow visualization tufts, boundary layer trips, and sandpaper can be used to simulate the fluid effects on the model under static conditions. This type of testing could be conducted at any point during the year as it is not temperature dependent, and would help to correlate the measured aerodynamic performance of the model and the observations from the videos and photography.

9.0 References

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Appendix A – Run Log

Date	NRC Run#	EASA Run#	Objective	Run Title/Comment	Hinge Gap (mm)	Elevator Deflection Scenario	V_R (kts)	Fluid	Ramp (s)	OAT (°C)	WAT (°C)
15-Dec-14			Client/APS arrival and set-up								
	5	1	Check aerodynamic zero of model		4	-	60:120	-	-	-	-
	6	2	Phase 1 - Establish Evaluation Criteria		4	1	115	Dry	-	-	-
	7	3	Phase 1 - Establish Evaluation Criteria		4	2	105	Dry	-	-	-
	8	4	Phase 1 - Establish Evaluation Criteria		4	1	115	Dry	-	-	-
	9	5	Phase 1 - Establish Evaluation Criteria		4	2	105	Dry	-	-	-
	10	6	Phase 1 - Establish Evaluation Criteria		4	1	115	Dry	-	-	-
	11	7	Phase 1 - Establish Evaluation Criteria		4	2	105	Dry	-	-	-
	13	8	Phase 1 - Establish Evaluation Criteria		2	1	115	Dry	-	-	-
	14	9	Phase 1 - Establish Evaluation Criteria		2	2	105	Dry	-	-	-
	15	10	Phase 1 - Establish Evaluation Criteria		2	1	115	Dry	-	-	-
	16	11	Phase 1 - Establish Evaluation Criteria		2	2	105	Dry	-	-	-
	18	12	Phase 1 - Establish Evaluation Criteria		8	1	115	Dry	-	-	-
	19	13	Phase 1 - Establish Evaluation Criteria		8	2	105	Dry	-	-	-
	20	14	Phase 1 - Establish Evaluation Criteria		8	1	115	Dry	-	-	-
	21	15	Phase 1 - Establish Evaluation Criteria		8	2	105	Dry	-	-	-
	23	16-1	Phase 2 - Identify Contributing Variables	Error: Interlock tripped, deactivated motion system during run	2	2	105	IV-A75	-	-	-
	24	16-2	Phase 2 - Identify Contributing Variables	Testing system	2	2	105	IV-A75	-	-	-
	25	17	Phase 2 - Identify Contributing Variables		2	2	105	IV-A75	11.9	0.8	2.9
16-Dec-14	27	18	Phase 2 - Identify Contributing Variables		2	1	115	IV-A75	17.9	-0.5	1.9
	29	19	Phase 2 - Identify Contributing Variables	Additional deflection at end of profile back to -2deg	2	2	115	IV-A75	18.0	-0.7	2.2
	30	20	Phase 2 - Identify Contributing Variables		2	2	105	IV-L	12.0	-0.8	2.4
	31	21	Phase 2 - Identify Contributing Variables		2	1	115	IV-L	18.0	-0.8	0.2
	32	22	Phase 2 - Identify Contributing Variables	Repeat without cleaning model btw. runs	2	1	115	IV-L	17.9	-0.8	-0.1
	33	23	Phase 2 - Identify Contributing Variables		2	1	115	II-F	18.0	-0.8	1.9
	34	24	Phase 2 - Identify Contributing Variables		2	2	105	II-F	11.4	-0.6	2.9
	35	25	Phase 2 - Identify Contributing Variables	Repeat without cleaning model btw. runs	2	2	105	II-F	11.4	-0.7	0.4
	36	26	Phase 3 - Attempt to rectify problem		2	2	105	III-P50	11.6	-0.6	2.7
	37	27	Phase 3 - Attempt to rectify problem		2	1	115	III-P50	17.5	-0.4	2.3
	38	28	Phase 3 - Attempt to rectify problem	Repeat of run 31 but fluid sprayed	2	1	115	IV-L	17.0	-0.4	2.9
	39	29	Phase 2 - Identify Contributing Variables	Repeat run	2	3	115	IV-L	-	-0.6	2.5
17-Dec-14	41	30	Morning shakedown		8	1	115	Dry	-	-	-
	42	31	Phase 2 - Identify Contributing Variables		8	1	115	IV-L	17.9	0.7	3.4
	43	32	Phase 2 - Identify Contributing Variables		8	1	115	II-F	18.0	0.8	4.0
	44	33	Phase 2 - Identify Contributing Variables		8	1	115	IV-A75	18.0	0.8	4.1
	45	34	Phase 2 - Identify Contributing Variables		8	2	105	IV-A75	11.9	1.0	3.6
	46	35	Phase 2 - Identify Contributing Variables		8	1	115	III-P50	17.9	1.0	3.9
	47	36	Phase 2 - Identify Contributing Variables	Error: Supposed to be Light Profile	8	1	115	III-P50	-	-	-
	48	37	Phase 2 - Identify Contributing Variables		8	2	105	III-P50	12.0	1.1	2.6
	49	38	Phase 2 - Identify Contributing Variables		10	1	115	IV-L	18.1	1.1	3.6
	50	39	Phase 2 - Identify Contributing Variables		10	1	115	II-F	18.1	1.1	3.8
	52	40	Phase 2 - Identify Contributing Variables		4	1	115	II-F	17.9	1.0	3.7
18-Dec-14	54	41	Morning shakedown		4	1	115	Dry	-	-	-
	55	42	Phase 2 - Identify Contributing Variables		4	1	115	IV-L	18.0	-0.1	0.2
	57	43	Optional lower priority test	Target top speed of 115kts	4	5	105	IV-L	12.0	0.0	0.0
	58	44	Optional lower priority test	No hold before rotation	4	4	115	IV-L	-	0.0	0.0
	60	45	Optional lower priority test	Diluted fluid	4	1	115	IV-L (75/25)	18.0	-0.2	0.1
	61	46	Phase 2 - Identify Contributing Variables		4	1	115	IV-A75	18.0	-0.1	0.0
	62	47	Optional lower priority test	2-step process	4	1	115	TI + IV-A75	18.0	-0.3	0.1
	63	48	Phase 2 - Identify Contributing Variables		4	1	115	III-P50	17.9	-0.6	-0.2
	64	49	Optional lower priority test	Run tunnel with elevator at -13, stop, clean off upper surface, run profile	4	1	115	IV-L	18.0	-1.2	-0.8
19-Dec-14	65	-	Morning shakedown		4	1	115	Dry			
	66	50	Phase 2 - Identify Contributing Variables		4	1	115	IV-L	18.6	-7.6	-5.9
	67	51	Phase 2 - Identify Contributing Variables		4	1	115	II-F	19.1	-7.7	-6.1
	68	52	Phase 2 - Identify Contributing Variables	Error in profile - only use data up to -4 deg	4	2	105	II-F	13.0	-7.5	-6.1
	70	53	Phase 2 - Identify Contributing Variables		4	1	115	II-F (75/25)	18.5	-6.9	-6.2
	71	54	Phase 2 - Identify Contributing Variables		4	1	115	IV-A75	18.9	-6.4	-5.4
	72	55	Phase 2 - Identify Contributing Variables		4	1	115	III-P50	18.9	-4.8	-5.5
	73	56	Optional lower priority test		4	1	115	Type I	18.4	-4.6	-3.9
	74	57	Optional lower priority test	2-step process	4	1	115	TI + II-F	19.8	-4.8	-3.7
	75	58	Phase 3 - Attempt to rectify problem	Fluid on underside of model	4	1	115	IV-L	19.5	-4.8	-2.3
	76	59	Optional lower priority test	Downwash: -3.5 deg	4	1	115	Dry	-	-	-
	77	60	Optional lower priority test	Trim tab: 12 deg	4	1	115	Dry	-	-	-
20-Dec-14	78	61	Morning shakedown	Trim tab: 8 deg	4	1	115	Dry	-	-	-
	79	62	Optional lower priority test	Trim tab: 4 deg	4	1	115	Dry	-	-	-
	80	63	Phase 4 - Ice under model		4	1	115	Dry	-	-	-
	81	64	Phase 2 - Identify Contributing Variables	Coldest case	4	1	115	IV-L	23.7	-10.7	-7.8
	82	65	Optional lower priority test	Downwash: -3.5 deg	4	1	115	IV-L	19.3	-9.8	-7.3
	83	66	Optional lower priority test	Trim tab: 4 deg	4	1	115	IV-L	19.0	-8.7	-5.8

Appendix B – Complete Test Results

The aerodynamic data from the test program and the run log have been provided to EASA on DVD.

The video and still photos from the NRC cameras and the APS cameras have been provided in full to EASA on Blu-Ray.

Fluid thickness, temperature and brix data forms completed by APS are provided in this appendix. They are also provided in the APS report to the NRC (Ruggi, 2015).

EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B1: EASA TEST # 16

AD-49 75/25

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 15th, 2014

Run: 16 (26)

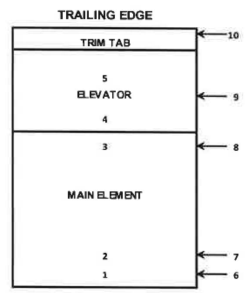
WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	1.4	1.6		1.75
7				
TBD___				
Time:	15:58:14	16:04:01		16:19:26

1.4
2.1

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	28.5		
4			
TBD___			
Time:	16:04:01		

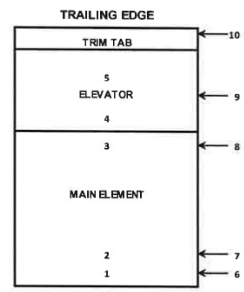
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	80		
3			
4	55		
5			
6	30		
7	0		
8	0		
9			
10			
Time:	16:09:23		

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

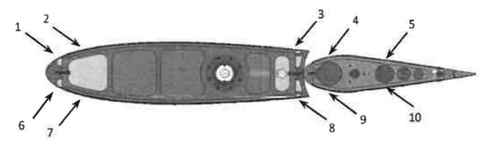


Comments:___________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY
ASSISTED BY: CB

General Comments:___________________

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B2: EASA TEST # 17

AD-49 75/25

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 15 2014

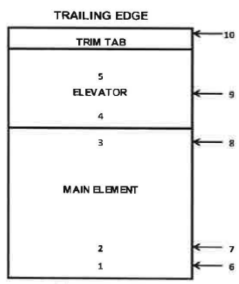
Run: 17 (26)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	3.8	3.8		4.0
7				
TBD___				
Time:	16:43:53	16:52:58		17:19:45

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	28.75		33.5
4			
TBD___			
Time:	16:59:10		17:17:11

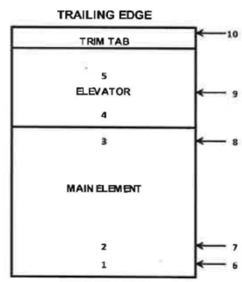
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70		4
3			
4	50		
5			
6	30		3
7	0		4
8	0		0
9			10
10			
Time:	16:59:38		17:17:11

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

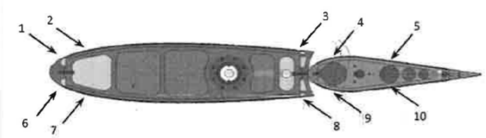


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY
ASSISTED BY: CB

General Comments: ________

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Figure B3: EASA TEST # 18

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

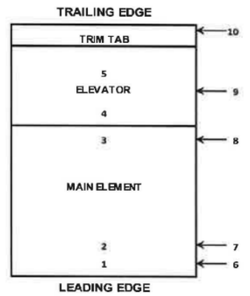
Run: 18 (14)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	3.4	4.5	/	1.4
7				
TBD___				
Time:	8:24:06	8:43:15	/	8:45:52

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	28.25	/	31.75
4			
TBD___			
Time:	8:33:54	/	8:55:24

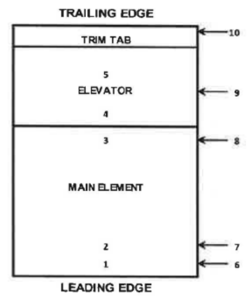
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70	/	4
3			
4	55	/	3
5			
6	30		3
7	0	/	4
8			6
9	0	/	6
10			
Time:	8:33:54	/	8:53:20

H-Stab and Plate Condition
Before the Takeoff Run
Time:___________

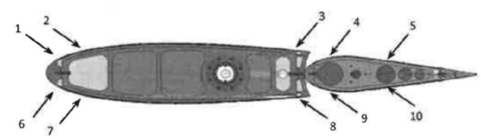


Comments:___________

H-Stab and Plate Condition
After the Takeoff Run
Time:___________



Comments:___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:___________

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B4: EASA TEST # 19

AD 49   25/25

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

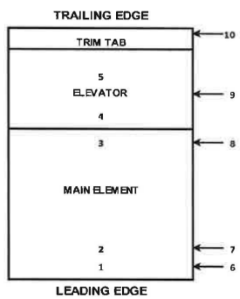
Run: 19 (14)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.0	4.1	/	1.7
7				
TBD__				
Time:	9:13:13	9:29:5	/	9:32:50

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	28.75	/	31.75
4			
TBD__			
Time:	9:21:04	/	9:42:33

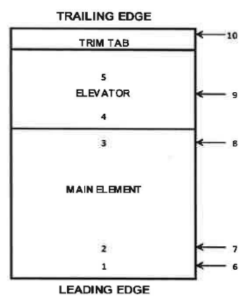
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70	/	5
3			
4	60	/	5
5			
6	30	/	<1
7	0	/	<1
8	0	/	8
9	0	/	8
10			
Time:	9:21:04	/	9:41:35

H-Stab and Plate Condition
Before the Takeoff Run
Time:__________

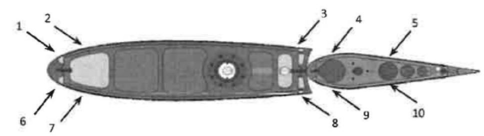


Comments:______________________

H-Stab and Plate Condition
After the Takeoff Run
Time:__________



Comments:______________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B5: EASA TEST # 20

LAUNCH IV

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

Run: 20 (21)

WING TEMPERATURE (Taken From NRC Logger)

H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	3.85	4.0	/	2.0
7				
TBD___				
Time:	9:56:12	10:07:23	/	10:12:07

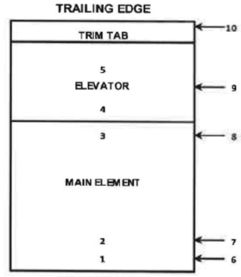
FLUID BRIX

H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37	/	36.25
4			
TBD___			
Time:	10:03:24	/	10:18:59

FLUID THICKNESS (mil)

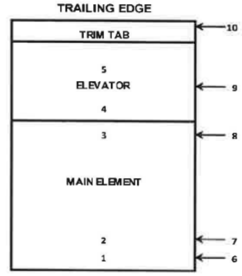
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	60	/	6
3			
4	45	/	6
5			
6	45		1
7	0	/	4
8	0		9
9	0	/	20
10			
Time:	10:03:24	/	10:18:37

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

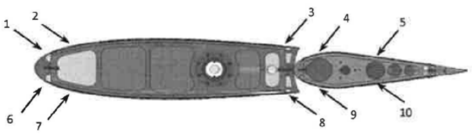


Comments:___________________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________________________

OBSERVER: DY

ASSISTED BY: CB

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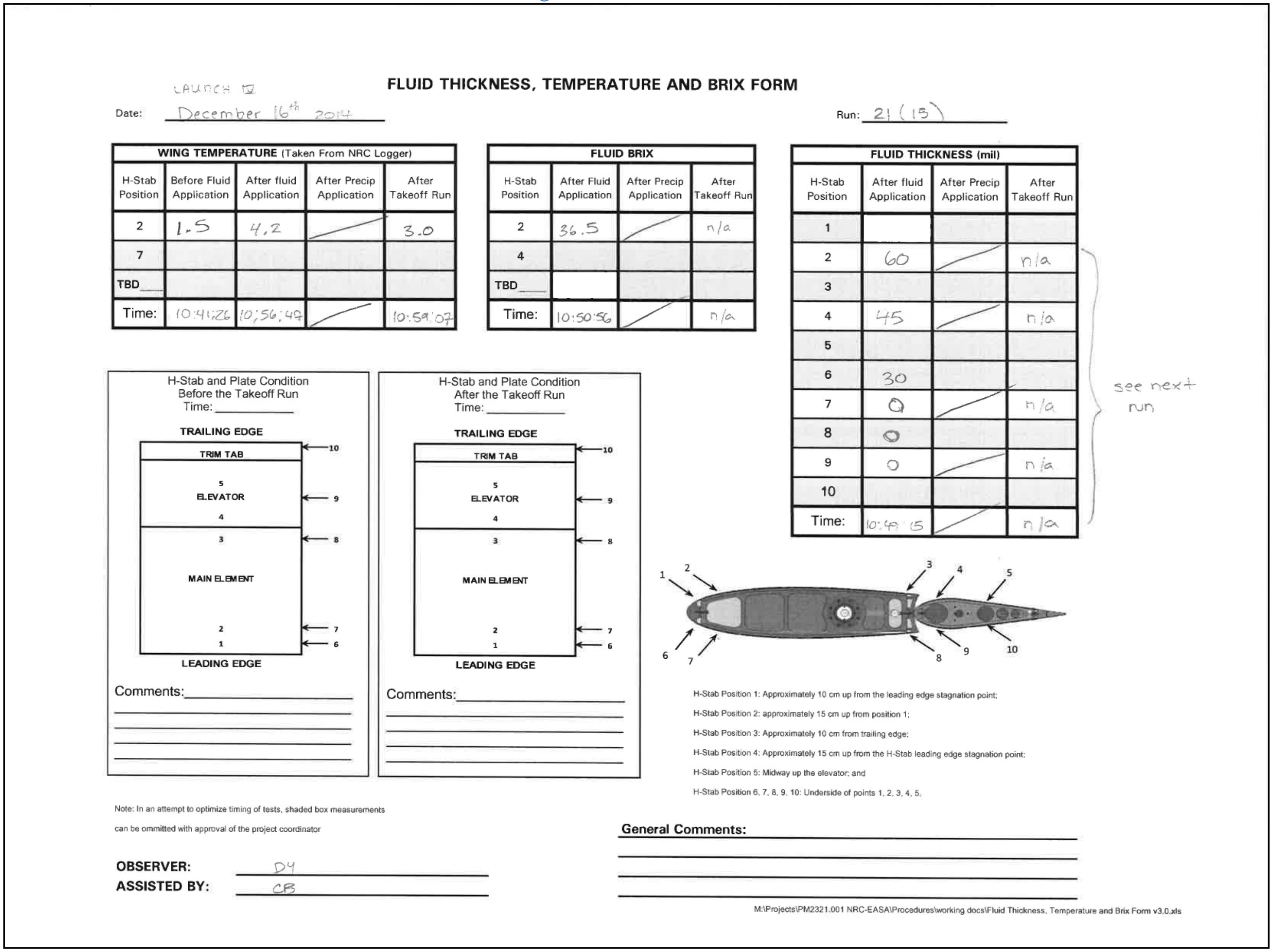
Figure B6: EASA TEST # 21



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

LAUNCH ☑

Date: December 16th 2014

Run: 21 (15)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	1.5	4.2	/	3.0
7				
TBD___				
Time:	10:41:26	10:56:49	/	10:59:07

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.5	/	n/a
4			
TBD___			
Time:	10:50:56	/	n/a

FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	60	/	n/a
3			
4	45	/	n/a
5			
6	30		
7	0	/	n/a
8	0		
9	0	/	n/a
10			
Time:	10:49:15	/	n/a

see next run

H-Stab and Plate Condition Before the Takeoff Run
Time: ___________

TRAILING EDGE / TRIM TAB / ELEVATOR / MAIN ELEMENT / LEADING EDGE

Comments: ___________

H-Stab and Plate Condition After the Takeoff Run
Time: ___________

TRAILING EDGE / TRIM TAB / ELEVATOR / MAIN ELEMENT / LEADING EDGE

Comments: ___________

H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY
ASSISTED BY: CB

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Figure B7: EASA TEST # 22

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

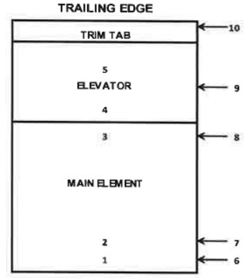
Run: 23 (13)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.0	3.7	/	2.3
7				
TBD___				
Time:	11:33:40	11:45:50	/	11:49:37

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.75	/	37.75
4			
TBD___			
Time:	11:40:50	/	11:53:29

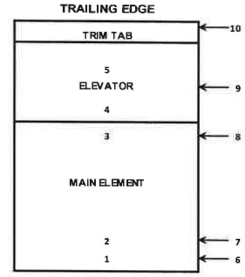
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	50	/	2
3			
4	45	/	4
5			
6			<1
7	0	/	4
8	0		5
9	0	/	5
10			
Time:	11:41:22	/	11:53:29

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

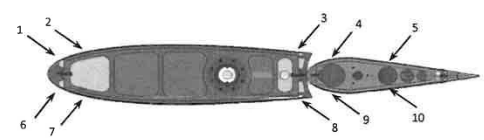


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY
ASSISTED BY: CB

General Comments: ________

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B8: EASA TEST # 23

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

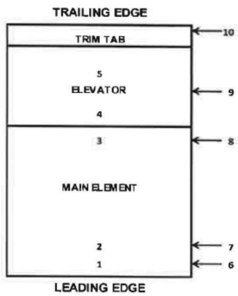
Run: 23 (15)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.0	3.7	/	2.3
7				
TBD___				
Time:	11:33:40	11:45:50	/	11:49:37

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	37.75	/	37.75
4			
TBD___			
Time:	11:40:50	/	11:53:29

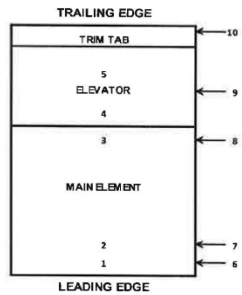
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	50	/	2
3			
4	45	/	4
5			
6			<1
7	0	/	4
8	0		5
9	0	/	5
10			
Time:	11:41:22	/	11:53:29

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

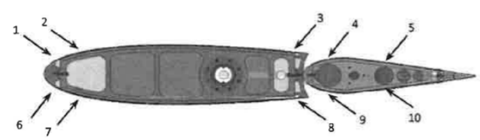


Comments: ______________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ______________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ______________________

OBSERVER: DY

ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B9: EASA TEST # 24

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th, 2014

Run: 24 (19)

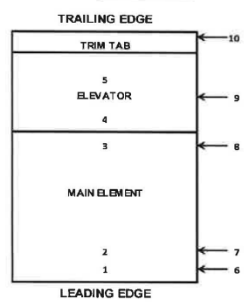
WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	5.0	4.9		3.4
7				
TBD___				
Time:	12:33:49	12:49:		12:54:01

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.5		
4			
TBD___			
Time:	12:40:30		

FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55		
3			
4	40		
5			
6	30		
7	0		
8	0		
9	0		
10			
Time:	12:41:00		

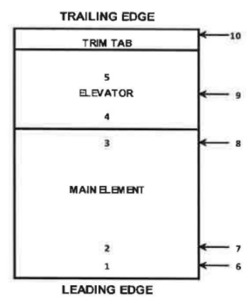
see next run (25)

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

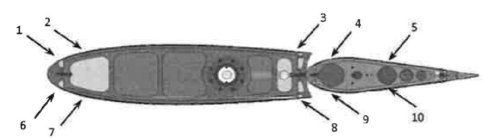


Comments:

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:

OBSERVER: DY
ASSISTED BY: CB

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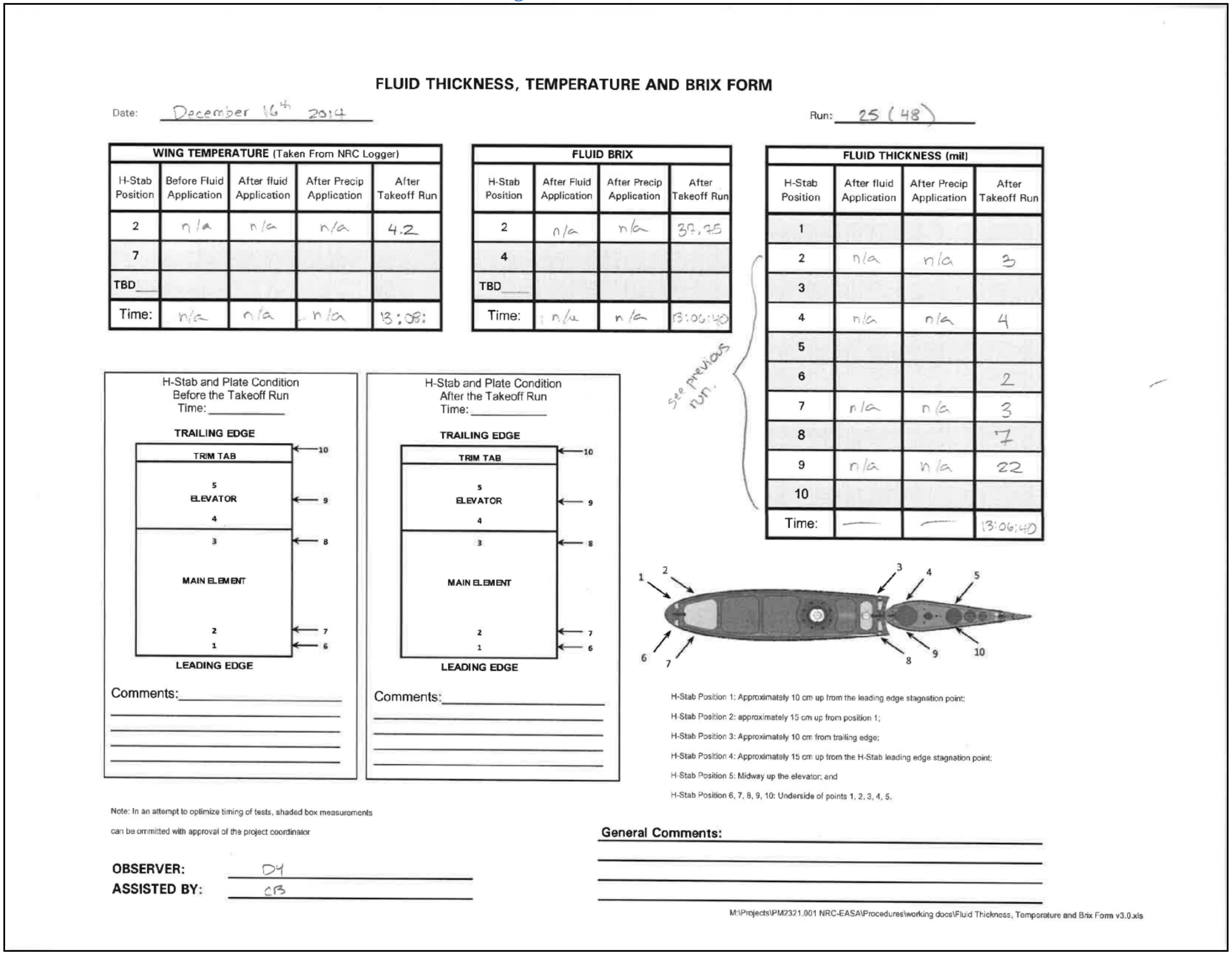
Figure B10: EASA TEST # 25



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014 Run: 25 (48)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	n/a	n/a	n/a	4.2
7				
TBD___				
Time:	n/a	n/a	n/a	13:08:

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	n/a	n/a	37.25
4			
TBD___			
Time:	n/a	n/a	13:06:40

FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	n/a	n/a	3
3			
4	n/a	n/a	4
5			
6			2
7	n/a	n/a	3
8			7
9	n/a	n/a	22
10			
Time:	—	—	13:06:40

see previous run.

H-Stab and Plate Condition Before the Takeoff Run Time: ___

TRAILING EDGE / TRIM TAB / ELEVATOR / MAIN ELEMENT / LEADING EDGE

Comments: ___

H-Stab and Plate Condition After the Takeoff Run Time: ___

TRAILING EDGE / TRIM TAB / ELEVATOR / MAIN ELEMENT / LEADING EDGE

Comments: ___

H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___

OBSERVER: DY
ASSISTED BY: CB

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Figure B11: EASA TEST # 26

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th, 2014

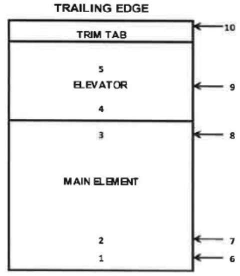
Run: 26 (33)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.0	4.0	—	2.0
7				
TBD___				
Time:	13:19:53	13:36:36	—	13:40:34

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	28.75	—	24
4			
TBD___			
Time:	13:32:04	—	13:48:09

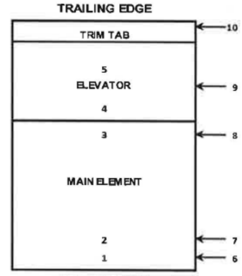
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	50	—	<1
3			
4	40	—	2
5			
6	28		<1
7	0	—	<1
8	0		6
9	0	—	6
10			
Time:	13:31:17	—	13:46:35

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

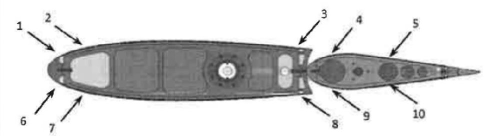


Comments:___________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;

H-Stab Position 2: approximately 15 cm up from position 1;

H-Stab Position 3: Approximately 10 cm from trailing edge;

H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;

H-Stab Position 5: Midway up the elevator; and

H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________________

OBSERVER: DY

ASSISTED BY: CB

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Figure B12: EASA TEST # 27

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

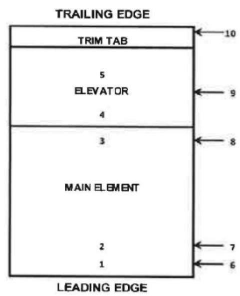
Run: 27 (31)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	3.4	4.1	/	1.9
7				
TBD___				
Time:	13:59:20	14:16:32	/	14:19:54

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	20	/	25 25
4			
TBD___			
Time:	14:09:13	/	14:28:07

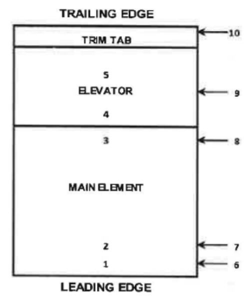
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55	/	<1
3			
4	40	/	2
5			
6	30		<1
7	0	/	<1
8	0		6
9	0	/	11
10			
Time:	14:09:13	/	14:28:07

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

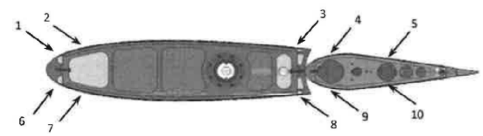


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY

ASSISTED BY: CB

General Comments: ___________

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Figure B13: EASA TEST # 28

IV LAUNCH

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

Run: 28 (46)

WING TEMPERATURE (Taken From NRC Logger)

H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.5	5.5	/	2.8
7				
TBD___				
Time:	14:46:00	15:05:00	/	15:08:53

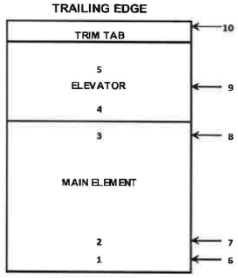
FLUID BRIX

H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.75	/	35.25
4			
TBD___			
Time:	15:00:00	/	15:12:59

FLUID THICKNESS (mil)

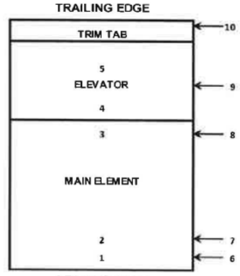
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	45	/	4
3			
4	50	/	7
5			
6	<1		<1
7	0	/	5
8	0		1
9	0	/	12
10			
Time:	15:00:00	/	15:15:26

H-Stab and Plate Condition
Before the Takeoff Run
Time:___________

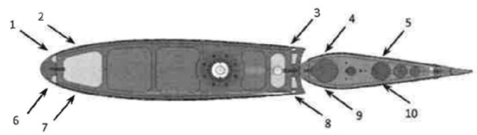


Comments:___________

H-Stab and Plate Condition
After the Takeoff Run
Time:___________



Comments:___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:___________

OBSERVER: DY

ASSISTED BY: CB

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Figure B14: EASA TEST # 29

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 16th 2014

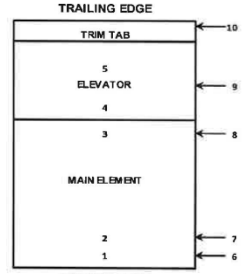
Run: 29 (45)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.5	4.3	/	3.0
7				
TBD___				
Time:	15:27:30	5:43:50	/	15:46:30

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.75	/	36.0
4			
TBD___			
Time:	15:38:04	/	15:55:18

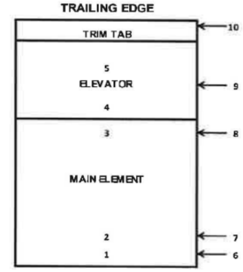
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55	/	4
3			
4	50	/	5
5			
6	30		<1
7	0	/	4
8	0		8
9	0	/	24
10			
Time:	15:38:06	/	15:55:18

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

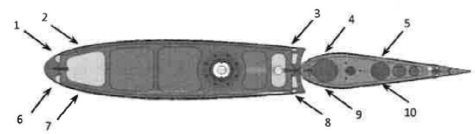


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ________

OBSERVER: DY
ASSISTED BY: CB

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Figure B15: EASA TEST # 31

MP IN LAUNCH

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17th 2014

Run: 31 (27)

WING TEMPERATURE (Taken From NRC Logger)

H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.0	5.2	/	3.7
7				
TBD___				
Time:	8:28:10	8:45:45	/	8:47:42

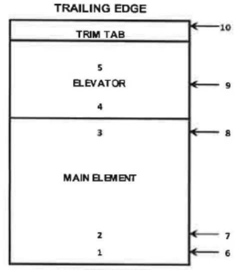
FLUID BRIX

H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.5	/	34.5
4			
TBD___			
Time:	8:35:35	/	8:56:34

FLUID THICKNESS (mil)

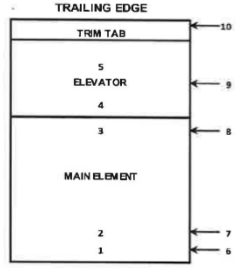
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	65	/	2
3			
4	45	/	10
5			
6	30	/	<1
7	0	/	3
8	0	/	6
9	0	/	10
10			
Time:	8:35:45	/	8:56:34

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

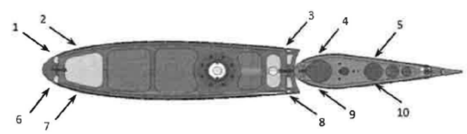


Comments:___________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:___________________

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B16: EASA TEST # 32

MP II FLIGHT

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17 2014

Run: 32 (214)

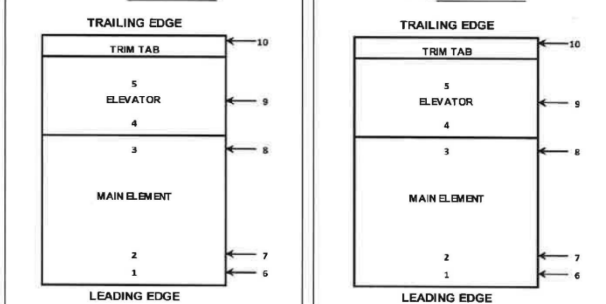
WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	5.7	6.1	/	4.0
7				
TBD___				
Time:	9:21:50	9:40:00	/	9:42:04

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.5	/	34.5
4			
TBD___			
Time:	9:31:05	/	9:50:50

FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	60	/	4
3			
4	40	/	5
5			
6	28	/	<1
7	0	/	4
8	0	/	8
9	0	/	10
10			
Time:	9:31:25	/	9:50:30

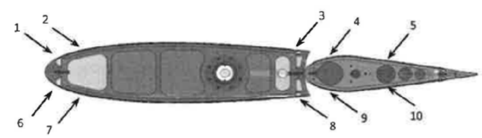
H-Stab and Plate Condition Before the Takeoff Run Time:__________

H-Stab and Plate Condition After the Takeoff Run Time:__________



Comments:__________

Comments:__________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:

OBSERVER: DY

ASSISTED BY: CB

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Figure B17: EASA TEST # 33

AD-49 75/25

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17 2014

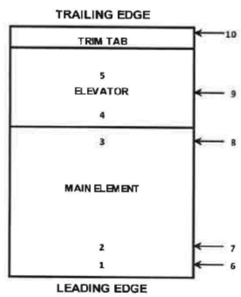
Run: 33 (25)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	5.7	5.4	/	4.0
7				
TBD___				
Time:	10:08:12	10:24:58	/	10:28:05

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	29.0	/	29.0
4			
TBD___			
Time:	10:15:26	/	10:35:04

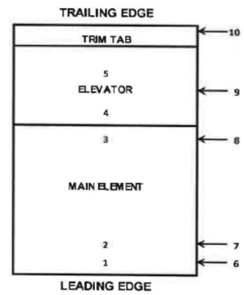
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	80	/	<1
3			
4	60	/	11
5			
6	40		<1
7	0	/	1
8	0		8
9	0	/	10
10			
Time:	10:15:17	/	10:35:04

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

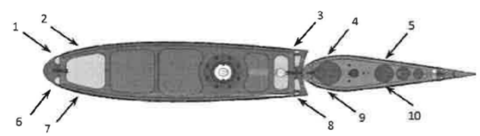


Comments:________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments:________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:________

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B18: EASA TEST # 34

AD 49 - 95/25

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17 2014

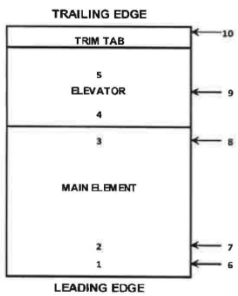
Run: 34 (28)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	5.5	4.8		3.7
7				
TBD___				
Time:	10:51:22	11:07:30		11:11:22

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	27.5		28.25
4			
TBD___			
Time:	10:58:09		11:18:04

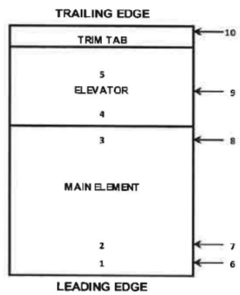
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	80		3
3			
4	60		7
5			
6	30		2
7	0		2
8	0		10
9	0		26
10			
Time:	10:59:10		11:18:04

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

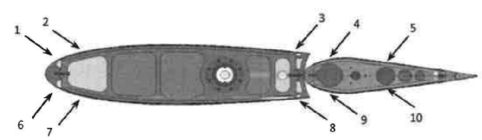


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;

H-Stab Position 2: approximately 15 cm up from position 1;

H-Stab Position 3: Approximately 10 cm from trailing edge;

H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;

H-Stab Position 5: Midway up the elevator; and

H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY

ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B19: EASA TEST # 35

PG 50/50

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17 2014

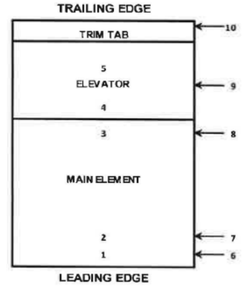
Run: 35 (37)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.7	5.8		3.3
7				
TBD___				
Time:	11:34:33	11:58:17		12:00:00

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	20.25		24
4			
TBD___			
Time:	11:45:02		12:00:00

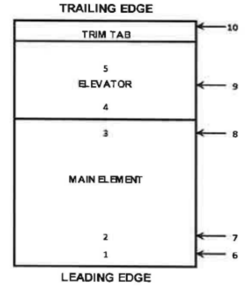
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	65		5
3			
4	35		4
5			
6	35		2
7	0		4
8	0		10
9	0		10
10			
Time:	11:45:14		12:05:20

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

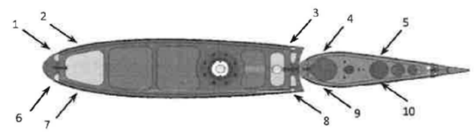


Comments:________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments:________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: M B-K
ASSISTED BY: CB

General Comments:

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Figure B20: EASA TEST # 36

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17, 2014

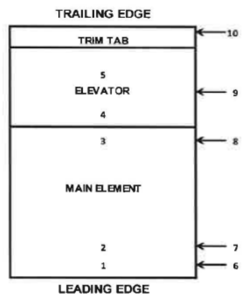
Run: 36 (38)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.4	4.9	/	3.4
7				
TBD___				
Time:	13:02:00	13:16:26	/	13:20:08

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	20.5	/	
4			
TBD___			
Time:	13:10:05	/	

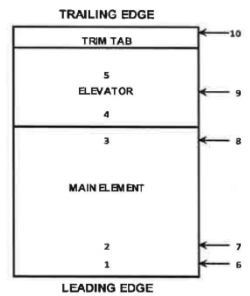
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70	/	
3			
4	40	/	
5			
6	28		
7	0	/	
8	0		
9	0	/	
10			
Time:	13:10:05	/	

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

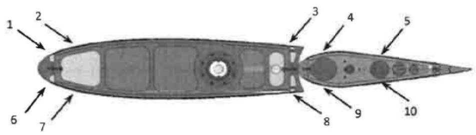


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY
ASSISTED BY: CB

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Figure B21: EASA TEST # 37

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17th 2014

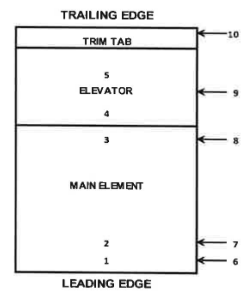
Run: 37 (38)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.1	4.4	/	3.3
7				
TBD___				
Time:	13:37:00	13:49:49	/	13:52:52

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	19.75	/	19.5
4			
TBD___			
Time:	13:43:04	/	13:58:33

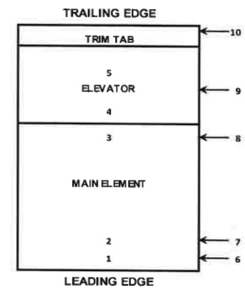
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55	/	<1
3			
4	40	/	2
5			
6	30	/	<1
7	0	/	<1
8	0		4
9	0	/	8
10			
Time:	13:43:04	/	13:59:30

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

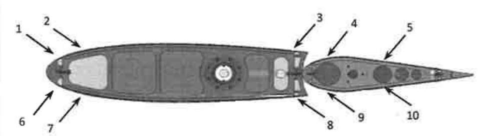


Comments:________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments:________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY
ASSISTED BY: CB

General Comments:________________

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B22: EASA TEST # 38

MP IV LAUNCH

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 17th 2014

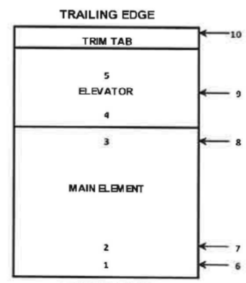
Run: 38 (27)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.3	4.9		4.2
7				
TBD___				
Time:	14:11:30	14:27:30		14:31:30

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36		32.25
4			
TBD___			
Time:	14:19:15		14:39:20

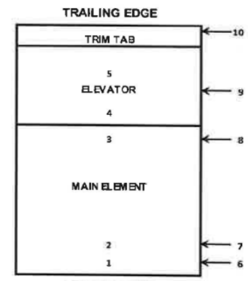
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55		4
3			
4	50		8
5			
6	30		<1
7	0		3
8	0		10
9	0		14
10			
Time:	14:20:30		14:38:21

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

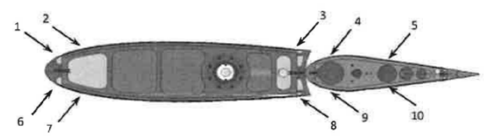


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY

ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B23: EASA TEST # 39

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP II FLIGHT
Date: December 17 2014

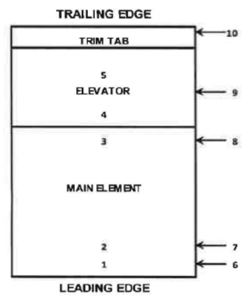
Run: 39 (27)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	5.1	5.1		4.9
7				
TBD___				
Time:	14:48:26	15:00:30		15:02:56

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.0		31.0
4			
TBD___			
Time:	14:55:51		15:14:07

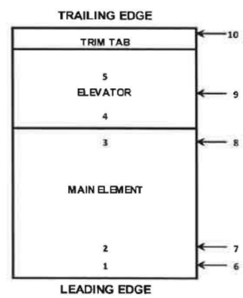
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55		5
3			
4	50		8
5			
6	30		<1
7	0		3
8	0		8
9	0		12
10			
Time:	14:56:26		15:19:55

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

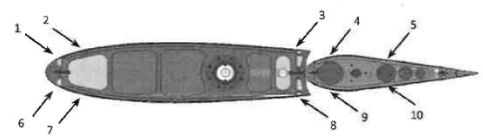


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY
ASSISTED BY: CB

General Comments: ___________

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Figure B24: EASA TEST # 40

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP 11 FLIGHT

Date: December 17, 2014

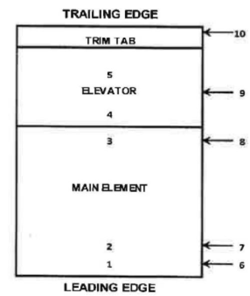
Run: 40 (25)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	4.0	4.0	/	3.9
7				
TBD___				
Time:	15:32:40	15:45:14	/	15:49:27

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.25	/	29.75
4			
TBD___			
Time:	15:39:45	/	15:56:[illegible]0

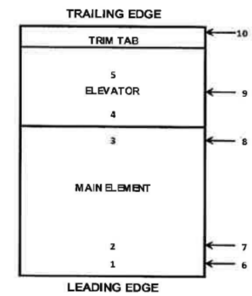
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55	/	8
3			
4	40		8
5			
6	40	/	7
7	0	/	4
8	0		10
9	0	/	16
10			
Time:	15:39:35	/	15:55:30

H-Stab and Plate Condition
Before the Takeoff Run
Time: ____________

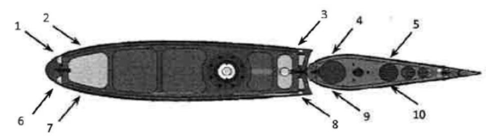


Comments: ____________

H-Stab and Plate Condition
After the Takeoff Run
Time: ____________



Comments: ____________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ____________

OBSERVER: DY

ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B25: EASA TEST # 42

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP W LAUNCH
Date: December 18th 2014

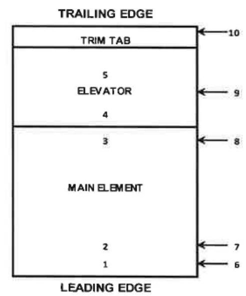
Run: 42 (25)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	1.6	2.8	/	8.0
7				
TBD___				
Time:	8:31:34	8:45:40	/	8:43

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.5	/	35.0
4			
TBD___			
Time:	8:40:12	/	

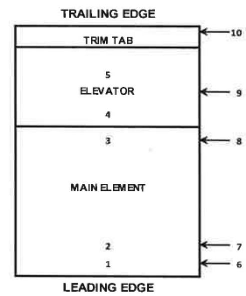
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	60	/	4
3			
4	45	/	5
5			
6	40		<1
7	0	/	5
8	0		9
9	0	/	12
10			
Time:	8:40:00	/	8:56:05

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

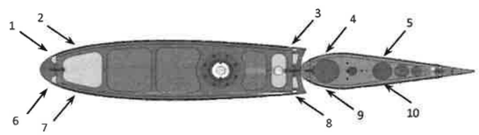


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY
ASSISTED BY: CB

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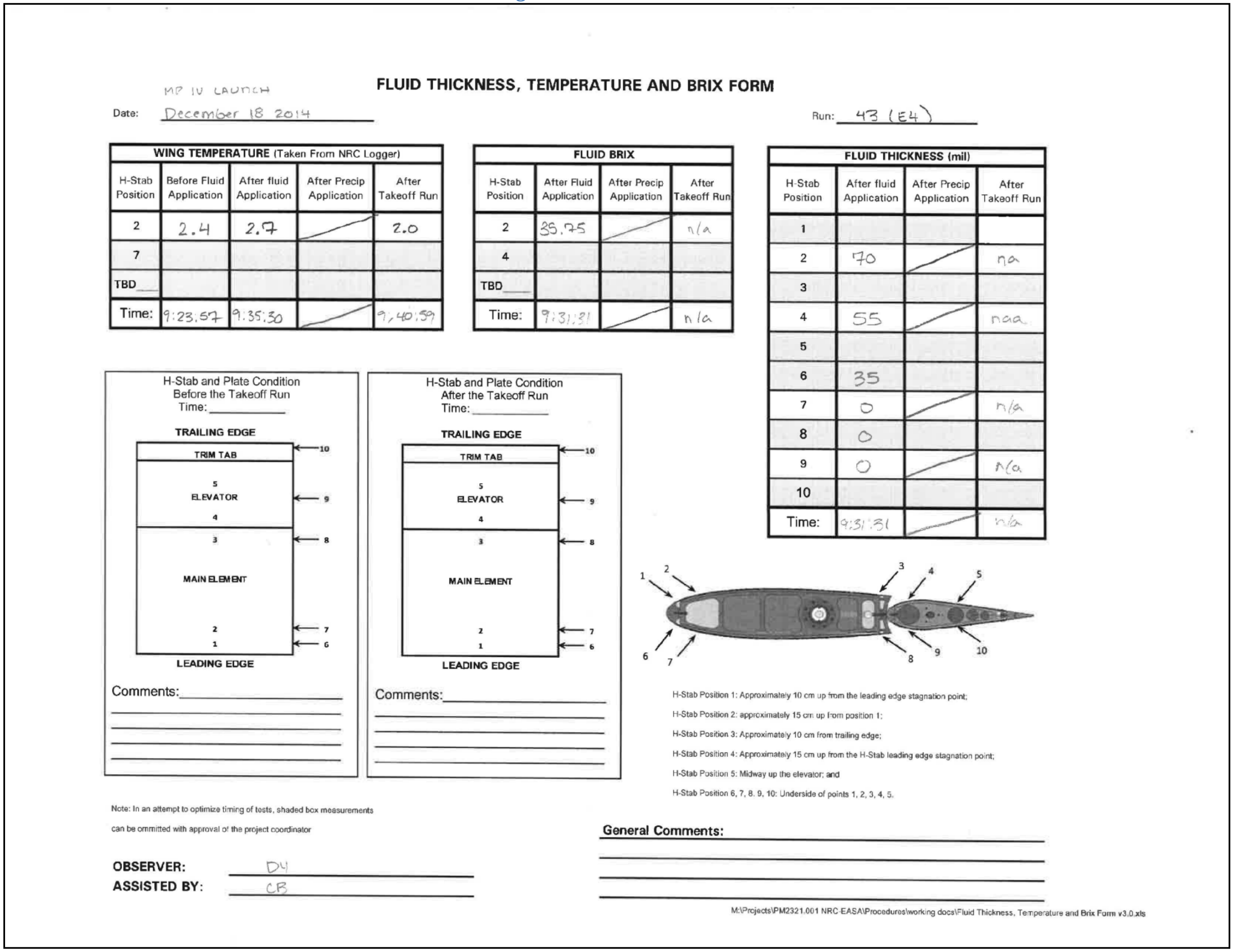
EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B26: EASA TEST # 43



FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP IV LAUNCH

Date: December 18 2014

Run: 43 (E4)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	2.4	2.7		2.0
7				
TBD___				
Time:	9:23:57	9:35:30		9:40:59

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.75		n/a
4			
TBD___			
Time:	9:31:31		n/a

FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70		na
3			
4	55		naa
5			
6	35		
7	0		n/a
8	0		
9	0		n/a
10			
Time:	9:31:31		n/a

H-Stab and Plate Condition Before the Takeoff Run
Time: ________

TRAILING EDGE / TRIM TAB / 5 / ELEVATOR / 4 / 3 / MAIN ELEMENT / 2 / 1 / LEADING EDGE / 10 / 9 / 8 / 7 / 6

Comments:

H-Stab and Plate Condition After the Takeoff Run
Time: ________

TRAILING EDGE / TRIM TAB / 5 / ELEVATOR / 4 / 3 / MAIN ELEMENT / 2 / 1 / LEADING EDGE / 10 / 9 / 8 / 7 / 6

Comments:

H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B27: EASA TEST # 44

MP IV LAUNCH

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 18 2014

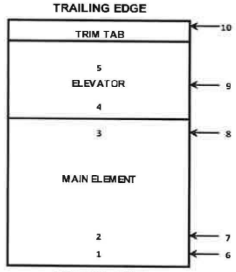
Run: 44 (E5)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	2.1	2.4	/	1.5
7				
TBD___				
Time:	9:53:34	10:05:25	/	10:09:00

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.25	/	n/a
4			
TBD___			
Time:	10:00:15	/	n/a

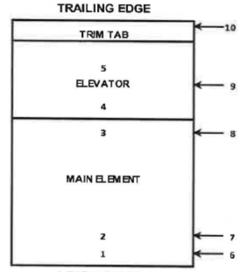
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70	/	n/a
3			
4	50	/	n/a
5			
6	35		
7	0	/	n/a
8	0		
9	0	/	n/a
10			
Time:	10:00:20	/	n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

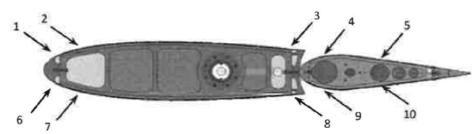


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:

OBSERVER: DY
ASSISTED BY: CB

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Figure B28: EASA TEST # 45

IV LAUNCH 75/25

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 18 2014

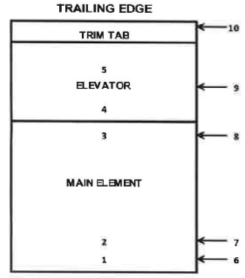
Run: 45 (30)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	1.2	1.9	/	1.1
7				
TBD___				
Time:	10:22:40	10:38:26	/	10:41:43

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	28.25	/	31.0
4			
TBD___			
Time:	10:34:33	/	10:49:33

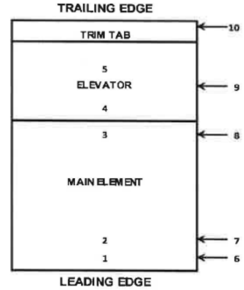
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	112	/	4
3			
4	104	/	10
5			
6	70		<1
7		/	4
8			5
9		/	20
10			
Time:	10:34:33	/	10:47:33

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

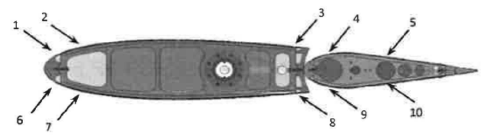


Comments:___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:___________

OBSERVER: DY

ASSISTED BY: CB

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Figure B29: EASA TEST # 46

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 18 2014

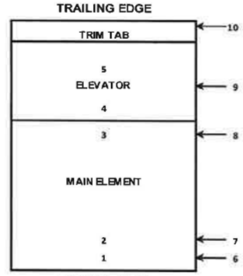
Run: 46 (25)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	1.5	2.3	/	[illegible]
7				
TBD___				
Time:	11:00:00	11:14:20	/	

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	23.5	/	n/a
4			
TBD___			
Time:	11:09:52	/	n/a

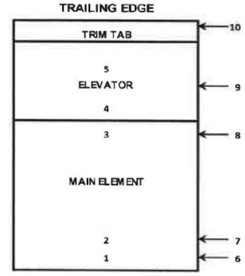
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70	/	n/a
3			
4	60	/	n/a
5			
6	40		
7	0	/	n/a
8	0		
9	0	/	n/a
10			
Time:	11:09:40	/	n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

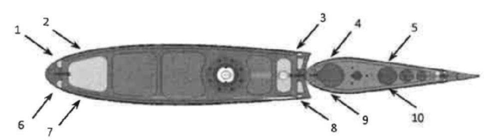


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ________

OBSERVER: DY
ASSISTED BY: CB

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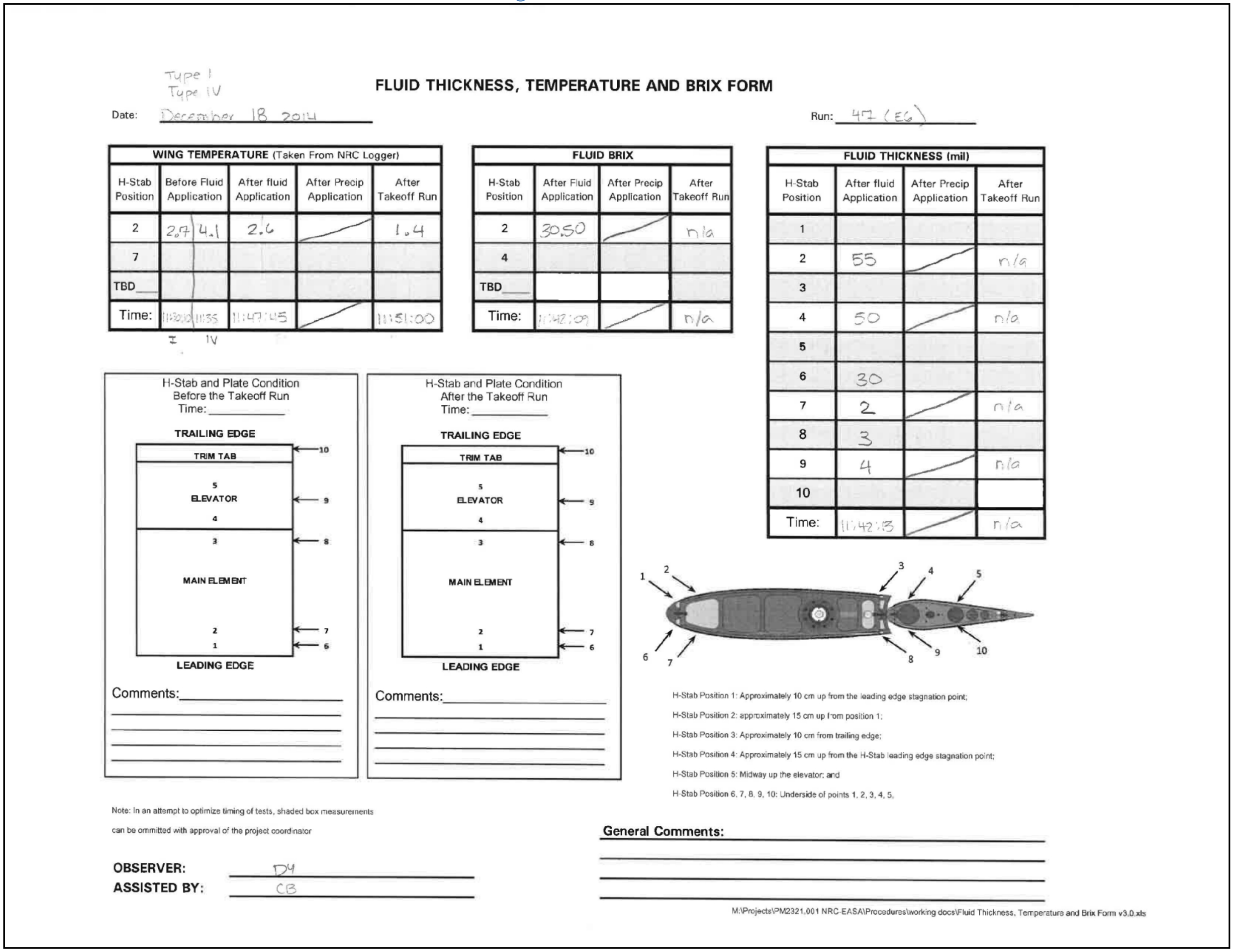
EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B30: EASA TEST # 47



Type I
Type IV

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 18 2014

Run: 47 (EG)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	2.7 | 4.1	2.6		1.4
7				
TBD___				
Time:	11:30:00 | 11:35	11:47:45		11:51:00

I IV

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	30.50		n/a
4			
TBD___			
Time:	11:42:09		n/a

FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55		n/a
3			
4	50		n/a
5			
6	30		
7	2		n/a
8	3		
9	4		n/a
10			
Time:	11:42:13		n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time:________

TRAILING EDGE
TRIM TAB
5
ELEVATOR
4
3
MAIN ELEMENT
2
1
LEADING EDGE
10 9 8 7 6

Comments:________

H-Stab and Plate Condition
After the Takeoff Run
Time:________

TRAILING EDGE
TRIM TAB
5
ELEVATOR
4
3
MAIN ELEMENT
2
1
LEADING EDGE
10 9 8 7 6

Comments:________

1 2 3 4 5 6 7 8 9 10

H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:________

OBSERVER: DY
ASSISTED BY: CB

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Figure B31: EASA TEST # 48

PG 50/50

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 18th 2014

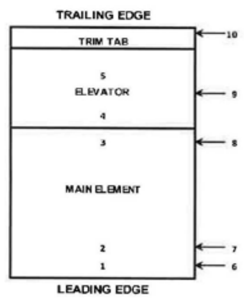
Run: 48 (25)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	1.2	2.0	/	0.5
7				
TBD___				
Time:	12:31:00	12:40:29	/	12:49:50

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	22.5	/	
4			
TBD___			
Time:	12:40:55	/	

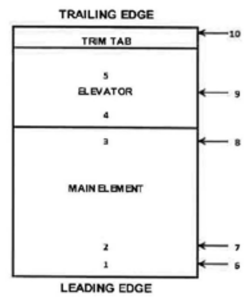
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55	/	
3			
4	35	/	
5			
6	30		
7	0	/	
8	0		
9	0	/	
10			
Time:	12:40:05	/	

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

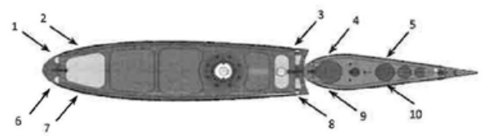


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY
ASSISTED BY: CB

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Figure B32: EASA TEST # 49

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP IV LAUNCH

Date: December 18th 2014

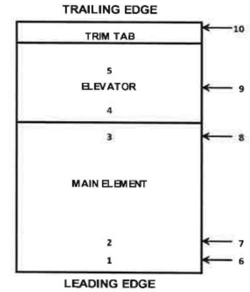
Run: 49 (39)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	1.0	1.9	/	0.7
7				
TBD___				
Time:	13:05:53	13:21:18		13:40:43

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.75		
4			
TBD___			
Time:	13:15:00		

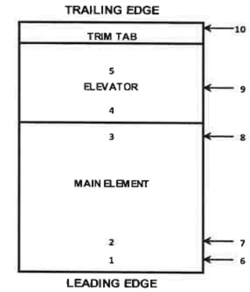
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70		
3			
4	55		
5			
6	35		
7	0		
8	0		
9	0		
10			
Time:	13:15:00		

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

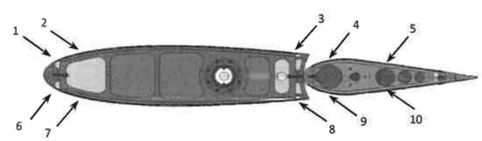


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ________

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B33: EASA TEST #50

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 19th 2014

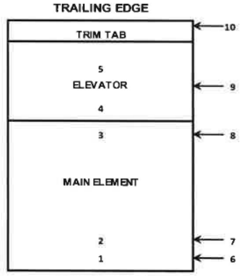
Run: 50 (18)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-3.7	-2.1		-4.3
7				
TBD___				
Time:	7:31:56	7:46:36		7:50:23

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.0		38.0
4			
TBD___			
Time:	7:40:56		7:53:12

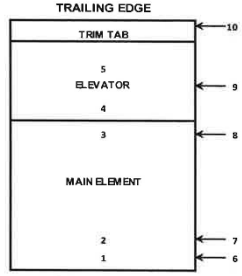
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	60		4
3			
4	50		4
5			
6	35		<1
7	0		4
8	0		6
9	0		14
10			
Time:	7:40:40		7:53:12

H-Stab and Plate Condition Before the Takeoff Run
Time: ___________

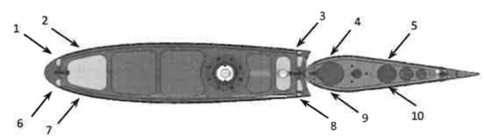


Comments: ___________

H-Stab and Plate Condition After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY
ASSISTED BY: CB

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Figure B34: EASA TEST #51

MP II FLIGHT

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 19th 2014

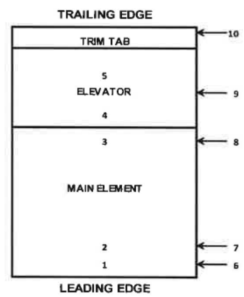
Run: 51 (16)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-3.5	-1.8		-4.1
7				
TBD___				
Time:	8:09:50	8:23:15		8:25:50

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.25		38
4			
TBD___			
Time:	8:18:45		8:35:50

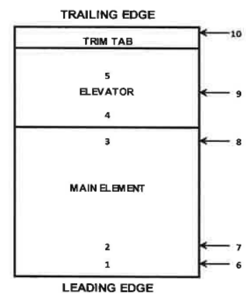
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	50		4
3			
4	45		4
5			
6	28		1
7	0		4
8	0		6
9	0		12
10			
Time:	8:18:40		8:35:50

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

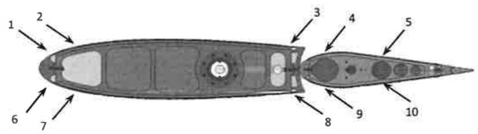


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___________

OBSERVER: DY
ASSISTED BY: CB

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Figure B35: EASA TEST #52

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP 11 FLIGHT

Date: December 19 2014

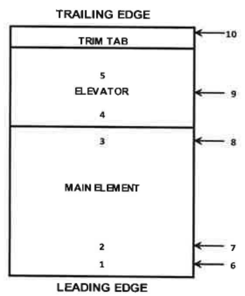
Run: 52 (22)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-3.8	-2.2	/	-4.2
7				
TBD___				
Time:	8:45:16	9:00:25	/	9:03:30

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.5	/	n/a
4			
TBD___			
Time:	8:55:40	/	n/a

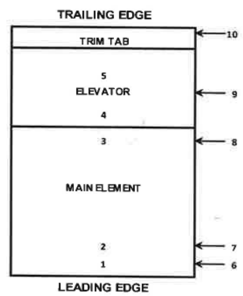
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55	/	n/a
3			
4	40	/	n/a
5			
6	30		
7	0	/	n/a
8	0		
9	0	/	n/a
10			
Time:	8:55:28	/	n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time:___________

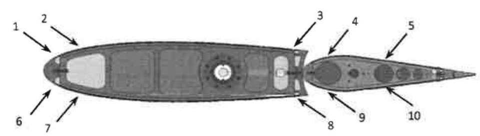


Comments:___________

H-Stab and Plate Condition
After the Takeoff Run
Time:___________



Comments:___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:___________

OBSERVER: DY

ASSISTED BY: CB

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Figure B36: EASA TEST #53

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP 11 FLIGHT 75/25

Date: December 19 2014

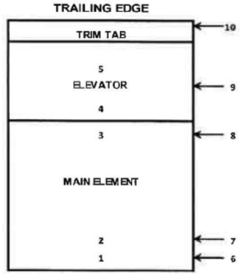
Run: 53 (29)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-4.0	-3.0		-5.6
7				
TBD___				
Time:	9:24:00	9:42:05		9:44:36

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	29.5		n/a
4			
TBD___			
Time:	9:36:03		n/a

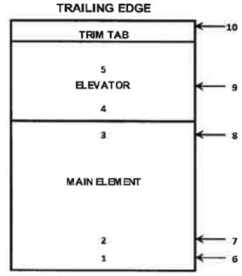
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	80		n/a
3			
4	96		n/a
5			
6	65		
7	0		n/a
8	0		
9	0		n/a
10			
Time:	9:36:26		n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

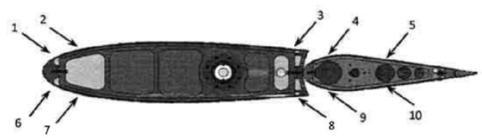


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ________

OBSERVER: DY

ASSISTED BY: CB

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Figure B37: EASA TEST #54

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

AD 49 75/25

Date: December 19 2014

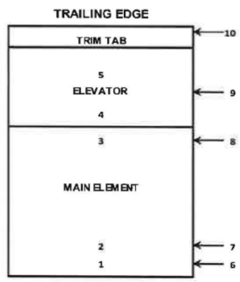
Run: 54 (17)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-4.5	-2.2	/	-5.7
7				
TBD___				
Time:	9:59:30	10:11:22	/	10:14:13

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	28.5	/	
4			
TBD___			
Time:	10:08:30	/	

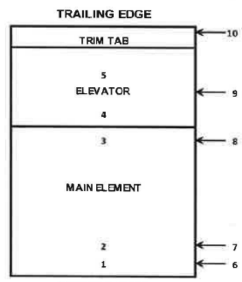
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	70	/	
3			
4	55	/	
5			
6	45		
7	0	/	
8	0		
9	0	/	
10			
Time:	10:08:30	/	

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

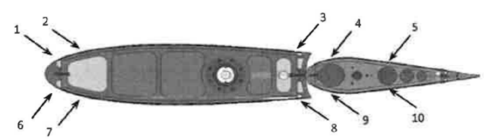


Comments: ___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments: ___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY

ASSISTED BY: CB

General Comments: ___________

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Figure B38: EASA TEST #55

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

PGA 50/50

Date: December 19 2014

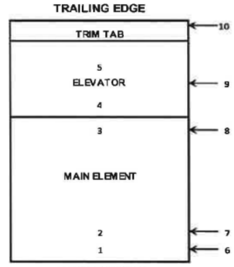
Run: 55 (32)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-3.3	-2.8		-5.3
7				
TBD___				
Time:	10:31:00	10:45:17		10:47:57

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	21.5		n/a
4			
TBD___			
Time:	10:39:58		n/a

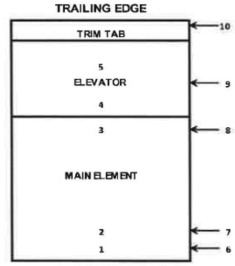
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55		n/a
3			
4	35		n/a
5			
6	24		
7	0		n/a
8	0		
9	0		n/a
10			
Time:	10:39:51		n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

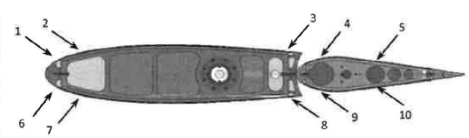


Comments:___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:___________

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B39: EASA TEST #56

Type I E-188

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 19 2014

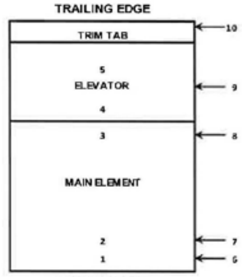
Run: 56 (E7)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-3.2	0.5		-2.6
7				
TBD___				
Time:	11:35:40	11:49:49		11:52:16

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	30.0		—
4			
TBD___			
Time:	11:44:45		

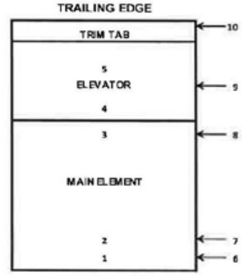
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	3		<1
3			
4	<1		<1
5			
6	<1		<1
7	<1		<1
8	<1		<1
9	<1		<1
10			
Time:	11:44:20		12:02:22

H-Stab and Plate Condition
Before the Takeoff Run
Time:___________

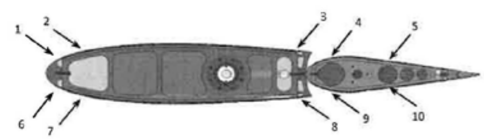


Comments:___________

H-Stab and Plate Condition
After the Takeoff Run
Time:___________



Comments:___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

OBSERVER: DY
ASSISTED BY: CB

General Comments:___________

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Figure B40: EASA TEST #57

LIFT OFF P=188
MP 11 FLIGHT

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 19 2014

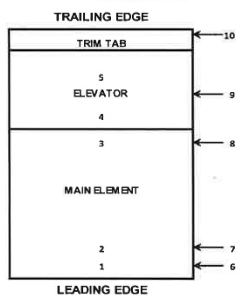
Run: 57 (E9)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-0.7	0.2		-2.3
7				
TBD___				
Time:	12:13:47	12:33:00		12:37:00

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.0		n/a
4			
TBD___			
Time:	12:27:00		n/a

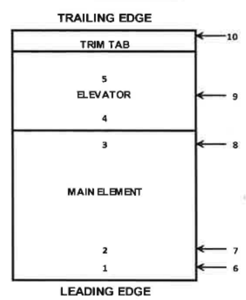
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	50		n/a
3			
4	50		n/a
5			
6	30		
7	0		n/a
8	0		
9	0		n/a
10			
Time:	12:24:55		n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

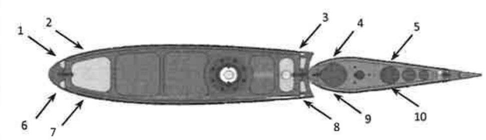


Comments:___________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;

H-Stab Position 2: approximately 15 cm up from position 1;

H-Stab Position 3: Approximately 10 cm from trailing edge;

H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;

H-Stab Position 5: Midway up the elevator; and

H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:

OBSERVER: DY

ASSISTED BY: CB

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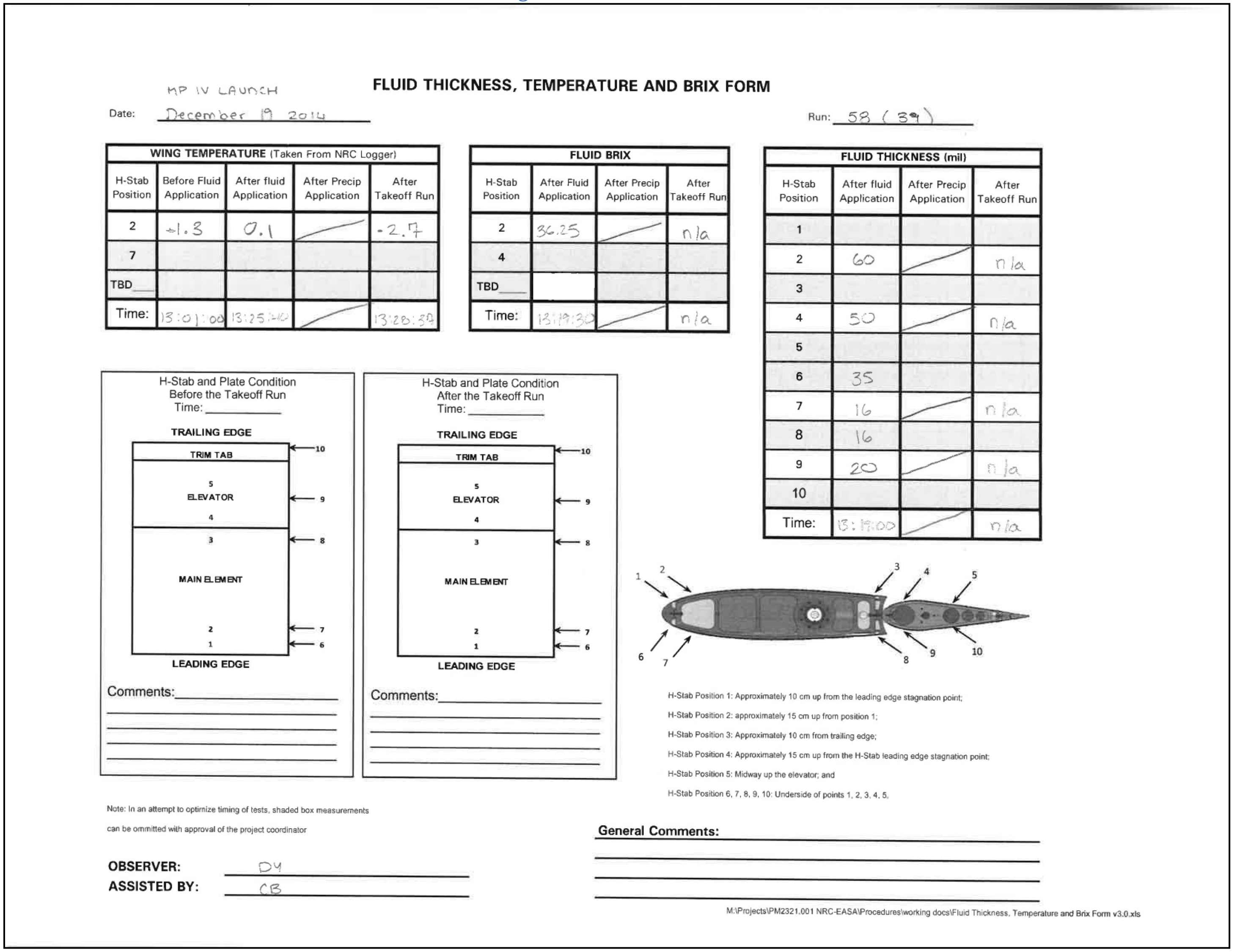
EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B41: EASA TEST #58



MP IV LAUNCH

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 19 2014

Run: 58 (39)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	+1.3	0.1	/	-2.7
7				
TBD___				
Time:	13:01:00	13:25:40	/	13:28:39

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.25	/	n/a
4			
TBD___			
Time:	13:19:30	/	n/a

FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	60	/	n/a
3			
4	50	/	n/a
5			
6	35		
7	16	/	n/a
8	16		
9	20	/	n/a
10			
Time:	13:19:00	/	n/a

H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ___

OBSERVER: DY
ASSISTED BY: CB

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Figure B42: EASA TEST #64

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

MP IV LAUNCH

Date: December 20 2014

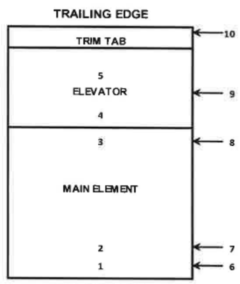
Run: 64 (24)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-7.5	-4.8		-7.8
7				
TBD___				
Time:	8:24:30	8:40:58		8:43:58

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.0		n/a
4			
TBD___			
Time:	8:35:30		n/a

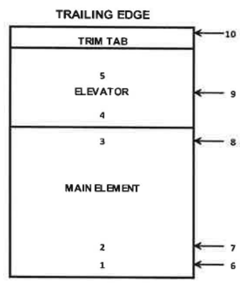
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	55		n/a
3			
4	45		n/a
5			
6	30		
7	0		n/a
8	0		
9	0		n/a
10			
Time:	8:35:35		n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

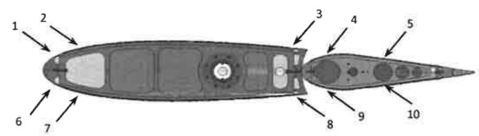


Comments:________________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments:________________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:________________________

OBSERVER: DY

ASSISTED BY: CB

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Figure B43: EASA TEST #65

HP IV LAUNCH

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 20th 2014

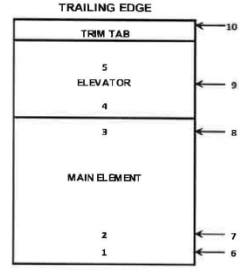
Run: 65 (49)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-7.0	-5.0		-6.6
7				
TBD___				
Time:	8:59:40	9:12:30		9:15:28

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	36.25		n/a
4			
TBD___			
Time:	9:07:17		n/a

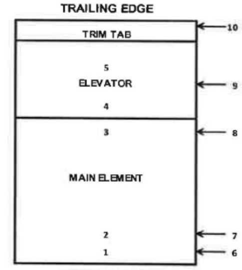
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	65		n/a
3			
4	45		n/a
5			
6	35		
7	0		n/a
8	0		
9	0		n/a
10			
Time:	9:07:30		n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ________

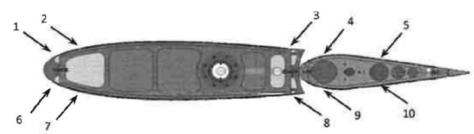


Comments: ________

H-Stab and Plate Condition
After the Takeoff Run
Time: ________



Comments: ________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point;
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments: ________

OBSERVER: DY
ASSISTED BY: CB

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EASA De-Icing Fluid Tests (DIFT) on a Horizontal Stabilizer Section at the NRC PIWT

Figure B44: EASA TEST #66

FLUID THICKNESS, TEMPERATURE AND BRIX FORM

Date: December 20, 2014

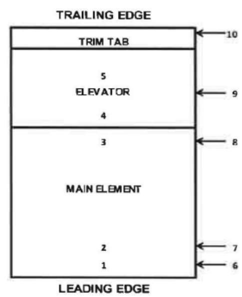
Run: 66 (E12)

WING TEMPERATURE (Taken From NRC Logger)				
H-Stab Position	Before Fluid Application	After fluid Application	After Precip Application	After Takeoff Run
2	-5.1	-4.7	/	n/a
7				
TBD___				
Time:	9:32:50	9:04:30	/	n/a

FLUID BRIX			
H-Stab Position	After Fluid Application	After Precip Application	After Takeoff Run
2	35.5	/	n/a
4			
TBD___			
Time:	9:39:39	/	n/a

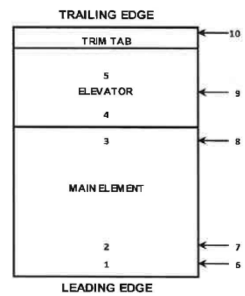
FLUID THICKNESS (mil)			
H-Stab Position	After fluid Application	After Precip Application	After Takeoff Run
1			
2	65	/	n/a
3			
4	55	/	n/a
5			
6	45		
7	0	/	n/a
8	0		
9	0	/	n/a
10			
Time:	9:39:39	/	n/a

H-Stab and Plate Condition
Before the Takeoff Run
Time: ___________

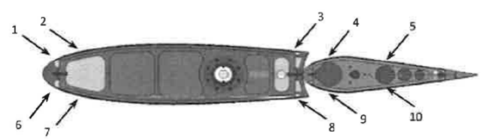


Comments:___________________

H-Stab and Plate Condition
After the Takeoff Run
Time: ___________



Comments:___________________



H-Stab Position 1: Approximately 10 cm up from the leading edge stagnation point:
H-Stab Position 2: approximately 15 cm up from position 1;
H-Stab Position 3: Approximately 10 cm from trailing edge;
H-Stab Position 4: Approximately 15 cm up from the H-Stab leading edge stagnation point;
H-Stab Position 5: Midway up the elevator; and
H-Stab Position 6, 7, 8, 9, 10: Underside of points 1, 2, 3, 4, 5.

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

General Comments:___________________

OBSERVER: DY
ASSISTED BY: CB

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Figure B45: Fluid Thickness Conversion Table

FILM THICKNESS CONVERSION TABLE

RECTANGULAR GAUGE			OCTAGON GAUGE		
Reading*	Calculated Thickness		Reading*	Calculated Thickness	
(mil)	(mil)	(mm)	(mil)	(mil)	(mm)
			0.4	0.8	0.0
1.0	1.5	0.0	1.1	1.3	0.0
			1.5	1.9	0.0
2.0	2.5	0.1	2.2	2.4	0.1
			2.6	2.7	0.1
3.0	3.5	0.1	2.8	3.2	0.1
			3.6	3.9	0.1
4.0	4.5	0.1	4.1	4.4	0.1
			4.7	4.9	0.1
5.0	5.5	0.1	5.1	5.6	0.1
6.0	6.4	0.2	6.0	6.4	0.2
			6.6	7.0	0.2
7.0	7.5	0.2	7.3	7.5	0.2
8.0	8.5	0.2	7.7	7.8	0.2
9.0	9.5	0.2	7.9	9.0	0.2
10	11	0.3	10	11	0.3
11	12	0.3			
12	13	0.3	12	13	0.3
14	15	0.4	14	15	0.4
16	18	0.4	16	18	0.4
18	19	0.5			
20	21	0.5	20	23	0.6
22	23	0.6			
24	25	0.6	25	28	0.7
26	27	0.7			
28	29	0.7			
30	33	0.8	30	33	0.8
35	38	1.0	35	38	1.0
40	43	1.1	40	43	1.1
45	48	1.2			
50	53	1.3	48	56	1.4
55	58	1.5			
60	63	1.6			
65	68	1.7	64	80	2.0
70	75	1.9			
80	88	2.2	80	88	2.2
			96	100	2.5
			104	108	2.7
			112	116	2.9
			119	123	3.1
			127	131	3.3
			134	138	3.5
			142	146	3.7
			150	154	3.9
			158	179	4.5
			200	225	5.7
			250	275	7.0
			300	350	8.9
			400	400	10.2

* Reading of last wetted tooth.

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