TP 13946E

THE DETECTION OF FROZEN CONTAMINATION ON AIRCRAFT SURFACES

A Report on Behalf of the “Representative Surfaces” Working Group

Prepared for

Transportation Development Centre
Transport Canada

by

F.W. Eyre & Associates

September 2002

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16. Abstract

Field tests conducted during the winters of 1994-95 and 1995-96 revealed apparent improper location of representative surfaces. These surfaces, typically found at in-board wing locations, were intended to assist pilots with recognition of the onset of failure of anti-icing fluids, which are used to provide protection during winter precipitation. As a result the Transport Canada Standing Committee on Operations Under Icing Conditions appointed a Working Group in June 1996 to study the problem and to make appropriate recommendations.

The Working Group addressed the issues related to the origin and purposes of representative surfaces and reviewed available data on anti-icing fluid distribution on wings and on anti-icing fluid failure. Positive and negative operational experience with the use of representative surfaces was also evaluated. As a result, representatives of regulatory agencies and the airline industry recommended development and implementation of appropriate theoretical, laboratory, and field test programs.

The output of these programs showed that the representative surfaces in use were not appropriate and concluded that “pre-take-off inspection should be concentrated on the leading edge in conjunction with the trailing edge. The trailing edge control surfaces and/or spoilers usually provide an early indication of imminent fluid failure on the leading edge.”

The Working Group mandate was fulfilled.

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16. Résumé

Des essais en vraie grandeur menés au cours des hivers 1994-1995 et 1995-1996 ont révélé que les emplacements des surfaces représentatives étaient apparemment mal choisis. Ces surfaces, habituellement situées à proximité de l'emplanture de l'aile, ont pour but d'aider les pilotes à reconnaître la perte d'efficacité des liquides anti-givre utilisés pour protéger les ailes contre le givrage, sous des précipitations hivernales. En juin 1996, le Comité permanent Opérations dans des conditions givrantes de Transports Canada mettait sur pied un groupe de travail chargé d'étudier le problème et de formuler des recommandations.

Le groupe de travail s'est d'abord familiarisé avec l'origine des surfaces représentatives et leurs buts, avant de revoir l'information disponible sur la distribution du liquide anti-givre sur les ailes et sur la perte d'efficacité des liquides. Des témoignages, autant favorables que défavorables, concernant l'utilisation des surfaces représentatives en situation réelle, ont également été évalués. À l'issue de cette phase des travaux, des représentants d'organismes de réglementation et de l'industrie aéronautique ont recommandé le développement et la mise en œuvre de programmes d'essai théoriques, en laboratoire et sur le terrain.

Ces programmes d'essai ont révélé que les surfaces représentatives en usage étaient mal choisies. Ils ont mené à la conclusion que l'inspection avant le décollage devrait viser avant tout le bord d'attaque et le bord de fuite de l'aile. Les gouvernes et/ou les déporteurs (*spoilers*) du bord de fuite donnent habituellement des signes précoces d'une perte d'efficacité imminente du liquide sur le bord d'attaque.

Le groupe de travail a terminé son mandat.

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Foreword

The Transportation Development Centre of Transport Canada undertook an aviation ground operations research program that included a series of field tests, conducted during the winter of 1995 under natural winter precipitation conditions to observe the condition of aircraft wings immediately prior to takeoff.

The regulations require a pre-takeoff inspection under conditions of winter precipitation. At that time the regulations permitted the use of representative surfaces, which were designated areas that could be readily and clearly observed by flight crew during day and night operations and that were suitable for judging whether critical surfaces were contaminated. The field tests revealed that a pilot who used these representative surfaces might conclude that the aircraft was safe for takeoff when it was not.

This report was commissioned to serve as a reference on the activities of the Working Group set up by the Canadian Aviation Regulation Advisory Council (CARAC) to address this problem.

The Working Group fulfilled its mandate. As a result, regulatory authorities issued an Advisory Circular to define the areas of the wings where pilots should concentrate their inspection, and standards were revised to improve pertinent deicing procedures.

Barry Myers
Aviation Winter Operations R&D
Transportation Development Centre
Transport Canada

Avant-Propos

Le Centre de développement des transports de Transports Canada mène un programme de recherche sur les opérations de dégivrage au sol des aéronefs. À l'hiver 1995, une série d'essais en vraie grandeur a été réalisée dans des conditions de précipitations naturelles. Ces essais consistaient à observer l'état des ailes des avions immédiatement avant le décollage.

La réglementation exige des pilotes que, dans des conditions de précipitations hivernales, ils procèdent à une inspection de l'avion avant de décoller. À l'époque, il leur était permis d'utiliser des surfaces représentatives, c'est-à-dire des zones désignées, facilement et clairement observables de nuit comme de jour, pour juger si les surfaces critiques étaient contaminées. Les essais en vraie grandeur ont révélé qu'un pilote qui se fiait à ces surfaces représentatives pouvait conclure à tort que l'avion pouvait décoller en toute sécurité.

Le présent rapport vise à documenter les activités du groupe de travail mis sur pied par le Conseil consultatif sur la réglementation aérienne canadienne (CCRAC) pour se pencher sur ce problème.

Le groupe de travail a rempli son mandat. Les autorités se sont inspirées des travaux du groupe pour publier une Circulaire d'information qui définit les zones des ailes sur lesquelles les pilotes devraient désormais concentrer leur inspection, et pour revoir les normes relatives aux procédures de dégivrage.

Barry Myers
Opérations hivernales de l'aviation, R&D
Centre de développement des transports
Transports Canada

Executive Summary

In June 1996 the Transport Canada Standing Committee on Operations Under Icing Conditions appointed a Working Group to study the problem of using representative surfaces to determine whether critical aircraft surfaces are contaminated. The circumstances leading to the formation of the Representative Surfaces Working Group are outlined, as are its composition and terms of reference. Applicable regulations and standards, and official advisory material pertinent to the use of representative surfaces are quoted.

Data initially available indicated that approved representative surfaces might not always be effective, but the extent of this possible problem was not known. Theoretical studies, a test program and a survey of pilots, initiated by the Transportation Development Centre to provide a more extensive and appropriate knowledge base, are described.

An analysis of the physical behaviour of anti-icing fluid on aircraft wings showed that initial fluid failure and subsequent failure progression will occur at leading and trailing edges, with specific locations subject to surface geometric discontinuities and wing profile design. Field tests showed that early fluid failure and progression occurred at the leading and trailing edges of aircraft with leading edge devices. Early failure occurred on the spoilers and at the wing tip and trailing edges of the hard-wing aircraft tested. The survey of pilots revealed that pilots do not often experience takeoff close to the end of the holdover time and gain little experience with recognition of fluid failures.

A preliminary analysis of the comparative risks associated with takeoff under winter precipitation conditions with visual vs. instrumented detection of failed fluid concluded that, in principle, instruments are more effective in detectng imminent fluid failure than the human observer. An array of three or more point detection sensors per wing would involve less risk of accident than a visual inspection from within the aircraft.

In the survey, pilots reported that the representative surfaces typified the surface condition “well” or “very well”, but it was noted that in practice pilots do not develop significant experience of takeoff close to the end of the holdover time and the pilots’ reports appear to be an indication of false confidence.

As a result of this work the Representative Surfaces Working Group concluded that “pre-take-off inspection should be concentrated on the leading edge in conjunction with the trailing edge. The trailing edge control surfaces and/or spoilers usually provide an early indication of imminent fluid failure on the leading edge.” It also compiled a set of specific recommendations, proposed these recommendations to the Chair of the Standing Committee on Operations Under Icing Conditions, and thus fulfilled its mandate.

Following the tabling of the Working Group recommendations, Transport Canada, Commercial and Business Aviation issued Advisory Circular #113 in the fall of 1998 to initiate appropriate action by operators.

Sommaire

En juin 1996, le Comité permanent Opérations dans des conditions givrantes de Transports Canada mettait sur pied un groupe de travail chargé d'étudier le problème de l'utilisation des surfaces représentatives pour déterminer si les surfaces critiques d'un aéronef sont contaminées. Le rapport rappelle les circonstances qui ont mené à la formation du groupe de travail sur les surfaces représentatives, ainsi que la composition du groupe et son mandat. Il cite également les règlements et normes en vigueur, de même que les documents d'information officiels se rapportant à l'utilisation des surfaces représentatives.

Les premières données obtenues faisaient douter de la pertinence des surfaces représentatives approuvées, mais il restait à cerner l'ampleur du problème. Le Centre de développement des transports a donc réalisé des études théoriques, un programme d'essais et une enquête auprès de pilotes, afin d'avoir une base de connaissances plus complète et plus appropriée sur la question.

L'étude du comportement physique des liquides anti-givre sur des ailes d'avions a révélé que les premiers signes de perte d'efficacité apparaissent sur le bord d'attaque et le bord de fuite, celle-ci progressant ensuite à partir de ces zones. Les endroits précis dépendent des discontinuités géométriques de la surface et du profil de l'aile. Les essais en vraie grandeur ont confirmé que la perte d'efficacité se manifeste d'abord sur le bord d'attaque et le bord de fuite des avions munis de dispositifs de bord d'attaque. Dans le cas de l'avion à bec de bord d'attaque fixe mis à l'essai, une perte d'efficacité précoce a été observée sur les déporteurs (*spoilers*) ainsi qu'au bout des ailes et sur les bords de fuite. L'enquête menée auprès des pilotes a révélé qu'il leur arrive rarement de décoller alors que la durée d'efficacité des liquides achève et qu'ils sont donc peu habitués à reconnaître les signes de perte d'efficacité.

Une analyse préliminaire des risques comparatifs associés au décollage dans des conditions de précipitations hivernales, selon que la contamination est détectée par observation visuelle ou à l'aide de capteurs, a mené à conclure qu'en principe, les capteurs sont supérieurs à l'observation visuelle pour détecter la perte d'efficacité imminente d'un liquide. Un arrangement de trois capteurs ponctuels ou plus par aile entraînerait un risque d'accident moindre qu'une observation visuelle depuis l'intérieur de la cabine de pilotage.

Lors de l'enquête, les pilotes ont déclaré que les surfaces représentatives représentaient «bien» ou «très bien» l'état des surfaces, mais il convient de rappeler que dans les faits, les pilotes sont rarement amenés à décoller alors que la durée d'efficacité des liquides achève. Leurs déclarations semblent donc indicatrices d'une fausse confiance.

Au terme de ses travaux, le groupe de travail sur les surfaces représentatives a conclu que l'inspection avant le décollage devrait viser avant tout le bord d'attaque et le bord de fuite de l'aile. Les gouvernes et/ou les déporteurs du bord de fuite donnent habituellement des signes précoces d'une perte d'efficacité imminente du liquide sur le bord d'attaque. Le groupe a également formulé un ensemble de recommandations précises, qu'il a soumises au président du Comité permanent Opérations dans des conditions givrantes, s'acquittant ainsi de l'ensemble de son mandat.

Donnant suite aux recommandations du groupe de travail, Aviation commerciale et d'affaires de Transports Canada publiait, à l'automne 1998, la Circulaire d'information n^{o} 113 incitant les exploitants d'aéronefs à prendre les mesures appropriées.

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1. INTRODUCTION

Holdover time (HOT) tables, which are used by pilots as advisory material to estimate the period following de/anti-icing during which takeoff can safely be accomplished were originally based on anecdotal data. Work conducted under the auspices of the Dryden Commission Implementation Project, created following the crash of a Fokker F-28 at Dryden, Ontario, in March 1989, included a series of field tests under natural winter precipitation conditions to observe the condition of aircraft wings at the end of the holdover time.

Aircraft were made available by a number of Airlines for the conduct of these tests during the winter of 1994-95 and 1995-96. The wings of the aircraft used for the tests were in general marked with representative surfaces to help the pilot assess the condition of the wings during a visual inspection from within the cockpit or cabin immediately prior to start of the takeoff run. These surfaces were typically painted in contrasting black and white stripes and located close to the fuselage to facilitate viewing by the pilot. Their location and area had been chosen on the basis that conditions on the selected surfaces were representative of conditions elsewhere on the critical surfaces, with critical surfaces defined by the regulations as the wings, control surfaces, rotors, propellers, upper surface of the fuselage on aircraft that have rear-mounted engines, horizontal stabilizers, vertical stabilizers or any other stabilizing surface of an aircraft.

Following saturation of the anti-icing fluid by frozen precipitation it was observed that, contrary to expectations, the initial build-up of unabsorbed ice and slush did not occur at the representative surfaces. In one case, a Boeing 737, the fluid tended to flow and pool at the wing mid-chord section close to the fuselage, which was also the location of the representative surface. The representative surface remained “protected” by the fluid while extensive frozen contamination developed over the rest of the wing. In another case, a Douglas DC9, there was no pooling of the fluid at the inboard mid-chord location, which was also the location of the representative surface. Again, as with the case of the Boeing 737, there was extensive frozen contamination of the wing prior to significant contamination of the representative surface. It was evident that it would be possible for a pilot who used these representative surfaces during winter operations to conclude that the condition of the aircraft was safe for takeoff when in fact this was not the case.

These findings were reported to the Transport Canada Standing Committee on Operations Under Icing Conditions in June 1996. As a result a Working Group was formed to study the problem and to make appropriate recommendations.

2. THE REGULATORY ENVIRONMENT

2.1 Canadian Regulations and Standards

Canadian Aviation Regulations (CAR 602.11) Part VI – General Operating and Flight Rules, Subpart 2 – Operating and Flight Rules, Division I – General state that “no person shall conduct or attempt to conduct a take-off in an aircraft that has frost, ice or snow adhering to any of its critical surfaces." The pertinent Commercial Air Service Standards (CASS), 622.11, Part VI – General Operating and Flight Rules, Subpart 2 – Operating and Flight Rules, applicable at the time of Working Group activities state that "in order to operate an aircraft under icing conditions in accordance with the requirements of CAR Section 602.11, an operator must have a program as specified in these standards and the dispatch and take-off of the aircraft shall comply with that program."

With respect to the use of representative surfaces the following extracts from the CASS applied:

> 7.0 Aircraft Inspection and Reporting Procedures
> When and where applicable, the operator's Program must document the guidelines and procedures to be followed by flight crew and other personnel for detecting contamination on the critical surfaces of aircraft.
>
> 7.1 Inspection Procedures
> Two types of inspections, as defined in section 2.0 of these Standards, meet regulatory requirements. They are the Critical Surface Inspection and the Pre-take-off Contamination Inspection. Under icing conditions, the Critical Surface Inspection is mandatory; however, depending on the requirements of the operator's Program, the Pre-take-off Contamination Inspection may not be required. In its section on inspection procedures, the operator's manual must describe the techniques to be used in contamination recognition and the conduct of the two types of inspection.
>
> 7.1.1 Contamination Recognition
> Inspection procedures must describe the techniques to be used for detecting frost, ice, and snow and for determining if they are adhering to critical surfaces. These techniques must be specified in the operator's Program and may include the use of holdover timetables, tactile inspection, examination of one or more representative aircraft surfaces, or sensors.
>
> 7.1.1.3 Examination of one or more representative aircraft surfaces may be used for the Pre-take-off Contamination Inspection, which does not require a tactile examination. This technique may be used when the aircraft manufacturer has identified representative aircraft surfaces that can be readily and clearly observed by flight crew during day and night operations and that are suitable for judging whether critical surfaces are contaminated or not. When the aircraft is de-iced/anti-iced, the representative surface must be treated first during final application of fluid. If no representative aircraft surfaces have been identified by the aircraft manufacturer, an operator may offer one or more representative surfaces for approval by the Regional Director, Air Carrier or Chief, Airline Inspection; such a submission must be accompanied by technical data supporting the use of these surfaces as representative.

2.2 Application of the Regulations and Standards

Paragraph 7.1.1.3 of the CASS refers to the identification of a representative surface by an airframe manufacturer; however, no airframe manufacturers have specified representative surfaces. The provision that the operator may offer a representative surface therefore generally applied. Transport Canada in turn issued *Guidelines for the Approval of Representative Aircraft Surfaces* to personnel responsible for pertinent processing and approvals. These Guidelines are reproduced in Appendix A.

In summary, the surfaces must be readily visible from inside the aircraft, they must be symmetrically located on both sides of the aircraft, they must be unheated and not affected by propwash, the marking must include contrasting colours, the location must not be one where fluids would tend to "pond" or "pool", and fluid application procedures must require that the representative surface be treated first. The Guidelines were made available to air carriers and an inventory of representative surfaces was maintained by Transport Canada.

3. THE REPRESENTATIVE SURFACES WORKING GROUP

3.1 Mandate

The Representative Surfaces Working Group was established within Technical Committee VII - Commercial Air Service Operations (CASO) of the Canadian Aviation Regulation Advisory Council (CARAC).

The Working Group comprised representatives from:

- Air Carriers (Air Canada, Canadian Airlines International)
- Transport Canada (Civil Aviation, Transportation Development Centre)
- National Research Council Canada (Institute for Aerospace Research)
- Canadian Airline Pilots Association
- Air Transport Association of Canada
- National Defence

The working group's objectives were to determine whether representative surfaces could be used to provide a reliable first indication of anti-icing fluid failure and, as appropriate, to make recommendations for the continued use or elimination of representative surfaces and for alternative methods of fluid failure/fluid thinning detection.

The findings and recommendations of the Working Group were to be reported back to the Chair, Transport Canada Standing Committee on Operations Under Icing Conditions for appropriate action.

The terms of reference of the Working Group are given in Appendix B, together with a list of participating members and a calendar of principal activities.

3.2 Reference Data

3.2.1 Aircraft Critical Surfaces

Canadian Aviation Regulations (CAR) 602.11, Part VI – General Operating and Flight Rules, Subpart 2 – Operating and Flight Rules, Division I – General, define critical surfaces as follows:

> (1) In this Section, “critical surfaces” means the wings, control surfaces, rotors, propellers, horizontal stabilizers, vertical stabilizers or any other stabilizing surface of an aircraft and, in the case of an aircraft that has rear-mounted engines, includes the upper surface of its fuselage.

The regulations further require that:

> (2) No person shall conduct or attempt to conduct a take-off in an aircraft that has frost, ice or snow adhering to any of its critical surfaces.

Thus, for safety, the representative surface must display a condition characteristic of the worst condition occurring anywhere on the critical surfaces. In other words, the onset of adhesion of frozen contamination on the representative surface must coincide with (or occur earlier than) the onset of adhesion of frozen contamination wherever it might occur on a critical surface.

By definition the clean condition of all of the critical surfaces is critical to the safe takeoff of the aircraft. However, particular attention is paid to the wings, in part because of the known sensitivity of the wing aerodynamics to even low levels of contamination.

It has been shown [1, 2] that roughness, such as frost, with a profile height of only 0.3 mm (0.012 in.) on a 3 m (10 ft.) chord hard wing can reduce the maximum achievable lift of the wing significantly. During normal operation, the pilot may be completely unaware of this potential hazard. In the case of an engine-out at takeoff in a crosswind, conditions could exist where the result of such apparently minor contamination could be a catastrophic loss of roll control.

3.2.2 De/Anti-icing Procedures

Low viscosity glycol-based fluids intended for de-icing are referred to as Type I fluids. Type I fluids are normally heated to a temperature up to 85ºC (185ºF) for application. Fluids with thickeners added to increase their viscosity and remain on the wings until after the takeoff roll has begun are referred to as Type II fluids. Fluids, further modified, for anti-icing protection of commuter aircraft are designated as Type III fluids, and recently developed long-life anti-icing fluids have been designated as Type IV fluids. Under some circumstances heated Type II and Type IV fluids are used for deicing. The fluids are designed and tested to meet rigorous performance criteria as set out in SAE Aerospace Material Standards AMS 1424 for Type I fluids and AMS 1428 for Types II, III, and IV fluids.

A heated deicing fluid used for the removal of frost, ice, snow or slush from aircraft critical surfaces may also perform the function of an anti-icing fluid, or may be followed by application of a cold, dedicated anti-icing fluid. In some cases infrared deicing is performed as an alternative to use of glycol-based fluids. In such a case an anti-icing fluid must be applied following deicing, if there is ongoing precipitation.

Methods for deicing aircraft and application of de/anti-icing fluid(s) are covered by SAE Aerospace Recommended Practice ARP4737 *Aircraft Deicing/Anti-icing Methods*. The recommended fluid application strategy for the wings and tail plane is to spray starting at the tip and moving towards the wing root, spraying from the highest point of surface camber to the lowest. Thus the application of the fluid follows the natural flow of the fluid on the wing under gravity. Both sides of the aircraft should be treated symmetrically. This procedure is generally followed by all operators.

It should be noted that the foregoing recommended procedure is not generally compatible with CASS 622.11, ¶ 7.1.1.3 "… When the aircraft is de-iced/anti-iced, the representative surface must be treated first during final application of fluid. …" since the representative surface is located for easy viewing and therefore, typically, close to the wing root.

4. WORKING GROUP ACTION

A calendar of the principal actions of the Working Group is given at the end of Appendix B following the terms of reference.

4.1 Representative Surfaces – Background

In order to provide a framework for subsequent work and in accordance with the terms of reference, the following background issues were addressed:

- How representative surfaces came about
- Where they are located
- How they are marked
- What they are intended to do

Representative surfaces in one form or another have been in use for many years based on pilot experience.[1] Reference is also made to representative surfaces in the U.S. Code of Federal Regulations, Part 121.629 (c) (4). The concept of the use of a representative surface was extended and formalized in the Canadian Regulatory Standards following the release of the Dryden Commission report on the crash of a Fokker F-28 at Dryden, Ontario in March 1989, and the term was incorporated in the regulations cited in Section 2 of this report.

In 1995, in support of the pertinent standards, Transport Canada issued *Guidelines for the Approval of Representative Surfaces* to personnel responsible for the processing and approval of aircraft representative surfaces, and also made them available to air carriers. The text of these Guidelines is given in Appendix B.

[1] Pilots have long observed that on certain high-wing aircraft (where the condition of the wings could not readily be seen) the windshield wipers served as an effective representative surface. Accumulation of freezing precipitation on the wipers provided an indication that the onset of adhering contamination on the wings was imminent.

The Standards define the role and general limitations for use of representative surfaces:

> Examination of one or more representative aircraft surfaces may be used for the Pre-take-off Contamination Inspection, which does not require a tactile examination. This technique may be used when the … representative aircraft surfaces … can be readily and clearly observed by flight crew during day and night operations and … are suitable for judging whether critical surfaces are contaminated or not."

The Guidelines clearly identify limitations as to where the representative surfaces may be located, how they are to be marked, and what they are intended to do. The specific location and marking is then left to the carrier:

> A representative aircraft surface is a portion of the aircraft which can be readily and clearly observed by flight crew from inside the aircraft to judge whether the surface has become contaminated or not. By determining the state of the representative surface, it can then be reasonably expected that other critical surfaces are in the same (or better) condition.
>
> The presence of a contrasting colour on the representative surface is necessary under some circumstances to visually detect frozen contamination. If the proposed surface does not contain such contrast, painting a portion of the representative surface in a contrasting colour is required.
>
> In addition to the representative surface, other surfaces which are visible from inside the aircraft should be inspected for contamination whenever possible. For example, the inboard sections of a wing may be designated as representative surfaces, however in suitable lighting conditions it may be possible to view the entire wing upper surface in order to enhance the pre-takeoff contamination inspection.
>
> Flight crew personnel should be made aware that the use of a representative surface for contamination detection may not be feasible in poor weather or lighting conditions. Even the presence of residual de/anti-icing fluid on cabin windows may make a proper visual check difficult or impossible. Returning to the ramp for further de/anti-icing is not an admission of failure; it is simply recognition that the use of a representative surface is not viable 100% of the time.

4.2 Review of Available Test Data

The Working Group reviewed available test data.

Pictorial data taken from a sample test conducted on a Douglas DC9 during the winter of 1994-95 is given in Figure 1, based on data from [3]. After some 10 to 12 minutes, failure of the Type I fluid, which had been used as an anti-icing fluid, extended over some 10% of the wing area, including a strip along the entire leading edge. However, with the exception of a small area at an access panel, the fluid on the representative surface area continued to absorb precipitation until 15 to 17 minutes after initial fluid application. External test team observers identified the small failed area of fluid on the representative surface, but observers inside the aircraft did not identify this local fluid failure.

At the Working Group's first meeting it was noted that although a limited number of tests had shown that representative surfaces in use were not in fact representative of conditions on the wing, there was insufficient data on which to base any recommendations as to whether the observations made were isolated incidents, or whether the problem was general (i.e. what action should be taken). It was therefore recommended by the Working Group, in accordance with the terms of reference that the Transportation Development Centre (TDC) of Transport Canada organize and conduct appropriate theoretical and field-test programs.

4.3 TDC Studies

TDC undertook three sets of studies:

1) Theoretical (mathematical) modelling of anti-icing fluid behaviour on a wing when subject to winter precipitation conditions so that the physical behaviour of the fluid could be understood, and so that identification of suitable representative surfaces might be possible.
2) Field tests with sample airline service aircraft to observe the patterns of failure of anti-icing fluid on wings under a range of winter precipitation conditions, and to see whether the representative surfaces were valid.
3) A survey of pilot experience under winter precipitation takeoff conditions, together with a risk assessment of takeoff under winter precipitation takeoff conditions, and a comparative assessment of visual and instrumented inspection of critical surfaces.

In addition, wind tunnel tests were conducted by National Research Council Canada's Institute for Aerospace Research, which addressed the issue of airfoil performance at takeoff with contaminated fluid present. These wind tunnel studies did not directly address the issue of representative surfaces, but did contribute to an understanding of the behaviour of contaminated fluid on a wing. The issues of airfoil flap performance with de/anti-icing fluids and freezing precipitation, and takeoff performance degradation with contaminated fluid runback are addressed in [15] and [16], respectively.

The pertinent methodologies, observations, discussions and conclusions are given in detail in [2-13, inclusive] by the organizations who were contracted to do the work.

4.3.1 Theoretical Modelling

In the initial work, simplified models were developed to address the behaviour of fluid on a flat, inclined plate (e.g. [4]). Precipitation was simulated as a general mass transfer of water onto the surface of the fluid. Wind effects were ignored. This simplistic approach was extended in [5] so that the progression of fluid failure on a flat plate exposed to freezing precipitation could be predicted. (In later work the precipitation was incorporated as finite impact points on the fluid surface together with latent heat effects due to the change of state from solid to liquid of the precipitation, and also the effects of dispersion of the precipitate into the fluid.)

Development of these simplistic models, coupled with concurrent observations of fluid behaviour on a wing surface during simulated takeoff studies in a wind tunnel, served to provide an understanding of the physics involved in the behaviour of anti-icing fluid when exposed to freezing precipitation.

The predominant characteristics are:

- A tendency for fluid thinning at the leading and trailing edges where the surface slope is greatest and the gravity effects are most pronounced. This effect leads to early fluid failure at the leading and trailing edge.
- Little or no transfer of fluid due to gravity across surface discontinuities. Thus as fluid flows off, say, a spoiler or aileron, there is no replacement fluid flowing across the hinge line to replace the "lost" fluid (i.e. local fluid failures occur at surface discontinuities).
- Airflow (wind) tends to deposit precipitate at the leading and trailing edges and, to some extent, at wing tips. Failure occurs first at leading edges and trailing edges where there is a higher precipitation rate.
- Note: In a predominant crosswind there is significant deposition close to the fuselage on both sides of the aircraft, though the fluid at the mid-chord area where there is little or no gravity flow prevents early failure.
- Deicing involves significant addition of heat. This heat is dissipated most rapidly at areas of low thermal inertia – leading edges, trailing edges (in particular trim tabs, ailerons), and wing tips – leading to reduced protection at these locations.

The combination of these factors shows that initial fluid failure and fluid failure progression will occur at leading and trailing edges, with local fluid failures subject to wing design.

In a further study [6], the issue of adhesion of freezing precipitate to the aircraft surface following initial slush formation was addressed. This was not pursued further in the present context.

4.3.2 Field Tests

Field Test Program

TDC, in cooperation with the airline industry, organized a field test program in which service aircraft were observed under conditions of natural precipitation after deicing or de/anti-icing treatment by regular service crews. Extensive measurements of wing surface conditions were recorded and in some instances pilots were asked to report their opinions on the condition of the wings as observed from inside the aircraft. These observations were compared with observations by test personnel from outside the aircraft where close inspection, unaffected by residual fluid and precipitate on the windows, was possible.

The tests were performed during the winter of 1996-97 [7]. Data recorded during conduct of tests in the winter of 1995-96 [8] were also included in the overall database.

A total of 132 full-scale static aircraft tests were conducted. Eight additional tests were also conducted to address related issues. These tests, summarized in Table 1, involved commuter turbo-prop aircraft (ATR42, Fairchild Metroliner, DeHavilland Dash-8), commuter jet aircraft (Canadair CL65, British Aerospace Bae-147), hard-wing aircraft (Canadair CL65, Fokker F100), and aircraft with leading edge devices (Douglas DC9, Boeing 737, Airbus A320). Test variables included use of Types I, II, and IV fluids, different aircraft orientations to the predominant wind direction, different wind strengths, a full range of precipitation types, and a range of temperatures.

Observations were made of fluid failure patterns and failure propagation, and extensive measurements were made of fluid thickness distributions and thickness histories. In addition to measurements taken during fluid failure tests, extensive dedicated fluid thickness tests were also conducted [9].

Test Observations

Sample test observations of fluid failure initial onset and progression are shown in Figures 2 and 3 for a Boeing B-737 and a Fokker F-100, respectively. For the B-737 aircraft with leading edge devices and pylon-mounted engines, after first indications of slush build-up (fluid failure), the failure progresses on leading and trailing edges simultaneously, whereas on the hard-wing F-100 there is significant contamination on the trailing edge before the leading edge is seriously affected. (A comparison of times for contamination progression for the two aircraft cannot be made because of the different test conditions.)

In Figures 4 and 5 examples of frequency of occurrence of failure at a given location are given for the same two aircraft. The wings have been marked out in an arbitrary grid pattern and the number of times failure has occurred within a given grid area by the time 10% of the total wing area is contaminated is indicated. In the case of the B-737 the representative surface had evidence of fluid failure in only one of 16 tests, whereas failure occurred at the leading edge, immediately outboard of the pylons, in every test. In the case of the F-100, in 13 of 13 tests failure occurred at the trailing edge and on the spoilers whereas failure occurred at the leading edge 1/3 of the time or less. The F-100 provided by American Airlines and used for the tests did not have a representative surface marked on the aircraft. The Fokker F-28 aircraft with similar wings (and operated by Canadian carriers), which would be expected to have similar failure patterns, had representative surfaces marked by a full chord length band in the areas identified by grids 30, 31 and 32 of Figure 5. As can be seen in the figure, such representative surfaces would be valid at the trailing edge but not at the leading edge.

In Figure 6 sample thickness distribution measurements for four different aircraft are illustrated. The measurements were repeated at intervals after initial application and were observed to remain stable after 4 to 6 minutes for Type I fluids and 10 to 14 minutes for Type IV fluids. The examples serve to show the wide variation of thickness distributions that can occur in part as a result of variations in initial fluid application. However, as reported in [9], all measurements showed that the leading edge experienced the lowest values of fluid film thickness, with flaps and ailerons as the second most sensitive area. Thus these areas would have the lowest capability to absorb freezing precipitation.

4.3.3 Survey of Pilot Experience

Operational Experience

A risk analysis of takeoff under winter precipitation conditions [10] and a survey of Canadian pilots [11] were undertaken to address the risks and experience associated with critical surface visual inspection immediately prior to takeoff. The survey was subsequently extended to cover U.S. pilots [12].

The pilots reported that the representative surfaces typified the surface condition "well" or "very well", but it was noted that in practice pilots do not develop significant experience of takeoff close to the end of the holdover time, and the pilots' reports appear to be an indication of false confidence. Comments by many pilots referred to inspection of "Rep. Surfaces" rather than critical surfaces and implied that critical surfaces were not properly inspected [11 – Section 2.5 Assessment of Wing Condition in Pre-take-off Inspection]. The lack of experience of conducting inspections near the end of the holdover time means that pilots do not become familiar with recognition of fluid failure.

The findings from the survey of U.S. pilots followed the same pattern but differed in some details. Many U.S. pilots commented that the wing *was* the representative surface, though few pilots gave examples of when designated representative surfaces did not represent the condition of the wing. A number of pilots mentioned that assessment of conditions was easier on black surfaces, but one pilot pointed out that black surfaces absorb more heat and are often clean when the rest of the wing is contaminated [12 – Section 2.5 Assessment of Wing Condition in Pre-take-off Inspection).

Risk Assessment

A preliminary analysis of the comparative risks associated with takeoff under winter precipitation conditions with visual vs. instrumented detection of failed fluid was conducted [10, 11, 12]. It was found that, in principle, instruments are more effective at detection of imminent fluid failure than the human observer.

An interesting point was made as a result of the field- test observation that the rate of fluid failure propagation and slush adhesion to the wing is very rapid following initial fluid failure of a Type I fluid when used as an anti-icing fluid. The risk assessment study showed that at the end of the holdover time it is possible for the pilot to verify that the wings are clean when viewed from the cabin, but that the fluid would have failed over a significant area of the wing by the time the pilot has returned to the cockpit and prepared to start the takeoff roll.

Evaluation of Sensors as Aids to Pilots for Failed Fluid Detection

An evaluation of the possible application of point detection sensors was made. Sample installations and experience are given in [13] as well as [14] (published after fulfillment of the Working Group mandate).

As a result of the field-test measurements, a method was evolved whereby an array of point detection sensors could warn of impending fluid failure even though it did not occur at the sensor location. However, application of the pertinent algorithm may yield conservative holdover times (see [7]).

The risk assessment analysis concluded that an array of three or more point detection sensors per wing would involve less risk of accident than a visual inspection from within the aircraft.

4.4 Working Group Deliberations

It was emphasized by the aerodynamicists in the Working Group that the leading edges of airfoil sections are the areas of greatest concern, since it is in these regions that protective fluid is most prone to local "thinning" (therefore affording the least protection), and degradation of the aerodynamic performance of the airfoil due to any roughness present is most pronounced. This observation would apply to wings, control surfaces, vertical stabilizers and engine inlets. The opinion was that pilots should concentrate visual inspection on wing leading edges.

NRC Aerodynamics Laboratory personnel had studied the general problem of aircraft takeoff safety and had noted that the patterns of anti-icing fluid failure under conditions of winter precipitation might be common to specific aircraft types, i.e. hard-wing aircraft, those with leading edge devices, those with turbo-propeller "commuter aircraft" type wing sections, and those with supercritical wing sections. These observations were tabled and discussed.

The data generated by the TDC program was reviewed, and the Working Group made the following observations:

1. The location on the wing where de/anti-icing fluid first failed was different for each of the limited number of aircraft tested. Failure progression on aircraft of a given type was similar, as anticipated by NRC.
   Note: It was not practicable to test all existing aircraft models.

2. For a given aircraft type, the locations on the wing where early de/anti-icing fluid failure first occurred did not vary significantly with weather conditions.
   Note: Not every possible combination of weather conditions was experienced during the test program.

3. Failure patterns, under given weather conditions and aircraft orientation, were the same for Type I and Type IV fluid applications.

4. First failure occurred in the areas of the leading and trailing edges on the aircraft with leading edge devices, which were tested.

5. First failure occurred on the spoilers and at the wing tip and trailing edges on the hard-wing aircraft tested.
   Note: The leading edges should always be checked because they are critical to aircraft performance.

6 Erratic failure initiation and early progression can occur, which might be related to inadequate fluid application. The pertinent areas of frozen contamination are small, and after a short period of time the patterns of failure progression on aircraft of a given type are similar.

7. In the small number of cases where first failure was observed at the mid-chord section associated with discontinuities at inspection panels, etc., this local failure did not progress significantly.

8. A statistically significant database of observations of fluid behaviour on aircraft under conditions of winter precipitation now exists, though for some aircraft types the test sample is small.

The list of approved representative surfaces for aircraft in service in Canada maintained by Transport Canada at the time of formation of the Working Group was reviewed and many were considered to be inappropriate. The list, with comments is given in Table 2.

The possibility of recommending that unsuitable identification of representative surfaces already painted onto wings should be removed was discussed. The pilots commented that the contrasting markings of existing markings make it easier to identify ice formation due to freezing rain, drizzle or fog. It was also noted that removal of the existing painted areas would be expensive. No recommendation was made.

5. CONCLUSIONS

The conduct of the work by TDC and by NRC led to significant conclusions pertinent to the condition of an aircraft towards the end of the holdover time and to the conduct of the pre-takeoff inspection.

With respect to the representative surfaces, the Working Group examined the data and concluded that, in general, representative surfaces were not appropriately located and that, in many cases, meaningful location would not be possible. Significant discussion addressed the issue as to whether the Pilot in Command (PIC) should (a) seek to identify the first indication of fluid failure wherever it might occur, and if so what guidelines should be given, or (b) ensure that the wing leading edges are clean at start of takeoff, since these are the areas most sensitive to the effects of contamination.

It was concluded that "pre-take-off inspection should be concentrated on the leading edge in conjunction with the trailing edge. The trailing edge control surfaces and/or spoilers usually provide an early indication of imminent fluid failure on the leading edge."

6. Working Group Report to the Chair, SCOUIC

The final recommendations of the Working group were presented to the Chair, Transport Canada Standing Committee on Operations Under Icing Conditions (SCOUIC) on 29 April 1998.

The Working Group background and activities were reviewed together with a calendar of principal activities.

The conclusions and recommendations were tabled.

Note: In the opinion of the Working Group the Inventory of Representative Surfaces referred to in the Guidelines is no longer valid. The decision to update/continue this document rests with Transport Canada.

7. Working Group Recommendations

As a result of field test observations, the Working Group recommended that an Air Carrier Advisory Circular (ACAC) be issued to further clarify the use of representative surfaces and the conduct of pre-takeoff inspection under conditions of winter precipitation:

1.1 PIC inspection of the aircraft critical surfaces prior to take-off should be focused on the sections of the leading edge close to the fuselage (the wing high lift area) and ahead of the aileron (the roll control area), where these are visible.

1.2. The PIC should also note that early failure of a protective fluid may also occur on the ailerons, spoilers or flaps.

1.3. The PIC should not rely on representative surfaces located at a mid-chord section of the wing. However, where mid-chord representative surfaces have already been identified by a painted area they may be found to facilitate the identification of hoar frost or clear ice.

It was further recommended that the text of CASS 622.11 ¶ 7.1.1.3 be revised to delete the requirement that when the aircraft is deiced/anti-iced the representative surface must be treated first during final application of fluid.

A recommendation that the *Guidelines for the Approval of Representative Surfaces* should be revised was not implemented.

8. IMPLEMENTATION OF RECOMMENDATIONS

Following the tabling of the Working Group recommendations, Advisory Circular #113 was prepared and issued by Transport Canada, Commercial and Business Aviation in the fall of 1998 and contained the following note:

> **SAFE TAKE-OFF**
>
> **Representative Surfaces**
>
> Representative surfaces that can be clearly observed by flight crew from inside the aircraft may be suitable for judging whether or not critical surfaces are contaminated.
>
> Research has indicated that fluid failure occurs last at the mid chord sections of wings. Therefore, whether painted or not, areas located at mid chord sections of wings and previously used for checking fluid conditions are not suitable for evaluating fluid failure and should no longer be used exclusively as representative surfaces.
>
> Pre-take-off contamination inspections should concentrate on the leading edge in conjunction with the trailing edge of the wing. Dependent upon aircraft configuration, wing spoilers may also be used to provide an indication of fluid condition.

The foregoing text is an extract from Transport Canada, Commercial and Business Aviation Advisory Circular (CBAAC) #0194, dated 28 November 2001, which repeats in part and supersedes the original earlier Advisory Circular.

CASS 622.11 ¶ 7.1.1.3 has been revised and now reads as follows:

> Examination of one or more representative aircraft surfaces may be used for the Pre-take-off Contamination Inspection, which does not require a tactile examination. This technique may be used when the aircraft manufacturer has identified representative aircraft surfaces that can be readily and clearly observed by flight crew during day and night operations and that are suitable for judging whether critical surfaces are contaminated or not. If no representative aircraft surfaces have been identified by the aircraft manufacturer, an operator may offer one or more representative surfaces for approval by the Regional Director, Air Carrier or Chief, Airline Inspection; such a submission must be accompanied by technical data supporting the use of these surfaces as representative.

Transport Canada no longer maintains a record of Approved Representative Surfaces.

Postscript

Completion of Working Group Mandate

The objective of the CARAC Technical Committee VII CASO Representative Surfaces Working Group was addressed within the scope and methodology of the terms of reference.

The Working Group proposed recommendations to the Chair of the Transport Canada Standing Committee on Operations Under Icing Conditions and fulfilled its mandate.

TABLE 1
LISTING OF AIRCRAFT FULL-SCALE TESTS (1992 TO 1997)

Row #	ID #	Test Loc.	Date	A/C Type	Number of Tests	Start Time	Comments	Descr.
1	5	BDL	Jul-18-96	MD-88	1			CSW
2	1	YUL	Apr-15-96	MD-88	1			CSW
3	2	YUL	Apr-18-96	MD-88	1			CSW
4	3	YUL	Apr-18-96	RJ	1			CSW
5	4	YUL	Apr- 25-96	MD-88	1			CSW
6		DEN	Jan. 14- Mar. 21, 1992	B-737	22		Snow (TI & TII Fluids) United Airlines	FF
7		DEN	Nov. 20, 1992- Mar 12, 1993	B-727	24		Snow (TI & TII Fluids) United Airlines	FF
8		YOW	March 18-19, 93	F-28 Wing Plate	10		Freezing Fog	FF
9		YOW	March 18-19, 93	King Air	11		Freezing Fog	FF
10		YOW	May-05-93	F-28 Wing Plate	9		Freezing Rain/Drizzle	FF
11		RIG	March 18-19, 93	King Air Wing Stabilizer	1		Simulated Snow	FF
12		YUL	Mar-10-94	Citation II - Metroliner	5			FF
13	1	YUL	Jan-17-95	DC-9	1		Dry run	FF
14	2	YUL	Jan-17-95	DC-9	1		Dry run	FF
15	3	YUL	Jan-17-95	DC-9	I		Dry run	FF
16		YTH	Feb-09-95	HS-748	2		Frost Removal - Calm Air	HA
17	LI	YUL	Feb-24-95	DC-9	1	0:06		FF
18	L2	YUL	Mar-06-95	DC-9	1	0:44		FF
19	L3	YUL	Mar-06-95	DC-9	1	2:27		FF
20	L4	YUL	Mar-06-95	DC-9	1	3:58		FF
21	L5	YUL	Mar-06-95	DC-9	1	4:47		FF
22	L6	YUL	Mar-08-95	DC-9	1	23:37		FF
23	L7	YUL	Mar-09-95	DC-9	1	1:52		FF
24	L8	YUL	Mar-09-95	DC-9	1	2:35		FF
25	L9	YUL	Mar-09-95	DC-9	1	3:44		FF
26	1	YUL	Feb-28-96	DC-9	1	2:25	Dry run	FF
27	1	YUL	Feb-28-96	DC-9	1	2:25		FF
28	2	YUL	Feb-28-96	DC-9	1	4:04		FF
29	39	YUL	Dec-13-96	F100	1		Dry run	FF
30	40	YUL	Dec-13-96	F100	1		Dry run	FF
31	1	YUL	Jan-16-97	B-737	1	4:07		FF
32	2	YUL	Jan-I6-97	B-737	1	4:14		FF
33	3	YUL	Jan-16-97	B-737	1	5:14		FF
34	4	YUL	Jan-16-97	B-737	1	5:16	Test stopped	FF
35	5	YUL	Jan-22-97	B-737	1	3:54		FF
36	6	YUL	Jan-22-97	B-737	1	4:01		FF
37	8	YUL	Jan-22-97	B-737	1	4:38		FF
38	9	YUL	Jan-25-97	B-737	1	2:30		FF
39	10	YUL	Jan-25-97	B-737	1	2:35	Test stopped	FF
40	13	YUL	Jan-28-97	B-737	1	1:54		FF
41	14	YUL	Jan-28-97	B-737	1	2:06		FF
42	15	YUL	Jan-28-97	B-737	1	2:39		FF
43	16	YUL	Jan-28-97	B-737	1	3:32		FF
44	17	YUL	Jan-28-97	B-737	1	4:09		FF
45	18	YUL	Feb-05-97	F100	1	1:38		FF
46	19	VUL	Feb-05-97	F100	1	2:14		FF
47	20	YUL	Feb-05-97	F100	1	2:51		FF
48	21	YUL	Feb-05-97	F100	1	3:40		FF
49	22	YUL	Feb-05-97	F100	1	4:18		FF
50	23	YUL	Feb-05-97	F100	1	4:23		FF
51	24	YUL	Feb-21-97	B-737	1	1:45		FF
52	25	YUL	Feb-21-97	B-737	1	1:53		FF
53	26	YUL	Feb-21-97	B-737	1	2:37		FF
54	29	YUL	Mar-06-97	F100	1	1:30		FF
55	30	YUL	Mar-06-97	F100	1	1:41		FF
56	31	YUL	Mar-06-97	F100	1	2:18		FF
57	32	YUL	Mar-06-97	F100	1	3:24		FF
58	33	YUL	Mar-06-97	F100	1	3:27		FF
59	34	YUL	Mar-06-97	F100	1	3:52		FF
60	35	YUL	Mar-06-97	F100	1	3:59		FF
61	36	YUL	Mar-14-97	ATR 42	1	11:36		FF
62	37	YUL	Mar-14-97	ATR 42	1	12:17		FF
63	38	YUL	Mar-14-97	ATR 42	1	12:20		FF
64	T1	YYT	Feb-23-95	DC-9	1	1:23		FF
65	T1	YYT	Feb-23-95	DC-9	1	1:23		FF
66	T2	YYT	Feb-23-95	DC-9	1	2:57		FF
67	T2	YYT	Feb-23-95	DC-9	1	2:57		FF
68	T3	YYT	Mar-01-95	DC-9	1	0:45		FF
69	T3	YYT	Mar-01-95	DC-9	1	0:45		FF
70	T4	VYT	Mar-01-95	DC-9	1	2:23		FF
71	T4	YYT	Mar-01-95	DC-9	1	2:23		FF
72	T5	YYT	Mar-01-95	DC-9	1	3:34		FF
73	T5	YYT	Mar-01-95	DC-9	1	3:34		FF
74	T6	YYT	Mar-08-95	DC-9	1	2:18		FF
75	T6	YYT	Mar-08-95	DC-9	1	2:18		FF
76	T7	YYT	Mar-08-95	DC-9	1	3:11		FF
77	T7	YYT	Mar-08-95	DC-9	1	3:11		FF
78	T8	YYT	Mar-08-95	DC-9	1	3:45		FF
79	T8	YYT	Mar-08-95	DC-9	1	3:45		FF
80	T9	YYT	Mar-08-95	DC-9	1	4:18		FF
81	T9	YYT	Mar-08-95	DC-9	1	4:18		FF
82		YMX	Mar-12-95	B-737	2		ZR - Allied Signal	FF
83	T10	YYT	Mar-15-95	BAe-146	1	1:23		FF
84	T10	YYT	Mar-15-95	BAe-146	1	1:23		FF
85	T11	YYT	Mar-15-95	BAe-146	1	3:05		FF
86	T11	YYT	Mar-15-95	BAe-146	1	3:05		FF
87		YUL	Mar-28-95	DC-9	4			HW
88		YUL	Apr-05-95	DC-9	4			HW
89		YUL	Apr-07-95	DC-9	3			HW
90	T12	YYT	Apr-27-95	DC-9	1	1:47		FF
91	T12	YYT	Apr-27-95	DC-9	1	1:47		FF
92	T13	YYT	Apr-27-95	A320	1	3:10		FF
93	T13	YYT	Apr-27-95	A320	1	3:10		FF
94	T14	YYT	Apr-27-95	A320	1	4:39		FF
95	T14	YYT	Apr-27-95	A320	1	4:39		FF
96	1	YYZ	Jan-05-95	B-737	1		Dry run	FF
97	2	YYZ	Jan-05-95	B-737	1		Dry run	FF
98	3	YYZ	Jan-05-95	B-737	1		Dry run	FF
99	Z1	YYZ	Feb-21-95	B-737	1	0:48		FF
100	Z2	YYZ	Feb-21-95	B-737	1	2:14		FF
101		YUL	Mar-10-94	Metroliner	1			FT
102		YMX	Mar-23-95	B-737	1		Allied Signal	FT
103	1	YUL	14-15 Feb. 1996	RJ	1			FT
104	2	YUL	14-15 Feb. 1996	RJ	1			FT
105	3	YUL	14-15 Feb. 1996	RJ	1			FT
106	4	YUL	14-15 Feb. 1996	RJ	1			FT
107	1	YUL	11-12 Mar. 1996	DC-9	1			FT
108	2	YUL	11-12 Mar. 1996	DC-9	1			FT
109	3	YUL	11-12 Mar. 1996	DC-9	1			FT
110	4	YUL	11-12 Mar. 1996	DC-9	1			FT
111	5	YUL	11-12 Mar. 1996	DC-9	1			FT
112	6	YUL	11-12 Mar. 1996	DC-9	1			FT
113	1	YUL	28-29 Mar. 1996	A320	1			FT
114	2	YUL	28-29 Mar. 1996	A320	1			FT
115	3	YUL	28-29 Mar. 1996	A320	1			FT
116	4	YUL	28-29 Mar. 1996	A320	1			FT
117	5	YUL	28-29 Mar. 1996	A320	1			FT
118	1	YUL	Dec-13-96	F100	1			FT
119	2	YUL	Dec-13-96	F100	1			FT
120	3	YUL	Jan-16-97	B-737	1			FT
121	4	YUL	Jan-22-97	B-737	1			FT
122	5	YUL	Jan-25-97	B-737	1			FT
123	6	YUL	Jan-25-97	B-737	1			FT
124	7	YUL	Feb-04-97	ATR42	1			FT
125	8	YUL	Feb-04-97	ATR42	1			FT
126	9	YUL	Feb-07-97	ATR42	1			FT
127	10	YUL	Feb-07-97	ATR42	1			FT
128	11	YUL	Feb-21-97	B-737	1			FT
129	12	YWG	Mar-08-97	DHC-8	1			FT
130	13	YWG	Mar-08-97	DHC-8	1			FT
131	14	YWG	Mar-08-97	DHC-8	1			FT
132	15	YWG	Mar-08-97	DHC-8	1			FT
133	16	YWG	Mar-08-97	DHC-8	1			FT
134	17	YWG	Mar-08-97	DHC-8	1			FT
135	18	YMX	Apr-09-97	B-737	1			FT
136	19	YMX	Apr-09-97	B-737	1			FT
137	20	YMX	Apr-09-97	B-737	1			FT
138	21	YMX	Apr-09-97	B-737	1			FT
139	22	YMX	Apr-09-97	B-737	1			FT
140	23	YMX	Apr-09-97	B-737	1			FT

FF = Fluid Failure
CSW = Cold-Soaked Wing
HW = Hot Water
HA = Hot Air
FT = Fluid Thickness

TABLE 2

APPROVED REPRESENTATIVE SURFACES – 1995

(Based on Transport Canada regional office records reported to head office)

A/C type	Airline	Approved Surfaces, 1995	***Comments*** (based on interpretation of test data)
Airbus A310	All	Mid-chord station close inboard	*Unsuitable*
Airbus A320	All	Mid-chord station close inboard	*Unsuitable*
ATR42	All	Roll spoilers	*Probably O.K; Add L.E. where visible*
BAe 146	All	Portion of L.E., Inboard flap	*Possibly O.K.; Add L.E. where visible*
B'craft KA100	All	Full chord at aileron inboard	*Mid-chord portion should be removed*
B'craft KA100	All	Full chord at aileron inboard in some cases	*See above*
B'craft SKA200	All	L.E., full chord at aileron inboard in some cases	*See above*
B'craft 1900D	All	L.E., full chord at aileron inboard in some cases	*See above*
Boeing 727	All	Outboard spoilers	*O.K.*
Boeing 737	All	Mid-chord stations	*Unsuitable*
Boeing 747	All	Mid-chord station close inboard	*Unsuitable*
Boeing 757	Air Transat	Inboard spoilers	*O.K.*
Boeing 767	All	Mid-chord station close inboard	*Unsuitable*
C'dair Challenger	All	Mid-chord station squares	*Unsuitable*
C'dair CL65	All	Mid-chord station close inboard	*Unsuitable*
Cessna Citation	All	Mid-chord stations	*Unsuitable*
Convair 580	All	Mid-chord, 39 ft. from cockpit	*Unsuitable*
DHC Dash 7	All	Ground spoilers, Roll spoilers	*Probably O.K.*
DHC Dash8	All	Outboard roll spoilers, leading edge where visible, Trailing edge of inboard flap (visible from row 9)	*Probably O.K.*
DHC Twin Otter	All	No record	
Douglas DC3	All	Mid-chord, outboard of engines	*Unsuitable*
Douglas DC9	All	Mid-chord station close inboard	*Unsuitable*
Douglas DC10	All	Mid-chord station close inboard	*Unsuitable*
Falcon 20	All	Chord section, 10 ft. from tip	*Possibly O.K.*
Fokker F28	All	Outboard wing panels- Full chord length	*Add: Spoilers*
Gulfstream G1	All	Mid-chord area	*Unsuitable*
HS748	Air Creebec	L.E., full chord at aileron inboard	*Mid-chord portion should be removed*
HS748	West wind	Mid-chord area	*Replace with mod'd Aircreebec Surface*
HS748	CalmAir	Mid-chord area	*Replace with mod'd Aircreebec Surface*

TABLE 2 (Cont.)

A/C type	Airline	Approved Surfaces, 1995	***Comments*** (based on interpretation of test data)
Jetstream 31	All	Mid-chord area	*Unsuitable*
Jetstream 41	All	Portion of L.E., Inboard flap	*Possibly O.K.*
Lockheed L1011	All	Mid-chord station close inboard	*Unsuitable*
Saab 340		L.E.,Tailplane L.E.'s	*O.K.*
Fairchild Metroliner	Jetall	Mid-chord station squares	*Unsuitable*
Fairchild Metroliner	Bearskin	L.E.,Tailplane L.E.'s	*O.K.*
Short SD-330	All	Not defined	-
Short SD-360	All	Nose ahead of windshield	-

FIGURE 1
SAMPLE FAILURE PROGRESSION FOR A TYPE I FLUID
MARCH 06/95, Test ID: #L2

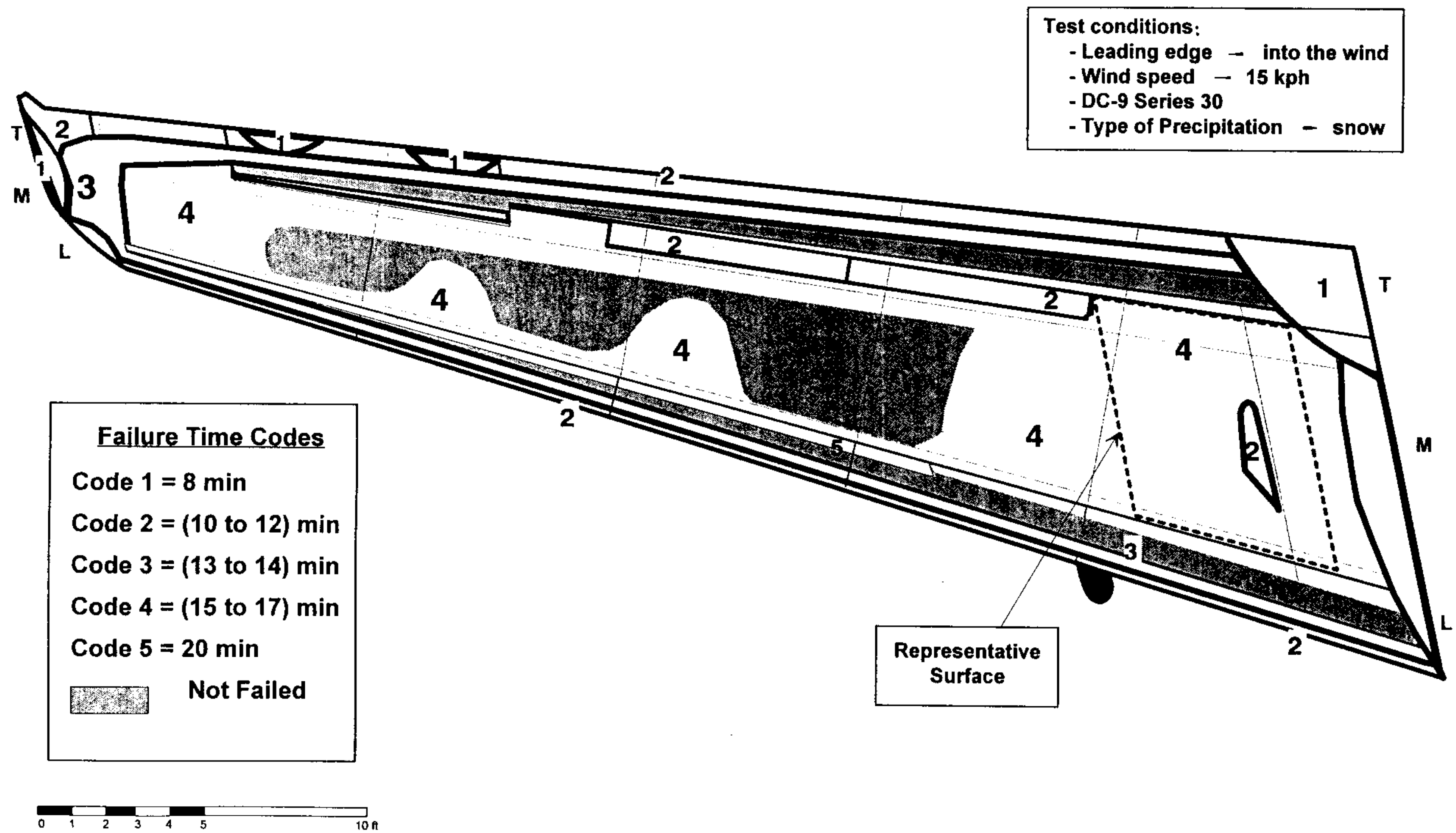


FIGURE 2
SAMPLE FAILURE PROGRESSION FOR A TYPE IV FLUID ON A BOEING 737
FEB. 21/97, Test ID: #24 [Wind: 6km/h, Temp. –3.2^{0}C, snow @ 20.9gm/dm^2/h]

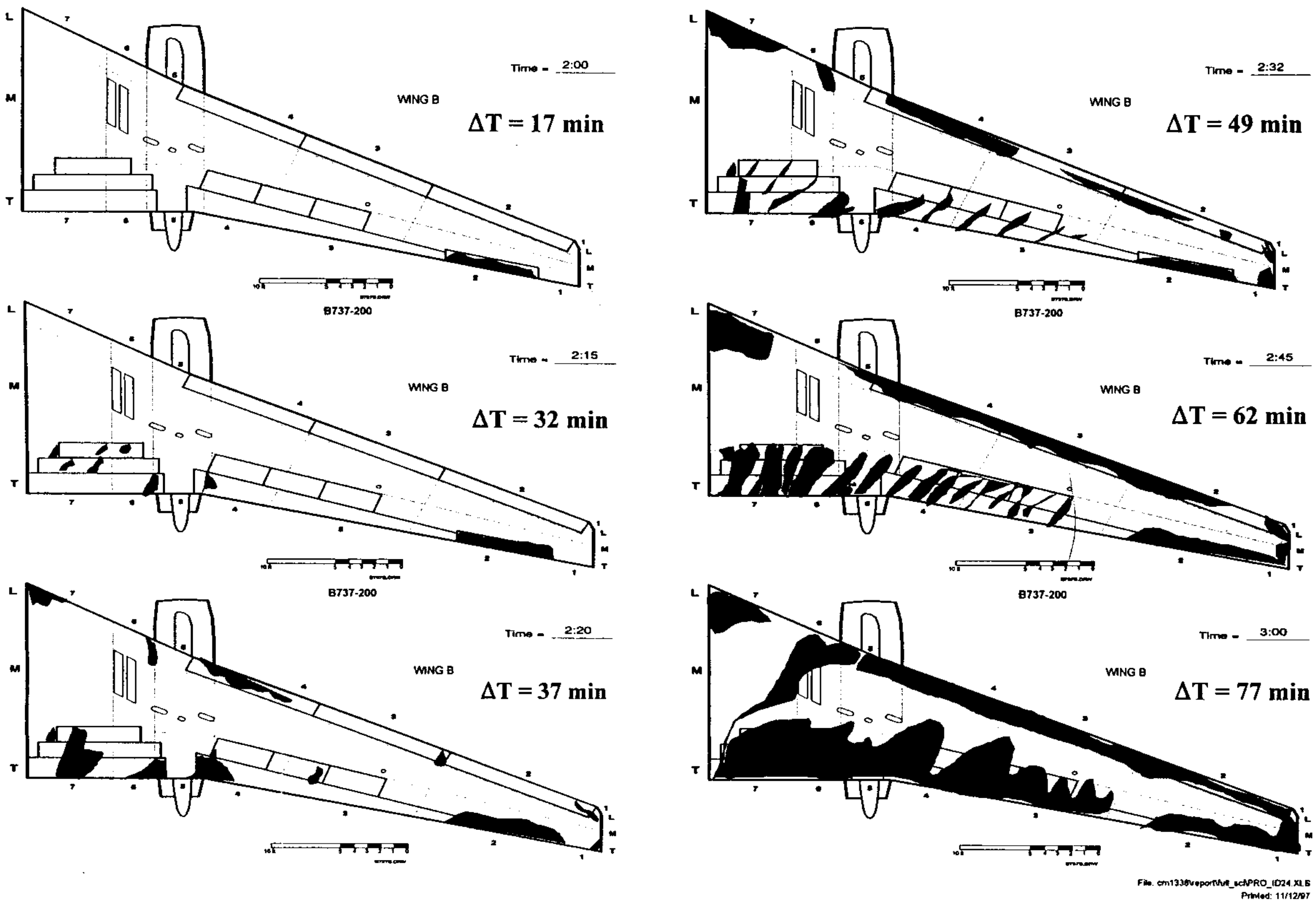


FIGURE 3
SAMPLE FAILURE PROGRESSION FOR A TYPE IV FLUID ON A FOKKER F100

MAR. 06/97, Test ID: #31 [Wind: 17km/h, Temp. –3.8^{0}C, snow @ 6.1gm/dm^2/h]

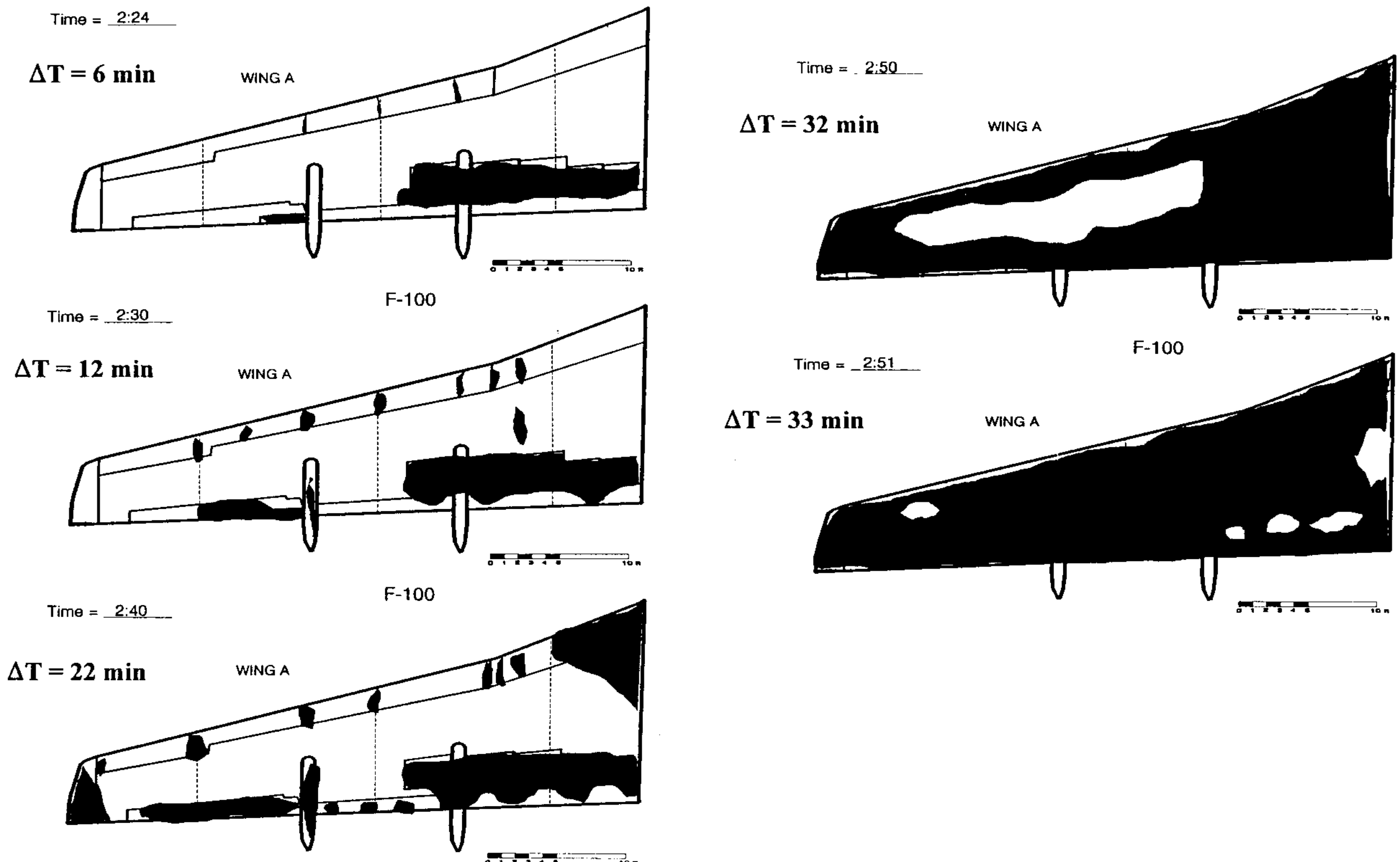
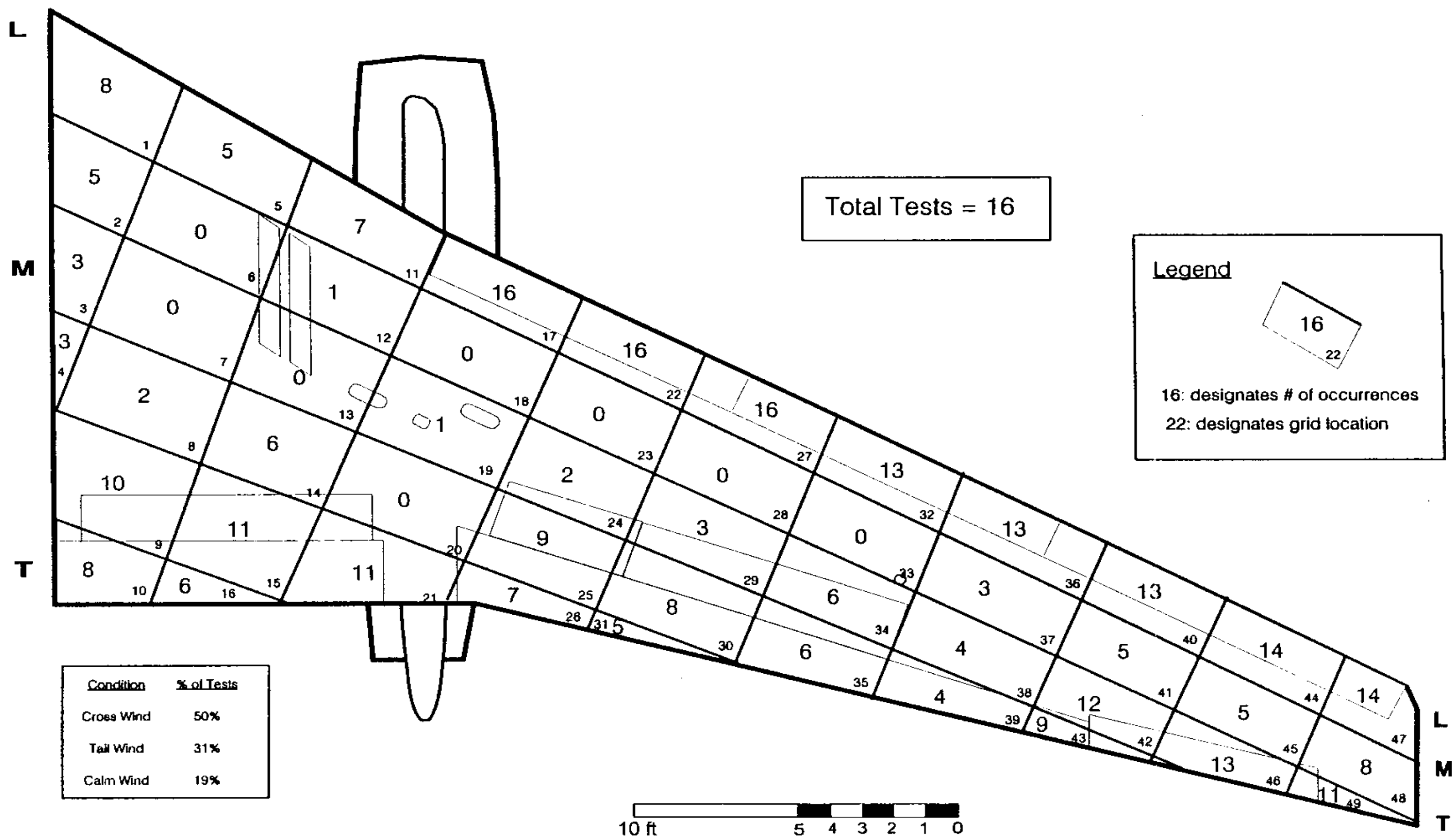


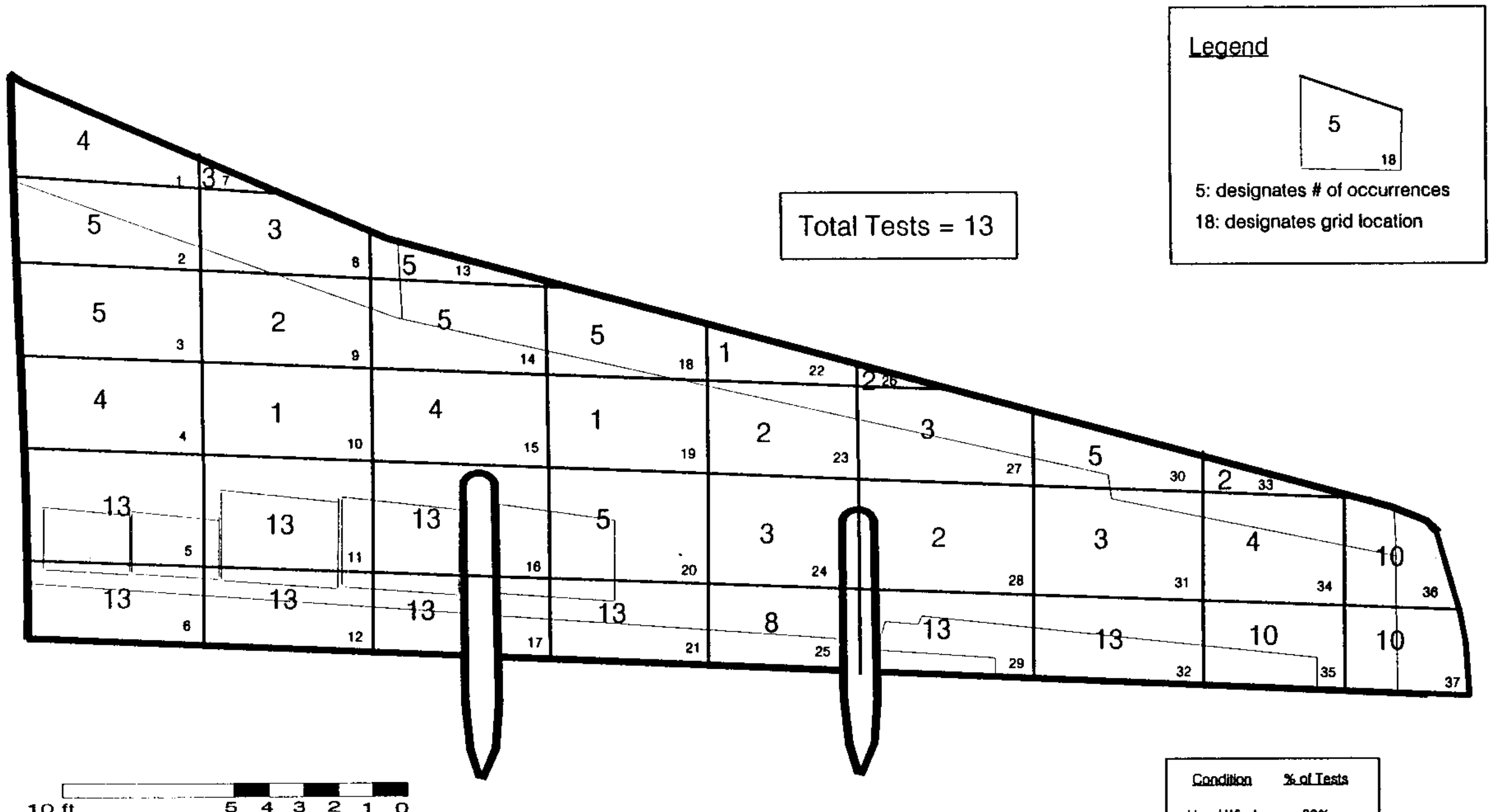
FIGURE 4
FREQUENCY OF CONTAMINATION DISTRIBUTION (FLUID FAILED) FOR FAILURE PROGRESSION TO 10% OF WING AREA ON A BOEING 737



Condition	% of Tests
Cross Wind	50%
Tail Wind	31%
Calm Wind	19%

Note: Occurrence was counted when any amount of failure was present in the grid

FIGURE 5
FREQUENCY OF CONTAMINATION DISTRIBUTION (FLUID FAILED) FOR FAILURE PROGRESSION TO 10% OF WING AREA ON A FOKKER F100

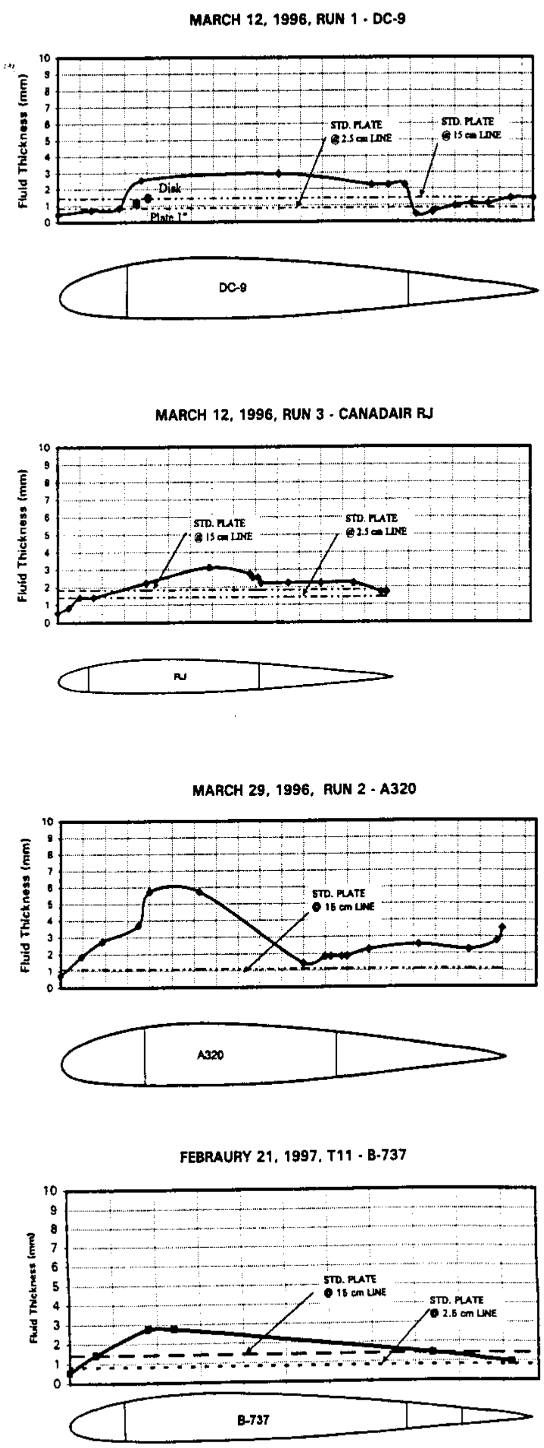


Note: Occurrence was counted when any amount of failure was present in the grid

Condition	% of Tests
Head Wind	23%
Cross Wind	31%
Tail Wind	46%

FIGURE 6

TYPE IV FLUID THICKNESS (STABILIZED) PROFILE OF A DC-9, RJ, AIRBUS A320, AND BOEING 737



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Appendix A

GUIDELINES FOR THE APPROVAL OF REPRESENTATIVE AIRCRAFT SURFACES

DEC 1995

GUIDELINES FOR THE APPROVAL OF REPRESENTATIVE AIRCRAFT SURFACES

BACKGROUND

In accordance with the Ground Icing Operations Standard, an operator may submit one or more Representative Aircraft Surfaces for approval by the Regional Director, Air Carrier or the Chief, Airline Inspection. Submissions must be accompanied by data supporting the use of a surface as being "representative" of the condition of other critical aircraft surfaces during ground icing conditions. The purpose of this paper is to provide guidance to personnel who are responsible for the processing and approval of representative aircraft surfaces.

A representative aircraft surface is a portion of the aircraft which can be readily and clearly observed by flight crew from inside the aircraft to judge whether the surface has become contaminated or not. By determining the state of the representative surface, it can then be reasonably expected that other critical surfaces are in the same (or better) condition.

APPROVAL GUIDELINES

Wherever possible, the operational experience of the air carrier should be taken into consideration in the approval process. The following guidelines may be used in the processing and approval of representative surfaces for aircraft whose manufacturer has not designated such a surface.

- The surface must be clearly visible and close enough for the viewer to determine that it is free of contamination. The location of the representative surface and the position inside the aircraft from which the surface is to be viewed must be specified for each aircraft type. This information must be clear, concise and readily available on the flight deck.

- If the surface is not adequately visible under all weather and lighting conditions, restrictions on its use must be clearly identified. Consideration should be given to locating representative surfaces in areas which can be illuminated by aircraft external lighting systems.

- Whenever possible, representative surfaces should be designated on both sides of the aircraft in the event that, due to strong winds during taxi or other conditions, one side of the aircraft became contaminated before the other.

- Representative surfaces must be located on a critical surface as defined by regulation, however some critical surfaces such as propellers would not be acceptable.

- The surface must be unheated, whether directly or indirectly, by pneumatics, hydraulics or any other source of heat which could delay the onset of contamination. The surface must not be affected by propwash.

- The presence of a contrasting colour on the representative surface is necessary under some circumstances to visually detect frozen contamination. If the proposed surface does not contain such contrast, painting a portion of the representative surface in a contrasting colour is required.

- The representative surface must not be located in an area where FPD fluids would tend to naturally migrate or "pond" causing the fluid to fail more slowly than on other critical surfaces. The representative surface is the first area to be treated with FPD fluid and it is on this surface that fluid would initially fail under normal circumstances.

PROCEDURAL GUIDELINES

When conducted by competent and thoroughly trained personnel, pre-takeoff contamination inspections carried out from inside the aircraft using representative aircraft surfaces can yield significant operational and economic benefits. Therefore, the operator's Ground Icing Operations Program must specify that adequate ground and flight crew training will be conducted regarding the purpose, limitations and procedures to be followed with respect to representative surfaces, as well as the following:

- The use of representative surfaces for contamination detection during freezing precipitation conditions may not be effective because of the difficulties involved in the visual detection of clear ice. If operations are to be conducted in light freezing rain or freezing drizzle conditions, Type II anti-icing FPD fluids are strongly recommended. Operations should be planned to enable the aircraft to take off within the available holdover time.

- In addition to the representative surface, other surfaces which are visible from inside the aircraft should be inspected for contamination whenever possible. For example, the inboard sections of a wing may be designated as representative surfaces, however in suitable lighting conditions it may be possible to view the entire wing upper surface in order to enhance the pre-takeoff contamination inspection.

- For aircraft where it is necessary for one pilot to leave the flight deck in order to accomplish the pre-takeoff contamination inspection, there is the potential for disruption of the normal "flow" of checklists and other pre-takeoff duties. The operator's plan should therefore specify at what point the inspection should take place in order to minimize any such disruption.

- Flight crew personnel should be made aware that the use of a representative surface for contamination detection may not be feasible in poor weather or lighting conditions. Even the presence of residual de/anti-icing fluid on cabin windows may make a proper visual check difficult or impossible. Returning to the ramp for further de/anti-icing is not an admission of failure; it is simply recognition that the use of a representative surface is not viable 100% of the time.

ADMINISTRATION

Although the preceding guidelines are primarily intended for Transport Canada personnel, they may be distributed as required to air carriers wishing to utilize representative surfaces in their aircraft operations. TCA headquarters has compiled a preliminary inventory of approved representative surfaces based on information collected early in 1995. Any new representative surfaces should be forwarded to headquarters as they are approved in order for a current inventory to be maintained. In addition to the data listed on the attached table, a diagram or photograph of the approved representative surface should be included with each submission. The diagrams and other supporting information will be kept in headquarters, however TCA Air Carrier personnel may request copies of this documentation in order to assist in the processing of new approvals.

Comments and recommendations regarding these guidelines should be forwarded to the Chief, Air Carrier Operational Standards (AARXB).

AARXB

December 13, 1995

Appendix B

REPRESENTATIVE SURFACES WORKING GROUP
TERMS OF REFERENCE

CANADIAN AVIATION REGULATION ADVISORY COUNCIL (CARAC)

Technical Committee VII - Commercial Air Service Operations (CASO)

TERMS OF REFERENCE

REPRESENTATIVE SURFACES WORKING GROUP

BACKGROUND:
At the semi-annual meeting of the Standing Committee On Aircraft Operations Under Icing Conditions held on June 12, 1996 concerns were raised about the suitability of the present identification and use of representative surfaces for the pre-take-off contamination inspection under conditions of freezing precipitation. It was proposed and accepted that a Working Group should be established to study the issues raised.

OBJECTIVE:
To determine if representative surfaces can be used to provide a reliable first indication of anti-icing fluid failure.

SCOPE:
The scope is limited to aircraft in service in Canada that are certificated for flight in icing conditions and the operating practices for those aircraft in ground icing conditions.

METHODOLOGY:
Define how representative surfaces came about, where they are located, how they are marked, and what they are intended to do.

Review research on anti-icing fluid failure/fluid thinning that has been conducted on representative surfaces.

Identify positive and negative operational experience with the use of representative surfaces as indicators of fluid failure/fluid thinning.

Consult with representatives of regulatory agencies and the airline industry for the possible development and implementation of appropriate theoretical, laboratory and field test programs.

Make recommendations for the continued use or elimination of representative surfaces and recommend alternate methods of fluid failure/fluid thinning detection.

WORKING GROUP:
The Working Group has been designated by the Standing Committee on Operations Under Icing Conditions as follows:

Working Group Leader:
F. W. Eyre, Consultant to the Transportation Development Centre (TDC)

Members:[A1]

Dr. M. Beyers	Institute for Aerospace Research, National Research Council
Maj. M. Doiron	National Defence Canada
B. DuPerron	Canadian Airlines International Limited
F. Flood	Canadian Airline Pilots Association (CALPA)
P.Gerhart	Transport Canada - Commercial and Business Aviation Ontario Region
D. Legge	Air Canada
B.B. Myers	Transportation Development Centre
J. Squires	Air Transport Association of Canada (ATAC)
K. Walper	Transport Canada - Commercial and Business Aviation Operational Standards

Note: Members may be accompanied by advisors at meetings.
An FAA representative will be invited to attend meetings as an observer.

Due to the difficulty of assembling the full Working Group, it is proposed that:

(1) Members may nominate alternates,
(2) Six members including at least representatives from Transport Canada Commercial and Business Aviation Operational Standards and TDC would constitute a Quorum, and
(3) No decisions would be taken/finalized until all members have been contacted/balloted

Airline representatives will be requested to inform/co-ordinate with airline engineering staff as appropriate.
Airframe and instrumentation manufacturers will be called upon as resource organizations to assist with the study of problems and to address the objectives.

TECHNICAL COMMITTEE:
The Technical Committee has the authority to accept, reject or send issues back to the group for further study. If the Technical Committee decides to send recommendations to the Transport Canada Aviation Regulatory Committee, it may append its own comments to the Working Group's recommendations. The Technical Committee will not revise the recommendations since they are a product of expertise which they themselves may not possess. This process is reflected in the CARAC Charter and Procedures. On issues where there is no consensus in the Working Group, the recommendations will be identified as a recommendation of the Working Group Leader.

[A1] A list of participating members is given at the end of this Appendix

REPORTING:
The Working Group will report to the Standing Committee Chair. The agenda, decision record, recommendations and information to be disseminated to the aviation industry will be forwarded to the Standing Committee Chair as soon as possible following each Working Group meeting. The Working Group will function in English.
The Working Group will endeavour to reach a unanimous position on points raised. Any dissenting views will be recorded in the decision record.
All communication to the Standing Committee will be coordinated through the Working Group Leader.
The Standing Committee Chair will report the Working Group's findings and recommendations to the Technical Committee.

TIMING:
The date of the initial meeting will be determined following the acceptance of the terms of reference by the Technical Committee.

An expanded methodology and possible near-term actions that can be implemented before winter '96/'97 will be included in the agenda for the first Working Group meeting.

A progress report will be tabled at the Standing Committee meeting planned for October 1996.

BUDGET:
Costs incurred by organizations outside Transport Canada Safety and Security are expected to be borne by those organizations.

ADMINISTRATIVE SUPPORT:
The Transportation Development Centre will provide administrative support to the Working Group.

M.R. Preuss
Chair
Standing Committee on Operations
Under Icing Conditions

F.W. Eyre
Working Group Leader
Representative surfaces Working Group

Approved:

________________________ Date:

A.J. LaFlamme
Chair
CARAC Technical Committee VII
Commercial Air Service Operations

Representative Surfaces Working Group Members/ Meeting Participants

Name	Affiliation
M. Beyers	NRC/IAR
Maj. M. Dorion	DND, Dir. Air Reqs.
J. Dueck	Canadian Reg'l Airlines
B. DuPerron*	Canadian Airlines Int'l Ltd.
F. Eyre	TDC
F. Flood	CALPA
P. Gerhart	T.C. Com. & Bus. Aviat., Ont.
D. Legge	Air Canada
B. Myers	TDC
R. Palmer	Canadian Airlines Int'l Ltd.
J. Squires	ATAC
R. Tidy	T.C. Airworthiness
K. Walper	T.C.

*represented by R. Palmer at meetings

Calendar of Principal Events

1) First Working Group meeting 03-Oct-96

- The Problem was defined: the existing locations of Representative surfaces were in many cases not suitable. An adequate database did not exist as a basis on which to correct the situation.
- The Group agreed that any final recommendations should include a reference to check wing leading edges.
- Due to the lack of test data, it was recommended that TDC should obtain more test data.
- Further, TDC should explore the use of frozen contamination detection sensors.

Report to Standing Committee 01-May-97

- 40 tests were conducted during the '96-'97 winter
- Preliminary observations:
    - Early fluid failures occurred at leading and trailing edges.
    - Failure was often difficult to identify
    - The delay between trailing and leading edge failures was short.
- The data had not been reduced prior to the Standing Committee meeting, accordingly no Working Group meeting had been held.

Draft interim report issued to members for comment - September '97

- Full data analysis still not completed.
- Failures patterns appear to be aircraft specific.
- First failure location is weather specific.
- First failures occur on leading and trailing edges, and in some cases, at the wing tips.

Report to standing committee 01-Oct-97

Draft interim report presented. It was also noted:

- Hard-wing aircraft have first failure at the spoilers and trailing edges.
- The patterns of failure for a given aircraft are repeatable, but the time to failure on both wings may not be the same under predominantly crosswind conditions.

Working Group meeting 01-Apr-98

The review of available test data by the Working Group was completed. Final recommendations were prepared.

The final recommendations of the Working Group were presented to the Chair, Transport Canada Standing Committee on Operations Under Icing Conditions (SCOUIC) on 29 April 1998.