EASA De-Icing Fluid Tests on a Horizontal Stabilizer Section at the NRC Propulsion and Icing Wind Tunnel

Presented by Catherine Clark, P.Eng.
23 March 2015
NRC Aerospace – Reducing Aviation Icing Risks

Contributions from Marco Ruggi, Eng., APS Aviation Inc.

Agenda

DIFT Research Project Definition (1120h – 1200h)

- Project Summary (Background, Objectives, Participants, Timeline)
- Task T1 – Literature Review
- Task T2 – Model Design and Construction
- Task T3 – Development of Test Procedures
- Task T4 – Main Test Program (Set-up and Calibrations)
- Task T5 – Data Reduction

DIFT Research Project Results (1315h – 1400h)

- Task T4 – Main Test Program (Schedule)
- Task T5 – Data Analysis

De-Icing Fluid Tests Research Project Results

National Research Council Canada
Conseil national de recherches Canada

Task T4 – Main Test Program

December 2014

Task T4 – Main Test Program
Schedule

The main test program was conducted over a period of six (6) days from December 15-20, 2014.

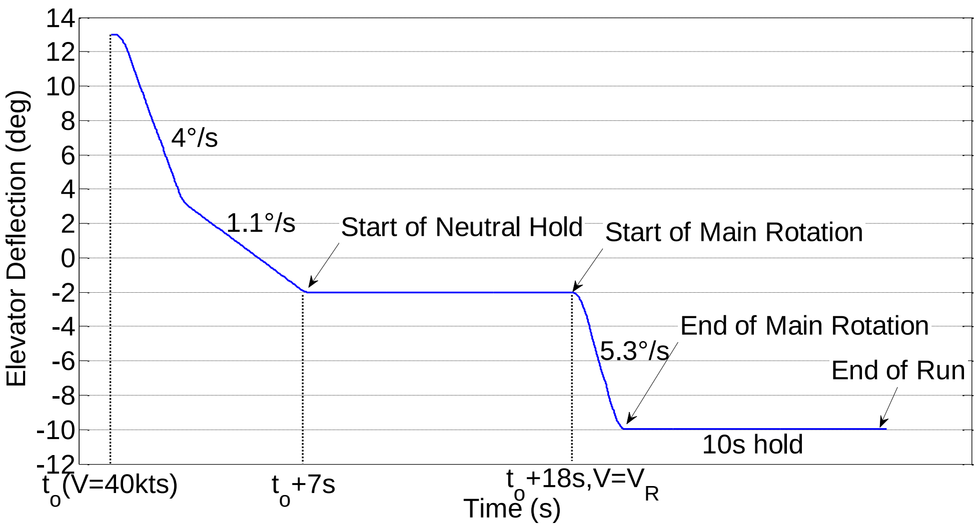
EASA representatives (Emmanuel Cayrol and Alberto Fernandez-Lopez) were present throughout the entire test program, and representatives from Transport Canada visited throughout the week.

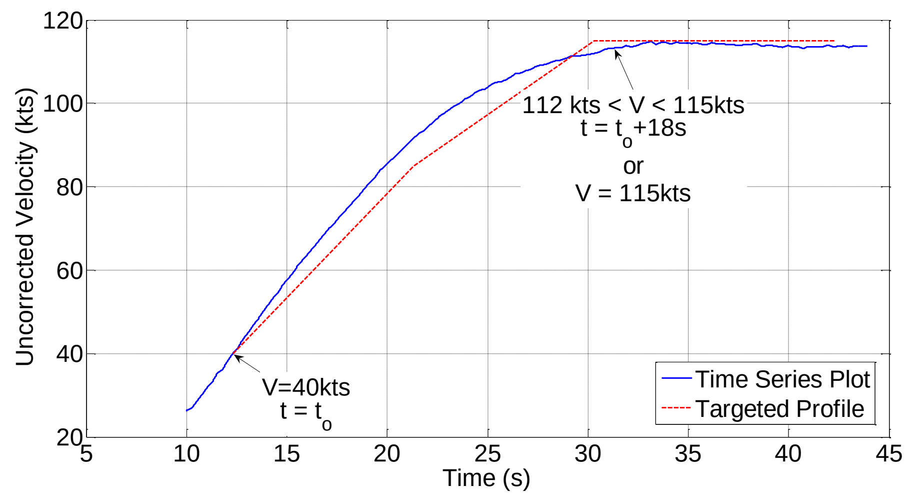
The PIWT and related equipment (including the model and elevator rotation and instrumentation) were operated by NRC personnel.

Activities with respect to deicing fluid acquisition, collection, application, and contamination were performed by APS staff.

Task T4 – Main Test Program
Interpretation of results

As an example, the following slides will examine the time series data for a Scenario 1 take-off profile using IV-L fluid and 115kts rotation speed at the four points of interest (NRC Run#55). The hinge gap was set to 4 mm.





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Task T4 – Main Test Program
Interpretation of results

NRC Run #55 – Scenario 1, 115kts acceleration profile, IV-L Fluid

Upper Surface (NRC Roof Camera)

http://youtu.be/uqbUwYql1Wc

Lower Surface (NRC Floor Camera)

http://youtu.be/YN3O5_81Vkk

Task T4 – Main Test Program
Interpretation of results

NRC Run #55 – Scenario 1, 115kts acceleration profile, IV-L Fluid

Upper Surface (APS Canon)

http://youtu.be/aMAgizh-tEE

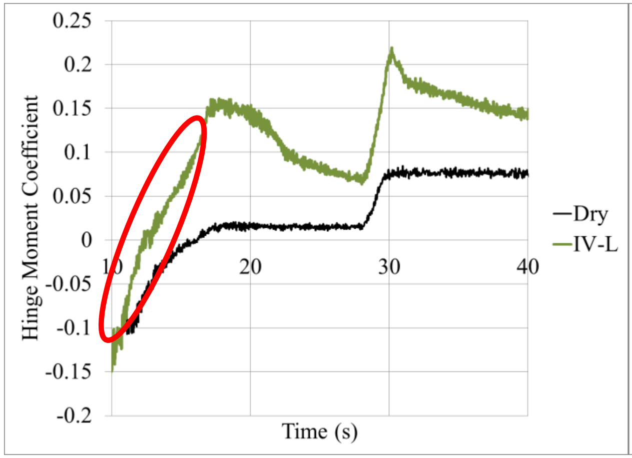
Lower Surface (APS Go-Pro)

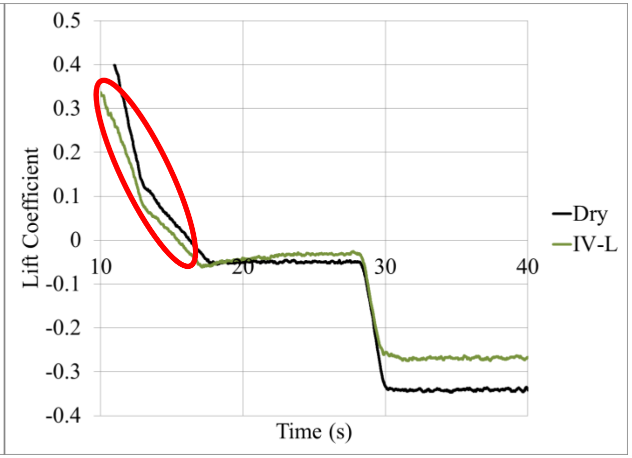
http://youtu.be/MfxGHlxELrg

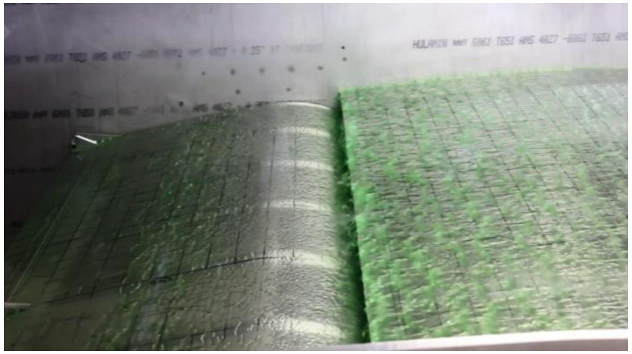
Task T4 – Main Test Program
Interpretation of results

Prior to Start of Neutral Hold

- Fluid motion as airspeed increases is due to shear forces
- Fluid is trapped in the hinge gap area due to gravity and dynamic pressure forces
- As elevator rotates to neutral position this fluid is flushed to the lower surface of the elevator







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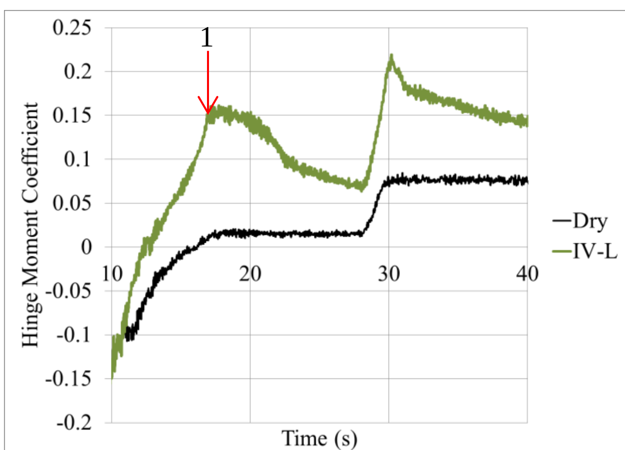
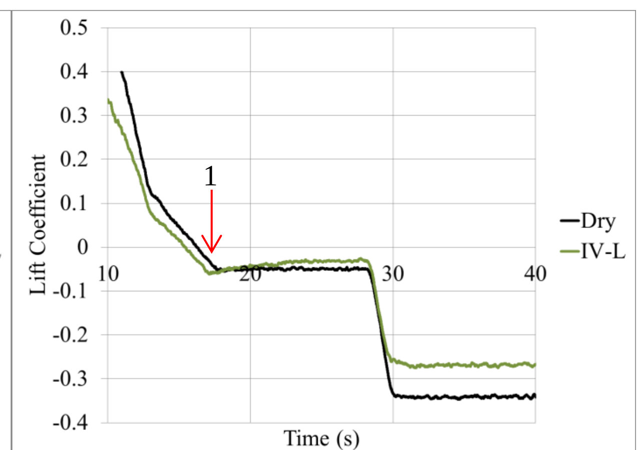
Task T4 – Main Test Program

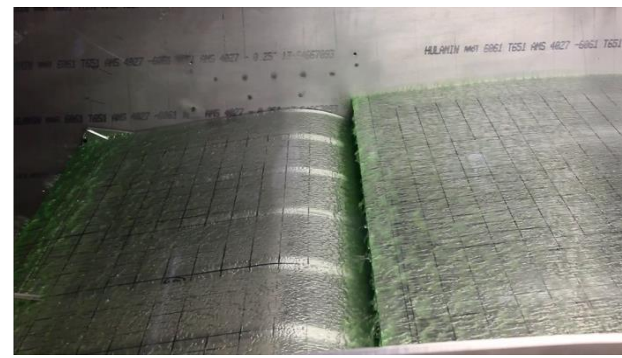
Interpretation of results

Point 1 – Start of Neutral Hold (δ_E = -2°)

- Noticeable amount of fluid remaining on upper surface
- Lower surface of elevator is almost fully contaminated with fluid that was flushed through the hinge gap as the elevator rotated to neutral
- No fluid on lower surface of main element







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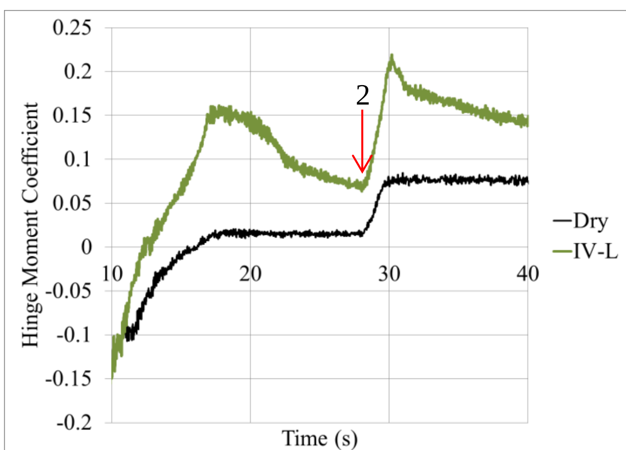
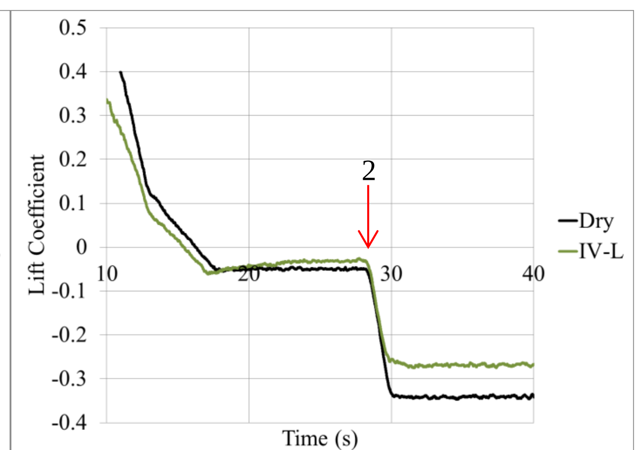
Task T4 – Main Test Program

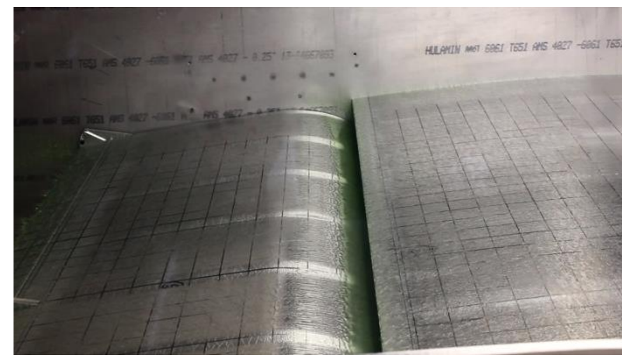
Interpretation of results

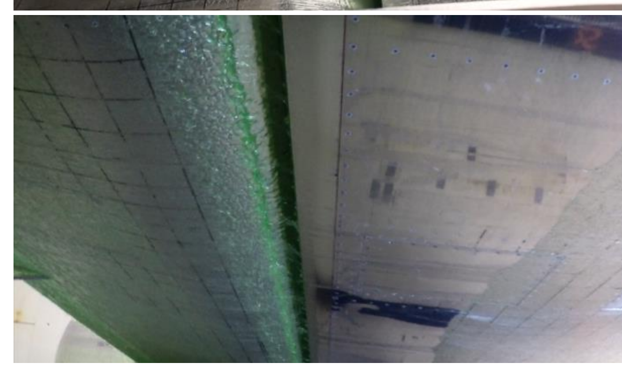
Point 2 – Start of Main Rotation (δ_E = -2°)

- Most fluid has sheared off the upper surface and elevator during the hold period
- Stagnation points on upper and lower surfaces of elevator keep some amount of fluid trapped in the hinge gap area
- Thin layer of fluid from leading edge is moving downstream on lower surface of main element





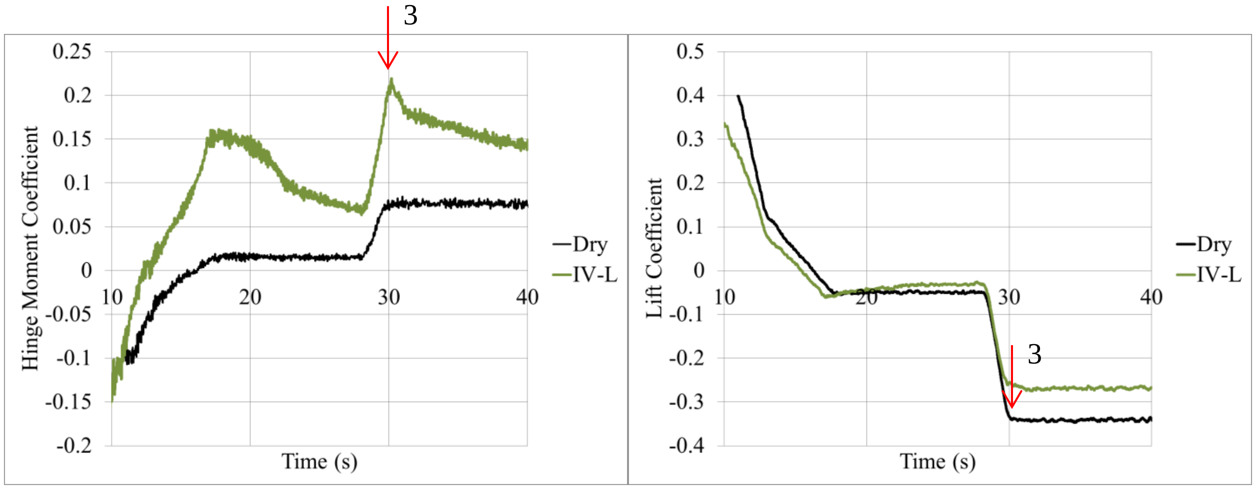


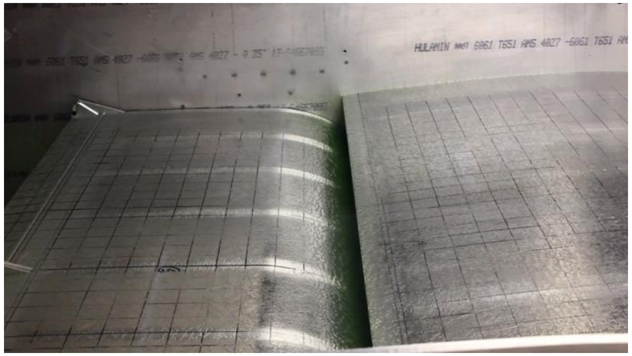


Task T4 – Main Test Program
Interpretation of results

Point 3 – End of Main Rotation ($\delta_E = -10°$)

- Increased pressure differential and change in stagnation points on elevator flush the fluid previously trapped in hinge gap area to lower surface of the elevator
- Minimal fluid remaining on upper surface
- Fluid continues moving downstream on lower surface of main element

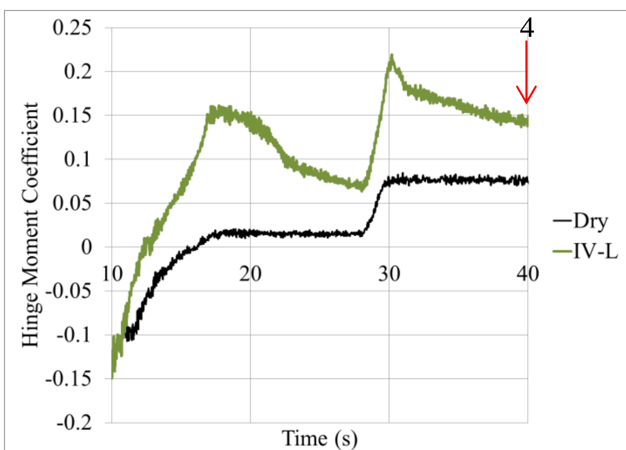


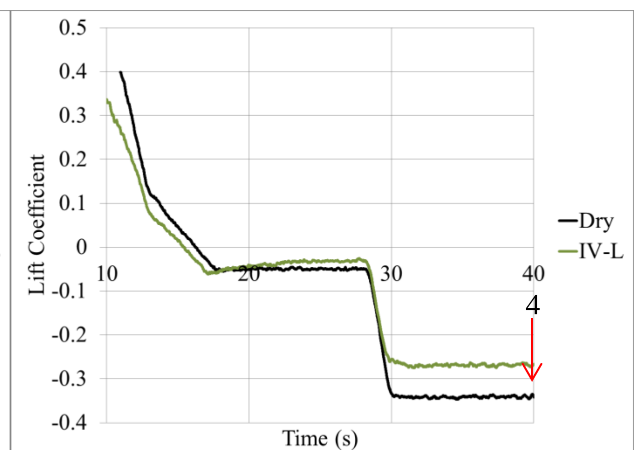


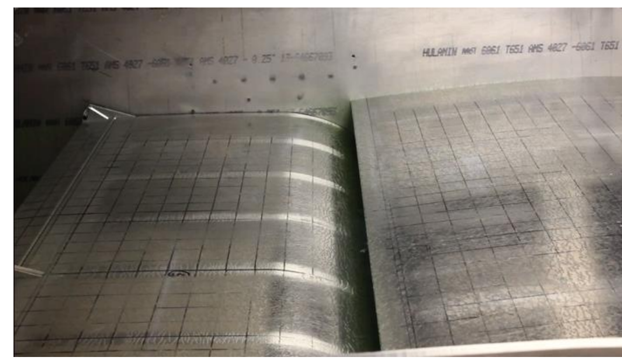
Task T4 – Main Test Program
Interpretation of results

Point 4 – End of Run (δ_E = -10°)

- Lower surface of main element completely covered in fluid
- C_h improves during hold period as fluid is sheared off the model
- Fluid near downstream end of elevator is slow to clean off, may be due to flow separation







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Task T5 – Data Analysis

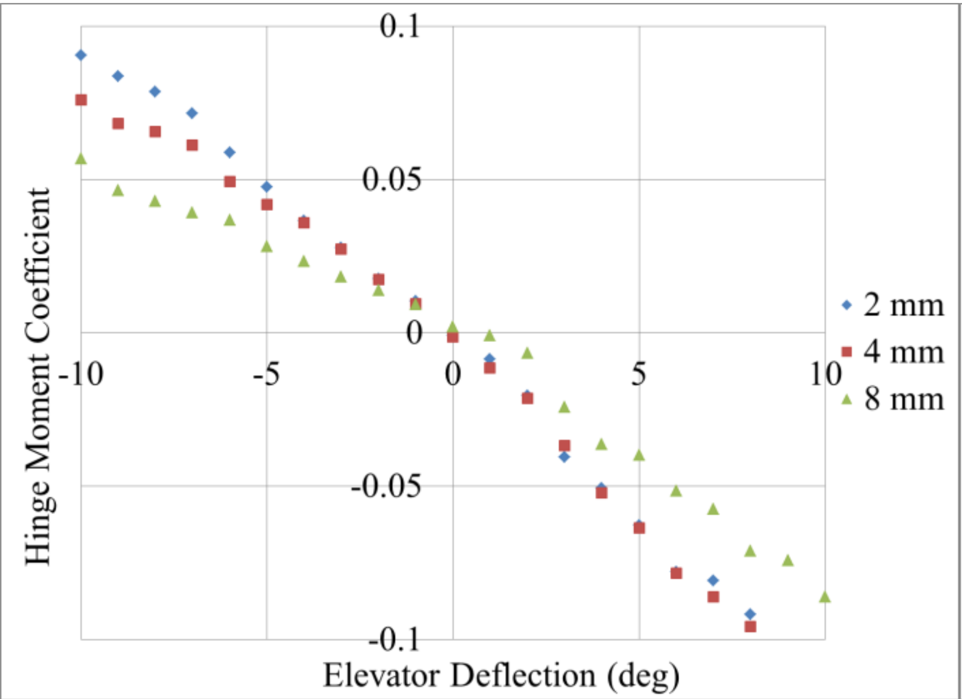
January 2015

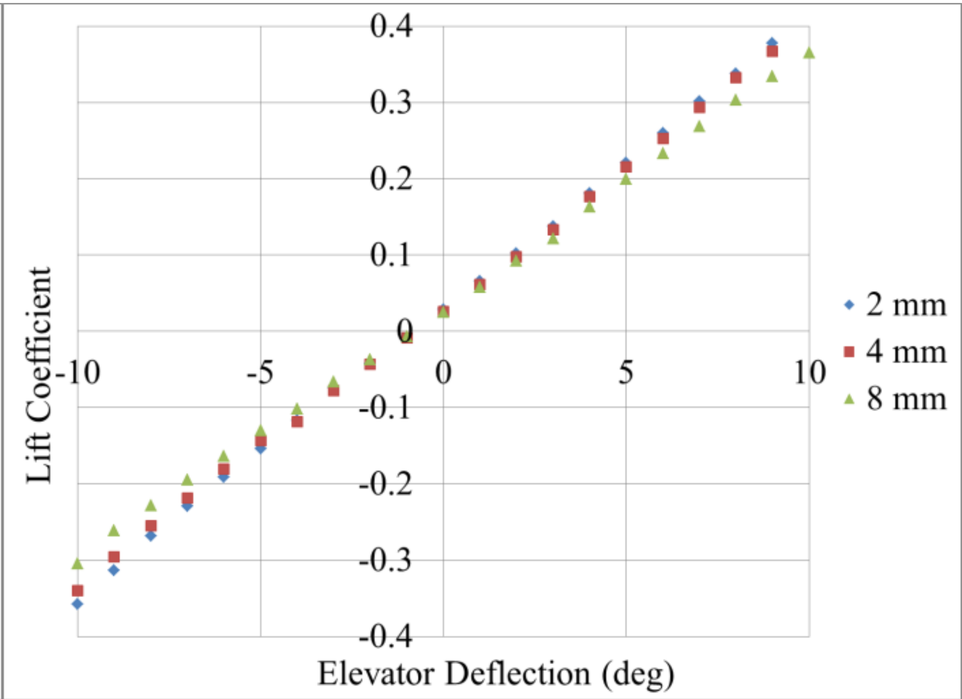
Task T5 – Data Analysis

Phase 1: Establish Evaluation Criteria

Three different hinge gap sizes were tested: 2 mm, 4 mm and 8 mm

Repeatability of the dry model performance is on average ±0.002 C_h and ±0.004 C_l. Due to backlash in the system, there is an estimated uncertainty in the elevator of ±0.45°.



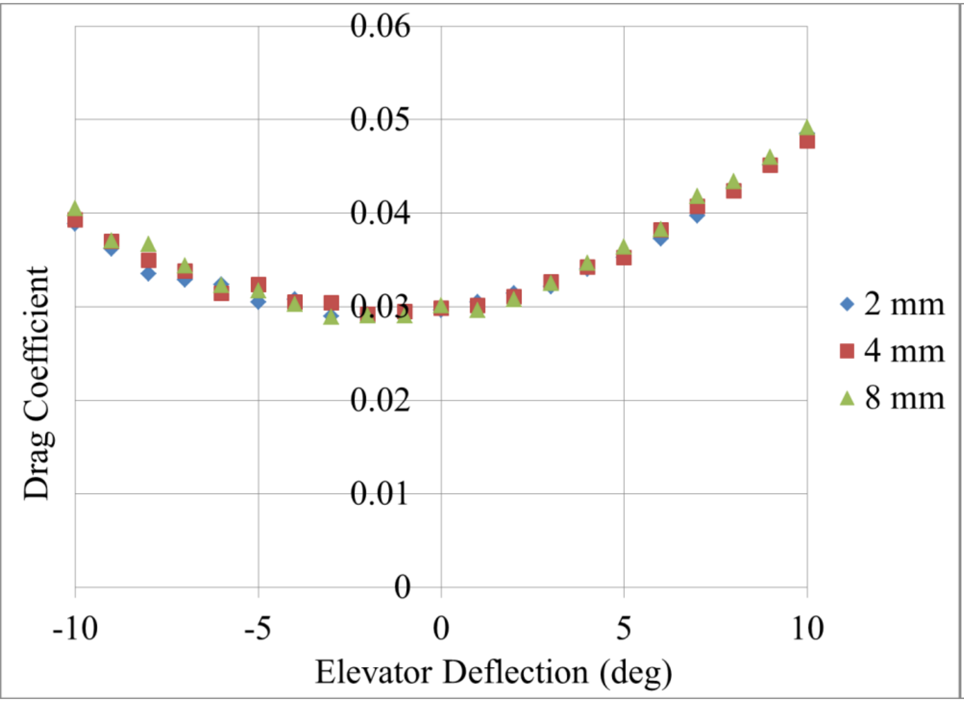


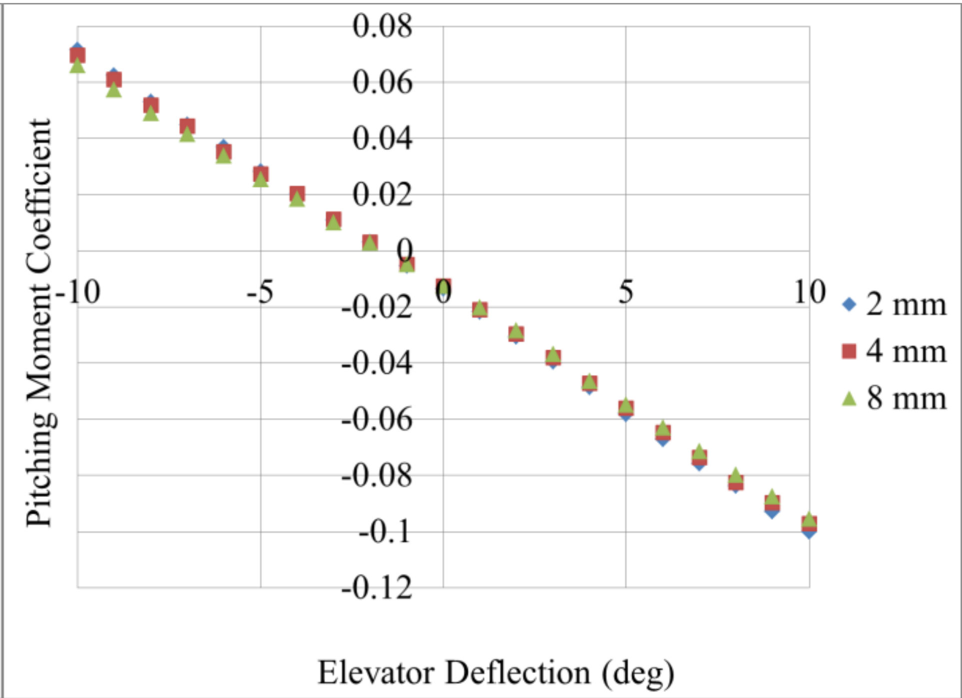
Task T5 – Data Analysis

Phase 1: Establish Evaluation Criteria

Drag and pitching moment are presented for the dry cases. For the fluid cases only C_h and C_l are presented, as they are better indicators of the fluids' effects on the horizontal stabilizer performance.

Repeatability of the dry model performance is on average ±0.0007 C_d and ±0.001 C_m.

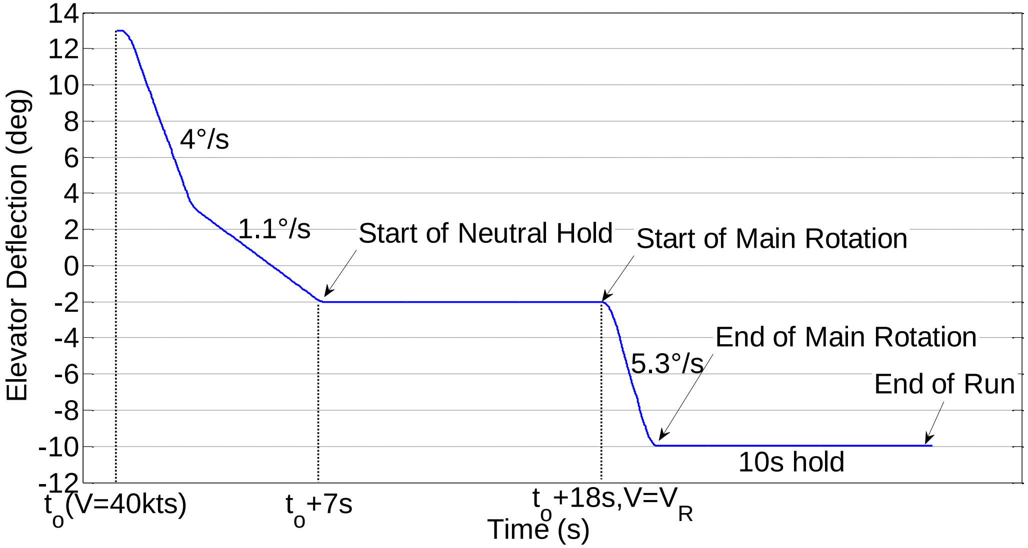


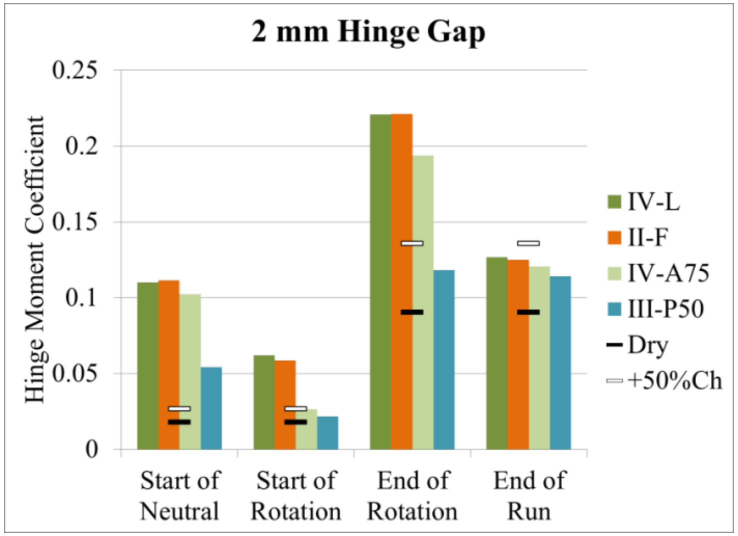


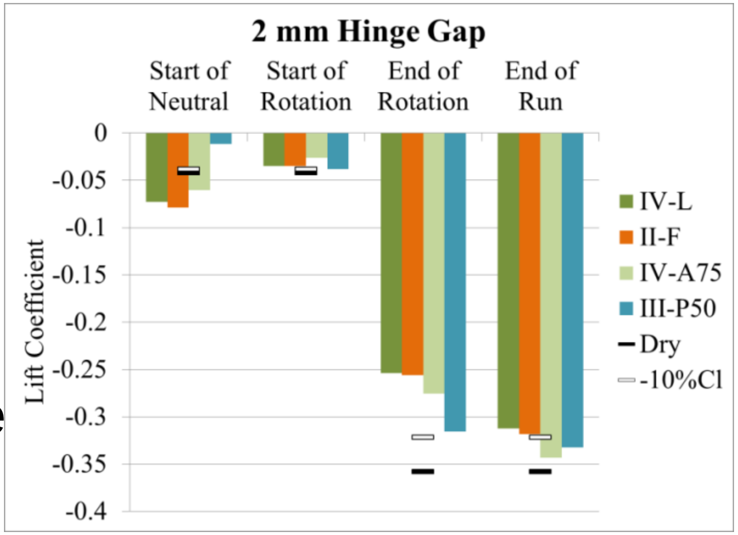
Task T5 – Data Analysis

Phase 2: Identify Contributing Variables

Effect of Fluids – Scenario 1, 115 kts



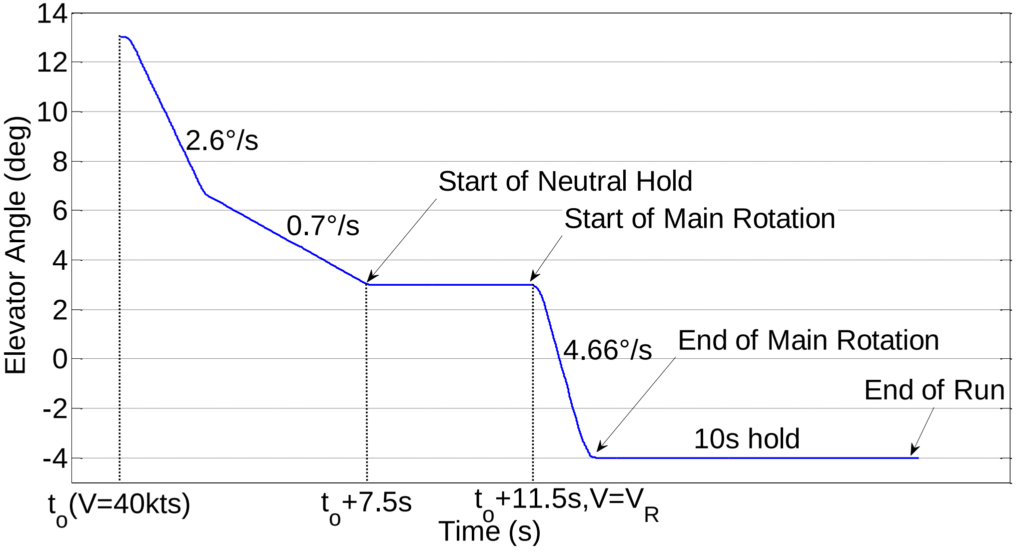




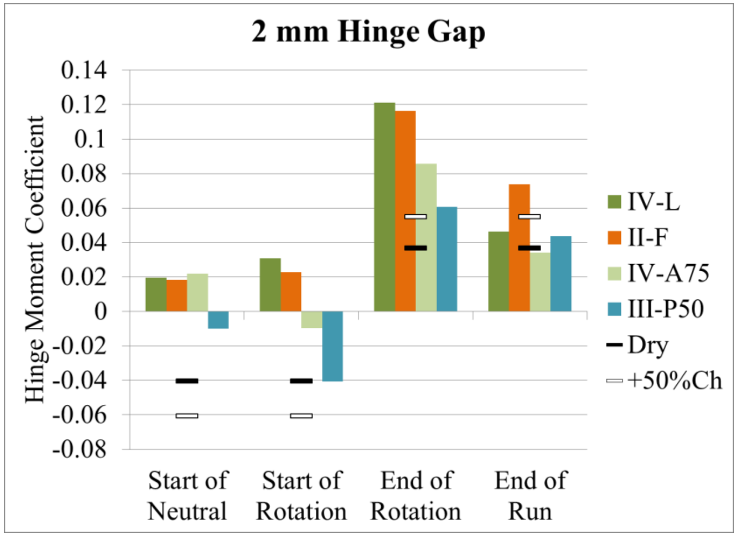
- Fluids IV-L and II-F have similar effects
- Fluid IV-A75 has highest viscosity but better performance than IV-L and II-F
- Low-viscosity III-P50 has best performance

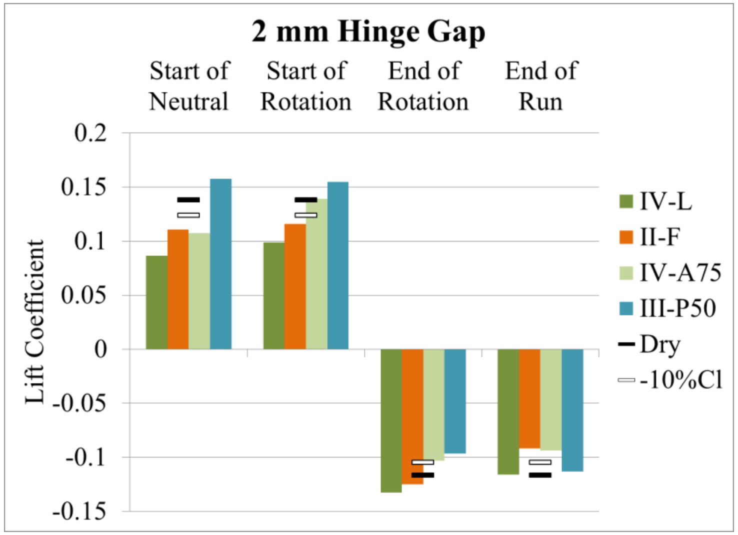
Task T5 – Data Analysis
Phase 2: Identify Contributing Variables

Effect of Fluids – Scenario 2, 105 kts



- Similar trends to Scn. 1 profiles
- Shorter hold period results in less time to ‘clean’ the model so start of neutral and start of rotation performance is similar





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Task T5 – Data Analysis
Phase 2: Identify Contributing Variables

Effect of Hinge Gap

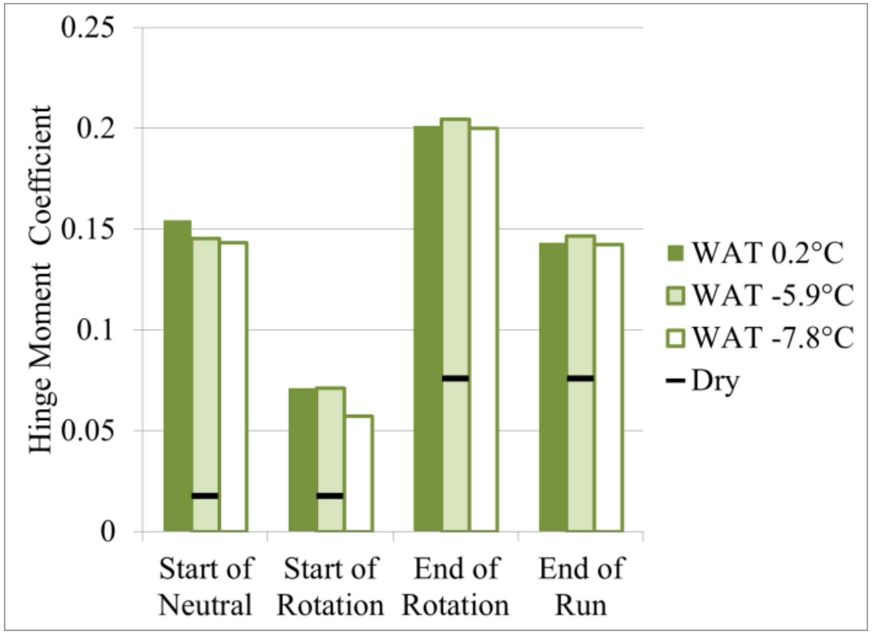
- Both Scenario 1 and Scenario 2 profiles were run with fluids for hinge gap sizes of 2 mm, 4 mm and 8 mm
- Generally larger hinge moment coefficient as hinge gap increases and there is a larger area for fluid to flow through onto the lower surface of the elevator
- Overall trends the same for all hinge gap sizes

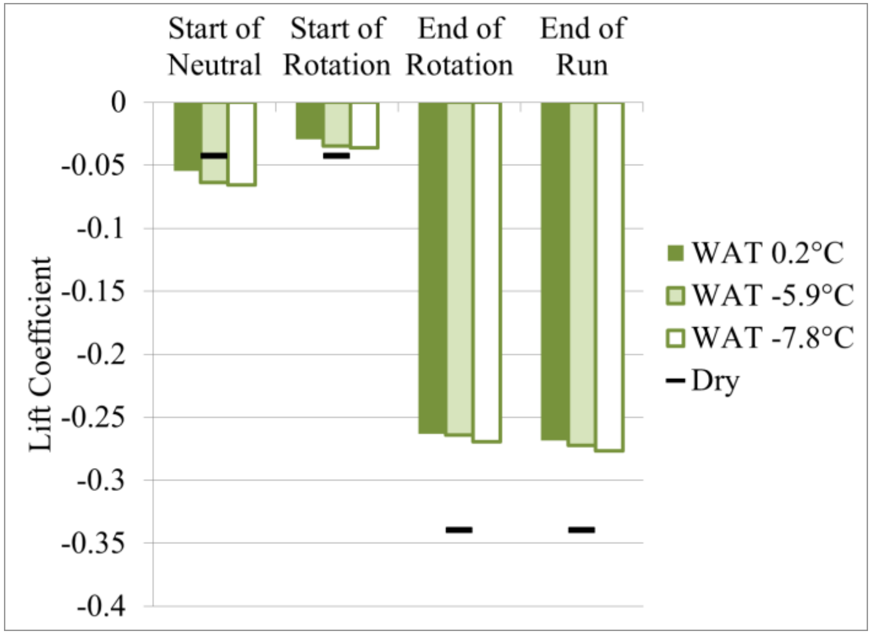
Task T5 – Data Analysis

Phase 2: Identify Contributing Variables

Effect of Temperature – 4 mm gap, Scenario 1, 115 kts

- Over the range of temperatures available there was no significant difference in performance
- Similar results were found for IV-L (shown below), II-F, IV-A75 and III-P50 fluids (positive cases)

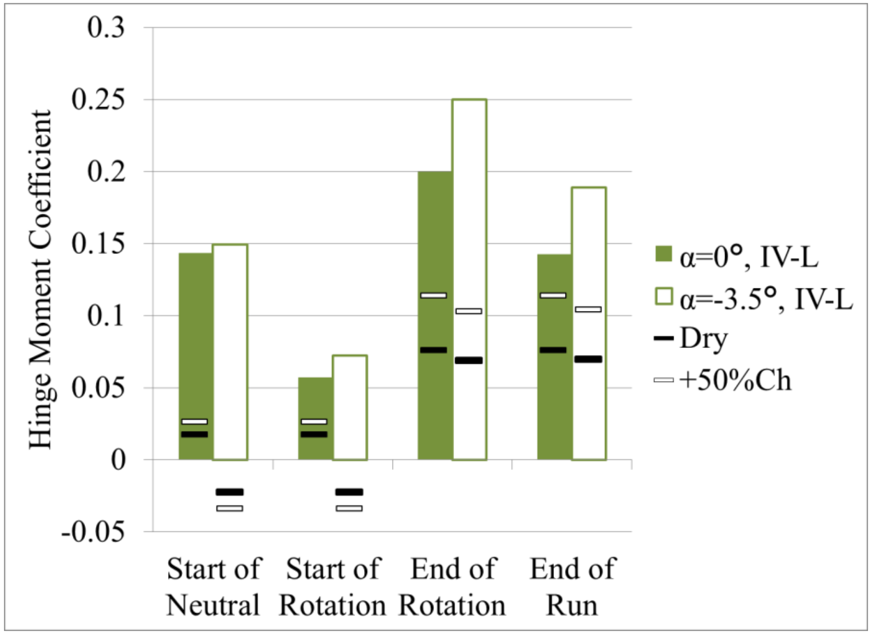


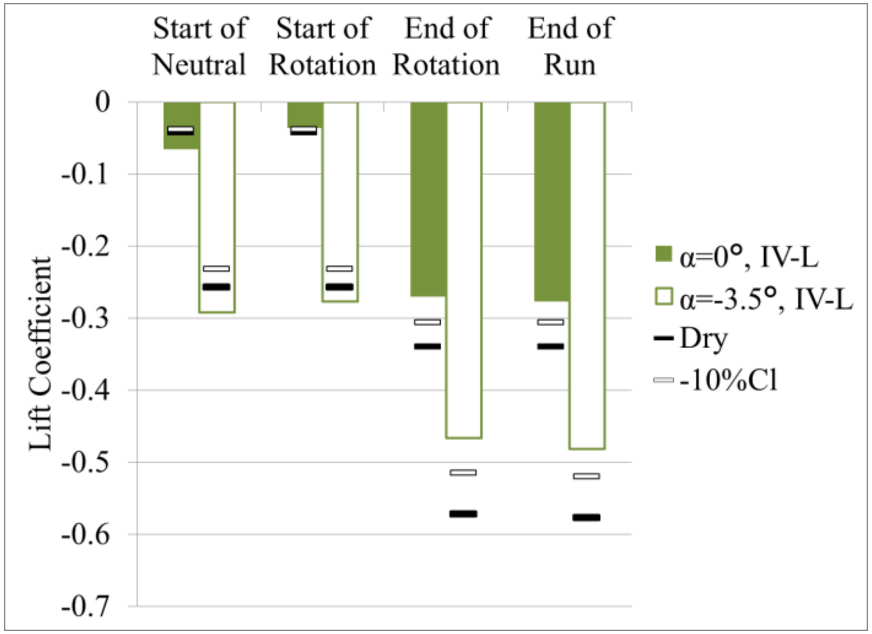


Task T5 – Data Analysis
Phase 2: Identify Contributing Variables

Effect of Downwash – 4 mm gap, Scenario 1, 115 kts, α = -3.5°

- Downwash effects create larger difference between wet and dry C_h values and comparable differences in C_l
- This effect was assessed by means of a single test run so conclusions should not be generalised without more data





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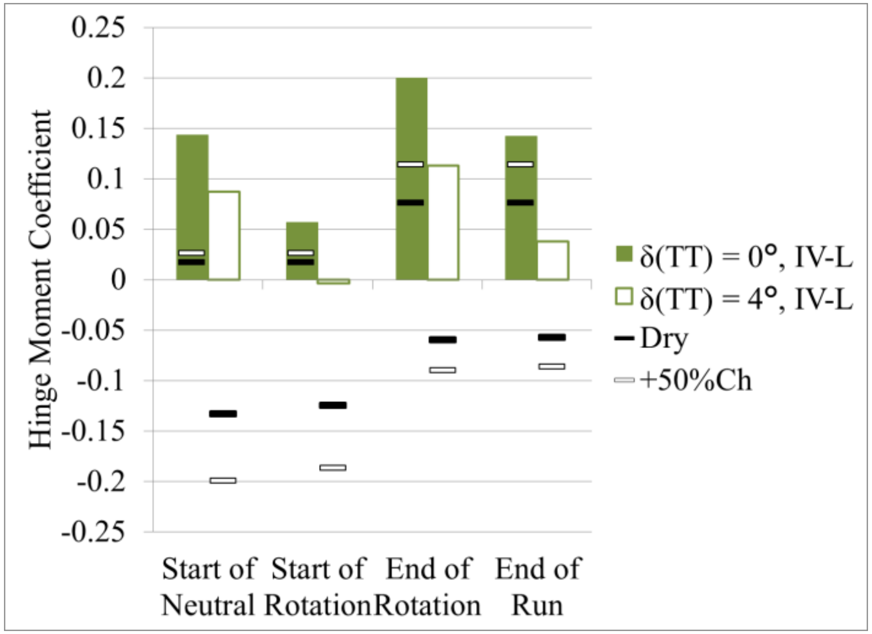
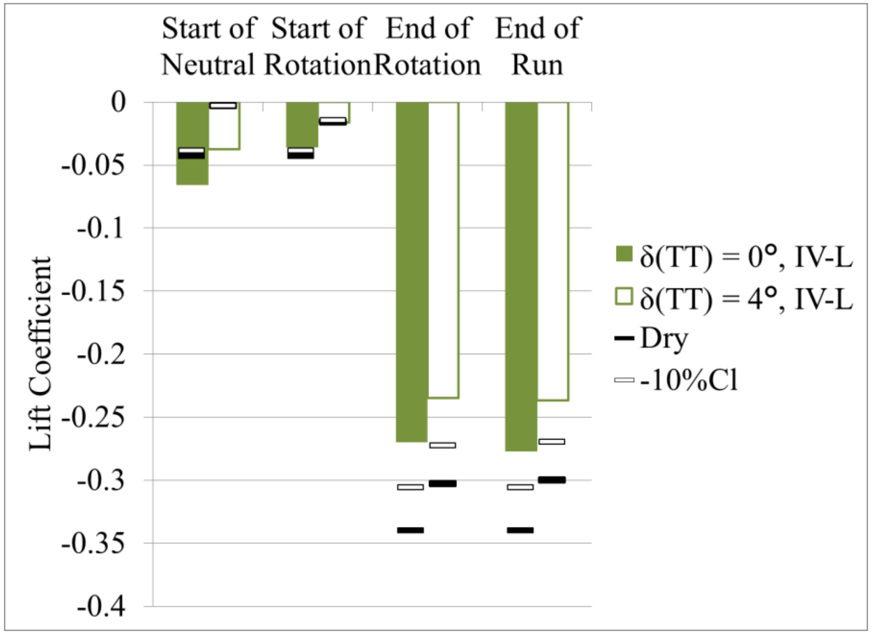
Task T5 – Data Analysis

Phase 2: Identify Contributing Variables

Effect of Trim Tab – 4 mm gap, Scenario 1, 115 kts, $\delta_{TT(fixed)} = 4°$

- Trim tab reduces absolute value of loads on elevator, note that this configuration is not representative of a real aircraft configuration
- Trim tab creates larger difference between wet and dry C_h values and comparable differences in C_l



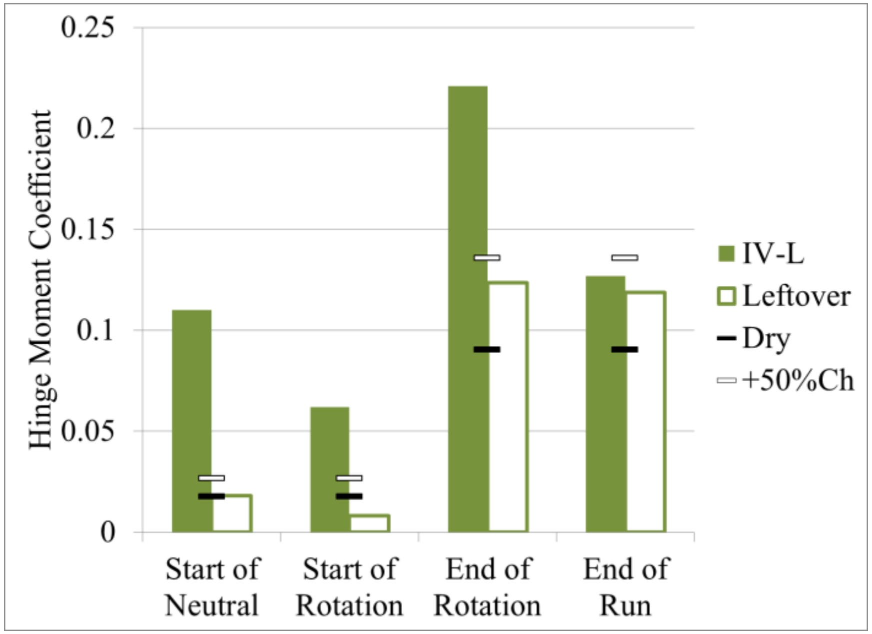


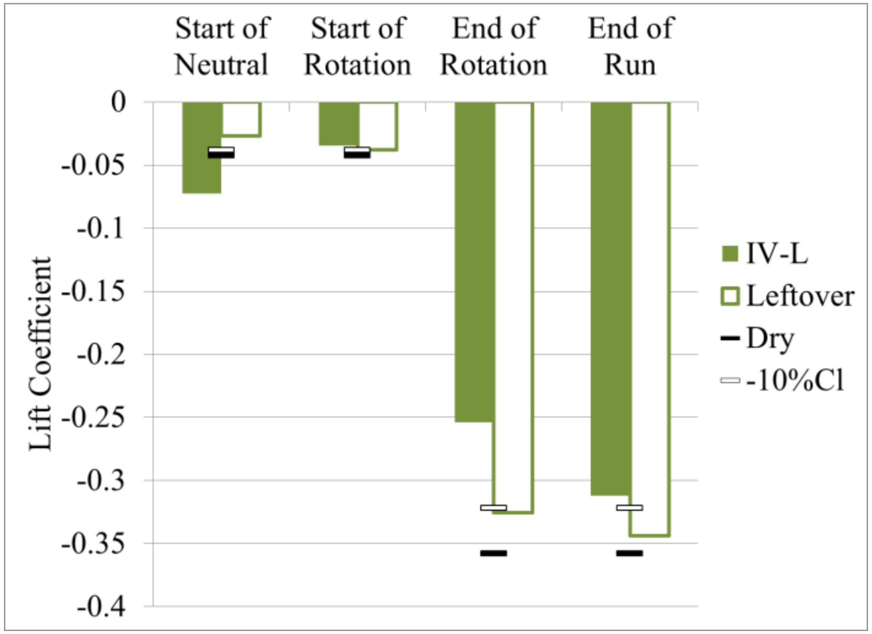
Task T5 – Data Analysis

Phase 2: Identify Contributing Variables

Effect of Leftover Fluid – 2 mm gap, Scenario 1, 115 kts

- After a regular run with IV-L fluid, the model was not cleaned and the test was repeated to look at the effects of leftover fluids remaining in areas of low aerodynamic pressure (simulated aborted take-off run)
- Aerodynamic performance is within defined limits (negative case)

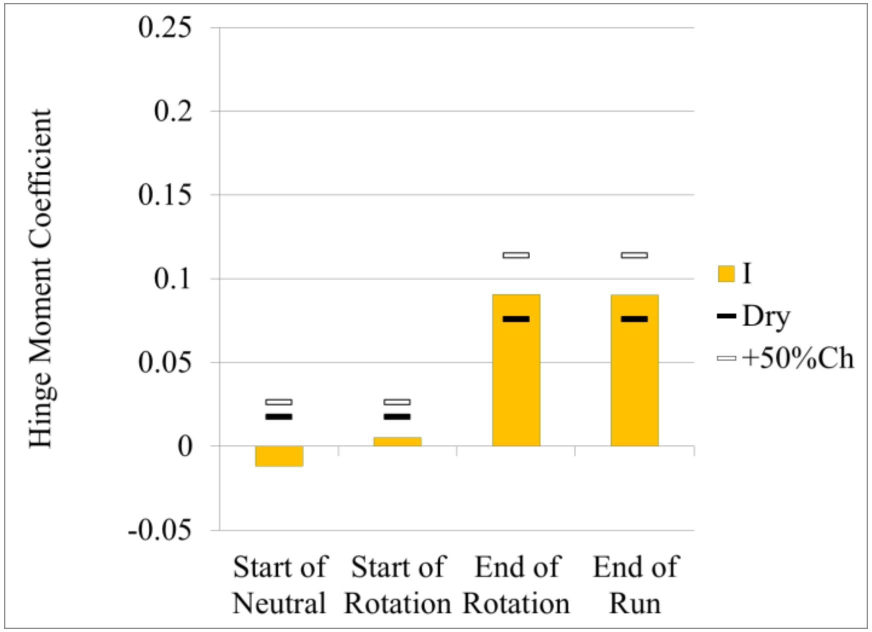


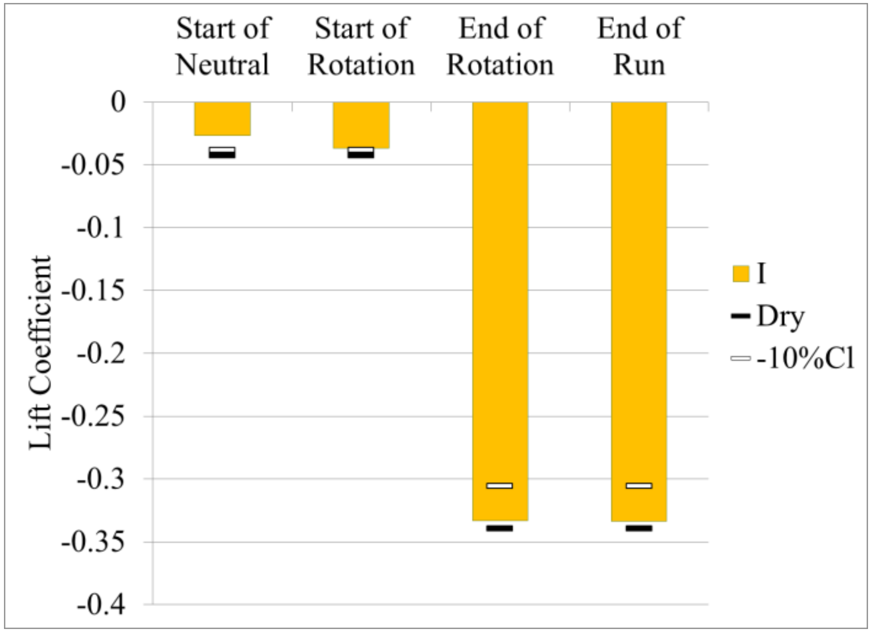


Task T5 – Data Analysis
Phase 3: Attempt to Rectify Rotation Difficulties

Type I Fluid Application – 4 mm gap, Scenario 1, 115 kts

- Type I fluid with low viscosity applied
- Minimal effect on C_h and C_l compared to thickened fluids
- Aerodynamic performance is within defined limits (negative case)



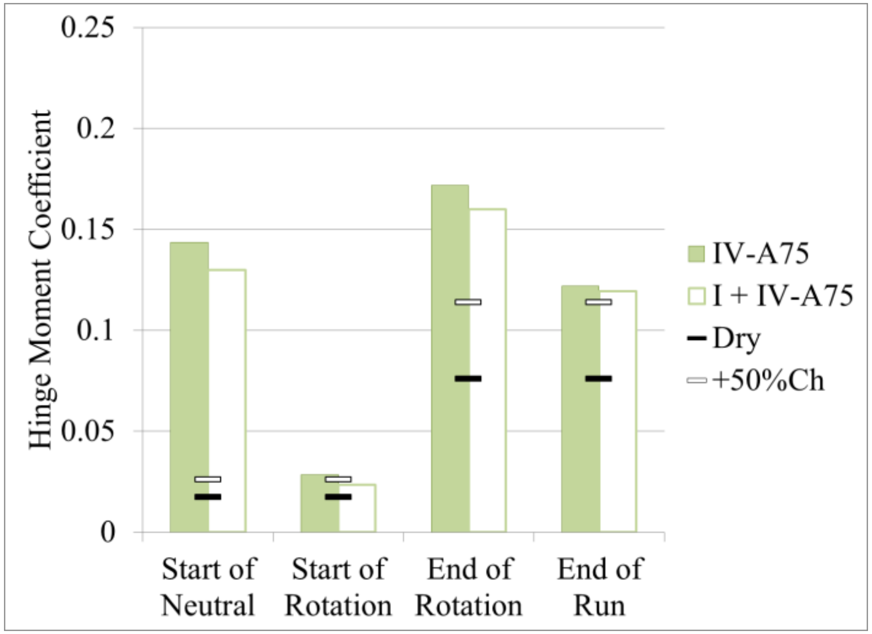


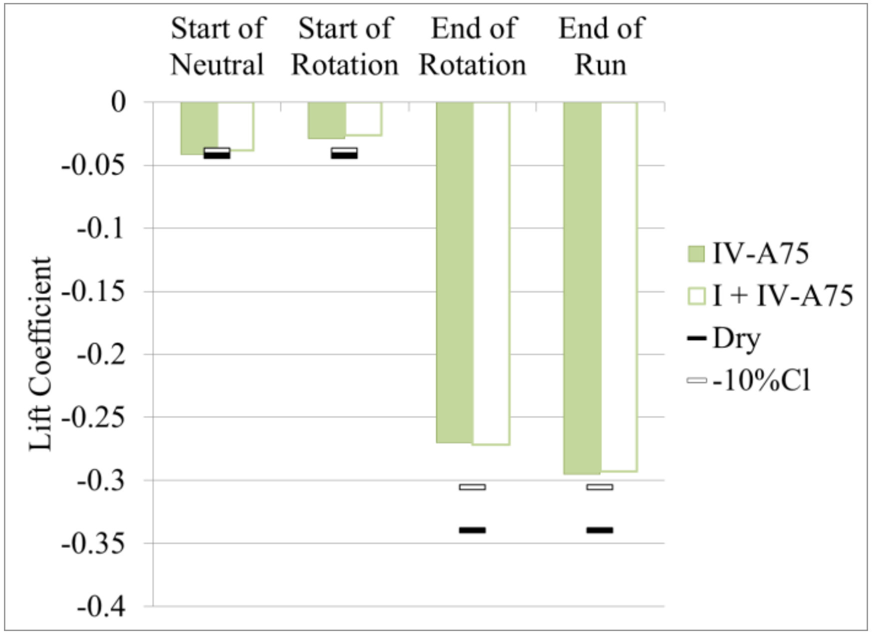
Task T5 – Data Analysis

Phase 3: Attempt to Rectify Rotation Difficulties

Two-Step De-Icing Process – 4 mm gap, Scenario 1, 115 kts

- A two-step de-icing process was tested using a Type I fluid followed by either a Type II fluid or a Type IV fluid (shown below)
- The results show that the addition of a de-icing step with a Type I fluid has no significant impact on the results (remains positive case)





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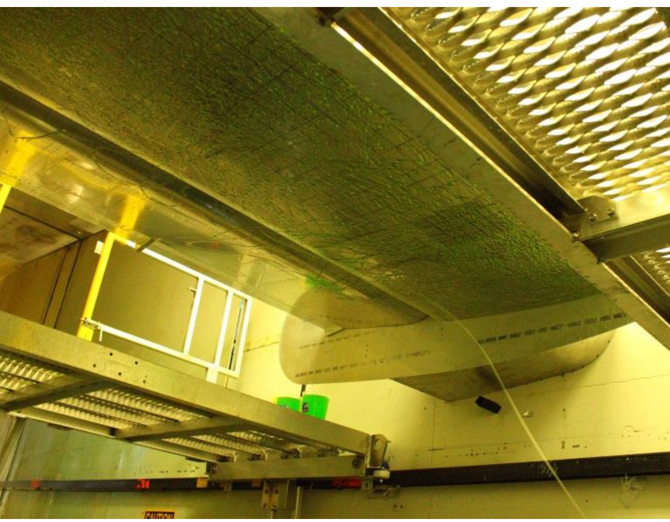
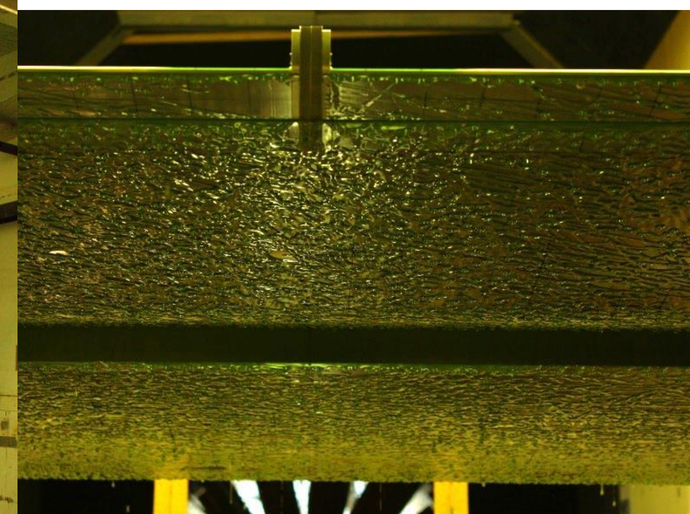
Task T5 – Data Analysis
Phase 3: Attempt to Rectify Rotation Difficulties

Fluid Sprayed on Underside of Model – 4 mm gap, Scenario 1, 115 kts

- Was suggested that spraying the underside of the horizontal stabilizer may ‘balance out’ the problem



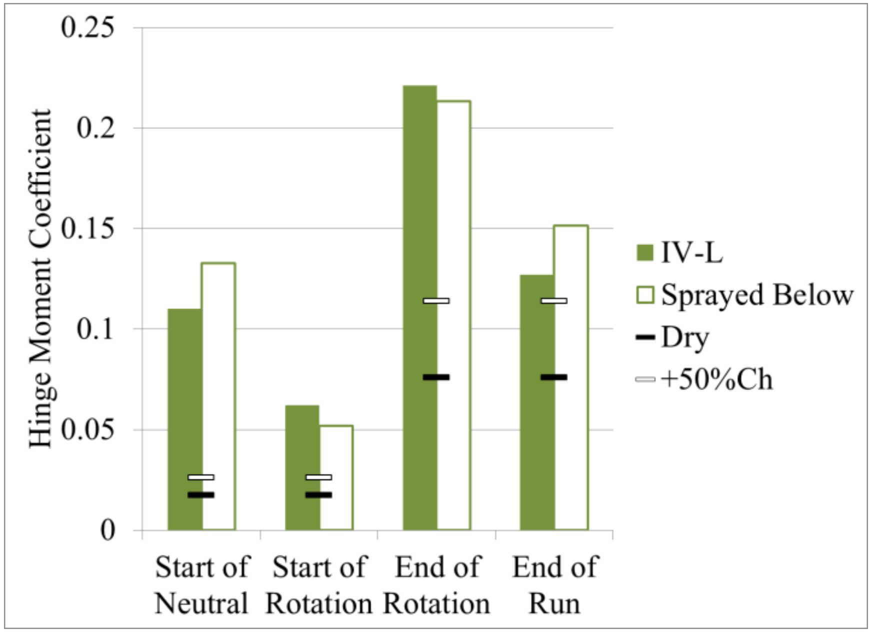


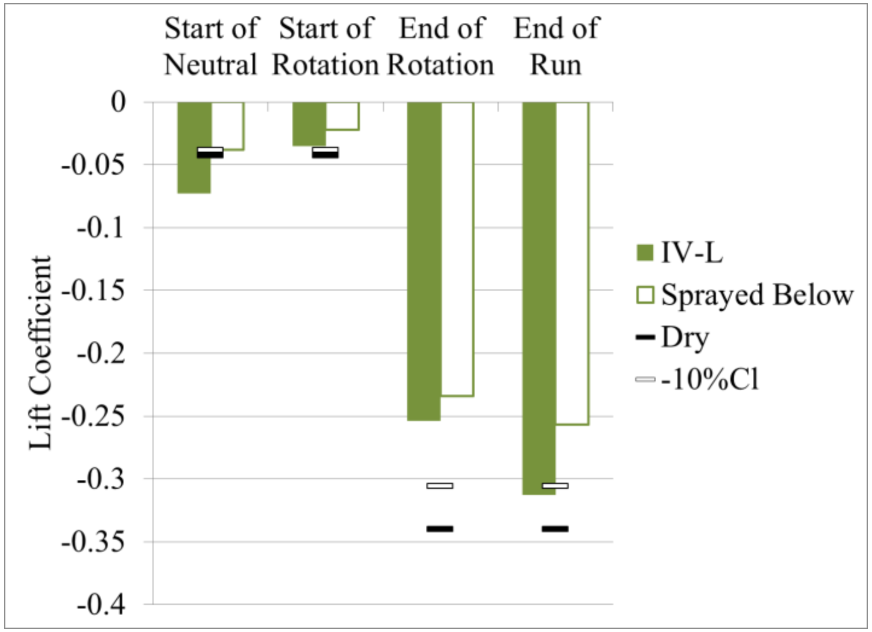
Task T5 – Data Analysis

Phase 3: Attempt to Rectify Rotation Difficulties

Fluid Sprayed on Underside of Model – 4 mm gap, Scenario 1, 115 kts

- The results show small changes in C_h and overall lower C_l
- Spraying fluid on the underside of the model, in addition to the fluid on the upper surface, increases the amount of fluid on the lower surface of the elevator during the run (remains positive case)





Task T5 – Data Analysis

Phase 3: Attempt to Rectify Rotation Difficulties

Fluid Dilution – 4 mm gap, Scenario 1, 115 kts

- II-F And IV-L were diluted to examine the effects of the corresponding viscosity changes on the horizontal stabilizer
- For these fluids, the 75/25 dilutions have higher viscosities than the neat fluid condition

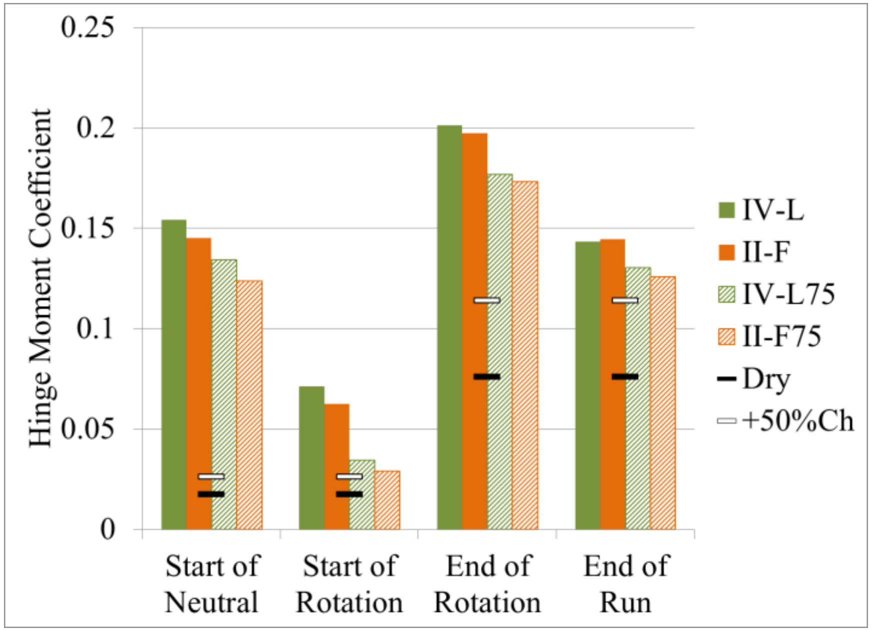
Test Ref.	Dilution	Measured Viscosity (mPa-s)
IV-L75	75/25	21,800
II-F75	75/25	20,300
IV-L	100/0	15,760
II-F	100/0	13,600

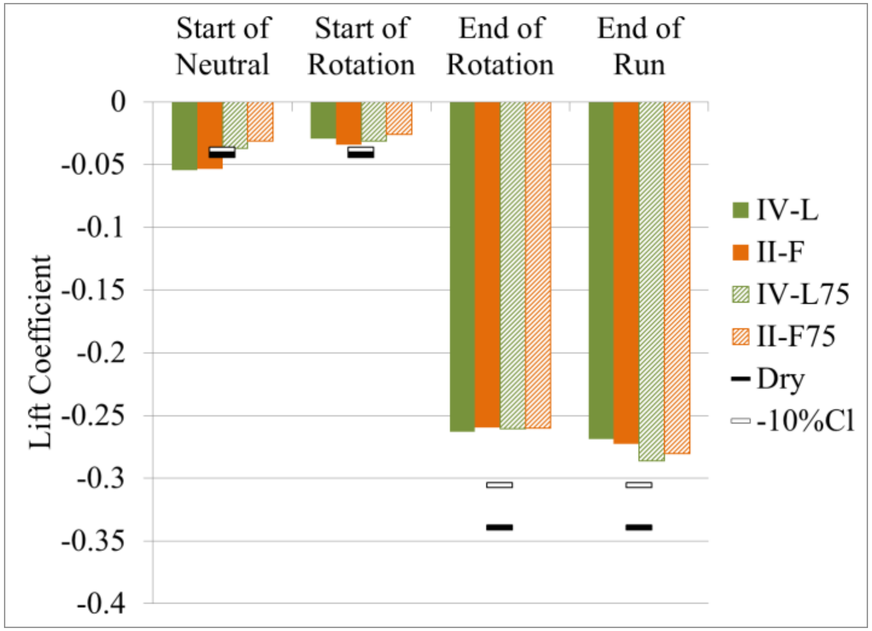
Task T5 – Data Analysis

Phase 3: Attempt to Rectify Rotation Difficulties

Fluid Dilution – 4 mm gap, Scenario 1, 115 kts

- The results show that diluting the fluid improves the C_h although they remain as positive cases
- The higher viscosity may prevent the fluid from easily flowing through the gap and contaminating the lower surface of the elevator





Summary and Recommendations

Summary and Recommendations

Phase 1: Establish Evaluation Criteria

- 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.

- Positive test cases (+50% C_h, -10% C_l) were observed for most cases with Type IV fluids regardless of the gap size or take-off rotation profile.

Summary and Recommendations

Phase 2: Identify Contributing Variables

- 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.

- Fluid viscosity has a significant impact on the resulting hinge moment and lift coefficients.

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

Summary and Recommendations

Phase 3: Attempt to Rectify Rotation Difficulties

- Simulated main-wing downwash did not improve the performance of the model with fluids, although conclusions should not be generalised without more data.

- The effects of a fixed-position trim tab were nominally investigated in this research program. 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 had minimal impact on the aerodynamic performance of the model (negative case).

- The application of a Type I fluid had minimal impact on the aerodynamic performance of the model (negative case).

Summary and Recommendations

Phase 3: Attempt to Rectify Rotation Difficulties

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

- Spraying fluid on the underside of the model in addition to the fluid on the upper surface did not improve the model performance.

- Diluting the IV-L and II-F fluids increases their viscosity. The results show 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.

Summary and Recommendations

Proposed Future Work

- Fluid viscosity has a significant effect on the aerodynamic performance of the horizontal stabilizer. Evaluating the effects of contamination such as snow, freezing rain, and other holdover time related conditions could provide additional insight, as the precipitation acts to dilute the fluids.

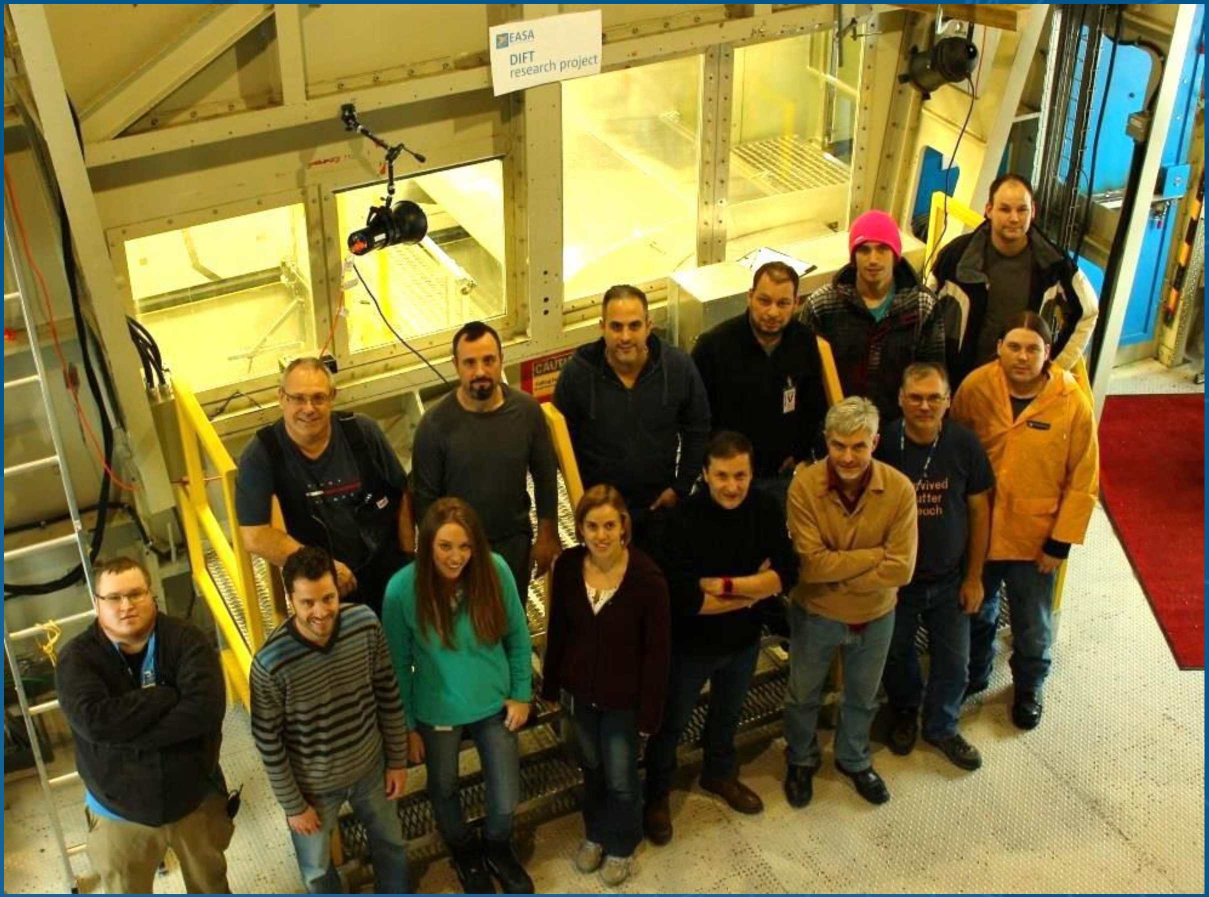
- Additional viscosity profiling tests could be performed to better understand the correlation between viscosity, shear forces, and aerodynamic performance.

- 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.

Summary and Recommendations
Future Work

- 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 work was funded by Transport Canada in March 2015. Analysis of results is in progress.*



Thank you

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