



Scaling of Lift Degradation due to Anti-Icing Fluids Based Upon the Aerodynamic Acceptance Test

In recent years, the FAA has worked with Transport Canada, National Research Council Canada (NRC) and APS Aviation, Inc. to develop allowance times for aircraft operations in ice-pellet precipitation. These allowance times are critical to ensure safety and efficient operation of commercial and cargo flights. Wind-tunnel testing with uncontaminated anti-icing fluids and fluids contaminated with simulated ice pellets had been carried out at the NRC Propulsion and Icing Wind Tunnel (PIWT) to better understand the flowoff characteristics and resulting aerodynamic effects. The percent lift loss on the thin, high-performance wing model tested in the PIWT was determined at 8 deg. angle of attack and used as one of the evaluation criteria in determining the allowance times. Because it was unclear as to how performance degradations measured on this model were relevant to an actual airplane configuration, some means of interpreting the wing model lift loss was deemed necessary. This paper describes how the lift loss was related to the loss in maximum lift of a Boeing 737-200ADV airplane through the Aerodynamic Acceptance Test (AAT) performed for fluids qualification. A loss in maximum lift coefficient of 5.24% on the B737-200ADV airplane (which was adopted as the threshold in the AAT) corresponds to a lift loss of 7.3% on the PIWT model at 8 deg. angle of attack. There is significant scatter in the data used to develop the correlation related to varying effects of the anti-icing fluids that were tested and other factors. A statistical analysis indicated the upper limit of lift loss on the PIWT model was 9.2%. Therefore, for cases resulting in PIWT model lift loss from 7.3% to 9.2%, extra scrutiny of the visual observations is required in evaluating fluid performance with contamination.



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Outline

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Introduction

- The FAA, Transport Canada, APS Aviation and NRC have been conducting research to develop allowance times for airplane operations in ice-pellet precipitation.
- These allowance times are important for sustained airport ground operations while maintaining flight safety.
- Ice pellets imbedded in anti-icing fluids exhibit different behavior than other forms of precipitation such as snow, freezing drizzle and freezing rain.
- This precludes the establishment of hold-over times (HOTs) that govern ground operations for other forms of precipitation.
- Therefore, testing specific to ice-pellet precipitation is required.





Introduction

- Collaborative research among FAA, TC, NRC and APS was initially conducted in March 2006.
 - Takeoff profiles conducted with a test airplane.
 - The criterion applied to determine allowance times was visual observation of fluid flowoff behavior with ice pellets.
- In later years, tests were conducted in the NRC's Propulsion and Icing Wind Tunnel (PIWT).
 - Measured lift degradation due to the contaminated fluid was also used in developing allowance times.
 - This led to concerns regarding how the model lift degradation scaled to full-scale airplane configurations.
 - The purpose of this paper is to address this concern.
- Results of the ice-pellet allowances times testing has been presented by Clark and MacMaster, AIAA Paper 2012-2799.



Objective and Approach

Objective

- Relate the lift losses due to uncontaminated anti-icing fluids measured on the model in the NRC PIWT to potential reductions in maximum lift on a full-scale airplane.
- Use this result to develop a lift-loss criterion that can be used in developing ice-pellet allowance times.

Approach

- Review the Aerodynamic Acceptance Test (AAT) that is used for fluids qualification.
- Use the results of the AAT to determine the effect of anti-icing fluids on airplane maximum lift.
- Apply these results to the lift losses measured on the PIWT model.

Aerodynamic Acceptance Test (AAT)

- SAE Aerospace Standard AS5900
- Qualify deicing and anti-icing fluids.
- Fluid test samples are applied to a horizontal flat plate in a small-scale refrigerated wind at typical operational temperatures (0 to -30°C).
- Airflow accelerated to 127 knots in 25 seconds.
- The boundary-layer displacement thickness, δ^* , is measured at a location 5 ft (1.5 m) downstream of the flat-plate leading edge at 30 seconds.
- Fluid acceptance based upon the measured δ^* compared to a threshold value set according to AS5900.

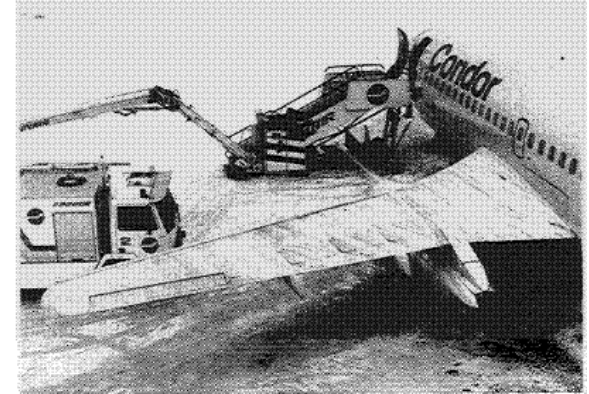


Anti-Icing Materials Laboratory at
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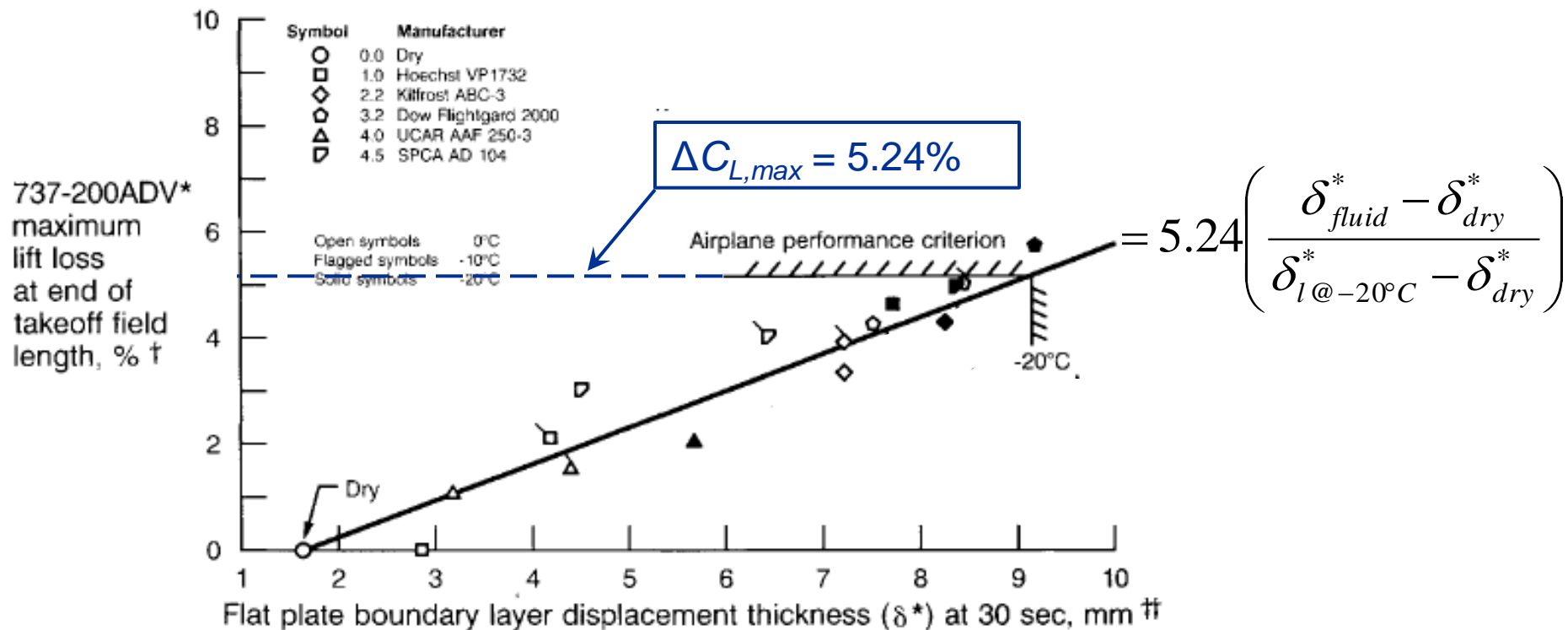
Research Basis of the AAT

- Large research program designed to characterize deicing/anti-icing fluid behavior and aerodynamic effects on transport airplanes.
 - Led by Eugene Hill and Thomas Zierten at Boeing.
 - Takeoff profile flight tests conducted using a B737-200ADV airplane.
 - NASA IRT tests conducted using 3D half-plane and 2D airfoil subscale models of the B737-200ADV configuration.
 - Fluid flowoff tests conducted on a flat plate in a small-scale refrigerated wind tunnel with of operational temperatures and air speeds.
- Results showed that the fluids caused premature boundary-layer growth which resulted in the observed aerodynamic performance degradation.



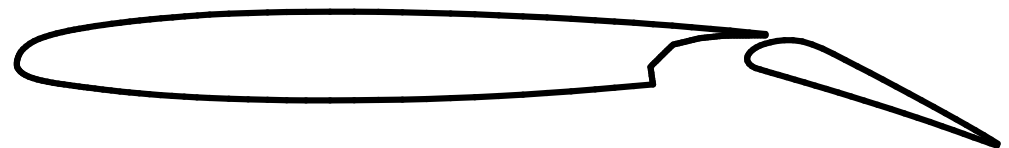
Research Basis of the AAT

- Hill and Zierten developed a series of correlations to relate δ^* measured on the flat-plate in the small-scale wind tunnel to percent reduction in maximum lift coefficient on the B737-200ADV airplane.



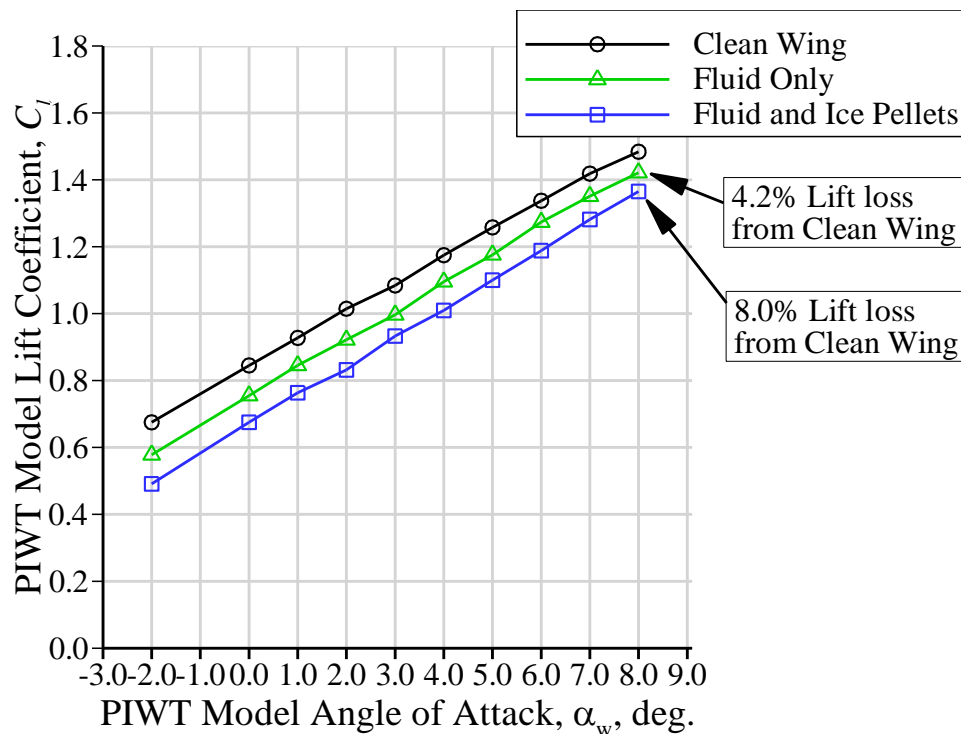
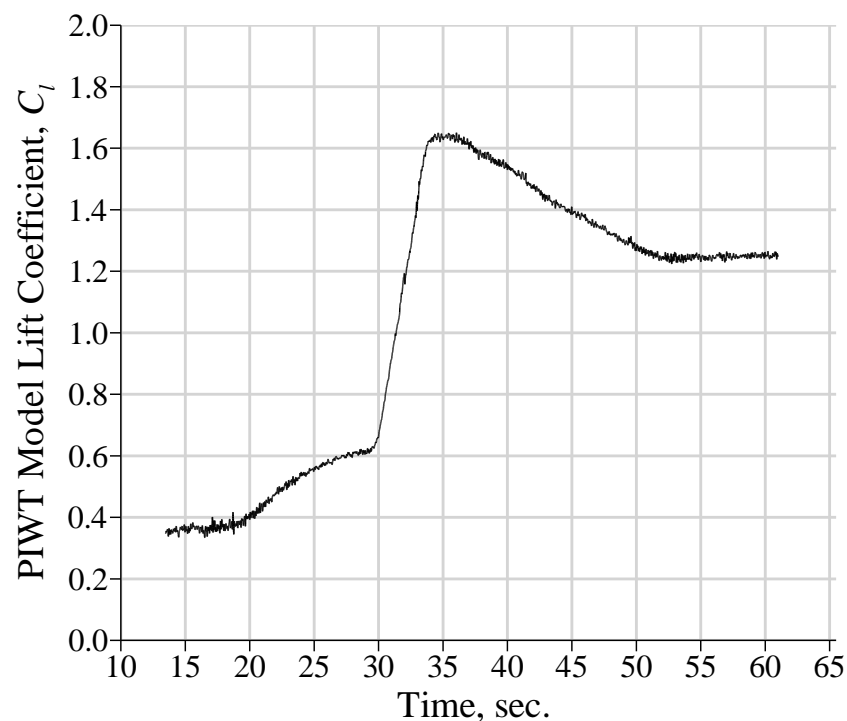
Experimental Methods

- Fluid tests conducted at NRC's Propulsion and Icing Wind Tunnel (PIWT).
- Test section dimensions 16.4 ft (5 m) high by 10 ft. (3 m) wide with external force balance.
- The 2D airfoil model was typical of regional jet transport wings with hard leading edges.
 - 6 ft. (1.8 m) chord by 7.9 ft (2.6 m) span mounted horizontally between two endplates.
 - The model span resulted in 1 ft (0.3 m) gaps between the endplates and test section sidewalls.
 - The model had a single-element slotted flap fixed at 20 deg. for this work.



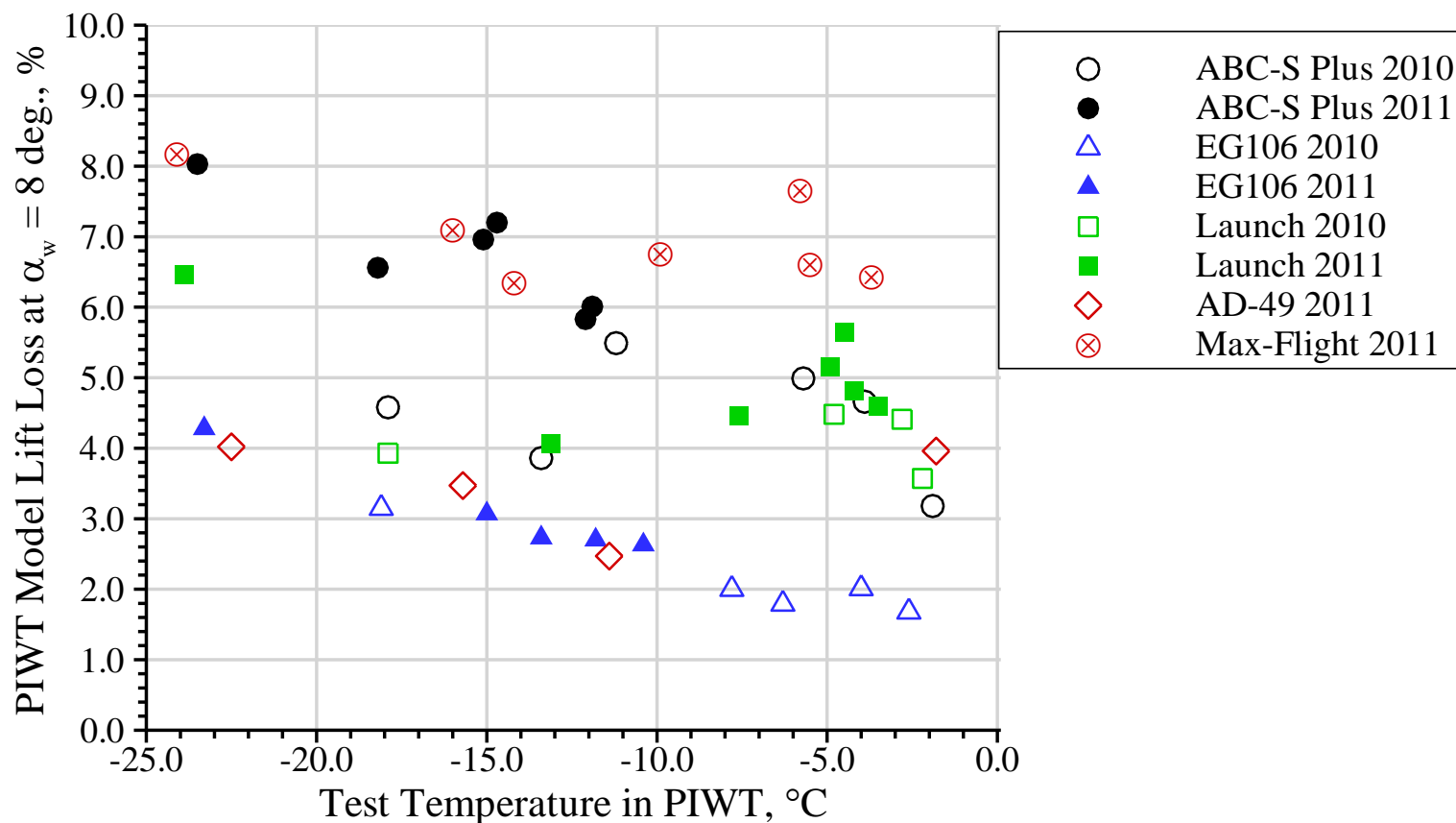
Experimental Methods

- Simulated takeoff performed with fluid samples.
 - The tunnel airflow was accelerated to 100 knots in less than 31 sec.
 - The model was then rotated from $\alpha = -2$ to 8 deg.



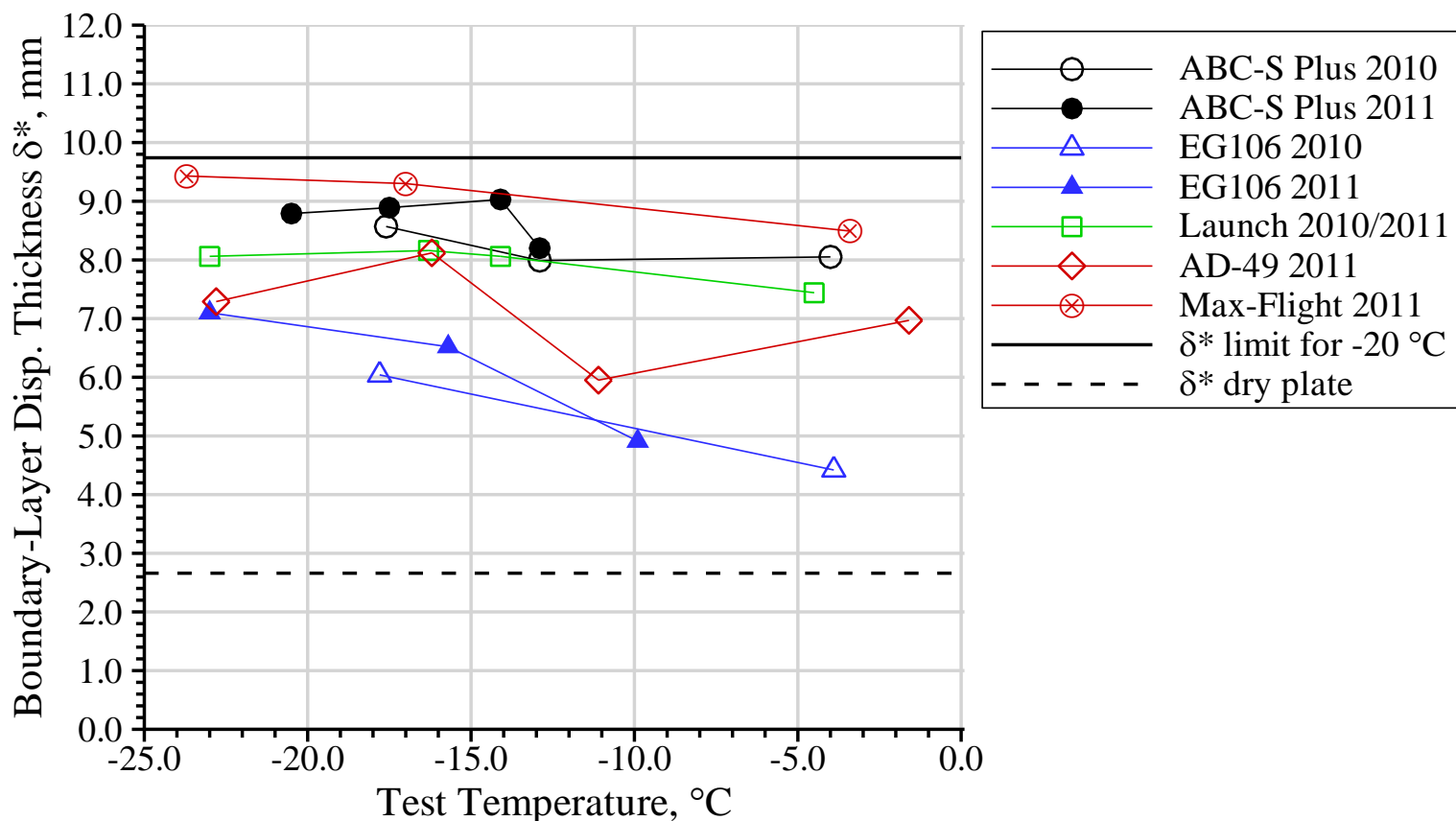
PIWT Test Results

- Summary of uncontaminated fluid test results from 2010 and 2011 test campaigns.
- Five Type IV anti-icing fluids were tested.



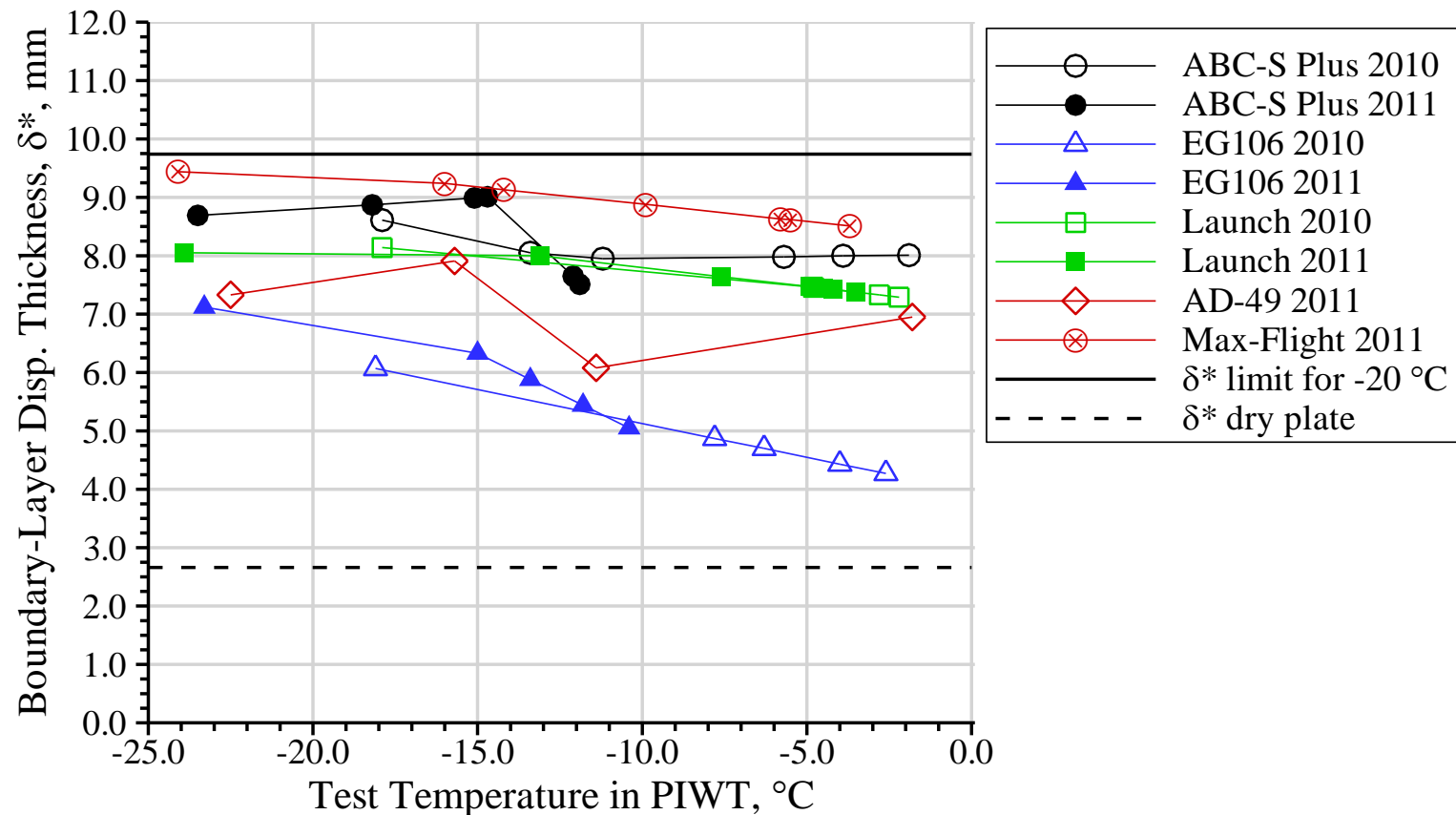
AAT Results

- Results of SAE AS5900 Aerodynamic Acceptance Test.
- 2010 and 2011 PIWT test campaign fluid samples.



Application of AAT Results

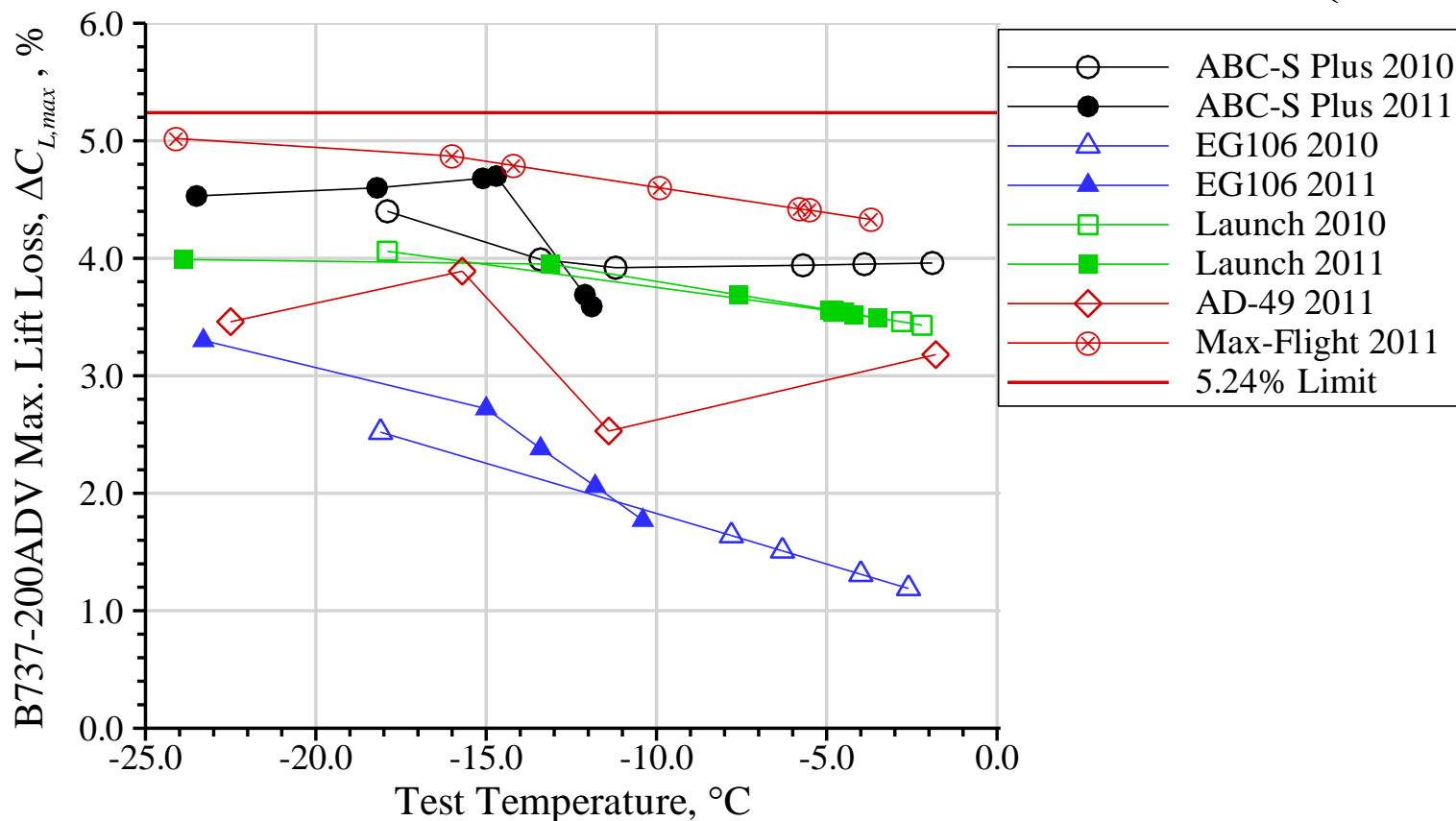
- Linear interpolation was performed to adjust the AAT results.
- Air temperatures for the PWIT tests were not identical to the AAT temperatures.



Application of AAT Results

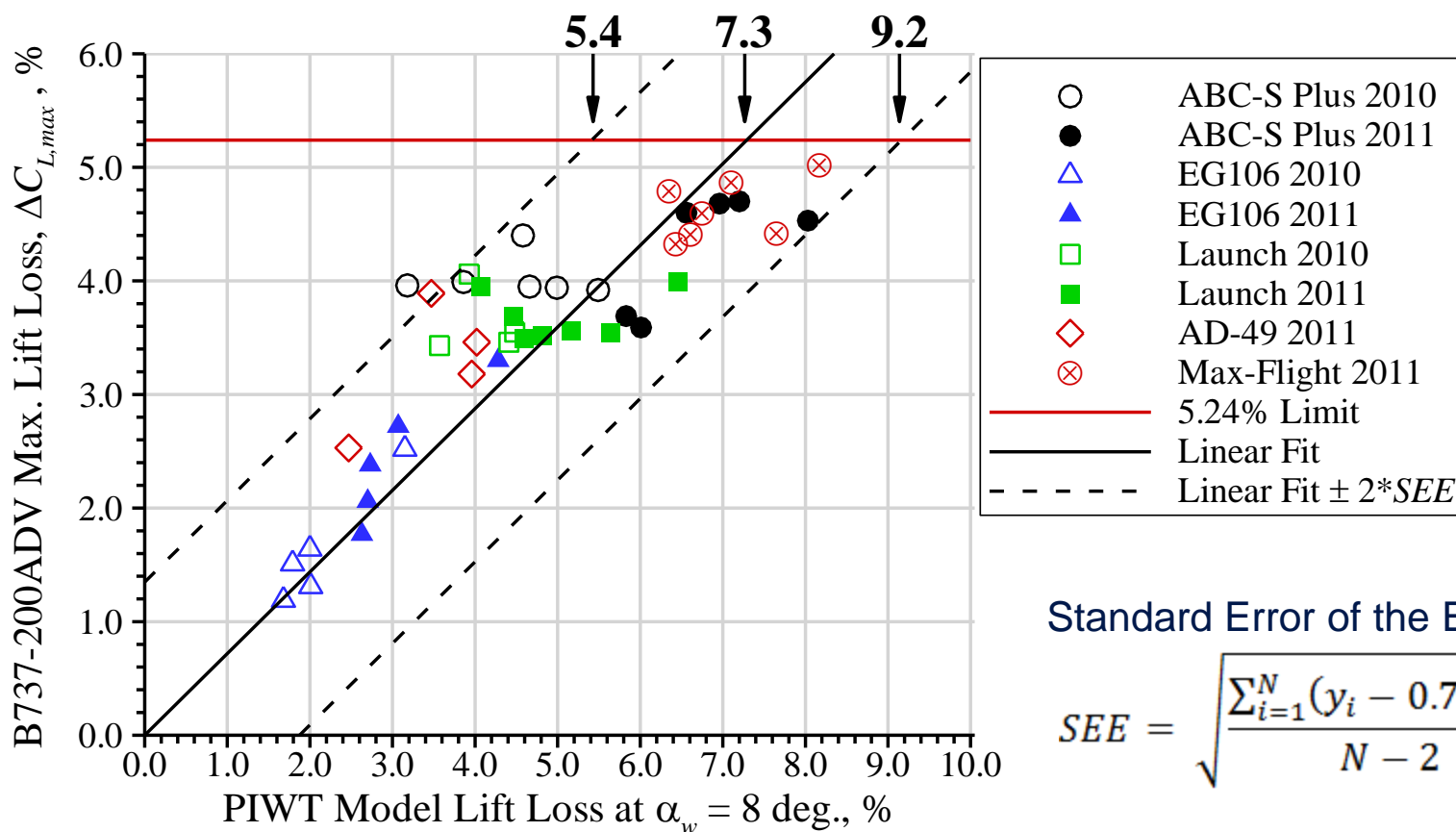
- Percent reduction in maximum lift on the B737-200ADV airplane was calculated using the Hill and Zierten correlation:

$$\Delta C_{L,\max} = 5.24 \left(\frac{\delta_{fluid}^* - \delta_{dry}^*}{\delta_{l@-20^\circ C}^* - \delta_{dry}^*} \right)$$



Correlation to PIWT Model Lift Loss

- Percent reduction in maximum lift on the B737-200ADV airplane was then correlated to the lift loss measured on the PIWT model at $\alpha_w = 8$ deg.



Standard Error of the Estimate

$$SEE = \sqrt{\frac{\sum_{i=1}^N (y_i - 0.72x_i)^2}{N - 2}}$$



Lift Loss Scaling Summary

- The basis of the AAT suggests a linear relationship between full-scale B737-200ADV maximum lift loss ($\Delta C_{L,max}$) and the flat-plate, boundary-layer displacement thickness, δ^* , measured per SAE AS5900.
- Fluid samples used in 2010 and 2011 PIWT campaigns were tested according to AS5900 at AMIL in March 2011.
- The resulting δ^* data were used to relate the PIWT model lift loss measured at $\alpha_w = 8$ deg. to $\Delta C_{L,max}$ on the B737-200ADV airplane.
- The data show that $\Delta C_{L,max} = 5.24\%$ on the B737-200ADV airplane is equivalent to a lift loss of 7.3% on the PIWT model at $\alpha_w = 8$ deg.
 - An upper range of 9.2% lift loss on the PIWT model is suggested to account for scatter in the data.



Comments on PIWT Tests and Results

- This correlation was developed as means to relate the 2D model results to full-scale airplane data and address other concerns raised in regard to this work:
 - A 2D model with endplates was used instead of a 3D geometry more representative of an airplane wing.
 - Lift degradation was measured at $\alpha_w = 8$ deg. on the 2D model instead of at stall.
 - Ground effect during takeoff acceleration and rotation was not simulated.
 - The chord-Reynolds number was small relative to most airplanes.
 - The 6 ft (1.8 m) chord length model was small relative to most airplane wing sections.
 - The large model size and the proximity of the wind-tunnel walls resulted may have uncorrectable effects on the aerodynamic data and performance.
 - The rotation speed used in the PIWT tests (100 knots) was low relative to typical rotation speeds.



Comments on PIWT Tests and Results

- Many of these concerns were also raised in the development of the AAT and were addressed by Hill and Zierten.
- The experimental methods used in the current PIWT testing closely follows the 2D model test methods used in the development of the AAT as well as standard wind-tunnel test methods.
- Adverse effects due to model scale, Reynolds number and tunnel installation are negligible.
- The rotation speed of 100 knots used in the PIWT tests is low relative to that used in the AAT (127 knots) and typical airplane rotation speeds.
 - Hill and Zierten showed that the lift degradation decreases with increasing rotation speed, meaning that the present results are likely conservative.
 - If the effect of rotation speed on percent lift loss is linear, then this may be accounted for in the correlation developed here.
 - More data may be needed to fully address this concern.



Conclusion

- Lift degradation due to anti-icing fluids on the 2D PIWT model have been correlated to the loss in maximum lift coefficient on a B737-200ADV airplane via the Aerodynamic Acceptance Test.
- PIWT model lift losses in the range of 7.3% to 9.2% may exceed the B737-200ADV performance limit of 5.24% ($\Delta C_{L,max}$).
- This lift loss range (7.3% to 9.2%) is suggested as a criterion in establishing ice-pellet allowance times in addition to the visual observations of the fluid/contamination behavior.
- While this correlation provides a means to incorporate an aerodynamic performance criterion into the development of allowance times, the result combines performance degradation relative to the B737-200ADV airplane and visual observations on the 2D PIWT model.
- It is unclear if visual observations of ice-pellet contamination testing on the B737-200ADV airplane would lead to similar allowance times.