TP 14195E

AERODYNAMIC FLOW-OFF OF PARTIALLY EVAPORATED AIRCRAFT GROUND ANTI-ICING FLUIDS

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by

Anti-icing Materials International Laboratory (AMIL)

Université du Québec à Chicoutimi (UQAC)

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by

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November 2003

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16. Abstract

Holdover Time Guidelines published by Transport Canada for ground aircraft de/anti-icing fluids under different forms of freezing precipitation show that in frost conditions an SAE Type IV fluid can protect a wing from frozen deposits for up to 18 hours. If the forecast humidity is absent, however, then the fluid may dry out and may not flow off the wing at take-off as prescribed.

Three methods of drying out fluids were investigated and the aerodynamic acceptance of the partially evaporated fluids was assessed.

1. Fluids were dried out to a 20% weight reduction and their viscosity measured as per an existing fluid certification test. Results showed that one low viscosity measurement does not ensure aerodynamic performance at all temperature intervals.
2. Fluids were left overnight in a wind tunnel. Unfortunately, the humidity could not be controlled in this set-up; however, results showed that the aerodynamic performance of the exposed fluids was acceptable.
3. Proportional dry out in a controlled temperature and humidity environment. This method was the most representative of real-life conditions. Results showed no change in the Boundary Layer Displacement Thickness for the fluids that had been dried out compared with fluids that had not been dried out.

These tests suggest that fluids that are left exposed on an airplane wing overnight when no frost occurs, under low or reasonable humidity, will have acceptable aerodynamic flow-off, based on the AS5900 aerodynamic acceptance test.

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16. Résumé

D'après les lignes directrices de Transports Canada concernant la durée d'efficacité des liquides dégivrants et antigivrants appliqués au sol sur les aéronefs sous différents types de précipitations, dans des conditions givrantes, un liquide de type IV de la SAE peut protéger une aile contre l'accumulation de givre pendant une période pouvant atteindre 18 heures. Mais si l'apport d'humidité prévu ne se matérialise pas, le liquide risque alors de s'assécher et de ne pas s'écouler au décollage, comme il le devrait.

Trois méthodes d'assèchement des liquides ont été étudiées, en vue d'évaluer l'acceptabilité sur le plan aérodynamique de liquides partiellement évaporés.

1. Les liquides ont été asséchés jusqu'à une réduction de 20 p. cent de leur poids, et leur viscosité a été mesurée au moyen d'un essai normalisé de certification des liquides. Les résultats ont révélé qu'une mesure de faible viscosité ne garantit pas une performance aérodynamique acceptable dans toutes les plages de températures.
2. Les liquides ont séjourné toute une nuit dans une soufflerie. Malheureusement, l'installation ne permettait pas de commander le degré d'humidité; les résultats ont toutefois révélé une performance aérodynamique acceptable des liquides.
3. Les liquides ont été asséchés jusqu'à un degré déterminé dans un environnement à température et humidité contrôlées. Cette méthode est celle qui se rapprochait le plus d'une situation réelle. Les résultats n'ont indiqué aucune différence d'épaisseur de déplacement de la couche limite des liquides asséchés, comparativement à des liquides non asséchés.

Ces essais donnent à penser que les liquides qui passent toute une nuit sur une aile d'avion à l'extérieur, en l'absence de précipitations givrantes et à un degré d'humidité faible ou raisonnable, afficheront un écoulement aérodynamique acceptable, d'après l'essai d'acceptabilité aérodynamique AS5900.

17. Mots clés
Liquides antigivrage, liquides de type IV, dégivrage, assèchement, évaporation des liquides, décollage, acceptabilité aérodynamique

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Of course, the project could not have been realized without the dedicated and competent AMIL testing and technical staff, particularly Nathalie Gagné, Daniel Mercier, Carol Mercier, Elizabeth Crook, Martin Truchon, Shan Yang and Michelle Simard.

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EXECUTIVE SUMMARY

Anti-icing fluids are sprayed on aircraft surfaces as protection against winter precipitation, which can freeze to the surface, rendering it rough, aerodynamically unacceptable and possibly hazardous. The fluids provide protection for a limited period of time under conditions of continual moisture deposit. Guidelines known as holdover times are provided based on well-defined test protocols.

The Holdover Time Guidelines are published by Transport Canada for ground aircraft deicing/anti-icing fluids under different forms of freezing precipitation such as snow, frost and light freezing rain. The tables show that in frost conditions, a Society of Automotive Engineers (SAE) Type IV fluid can protect a wing from frozen deposits for up to 18 hours. If the forecast humidity is absent, then the fluid may dry out and not flow off the wing at takeoff as prescribed.

This study was undertaken to investigate different methods for drying out fluids and evaluating the aerodynamic acceptance of such partially evaporated fluids. Aerodynamic acceptance was evaluated according to Aerospace Standard AS 5900 (Standard Test Method for Aerodynamic Acceptance of SAE AMS 1428 Aircraft Deicing/Anti-icing Fluids) for the high speed ramp.

Three methods for drying out fluids were investigated:

1) The first method was conducted as part of Aerospace Materials Specification AMS1428D. It involved drying out 800 mL of fluid at 23°C and relative humidity < 50 percent to a 20 percent weight reduction. For the AMS test, the dried out fluid's Brookfield viscosity must not exceed 500 mPa·s when measured at 20°C, 3 rpm and LV1 spindle, to pass the test. For this study, aerodynamic acceptance tests were conducted on the dried out samples.
2) The second method consisted of leaving a layer of fluid overnight on the wind tunnel test section floor before performing the aerodynamic acceptance test (rather than the usual five minute wait-exposure time).
3) The third method involved measuring the amount of evaporation of a sample in a controlled temperature and humidity environment and then drying out the same relative amount on a larger sample at room temperature to have the quantities required for an aerodynamic acceptance test.

The first AMS1428D dry-out method involved 20 percent weight reduction and measurement of viscosity. If below 500 mPa·s at 20°C, fluid passes. The test method was simple to perform. The results of this test showed that one low viscosity measurement does not ensure acceptable aerodynamic performance at every temperature interval.

The second dry-out method involved leaving the fluids overnight in a wind tunnel. It was a more complex test that involved occupying the wind tunnel for long periods of time. The humidity could not be controlled in the current set-up. The test results showed aerodynamic performance as part of AS5900 of the exposed fluids was acceptable.

The third dry-out method involved a proportional dry-out in a controlled temperature and humidity environment. It was the most representative of real conditions under which a fluid dries out. The results of the tests showed no change in the Boundary Layer Displacement Thickness of the dried out fluids with respect to the fluids that were not dried out.

The results of these tests suggested that if left exposed on an airplane wing overnight without frost, under low wind and reasonable humidity, the fluid will have acceptable aerodynamic flow-off according to the AS5900 aerodynamic acceptance test.

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Des liquides antigivrage sont vaporisés sur les surfaces des aéronefs pour les protéger contre les précipitations hivernales qui peuvent geler sur la surface et rendre celle-ci rugueuse et inacceptable sur le plan aérodynamique, ce qui peut représenter un danger. Ces liquides assurent une protection pendant une période déterminée, dans des conditions d'apport d'humidité continu. Des lignes directrices, ou «tableaux de durées d'efficacité», fondées sur des protocoles d'essai rigoureux, encadrent l'utilisation de ces liquides.

Les lignes directrices sur les durées d'efficacité publiées par Transports Canada concernent les liquides de dégivrage/antigivrage appliqués au sol sur les aéronefs soumis à différentes formes de précipitations givrantes, comme la neige, le givre et la pluie verglaçante légère. Selon ces tableaux, dans des conditions givrantes, un liquide de type IV de la SAE (*Society of Automotive Engineers*) peut protéger une aile contre l'accumulation de givre pendant une période pouvant atteindre 18 heures. Mais si l'apport d'humidité prévu ne se matérialise pas, le liquide risque alors de s'assécher et de ne pas s'écouler au décollage, comme il le devrait.

La présente étude avait pour objectif d'étudier différentes méthodes pour assécher les liquides et évaluer l'acceptabilité aérodynamique de ces liquides partiellement évaporés. L'acceptabilité aérodynamique a été évaluée conformément à la méthode prescrite par la norme AS 5900 (*Standard Test Method for Aerodynamic Acceptance of SAE AMS 1428 Aircraft Deicing/Anti-icing Fluids*) pour les essais aérodynamiques à haute vitesse.

Trois méthodes d'assèchement des liquides ont été étudiées :

1) La première méthode est celle prescrite par la norme AMS1428D (*Aerospace Materials Specification*). Elle consiste à assécher 800 mL de liquide à 23 °C jusqu'à une réduction de 20 p. 100 de son poids, dans des conditions d'humidité relative inférieure à 50 p. 100. Pour réussir l'essai AMS, la viscosité Brookfield du liquide asséché ne doit pas dépasser 500 mPa·s, lorsque mesurée à 20 °C, à 3 tr/min, avec un fuseau LV1. Aux fins de la présente étude, les essais d'acceptabilité aérodynamique ont été réalisés sur les échantillons asséchés.
2) La deuxième méthode a consisté à laisser une couche de liquide séjourner toute une nuit (plutôt que les cinq minutes habituelles) sur le plancher de la veine d'essai de la soufflerie avant de procéder à l'essai d'acceptabilité aérodynamique.
3) La troisième méthode a consisté à mesurer le degré d'évaporation d'un échantillon dans un environnement de température et d'humidité contrôlées, puis à laisser un plus grand échantillon s'évaporer jusqu'au même degré à la température ambiante, de manière à obtenir les volumes nécessaires à un essai d'acceptabilité aérodynamique.

La première méthode d'assèchement, soit celle de la norme AMS1428D, comportait une réduction de 20 p. 100 du poids et la mesure de la viscosité. Pour réussir l'essai, le fluide doit afficher une viscosité inférieure à 500 mPa·s à 20 °C. La méthode d'essai s'est révélée facile à exécuter. Les résultats ont révélé qu'une mesure de faible viscosité ne garantit pas une performance aérodynamique acceptable dans toutes les plages de températures.

La deuxième méthode, qui consistait à laisser les liquides passer toute une nuit dans une soufflerie, était plus complexe, et elle obligeait les chercheurs à accaparer la soufflerie pendant de longues périodes. De plus, l'installation ne permettait pas de commander le degré d'humidité. Les

résultats ont indiqué que la performance aérodynamique des fluides était acceptable, selon la norme AS5900.

La troisième méthode comportait un assèchement proportionnel de deux échantillons de liquide dans un environnement à température et humidité contrôlées. Cette méthode était la plus représentative des conditions dans lesquelles un liquide s'assèche. Les résultats n'ont indiqué aucune différence entre l'épaisseur de déplacement de la couche limite des liquides, qu'ils soient asséchés ou non.

Les résultats de ces essais mènent à conclure que des liquides laissés pendant toute une nuit à l'air libre sur une aile d'avion, sans précipitation givrante et dans des conditions de vent faible et d'humidité raisonnable, auront un écoulement aérodynamique acceptable, selon l'essai d'acceptabilité aérodynamique de la norme AS5900.

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GLOSSARY

Abbreviations

AS	Aerospace Standard
AMIL	Anti-icing Materials International Laboratory
AMS	Aerospace Material Specification
BLDT	Boundary Layer Displacement Thickness
FPET	Flat Plate Elimination Test
LOUT	Lowest Operational Use Temperature. For this study this was considered the lowest aerodynamically acceptable temperature.
n.m.	Not measured
SAE	Society of Automotive Engineers

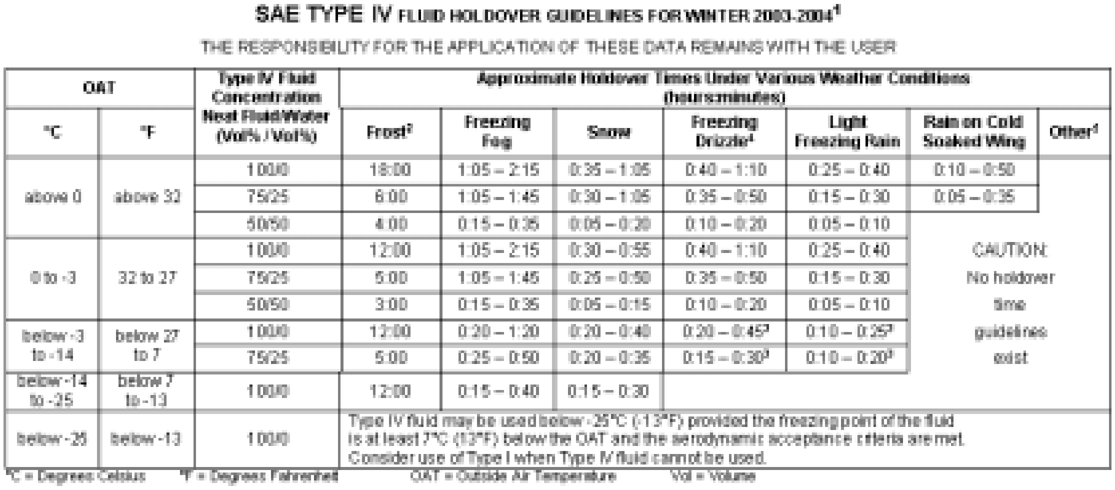
Parameters

c	Cross section perimeter at Station 3 of wind tunnel
D_0	Maximum acceptable value for δ^*_f at 0°C
D_{20}	Maximum acceptable value for δ^*_f at -20°C
P	Static Pressure
Rh	Relative humidity (percent)
S	Test section duct cross section area
T_a	Air temperature
T_f	Fluid temperature (deicing/anti-icing fluid)
U_α	Free flow speed
δ^*_{ave}	BLDT perimeter average between δ^*_f and δ^*_d
δ^*_d	BLDT over dry surface (at Station 3)
δ^*_f	BLDT over fluid-coated surface (at Station 3)
δ^*_r	δ^*_f value for reference fluid
ρ	Gas density mass per unit volume

1. INTRODUCTION

Anti-icing fluids are sprayed on aircraft surfaces as protection against winter precipitation, which can freeze to the surface, rendering it rough and aerodynamically unacceptable, possibly hazardous. The fluids provide protection for a limited period of time under conditions of continual moisture deposit. Guidelines known as holdover times are provided based on well-defined test protocols.

These Holdover Time Guidelines are published by Transport Canada for ground aircraft deicing and anti-icing fluids under different forms of freezing precipitation such as snow, frost and light freezing rain. Figure 1 is an example of such a table. The table shows that in frost conditions, an SAE Type IV fluid can protect a wing from frozen deposits for up to 18 hours. Although the fluid may have a capacity to protect against ice formation for that time (as determined from simulated frost endurance tests), fluids used to provide overnight protection from frost may be left on a wing surface for several hours. If the forecast humidity is absent then the fluid may dry out and not flow off the wing at takeoff as prescribed.



SAE TYPE IV FLUID HOLDOVER GUIDELINES FOR WINTER 2003-2004[1]

THE RESPONSIBILITY FOR THE APPLICATION OF THESE DATA REMAINS WITH THE USER

OAT		Type IV Fluid Concentration Neat Fluid/Water (Vol% / Vol%)	Approximate Holdover Times Under Various Weather Conditions (hours:minutes)						
°C	°F		Frost[2]	Freezing Fog	Snow	Freezing Drizzle[4]	Light Freezing Rain	Rain on Cold Soaked Wing	Other[4]
above 0	above 32	100/0	18:00	1:05 – 2:15	0:35 – 1:05	0:40 – 1:10	0:25 – 0:40	0:10 – 0:50	
		75/25	6:00	1:05 – 1:45	0:30 – 1:05	0:35 – 0:50	0:15 – 0:30	0:05 – 0:35	
		50/50	4:00	0:15 – 0:35	0:05 – 0:20	0:10 – 0:20	0:05 – 0:10		
0 to -3	32 to 27	100/0	12:00	1:05 – 2:15	0:30 – 0:55	0:40 – 1:10	0:25 – 0:40	CAUTION: No holdover time guidelines exist	
		75/25	5:00	1:05 – 1:45	0:25 – 0:50	0:35 – 0:50	0:15 – 0:30		
		50/50	3:00	0:15 – 0:35	0:05 – 0:15	0:10 – 0:20	0:05 – 0:10		
below -3 to -14	below 27 to 7	100/0	12:00	0:20 – 1:20	0:20 – 0:40	0:20 – 0:45[3]	0:10 – 0:25[3]		
		75/25	5:00	0:25 – 0:50	0:20 – 0:35	0:15 – 0:30[3]	0:10 – 0:20[3]		
below -14 to -25	below 7 to -13	100/0	12:00	0:15 – 0:40	0:15 – 0:30				
below -25	below -13	100/0	Type IV fluid may be used below -25°C (-13°F) provided the freezing point of the fluid is at least 7°C (13°F) below the OAT and the aerodynamic acceptance criteria are met. Consider use of Type I when Type IV fluid cannot be used.						

°C = Degrees Celsius °F = Degrees Fahrenheit OAT = Outside Air Temperature Vol = Volume

Figure 1 A page of the Transport Canada winter 2003-2004 Holdover Time (HOT) Guidelines with frost endurance times up to 18 hours

In this study, laboratory tests were performed to establish through experiment the effects of overnight dry-out on the performance of a selection of anti-icing fluids.

All certified anti-icing fluids must meet Aerospace Material Specification AMS1428D. This specification stipulates tests for anti-icing fluids. The following tests to evaluate fluids following dry-out were selected for these trials:

1) **Exposure to Dry Air,** paragraph 3.2.2.2, which simulates fluid behaviour following overnight exposure to dry air. This test involves exposing the fluid to dry air, which results in a weight reduction of 20 percent. To pass, the dried out fluid's Brookfield viscosity must not exceed 500 mPa·s when measured at 20°C, 3 rpm and the LV1 spindle.
2) **Dry-out by Exposure to Cold Dry Air**, paragraph 3.2.2.3, which simulates fluid dry-out in cold air on the ramp and aircraft, including aerodynamically quiet areas. This test

involves exposing the fluid to dry air at 1°C for 24 hours. To pass, the fluid must have an acceptable residue that can be rinsed off the test plate.

3) **Successive Dry-out and Rehydration**, paragraph 3.2.2.4, which simulates the formation of dried residues and for such to form gels upon rehydration. This tests involves immersing a test plate into fluid and drying it out for a number of repetitions. The plate is then immersed in water and the weight of the rehydrated residue is reported.

Although these tests address the nature of the dry-out residue, none evaluates its aerodynamic performance. Furthermore, the test of exposure to dry air implies that a fluid of 500 mPa·s would have a viscosity demonstrating acceptable aerodynamic performance, which may not necessarily be true. As a result, additional tests were performed to evaluate the aerodynamic performance of dried out fluids to ensure the long frost times of the Holdover Time Guidelines. A secondary objective was to determine or evaluate a test procedure for possible inclusion in AMS1428 for dry-out that is more representative of real outdoor conditions.

1.1 Objectives

The objectives of this study were to determine whether an anti-icing fluid used for frost protection has acceptable aerodynamic flow-off characteristics and to evaluate a test method to evaluate dried out fluids and their aerodynamic performance.

1.2 Scope

Testing involved Flat Plate Elimination Tests (FPET) for aerodynamic acceptance as per AS5900 for the high speed ramp at approximately 0°C, -10°C, and -20°C temperature intervals on samples dried out by different means.

2. METHODOLOGY

These tests involved running aerodynamic acceptance tests on dried out fluids. Therefore, the methodology consisted of two steps: (1) Partially evaporating, drying out, or exposing the test fluids, (2) Aerodynamic acceptance testing according to AS5900 for the high speed ramp.

2.1 Fluid Evaporation

The partially evaporated fluids were achieved in three ways: (1) Using a 20 percent weight loss as in paragraph 3.2.2.2 of AMS1428D, (2) Overnight exposure in the wind tunnel, (3) Proportional dry-out in a controlled temperature and humidity environment.

2.1.1 Twenty Percent Weight Loss

This method of drying out the fluids was performed according to AMS1428D paragraph 3.2.2.2. The procedure consisted of drying out 800 mL of fluid in 200 x 200 x 50 mm glass trays. The test required that humidity remain below 50 percent at a temperature of 23°C ± 3°C. For this study the fluid trays were placed under a fume hood to promote evaporation to obtain the required 20 percent weight loss. A number of trays of each fluid were made to achieve the quantities needed to run aerodynamic acceptance tests afterwards.

2.1.2 Overnight in Wind Tunnel

The standard Flat Plate Elimination Test (FPET) or aerodynamic acceptance test as per AS5900 [1] for the high speed ramp is described in section 2.2. It involves subjecting a 2 mm layer of fluid to a wind tunnel acceleration from 5 m/s to 65 m/s over 30 seconds. Prior to this acceleration there is a 5 minute wait time with the fluid on the test duct floor at test temperature with a wind speed up to 5 m/s to equilibrate the fluid temperature with the air.

For this fluid dry-out method, the fluids were left overnight on the wind tunnel floor at test temperature. These tests were performed by pouring the fluid onto the test section duct floor late in the afternoon. The fluid was left in the wind tunnel overnight at the test temperature and a low wind speed of about 5 m/s. The humidity was not controlled. The next morning, an FPET according to the high speed ramp test of AS 5900 [1] was performed. Normally, in an FPET there is a 5 minute wait time before acceleration; for these tests the exposure time was in the order of 18 hours.

2.1.3 Equivalent Dry-out

Parts of this equivalent dry-out test procedure were decided upon by the dry-out working group. This group, as part of the SAE G-12 Fluids Subcommittee, was, at the same time as this study was underway, looking at a test method to replace the existing AMS1428 dry-out protocols that would be more representative of the conditions in which the fluids are drying out. The working group’s test involved drying out 1 mm of fluid in a 55 percent relative humidity environment for 12 hours at a target temperature below 0°C.

At AMIL, this was achieved by using the Humidity Chamber presented in Figure 2. It consisted of a enclosed glove box with recirculating air. The recirculating air passes through a molecular sieve that absorbs water and glycol vapour, thus lowering the humidity. In order to control the humidity, the motor was equipped with a computer-controlled on/off switch to regulate the humidity at 55 percent ± 2. The whole 90 x 65 x 75 cm glove box was housed in a climatic chamber to be able to dry out samples at the test temperature. Although the wind speed had not been agreed upon by the working group at the time of testing, a wind speed of 2.5 m/s was chosen to represent a mild wind. The horizontal wind speed was achieved by a set-up consisting of a small wind tunnel made of three small fans and a convergent cone under a Plexiglas box (Figure 3). Because of the limited space only small amounts of fluid were dried out in Petri dishes. The amount of evaporation was determined by weighing before and after, and the water change was determined by the refractive index. The same amounts of evaporation were then achieved at room temperature in pans as in section 2.1.1 under the fume hood to make the quantities required for the FPET.

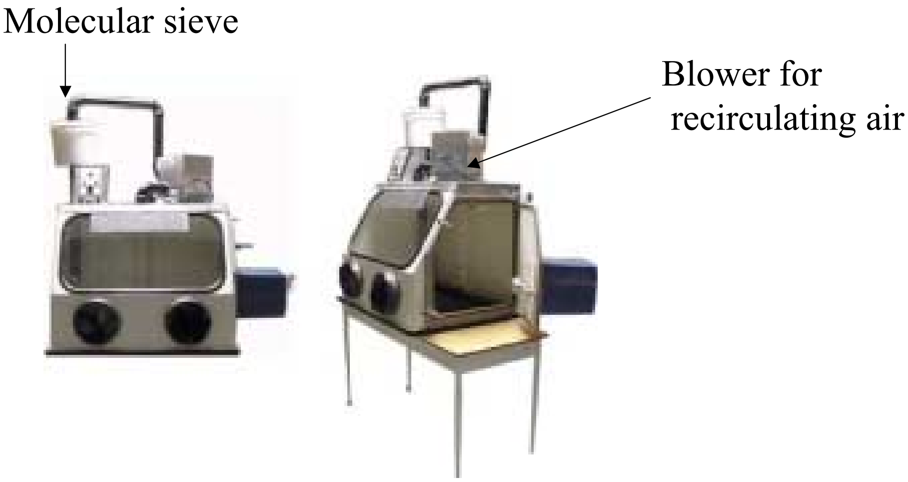


Figure 2 Humidity chamber

Figure 3 Small wind tunnel

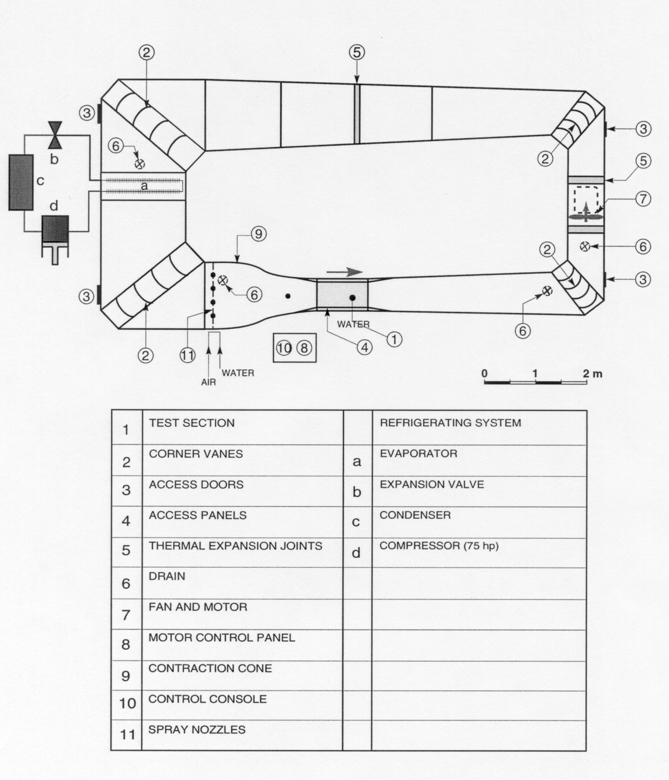
2.2 Wind Tunnel Testing

All dried out samples were tested in the wind tunnel according to the high speed ramp FPET procedure of AS5900. This is the same procedure used to certify fluids for aerodynamic acceptance. Since AMIL certifies all fluids for aerodynamic acceptance, FPET data on fluids that were not dried out was available for comparison.

The FPET procedure consists of submitting a 2 mm thick layer of anti-icing fluid covering a 1.6 m long, 300 mm wide test section duct floor of the wind tunnel (Figure 4) to a 2.6 m/s² air flow accelerating to 65 m/s, simulating an aircraft take-off of a large transport type jet aircraft (Figure 5). The BLDT on the flat plate is measured at pressure tap location # 3 (Figure 6), 30 seconds after the beginning of the simulated take-off. BLDT (δ*) and wind speed (V) are calculated using pressure difference equations 1 and 2 based on the conservation of mass and the Bernoulli equations:

$$\delta*_{ave} = \frac{1}{c}\left[\frac{(P_1 - P_2)}{(P_1 - P_2) + (P_2 - P_3)}\right] \tag{1}$$

$$V = \sqrt{\frac{2}{\rho}(P_1 - P_2) / \left[1 - \left(\frac{S_2}{S_1}\right)^2\right]} \tag{2}$$



1	TEST SECTION		REFRIGERATING SYSTEM
2	CORNER VANES	a	EVAPORATOR
3	ACCESS DOORS	b	EXPANSION VALVE
4	ACCESS PANELS	c	CONDENSER
5	THERMAL EXPANSION JOINTS	d	COMPRESSOR (75 hp)
6	DRAIN		
7	FAN AND MOTOR		
8	MOTOR CONTROL PANEL		
9	CONTRACTION CONE		
10	CONTROL CONSOLE		
11	SPRAY NOZZLES		

Figure 4 Luan Phan refrigerate icing wind tunnel

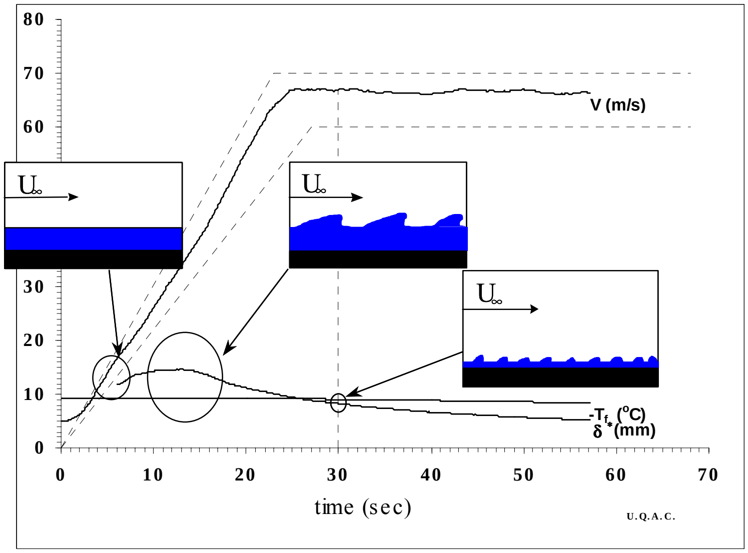


Figure 5 FPET test run for the high speed ramp

The FPET test procedure involves: pouring one litre of fluid onto the test duct floor; levelling it to an even 2 mm thickness; measuring the thickness; waiting 5 minutes at ≤ 5 m/s to equilibrate fluid and air temperatures; wind acceleration according to Figure 6, measuring the final fluid thickness to determine percentage elimination; and collecting samples of the remaining fluid to measure the refractive index to determine the change in the fluid water content.

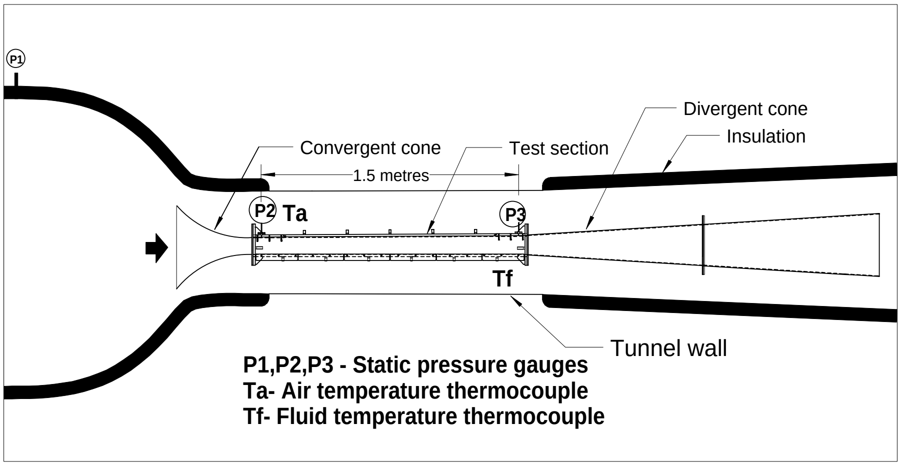


Figure 6 Test section box in wind tunnel

For a full certification of a candidate test fluid, sets of 3 FPETs are run at about 10º temperature intervals below 0°C. To determine an acceptance criteria limit, measurements are made at 0°C, -10°C, -20°C and -25°C of the reference military fluid and on dry tests, without fluid. Since the acceptance criteria can vary slightly from one test series to another due to differences in atmospheric pressure, humidity, temperature uniformity, etc., fluid data is always compared to this limit. The D0 and D20 values, which define the acceptance criteria limit (Figure 7), are determined using Equations 3 and 4:

$$D0=\delta_r^*+0.71\left(\delta_r^*-\delta_d^*\right) \text{ at } 0°\text{C} \qquad \textbf{(3)}$$

$$D20=\delta_r^*-0.18\left(\delta_r^*-\delta_d^*\right) \text{ at } -20°\text{C} \qquad \textbf{(4)}$$

where:

δ_r^* = the reference BLDT value at 0°C for **Equation 3** and at -20°C for **Equation 4**, obtained by interpolation from a straight line fitting of the reference BLDT values measured at 0°C, -10°C, -20°C and -25°C

δ_d^* = the average of all dry BLDT values measured

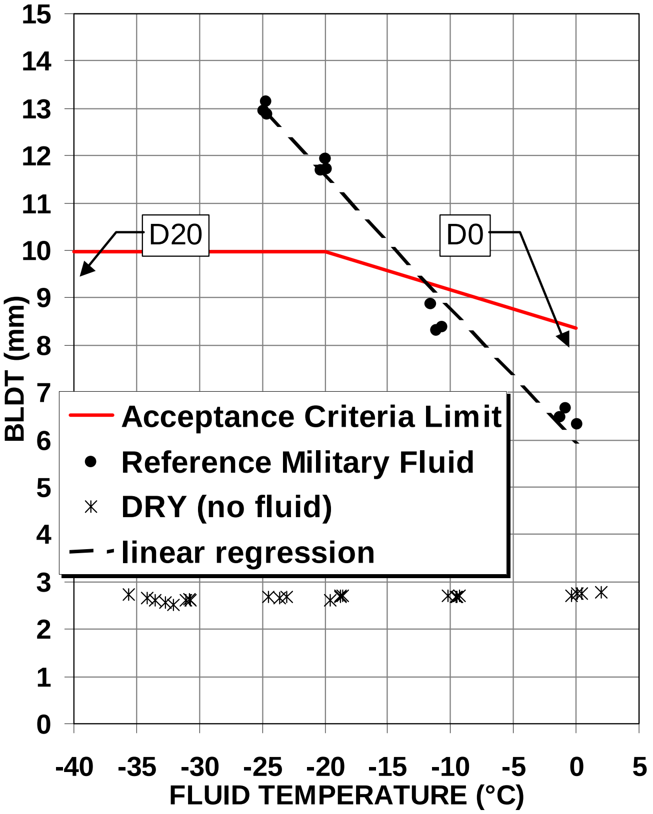


Figure 7 Example of the determination of an acceptance criteria

Candidate fluids are then compared against the acceptance criteria limit, since a fluid is acceptable "if none of the independent BLDT measurements is greater than the acceptance criteria" [1], i.e., all values measured on a candidate fluid must fall below the limit on the graph of Figure 7.

2.3 Test Fluids

Four certified Type IV anti-icing fluids were used for this study. Since the manufacturer's permission was not specifically obtained for this study, and since this report is a comparison of test methods and dry-out quantity and technique, the fluids are not identified. Suffice it to say that they were all Type IV fluids, either sent in for certification or left over from previous research studies.

3. RESULTS

3.1 Fluid 1

3.1.1 Fluid 1, Certification

Figure 1 presents the aerodynamic acceptance certification results of Fluid 1 with some adjustments. Since the objective of this study was to compare test methods and performances, not fluids, the identity of the fluids is not revealed. A number of these preliminary tests were conducted at the fluid's lowest aerodynamic acceptance temperature to study the worst case scenario. For most Type IV fluids this is the Lowest Operational Use Temperature (LOUT), which can also be governed by the freeze point plus 10°C, whichever is higher. For this report, LOUT and lowest aerodynamic acceptance temperature are used interchangeably. If the lowest aerodynamic acceptance temperature of the fluids were to be shown, certain fluids could be identified. Therefore, to compare all fluids on the same level, the lowest temperature was adjusted for all fluids to be -25°C. To do this, all results conducted at the LOUT were increased or lowered by the necessary number to fall to -25°C. For example, for a fluid that passes at -20°C, 5° was subtracted from all temperature values in that interval; for a fluid that passes at -30°C, 5° was added to the values that fall in the -30°C range.

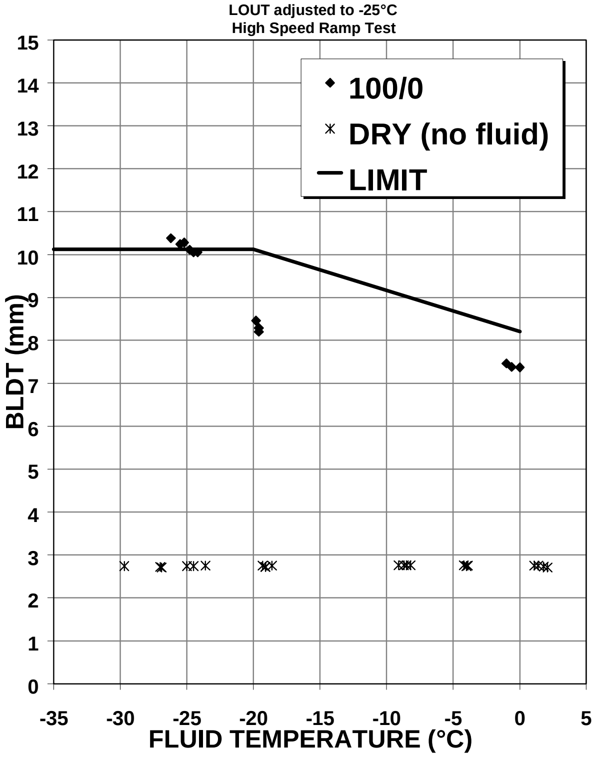


Figure 8 Certification test results of Fluid 1 with the LOUT adjusted to –25°C

3.1.2 Fluid 1, 20 Percent Reduction

The first test undertaken was the 20 percent weight loss. The procedure is described in section 2.1.3. These tests were conducted at -5°C and at the LOUT of the fluid. The results are shown in Figure 9. The results show a much lower BLDT at -5°C; at the LOUT, similar values, as compared to the certification of this fluid. Both dried out samples would be considered aerodynamically acceptable since they have a BLDT the same or less than the original certified fluid.

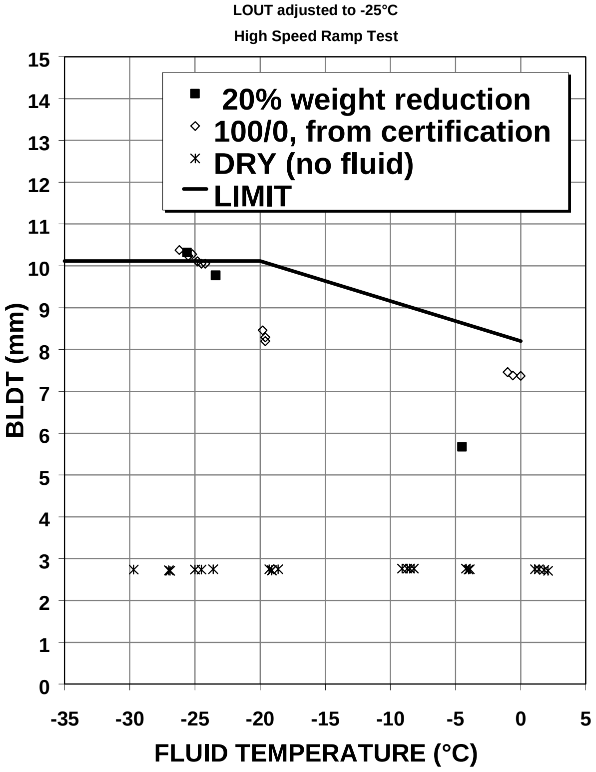


Figure 9 Fluid 1, certification and 20 percent weight loss results

3.1.3 Fluid 1, Overnight in Wind Tunnel

The second test undertaken was overnight in the wind tunnel. This test consisted of leaving the fluid on the test duct floor overnight and testing for aerodynamic acceptance in the morning. For these tests the humidity could not be controlled.

Table 1 presents the conditions and thickness of the fluids left overnight on the wind tunnel test section duct floor. At -5°C the humidity recorded was high; at the colder temperatures the relative humidity was lower. The table also presents the initial and final fluid thicknesses for the exposure. The difference in thickness is an indication of the amount of evaporation, although, since the fluid was not held in place longitudinally, fluid flow could have an effect. The table shows an increase in thickness at the warmest condition and a decrease at -15°C. At the LOUT there was no change in thickness.

Table 1 Overnight in wind tunnel dry-out conditions for Fluid 1

Test number	Air Temp (°C)	Fluid Temp (°C)	Humidity (%Rh)	Average wind speed (m/s)	Initial Thickness (mm)	Thickness after overnight dry-out (mm)	Δ thickness (%)
E778A322	-3.7	-3.1	76.1	4.8	1.950	2.144	+10
E583D879	-15.9	-14.3	66.9	4.6	1.778	1.654	-7
E778G746	-27.5*	-25.3*	51.1	4.8	1.975	1.975	0

*test conducted at LOUT, values adjusted to -25°C

Figure 10 shows the aerodynamic acceptance results of the fluid that spent the night in the wind tunnel with the certification results for comparison. The results show similar (within 0.5 mm) values for the overnight fluid as compared to the certification results at all temperatures. These variations are within the error of the test. Furthermore, there was no acceptance criteria limit calculated at the same time as the overnight tests with which to compare the results, and the certification tests were conducted at a much earlier date.

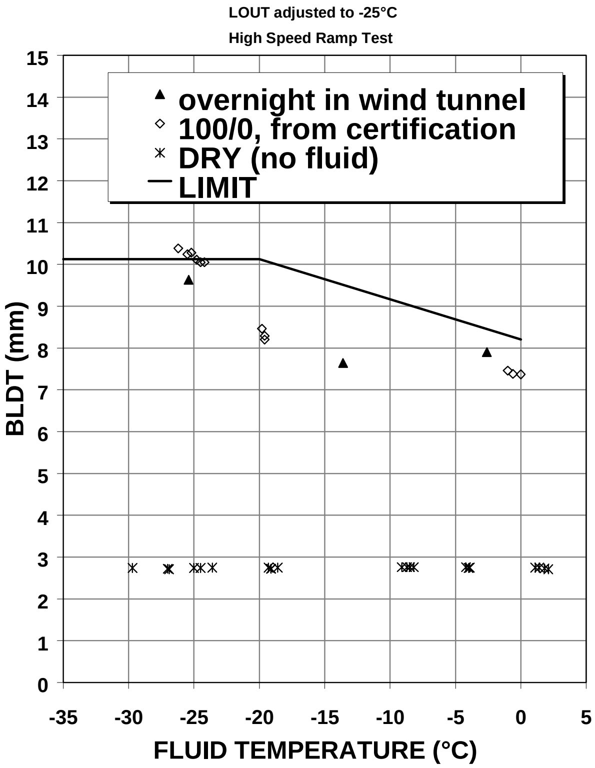


Figure 10 Fluid 1, with overnight in wind tunnel BLDT results

3.1.4 Fluid 1, Equivalent Dry-out

For these tests, small quantities of Fluid 1 were dried out in a constant humidity chamber at test temperature for 12 hours according to the procedure detailed in section 2.1.3. The proportion of fluid evaporation was determined, as well as the refractive index of the remaining fluid. Then, an equivalent proportion of a larger quantity of fluid was dried out at room temperature. Table 2 shows the weight proportion of fluid evaporated under the 55 percent Rh and at the test temperature. A sample was taken before and after to determine the water change using the refractive indices. The table shows the water change for the equivalent sample was in the same order as the water change at 55 percent Rh.

Table 2 Evaporation and water change for Fluid 1 dry-out samples

Fluid	Temperature (°C)	Evaporation at 55% Rh	Water change for 55% Rh	Equivalent evaporation at 20°C	Water change for equivalent
1	-5	34%	44%	33%	43%
		31%	42%	31%	36%
1	-10	31%	40%	30%	35%
		26%	39%	26%	29%
1	-20	16%	19%	16%	17%
		12%	16%	14%	17%

Figure 11 presents the wind tunnel results of the equivalent dry-out samples compared to the certification results. The figure shows the BLDT values are lower at -5°C and -10°C and are equivalent, or slightly lower, at -20°C.

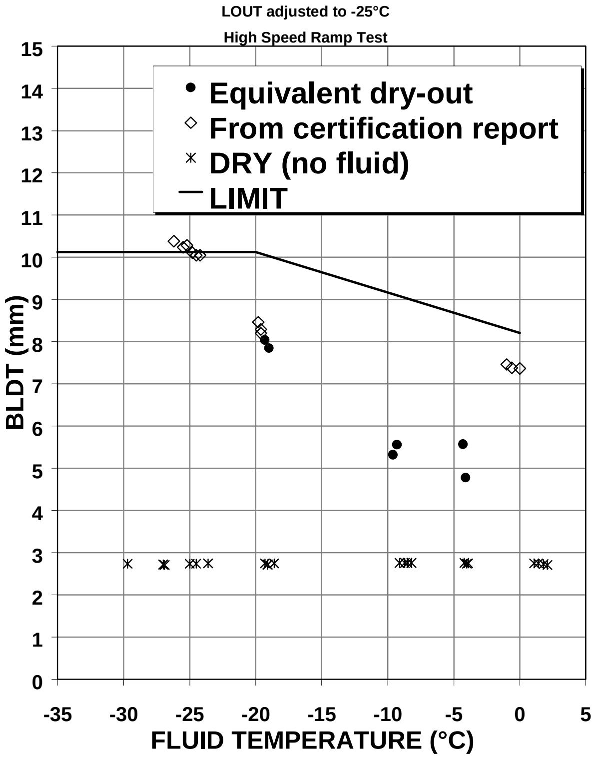


Figure 11 Fluid 1, with equivalent dry-out results

Brookfield viscosity measurements of the dried out samples were also performed. The absolute results are confidential; however, a comparison of the viscosities with the fluid that was not dried out is presented in Table 3. The table shows a sharp decrease in viscosity at all temperatures. These viscosity differences are reflected in the decrease in BLDT seen at -5°C and -10°C; however, at -20°C, the decrease in viscosity did not lead to a decrease in BLDT.

Table 3 Fluid 1, Brookfield viscosity comparison for equivalent dry-out samples

Temperature (°C)	ΔViscosity at 6 rpm	ΔViscosity at 30 rpm
-5	-99%	-97%
-10	-98%	n.m.
-20	-86%	-71%

3.2 Fluid 2

3.2.1 Fluid 2, Certification

Figure 12 presents the aerodynamic acceptance certification test results of Fluid 2. The lowest aerodynamic acceptance temperature, or LOUT in the case of this fluid, has been altered to be -25°C as with the other fluids so that it cannot be identified.

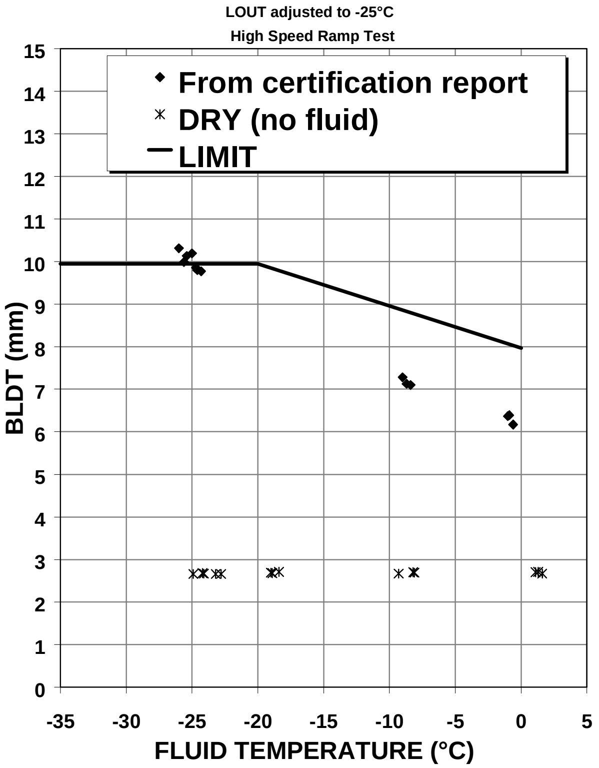


Figure 12 Certification test results of Fluid 2 with the LOUT adjusted to -25°C

3.2.2 Fluid 2, 20 Percent Weight Reduction

Sufficient quantities of Fluid 2 samples were dried out to a 20 percent weight loss according to the procedure described in section 2.1.3. These samples were then subjected to the aerodynamic acceptance test at -5°C and at its lowest aerodynamic acceptable temperature. The results are presented in Figure 13 with the lowest temperature tests adjusted to -25°C. For this fluid, both at -5°C, and the LOUT, the BLDT results are above the acceptance criteria limit and, therefore, not aerodynamically acceptable. Fluid 2 is a certified fluid, which implies that a 20 percent dried out sample of this fluid has a Brookfield viscosity at 20°C below 500 mPas. Figure 13 shows that this fact does not ensure aerodynamic acceptability of a fluid.

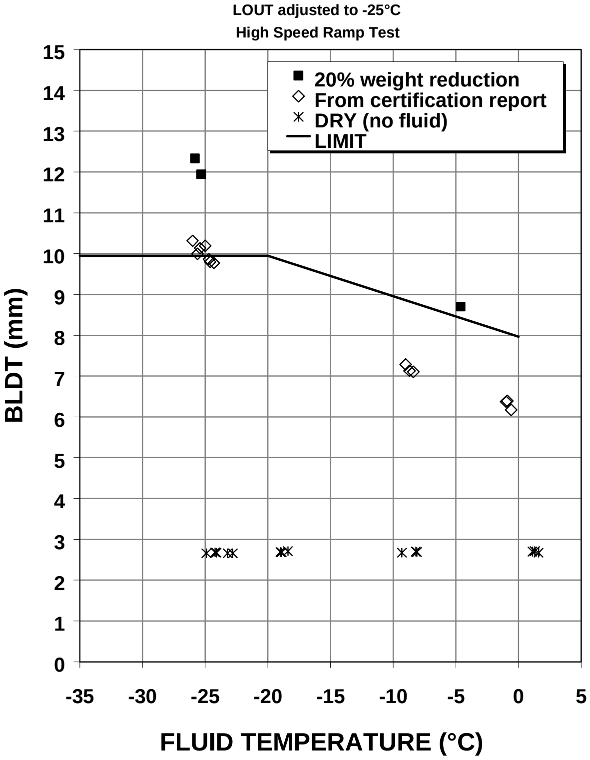


Figure 13 Fluid 2, certification and 20 percent weight loss results

3.2.3 Fluid 2, Overnight in Wind Tunnel

Fluid 2 samples were left overnight in the wind tunnel to dry out. The resulting temperature, humidity conditions and fluid heights are presented in Table 4. For this table, as with the others, the lowest temperature tests have been adjusted to a LOUT of -25°C. Therefore, for these tests, the overnight conditions had an air temperature 4°C below the LOUT shown by the -29°C value. The table shows that the humidity decreased with decreasing temperature and that the amount of evaporation, as represented by the relative thicknesses, increased with decreasing temperature. Indeed, at -5°C, the thickness increased overnight, implying some water was absorbed.

Table 4 Overnight in wind tunnel dry-out conditions for Fluid 2

Test number	Air Temp (°C)	Fluid Temp (°C)	Humidity (% Rh)	Average wind speed (m/s)	Initial Thickness (mm)	Thickness after overnight dry-out (mm)	Δ thickness (%)
C971B842	-6.6	-4.9	78.7	4.9	1.950	2.144	+10
C971D876	-17.7	-14.9	67.8	5.0	1.905	1.862	-2
E822F732*	-29.0*	-26.3*	56.5	4.8	1.975	1.975	0

*test conducted at LOUT, values adjusted to -25°C

Figure 14 presents the aerodynamic acceptance test results of the fluids left overnight in the wind tunnel for Fluid 2. The figure shows a lower BLDT value for the overnight sample than from the initial certification at -5°C, in the same range for -15°C and the LOUT. The -5°C and -15°C values are below the acceptance criteria and, therefore, aerodynamically acceptable. The LOUT value is in the same range as the certification values.

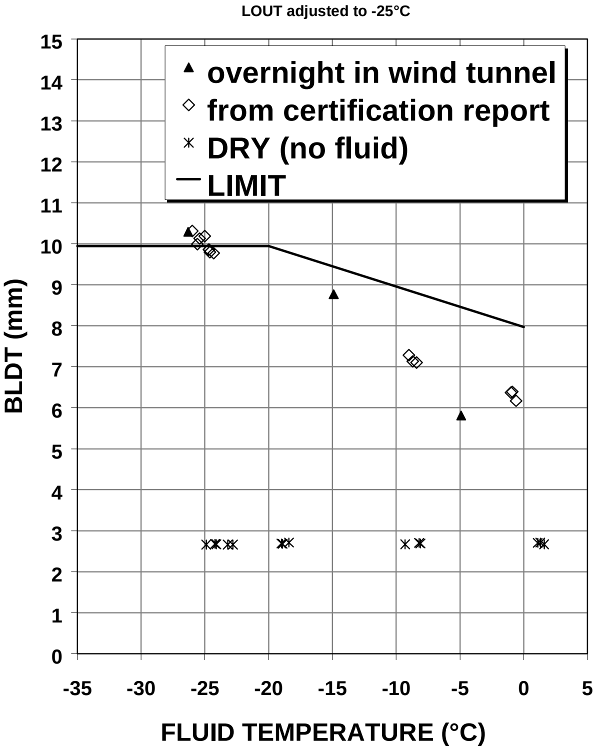


Figure 14 Fluid 2, with overnight in wind tunnel BLDT results

3.2.4 Fluid 2, Equivalent Dry-out

Small quantities of fluid samples were dried out for 12 hours in a controlled humidity and temperature environment as described in section 2.1.3. The resulting amount of evaporation is shown in Table 5. Then, larger amounts were dried out to an equivalent degree to make the required amounts of fluid for the wind tunnel testing, and the water change was determined from the refractive indices. The table shows that the water change for the equivalent samples was in the same range as that obtained at 55 percent Rh.

Table 5 Evaporation and water change for Fluid 2 dry-out samples

Fluid	Temperature (°C)	Evaporation at 55% Rh	Water change for 55% Rh	Equivalent evaporation at 20°C	Water change for equivalent
2	-5	11% 10%	11% 11%	11% 11%	12% 11%
2	-10	5.1% 4.2%	6.9% 5.4%	5.0% 4.7%	6.6% 5.8%
2	-20	1.7% 1.1%	2.0% 1.8%	1.8% 1.2%	1.7% 1.1%

The BLDT values from aerodynamic acceptance testing of the dried out samples are presented in Figure 15 and compared with certification test results. The dry-out BLDT results appear somewhat higher than the certification results; however, both sets were not tested simultaneously. When compared to their respective acceptance criteria, the relative values are similar.

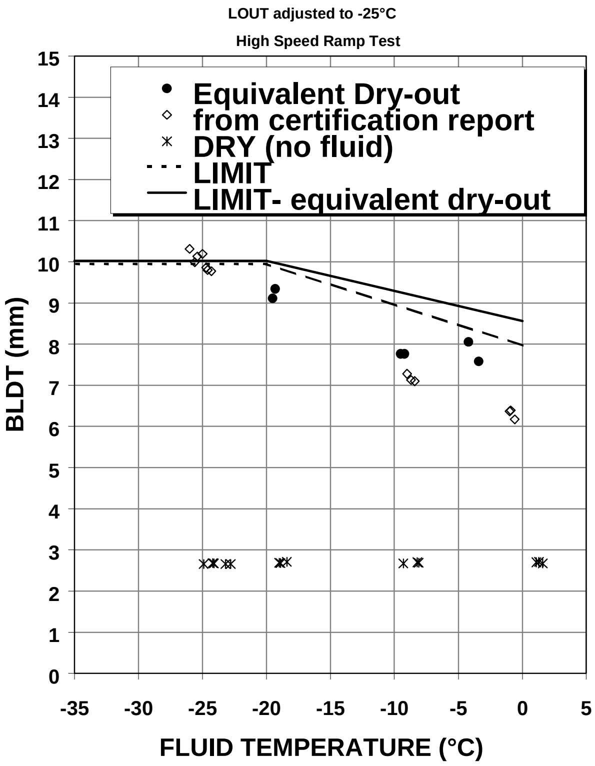


Figure 15 Fluid 2, with equivalent dry-out results

The Brookfield viscosities were measured on the original and dried out samples. The relative differences in viscosity are presented in Table 6. The results show slight increases in viscosity, which is reflected in the higher BLDT values seen in Figure 15.

Table 6 Fluid 2, Brookfield viscosity comparison for equivalent dry-out samples

Temperature (°C)	ΔViscosity at 6 rpm	ΔViscosity at 30 rpm
-5	+ 7%	+11%
-10	+ 9%	n.m.
-20	+ 24%	n.m.

3.3 Fluid 3

3.3.1 Fluid 3, Certification

Figure 16 presents the aerodynamic acceptance certification test results of Fluid 3. The results have been adjusted to give a passing temperature of -25°C, as with the other fluids, so that it cannot be identified.

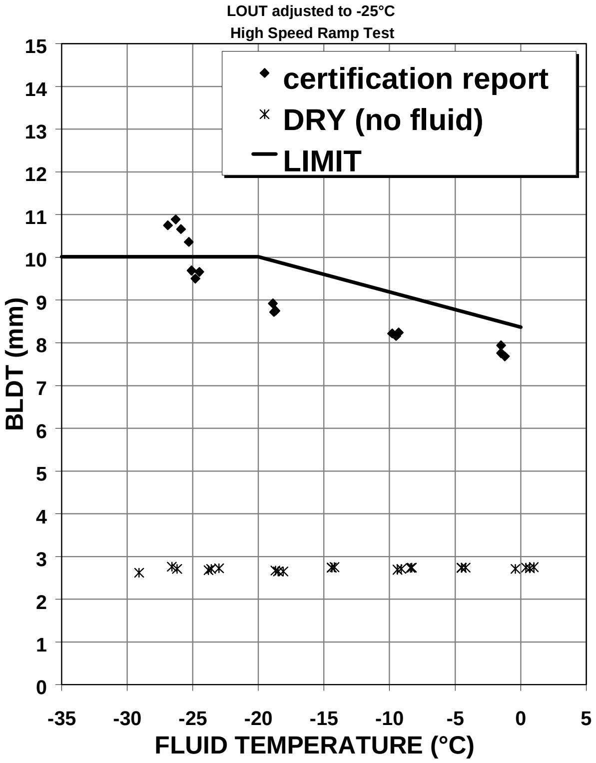


Figure 16 Certification test results of Fluid 3 with the LOUT adjusted to -25°C

3.3.2 Fluid 3, 20 Percent Reduction

Samples of Fluid 3 were dried out to a 20 percent weight loss according to the procedure described in section 2.1.3. These samples were subjected to the aerodynamic acceptance test at -5°C and at its lowest aerodynamic acceptable temperature. The results are presented in Figure 17 with the lowest temperature tests adjusted to -25°C. For this fluid at -5°C the BLDT results are below those of the fluids that were not dried out. At the LOUT the values are above those of the samples that were not dried out, as well as the acceptance criteria limit, and therefore not aerodynamically acceptable.

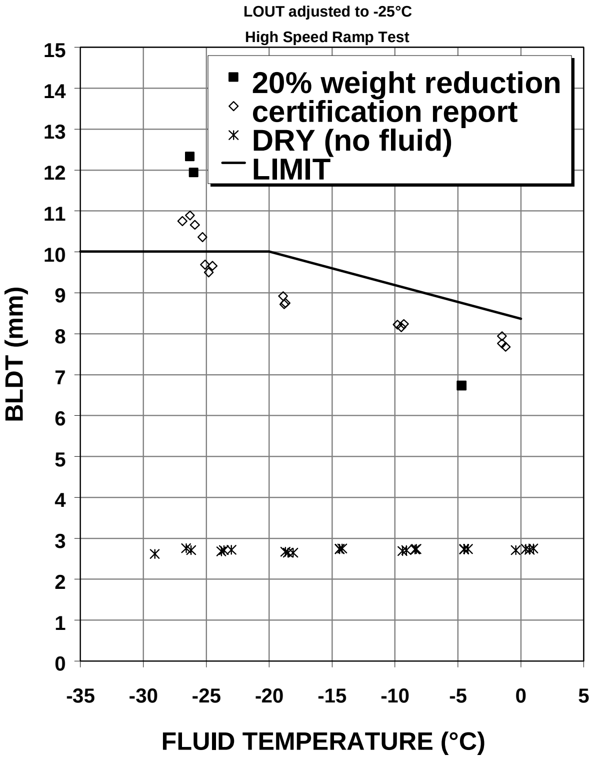


Figure 17 Fluid 3, certification and 20 percent weight loss results

3.3.3 Fluid 3, Overnight in Wind Tunnel

Fluid 3 samples were left overnight in the wind tunnel to dry out. The resulting conditions and fluid thickness changes are presented in Table 7. For this test series, as with others, the lowest temperature tests have been adjusted to give a LOUT of -25°C. The table shows that the humidity decreased with decreasing temperature and that fluid thickness change decreased with decreasing temperature. The change in fluid thickness may be the result of evaporation but it could also be influenced by fluid settling.

Table 7 Overnight in wind tunnel dry-out conditions for Fluid 3

Test number	Air Temp (°C)	Fluid Temp (°C)	Humidity (%Rh)	Average wind speed (m/s)	Initial Thickness (mm)	Thickness after overnight dry-out (mm)	Δ thickness (%)
E207B844	-5.3	-4.4	78.0	4.8	1.905	1.651	-13
E207D878	-14.0	-12.8	68.0	4.7	1.778	1.651	-7
E207F745*	-27.9*	-25.5*	52.7	4.8	1.975	1.975	0

*test conducted at LOUT, values adjusted to -25°C

In the morning, following exposure on the tunnel floor, the aerodynamic acceptance test was performed according to AS5900 for the high speed ramp. The results are presented in Figure 18, which shows that the BLDT results at -5°C and at the LOUT are in the same range as the fluid that was not dried out; at -10°C, the values are lower.

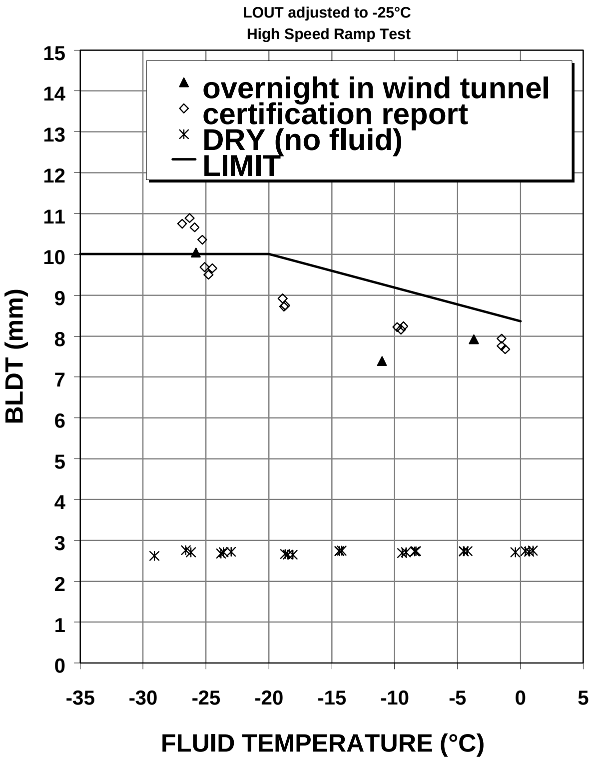


Figure 18 Fluid 3, with overnight in wind tunnel BLDT results

3.3.4 Fluid 3, Equivalent Dry-out

Small quantities of fluid samples were dried out for 12 hours in a controlled temperature and humidity environment as described in section 2.1.3. The resulting amount of evaporation is presented in Table 8. Then, larger quantities of the fluid were dried out to the same degree to make the required amounts of fluid for wind tunnel testing. The water changes were determined from the refractive indices before and after. Table 8 shows similar water changes for the dry-out samples at test temperature and room temperature.

Table 8 Evaporation and water change for Fluid 3 equivalent dry-out samples

Fluid	Temperature (°C)	Evaporation at 55% Rh	Water change for 55% Rh	Equivalent evaporation at 20°C	Water change for equivalent
3	-5	36% 36%	47% 47%	36% 36%	47% 46%
3	-10	31% 31%	40% 40%	30% 30%	36% 36%
3	-20	16% 15%	19% 17%	16% 14%	17% 14%

The BLDT values from aerodynamic acceptance testing are presented in Figure 19 compared with the certification results. The results show lower BLDT values at all three temperature intervals.

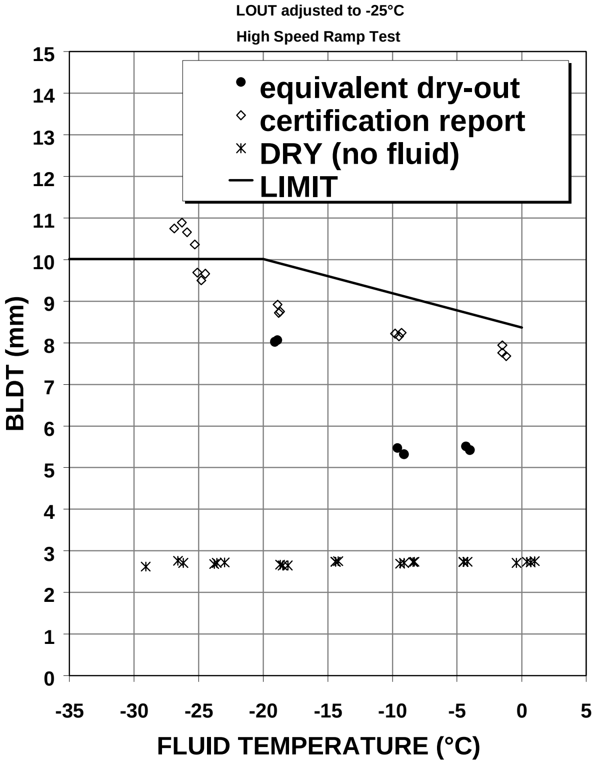


Figure 19 Fluid 3, with equivalent dry-out results

Table 9 presents the Brookfield viscosity data measured on the equivalent dried out samples with respect to their original viscosities. The table shows that in all cases the viscosity decreased significantly, reflected by the lower BLDTs observed (Figure 19), and that the viscosity decrease decreased with decreasing temperature.

Table 9 Fluid 3, Brookfield viscosity comparison for equivalent dry-out samples

Temperature (°C)	ΔViscosity at 6 rpm	ΔViscosity at 30 rpm
-5	-99%	-95%
-10	-97%	-93%
-20	-74%	n.m.

3.4 Fluid 4

3.4.1 Fluid 4, Certification

Two batches of Fluid 4 were used in order to have enough fluid for testing. Unfortunately, the two batches proved to have different aerodynamic behaviours. The first batch of Fluid 4 was for a certification test and its results are presented in Figure 20a, where the results have been adjusted to a -25°C LOUT as with the other fluids. The second batch of fluid was not for certification but had been sent to AMIL for research proposes only, which may explain why the two measured BLDT values on undried out samples fall above the acceptance criteria limit presented on Figure 20b. In this case the value at -25°C was measured at that temperature, and not adjusted to it.

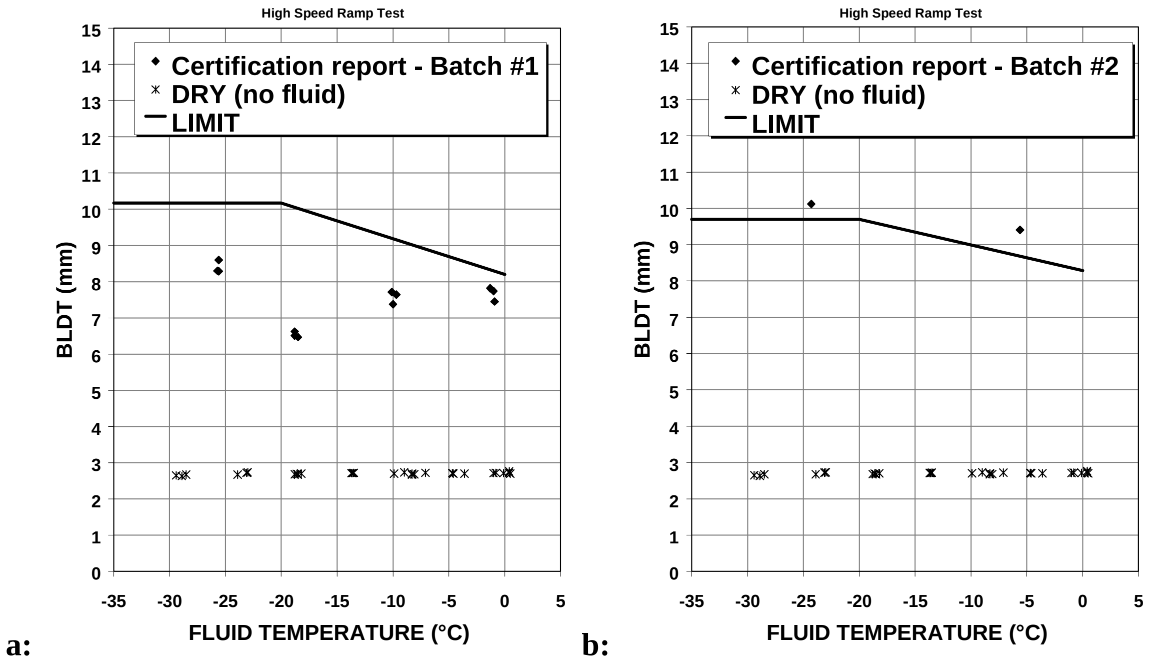


Figure 20 Certification test results of two batches of Fluid 4

3.4.2 Fluid 4, 20 Percent Weight Reduction

Samples of both batches of fluid were dried out to a 20 percent weight loss. Two samples of the first batch were tested at the LOUT and one of the second at -5°C, presented in Figure 21. The results show that in the lower temperature case the BLDT increased significantly as compared to the sample that was not dried out, despite the lower viscosity measured as required by the specification. At -5°C the BLDT decreased significantly.

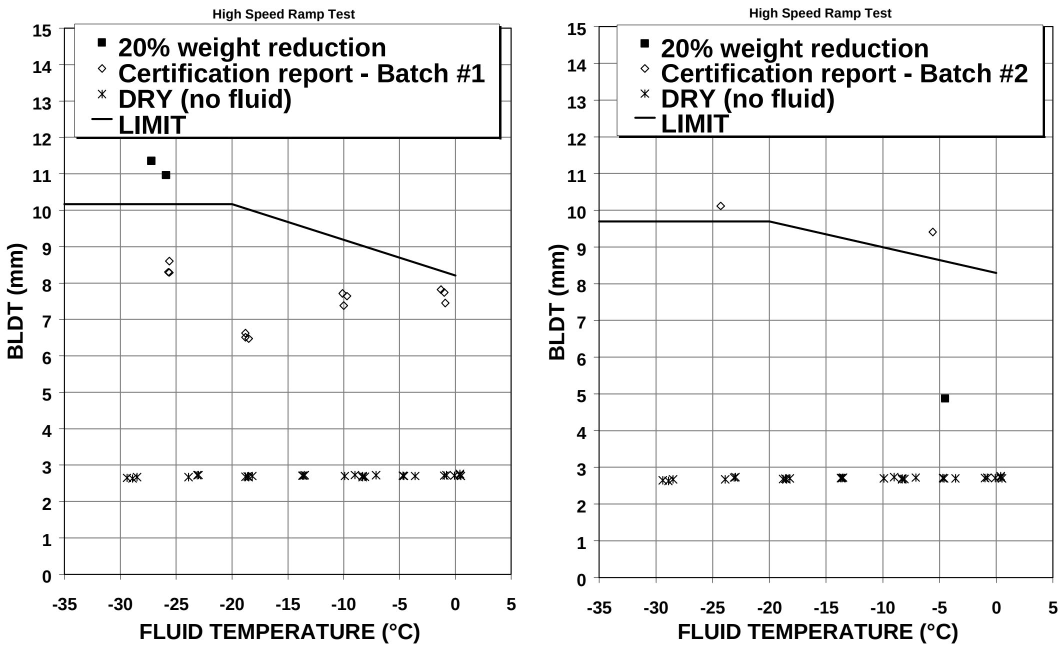


Figure 21 Fluid 4, certification and 20 percent weight loss results

3.4.3 Fluid 4, Overnight in Wind Tunnel

Fluid 4 samples were left overnight in the wind tunnel to dry out. The resulting conditions and fluid thickness change measured are presented in Table 10. The results for this fluid at the lowest temperature tested were adjusted to -25°C, as with the other fluids. Table 10 shows that the humidity decreased with decreasing temperature, and that the change in fluid thickness varied.

Table 10 Overnight in wind tunnel dry-out conditions for Fluid 4

Test number	Air Temp (°C)	Fluid Temp (°C)	Humidity (%Rh)	Average wind speed (m/s)	Initial Thickness (mm)	Thickness after overnight dry-out (mm)	Δ thickness (%)
C975B843	-5.6	-4.4	79.4	4.8	1.950	1.95	0
C975B153	-6.7	-5.4	79.9	5.0	1.800	1.733	-4
C975D877	-16.8	-14.8	70.0	4.7	1.905	1.524	-20
E190F733*	-26.5*	-23.6*	54.8	4.8	1.975	1.975	0
E190G747*	-27.9*	-25.8*	50.4	4.8	1.975	1.975	0

*test conducted at LOUT, values adjusted to -25°C

Figure 22 presents the aerodynamic acceptance test results of each batch of the fluids left overnight in the wind tunnel. The figure shows that the BLDT results at all temperatures, for both batches, are in the same range as the results obtained in the original certification of this fluid.

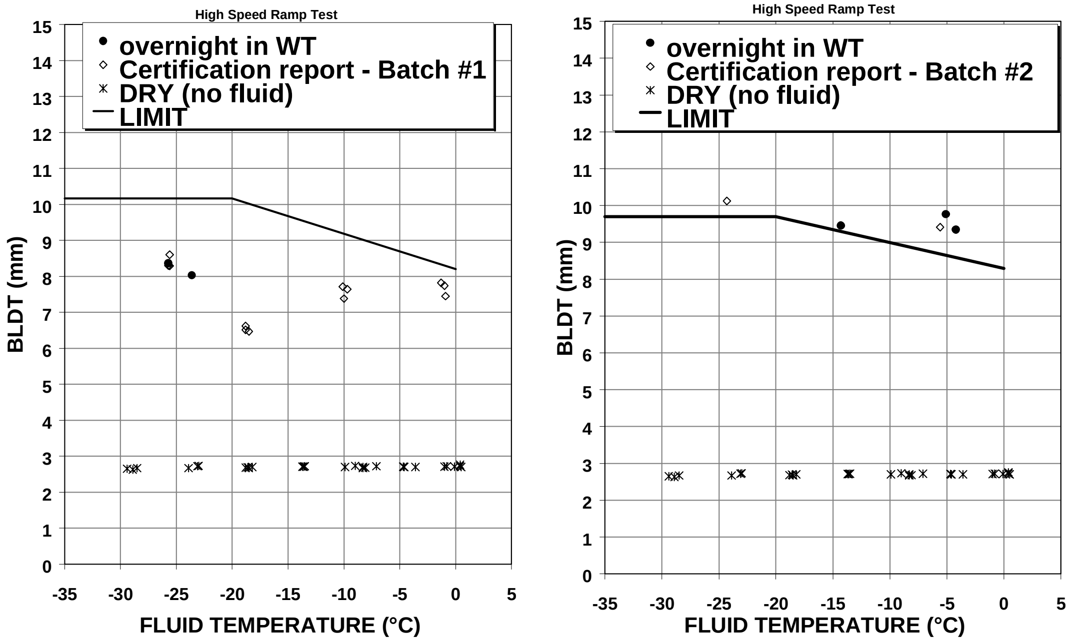


Figure 22 Fluid 4, with overnight in wind tunnel BLDT results

3.4.4 Fluid 4, Equivalent Dry-out

Small quantities of fluid samples were dried out for 12 hours in a controlled humidity and temperature environment as described in section 2.1.3. The resulting amount of evaporation is presented in Table 11. Then, equivalent amounts were dried out at room temperature to make up the required amounts of fluid for the wind tunnel testing. The water change values presented were determined from the refractive indices and appear similar for the evaporation at 55 percent Rh and test temperature as with those prepared at 20°C.

Table 11 Evaporation and water change for Fluid 4 dry-out samples

Fluid	Temperature (°C)	Evaporation at 55% Rh	Water change for 55% Rh	Equivalent evaporation at 20°C	Water change for equivalent
4	-5	17% 17%	21% 19%	16% 17%	17% 19%
4	-10	9.8% 9.6%	11% 7.8%	9.9% 6.9%	9.5% 7.6%
4	-20	2.3% 2.4%	2.9% 1.7%	2.2% 2.7%	2.5% 2.4%

The BLDT values from aerodynamic acceptance testing of these dried out samples are presented in Figure 23 compared with the certification aerodynamic test results. The results show a decrease in BLDT values at all temperatures.

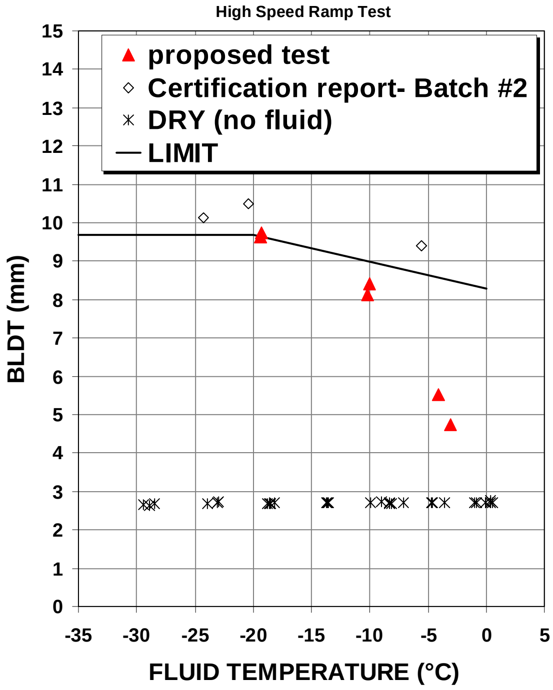


Figure 23 Fluid 4, with equivalent dry-out results

The Brookfield viscosities were measured on the original and dried out samples. The relative differences in viscosity are presented in Table 12. All dried out samples had lower viscosities, and the decreases were greater at the warmer temperatures, with less reduction at the colder temperatures.

Table 12 Fluid 4, Brookfield viscosity comparison for equivalent dry-out samples

Temperature (°C)	ΔViscosity at 6 rpm	ΔViscosity at 30 rpm
-5	-80%	-80%
-10	-48%	-46%
-20	-28%	n.m.

4. DISCUSSION

Table 13 presents a comparative summary of all the aerodynamic acceptance results on the dried out fluids presented. The table presents the three dry-out methods and how the BLDT was affected with respect to the original certification of the fluid. Down arrows indicate a decrease in BLDT (the greater the number of arrows, the greater the decrease), up arrows indicate an increase, and equal signs (=) indicate little, within error, or no change.

Table 13 Summary of change in BLDT or viscosity after dry-out by the three different methods

Fluid	20% weight reduction		Overnight in wind tunnel			Equivalent dry-out					
	-5°C	LOUT	-5°C	-15°C	LOUT	BLDT			Viscosity at 6 rpm at test temperature		
						-5°C	-10°C	-20°C	-5°C	-10°C	-20°C
1	↓↓	=	=	=	=	↓↓	↓↓	=	↓↓↓	↓↓↓	↓↓↓
2	↑	↑	↓	=	=	↑	=	=	↑	↑	↑
3	↓	↑	=	↓	=	↓↓	↓↓	↓	↓↓	↓↓	↓↓
4	↓↓	↑	=	=	=	↓↓	↓	↓	↓↓↓	↓↓	↓

Table 13 shows that for the current 20 percent reduction Exposure to Dry-air Dry-out tests, although all fluids should have a Brookfield viscosity of 500 mPa·s at 20°C, 3.0 rpm with the LV1 spindle, some fluids show an increase in BLDT. For one fluid (#2) the increase was at -5°C and three of the four fluids increased in BLDT at the LOUT. The LOUT may be considered an extreme condition, but the fact that for one fluid there was an increase in BLDT at -5°C suggests that an absolute viscosity range is not adequate to predict aerodynamic performance. Testing for the equivalent dry-out also showed that 20 percent weight reduction is an arbitrary value since dry-out percentages can be from 1 to 36 percent depending on fluid and temperature. The one advantage of this test is that it is simple to perform.

Drying out fluid by leaving it out overnight in the wind tunnel is a more involved test and required the occupation of the wind tunnel for extended periods of time. A main disadvantage is that the humidity in the wind tunnel cannot be controlled easily. Therefore, for the tests performed, the humidity was higher at the higher temperatures. At -5°C it was near 80 percent, at -15°C, 70 percent and at the fluids' LOUT it was 50 to 55 percent. The amount of fluid dry-out could not be precisely quantified. Unfortunately, samples were not taken in the morning following dry-out and before wind acceleration. A measurement of the fluid height in the morning was made, however, a decrease in height overnight may have partially been the results of some fluid settling as the lateral ends of the fluid layer were open. From measurements of the fluid heights before and after, dry-out appears to be in the +/- 10 percent range. These small amounts of evaporation are reflected by the small, if any differences in BLDT compared with the original certification tests. Not surprisingly, these tests showed no aerodynamic acceptance problems with the fluid, since the BLDTs were the same, or slightly lower, than the original values.

The equivalent dry-out tests, where the fluid was dried out in a controlled humidity and temperature environment, showed that for all but one fluid, the BLDTs of the dried out fluids were less than, or equivalent to, those that were not dried out. The one case where the BLDT was higher on the dried out fluid, Fluid 2 at -5°C, the value was still below the acceptance criteria and therefore could be considered aerodynamically acceptable. The dry-out step of this test can be carried out in a humidity chamber and a climatic chamber.

More work needs to be undertaken to improve the repeatability of the dry-out step. This could easily be achieved with minor modifications to reduce the turbulence of the wind. Special care was not taken for this study since the objective was to run preliminary tests. Brookfield viscosities before and after were also run on the dried out fluids to see if the viscosity can be an adequate screening tool for aerodynamics, since normally if the viscosity of a given fluid at a given temperature and adequate shear rate, decreases, the BLDT decreases as well. This way a fluid manufacturer, or others who do not easily have access to a wind tunnel, can screen for the test.

For three of the four fluids tested, the viscosity always decreased, while the BLDT either decreased or remained the same. Therefore, an examination of the viscosity data would suggest that for these fluids no additional aerodynamic acceptance tests should be required. However, the viscosity decreases were not quantitatively reflected in the BLDT measurements. For the other fluid (#2), the viscosity increased at all three temperature intervals. In this case, wind tunnel tests would be run on the dried out fluid to ensure their aerodynamic acceptance and only for one temperature interval, -5°C, did the BLDT increase as well. Therefore, the viscosity can screen for all fluids; however, an aerodynamic acceptance test would be required for those samples whose viscosity increased.

5. CONCLUSIONS

The objectives of this study were to determine whether an anti-icing fluid used for frost protection has acceptable aerodynamic flow-off characteristics and to evaluate a test method to evaluate dried out fluids and their aerodynamic performance. Three methods were investigated to dry out fluids.

The first method investigated is part of the AMS1428D fluid specification and involves drying fluids to a 20 percent weight reduction then measuring their viscosity, if it is below 500 mPa·s at 20°C, the fluid passes the test.

The test method proved to be simple to perform; however, other testing showed that the 20 percent dry-out is arbitrary as the dry-out percentage varies depending on fluid and temperature. The test results showed that one low viscosity measurement at room temperature does not ensure acceptable aerodynamic performance at other colder temperature intervals.

The second test method consisted of allowing the fluid to dry out overnight in wind tunnel. This test method proved to be more involved because of the occupation of the wind tunnel for long periods of time. The method was also limited somewhat since the humidity cannot be controlled in the current wind tunnel set-up. The test results showed that the aerodynamic performance of the exposed fluids was acceptable. However, the humidity during this test was higher than desired.

The third test method involved proportional dry-out in controlled temperature, humidity and wind speed environment. This test method was most representative of real conditions under which a fluid is drying out. Results of this testing showed no change or decrease in BLDT of the dried-out fluids with respect to the fluids that had not been dried out.

The results of these dry-out tests suggest that the tested fluids, if left exposed on an airplane wing overnight, when no frost occurs, under low wind and reasonable humidity, will have acceptable aerodynamic flow-off, based on the AS5900 aerodynamic acceptance test.

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6. RECOMMENDATIONS

Based on the preceding conclusions, the tested fluids can be left on a wing overnight under reasonable humidity and wind speed conditions.

Further investigations include:

- Development of a test protocol based on the equivalent dry-out test method to evaluate the aerodynamic acceptance of dried-out fluids, since this method is viable and more representative of real dry-out conditions than the existing dry-out test in the AMS1428D specification.
- Testing overnight in wind tunnel at low temperature with lower humidity, to be able to directly evaluate the aerodynamic performance of the actual dried out fluid, not as an equivalent as described above.

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