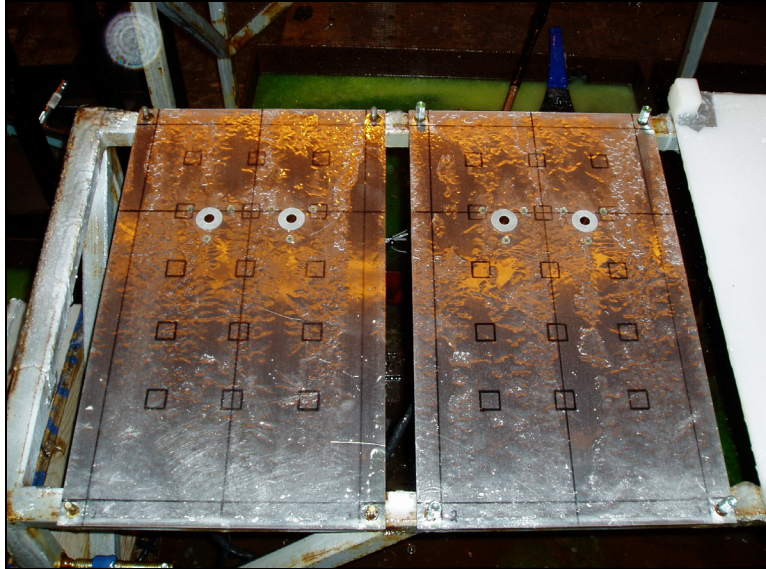


# A Sensor for Detecting Anti-Icing Fluid Failure: Phase I



*Prepared by*



*Prepared for*

**Transportation Development Centre**

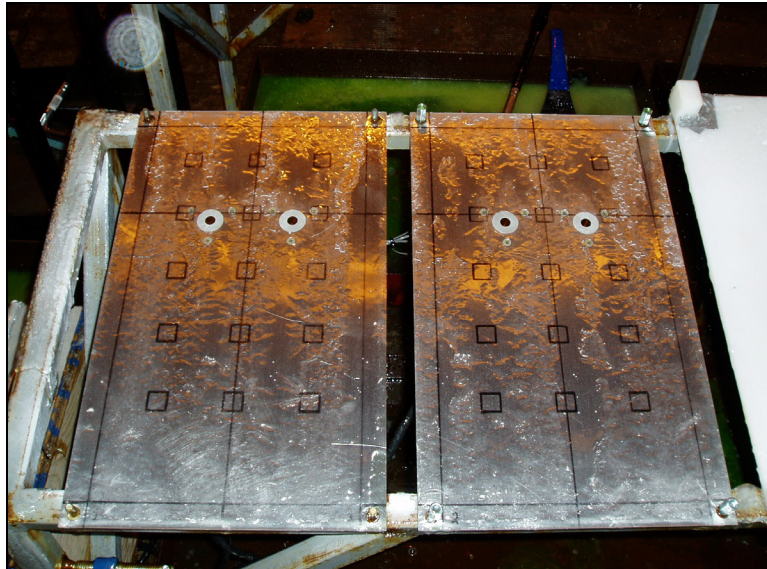
*In cooperation with*

**Civil Aviation  
Transport Canada**

December 2004  
Final Version 1.0



# A Sensor for Detecting Anti-Icing Fluid Failure: Phase I



By:

**Stephanie Bendickson**



December 2004  
Final Version 1.0

The contents of this report reflect the views of APS Aviation Inc. and not necessarily the official view or opinions of the Transportation Development Centre of Transport Canada.

The Transportation Development Centre does not endorse products or manufacturers. Trade or manufacturers' names appear in this report only because they are essential to its objectives.

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*This report was first provided to Transport Canada as Final Draft 1.0 in December 2004.  
It has been published as Final Version 1.0 in May 2020.*

*\*\*Final Draft 1.0 of this report was signed and provided to Transport Canada in December 2004. A Transport Canada technical and editorial review was subsequently completed and the report was finalized in May 2020; Jean Valiquette was not available to participate in the final review or to sign the current version of the report.*

## PREFACE

Under contract to the Transportation Development Centre of Transport Canada, APS Aviation Inc. has undertaken a research program to advance aircraft ground de/anti-icing technology. The specific objectives of the APS Aviation Inc. test program are the following:

- To develop holdover time data for all newly-qualified de/anti-icing fluids;
- To evaluate weather data from previous winters to establish a range of conditions suitable for the evaluation of holdover time limits;
- To compare endurance times from natural snow with those generated from simulations of laboratory snow;
- To compare fluid endurance time, holdover time and protection time;
- To compare snowfall rates obtained with a real-time snow precipitation gauge with rates obtained using rate pans;
- To further develop and to assist with the commercialization of Type III fluids;
- To develop a test procedure for evaluating forced air-assist systems;
- To conduct general and exploratory de/anti-icing research; and
- To evaluate the possibility of using a fluid failure sensor in holdover time testing.

The research activities of the program conducted on behalf of Transport Canada during the winter of 2003-04 are documented in nine reports. The titles of the reports are as follows:

- TP 14374E Aircraft Ground De/Anti-Icing Fluid Holdover Time Development Program for the 2003-04 Winter;
- TP 14375E Winter Weather Impact on Holdover Time Table Format (1995-2004);
- TP 14376E Endurance Time Testing in Snow: Comparison of Indoor and Outdoor Data for 2003-04;
- TP 14377E Adhesion of Aircraft Anti-Icing Fluids on Aluminum Surfaces;
- TP 14378E Evaluation of a Real-Time Snow Precipitation Gauge for Aircraft Deicing Operations (2003-04);
- TP 14379E Development of Holdover Time Guidelines for Type III Fluids;
- TP 14380E A Protocol for Testing Fluids Applied with Forced Air Systems;
- TP 14381E Aircraft Ground Icing General and Exploratory Research Activities for the 2003-04 Winter; and
- TP 14382E A Sensor for Detecting Anti-Icing Fluid Failure: Phase I.

In addition, the following interim report is being prepared:

- *Substantiation of Aircraft Ground Deicing Holdover Times in Frost Conditions.*

This report, TP 14382E, has the following objective:

- To evaluate the ability of a fluid failure sensor to replicate visual fluid failure determinations.

To satisfy this objective, a fluid failure sensor was acquired from Intertechnique and tested in natural snow and in simulated freezing rain, drizzle and fog.

## **PROGRAM ACKNOWLEDGEMENTS**

This multi-year research program has been funded by the Civil Aviation Group and Transport Canada with support from the Federal Aviation Administration, William J. Hughes Technical Center, Atlantic City, NJ. This program could not have been accomplished without the participation of many organizations. APS Aviation Inc. would therefore like to thank the Transportation Development Centre of Transport Canada, the Federal Aviation Administration, National Research Council Canada, the Meteorological Service of Canada, and several fluid manufacturers.

APS Aviation Inc. would also like to acknowledge the dedication of the research team, whose performance was crucial to the acquisition of hard data. This includes the following people: Stephanie Bendickson, Nicolas Blais, Richard Campbell, Michael Chaput, Sami Chebil, John D'Avirro, Peter Dawson, Marco Di Zazzo, Miljana Horvat, Mark Mayodon, Chris McCormack, Nicoara Moc, Catalin Palamaru, Filomeno Pepe, Marco Ruggi, Joey Tiano, Kim Vepsa, and David Youssef.

Special thanks are extended to Barry Myers, Frank Eyre and Yagusha Bodnar, who on behalf of the Transportation Development Centre, have participated, contributed and provided guidance in the preparation of these documents.

## **PROJECT ACKNOWLEDGEMENTS**

The author would like to acknowledge the significant contribution of Intertechnique to this project. In addition to providing a complete ice detection system, Intertechnique also provided training and guidance throughout the test season and duration of the project. In particular, the author would like to thank the contribution of Mr. François Larue of Intertechnique; without his support this project could not have been possible.



1. Transport Canada Publication No. <b>TP 14382E</b>		2. Project No. <b>5499-5501</b>		3. Recipient's Catalogue No.	
4. Title and Subtitle <b>A Sensor for Detecting Anti-Icing Fluid Failure: Phase I</b>				5. Publication Date <b>December 2004</b>	
				6. Performing Organization Document No. <b>CM1892.001</b>	
7. Author(s) <b>Stephanie Bendickson</b>				8. Transport Canada File No. <b>2450-BP-14</b>	
9. Performing Organization Name and Address <b>APS Aviation Inc. 634 Saint-Jacques St., 4<sup>th</sup> Floor Montreal, Quebec, H3C 1C7</b>				10. PWGSC File No. <b>MTB-3-01379</b>	
				11. PWGSC or Transport Canada Contract No. <b>T8200-033534/001/MTB</b>	
12. Sponsoring Agency Name and Address <b>Transportation Development Centre Transport Canada 800 René-Lévesque Blvd West, Suite 600 Montreal, Quebec, H3B 1X9</b>				13. Type of Publication and Period Covered <b>Final</b>	
				14. Project Officer <b>Antoine Lacroix for Barry Myers</b>	
15. Supplementary Notes (Funding programs, titles of related publications, etc.) Several research reports for testing of de/anti-icing technologies were produced for previous winters on behalf of Transport Canada. These are available from the Transportation Development Centre. Nine reports (including this one) were produced as part of this winter's research program. Their subject matter is outlined in the preface.					
16. Abstract <p>In recent years, research has been conducted to evaluate the variance in endurance times caused by individual variance in determination of fluid failure. In the winter of 2003-04, testing was conducted with the Intertechnique Ice Detection Evaluation System (IDES) in an attempt to determine if the technology could replace the visual determination of fluid failure.</p> <p>Due to limited funding being available, only a limited number of tests (54) were conducted. Tests were conducted in natural snow and simulated freezing rain, drizzle and fog with Type I, II and IV fluids.</p> <p>Based on the tests conducted, it was concluded that the IDES is currently not able to replicate a visual determination of failure. However, this may be partially a result of the IDES' inability to replicate a human observer, as opposed to being a result of its inability to detect fluid failure. The IDES consistently measured endurance times shorter than those measured by the human observer, it had difficulty detecting fluid failure with Type I fluids and it was better able to replicate visual endurance in warmer temperatures than in colder temperatures. No significant relationship was found between the IDES' ability to replicate visual endurance times and precipitation type or fluid type/dilution (Type II/IV fluids only).</p> <p>If the IDES manufacturer can adapt the system to better replicate the human eye, it is recommended that the system be tested again in the winter of 2004-05. If possible, a representative from the IDES manufacturer should be present during testing, especially during any simulated precipitation test session. It is also recommended that the fluid freeze point curves be checked for precision. If the system replaces the human observer, more sensors should be installed on each plate to better replicate the visual method of detecting fluid failure.</p> <p>Finally, it is recommended that while this technology is being developed, more individuals receive intense training in order to bring them to the "expert" level of evaluating fluid failure. A reference fluid may be a useful tool in this training.</p>					
17. Key Words <b>De/Anti-Icing Fluids, Holdover Times, Endurance Times, Fluid Failure, Sensors, Ice Detection</b>			18. Distribution Statement <b>Limited number of copies available from the Transportation Development Centre</b>		
19. Security Classification (of this publication) <b>Unclassified</b>		20. Security Classification (of this page) <b>Unclassified</b>		21. Declassification (date) <b>—</b>	22. No. of Pages <b>xviii, 28 apps</b>
					23. Price <b>—</b>



1. N° de la publication de Transports Canada <b>TP 14382E</b>		2. N° de l'étude <b>5499-5501</b>		3. N° de catalogue du destinataire		
4. Titre et sous-titre <b>A Sensor for Detecting Anti-Icing Fluid Failure: Phase I</b>				5. Date de la publication <b>Décembre 2004</b>		
				6. N° de document de l'organisme exécutant <b>CM1892.001</b>		
7. Auteur(s) <b>Stephanie Bendickson</b>				8. N° de dossier - Transports Canada <b>2450-BP-14</b>		
9. Nom et adresse de l'organisme exécutant <b>APS Aviation Inc. 634, rue Saint-Jacques, 4<sup>ième</sup> étage Montréal (Québec) H3C 1C7</b>				10. N° de dossier - TPSGC <b>MTB-3-01379</b>		
				11. N° de contrat - TPSGC ou Transports Canada <b>T8200-033534/001/MTB</b>		
12. Nom et adresse de l'organisme parrain <b>Centre de développement des transports Transports Canada 800, Boul. René-Lévesque Ouest, Bureau 600 Montréal (Québec) H3B 1X9</b>				13. Genre de publication et période visée <b>Final</b>		
				14. Agent de projet <b>Antoine Lacroix pour Barry Myers</b>		
15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.) Plusieurs rapports de recherche sur des essais de technologies de dégivrage et d'antigivrage ont été produits au cours des hivers précédents pour le compte de Transports Canada. Ils sont disponibles au Centre de développement des transports. Neuf rapports (dont celui-ci) ont été rédigés dans le cadre du programme de recherche de cet hiver. Leur objet apparaît à l'avant-propos.						
16. Résumé <p>Au cours des dernières années, des recherches ont été menées afin d'évaluer la variance dans les durées d'endurance causée par la variance individuelle observée dans la détermination de la défaillance d'un liquide. Des essais ont été effectués à l'aide du système d'évaluation de détection de givre d'Intertechnique (Intertechnique Ice Detection Evaluation System, ou IDES) durant l'hiver 2003-2004 dans le but d'établir si cette technologie pourrait remplacer la détermination visuelle de la défaillance d'un liquide.</p> <p>En raison d'un financement limité, seul un nombre réduit d'essais (54) ont pu être menés. Des tests ont été effectués sous neige naturelle et dans des conditions artificielles simulant de la pluie, de la bruine et du brouillard verglaçants, avec des liquides de types I, II et IV.</p> <p>Les essais menés ont permis de conclure que l'IDES n'est pas en mesure, à l'heure actuelle, de reproduire la détermination visuelle de la défaillance d'un liquide. Il est néanmoins possible que ces résultats soient dus, du moins en partie, à l'incapacité de l'IDES d'imiter le comportement d'un observateur humain plutôt qu'à son incapacité à détecter la défaillance d'un liquide. L'IDES a ainsi systématiquement mesuré des durées d'endurance inférieures à celles calculées par l'observateur humain. Il a éprouvé des difficultés à détecter la défaillance des liquides de type I, et a pu reproduire la détermination visuelle des durées d'endurance à des températures plus chaudes plus facilement qu'à des températures plus froides. Aucun lien significatif n'a été établi entre la capacité de l'IDES à reproduire les durées d'endurance déterminées visuellement et le type de précipitations, ou encore le type ou la dilution du liquide (liquides de types II/IV uniquement).</p> <p>Si le fabricant de l'IDES est en mesure d'adapter son système afin de permettre une meilleure imitation de l'œil humain, il est recommandé que celui-ci fasse à nouveau l'objet d'essais au cours de l'hiver 2004-2005. Si possible, un représentant du fabricant de l'IDES devrait être présent lors des tests, particulièrement durant les séances menées dans des conditions de précipitations simulées. Il est également recommandé que la précision des courbes des points de congélation des liquides soit vérifiée. Si ce système devait remplacer un observateur humain, davantage de détecteurs devraient être installés sur chaque plaque afin de mieux reproduire la méthode permettant de détecter visuellement la défaillance d'un liquide.</p> <p>Finalement, il est recommandé que pendant la mise au point de cette technologie, un plus grand nombre d'individus reçoivent une formation intensive leur permettant d'acquérir le statut « d'experts » dans l'évaluation de la défaillance d'un liquide. Un liquide de référence pourrait s'avérer un outil utile dans le cadre de cette formation.</p>						
17. Mots clés <b>Liquides de dégivrage et d'antigivrage, durées d'efficacité, temps d'endurance, défaillance d'un liquide, détecteurs, détection de givre</b>				18. Diffusion <b>Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.</b>		
19. Classification de sécurité (de cette publication) <b>Non classifiée</b>		20. Classification de sécurité (de cette page) <b>Non classifiée</b>		21. Déclassification (date) <b>—</b>	22. Nombre de pages <b>xviii, 28 ann.</b>	23. Prix <b>—</b>



## EXECUTIVE SUMMARY

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology. In recent years, one of these research activities has been the evaluation of variance in endurance times caused by individual variance in determination of fluid failure.

### Background

In the winter of 2002-03, tests were conducted to evaluate the influence of level of training, knowledge and experience on the ability to determine fluid failure. Results showed a significant amount of variance in the endurance times measured by intermediate and novice individuals. It was concluded there are three ways of obtaining consistent results during holdover time testing: to use the same experienced individual to conduct tests, to develop an intense training program or to develop technology to detect fluid failures. TC subsequently secured an ice detection system to test in the winter of 2003-04 in an attempt to advance current technology and stimulate future development.

### Methodology

The Intertechnique Ice Detection Evaluation System (IDES) uses an ultrasonic technology based on acoustic impedance measurements to detect ice. Its components include ice sensors (for these tests the ice sensors were installed in standard endurance time test plates), a control unit, a display unit, and a laptop computer equipped with specialized software that monitors output from the sensors.

Standard endurance time test protocol, with several additional requirements added, was used to conduct tests with the IDES. The additional requirements were related to the specialized IDES equipment and to the method of detecting fluid failure in simulated freezing precipitation. Tests were conducted with five fluids in natural snow, freezing drizzle, freezing rain and freezing fog.

### Data

Due to the limited funding available, only a limited number of tests (54) were conducted. In addition, because the project was "piggy-backed" onto other related projects, thorough observations were not recorded for every test. More tests were conducted in natural snow than in simulated freezing precipitation conditions, and more tests were conducted with Type IV fluid than with other fluid types.

## Analysis

The following observations were made based on the limited data set:

- The variance between visual and IDES endurance times was less than or equal to 10 percent in only 23 percent of the tests. Ten percent is the variance expected when a human observer determines fluid failure;
- The IDES consistently measured endurance times shorter than those measured by the human observer;
- The IDES had difficulty detecting fluid failure with Type I fluids, likely due to the mechanisms used to detect fluid failure;
- The IDES was better able to replicate visual endurance times in warmer temperatures than in colder temperatures; and
- No significant relationship was found between the IDES ability to replicate visual endurance times and precipitation type or Type II/IV fluid type/dilution.

## Conclusions

Based on the limited number of tests that were conducted, it was concluded that the IDES is currently not able to replicate a visual determination of failure. This may be partially a result of the IDES' inability to replicate a human observation, rather than its inability to detect ice. In fact, it is possible that in some cases the IDES more accurately measured a fluid's ability to offer ice protection.

## Recommendations

If the IDES manufacturer can adapt the system to better replicate the human eye, it is recommended that the system be tested again in the winter of 2004-05 in all precipitation conditions. If possible, a representative from the IDES manufacturer should be present during testing, especially during any simulated precipitation test session. It is also recommended that the fluid freeze point curves be checked for precision. If the system replaces the human observer, more sensors should be installed on each plate to better replicate the visual method of detecting fluid failure.

While this technology is being further developed, effort must still be made to reduce variance in endurance times caused by variance in visual determinations of fluid failure. It is recommended that an intense training program be put into place to achieve this objective. A reference fluid may be a useful tool in this training program.

## SOMMAIRE

En vertu d'un contrat avec le Centre de développement des transports (CDT) de Transports Canada (TC), APS Aviation Inc. (APS) a entrepris des activités de recherche visant à faire progresser les technologies associées au dégivrage et à l'antigivrage d'aéronefs au sol. Au cours des dernières années, l'une de ces activités de recherche s'est concentrée sur l'évaluation de la variance dans les durées d'endurance causée par la variance individuelle observée dans la détermination de la défaillance d'un liquide.

### Contexte

Au cours de l'hiver 2002-2003, des essais ont été menés afin d'évaluer l'influence du niveau de formation, des connaissances et de l'expérience sur la capacité à déterminer la défaillance d'un liquide. Les résultats obtenus ont démontré une variance importante dans les durées d'endurance mesurées par les individus de niveau intermédiaire et les novices. Il a été conclu qu'il existe trois façons d'obtenir des résultats cohérents dans le cadre des essais sur les durées d'efficacité : le recours aux mêmes personnes expérimentées pour la conduite des tests, l'élaboration d'un programme de formation intensive ou le développement de technologies de détection de défaillance des liquides. TC s'est doté par la suite d'un système de détection de givre aux fins d'évaluation durant l'hiver 2003-2004, dans le but de faire progresser les technologies actuelles et de stimuler les développements futurs.

### Méthodologie

Le système d'Intertechnique (Intertechnique Ice Detection Evaluation System, ou IDES) a recours à une technologie ultrasonique basée sur des mesures d'impédance acoustique permettant de détecter le givre. Ses composants incluent des détecteurs de givre (dans le cadre de ces tests, les détecteurs de givre étaient installés sur une plaque servant aux essais d'endurance standards), une unité de contrôle, une unité d'affichage, ainsi qu'un ordinateur portable équipé d'un logiciel spécialisé surveillant les données des détecteurs.

Pour mener les tests à l'aide de l'IDES, le protocole relatif aux essais d'endurance standards a été utilisé, en y ajoutant de nombreuses exigences, liées à l'équipement spécialisé de l'IDES et à la méthode de détection de la défaillance d'un liquide dans des conditions simulant des précipitations verglaçantes. Des tests ont été effectués avec cinq liquides sous neige naturelle et dans des conditions de bruine verglaçante, de pluie verglaçante et de brouillard verglaçant.

## Données

En raison d'un financement limité, un programme d'essai indépendant et approfondi n'a pas été possible, et seul un nombre réduit d'essais (54) ont pu être menés. De plus, ce programme venant s'ajouter à d'autres projets connexes, des observations détaillées n'ont pas été consignées pour tous les tests. Davantage de tests ont ainsi été menés sous neige naturelle que dans des conditions de précipitations verglaçantes simulées, et un plus grand nombre d'essais ont été effectués avec des liquides de type IV qu'avec d'autres types de liquides.

## Analyse

Les observations suivantes ont été faites en fonction de l'ensemble limité de données :

- La variance observée entre les durées d'endurance déterminées visuellement et celles déterminées par l'IDES était égale ou inférieure à 10 pour cent dans 23 pour cent des essais menés seulement. Ce taux de dix pour cent représente la variance attendue lorsqu'un observateur humain détermine la défaillance d'un liquide ;
- L'IDES a systématiquement mesuré des durées d'endurance inférieures à celles calculées par l'observateur humain ;
- L'IDES a éprouvé des difficultés à détecter la défaillance des liquides de type I, probablement en raison des mécanismes utilisés pour détecter la défaillance d'un liquide ;
- L'IDES a pu reproduire les durées d'endurance déterminées visuellement dans des températures plus chaudes que plus froides ; et
- Aucun lien significatif n'a été établi entre la capacité de l'IDES à reproduire les durées d'endurance déterminées visuellement et le type de précipitations, ou encore le type ou la dilution des liquides de types II/IV.

## Conclusions

Les essais de nombre limités menés ont permis de conclure que l'IDES n'est pas en mesure, à l'heure actuelle, de reproduire la détermination visuelle de la défaillance d'un liquide. Il est possible que ces résultats soient dus, du moins en partie, à l'incapacité de l'IDES d'imiter une observation humaine plutôt qu'à son incapacité à détecter le givre. Il est en fait possible, dans certains cas, que l'IDES ait pu mesurer plus précisément la capacité d'un liquide à offrir une protection contre le givre.

## Recommandations

Si le fabricant de l'IDES est en mesure d'adapter son système afin de permettre une meilleure imitation de l'œil humain, il est recommandé que celui-ci fasse à nouveau l'objet d'essais au cours de l'hiver 2004-2005, et ce, dans toutes les conditions de précipitations. Si possible, un représentant du fabricant de l'IDES devrait être présent lors des tests, particulièrement durant les séances menées dans des conditions de précipitations simulées. Il est également recommandé que la précision des courbes des points de congélation des liquides soit vérifiée. Si ce système devait remplacer un observateur humain, davantage de détecteurs devraient être installés sur chaque plaque afin de mieux reproduire la méthode permettant de détecter visuellement la défaillance d'un liquide.

Pendant que cette technologie continue de faire l'objet de mises au point, des efforts doivent encore être déployés afin de réduire la variance dans les durées d'endurance causée par la variance observée dans la détermination visuelle de la défaillance d'un liquide. Il est recommandé qu'un programme de formation intensive soit mis en place afin d'atteindre cet objectif. Un liquide de référence pourrait s'avérer un outil utile dans le cadre de ce programme de formation.

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## **GLOSSARY**

APS	APS Aviation Inc.
IDES	Ice Detection Evaluation System
NRC	National Research Council Canada
TC	Transport Canada
TDC	Transportation Development Centre

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## 1. INTRODUCTION

Under contract to the Transportation Development Centre (TDC) of Transport Canada (TC), APS Aviation Inc. (APS) has undertaken research activities to further advance aircraft ground de/anti-icing technology. In recent years, one of these research activities has been an attempt to standardize the determination of fluid failure.

### 1.1 Background

Initial work was conducted in the winter of 2001-02 and reported in the TC report, TP 13991E, *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter* (1).

In the winter of 2002-03, further work was undertaken to document the variance in endurance times attributable to level of experience of the individual. This work is documented in the TC report, TP 14156E, *Variance in Endurance Times of De/Anti-Icing Fluids* (2). These tests were conducted to evaluate the influence of level of training, knowledge and experience on an individual's ability to determine fluid failures. Results showed a significant amount of variance in the endurance times measured by intermediate (14 percent) and novice (22 percent) individuals. It was concluded there are three ways of obtaining consistent results during holdover time testing: to use the same experienced individual to conduct tests, to develop an intense training program, or to develop technology to detect fluid failures.

Over the past decade, several companies have developed technology in this area but none has successfully developed a technology to the level required by the industry. Based on recent developments and research, it was believed the Intertechnique Ice Detection Evaluation System (IDES), which was developed for on-wing ice detection, could be suitable for detecting fluid failure during endurance time testing. In the fall of 2003, APS approached Intertechnique on behalf of TC to ascertain their interest in having TC evaluate the IDES for use in endurance time testing. Intertechnique agreed and provided an IDES for testing in the winter of 2003-04. This report documents the subsequent testing.

### 1.2 Objective

The objective of this project was to evaluate the ability of the IDES to replicate visual fluid failure determinations. It should be noted that the objective was not to evaluate the ability of the IDES to detect fluid failure. The scope of work for this

project is outlined in an excerpt from the TDC work statement provided in Appendix A.

Limited funding was available for this project and testing was subsequently completed in conjunction with other projects and other testing. If funding had been available, and the project was conducted as an independent test program with a complete set of tests, the cost would likely have increased tenfold.

Instead, limited data and observations were collected, with the hope that the results would give an overall sense of the fluid failure sensor's ability to replicate the visual determination of fluid failure.

### 1.3 Report Format

The remainder of this report is organized into the following sections:

- a) Section 2 (Methodology) presents the procedure and methods used to conduct the tests;
- b) Section 3 (Data Collected) presents the data collected including number of tests conducted by precipitation condition and fluid type;
- c) Section 4 (Analysis) provides an analysis of the data, and of the ability of the IDES to replicate visual determination of fluid failure;
- d) Section 5 (Conclusions) provides conclusions from 2003-04 testing; and
- e) Section 6 (Recommendations) provides recommendations for future testing.

## 2. METHODOLOGY

The procedure, equipment, training, fluids, personnel and test locations involved in conducting tests with the IDES are outlined in this section.

### 2.1 Procedure

The procedure used to conduct tests with the IDES was the standard endurance time testing procedure with several additional requirements added. These requirements are described in Subsections 2.1.1 to 2.1.3.

The test procedure is included in Appendix B.

#### 2.1.1 Test Plates

The first requirement added was for tests to be conducted on standard endurance time test plates equipped with IDES sensors. Two test plates, each equipped with two sensors, were provided by Intertechnique.

#### 2.1.2 Equipment Monitoring

The second requirement added was monitoring of the IDES. The equipment was reset at the beginning of each test, following a thorough cleaning of the test plates. The computer equipment was monitored throughout the tests to ensure that it was functional and was recording data. Whenever possible, the time the IDES detected fluid failure was recorded manually (it was also recorded automatically in the data files).

#### 2.1.3 Procedure for Determining Fluid Failure

Standard test protocol dictates that fluid failure be recorded when frozen precipitation is present on five crosshairs on a standard endurance time test plate. During the majority of snow tests, the human observer determined fluid failure using this protocol. However, during several tests in snow and all tests in simulated freezing precipitation (freezing fog, freezing drizzle and freezing rain), the procedure was changed to closer replicate the way the IDES detects fluid failure. The revised procedure required that the human observer record fluid failure when frozen precipitation was seen on each individual sensor. Therefore, two values were recorded for each test plate. This is discussed further in Subsection 3.2.2.

It should be noted that in the majority of tests, the individual determining fluid failure did not observe the IDES output during the test.

## 2.2 Equipment

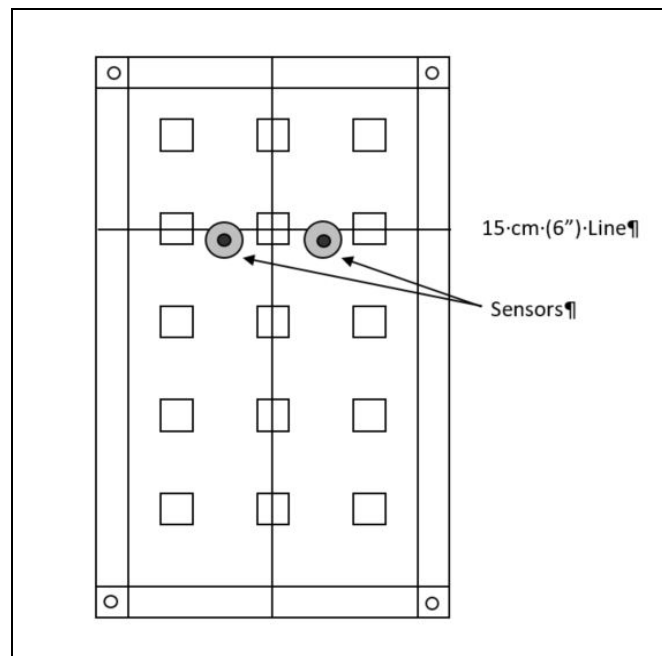
Along with standard endurance time test equipment, the specialized IDES equipment was required. This equipment was provided by Intertechnique.

### 2.2.1 IDES Components

The IDES has four components:

1. Ice detectors (seen installed in test plates in Figure 2.1 and Photo 2.1);
2. Display unit (see Photo 2.2);
3. Control unit (see Photo 2.3); and
4. Laptop computer with IDES software (see Photo 2.3).

It should be noted that the ice detectors are normally installed on aircraft and were installed on test plates only to meet the objectives of this test program.



**Figure 2.1: Standard Test Plate Equipped with IDES Sensors**



### 2.2.2 IDES Operating Principles

The IDES operates using ultrasonic technology. The system's patented technology uses acoustic impedance measurements to detect the presence of de/anti-icing fluids on its ice sensors. Below the surfaces of the sensors, there are transmitters and receivers. The transmitters send out signals, and depending on the condition of the surface (fluid or ice) a different signal will be reflected to the receiver. Based on the signals that are received and several other inputs, the system can determine if there is ice or fluid on the surface. If there is fluid on the surface, the IDES gives an indication of the fluid's condition.

One of the other system inputs is the fluid freeze point curve for the fluid being tested. Fluid freeze point curves for each test fluid were therefore required. These curves were obtained from the fluid manufacturers by Intertechnique. They will be discussed in more detail in Section 4.

Other IDES outputs include fluid dilution, fluid thickness and sensor/plate temperature.

### 2.2.3 IDES Software Versions

Two different versions of software were used during testing: Version 0 and Version 1. Version 0 was used for the first 26 tests. Following initial analysis of the results, Intertechnique provided an updated software package, Version 1, to APS. This package was installed on March 23, 2004, prior to Test 27 being conducted. All remaining tests were conducted using this software.

## 2.3 Personnel

Two individuals were required for testing. One individual set and monitored the IDES, prepared fluids and filled out the test session log. The second individual recorded fluid failure. A requirement of the procedure was that the individual recording fluid failure be an expert, as defined in TP 14156E (2):

*Expert: These individuals have comprehensive knowledge of fluid failure and extensive experience determining fluid failures.*

Two individuals classified as experts participated in the tests.

During snow testing, it was necessary to measure precipitation rates. During most test sessions, precipitation rates were already being measured for other projects and therefore it was not necessary to measure precipitation rates. However, when

precipitation rates were not being measured for other tests, the individual monitoring the IDES was also required to measure precipitation rates.

### 2.3.1 Training

Intertechnique provided training to APS researchers at a one day training session at the APS test site at Montreal – Pierre Elliot Trudeau International Airport. Intertechnique personnel were also present at the first test session to provide support and guidance.

## 2.4 Fluids

Kilfrost ABC-S, UCAR Ultra+, Octagon Max-Flight and Type I PG fluids were tested in all conditions. In addition, a non-certified Type II fluid, Kilfrost P1491, was added to the test plan for simulated freezing precipitation testing. The Type II and Type IV fluids were tested with varying viscosities, depending on the availability of samples. Neat, 75/25 and 50/50 dilutions of the Type II and Type IV fluids were tested. Type I fluids were always mixed to a 10° buffer for testing. Test fluid details are given in Table 2.1.

**Table 2.1: Test Fluids**

<b>Fluid</b>	<b>Fluid Type</b>	<b>Fluid Base</b>
Dow/UCAR Ultra +	Type IV	Ethylene-Glycol
Kilfrost ABC-S	Type IV	Propylene-Glycol
Kilfrost P1491 *	Type II	Propylene-Glycol
Octagon Max-Flight	Type IV	Propylene-Glycol
Various	Type I	Propylene-Glycol

\*This fluid is not certified

## 2.5 Test Locations

Tests were conducted in various winter precipitation conditions. Snow tests were conducted at the APS test site at Montreal – Pierre Elliot Trudeau International Airport. Simulated precipitation tests were conducted at the National Research Council Canada (NRC) Climatic Engineering Facility in Ottawa.

Photo 2.1: Test Plates Equipped with Ice Detection Sensors

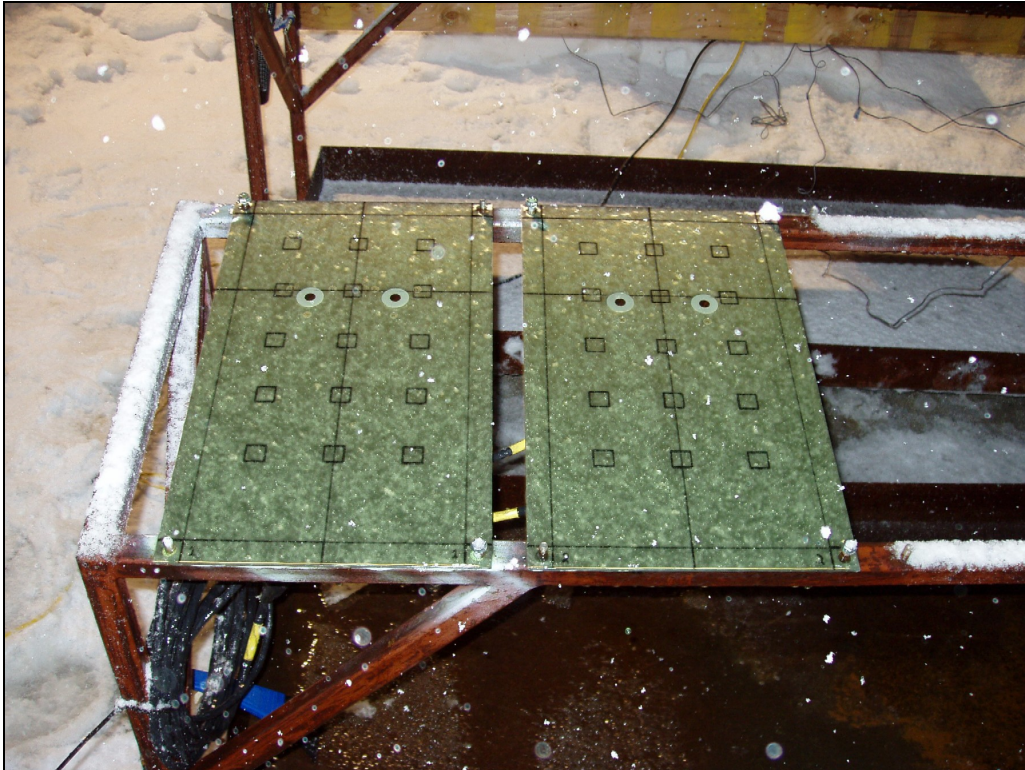


Photo 2.2: IDES Display Unit

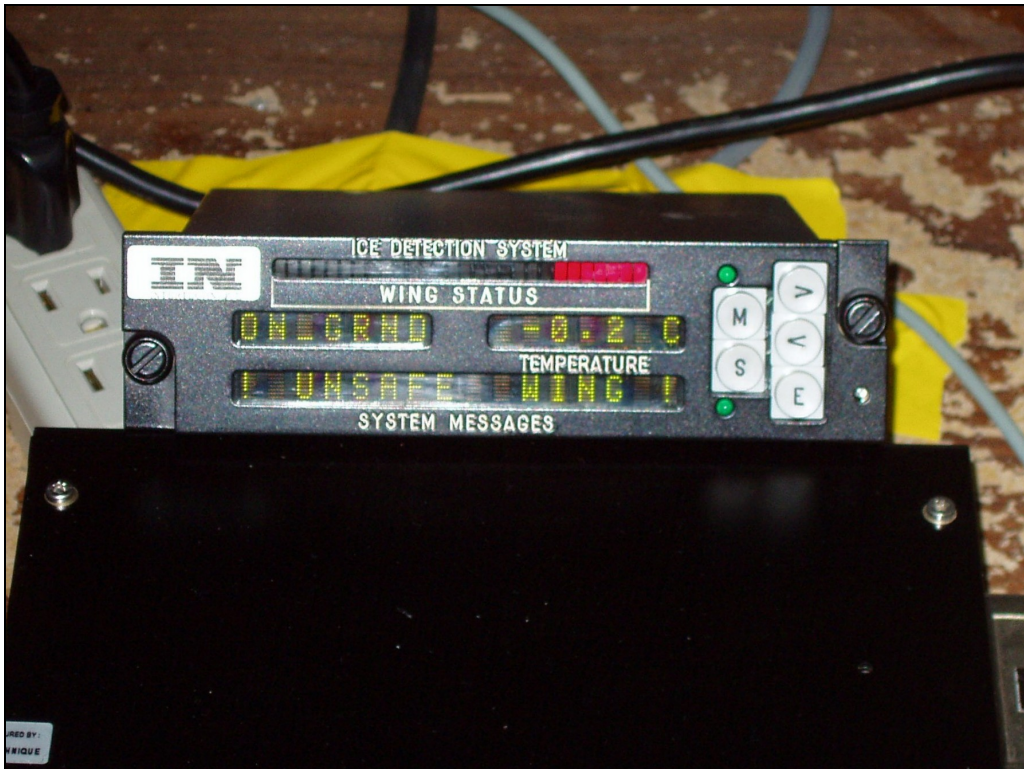


Photo 2.3: IDES Laptop Computer, Control Unit and Display Unit



### 3. DATA COLLECTED

The data collected is described in this section.

#### 3.1 Summary of Tests

The number of tests conducted by precipitation condition is shown in Table 3.1. The majority of tests were conducted in snow. The number of tests conducted by fluid type is shown in Table 3.2. The majority of tests were conducted with Type IV fluid.

**Table 3.1: Tests Conducted by Precipitation Condition**

Precipitation Type	Sensor Readings	Tests Conducted
Snow	60	30
Freezing Drizzle	14	7
Freezing Rain	16	8
Freezing Fog	18	9
<b>Total</b>	<b>108</b>	<b>54</b>

**Table 3.2: Tests Conducted by Fluid Type**

Fluid Type	Sensor Readings	Tests Conducted
Type I	16	8
Type II	16	8
Type IV	76	38
<b>Total</b>	<b>108</b>	<b>54</b>

#### 3.2 Log of Tests

The complete log of tests is included at the end of this chapter in Table 3.4.

##### 3.2.1 Test Parameters

The first eight columns give the test parameters as described in Table 3.3.

**Table 3.3: Test Parameters**

<b>Column Heading</b>	<b>Description</b>
Test #	Test number, numbered by precipitation type and date
Date	Date the test took place
Plate	All tests took place on either Plate A or Plate B
Precipitation Type	Natural snow or simulated freezing fog, freezing drizzle or freezing rain
Precipitation Rate	Rate of precipitation given in g/dm <sup>2</sup> /h
Temperature	Outside air temperature for snow tests, ambient air temperature for simulated precipitation tests. Given in degrees Celsius.
Fluid	Test fluid
Dilution	Test fluid dilution (concentrate/water)

### 3.2.2 Endurance Times

The ninth and tenth columns in the log give the visual and IDES endurance times measured. During initial testing in snow, one visual endurance time and two IDES endurance times were recorded for each test. Two IDES times were recorded because two sensors were installed on each plate and each sensor recorded fluid failure independently.

However, as described in Subsection 2.1.3, this procedure was changed for several snow tests and for simulated precipitation testing. During these tests, two visual endurance times and two IDES endurance times were measured for each test. Visual endurance times were recorded individually for each sensor, which produced two measurements for each test.

These differences can be seen in the log of tests. There are two entries (rows) for each test in the log – one for each sensor. In tests where only one visual endurance time was recorded, the visual endurance time cells have been merged and one number appears for both test entries.

As described in Subsection 2.2.3, the first 26 tests were conducted using Version 0 of the software. However, the IDES endurance times in these tests were later recalculated using software Version 1. The log of tests given in this chapter includes the Version 1 values, and not the earlier Version 0 values. For comparison

purposes, the Version 0 and Version 1 endurance times for the first 26 tests are included in Appendix C.

### 3.2.3 Visual – IDES Difference

The eleventh column shows the difference between the visual and IDES endurance times. This difference was calculated using the following formula:

$$\text{Difference} = \frac{\text{IDES Endurance Time} - \text{Visual Endurance Time}}{\text{Visual Endurance Time}}$$

Negative values indicate that the IDES detected fluid failure sooner than the human observer, and positive values indicate that the IDES detected fluid failure later than the human observer.

### 3.2.4 Test Values

The last column shows the test value, which is the value used in the analysis presented in Section 4. These values were calculated differently depending on the number of visual endurance times recorded for each test.

For tests in which two visual endurance times were recorded, the difference between the visual and IDES endurance times for each individual sensor is included as the test value (see calculation in Subsection 3.2.3).

For tests in which only one visual endurance time was recorded, the difference between the visual endurance time and the IDES endurance time for the sensor that detected ice first was used. For example, in Test 1 the visual endurance time was 61 minutes, one sensor endurance time was 53 minutes and one sensor endurance time was 54 minutes. The difference between 53 minutes and 61 minutes was taken as the test value.

Thus, for tests with two visual endurance times, two test values were generated, but for tests with one visual endurance time, only one test value was generated. In total 82 test values were used in the analysis.

3. DATA COLLECTED

Table 3.4: Log of Tests

Test #	Date	Precipitation		Temp. (°C)	Plate	Fluid	Dilution	Endurance Time			Test Value
		Type	Rate (g/dm <sup>2</sup> /h)					Visual (min)	IDES (min)	Diff.	
1	4-Feb-04	Snow	17.0	-0.3	A	UCAR Ultra +	Neat	60	55	-8%	-8%
1	4-Feb-04	Snow	17.0	-0.3	A	UCAR Ultra +	Neat		FND*	n/a	
2	4-Feb-04	Snow	17.0	-0.3	B	UCAR Ultra +	Neat	61	53	-13%	-13%
2	4-Feb-04	Snow	17.0	-0.3	B	UCAR Ultra +	Neat		54	-11%	
3	4-Feb-04	Snow	28.2	-1.0	A	Octagon Max-Flight	Neat	49	42	-15%	-21%
3	4-Feb-04	Snow	28.2	-1.0	A	Octagon Max-Flight	Neat		38	-21%	
4	4-Feb-04	Snow	28.2	-1.0	B	Octagon Max-Flight	Neat	49	43	-11%	-17%
4	4-Feb-04	Snow	28.2	-1.0	B	Octagon Max-Flight	Neat		41	-17%	
5	4-Feb-04	Snow	31.1	-1.1	A	Octagon Max-Flight	75/25	17	16	-7%	-8%
5	4-Feb-04	Snow	31.1	-1.1	A	Octagon Max-Flight	75/25		15	-8%	
6	4-Feb-04	Snow	31.1	-1.1	B	Octagon Max-Flight	75/25	16	17	1%	1%
6	4-Feb-04	Snow	31.1	-1.1	B	Octagon Max-Flight	75/25		17	2%	
7	4-Feb-04	Snow	75.7	-1.2	A	Kilfrost ABC-S	Neat	10	10	1%	1%
7	4-Feb-04	Snow	75.7	-1.2	A	Kilfrost ABC-S	Neat		10	6%	
8	4-Feb-04	Snow	75.7	-1.2	B	Kilfrost ABC-S	Neat	11	11	1%	1%
8	4-Feb-04	Snow	75.7	-1.2	B	Kilfrost ABC-S	Neat		13	19%	
9	4-Feb-04	Snow	68.5	-1.5	A	Kilfrost ABC-S	75/25	7	7	0%	0%
9	4-Feb-04	Snow	68.5	-1.5	A	Kilfrost ABC-S	75/25		8	15%	
10	4-Feb-04	Snow	68.5	-1.5	B	Kilfrost ABC-S	75/25	8	8	11%	-6%
10	4-Feb-04	Snow	68.5	-1.5	B	Kilfrost ABC-S	75/25		7	-6%	
11	4-Feb-04	Snow	34.6	-1.6	A	Type I PG	10° Buffer	3	4	43%	43%
11	4-Feb-04	Snow	34.6	-1.6	A	Type I PG	10° Buffer		4	50%	
12	4-Feb-04	Snow	34.6	-1.6	B	Type I PG	10° Buffer	3	4	61%	61%
12	4-Feb-04	Snow	34.6	-1.6	B	Type I PG	10° Buffer		5	65%	
13	4-Feb-04	Snow	31.6	-1.5	A	Octagon Max-Flight	50/50	9	8	-2%	-5%
13	4-Feb-04	Snow	31.6	-1.5	A	Octagon Max-Flight	50/50		8	-5%	
14	4-Feb-04	Snow	31.6	-1.5	B	Octagon Max-Flight	50/50	8	7	-10%	-16%
14	4-Feb-04	Snow	31.6	-1.5	B	Octagon Max-Flight	50/50		7	-16%	
15	4-Feb-04	Snow	25.4	-1.6	A	Kilfrost ABC-S	50/50	5	4	-15%	-15%
15	4-Feb-04	Snow	25.4	-1.6	A	Kilfrost ABC-S	50/50		7	43%	
16	4-Feb-04	Snow	25.4	-1.6	B	Kilfrost ABC-S	50/50	5	8	79%	79%
16	4-Feb-04	Snow	25.4	-1.6	B	Kilfrost ABC-S	50/50		14	202%	
17	6-Feb-04	Snow	17.7	-10.2	A	UCAR ULTRA +	Neat	57	57	0%	-4%
17	6-Feb-04	Snow	17.7	-10.2	A	UCAR ULTRA +	Neat		54	-4%	
18	6-Feb-04	Snow	17.7	-10.2	B	UCAR ULTRA +	Neat	60	57	-5%	-13%
18	6-Feb-04	Snow	17.7	-10.2	B	UCAR ULTRA +	Neat		53	-13%	
19	6-Feb-04	Snow	28.8	-9.8	A	Octagon Max-Flight	Neat	42	24	-42%	-42%
19	6-Feb-04	Snow	28.8	-9.8	A	Octagon Max-Flight	Neat		32	-24%	



3. DATA COLLECTED

Table 3.4: Log of Tests (cont'd)

Test #	Date	Precipitation		Temp. (°C)	Plate	Fluid	Dilution	Endurance Time			Test Value
		Type	Rate (g/dm <sup>2</sup> /h)					Visual (min)	IDES (min)	Diff.	
20	6-Feb-04	Snow	28.8	-9.8	B	Octagon Max-Flight	Neat	42	35	-17%	-18%
20	6-Feb-04	Snow	28.8	-9.8	B	Octagon Max-Flight	Neat		34	-18%	
21	6-Feb-04	Snow	20.8	-10.0	A	Kilfrost ABC-S	Neat	37	32	-13%	-18%
21	6-Feb-04	Snow	20.8	-10.0	A	Kilfrost ABC-S	Neat		30	-18%	
22	6-Feb-04	Snow	20.8	-10.0	B	Kilfrost ABC-S	Neat	36	34	-6%	-8%
22	6-Feb-04	Snow	20.8	-10.0	B	Kilfrost ABC-S	Neat		33	-8%	
23	6-Feb-04	Snow	6.6	-8.8	A	Octagon Max-Flight	75/25	110	68	-38%	-39%
23	6-Feb-04	Snow	6.6	-8.8	A	Octagon Max-Flight	75/25		68	-39%	
24	6-Feb-04	Snow	6.6	-8.8	B	Octagon Max-Flight	75/25	102	79	-22%	-38%
24	6-Feb-04	Snow	6.6	-8.8	B	Octagon Max-Flight	75/25		63	-38%	
25	23-Mar-04	Snow	6.0	-8.5	A	Kilfrost ABC-S	75/25	59	35	-42%	-42%
25	23-Mar-04	Snow	6.0	-8.5	A	Kilfrost ABC-S	75/25	41	23	-45%	-45%
26	23-Mar-04	Snow	6.0	-8.5	B	Kilfrost ABC-S	75/25	67	39	-42%	-42%
26	23-Mar-04	Snow	6.0	-8.5	B	Kilfrost ABC-S	75/25	67	37	-45%	-45%
27	23-Mar-04	Snow	73.6	-0.3	A	UCAR ULTRA +	Neat	14	16	15%	15%
27	23-Mar-04	Snow	73.6	-0.3	A	UCAR ULTRA +	Neat		16	17%	
28	23-Mar-04	Snow	73.6	-0.3	B	UCAR ULTRA +	Neat	15	16	5%	5%
28	23-Mar-04	Snow	73.6	-0.3	B	UCAR ULTRA +	Neat		16	6%	
29	4-Apr-04	Snow	3.4	-2.2	A	Kilfrost ABC-S	Neat	169	162	-5%	-5%
29	4-Apr-04	Snow	3.4	-2.2	A	Kilfrost ABC-S	Neat	175	167	-5%	-5%
30	4-Apr-04	Snow	3.4	-2.2	B	Kilfrost ABC-S	Neat	171	166	-3%	-3%
30	4-Apr-04	Snow	3.4	-2.2	B	Kilfrost ABC-S	Neat	170	161	-5%	-5%
31	19-Apr-04	Freezing Rain	25.0	-3.0	A	UCAR ULTRA +	Neat	43	39	-9%	-9%
31	19-Apr-04	Freezing Rain	25.0	-3.0	A	UCAR ULTRA +	Neat	41	34	-16%	-16%
32	19-Apr-04	Freezing Rain	25.0	-3.0	B	UCAR ULTRA +	Neat	43	36	-16%	-16%
32	19-Apr-04	Freezing Rain	25.0	-3.0	B	UCAR ULTRA +	Neat	42	34	-19%	-19%
33	20-Apr-04	Freezing Rain	13.0	-3.0	A	Kilfrost P1491	50/50	12	9	-24%	-24%
33	20-Apr-04	Freezing Rain	13.0	-3.0	A	Kilfrost P1491	50/50	12	9	-29%	-29%
34	20-Apr-04	Freezing Rain	13.0	-3.0	B	Kilfrost P1491	75/25	22	19	-16%	-16%
34	20-Apr-04	Freezing Rain	13.0	-3.0	B	Kilfrost P1491	75/25	24	18	-25%	-25%
39	20-Apr-04	Freezing Drizzle	13.0	-3.0	A	Octagon Max-Flight	50/50	26	19	-28%	-28%
39	20-Apr-04	Freezing Drizzle	13.0	-3.0	A	Octagon Max-Flight	50/50	24	16	-35%	-35%
35	21-Apr-04	Freezing Rain	25.0	-10.0	A	Octagon Max-Flight	75/25	28	27	-3%	-3%
35	21-Apr-04	Freezing Rain	25.0	-10.0	A	Octagon Max-Flight	75/25	28	26	-7%	-7%
36	21-Apr-04	Freezing Rain	25.0	-10.0	B	Octagon Max-Flight	Neat	12	FND*	n/a	n/a
36	21-Apr-04	Freezing Rain	25.0	-10.0	B	Octagon Max-Flight	Neat	12	FND*	n/a	n/a
37	21-Apr-04	Freezing Rain	13.0	-10.0	A	Type I PG	10° Buffer	7	13	75%	75%
37	21-Apr-04	Freezing Rain	13.0	-10.0	A	Type I PG	10° Buffer	7	13	90%	90%

3. DATA COLLECTED

Table 3.4: Log of Tests (cont'd)

Test #	Date	Precipitation		Temp (°C)	Plate	Fluid	Dilution	Endurance Time			Test Value
		Type	Rate (g/dm <sup>2</sup> /h)					Visual (min)	IDES (min)	Diff.	
38	21-Apr-04	Freezing Rain	13.0	-10.0	B	Type I PG	10° Buffer	7	13	95%	95%
38	21-Apr-04	Freezing Rain	13.0	-10.0	B	Type I PG	10° Buffer	7	14	109%	109%
40	21-Apr-04	Freezing Drizzle	13.0	-10.0	A	UCAR ULTRA +	Neat	48	40	-16%	-16%
40	21-Apr-04	Freezing Drizzle	13.0	-10.0	A	UCAR ULTRA +	Neat	48	38	-20%	-20%
41	21-Apr-04	Freezing Drizzle	13.0	-10.0	B	UCAR ULTRA +	Neat	47	49	5%	5%
41	21-Apr-04	Freezing Drizzle	13.0	-10.0	B	UCAR ULTRA +	Neat	47	37	-21%	-21%
42	21-Apr-04	Freezing Drizzle	5.0	-10.0	A	Kilfrost P1491	Neat	35	23	-34%	-34%
42	21-Apr-04	Freezing Drizzle	5.0	-10.0	A	Kilfrost P1491	Neat	35	23	-35%	-35%
43	21-Apr-04	Freezing Drizzle	5.0	-10.0	B	Kilfrost P1491	75/25	29	18	-37%	-37%
43	21-Apr-04	Freezing Drizzle	5.0	-10.0	B	Kilfrost P1491	75/25	29	17	-41%	-41%
44	20-Apr-04	Freezing Drizzle	5.0	-3.0	A	Type I PG	10° Buffer	27	33	24%	24%
44	20-Apr-04	Freezing Drizzle	5.0	-3.0	A	Type I PG	10° Buffer	26	34	30%	30%
45	20-Apr-04	Freezing Drizzle	5.0	-3.0	B	Type I PG	10° Buffer	28	FND*	n/a	n/a
45	20-Apr-04	Freezing Drizzle	5.0	-3.0	B	Type I PG	10° Buffer	34	FND*	n/a	n/a
46	22-Apr-04	Freezing Fog	5.0	-25.0	A	Octagon Max-Flight	Neat	27	3	-90%	-90%
46	22-Apr-04	Freezing Fog	5.0	-25.0	A	Octagon Max-Flight	Neat	27	3	-90%	-90%
47	22-Apr-04	Freezing Fog	5.0	-25.0	B	Octagon Max-Flight	Neat	27	3	-90%	-90%
47	22-Apr-04	Freezing Fog	5.0	-25.0	B	Octagon Max-Flight	Neat	27	3	-90%	-90%
48	22-Apr-04	Freezing Fog	2.0	-25.0	A	Kilfrost P1491	Neat	40	11	-73%	-73%
48	22-Apr-04	Freezing Fog	2.0	-25.0	A	Kilfrost P1491	Neat	40	10	-76%	-76%
49	22-Apr-04	Freezing Fog	2.0	-25.0	B	Kilfrost P1491	Neat	39	10	-73%	-73%
49	22-Apr-04	Freezing Fog	2.0	-25.0	B	Kilfrost P1491	Neat	39	8	-79%	-79%
50	22-Apr-04	Freezing Fog	2.0	-14.0	A	Kilfrost P1491	Neat	24	14	-42%	-42%
50	22-Apr-04	Freezing Fog	2.0	-14.0	A	Kilfrost P1491	Neat	24	14	-42%	-42%
51	22-Apr-04	Freezing Fog	2.0	-14.0	B	Kilfrost P1491	75/25	29	15	-46%	-46%
51	22-Apr-04	Freezing Fog	2.0	-14.0	B	Kilfrost P1491	75/25	29	15	-46%	-46%
52	19-Apr-04	Freezing Fog	5.0	-3.0	B	Octagon Max-Flight	50/50	62	52	-16%	-16%
52	19-Apr-04	Freezing Fog	5.0	-3.0	B	Octagon Max-Flight	50/50	56	44	-21%	-21%
53	19-Apr-04	Freezing Fog	2.0	-3.0	A	Type I PG	10° Buffer	25	FND*	n/a	n/a
53	19-Apr-04	Freezing Fog	2.0	-3.0	A	Type I PG	10° Buffer	25	FND*	n/a	n/a
54	19-Apr-04	Freezing Fog	2.0	-3.0	B	Type I PG	10° Buffer	24	FND*	n/a	n/a
54	19-Apr-04	Freezing Fog	2.0	-3.0	B	Type I PG	10° Buffer	24	FND*	n/a	n/a

\*FND = Failure not detected

## 4. ANALYSIS

The ability of the IDES to replicate visual determination of fluid failure is examined in this section.

### 4.1 Preface

As discussed in the introduction, the number of tests conducted was determined in part by available funding. As funding was limited, fewer tests were conducted than would be required for a complete and thorough analysis. The data has been analysed by precipitation condition, fluid type/dilution and temperature; however, only general conclusions can be made from this analysis. The complete data set is given in Table 3.4 and can be used for future reference and/or analysis.

### 4.2 Comparison of IDES and Visual Endurance Times

If the IDES were able to replicate visual endurance time determination, the difference between the IDES and visual endurance times should be less than 10 percent for each test. This value has previously been established as the amount of variance expected between tests when the same individual runs the tests with the same fluid in the same conditions.

In this limited series of tests, 23 percent of the IDES endurance times were within 10 percent of the visual endurance time. 40 percent were within 20 percent of the visual endurance time.

Figure 4.1 shows the test values generated in snow. 44 percent of IDES endurance times were within 10 percent of the visual endurance time and 68 percent were within 20 percent. The average absolute difference between the IDES and visual endurance times was 20 percent.

Figure 4.2 shows the test values generated in simulated precipitation. 8 percent of IDES endurance times were within 10 percent of the visual endurance time and 21 percent were within 20 percent. The average absolute difference between the IDES and visual endurance times was 43 percent.

Although there is a significant difference between snow and simulated precipitation results, this difference may be caused by the method by which test values were included in the analysis (see Subsection 3.2.4).

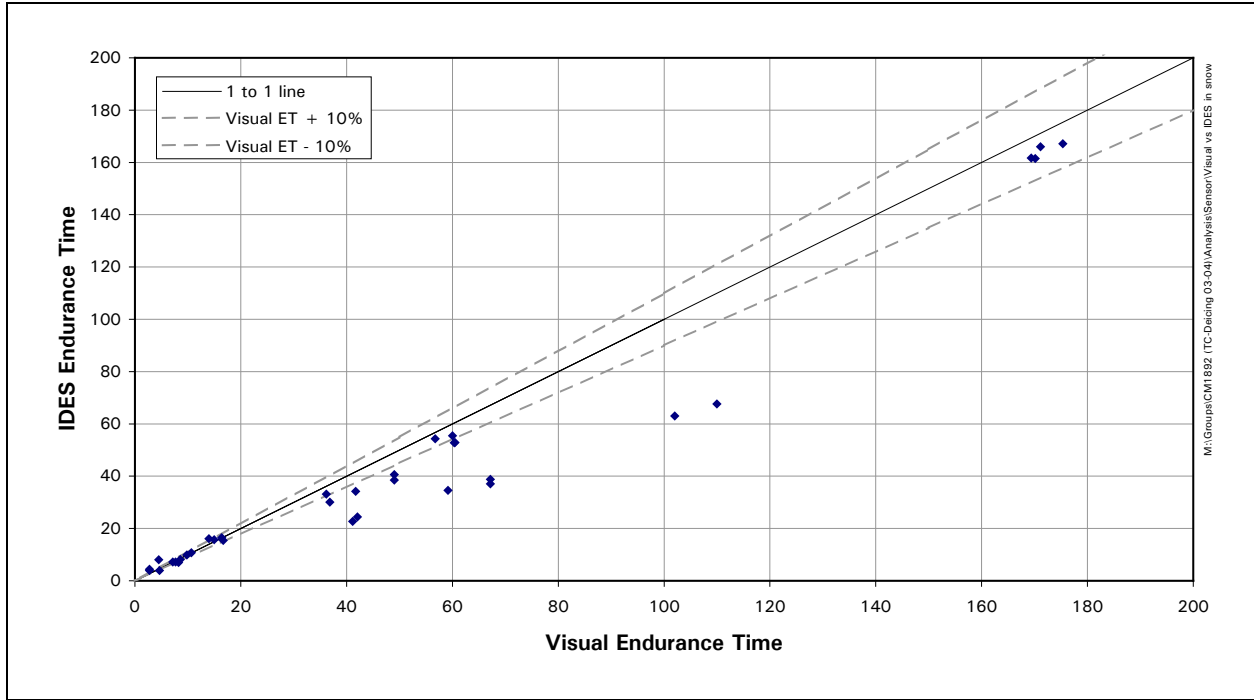


Figure 4.1: Sensor vs. Visual Endurance Times in Snow

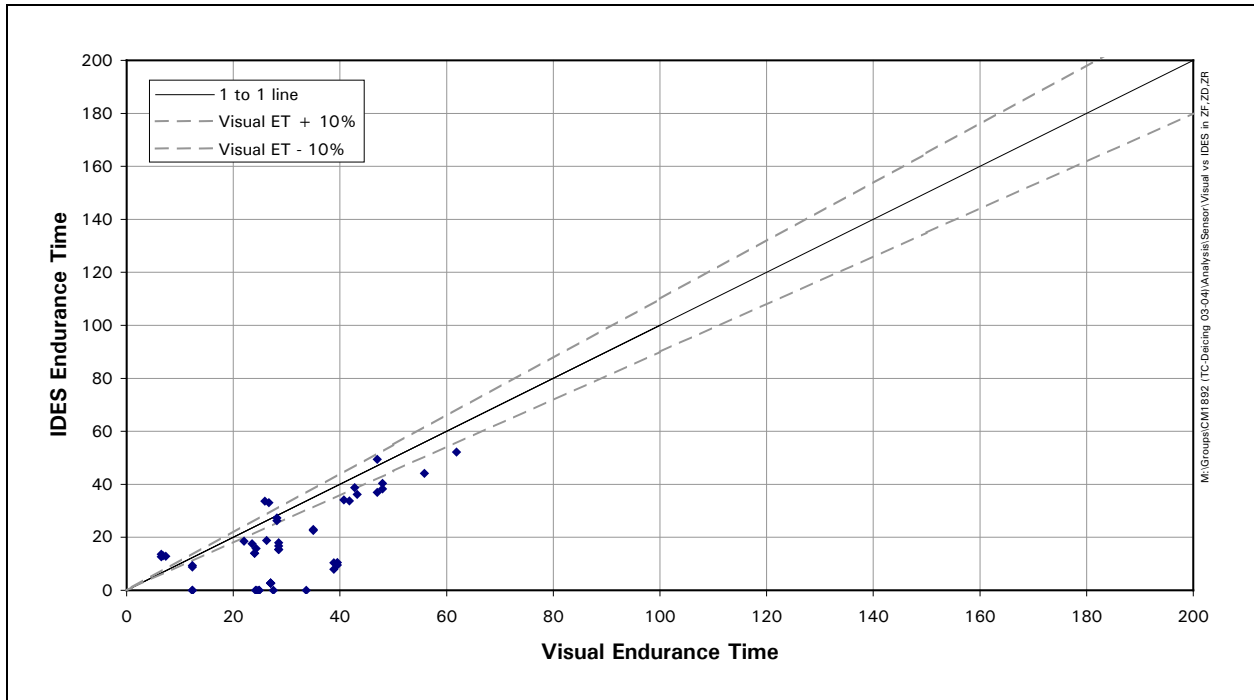


Figure 4.2: Sensor vs. Visual Endurance Times in Simulated Precipitation

### 4.3 Type I Fluid

The IDES had difficulty detecting failure in a significant number of tests with Type I fluids. In three of the eight tests conducted with Type I fluid, the IDES did not detect fluid failure. All of these tests were conducted in simulated precipitation (freezing drizzle, freezing fog) at  $-3^{\circ}\text{C}$ . The difficulty the IDES had with Type I fluids is likely a result of the IDES' mechanisms for detecting fluid failure.

The IDES uses two different mechanisms for detecting fluid failure (descriptions provided by the manufacturer).

1. Fluid Failure: When a fluid layer with or without the presence of frozen elements is covering the sensor and the freezing point of that fluid has reached or is greater than the plate temperature and the plate temperature is lower than  $0.5^{\circ}\text{C}$ , fluid failure is detected.
2. Frozen Adhering Contamination: When the IDES has detected the presence of frozen adhering contamination, fluid failure is detected. To identify frozen contamination, typically ice, the system may need a minimal thickness varying from approximately 0.1 mm to 0.2 mm depending on the contaminant structure.

Type I fluids are significantly thinner than other fluids, which causes difficulties for both failure detection mechanisms used by the IDES. First, when Type I fluids freeze, the ice is initially too thin for the IDES to detect frozen adhering contamination. Second, the IDES cannot measure the freezing point of the fluid when the fluid is less than 0.1 mm thick and therefore the difference between the fluid freezing point and the plate temperature cannot be used to detect fluid failure until the ice thickness has reach 0.15 mm. This appears to explain the significant number of fluid failures not detected with Type I fluids.

Because the results with Type I fluids were so varied, the Type I tests were removed from the analysis of results by test parameters presented in the next section.

### 4.4 Influence of Test Parameters

#### 4.4.1 Precipitation Type

The Type II and Type IV test values are shown by precipitation type in Figure 4.3. From left to right, snow, freezing rain, freezing drizzle and freezing fog results are shown.



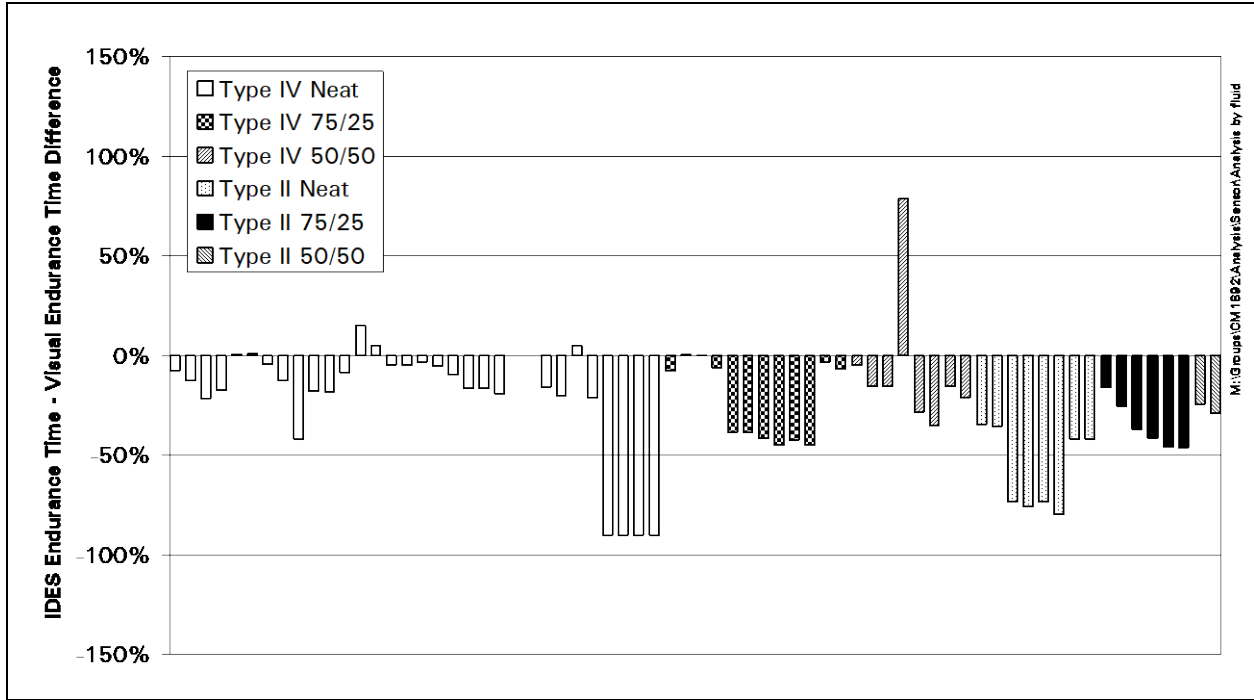


Figure 4.4: Type II/IV Results by Fluid Type/Dilution

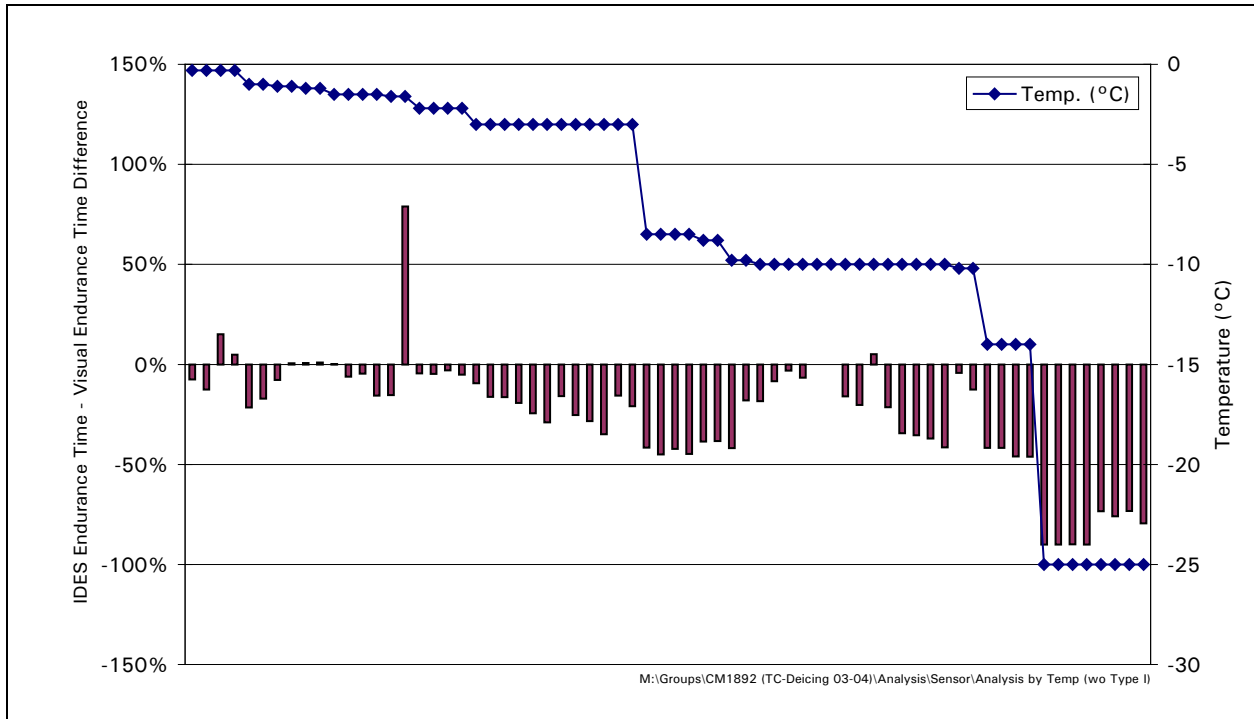


Figure 4.5: Type II/IV Results by Temperature

## 4.5 Tests with Failure Not Detected

In four of the fifty-four tests, the IDES did not detect fluid failure. Three of the four tests were with Type I fluid (Tests 45, 53 and 54). These results were discussed in Subsection 4.3.

The fourth test when the IDES did not detect fluid failure was Test 36. The test took place in freezing rain at  $-10^{\circ}\text{C}$  with Octagon Max-Flight. Based on visual observations, it appears this error occurred because ice was floating on top of the fluid. In other words, a layer of ice formed on top of the fluid while undiluted fluid remained underneath. The system is not able to detect contamination that lies on top of a significant layer of undiluted fluid.

In addition, during Test 1, one of the sensors did not detect fluid failure (the other did). The test took place in snow with UCAR Ultra+. During this test, the same fluid was poured simultaneously on two plates. One of the four sensors did not detect fluid failure. It is not clear why this occurred.

## 4.6 Fluid Freeze Point Curves

For the IDES to work properly, fluid freeze point curves accurate for any temperature and fluid dilution are required. If the curves are not precise at every temperature, it can have a significant impact on the test results. In other words, this variable may be responsible for some or all of the variance in the test results. This is significant.

## 4.7 Application of Test Results

To put into perspective the effect of replacing a human observer with the current IDES in endurance time testing, the following example is given. Results from Tests 27 and 2 will be used. In Test 27 the IDES measured an endurance time of 16 minutes, compared to 14 minutes recorded by the human observer, giving a 15 percent *longer* endurance time. In Test 2, which used the same fluid (UCAR Ultra+ neat), the IDES measured an endurance time of 53 minutes, 8 minutes less than the endurance time measured by the human observer. This gives a 13 percent *shorter* endurance time. As can be seen by these two tests, replacing a human observer with the IDES in its current stage of development would lead to significant variance in the endurance times measured during holdover time table development.



## 4.8 IDES Ability to Detect Ice vs. Replicate Human Observers

Although a significant amount of variance was observed between the endurance times measured by the IDES and human observer, the possibility that some of this variance is the result of the inability of the human observer to properly detect ice should be mentioned. In fact, it is possible that in some cases, the IDES more accurately measured a fluid's ability to offer ice protection. One possible scenario is that a layer of ice forms on the top of the fluid, but a thick layer of uncontaminated fluid remains between the ice and the plate. The human observer would determine the fluid had failed, but the IDES could accurately indicate that the fluid still offers protection from frozen adhered contamination.

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## 5. CONCLUSIONS

Several conclusions can be drawn from the limited tests conducted.

- a) The IDES is currently not able to replicate a visual determination of failure. This may be partially a result of its inability to replicate a human observation, rather than its inability to detect ice. In fact, it is possible that in some cases the IDES more accurately measured a fluid's ability to offer ice protection.
- b) The IDES consistently measured endurance times shorter than those measured by the human observer.
- c) The following relationships were seen between the IDES and test parameters:
  - Due to the methods the IDES uses to detect failure, it is better able to detect fluid failure with Type II and Type IV fluids than with Type I fluids;
  - The IDES was better able to replicate visual endurance in warmer temperatures than in colder temperatures; and
  - No significant relationship was found between the IDES ability to replicate visual endurance times and precipitation type or Type II/IV fluid type and dilution.
- d) As technology is currently not at a stage of development to be used in endurance time testing, at this time the best way to obtain consistent results during endurance time testing is to develop an intense training program.

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## 6. RECOMMENDATIONS

The following recommendations are made as a result of this research.

- a) If the IDES manufacturer can adapt the system to better replicate the human eye, it is recommended that the system be tested again in the winter of 2004-05 in all precipitation conditions. If possible, Intertechnique should be present at the simulated precipitation test session.
- b) The most accurate fluid freeze point curves possible should be used. This may require the conduct of freeze point tests to build new curves instead of relying on the curves provided by the fluid manufacturers.
- c) If the system replaces the human observer, each test plate should be equipped with fifteen sensors (one at each crosshair) and the computer programmed to recognize fluid failure has occurred when ice has been detected on any five of the fifteen crosshairs.
- d) While this technology is being further developed, effort still must be made to reduce variance in endurance times caused by variance in visual determinations of fluid failure. It is therefore recommended that an intense training program be put into place to increase the number of individuals who are considered "experts" at determining fluid failures. A reference fluid with known endurance times could be used during test sessions to illustrate the appearance of fluid failure while training individuals. The same fluid could later be used as a benchmark when new "experts" later conduct tests.

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## REFERENCES

1. Campbell, R, Chaput, M., *Aircraft Ground De/Anti-Icing Fluid Holdover Time and Endurance Time Testing Program for the 2001-02 Winter*, APS Aviation Inc., Transportation Development Centre, Montreal, December 2002, TP 13991E, XX (to be published).
2. Bendickson, S., *Variance in Endurance Times of De/Anti-Icing Fluids*, APS Aviation Inc., Transportation Development Centre, Montreal, December 2003, TP 14156E, 38.

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**APPENDIX A**

**TRANSPORTATION DEVELOPMENT CENTRE  
WORK STATEMENT EXCERPT –  
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2003-05**



**TRANSPORTATION DEVELOPMENT CENTRE  
WORK STATEMENT EXCERPT –  
AIRCRAFT & ANTI-ICING FLUID WINTER TESTING 2003-05**

**5.12 Minimizing Variance in HOT - Using Sensor Technology**

- a) Acquire an Intertechnique sensor or use the currently owned Allied Signal sensor and make it operational for testing;
- b) Collect data in various conditions, outdoor at the APS test site and indoor at the NRC facility;
- c) Analyze data and compare the sensor's ability to determine fluid failure relative to the ability of human failure determinations; and
- d) Prepare a report.

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## **APPENDIX B**

### **EXPERIMENTAL PROCEDURE – COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL**



CM1892.001

**EXPERIMENTAL PROCEDURE  
COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR  
AND BY TRAINED PERSONNEL**

Winter 2003-04

Prepared for

**Transportation Development Centre  
Transport Canada**

Prepared by: Stephanie Bendickson



Reviewed by: John D'Avirro



March 4, 2004  
Version 1.0

## EXPERIMENTAL PROCEDURE COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL

Winter 2003-04

### 1. BACKGROUND

In the winter of 2002-03, tests were conducted to evaluate the influence of level of training, knowledge and experience on the ability to determine fluid failures. Results showed a significant amount of variance in the endurance times measured by intermediate and novice individuals. It was concluded there are two ways of obtaining consistent results during holdover time testing: to use the same experienced individual to conduct tests and alternately, to develop technology to detect fluid failures.

Over the past decade several companies have developed technology in this area. However, none have been developed to the level required by the industry. Intertechnique has offered their Ice Detection Evaluation System (IDES) to Transport Canada for test purposes. On behalf of Transport Canada, APS will test the IDES this winter.

### 2. OBJECTIVES

The objective of these tests is to evaluate if the IDES measures endurance times similar to those measured by experienced individuals. If it does it may initiate the implementation of technology to standardize the fluid failure call.

### 3. PROCEDURE

Standard endurance time tests will be run on test plates equipped with sensors. Two test plates, each equipped with two sensors, will be used. The procedure is as follows:

1. Synchronize PC clock with test clocks;
2. Prior to pouring fluids, restart display unit by selecting "system restart" from the maintenance menu;
3. Select test fluid by scrolling through the select fluid menu. Select "generic PG fluid" if test fluid is not Kilfrost ABC-S, UCAR Ultra+ or Octagon Max-Flight;



COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL

4. Start long-term data recording by selecting data recording and holding the selection button for several seconds. When prompted select "yes" to start recording;
5. Pour fluids. The same fluid brand must be applied at the same time to both plates;
6. When one of the four sensors indicates "unsafe wing" record this time on the data form for the correct plate. Monitor the remaining sensors and record when one of them indicates failure on the second plate;
7. Several minutes after both the human failure call and the sensor failure call have been made, stop data recording by selecting "yes" in the data recording menu when prompted to stop data recording;
8. Repeat steps 2 to 6 for each test; and
9. At end of test session download data files to discs.

#### 4. FLUIDS

UCAR Ultra +, Octagon Max-Flight, Kilfrost ABC-S, and a Type I PG fluid will be tested. Additional fluids may be added to the test plan if they become available.

#### 5. PERSONNEL

Two individuals are required for these tests. One individual will be responsible for setting and monitoring the IDES computer, preparing fluids and recording when the sensor indicates fluid failure. The second individual will be responsible for determining and recording fluid failure as per standard holdover time testing procedure.

If precipitation rates are not being measured simultaneously for other projects, the first individual will be required to measure precipitation rates.

#### 6. TEST PLAN

Tests will be conducted in various winter precipitation conditions. Natural snow tests will be conducted at the APS test site at Montreal – Pierre Elliot Trudeau International Airport. A session test plan for these tests is shown in Table 1. Simulated precipitation tests will be conducted at the National Research Centre Climatic Engineering Facility in Ottawa. A test plan for simulated precipitation tests will be included in the procedure *Overall Test Program at NRC 2003-04*. It is anticipated that a minimum of six test sessions will take place: three in

**COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL**

natural snow and three in simulated precipitation conditions.

The goal for each test session is to complete all tests in the session test plan; however this will be constrained by weather conditions and all tests may not be conducted.

**Table 1: Session Test Plan**

Test #	Run #	Plate	Fluid	Dilution	Notes
1	1	A	UCAR Ultra +	100/0	
2	1	B	UCAR Ultra +	100/0	
3	2	A	Octagon Max Flight	100/0	
4	2	B	Octagon Max Flight	100/0	
5	3	A	Octagon Max Flight	75/25	If OAT is above -14°C
6	3	B	Octagon Max Flight	75/25	If OAT is above -14°C
7	4	A	Octagon Max Flight	50/50	If OAT is above -3°C
8	4	B	Octagon Max Flight	50/50	If OAT is above -3°C
9	5	A	Kilfrost ABC-S	100/0	
10	5	B	Kilfrost ABC-S	100/0	
11	6	A	Kilfrost ABC-S	75/25	If OAT is above -14°C
12	6	B	Kilfrost ABC-S	75/25	If OAT is above -14°C
13	7	A	Kilfrost ABC-S	50/50	If OAT is above -3°C
14	7	B	Kilfrost ABC-S	50/50	If OAT is above -3°C
15	8	A	Type I	10°C buffer	
16	8	B	Type I	10°C buffer	

**7. EQUIPMENT**

Table 2 lists the equipment required.

**Table 2: Equipment List**

Equipment	Provided by
Maintenance PC	Intertechnique
Test plates (2)	Intertechnique
Ice detectors (4)	Intertechnique
Controller unit	Intertechnique
Display and control unit	Intertechnique
Connection Cables	Intertechnique
Fluids	APS
Two-position test stand	APS

*COMPARISON OF ENDURANCE TIMES MEASURED BY SENSOR AND BY TRAINED PERSONNEL*

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## 8. DATA FORMS

Standard endurance time data forms will be used to record fluid failures. A test session log, shown in Figure 1, will be filled out for each test session.

## 9. SAFETY PRECAUTIONS

The following precautions will be taken when executing tests to ensure the safety of all personnel:

- Pathways, stairs and test areas are to be cleared of snow regularly;
- Appropriate footwear is to be worn by all personnel at the test site to prevent slipping;
- Warm clothing is to be worn by all personnel to prevent frostbite;
- Electrical appliances (including computers) are to be unplugged before any wires or connections are altered. If necessary, the affected breaker is to be turned off;
- If fluid comes into contact with skin, rinse hands under running water;
- If fluid comes into contact with eyes, flush with the portable eye wash station located inside the main trailer; and
- When operating snow blower use ear protection.



## **APPENDIX C**

### **COMPARISON OF IDES ENDURANCE TIMES WITH SOFTWARE VERSION 0 AND SOFTWARE VERSION 1**



Table C-1: IDES Endurance Times

Test #	Date	Precipitation		Temp. (°C)	Plate	Fluid	Dilution	Visual Endurance Time (min)	IDES Endurance Time (min)		Visual - IDES Diff.	
		Type	Rate (g/dm <sup>2</sup> /h)						Version 0	Version 1	Version 0	Version 1
1	4-Feb-04	Snow	17.0	-0.3	A	UCAR Ultra +	Neat	60.0	51.8	55.5	-14%	-8%
1	4-Feb-04	Snow	17.0	-0.3	A	UCAR Ultra +	Neat		FND*	FND*	n/a	n/a
2	4-Feb-04	Snow	17.0	-0.3	B	UCAR Ultra +	Neat	60.5	54.4	52.9	-10%	-13%
2	4-Feb-04	Snow	17.0	-0.3	B	UCAR Ultra +	Neat		54.0	54.0	-11%	-11%
3	4-Feb-04	Snow	28.2	-1.0	A	Octagon Max-Flight	Neat	49.0	44.4	41.8	-9%	-15%
3	4-Feb-04	Snow	28.2	-1.0	A	Octagon Max-Flight	Neat		38.5	38.5	-21%	-21%
4	4-Feb-04	Snow	28.2	-1.0	B	Octagon Max-Flight	Neat	49.0	45.3	43.5	-8%	-11%
4	4-Feb-04	Snow	28.2	-1.0	B	Octagon Max-Flight	Neat		40.9	40.6	-16%	-17%
5	4-Feb-04	Snow	31.1	-1.1	A	Octagon Max-Flight	75/25	16.7	16.0	15.5	-4%	-7%
5	4-Feb-04	Snow	31.1	-1.1	A	Octagon Max-Flight	75/25		15.4	15.4	-8%	-8%
6	4-Feb-04	Snow	31.1	-1.1	B	Octagon Max-Flight	75/25	16.4	18.3	16.5	11%	1%
6	4-Feb-04	Snow	31.1	-1.1	B	Octagon Max-Flight	75/25		20.2	16.8	23%	2%
7	4-Feb-04	Snow	75.7	-1.2	A	Kilfrost ABC-S	Neat	9.8	12.5	9.9	27%	1%
7	4-Feb-04	Snow	75.7	-1.2	A	Kilfrost ABC-S	Neat		26.1	10.4	165%	6%
8	4-Feb-04	Snow	75.7	-1.2	B	Kilfrost ABC-S	Neat	10.7	22.8	10.8	113%	1%
8	4-Feb-04	Snow	75.7	-1.2	B	Kilfrost ABC-S	Neat		26.7	12.7	150%	19%
9	4-Feb-04	Snow	68.5	-1.5	A	Kilfrost ABC-S	75/25	7.2	7.3	7.2	1%	0%
9	4-Feb-04	Snow	68.5	-1.5	A	Kilfrost ABC-S	75/25		10.1	8.2	40%	15%
10	4-Feb-04	Snow	68.5	-1.5	B	Kilfrost ABC-S	75/25	7.7	8.6	8.5	12%	11%
10	4-Feb-04	Snow	68.5	-1.5	B	Kilfrost ABC-S	75/25		9.7	7.2	27%	-6%
11	4-Feb-04	Snow	34.6	-1.6	A	Type I PG	10° Buffer	2.8	3.9	3.9	41%	43%
11	4-Feb-04	Snow	34.6	-1.6	A	Type I PG	10° Buffer		4.2	4.1	53%	50%
12	4-Feb-04	Snow	34.6	-1.6	B	Type I PG	10° Buffer	2.8	4.3	4.4	58%	61%
12	4-Feb-04	Snow	34.6	-1.6	B	Type I PG	10° Buffer		4.5	4.5	65%	65%
13	4-Feb-04	Snow	31.6	-1.5	A	Octagon Max-Flight	50/50	8.6	8.4	8.4	-2%	-2%
13	4-Feb-04	Snow	31.6	-1.5	A	Octagon Max-Flight	50/50		8.2	8.2	-5%	-5%

Table C-1: IDES Endurance Times (cont'd)

Test #	Date	Precipitation		Temp. (°C)	Plate	Fluid	Dilution	Visual Endurance Time (min)	IDES Endurance Time (min)		Visual - IDES Diff.	
		Type	Rate (g/dm <sup>2</sup> /h)						Version 0	Version 1	Version 0	Version 1
14	4-Feb-04	Snow	31.6	-1.5	B	Octagon Max-Flight	50/50	8.3	7.4	7.4	-10%	-10%
14	4-Feb-04	Snow	31.6	-1.5	B	Octagon Max-Flight	50/50		7.0	7.0	-16%	-16%
15	4-Feb-04	Snow	25.4	-1.6	A	Kilfrost ABC-S	50/50	4.7	4.0	4.0	-15%	-15%
15	4-Feb-04	Snow	25.4	-1.6	A	Kilfrost ABC-S	50/50		6.7	6.7	43%	43%
16	4-Feb-04	Snow	25.4	-1.6	B	Kilfrost ABC-S	50/50	4.5	8.1	8.1	79%	79%
16	4-Feb-04	Snow	25.4	-1.6	B	Kilfrost ABC-S	50/50		13.6	13.6	202%	202%
17	6-Feb-04	Snow	17.7	-10.2	A	UCAR ULTRA +	Neat	56.8	56.8	56.8	0%	0%
17	6-Feb-04	Snow	17.7	-10.2	A	UCAR ULTRA +	Neat		54.4	54.4	-4%	-4%
18	6-Feb-04	Snow	17.7	-10.2	B	UCAR ULTRA +	Neat	60.3	57.3	57.3	-5%	-5%
18	6-Feb-04	Snow	17.7	-10.2	B	UCAR ULTRA +	Neat		52.8	52.8	-13%	-13%
19	6-Feb-04	Snow	28.8	-9.8	A	Octagon Max-Flight	Neat	42.1	38.0	24.5	-10%	-42%
19	6-Feb-04	Snow	28.8	-9.8	A	Octagon Max-Flight	Neat		37.4	32.1	-11%	-24%
20	6-Feb-04	Snow	28.8	-9.8	B	Octagon Max-Flight	Neat	41.7	38.9	34.7	-7%	-17%
20	6-Feb-04	Snow	28.8	-9.8	B	Octagon Max-Flight	Neat		35.9	34.2	-14%	-18%
21	6-Feb-04	Snow	20.8	-10.0	A	Kilfrost ABC-S	Neat	36.8	32.4	32.0	-12%	-13%
21	6-Feb-04	Snow	20.8	-10.0	A	Kilfrost ABC-S	Neat		30.2	30.1	-18%	-18%
22	6-Feb-04	Snow	20.8	-10.0	B	Kilfrost ABC-S	Neat	36.2	36.8	33.9	2%	-6%
22	6-Feb-04	Snow	20.8	-10.0	B	Kilfrost ABC-S	Neat		35.4	33.1	-2%	-8%
23	6-Feb-04	Snow	6.6	-8.8	A	Octagon Max-Flight	75/25	110.0	69.0	68.2	-37%	-38%
23	6-Feb-04	Snow	6.6	-8.8	A	Octagon Max-Flight	75/25		68.1	67.6	-38%	-39%
24	6-Feb-04	Snow	6.6	-8.8	B	Octagon Max-Flight	75/25	102.0	82.6	79.4	-19%	-22%
24	6-Feb-04	Snow	6.6	-8.8	B	Octagon Max-Flight	75/25		68.2	63.0	-33%	-38%
25	23-Mar-04	Snow	6.0	-8.5	A	Kilfrost ABC-S	75/25	59.2	34.6	34.6	-42%	-42%
25	23-Mar-04	Snow	6.0	-8.5	A	Kilfrost ABC-S	75/25	41.2	23.1	22.7	-44%	-45%
26	23-Mar-04	Snow	6.0	-8.5	B	Kilfrost ABC-S	75/25	67.2	39.2	38.8	-42%	-42%
26	23-Mar-04	Snow	6.0	-8.5	B	Kilfrost ABC-S	75/25	67.2	37.1	37.1	-45%	-45%