TP 14082E

Benefit-Cost Analysis of Procedures for Accounting for Runway Friction on Landing

Prepared for:

Transportation Development Centre
Transport Canada

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SYPHER:MUELLER International Inc.

March 2003

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All monetary values are in Canadian dollars unless otherwise specified.

Un sommaire français se trouve avant la table des matières.

Transport Canada Transports Canada

PUBLICATION DATA FORM

1. Transport Canada Publication No.
TP 14082E

2. Project No.
5039

3. Recipient's Catalogue No.

4. Title and Subtitle
Benefit-Cost Analysis of Procedures for Accounting for Runway Friction on Landing

5. Publication Date
March 2003

6. Performing Organization Document No.

7. Author(s)
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8. Transport Canada File No.
2450-BP-14

9. Performing Organization Name and Address
Sypher:Mueller International Inc.
220 Laurier Ave. West, Suite 500
Ottawa, Ontario
Canada K1P 5Z9

10. PWGSC File No.
MTB-0-02365

11. PWGSC or Transport Canada Contract No.
T8200-0-0560/001/MTB

12. Sponsoring Agency Name and Address
Transportation Development Centre (TDC)
800 René Lévesque Blvd. West
Suite 600
Montreal, Quebec
H3B 1X9

13. Type of Publication and Period Covered
Final

14. Project Officer
A. Boccanfuso

15. Supplementary Notes (Funding programs, titles of related publications, etc.)
Co-sponsored by Transport Canada's Aerodrome Safety Branch

16. Abstract

A study was undertaken to better understand the use of currently available guidance material related to runway condition and to develop an economic rationale for making greater use of runway friction information. The study included a review of existing standards and guidance material, and analysis of runway conditions and reporting of friction at airports.

A survey of Canadian airline pilots on current practices, their use of guidance material and their views on accounting for runway friction was conducted. Past overrun accidents/incidents on landing were examined, and the risks on landing and the reduction in risks due to use of runway friction information was analyzed. The benefits and costs to air operators and passengers of accounting for runway friction in landing performance calculations using Canadian Runway Friction Index (CRFI) Tables from the Transport Canada Aeronautical Information Publication, a 115% adjustment factor and manufacturers' guidance material were estimated and benefit-cost ratios determined.

The study found that risks of overruns when landing on slippery runways are 13 times higher than on dry runways. Benefits of accounting for slippery runways using the CRFI Tables exceed the costs, particularly when there is little runway available above that required by current regulations. As a minimum, the 115% adjustment applicable to wet runways should be extended to slippery runways. Recommendations are made regarding changes to requirements for accounting for runway friction on landing.

17. Key Words
Aircraft, pilot, runway friction, landing procedures, guidance material, risk, safety, contaminated runway, ice, slippery, benefit-cost analysis, Canadian Runway Friction Index, CRFI

18. Distribution Statement
Limited number of copies available from the Transportation Development Centre

19. Security Classification (of this publication)
Unclassified

20. Security Classification (of this page)
Unclassified

21. Declassification (date)
—

22. No. of Pages
xxii, 60, apps

23. Price
Shipping/ Handling

Canada

Transports Canada Transport Canada

FORMULE DE DONNÉES POUR PUBLICATION

1. N° de la publication de Transports Canada
TP 14082E

2. N° de l'étude
5039

3. N° de catalogue du destinataire

4. Titre et sous-titre
Benefit-Cost Analysis of Procedures for Accounting for Runway Friction on Landing

5. Date de la publication
Mars 2003

6. N° de document de l'organisme exécutant

7. Auteur(s)
D.C. Biggs, G.B. Hamilton et K.D.J. Owen

8. N° de dossier - Transports Canada
2450-BP-14

9. Nom et adresse de l'organisme exécutant
Sypher:Mueller International Inc.
220 Laurier Ave. West, Suite 500
Ottawa, Ontario
Canada K1P 5Z9

10. N° de dossier - TPSGC
MTB-0-02365

11. N° de contrat - TPSGC ou Transports Canada
T8200-0-0560/001/MTB

12. Nom et adresse de l'organisme parrain
Centre de développement des transports (CDT)
800, boul. René-Lévesque Ouest
Bureau 600
Montréal (Québec)
H3B 1X9

13. Genre de publication et période visée
Final

14. Agent de projet
A. Boccanfuso

15. Remarques additionnelles (programmes de financement, titres de publications connexes, etc.)
Projet coparrainé par la Direction de la Sécurité des aérodromes de Transports Canada

16. Résumé

Une étude a été entreprise pour mieux comprendre l'utilisation des directives actuelles concernant l'état de surface des pistes et pour justifier économiquement l'utilisation accrue de l'information sur le coefficient de frottement des pistes. L'étude comprenait un examen des normes et directives existantes; elle portait également sur l'analyse de l'état de surface des pistes et sur la prise en compte de leur coefficient de frottement par les aéroports.

Les chercheurs ont mené une enquête auprès des pilotes de ligne canadiens pour connaître leurs pratiques, les méthodes qu'ils appliquent, leur utilisation des directives pertinentes et leur opinion sur la prise en compte du frottement des pistes. Ils ont examiné les accidents/incidents de dépassement de piste et analysé les effets que l'information sur le frottement des pistes pourrait avoir sur les risques à l'atterrissage et sur la diminution de ces risques. Ont également été évalués les coûts et les avantages, pour les exploitants aériens et pour les passagers, de la prise en compte du frottement des pistes pour calculer les performances à l'atterrissage d'après les tables du Coefficient canadien de frottement sur piste (CRFI, pour *Canadian Runway Friction Index*) de la Publication d'information aéronautique de Transports Canada, en appliquant un facteur de correction de 115 % et les directives des constructeurs.

Selon l'étude, un atterrissage sur piste glissante comporte un risque de dépassement de piste 13 fois plus élevé que pour un atterrissage sur piste sèche. Les avantages de la prise en compte du frottement des pistes lorsqu'on utilise les tables du CRFI sont supérieurs aux coûts associés, et plus particulièrement lorsque la longueur de piste est seulement légèrement plus grande que la longueur minimale exigée par la réglementation actuelle. Il faudrait au moins étendre aux pistes glissantes la correction de 115 % applicable aux pistes mouillées. Enfin, l'étude propose de modifier les modalités de prise en compte du frottement des pistes à l'atterrissage.

17. Mots clés
Avion, pilote, frottement, procédures d'atterrissage, directives, risque, sécurité, chaussée contaminée, glace, piste glissante, analyse coûts-avantages, coefficient canadien de frottement sur piste, CRFI

18. Diffusion
Le Centre de développement des transports dispose d'un nombre limité d'exemplaires.

19. Classification de sécurité (de cette publication)
Non classifiée

20. Classification de sécurité (de cette page)
Non classifiée

21. Déclassification (date)
—

22. Nombre de pages
xxii, 60, ann.

23. Prix
Port et manutention

Executive Summary

Introduction

Transport Canada (TC), in association with the Federal Aviation Administration (FAA), the U.S. National Aeronautics and Space Administration, and National Research Council Canada (NRC), implemented a five-year program for winter runway friction testing in 1995. The program expanded in 1996 to include other North American and European organizations, and has become a concerted international effort known as the Joint Winter Runway Friction Measurement Program. The program has led to the collection of a substantial database of aircraft and ground vehicle friction measurement data from various runways, and to the development of a greater understanding of the factors affecting runway friction, its measurement, and the relationship between runway friction and aircraft braking. For runways with compacted snow or ice contamination, or loose snow with shallow contaminant depth and therefore very little or no contaminant drag, the runway friction measurements were found to be consistent and correlate well with aircraft braking.

With this improved knowledge of runway friction, Transport Canada is looking at making better use of runway friction information in practice to reduce the risks and possibly operating costs. The objective of this study was to better understand the use of the currently available guidance material related to runway condition and to develop an economic rationale for changes requiring commercial air carriers operating passenger services using turbo-jet aircraft to account for slippery runways on landing.

Approach

Much of the benefit of accounting for runway friction will likely be due to a reduction in the risk of overrun accidents on landing. An analysis of the reduction in risks due to the use of runway friction information is therefore an important component of the benefit-cost analysis. The approach used to better understand the use of the currently available guidance material related to runway condition and to determine the benefits and costs of accounting for slippery runways was to:

- Review existing standards and guidance material;
- Review runway conditions and reporting of friction at airports;
- Conduct a survey of Canadian airline pilots on current practices, their use of guidance material and their views on accounting for runway friction;
- Examine past overrun accident/incident experience on landing, analyze the risks on landing and the reduction in risks due to use of runway friction information;
- Determine the incremental benefits and costs to airports of changes in the measurement and reporting of runway friction information;
- Analyze the benefits and costs to air operators and passengers of accounting for runway friction in landing performance calculations; and
- Determine overall benefits and costs, and the benefit-cost ratio.

Current Situation

The current TC and FAA regulations require the aircraft landing distance specified in the Aircraft Flight Manual (AFM) to be not more than 60% of the landing field length available. The regulations include a requirement for an additional 15% runway length when the destination runway is forecast to be wet at the time the aircraft is dispatched. Important implications of these regulations are as follows:

- Reverse thrust cannot be used in determining the AFM landing distance and landing field length for most aircraft types, although reverse thrust is typically used in operational situations to reduce stopping distance. Aircraft with reverse thrust therefore have an additional safety feature not accounted for in the regulations that is especially effective on slippery runways when braking friction is low.
- There is no requirement to adjust the landing distances to account for snow, ice or frost on the runway. The factor of 115% for wet runways does not have to be applied in these runway conditions.
- The requirement to adjust for a wet runway applies only at the time of dispatch and take-off – once airborne, if the runway conditions change and become wet, there is no requirement for the pilot to re-calculate the factored landing distance with the additional 15% margin.

The survey of Canadian airline pilots indicated that most pilots are aware of guidance material for operating on contaminated runways, and that most apply some adjustment factor to the landing field length when runways are slippery. The TC Aeronautical Information Publication includes tables, referred to as the CRFI Tables, derived from the Falcon-20 tests at North Bay, which provide adjustments to the landing field length for given Canadian Runway Friction Index (CRFI) values. However, most pilots surveyed indicated that their aircraft manuals and company material referred to reporting braking action as “good”, “medium” or “poor” and do not specifically refer to runway friction.

Runway condition data over a one- to three-year period was obtained for Calgary, Toronto, Ottawa and Halifax airports and analyzed in conjunction with data from five airports collected between 1988 and 1990. The frequency of slippery runways varies greatly between airports. Typical frequencies of contaminant types resulting in slippery runways and average CRFI values for each contaminant type are as follows:

Contaminant Type	During Winter Months	Over Year	Avg. CRFI
Ice	6.6%	2.8%	0.32
Compact Snow	2.4%	1.0%	0.32
Frost	0.7%	0.3%	0.41
Loose snow 1/8"	3.5%	1.4%	0.40
Any of above	13.2%	5.5%	

Source: Runway Surface Condition reports from airports.

Notes: Values applicable for contaminant type ≥ 20% of runway (but often <100%).
Runways typically treated to improve friction.

CRFI values vary significantly from these averages, as is shown in Figure 1. Over a year, approximately 0.5% of the time CRFI values are 0.2 or less, 2.1% are between 0.21 and 0.3, 1.7% are between 0.31 and 0.4, 0.8% are between 0.41 and 0.5, and 94.9% are 0.51 or greater.

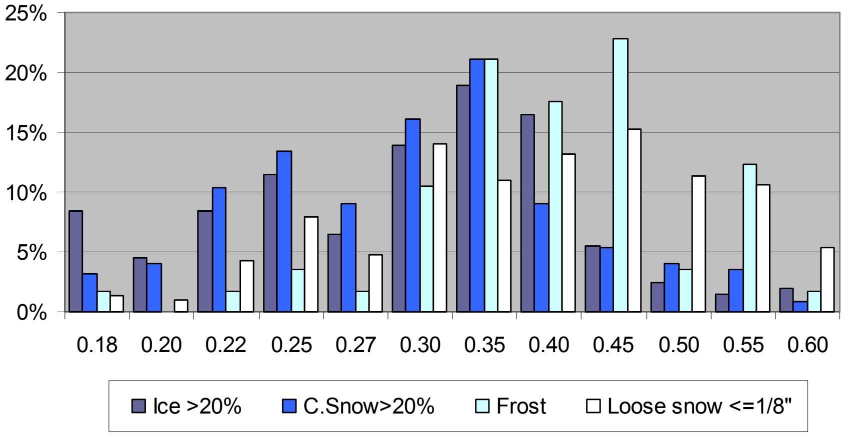

Figure 1. Average Distribution of CRFI Values by Contaminant Type at Canadian Airports

Benefit-Cost Analysis

The benefit-cost analysis compared the use of the CRFI Tables for accounting for slippery runways with use of the current regulations (no adjustment), the 115% wet runway adjustment, and adjustments based on the manufacturers' guidance material. For aircraft types where no manufacturer's guidance material was available, the adjustment was based on adjustments for similar aircraft.

The benefits of accounting for slippery runways were determined by estimating the reduction in accident costs. A model was developed to estimate the probability of overrun and the consequences when an overrun occurs. The landing distance was estimated from the AFM landing distance with adjustments for slippery runways based on analysis of Falcon-20 tests at North Bay by NRC and TC. The model allows for variation in air distance prior to touchdown, delay time, braking Mu on slippery runway, and the setting and application of brakes. The risk model was shown to be consistent with past history of overruns in Canada.

The costs to air carriers and passengers considered included delays until CRFI improves, cancelled or diverted flights, weight reductions, updating manuals, and additional training. Additional cost to airports will be small as CRFI values are already collected at all airports with paved runways with jet service. There is only one with gravel runway that may be affected, but an exemption is being considered for collection of CRFI on gravel runways. Possible additional costs to airports include the provision of CRFI values earlier in morning and changes in procedures and training to improve the consistency of reporting.

Conclusions

The risk of a jet aircraft overrunning the end of the runway on landing when the runway is slippery is approximately 13 times greater than when the runway is dry. The risks of overruns on landing for aircraft without reverse thrust are approximately 4 to 7 times greater than for aircraft with reverse thrust.

The overrun accident/incident rate of jet aircraft landing on a slippery runway in Canada over the period 1989 to 2001 was approximately 17 per million landings on slippery runways (excluding cases where aircraft went off the side of the runway). For commercial passenger jet aircraft the rate was 13 per million landings. Due to the small proportion of landings on slippery runways, the overrun accident/incident rate due to slippery runways over all landings was 1.3 per million, or 1.0 per million for commercial passenger jet aircraft. The consequences of these overruns also tend to be low, with no fatalities recorded in these types of accidents in the last 25 years in Canada.

The benefits of using the CRFI Tables to adjust landing field length (LFL) exceed the costs of doing so for all aircraft types when the LFL under current regulations equals the runway length available and the runway is very slippery (CRFI approximately 0.2).

For most jet aircraft landings in Canada, the runway length available far exceeds the LFL required and this provides an additional margin of safety above that provided by the regulations. The risk of an overrun when the runway is slippery is greatly reduced by this additional margin of safety. The additional runway length available will result in extremely few flights (less than 0.01%) being affected by LFL requirements that account for slippery runways using the CRFI Tables.

Considering only the benefits and costs to passenger and air carrier operations, the benefit-cost ratio for use of the CRFI Tables relative to the current regulations over all air carrier jet aircraft landings in Canada, allowing for the range in runway conditions and aircraft weights, is estimated to be approximately 4.7. Much of the benefit is attributed to a small number of landings of B747 aircraft on runways of 9,000 ft. or less.

Considering the benefits and costs to passengers and air carriers of operations, updating manuals and training, and the additional costs to the airport, the benefit-cost ratio for use of the CRFI Tables is estimated to be approximately 1.2.

Costs associated with extending the applicability of the 115% adjustment to LFL to cover slippery runways are low and the benefits for the few landings affected are very high giving a benefit-cost ratio of over 4. As a minimum, the 115% adjustment should be extended to slippery runways. Many pilots already use an adjustment of 115% or greater. Considering only the operational benefits and costs, the incremental benefits of moving from the 115% adjustment to the use of the CRFI Tables for slippery runways are slightly greater than the incremental costs (benefit-cost ratio of 1.1). However, if the costs of manual updates and training are considered, costs exceed the benefits.

Application of adjustments in LFL for slippery runways based on manufacturers' guidance material would result in very high costs if applied to all landings on slippery runways, irrespective of the actual CRFI value and braking information in the pilot reports (PIREPs). Under these conditions, the CRFI Table adjustment provides a very cost-effective alternative for accounting for slippery runways.

Recommendations

Based on the analysis of Canadian aircraft landing operations, it is recommended that:

- The 115% adjustment to the calculation of the required LFL for a wet runway applicable at the time of dispatch be extended to include runway conditions where the CRFI value is 0.5 or less, or where there is ice, compacted snow and/or shallow depth loose snow covering 20% or more of the runway.
- Guidance material be provided for turbo-jet aircraft by the air operator, which will allow the pilot of the aircraft to determine the runway distance required to land the aircraft when the runway is slippery due to ice, compact snow and/or shallow depth loose snow contamination. The guidance material may base the determination of the landing distance on a combination of the CRFI value, PIREP braking reports and the type and extent of snow/ice contamination on the runway, taking into consideration the time of the last reports. Guidance or other material provided by the manufacturer of the aircraft and the CRFI Tables provide acceptable sources of information for developing the guidance material. The procedures for determining landing distance should be easy to use so as to allow pilots to make the calculations while en route, just prior to landings if necessary.
- Consideration be given to allow an air carrier to exclude aircraft types from the above requirement where the adjusted LFL with a CRFI value of 0.18, allowing for the pressure-altitude of the airport, zero headwind and 0°C ambient temperature, is less than the runway length available at all airports where that carrier is approved to operate.

Sommaire

Introduction

En 1995, Transports Canada (TC), la Federal Aviation Administration (FAA), la U.S. National Aeronautics and Space Administration (NASA) et le Conseil national de recherches du Canada (CNRC) ont lancé un programme de cinq ans pour la mesure du coefficient de frottement des chaussées aéronautiques en conditions hivernales. Plus tard, en 1996, des organisations nord-américaines et européennes se sont jointes à ce projet, appelé depuis Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver. Ce programme a conduit à la constitution d'une base substantielle de données sur la mesure du frottement des pneus des aéronefs, sur les différents instruments employés pour mesurer le frottement sur piste, et au développement d'une meilleure connaissance des facteurs influant sur les procédures de mesure et sur la relation entre le coefficient de frottement et le freinage des aéronefs. Pour les pistes couvertes de neige tassée, de glace ou de neige folle en faible épaisseur influant peu ou pas sur la résistance à l'avancement, on a constaté que les mesures avaient donné des résultats uniformes, en corrélation avec les performances de freinage de l'aéronef.

Armé d'une connaissance plus approfondie des phénomènes de frottement des pistes, Transports Canada cherche à utiliser plus efficacement l'information accumulée, afin de réduire les risques et, lorsque c'est possible, les coûts d'exploitation. L'étude visait une meilleure compréhension de l'utilisation des directives actuelles sur l'état des pistes, et à montrer qu'il est économiquement justifié d'implanter des changements afin d'exiger que les transporteurs aériens commerciaux de passagers utilisant des avions à réaction tiennent compte de la glissance des pistes au moment de l'atterrissage.

Méthodologie

La prise en compte du frottement des pistes aura vraisemblablement comme avantage principal de réduire les risques de dépassement de piste à l'atterrissage. Une évaluation de la réduction des risques associée à l'utilisation de cette information constitue donc une composante importante de l'analyse coûts-avantages. Pour mieux comprendre l'utilisation des directives actuelles sur l'état des pistes et pour déterminer les avantages et les coûts de la prise en compte de la glissance des pistes, les chercheurs ont choisi les voies suivantes :

- Examiner les normes et les directives existantes.
- Examiner les conditions de piste ainsi que les pratiques de communication et d'utilisation de l'information sur le frottement des pistes dans les aéroports.
- Mener une enquête auprès des pilotes de ligne canadiens afin de connaître leurs pratiques actuelles, leur utilisation des directives et leur opinion sur la prise en compte du frottement des pistes.

- Examiner l’historique des accidents/incidents avec dépassement de piste à l’atterrissage; analyser les risques pour l’atterrissage de même que la possibilité de réduire ces risques en utilisant les informations sur le frottement.
- Déterminer les avantages et les coûts additionnels, pour les aéroports, des changements à la procédure de mesure et de signalement du frottement des pistes.
- Analyser les avantages et les coûts, pour les exploitants aériens et pour les passagers, découlant de la prise en compte du frottement dans le calcul des performances à l’atterrissage.
- Déterminer les avantages et les coûts globaux, ainsi que le ratio coûts-avantages.

Situation actuelle

Selon les règlements de Transports Canada (TC) et de la Federal Aviation Administration (FAA), la distance d’atterrissage indiquée dans le manuel de vol de l’appareil ne doit pas dépasser 60 % de la longueur de piste d’atterrissage disponible. Les règlements exigent une longueur additionnelle de 15 % si, au moment d’autoriser l’aéronef à décoller, il est prévu que la piste à destination sera mouillée. Ces règlements ont des répercussions importantes.

- Pour la plupart des types d’avions, on ne doit pas tenir compte de l’inversion de poussée pour déterminer la distance d’atterrissage et la longueur de piste requise selon les indications du manuel de vol, bien que ce système soit couramment utilisé par les pilotes pour réduire la distance de freinage. Les avions avec inversion de poussée bénéficient donc d’une marge de sécurité supplémentaire que la réglementation ignore, ce système étant particulièrement efficace sur les pistes glissantes opposant peu de frottement au freinage.
- Rien n’oblige à corriger les distances d’atterrissage en cas de piste enneigée, glacée ou givrée. Dans ces conditions, il n’est pas nécessaire d’appliquer le facteur de correction de 115 % pour piste mouillée.
- L’obligation de corriger la distance pour cause de piste mouillée ne s’applique qu’en fonction des conditions existant au moment de recevoir l’autorisation de décoller ou au décollage proprement dit. Si des conditions de piste mouillée surviennent pendant que l’avion est en route, le pilote n’a pas à recalculer avec la marge additionnelle de 15 % la distance d’atterrissage qui est déjà pondérée.

L’enquête auprès de pilotes de ligne canadiens a révélé que la plupart connaissent les directives concernant les opérations sur piste mouillée et appliquent effectivement la correction lorsque la piste est mouillée. Les tables de la Publication d’information aéronautique de TC, désignées comme les tables du Coefficient canadien de frottement sur piste (CRFI), sont établies d’après les résultats d’essais menés à North Bay avec un appareil Falcon 20, lesquels contiennent des facteurs de correction établis selon le CRFI. Or, la plupart des pilotes ont indiqué que les manuels de vol des appareils et les manuels des transporteurs se limitaient à qualifier le freinage par les termes «bon», «moyen» ou «faible», et que ces manuels ne mentionnaient pas spécifiquement le frottement de la piste.

Des données sur les états de surface des pistes aux aéroports de Calgary, Toronto, Ottawa et Halifax, recueillies sur des périodes d'un an à trois ans, ont été analysées conjointement avec les données sur cinq aéroports collectées entre 1988 et 1990. L'occurrence de pistes glissantes varie beaucoup entre les différents aéroports. On peut voir dans le tableau suivant le taux d'occurrences de contaminants rendant la chaussée glissante et les valeurs moyennes du CRFI obtenues avec chaque type de contaminant :

Contaminant	Durant l'hiver	Durant un an	CRFI moyen
Glace	6,6 %	2,8 %	0,32
Neige tassée	2,4 %	1,0 %	0,32
Givre	0,7 %	0,3 %	0,41
Neige folle, 1/8 po	3,5 %	1,4 %	0,40
Tous contaminants	13,2 %	5,5 %	

Source : Rapports des états de surface des pistes fournies par les aéroports
Notes : Valeurs applicables selon un contaminant ≥ 20 % de la piste (souvent <100 %).
Pistes habituellement traitées pour présenter un meilleur frottement.

Les valeurs du CRFI varient de façon significative par rapport à ces moyennes, comme l'illustre la figure 1. Sur une période d'un an, le CRFI est de 0,2 ou moins pendant 0,5 % du temps, entre 0,21 et 0,3 pendant 2,1 % du temps; entre 0,31 et 0,4 pendant 1,7 % du temps; entre 0,41 et 0,50 pendant 8 % du temps; et de 0,51 ou plus pendant 94,9 % du temps.

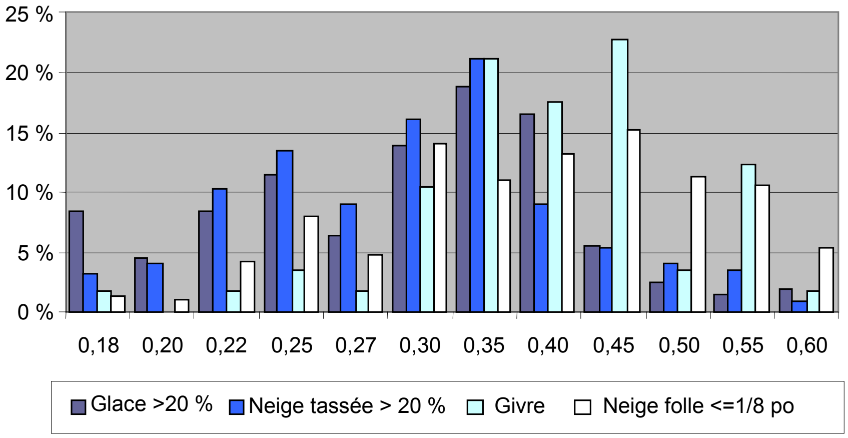

Figure 1 Distribution moyenne des valeurs du CRFI par type de contaminant dans les aéroports canadiens

Analyse coûts-avantages

L'analyse coûts-avantages comparait l'utilisation des tables du CRFI pour la prise en compte des chaussées glissantes au regard de la réglementation actuelle (sans correction), avec correction de 115 % pour piste mouillée, et avec corrections selon les directives des manuels de vol. Certains avions ne faisaient pas l'objet de directives en ce sens; dans ces cas, on appliquait un facteur de correction fondée sur les corrections utilisées pour des avions similaires.

Pour déterminer les avantages de tenir compte de l'état glissant de la piste, on a évalué la réduction conséquente des coûts associés aux accidents. Un modèle a été mis au point pour calculer la probabilité de dépassement de piste, et pour en évaluer les conséquences. La distance d'atterrissage a été estimée à partir de la distance indiquée dans le manuel de vol de l'avion, corrigée pour piste mouillée d'après les résultats d'essais effectués avec un Falcon 20, à North Bay, par le CNRC et par TC. Le modèle adopté prévoit les variations de la distance en vol avant le toucher, le temps de retard, le coefficient de frottement en freinage sur chaussée mouillée ainsi que le réglage et l'application des freins. Le modèle de risque s'est révélé conforme avec les statistiques sur les dépassements de piste au Canada.

Les coûts pour les exploitants aériens et pour les passagers comprenaient les retards pour cause de CRFI insatisfaisant, les annulations et les déroutements de vol, les réductions de la masse de l'avion, la mise à jour des manuels de vol et la formation supplémentaire requise. Le coût additionnel pour les aéroports sera faible étant donné que le CRFI est déjà mesuré dans tous les aéroports avec chaussées en dur et service d'avions à réaction. Un seul aéroport, avec piste en gravier, pourrait être touché par ces coûts, mais on étudie la possibilité d'exemption de collecte du CRFI dans le cas des pistes en gravier. D'autres coûts pourraient s'ajouter aux charges financières des aéroports, comme la communication du CRFI plus tôt dans la matinée ainsi que les coûts reliés aux modifications des procédures et à la formation nécessaire pour assurer l'uniformité au chapitre de la déclaration du CRFI.

Conclusions

Pour un avion à réaction se posant sur une surface mouillée, le risque de dépassement de piste est 13 fois plus élevé que sur piste sèche. En atterrissage avec un avion non équipé d'inverseurs de poussée, ce risque est de 4 à 7 fois plus grand que pour un avion qui en est muni.

Durant la période comprise de 1989 à 2001, le taux d'accidents/incidents de dépassement de piste par un avion à réaction en atterrissage sur piste glissante au Canada était d'environ 17 par million d'atterrissages (à l'exception des sorties latérales de piste). Pour les avions à réaction de transport de passagers, ce taux était de 13 par million d'atterrissages. En raison de la faible proportion d'atterrissages sur piste glissante, le taux global d'accidents/incidents de dépassement de piste dûs à la chaussée glissante était de 1,3 par million, ou de 1,0 par million dans le cas des avions de ligne à réaction. Les conséquences de ces dépassements sont plutôt faibles, aucune victime n'ayant été signalée au Canada pour ce type d'incident au cours des 25 dernières années.

L'avantage des tables du CRFI pour corriger la longueur de piste d'atterrissage (LFL, pour Landing Field Length) l'emporte sur les coûts associés à l'application du CRFI, et ce, pour tous les types d'avions, lorsque la LFL, selon la réglementation actuelle, est égale à la longueur de piste disponible et que la piste est très glissante (CRFI d'environ 0,2).

Pour la plupart des atterrissages d'avions à réaction, la longueur de piste disponible excède de beaucoup la LFL requise, ce qui constitue une marge de sécurité additionnelle par rapport à la réglementation, et réduit considérablement le risque de dépassement sur piste glissante. Avec la longueur additionnelle ainsi disponible, très peu de vols (moins de 0,01 %) seront affectés par les exigences de longueur de piste tenant compte de l'état glissant à l'aide des tables du CRFI.

Au seul examen des avantages et des coûts pour les passagers et les exploitants aériens, on estime que l'utilisation des tables du CRFI en fonction de la réglementation actuelle pour tous les atterrissages d'avions à réaction au Canada, en tenant compte des états de surface des pistes et de la masse des aéronefs, présente un ratio coûts-avantages d'environ 4,7. Une grande partie de cet avantage est attribuée au faible nombre d'atterrissages par des Boeing B747 sur pistes de 9 000 pieds ou moins.

Considérant les avantages et les coûts pour les passagers et les exploitants aériens, l'actualisation des manuels et la formation, ainsi que les coûts additionnels pour l'aéroport, le ratio coûts-avantages de l'utilisation des tables du CRFI est d'environ 1,2.

Les coûts associés à l'application d'un facteur de correction de 115 % à la LFL pour tenir compte d'un état glissant sont faibles et les avantages pour les quelques atterrissages affectés sont très importants, d'où un ratio coûts-avantages supérieur à 4. Il conviendrait au moins d'étendre la correction de 115 % aux pistes glissantes; beaucoup de pilotes utilisent déjà une correction de 115 % ou plus. En ne considérant que les avantages et les coûts pour les opérations aériennes, passer de la correction de 115 % à l'utilisation des tables du CRFI pour les pistes glissantes apporte des avantages légèrement supérieurs aux coûts additionnels (ratio coûts-avantages de 1,1). Or, lorsque les coûts d'actualisation des manuels et les coûts de formation entrent en jeu, les coûts dépassent les avantages.

L'application à la LFL des corrections pour piste glissante, fondée sur les directives du constructeur entraînerait des coûts très élevés si elle était étendue à tous les atterrissages sur piste mouillée, sans tenir compte de la valeur réelle du CRFI et du compte rendu de pilote (PIREP) sur le freinage. Dans ces conditions, la correction des distances d'atterrissage de la table du CRFI est une solution de rechange très rentable pour la prise en compte des phénomènes glissants.

Recommandations

À la lumière d'une analyse des atterrissages d'aéronefs au Canada, il est recommandé :

- que la correction de 115 % appliquée au calcul de la LFL requise pour une piste glissante, applicable au moment de l'autorisation soit étendue de manière à tenir compte des conditions de piste donnant un CRFI de 0,5 ou moins, ou de conditions de glace, de neige tassée et/ou de neige folle en faible épaisseur couvrant au moins 12 % de la surface de la piste;

- que des directives concernant les avions à réaction soient fournies par l'exploitant aérien pour que le pilote puisse déterminer la longueur de piste nécessaire pour un atterrissage sur une piste rendue glissante par la présence de glace, de neige tassée ou de neige folle en faible épaisseur. Ces directives pourront être fondées sur la détermination de la distance d'atterrissage pour une combinaison de la valeur du CRFI, des compte rendus du pilote sur le freinage, et du type et de l'importance de la contamination neige/glace sur la piste, en tenant compte de l'heure de publication des derniers rapports. Les directives ou toute autre information fournie par le constructeur de l'appareil, de même que les tables du CRFI constituent une source acceptable pour l'élaboration de ces directives. Déterminer la distance d'atterrissage doit être simple : les calculs doivent être réalisables en route par les pilotes, juste avant l'atterrissage s'il le faut; et
- que l'exploitant aérien doit pouvoir soustraire certains types d'avions de ces exigences lorsque la LFL corrigée par un CRFI de 0,18, à l'altitude-pression de l'aéroport, vent debout nul et température ambiante de 0 °C, est inférieure à la longueur de piste disponible à tous les aéroports auxquels il est autorisé à atterrir.

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Glossary of Terms

AC	Advisory Circular
AFM	Aircraft Flight Manual
AFTN	Automated Fixed Telecommunications Network
AIP	Aeronautical Information Publication
ALPA	Air Line Pilots Association
AMSCR	Aircraft Movement Surface Condition Reporting
AOM	Aircraft Operating Manual
ATC	Air Traffic Control
ATSB	Australian Transport Safety Bureau
B:C Ratio	Benefit-cost ratio
CAR	Canadian Aviation Regulations
CRFI	Canadian Runway Friction Index
CRJ	Canadair Regional Jet
FAA	Federal Aviation Administration
JAA	European Joint Aviation Authority
JBI	James Brake Index
LFL	Landing Field Length (factored landing distance)
PIREPS	Pilot reports
RJ	Regional jet
RSC	Runway surface condition
TC	Transport Canada
TSB	Transportation Safety Board of Canada
V_{MCL}	Minimum control speed during approach and landing with all engines operating
V_s	Stall speed

1. INTRODUCTION

1.1 Background

Transport Canada (TC), in association with the Federal Aviation Administration (FAA), the U.S. National Aeronautics and Space Administration, and National Research Council Canada, implemented a five-year program for winter runway friction testing in 1995. The program expanded in 1996 to include other North American and European organizations, and has become a concerted international effort known as the Joint Winter Runway Friction Measurement Program [1]. The program has led to the collection of a substantial database of aircraft and ground vehicle friction measurement data from various runways, and to the development of a greater understanding of the factors affecting runway friction, its measurement, and the relationship between runway friction and aircraft braking. For runways with compacted snow or ice contamination, or loose snow with shallow contaminant depth and therefore very little or no contaminant drag, the runway friction measurements were found to be consistent and correlate well with aircraft braking [2,3].

With this improved knowledge of runway friction, Transport Canada is looking at making better use of runway friction information in practice to reduce the risks and possibly operating costs. The types of changes being considered relate to:

- The standardized reporting of runway friction in Aerodrome Standards;
- The provision of material relating aircraft braking coefficients to take-off and landing performance in the Aircraft Flight Manual (AFM); and
- The use of runway friction information for particular types of runway contamination in Operating Standards for Commercial Aviation.

Accountability of runway conditions on take-off has been the subject of intense study and debate for at least ten years. Since the early 1990s the European Joint Aviation Authority (JAA) has required manufacturers to provide guidance material for runway conditions on take-off in the AFM. The performance calculations could include allowance for reverse thrust and a 15 ft. screen height. Manufacturers were not required to conduct further testing – the material could be based on theoretical drag and braking calculations. JAA now has operating regulations requiring accountability for wet runways for all aircraft on take-off, while the FAA included the requirement only for newly certified aircraft. TC has followed the same course as the FAA. The FAA-JAA harmonization group has not been able to solve the differences due to FAA concerns with the economic burden on U.S. carriers from the use of JAA's procedures. Sypher conducted a study [4] in 1993-94 of the risks, benefits and costs in Canada of runway condition accountability on take-off using the JAA procedures. This study found that if take-off weight could be reduced by reducing cargo, costs were close to the benefits, but if passengers were off-loaded, costs exceeded the benefits. However, the study also showed that the risks for take-offs on contaminated runways under current regulations were higher than generally accepted risks in aviation.

For landings, current TC and FAA regulations include a requirement for an additional 15% runway length when the destination runway is forecast to be wet at the time the aircraft is dispatched.

1.2. Objectives

The objective of this study was to better understand the use of the currently available guidance material related to runway condition and to develop an economic rationale for the changes being considered. More specifically:

- To determine to what extent guidance material on the effects of runway condition on landing performance is available and being used by pilots, and the potential for more effective use of runway friction information;
- To determine the benefits and costs of providing and using runway friction information by:
    - airport operators – provision and use for runway maintenance,
    - aircraft operators – use of runway friction information for landing in comparison to the cases where guidance material is, and is not, used;
- To determine the benefit-cost ratios of accounting for runway friction on landing; and
- To develop a strategy for reducing risks in a cost-effective manner by implementing procedures for accounting for runway friction.

1.3. Scope

The scope of the study included all passenger-carrying jet aircraft operated by Canadian registered commercial air operators. The analysis focused on the most common aircraft types, and types for which information was available.

For the purposes of this analysis, the runway is considered to be slippery when:

- Ice, compact snow or frost cover 20% or more of the runway, or
- Loose snow of less than or equal to a depth of 1/8 in. covers 20% or more of the runway.

2. APPROACH

Much of the benefit of accounting for runway friction will likely be due to a reduction in the risk of overrun accidents on landing. An analysis of the reduction in risks due to the use of runway friction information is therefore an important component of the benefit-cost analysis. The approach used to better understand the use of the currently available guidance material related to runway condition and to determine the benefits and costs of accounting for slippery runways was to:

- Review existing standards and guidance material;
- Review runway conditions and reporting of friction at airports;
- Conduct a survey of airline pilots on current practices, their use of guidance material and their views on accounting for runway friction;
- Examine past overrun accident/incident experience on landing, analyze the risks on landing and the reduction in risks due to use of runway friction information;
- Determine the incremental benefits and costs to airports of changes in the measurement and reporting of runway friction information;
- Analyze the benefits and costs to air operators and passengers of accounting for runway friction in landing performance calculations; and
- Determine overall benefits and costs, and the benefit-cost ratio.

The survey of commercial airline pilots was conducted in 2001 and the results are given in a separate report [5]. The survey was distributed to 2,450 airline pilots in Canada and 393 responses were received. Findings from this survey are included in the discussion and analyses given in this report.

3. CURRENT SITUATION

3.1 Landing Distances and Field Length Requirements

The landing distance requirements for operation of jet aircraft on commercial service are given in Part V – Airworthiness and Part VII – Commercial Air Services of the Canadian Aviation Regulations (CARs). The relevant sections of the regulations are given in Appendix A of this report. The airworthiness regulations give the following requirements for the landing distance given in the AFM:

- Landing distance is the horizontal distance from a point 50 ft. above the landing surface to where the aircraft comes to a full stop;
- A stabilized approach must be used with air speed not less than 1.3 V_S or V_{MCL}, whichever is greater, maintained down to 50 ft. height (where V_S is the stall speed and V_{MCL} is the minimum control speed during approach and landing with all engines operating);
- Accepted procedures for service operation must be followed, and these must not require exceptional piloting skills or alertness, or be made with excessive braking, vertical acceleration, nose over, etc.;
- Landing distance is determined on a level, smooth, dry, hard-surface runway;
- Landing distance must include correction factors for 50% of the headwind and 150% of the tailwind; and
- Landing distance must exclude the use of any device that depends on the operation on any engine, e.g., reverse thrust.

In addition, the AFM of transport category aeroplanes must contain approved guidance material that covers take-off and landing of aeroplanes for operation on wet and contaminated runways. This requirement only applies to aeroplanes whose date of application for a type approval was made after the applicability date of August 1, 1992.

The Commercial Air Service regulations place the following requirements on the dispatch of aircraft:

- The weight of the aeroplane on landing at either the destination or alternate aerodrome will allow a full-stop landing within 60% of the landing distance available for turbo-jet aeroplanes and within 70% of landing distance available for propeller driven aeroplanes. The factored landing distance is referred to as the landing field length (LFL) required;
- The landing distance must take into account the pressure-altitude at the destination and alternate aerodrome and 50% of the reported headwind or 150% of the reported tailwind; and

- When weather reports or forecasts indicate that the runway may be wet at the estimated time of arrival, the air operators shall not dispatch or conduct a take-off of a jet aircraft unless the landing distance available at the destination aerodrome is at least 115% of the factored landing distance satisfying the requirements above, or by a smaller factor (but not less than 100%) if such a factor is specified in the AFM for landing distances on wet runways.

Important implications of these regulations are that:

- The landing distances in the AFM are for landing on a dry runway and include no safety factors other than the possible use of reverse thrust, which cannot be used in determining the AFM landing distance for most aircraft types but which can be used in operational situations to reduce stopping distance;
- There is no requirement to adjust the landing distances to account for snow, ice or frost on the runway. The factor of 115% for wet runways does not have to be applied in these runway conditions; and
- The requirement to adjust for a wet runway applies only at the time of dispatch and take-off – once airborne, if the runway conditions change and become wet, there is no requirement for the pilot to re-calculate the factored landing distance with the additional 15% margin.

3.2. Available Guidance Material

Approved guidance material for operating on contaminated runways must be included in the AFM of transport category aeroplanes type certificated after August 1, 1992.

The aircraft operating manual (AOM) is the most common source of guidance material for operating on wet and contaminated runways. In the survey of airline pilots, 75% of pilots of jet aircraft indicated they used this source. Over 70% indicated that other company material is available on wet and contaminated runway operations. Information from other company material is particularly common for pilots of regional jets and turboprops.

Transport Canada has issued several publications on operations on wet and contaminated runways for use as guidance material for pilots. These include:

- AIP – Sections 1.6 – Runway Friction Index [6]
- Commercial and Business Aviation Advisory Circular AC 164 – Canadian Runway Friction Index [7]

Both these publications include tables specifying adjustments to landing distances for specific Canadian Runway Friction Index (CRFI) values for jet and turboprop aircraft with and without reverse thrust. These tables are generally referred to as the CRFI Tables. These tables were developed based on the results of extensive tests conducted as part of the winter runway friction testing program conducted at North Bay. The landing distance adjustments given in the tables were developed to represent 95% confidence intervals for the landing distance for given CRFI values [3,8]. However, as shown in Appendix B, the tables provide a much greater safety factor than this, likely about 1:10,000.

The survey of airline pilots indicated that 50% of pilots of regional jets and 60% of pilots of larger jets make use of this material. In addition to the above documents, TC issues the an Aerodrome Safety Circular – ASC 2000-002 Aircraft Movement Surface Condition Reporting (AMSCR) for Winter Operations [9] that describes the procedures used by airports to measure and report CRFI values.

Other sources of guidance material include:

- The Jeppensen manual;
- Industry and association journals, magazines and safety material, and
- Aircraft manufacturer material.

Most of the guidance material refers to the runway friction, or CRFI value; however, only TC publications AIP and AC 164 provide a means of adjusting landing distances for specific CRFI values.

The two major aircraft manufacturers use difference methods of classifying runway conditions for determining landing distances, neither of which refer specifically to the runway friction. Boeing provides adjustments for the aircraft braking, which is typically classified as good, medium (fair) or poor. Braking reports are received from the tower or Automatic Terminal Information Service (ATIS) based on the most recent reports of braking action provided by pilots of aircraft that have just landed. Some operators provide a means of choosing the braking classification based on the friction values and/or type of contamination. Airbus provides adjustments based on the type and depth of contaminant on the runway.

3.3. Availability of CRFI

CRFI values are included, when appropriate, in the AMSCR produced by the airport. AMSCRs are issued whenever there is a significant change in runway surface conditions, or a minimum of once every eight hours. CRFI values are included in the AMSCR whenever there is ice (including wet ice or slush over ice), frost, compacted snow, loose snow not exceeding 1 in. in depth on the runway, or sand, aggregate anti-icing or de-icing chemicals have been applied to the runway. CRFI values are not reported if the runway is simply wet or slush covered, or has loose snow over 1 in. deep. The CRFI reporting requirements and procedures are given in the ASC 2000-002 [9] and the Airport Winter Maintenance Manual TP 659 [10].

Runway surface condition (RSC) and CRFI NOTAMS[1] are issued to alert pilots to conditions of snow, ice, slush, water, etc. that could affect aircraft braking performance. Friction values of 0.40 or less are disseminated on the Automated Fixed Telecommunications Network (AFTN), and readings of 0.30 or less are forwarded immediately to the applicable Air Traffic Services unit for relay to inbound flights.

CRFI values are currently provided at all airports in Canada that have paved runways and jet services operated under CAR 704 or 705. Regulations requiring CRFI to be provided at all airports with international service under CAR 705 or domestic service under CAR 703 and 704 (using 20+ seat aircraft) have been proposed and are currently under review by a TC Working Group. An exemption for airports with only gravel runways is being considered.

3.4. Pilots' Use of CRFI and Guidance Material

Airline pilots consider the CRFI value to be an important indicator of runway condition and monitor it closely. The primary uses of the CRFI values, and the percentage of pilots in the survey indicating this use, are:

- Determine crosswind limits – 91%;
- Determine landing distances/weights – 84%;
- Adjust actions to reduce risks – 77%; and
- Determine take-off weights/distances – 60%.

CRFI values can be used to adjust landing distances either directly from the CRFI Tables included in the AIP and AC 164, or indirectly in choosing the braking effectiveness or contaminant type for use in adjustments specified in the AOM or company or other guidance material. Although there is no regulation covering the use of guidance information for adjusting landing distances on slippery runways, pilots would typically first use approved data provided in the AFM/AMO if available, then unapproved (supplemental) data in the AFM/AOM if available, then third party data acceptable to the governing authority if available, and finally, in the absence of the other three, the CRFI Tables. Adjustments determined using the CRFI Tables may also be used if they provide longer landing distances than those provided by the other material. In the survey of pilots, pilots indicated that they found the CRFI Tables difficult to use and this likely discourages their use on a routine basis.

Some airlines provide guidance material to pilots relating runway friction on runways with snow and ice contamination to braking effectiveness. This material varies between operators. Examples of the type of guidance information provided by two airlines are given in Table 3.1.

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[1] NOTAM is a notice containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

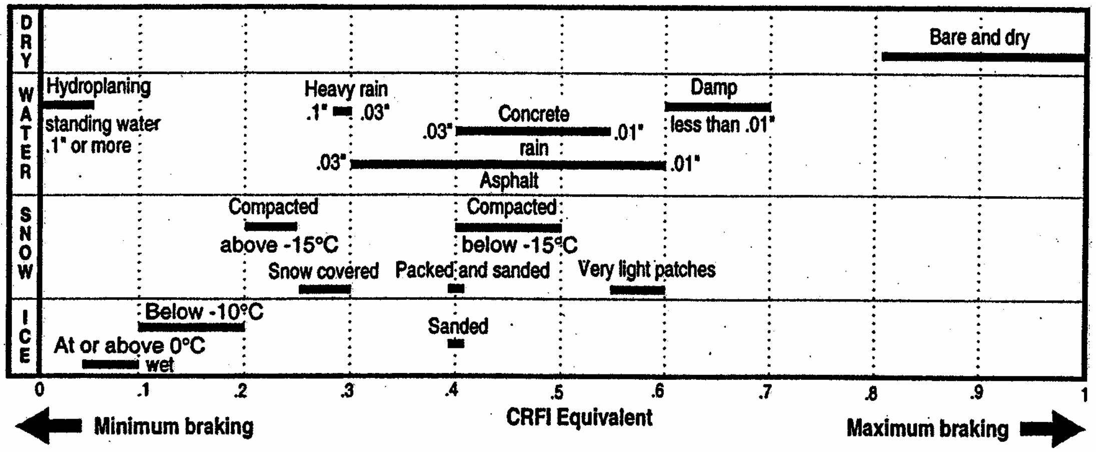
Table 3.1 Examples of Guidance Information to Pilots for Relating Runway Friction and Braking Effectiveness from Two Airlines

Airline 1		Airline 2	
Braking	CRFI Range	Braking	Typical CRFI*
Good	0.40 or more	Normal	0.6 or above
Medium/Good	0.39 to 0.36	Good	0.65 to 0.40
Medium	0.35 to 0.30	Fair	0.50 to 0.30
Medium/Poor	0.29 to 0.26	Poor	0.35 to 0.20
Poor	0.25 or less	Nil	0.25 or less

* Note that ranges of typical CRFI values overlap in the classification for Airline 2.
Source: Confidential

The guidance material notes that the term "good" is a comparative term and pilots should not expect to find conditions the same as when landing on a bare and dry runway, but that the aeroplane should not experience directional control or braking difficulties because of the runway condition.

A.I.P. Canada provides a diagram, given in Figure 3.1, showing the typical range of CRFI values for various runway surface conditions.



Source: A.I.P. Canada, Section 1.6.6, Table 4

Figure 3.1 Runway Surface Condition (RSC) and CRFI Equivalent

Comments provided by pilots in the survey indicate that the pilots currently find the CRFI Tables difficult to use in their current format and that they would like them to be available for their specific aircraft type in simple easy-to-use charts suitable for quick reference. Almost 20% of pilots indicated that they have never had training on the use of runway friction information. Pilots receiving training in the past 12 months varied greatly by aircraft category: 84% of RJ pilots received such training but only 45% of pilots of larger jet aircraft received the training.

Some of the concerns with the use of CRFI values in determining landing distances expressed by pilots are given below.

- Frequency with which the CRFI values are updated – CRFI values can change rapidly in some conditions and are not always updated frequently enough.
- Timeliness in providing pilots with the latest CRFI values is not always good.
- Variation in the runway friction along the runway – if CRFI is much lower on some parts of the runway, the stopping distance may be much greater if braking is on that section, and crosswind limits should be greater on those sections.
- Accuracy of the CRFI value for predicting stopping distance at the time of landing – CRFI may have changed since the time it was measured and friction may vary along the runway.
- Use of CRFI values in determining landing distances and allowed landing weight at the time the aircraft is dispatched – CRFI values may change significantly by the time the aircraft arrives at the destination, typically 1-3 hours later for most domestic flights. Forecasts of CRFI values are not available and would likely not be very accurate.
- Other information available from PIREPS on braking effectiveness can provide a good if not better means of determining adjustments to landing distances, and the use of CRFI values should not preclude the use of this other information.

3.5 Precautions Taken by Pilots to Reduce Risks on Slippery Runways

The survey of airline pilots indicated that pilots adjust their procedures to reduce the risks when runways are slippery. Most pilots indicated that they take one or more of the following actions: firm touchdown (don’t float), higher autobrake setting (typically medium), quick application of maximum reverse thrust (once directional control has been maintained), high landing flap setting, and airspeed at or slightly below reference speed. A number indicated that they try to touch down at the 1,000 ft. mark or a little before. The actions taken by pilots to reduce the risks can significantly reduce the landing distance and the likelihood of an overrun when operating on slippery runways. These actions should be reflected in the aircraft overrun rate on landing and it is important that the risk and benefit-cost analyses of accounting for slippery runways be consistent with the actual aircraft overrun rate.

Any changes in procedures that pilots do make should be reflected in the adjusted landing distances for slippery runways so that the adjustments are not overly conservative. If pilots do not currently use some of these procedures, perhaps they should be recommended in guidance material for landing on slippery runways where it is appropriate for the aircraft type.

4. RISKS DUE TO SLIPPERY RUNWAYS

4.1. Understanding the Risks

On a dry runway under good conditions and if everything goes as planned, an aircraft should be able to stop within the landing distance given in the AFM. However, the minimum field length that must be available for the landing is 66.7% greater than the AFM landing distance for jet aircraft when the runway is not wet. This safety margin allows for longer than expected landing distances due to factors such as varying winds, pilot variation/error, equipment malfunction, worn brakes and runway contamination. An additional 15% field length is required if the runway is wet. In most aircraft landings the runway length available, including stop-way if present,[2] is greater than the landing field length required and thus there is additional runway for the aircraft to stop if required. This is best illustrated by consideration of an aircraft landing under various conditions.

Figure 4.1 illustrates three landings on slippery runways, where the aircraft is at the same landing weight, but increasing runway lengths are available. The figure shows the AFM landing distance, LFL required under current regulations, excess runway available under the regulations and the additional runway length required, under three different situations.

A. The field length required is equal to the runway length available. In this situation, the landing weight would likely have been restricted by the available runway length. There is no excess runway available to stop the aircraft above that provided by the regulations.

B. The runway length available is equal to the field length required, adjusted for a wet runway. In these situations there is some excess runway available for landing above LFL required by the current regulation, and the additional runway required is reduced. Most pilots indicated that, although not required, as a minimum they make the 15% wet runway adjustment when the runway is slippery due to snow/ice contamination.

C. The runway length available is greater than the field length required even when adjusted for a wet runway. In this situation, the landing weight is not restricted by the runway length available and there is even more excess runway distance available, resulting in an even shorter additional runway required.

Thus, the margin of safety in the runway distance available for landing is significantly greater than that provided by the regulations, and this reduces the frequency and consequences of overruns.

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[2] When referring to runway length available on landing in this report, the length of the stopway , if available, is also included.

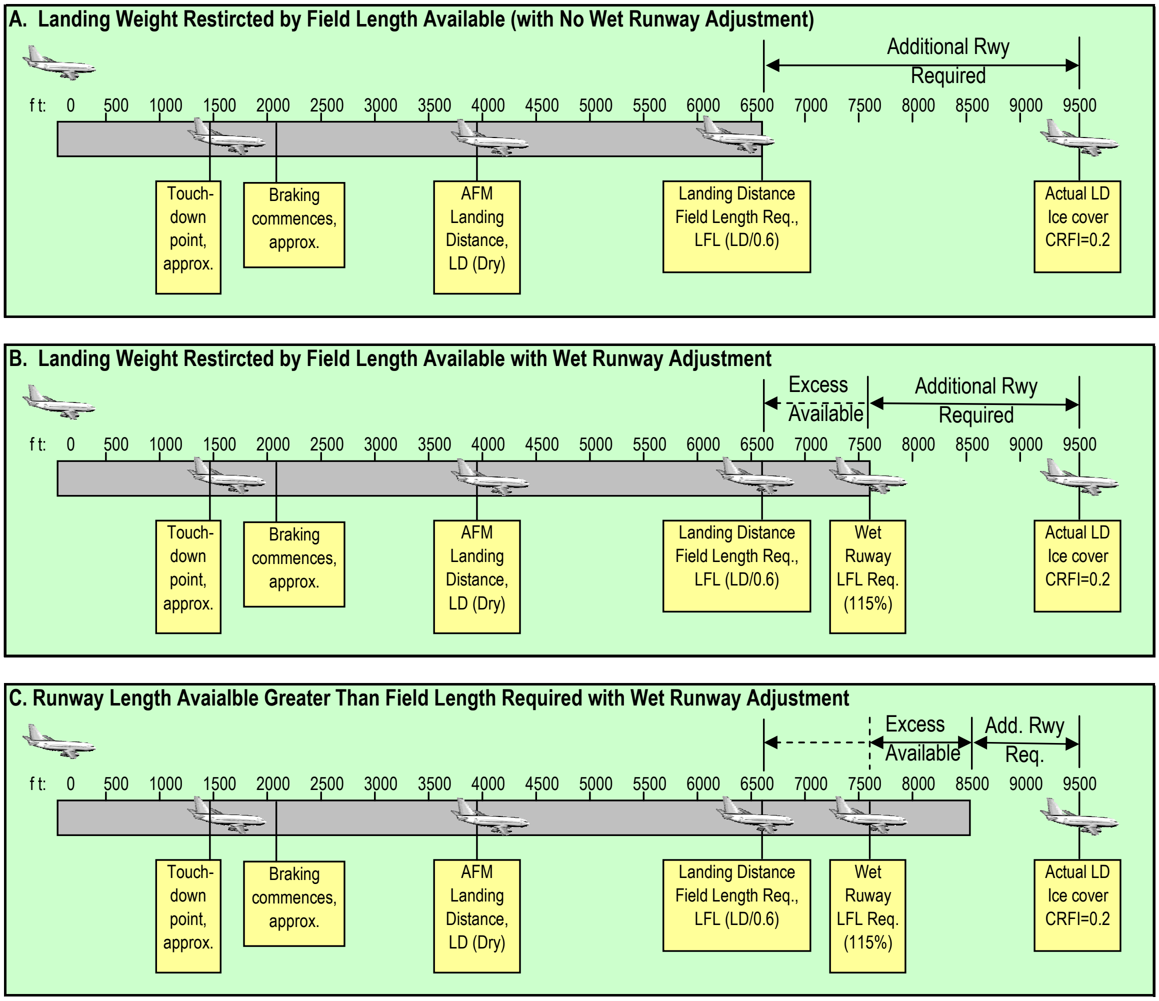

Figure 4.1 Examples of Aircraft Landing Distance, the Excess Runway Available and the Additional Runway Required

4.2. Accident/Incident Analysis

An analysis was conducted of accidents and incidents where the aircraft overran the runway on landing to determine the extent of the problem, the common causal factors, the degree to which slippery runways were a factor, the relative risks landing on a dry and slippery runway, accident/incident rates per landing, and the likelihood of damage to the aircraft, injuries and fatalities.

The analysis focused on Canadian data as it provides the best indication of the risks to Canadian operators and passengers, and the potential benefits of changes in the CARs to account for slippery runways. Due to the small number of landing overrun accidents in Canada, accidents in the U.S. and worldwide were also considered. However, the exposure to risk, i.e., the number/proportion of landings on slippery runways due to snow/ice contamination, is very different in Canada from other countries, and their accident history is of limited value without accounting for the differences in exposure.

The Transportation Safety Board of Canada (TSB) maintains a database of all aircraft accident and incidents occurring in Canada or involving Canadian registered aircraft. Summaries were provided by the TSB of all occurrences (i.e., incidents and accidents) since 1989 involving jet aircraft or turboprops over 12,500 lb. where the aircraft left the runway while landing, excluding those where the aircraft did not touch down on the runway. Flights of military and government aircraft, flights where the aircraft was being tested (e.g., after maintenance) and flight training flights were also excluded. In addition, all accidents in Canada on the TSB database involving jet aircraft that left the runway while landing were examined. A longer time period was not used for incidents because data on incidents prior to 1989 is incomplete and therefore not as useful for examining risks.

The summaries obtained from the TSB included date, location, operator, aircraft make/model, a categorization and description of the event(s) leading to the occurrence, the phase of flight, injuries, and a qualitative description of the occurrence.

Occurrences were not selected based on runway condition, but runway condition was examined to determine whether it was a factor in the accident and to determine the relative risks. The runway condition fields in the incident reports are rarely completed and the runway condition had to be inferred from the event category and description, and from the qualitative summary.

In addition to the occurrences where the aircraft overran the runway on landing, a significant proportion of occurrences involve the aircraft leaving the side of the runway and sometimes then going beyond the end of the runway. Some of these accidents are similar to overrun accidents and may have been prevented by accounting for slippery runways in determining landing distances. In others, factors other than stopping distance led to the occurrence. An example is crosswind, which can cause the aircraft to drift sideward, particularly on slippery runways. The analysis focused on overruns, but the relative risk of “off-side of runway” occurrences on slippery runways was also considered.

The TSB database includes only four accidents involving transport category aircraft where the aircraft overran the runway on landing, and one of these involved a piston aircraft.[3] The four transport category aircraft accidents are summarized in Table 4.1.

Prior to 1989 there was only one overrun accident involving a jet aircraft, a DC-8. There were no fatalities or injuries in that accident. The only factor given in the accident report was that the aircraft landed long. No mention was made of the runway or weather conditions in the accident report. This accident provides little insight into the risks of landing overrun accidents and was therefore not considered further except in estimating the overrun accident rate. The two accidents since 1989 were considered in the analysis of occurrences given below.

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[3] A sixth accident (Occ. # A88P0029, 21-Feb-1988, B737 at Vancouver) had the Event Category miscoded as Runway Overrun when the aircraft was actually standing at the gate.

Table 4.1 Landing Overrun Accidents of Transport Category Aircraft in Canada 1978 - 2001

Year	Airport	Aircraft Type	Operator	Factors	Aircraft Damage	Minor injuries
1978	Gander	DC-8	Flying Tiger	Landed long	Substantial	0
1978	Komakuk	DC-3	Kenn Borek Air	Incorrect wind report	Substantial	0
1999	St. John's	F-28	Inter Canadien	No reverse thrust	Substantial	7
2001	St. John's	B737	Royal		Substantial	0

A total of 30 landing occurrences involving jet aircraft and a further 19 involving turboprop aircraft were identified.[4] The ratio of turboprop to jet occurrences is 0.6, much lower than the ratio of movements of turboprop aircraft over 5.67 tonnes to movements of jet aircraft (approximately 2.5). This indicates that the risk of overruns is much less for turboprop aircraft, although underreporting of overrun incidents where there were no injuries and little or no aircraft damage may have contributed to the comparatively low risk factor.

The landing occurrences for Canadian registered jet aircraft since 1989 in North America are summarized in Table 4.2. Important points regarding these occurrences are summarized below.

- In 10 of the 17 overrun occurrences (59%) the runway was slippery due to snow/ice contamination. This is far greater than the proportion of landings conducted on slippery runways.
- There were three occurrences where the aircraft left the side of the runway and the runway was slippery due to snow/ice contamination, and in one of these the aircraft stopped beyond the end of the runway. Thus, measures to reduce the risk of overruns on slippery runways will address most (75%) of the occurrences on slippery runways.
- 60% of overrun occurrences involved large passenger-carrying aircraft on scheduled or major charter service, the percentage being similar both overall and on slippery runways. Of the other occurrences, 17% were cargo aircraft and 23% were small corporate jets operated privately or on charter service. Since approximately 90% of jet aircraft movements are conducted by large passenger aircraft, the risk of aircraft overruns is far greater for cargo and corporate jet aircraft.

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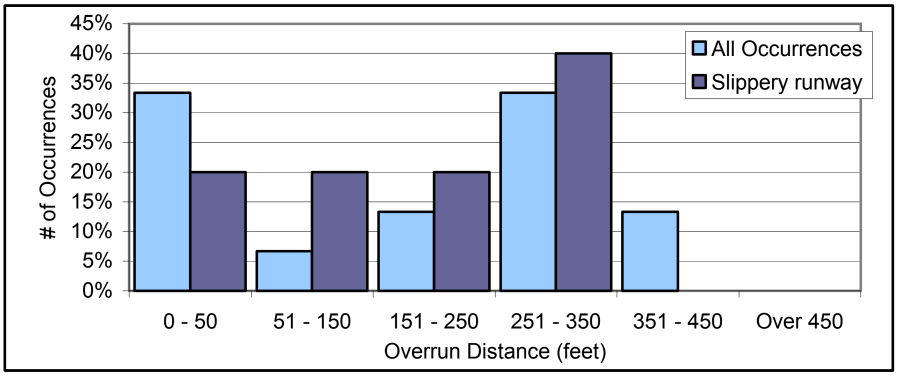
[4] One incident occurring in Fiji on a wet runway involving a Canada 3000 charter jet flight was not considered.

Table 4.2 Summary of Occurrences in Canada on Landing where the Aircraft Overran or Left the Side of the Runway

Year	Airport	Aircraft Type	Operator	Service Type	Over-run ft	Runway Condition	Factors	Aircraft Damage	Minor injuries	Terrain/ Hit
Overrun										
1989	Saskatoon	B737	Canadian	Scheduled	10	Wet	Landed long	Very minor	0	
1990	Gander	DC-8	Rosenbalm Aviation	M.Charter	350	Snow		None	0	
1990	Quebec	DC-8	Nationair	M.Charter	300	Snow, slush, CRFI used 0.38, est. 0.3	Landed long (2600 ft)	None	0	
1990	Deer Lake	BAE 146	Air Nova	Scheduled	30	Slippery		None	0	Flat
1994	Terrace	BAE 146	Air BC	Scheduled	300	Ice & slush		None	0	
1994	Ottawa	A320	Air Canada	Scheduled			Long landing (4000 ft) High and fast	None	0	
1995	St. John's	B727	Royal	Scheduled	300		Landed long	Minor	0	
1999	**St. John's**	**F-28**	**Inter Canadien**	**Scheduled**	**400**		**No rev thrust**	**Substantial**	**7**	
1999	Terrace	BAE 146	Air BC	Scheduled	400		Landed long (3000 ft) Windshear	None	0	
1999	Sandspit	F-28	Canadian	Scheduled	200	100% snow covered, reported CRFI =.53	No rev thrust	None	0	Stopway
2000	Fredericton	F-28	Canadian	Scheduled	300	50%B&D 50% thin slush 1/4"	Speed high No rev thrust	Minor	0	
1989	Halifax	DC-8	Air Canada	Cargo				Minor	0	
1995	Sherbrooke	LR35	Sky Service	Charter	75	Just cleared, thin coat snow last 1000'	No rev thrust	None	0	Deep snow 26"
1995	Detroit City US	LR55	Leased	Private	50	Ice covered on last 1000'	No rev thrust	Minor	0	Hit picket fence
1996	Moncton	B727	Kelowna Flight Craft	Cargo	154	100% Slush 0-1/2" with ice under slush at ruway end	Landed long (1850 ft) Not full rev thrust	None	0	Flat
1998	Peterborough	Falcon 20	Reliant Airlines	Charter			No rev thrust	Minor	0	
1998	Mackenzie	LR35	Canada Jet Charters	Charter	10	Slush light layer	No rev thrust. Drag chute not deployed	None	0	
2001	**St. John's**	**B737**	**Royal**	**Cargo**	**20**			**Substantial**	**0**	**Deep snow**
Off Side and Beyond End of Runway										
1991	Moncton	DC-8	Air Canada	Charter				None	0	
1991	Halifax	DC-9	Air Canada	Scheduled					0	
1998	Calgary	DC-9	Air Canada	Scheduled		Snow, freezing fog		None	0	
1996	Hamilton	B727	Kelowna Flight Craft	Cargo			Windshear	Minor	0	
1999	Trenton, NS	Astra SPX	Jetport	Charter				None	0	
Off Side of Runway										
1993	Calgary	A320	Canadian	Scheduled				None	0	
1996	Fredericton	CRJ	Air Canada	Scheduled				None	0	
1999	Halifax	F-28	Inter Canadien	Scheduled		100% slush 1/8"	Gust winds with dir changes	None	0	
2000	Edmonton	DC-9	Air Canada	Scheduled			Engine failure	None	0	
1993	Roberval	CL-601-1A	Aerien du Quebec	Private		Wet & icy patches towards end of rwy		None	0	
1998	Sudbury	LR112	Samaritan Air Serv.	Charter			Nose gear malfunction		0	
1998	Whitecourt	C550	Sunwest	Charter				None	0	
2000	Montreal Dorva	Gulfstream I	Airwave Transport	Cargo			Landing gear malfunction		0	

Note: Landings on runways with snow/ice contamination are highlighted

- Few aircraft overruns result in accidents (i.e., serious injuries or substantial aircraft damage). Only two of the 17 overrun occurrences were accidents (12%) and in neither was the runway slippery. In both accidents the aircraft was substantially damaged, but there were no serious injuries or fatalities. In one there were seven minor injuries. In almost 60% of the overruns there was no damage to the aircraft and no injuries. Considering only the overruns on slippery runways, there was no damage or injuries in 80% of the overruns.
- Overrun distances in these occurrences varied from 10 to 400 ft. as illustrated in Figure 4.2.



Source: TSB Aviation Occurrence Database, 2001

Figure 4.2 Distribution of Overrun Distances for Occurrences where Canadian Jet Aircraft Overran Runway 1989-2001

Of the 13 occurrences where the aircraft ran off the side of the runway, the runway was slippery due to snow/ice contamination in only three (23%) occurrences. Crosswinds or gusty winds with directional changes are more likely to be a factor in these occurrences, particularly for the smaller, turboprop aircraft (not shown in table). There were no injuries in these occurrences and in only one was the aircraft damaged, the damage being minor.

Detailed investigations are conducted for few occurrences and most reports do not include the factors that led up to the event. The category event description and the qualitative summary usually provide some indication of these factors and they were used to determine the factors given in Table 4.2. The important factors are summarized below.

- The runway condition being slippery is the most common factor (59% of overruns).
- Landed long (i.e., well beyond the 1,000 to 1,500 ft. jet aircraft typically touch down) is the next most common factor. “Landed long” was a factor in six occurrences, or 43% of the 14 occurrences where a factor, including runway condition, was identified.

- High speed was given as a factor in two occurrences (14% of occurrences where a factor was identified).
- A relatively high proportion of the occurrences involved aircraft without reverse thrust – 41% of occurrences compared to only approximately 25% of landing being conducted by jet aircraft without reverse thrust in Canada.[5] In addition, reverse thrust not being applied fully was a factor in one occurrence. Including this occurrence no/inadequate reverse thrust was a factor in 47% of the overruns. No/inadequate reverse thrust is a much more common factor in overruns on slippery runways – 60% compared to 29% when runway was not slippery. The high proportion of small corporate jets involved in overrun occurrences is likely due to the unavailability of reverse thrust in many of these aircraft.

There were too few accidents and too little information to relate the consequences of the occurrences to the terrain at the end of the runway. Of the two accidents where the aircraft suffered substantial damage, in one the F-28 aircraft overran by 400 ft., while in the other a B737 overran by only 20 ft. into deep snow.

Examination of the overrun occurrences involving turboprop aircraft provided little more insight into risks of landing on slippery runways. The incident reports for occurrences of the smaller aircraft tend to be less complete than for larger aircraft, making interpretation of results difficult. Of the reports for the eight overruns, only one mentioned the runway was slippery (CRFI of 0.35-0.37) and another indicated the runway was wet and flooded and hydroplaning occurred. In the only occurrence where the aircraft went beyond the threshold after leaving the side of the runway, the runway was given as 100% snow-covered and slippery. Damage to the aircraft tended to be greater for turboprop aircraft than jets. In three of the eight overruns the aircraft was substantially damaged and in another it was destroyed. Despite the greater damage, injuries only occurred in one of the overruns, these being minor injuries to three people in the accident where the aircraft was destroyed.

International Comparison

These findings are similar to the findings of Kirkland and Caves [11] in an analysis of 137 jet and turboprop landing overrun occurrences in the U.S., UK, Australia and Canada. Their database had an overrepresentation of accidents due to the unavailability of reports for many overrun incidents. Some of their findings relevant to the current study are summarized below.

- Touchdown points in overrun accidents were typically much farther down the runway than in non-overrun landings. For example, in 33% of overrun landings, the aircraft touched down past 2,500 ft. from the threshold, but only 5% of non-overrun landings touched down this far down the runway.
- Landing speed was known to have been excessive in 22% of landing overruns.

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[5] Based on aircraft movements data for jet aircraft at airports in Canada between Oct. 2000 and Sep. 2001 provided by Aviation Statistics, Statistics Canada.

- Only 30% of landing overruns occurred on dry runways, 20% occurred on runways that were very wet or flooded, and 9% were on runways contaminated by snow, ice or slush. The low proportion with snow/ice contamination is related to the low occurrence of these conditions in the countries included in the database.
- Other factors that were commonly associated with overruns on landing in order of importance were:
  - Wet weather,
  - Tailwind,
  - Poor visibility,
  - Aircraft equipment or functional problem after touchdown,
  - Improper use of aircraft equipment,
  - Poor approach planning, and
  - Procedures not followed.
- Average overrun distances were around 100 ft. with almost all being less than 1,000 ft.
- In 80% of accidents where the aircraft was substantially damaged or destroyed, the aircraft encountered an obstacle on the overrun, and in 95% of overruns where an obstacle was not encountered the aircraft suffered little or no damage.

A study by the Australian Transport Safety Bureau (ATSB) in 2000 of landing overrun accidents worldwide found similar results. Of 111 jets overrun accidents between 1970 and 1998 (excluding those with mechanical failure that led to the accident):

- in 38% the aircraft landed long and/or fast on a water-affected runway;
- in 32% touchdown was apparently normal on a water-affected runway; and
- in 30% the aircraft landed long and/or fast on a dry runway.

Preliminary data on 11 jet overrun accidents in 1999 collected by the ATSB indicated that the aircraft landed long and/or fast on a water-affected runway in 45% of cases and in poor weather conditions (runway conditions not stated) in a further 18% of cases.

The ATSB reports indicated that a study of accidents and movement data at western European airports examined 91 overruns and found the accident risk for aircraft operations on water-affected runways to be four times greater than on dry runways.

Overrun Rates

Accident and overrun rates per landing were estimated based on the TSB occurrence data excluding cases where the aircraft went off the side of the runway, and movement data obtained from Statistics Canada.

The landing overrun accident rate for jet aircraft, based on the three accidents and 11.9 million landings since 1978, is estimated to be 0.25 accidents per million landings.

The runway was not identified as slippery in any of the reports for these three accidents. Rather than give an accident rate of zero, which clearly is not a true indication of the risk, the accident rate is given as less than the rate had one accident occurred. Approximately 8% of landings, or 952,000, were conducted on runways contaminated with ice, compact snow or loose snow less than ¼ in. deep from 1978 to 2001 based on data reported by Sypher [12]. The landing overrun accident rate on slippery runways is therefore less than 1.0 per million landings.

The occurrence data since 1989 provides a better indication of the likelihood of landing overruns. During the period over which the occurrence data was collected, 1989 to October 2001, there were 6.77 million landings of jet aircraft at Canadian airports. Based on 2000-01 data, 87% or 5.89 million of these landings were by large passenger aircraft and 0.88 million (13%) by corporate or cargo jet aircraft. The rates for landing overruns of jet aircraft since 1989 when the runway is slippery due to snow/ice contamination and not slippery were determined and are given in Table 4.3.

Table 4.3 Landing Overrun Rates (per million landings) for Jet Aircraft in Canada* 1989-2001

Aircraft Type	Not Slippery Runways		Slippery Runways	
	Number of Occurrences	Rate per M. Landings	Number of Occurrences	Rate per M. Landings
Large Passenger	5	0.92	6	12.7
Corporate/Cargo	3	3.70	3	42.6
Total	8	1.28	9	16.6

* One occurrence of corporate aircraft in Detroit, Michigan, was excluded from set of occurrences in Table 4.2

The analysis indicates that:

- The risk of an overrun is 13 times greater on a slippery runway than under other runway conditions. This ratio is similar for both large passenger aircraft and for corporate and cargo aircraft; and
- The risk of an overrun on slippery runways is over three times greater for corporate and cargo jet aircraft than for large passenger jets.

The landing overrun rate over all jet aircraft of 2.5 per million landings (found by combining rates for slippery and not slippery runways) is much greater than the rate of 0.64 per million landings for jet and turboprop aircraft given by Kirkland and Caves [11]. Their database was incomplete and led to a much lower rate than is actually the case.[6]

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[6] Kirkland and Caves give a rate of 0.32 per million movements based on 13 jet and turboprop overruns in Canada between 1980 and 1998. This compares to 17 jet overruns since 1989. In addition, they appear to have used the total movements of jet and turboprop aircraft in Canada, including small turboprops for which data on incidents is very incomplete.

Overrun rates are 30% higher if incidents where the aircraft ran off the side of the runway and beyond the runway threshold are included. Some of these incidents may be prevented by requirements to adjust LFLs for runway friction. Most of the cases where the aircraft ran off the side of the runway, but not beyond the runway threshold, would not be affected by such a requirement based on examination of the incidents.

The overrun occurrences for turboprop aircraft from the TSB database indicates that the frequency of overruns is less for turboprop aircraft, but that when an overrun occurs the consequences, in terms of aircraft damage and injuries, are greater.

4.3 Pilots' Experience

The survey of pilots included a section on the frequency with which they experienced safety concerns. The results are summarized below.

Pilots were asked to indicate how often they had experienced loss of control when landing on a runway that was icy or covered with compacted snow. Figure 4.3 shows the frequency with which pilots felt that braking was significantly reduced. Most pilots (90%) experienced significant loss of braking on landings last winter, typically between one and five times. Pilots of turboprop and small jet aircraft experienced these situations more often than pilots of larger jet aircraft, partly due to the greater number of landings they perform.

Figure 4.4 presents the frequency that pilots indicated their aircraft slipped sideways while landing on low friction runways due to crosswinds last winter. Occurrences of slipping sideways occurred much more frequently for pilots of smaller aircraft than for pilots of the larger aircraft. Occurrences of the aircraft slipping sideways were much less frequent than occurrences of significant reductions in braking, especially for larger jet aircraft.

Ten percent of pilots indicated that on at least one occasion while landing last winter they were close to not being able to stop on the available runway. For most of these pilots (85%) this occurred once last winter. A small number of the pilots responding to the survey (2%) had experienced situations in the previous five years where their aircraft had run off the side or end of the runway due to the runway being slippery. Several pilots commented that they had slipped sideways many times on taxiways.

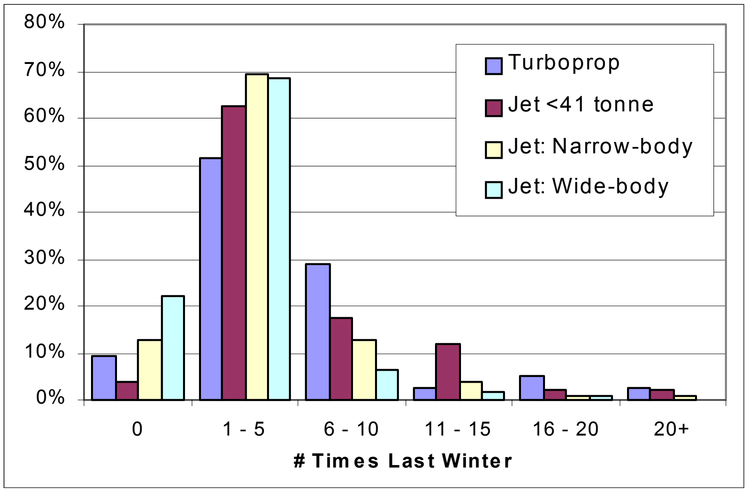

Figure 4.3 Frequency Pilots Indicated Braking was Significantly Reduced on Landing

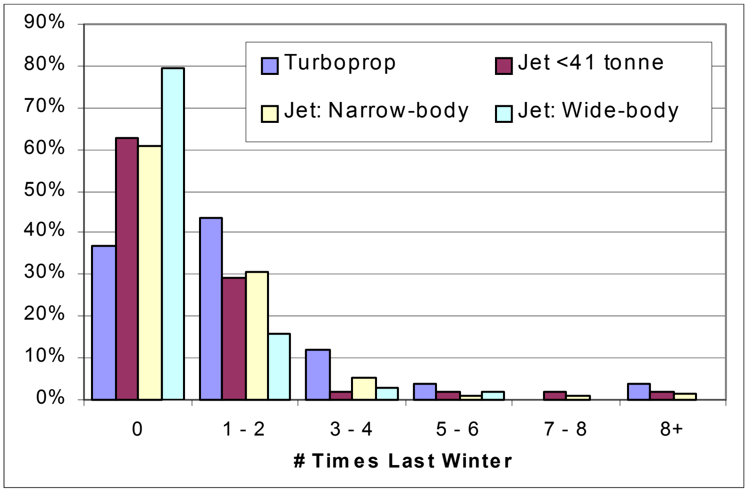

Figure 4.4 Frequency Pilots Indicated their Aircraft Slipped Sideways while Landing

The numbers of incidents reported by the pilots, given above, were combined with their reported numbers of flights to estimate the frequency of occurrence of these safety concerns. The estimates are provided in Table 4.4. When the frequencies of landings are taken into account, the likelihood of these types of occurrences is similar for the different categories of aircraft. The pilots' experiences clearly indicate that low runway friction does lead to numerous safety concerns in current operations despite the small number of accidents that have occurred.

Table 4.4 Frequency of Occurrence per 1,000 Flights of Safety Concerns on Landing

Safety Concern	Turbo-prop	Jet <41 tonne	Jet: Narrow body	Jet: Wide-body	Total
Braking significantly reduced	9.4	11.2	12.5	17.3	11.7
Slipped sideways due to X-winds	2.8	1.7	3.8	2.7	2.9
Close to not stopping on runway	0.18	0.53	0.47	0.37	0.36
Ran off side or end of runway	0.02*	0.01*	0.01*	0.03*	0.015

* Very approximate as they are based on small number of incidents

The rate of occurrences where the aircraft ran off the side or end of the runway of 0.015 per thousand landings, equivalent to 15 per million landings, is higher than the corresponding rate of 4.5 per million landings (2.5 for overruns and 2.0 for off-side occurrences) based on the TSB data. The discrepancy could be due to several reasons, including:

- Underreporting of overruns, particularly where there were no injuries and little or no damage, which would be more common for cargo, small charter and private aircraft flights; and
- The sample of pilots responding to the survey may have included a higher proportion of pilots who have experienced safety concerns on slippery runways as these pilots are more likely to respond to the survey.

4.4 Frequency of Slippery Runways

The frequency of slippery runways due to snow and ice contamination and the degree of slipperiness, as measured by the CRFI value, vary greatly across airports and depend on the type of contamination. CRFI values are not always available when the runway has some ice, compact snow or frost contamination. Therefore, the approach used was to determine the percentages of the time the runways had ice, snow and/or frost contamination, and to determine the distribution of CRFI values for a given contaminant type. Analyzing the frequency of slippery runways in this way allows the reductions in risk of manufacturers' guidance material to be analyzed since some manufacturers provide adjustments in landing distances for specific contaminant types, rather than CRFI values.

An analysis of runway surface condition reports from five airports for the years 1988-1990 was provided in the 1991 Sypher report on take-off risks on contaminated runways [12]. The report provided estimates of the average percentage of the time a section of runway is contaminated, and these are summarized in Table 4.5 for ice, compact snow, frost and shallow depth (1/8 in. or less) loose snow.

Table 4.5 Average Percentage of the Time a Section of Runway is Slippery by Contaminant Type, 1988-1990

Contaminant Type	Ottawa	Halifax	Calgary	Prince George	Edmonton	Average
Ice	3.1%	5.6%	0.8%	3.3%	3.4%	3.2%
Compact Snow	na	1.0%	0.3%	0.2%	0.8%	0.6%
Frost	0.2%	0.6%	0.0%	0.3%	0.4%	0.4%
Loose snow ≤ 1/8"	1.3%	2.0%	0.8%	2.8%	1.0%	1.6%
Total	4.6%	9.2%	1.9%	6.6%	5.6%	5.7%
Total % of Winter	11.0%	22.0%	4.5%	15.8%	13.4%	13.8%

Source: Sypher [12] (values for 5 winter months converted to yearly by multiplication by ratio 5/12)
na – Compact snow not used as a contaminant type at Ottawa airport at that time

Runway condition reports were obtained in electronic format from four airports for use in determining the distribution of CRFI values for a given runway type. The data was extracted for the period that the airport had been using the Tracker Two System[7] for recording runway surface condition reports. The airports and the years for which data was retrieved were as follows:

- Halifax – November 1999 to March 2002
- Calgary – October 1998 to January 2002
- Toronto – November 2000 to March 2002
- Ottawa – December 2001 to April 2002

The time period between successive reports for a particular runway was used to estimate the proportion of the time the runway was contaminated. The estimated percentages of time in the year that runways were slippery by contaminant type are shown in Table 4.6. Times were included when 20% or more of the runway had that type of contamination. The percentage of time at least 20% of the runway has ice, compact snow, frost or shallow loose snow contamination, but is less than 20% for each of the four contaminant types, is also included. Since the runway may have more than 20% of two or more contaminant types, the percentages for the combined contaminant types are not the sum of the individual types given the table. The high percentage of the time the runway was icy at Ottawa is only based on data for one winter and is therefore less reliable for indicating longer term trends. The runways were least frequently slippery at Toronto, followed by Calgary, which also had low contamination frequency in the earlier study. The average time the runway is icy over the four airports varies greatly depending on whether a simple average of the percentages for each airport is used (weighting Ottawa equally with the others), or whether the data for the four airports is combined (giving more weight to airports with more data). The averages determined in both ways are given in the far right columns of the table.

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[7] System developed by Tradewinds Scientific Ltd., Ottawa, Ontario

Table 4.6 Average Percentage of the Time Runway is Slippery by Contaminant Type, 1999-2002*

Contaminant Type	Halifax	Ottawa	Toronto	Calgary	Average of 4 airports	Average of all data
No. winters of data	*3*	*1*	*2*	*3*	*9*	*9*
Ice ≥ 20%	2.2%	10.1%	0.1%	0.7%	3.3%	1.3%
Compact Snow ≥ 20%	3.1%	1.0%	0.9%	0.7%	1.4%	1.4%
Frost ≥ 20%	0.3%	0.0%	0.0%	0.6%	0.2%	0.3%
Loose snow ≤ 1/8"	0.3%	0.7%	1.1%	2.9%	1.2%	1.4%
Ice/Compact snow/ frost ≥ 20% excl. above	0.0%	0.9%	0.0%	0.1%	0.3%	0.1%
Combined ≥ 20%	5.5%	12.3%	2.1%	5.0%	6.2%	4.3%

Source: Electronic copies of runway surface condition reports

* Years of data vary by airport as noted in the text

Based on all the data from both time periods, 1988-1990 and 1999-2002, and all the airports, typical percentages of time the runway is slippery due to ice, compact snow and frost contamination was estimated to be:

• Ice	2.8% of year	6.6% of the 5 winter months
• Compact snow	1.0% of year	2.4% of the 5 winter months
• Frost	0.3% of year	0.7% of the 5 winter months
• Loose snow ≤ 1/8 in.	1.4% of year	3.5% of the 5 winter months
• Overall	5.5% of year	13.2% of the 5 winter months

Typical CRFI values and the variation in these values for the different contaminant types were investigated using the runway surface condition reports in the recent data set for which CRFI values were present. Table 4.7 gives the average CRFI values for when at least 50%, 20% and 5% of the runway is contaminated with ice, compact snow, frost and shallow loose snow, and average values for each airport. The average CRFI values are similar for when the runway has 5% or more, or 20% or more, of ice contamination, but the CRFI values are 0.05 lower when 50% or more of the runway is icy. With compact snow the average CRFI values are slightly greater than with ice contamination, and are even higher with frost and shallow loose snow.

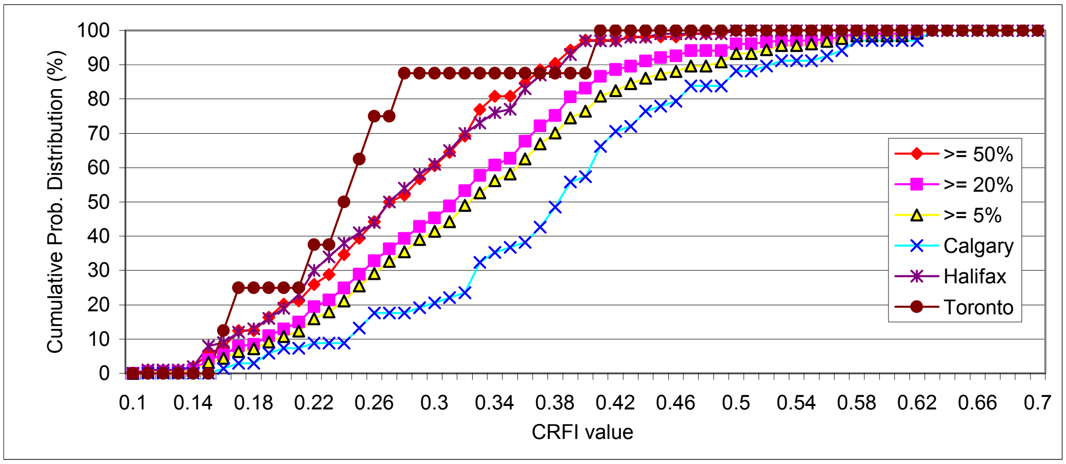
The CRFI values from the RSC reports when the runway has ice contamination tend to be greater than values typically associated with ice. This is likely due to two factors: often only a portion of the runway is covered by ice and friction on the other parts of the runway may be much higher; and, being at an airport under operational conditions, the ice has been treated to improve the friction as much as possible.

The cumulative distribution of the CRFI values at the four airports when the runway is icy is illustrated in Figure 4.5. The figure shows that the CRFI values for a given contaminant type vary between airports. The CRFI values tend to be lower at Toronto and higher at Calgary when the runway is icy. The differences could be due to environmental or treatment factors, or to the measurement procedures. For example, a lower distribution of CRFI values would be found if CRFI measurements are taken only under poor conditions when the runway would be more likely to be slippery. When runway demand is high, the delay to aircraft is likely taken into account when deciding whether to take a measurement as this necessitates closing the runway for 5 to 10 minutes. This could partly explain the lower distribution for Toronto. In these high-demand situations there will be current PIREPs on aircraft braking that pilots use to assess the slipperiness of the runway.

Table 4.7 Average CRFI Values for Various Proportions of the Runway Contaminated and for Each Airport

Contaminant	% of Runway with Contaminant:			Airport			
Type	≥ 50%	≥ 20%	≥ 5%	Calgary	Halifax	Toronto	Ottawa
Ice	0.28	0.32	0.33	0.38	0.28	0.25	0.32
Compact Snow	0.29	0.32	0.37	0.42	0.28	0.29	0.29
Frost	0.37	0.41	0.41	0.41	0.39	ns	Ns
Loose snow ≤1/8”	0.39	0.40	0.40	0.46	0.30	0.29	0.33

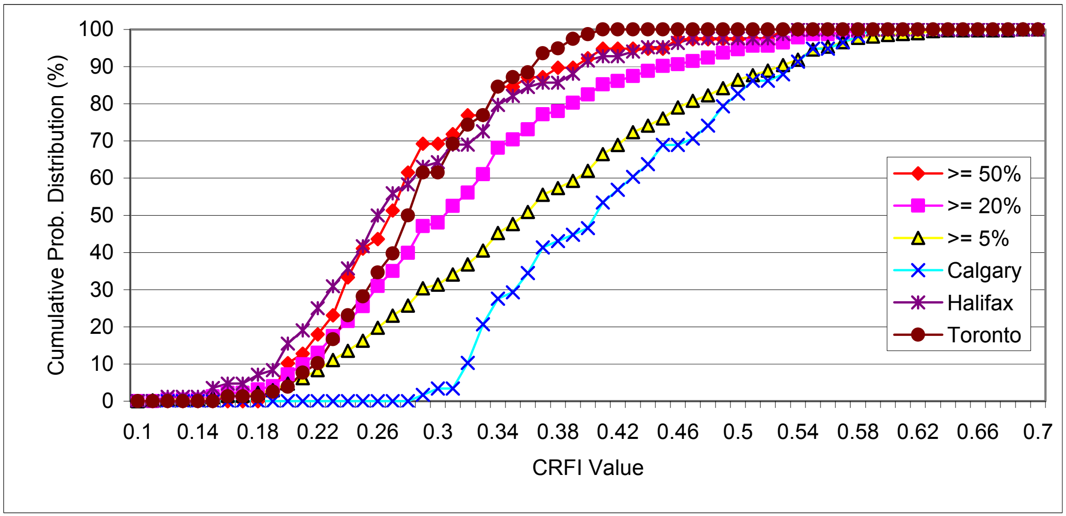
Source: Electronic copies of runway surface condition reports 1999-2002 (years of data vary by airport)
Notes: Contaminant type often <100% covered and CFRI value influenced by surface condition of other parts of the runway.
Runways typically treated to improve friction.
ns Insufficient CRFI values (average only given for 8 or more CRFI values)



Source: Electronic copies of runway surface condition reports 1999-2002 (years of data vary by airport)
Note: Ottawa also included in distributions for 5, 20 and 50% or more of runway contaminated.

Figure 4.5 Distribution of CRFI Values when the Runway is Contaminated with Ice for Various Proportions of the Runway Contaminated

The cumulative distributions of the CRFI values at the four airports when the runway is contaminated with compact snow are illustrated in Figure 4.6. A similar trend in CRFI values between airports is found as for ice contamination. Calgary has a very low occurrence of CRFI values under 0.3 on runways with compacted snow compared to the other airports analyzed.



Source: Electronic copies of runway surface condition reports 1999-2002 (years of data vary by airport)

Note: Ottawa also included in distributions for 5, 20 and 50% or more of runway contaminated.

Figure 4.6 Distribution of CRFI Values when the Runway is Contaminated with Compact Snow for Various Proportions of the Runway Contaminated

The breakdown of the range of CRFI values used in the CRFI Tables was also used in the risk analysis. The frequencies of CRFI values in each cell of the range are given in Table 4.8. These percentages are based on CRFI values over all four airports when the runway was at least 20% contaminated with the particular contaminant type.

Table 4.8 Frequency Distribution of CRFI Values by Contaminant Type Used in the Risk Analysis

Contaminant	0.18	0.2	0.22	0.25	0.27	0.3	0.35	0.4	0.45	0.5	0.55	0.6
Ice	8.5%	4.5%	8.5%	11.4%	6.5%	13.9%	18.9%	16.4%	5.5%	2.5%	1.5%	2.0%
Comp.Snow	3.1%	4.0%	10.3%	13.5%	9.0%	16.1%	21.1%	9.0%	5.4%	4.0%	3.6%	0.9%
Frost	1.8%	0.0%	1.8%	3.5%	1.8%	10.5%	21.1%	17.5%	22.8%	3.5%	12.3%	1.8%
Loose snow ≤ 1/8”	1.4%	1.0%	4.2%	7.9%	4.8%	14.0%	11.0%	13.1%	15.2%	11.4%	10.6%	5.3%

Source: Electronic copies of runway surface condition reports 1999-2002 (years of data vary by airport)

4.5 Risk Analysis

4.5.1 Description of Approach Used

In considering the risks of an undesirable outcome, both the probability of the outcome and the consequences of that outcome must be considered. In the risk analysis of landing overrun accidents, the probability of an overrun occurring and the expected consequences, in terms of fatalities, injuries and aircraft damage, are considered. Risks associated with leaving the side of the runway due to crosswinds were not considered.

The rates of overruns and overrun accidents, and the proportion where injuries and aircraft damage occurred provide some indication of the risks. However, due to the very low probability of serious accidents and the limited number of accidents, the accident rates can be a misleading indicator of risk, as is the case for landing accidents on slippery runways discussed above. These rates do not provide a good indication of the likely benefits of specific measures to reduce the risks. The use of a risk analysis model can make better use of available information and provide a better understanding of the factors affecting the risk and estimates of the reductions in risk of specific measures. The estimated risks under past conditions using the model should be consistent with observed accident experience.

An analysis of the risks was undertaken by modelling the factors affecting landing distances and the likelihood of these effects. Many of the factors affecting landing distances are present during every landing and contribute to the uncertainty in stopping distance and the associated risks. The factors considered were:

- The touchdown distance from the runway threshold that is affected by factors such as height above the runway threshold on approach, approach speed, approach angle, winds, etc.;
- Delay time between touchdown and application of wheel brakes;
- Error in setting and/or applying brakes, or malfunction of brakes;
- Availability and correct application of reverse thrust; and
- The slipperiness of the runway and its effect on aircraft braking distance.

The variation in these factors all lead to uncertainties in the actual stopping distance on a particular landing. By estimating the cumulative effect of these factors on the landing distance, applying the probabilities of each and summing over all possibilities, it is possible to estimate the probability distribution of the landing distance. The method used for estimating this distribution of landing distance is provided in Appendix C. The probability of an overrun can be determined by summing the distribution over predicted landing distances greater than the runway length available. The expected consequences of the overrun can then be determined by estimating the number of fatalities and injuries and the value of damage to the aircraft based on the additional distance required and the terrain at the end of the runway.

The analysis was conducted for a given aircraft type landing at a given airport, and repeated for each airport and aircraft type operating at that airport. It was assumed that the longest runway was used, except at Toronto's Lester B. Pearson International Airport due to the different lengths of its parallel runways. At Toronto, the landings were assumed to be evenly split between the longest runway (15/33 11,050 ft.) and the shorter runway (06R/24L 9,500 ft.) for all aircraft but the B747, which were all assumed to land on the longest runway. Zero wind and runway gradient, and a temperature of 0°C were assumed. Typical variation in landing weight was modelled. Where the LFL required at a given weight was greater than the runway length available, the weight was reduced to the maximum allowed value. The method for adjusting landing distance for aircraft weights less than the maximum allowed weight and for airport altitudes above sea level was the same as that used in the 1994 Sypher study [4].[8] The model was used to estimate the risks on dry runways and on slippery runways using the likelihood of snow, ice/frost contamination and the distribution of CRFI values for each of those conditions. The risks for a particular aircraft type and airport due to slippery runways are then found by subtracting the risks on dry runways.

Overall risks are found by estimating the aircraft type-airport risks for each airport and aircraft type, multiplying by the number of landings of that aircraft type at that airport, and summing over all airports and aircraft types.

4.5.2 Determining Consequences of an Overrun

The consequences of an overrun, or the potential benefits of preventing the overrun, were estimated using the same approach as that used by Sypher [4] in their benefit-cost analysis of measures to account for effects of runway contamination on aircraft take-off performance.

The consequences of an accident were measured in terms of number of fatalities, numbers of serious injuries and the cost of damage to the aircraft. Total costs in dollar terms are estimated by placing a value on each fatality and serious injury. The values used were $3,000,000 and $850,000, respectively. These values correspond to values used in other benefit-cost analyses for Transport Canada [13,14].[9]

The approach used in the earlier Sypher report [4] was to provide a relationship for estimating the expected numbers of fatalities and serious injuries and the expected aircraft damage given the overrun distance and the distance to a ditch/embankment or water. These relationships were developed based on examination of jet take-off accidents where the aircraft rejected take-off and overran the runway. The consequences of landing overruns reviewed in Section 4.1 were compared with the

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[8] From Appendix K: weight and altitude factors, Cw and Ca, were estimated for landing distances. The following values were used: Ca=1.0056 for B777, 1.020 for B757, 1.010 for other aircraft, Cw=0.9846 for A320, 0.9835 for B737, 0.985 for B777, B767 & B727, 0.990 for B747, BAe146 & F28, 0.991 for DC9 and 0.9857 for B757.

[9] Based on costs of $2.5 million and $700,000. Values ere increased by a factor of 1.2 to allow for inflation since that time.

predictions of the earlier relationships. The injuries and aircraft damage in the landing overruns were found to be consistent with the estimates of "medium" costs from the earlier study, but the "upper limit" costs do not appear appropriate. The consequences of overruns would generally be expected to be similar in landings and aborted take-offs, although the potential for a major catastrophe is greater for take-offs due to the generally greater fuel load. The "medium" costs from the earlier study [4] were used in this study with one small change[10] and "upper limit" costs were not used. Equations for calculating the fatalities, injuries and aircraft damage are given in Appendix K of [4]. The likelihood of a particular person onboard being killed when an aircraft overruns the runway and hits and ditch, embankment or water is less in large aircraft than in a small aircraft due to the cushioning effect of the larger aircraft. To allow for this, the estimated number of fatalities was adjusted based on maximum aircraft landing weight so that for a given overrun distance, fatalities are reduced by 20% in a B747 and increased by 10% for a CRJ.[11] The relationships between overrun distance and numbers of fatalities (without the adjustment) and aircraft damage are illustrated in Figures 4.7 and 4.8.

As in the earlier Sypher study [4], the overrun distance is estimated to be 50% of the additional runway required.

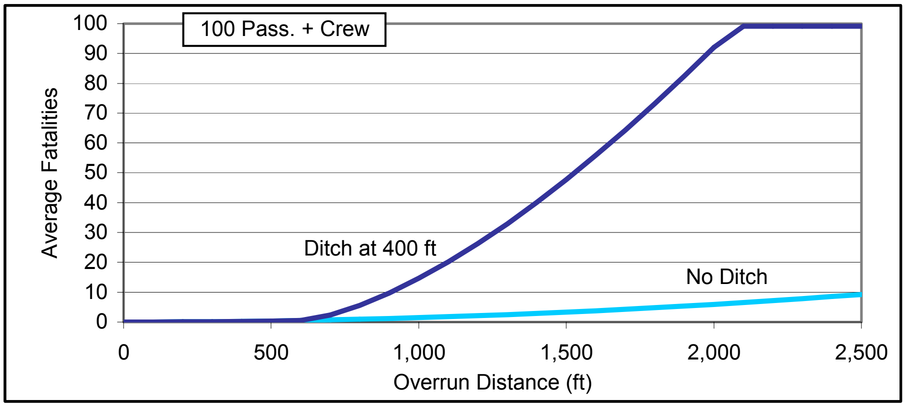

Figure 4.7 Predicted Fatalities versus Overrun Distance for Flat Overrun Area and for when Ditch/Embankment/Water is 400 ft. Beyond Stopway

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[10] The parameter relating aircraft damage to distance of overrun, DBDAD in Appendix K of [4] was increased from 750 to 850.

[11] The estimated fatalities were adjusted by the factor: 1 + 0.125 x (100,000 – LDWGT(lb.))/100,000

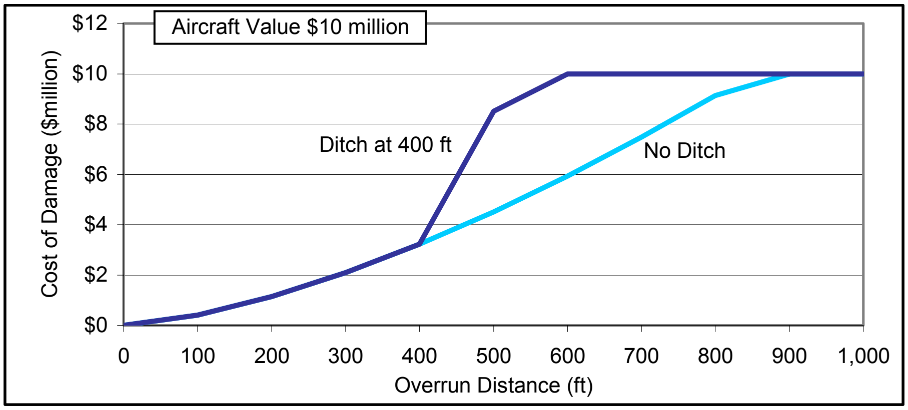

Figure 4.8 **Predicted Aircraft Damage versus Overrun Distance for Flat Overrun Area and for when Ditch/Embankment/Water is 400 ft. Beyond Stopway**

4.5.3 Estimated Risks

The current risks estimated using the risk model are illustrated through the use of an example using a Canadair Regional Jet (CRJ) aircraft under various conditions. The risks are similar for other aircraft types after allowing for the different landing distances and lengths of runways these aircraft typically operate on. The CRJ has reverse thrust and it is assumed that reverse thrust is used when runway conditions are slippery. The LFLs at maximum landing weight for the CRJ modelled are as follows:[12]

• Current regulations	Dry runway	4,850 ft.
	Wet runway	5,578 ft.
• Manufacturer's guidance material	Ice	8,585 ft.
	Compact snow	5,723 ft.

The probability distributions for actual landing distances of a CRJ aircraft landing on a 4,850 ft. slippery runway with CRFI values of 0.2, 0.3, 0.4 and 0.6, estimated using the risk model, are shown in Figure 4.9 and the values are given in Table 4.9. In this example the maximum landing weight and the runway length required for that weight have been used, thus only the dry regulated margin of safety is available. Under good braking conditions, CRFI = 0.6, most landing distances are between 3,000 and 4,200 ft., and the chance of an overrun is very low – about 7 in 10,000. As the runway becomes more slippery, the distribution moves to the right, i.e., landing distances become longer, and the distribution becomes more spread out. For a CRFI of 0.2, typical of icy runways, 54% of landings would require over 5,000 ft. of runway. If pilots at least applied the 115% adjustment for wet runways in these conditions, the proportion to overrun would be reduced to about 2%. It should be noted that this example does not represent the large majority of take-offs, where the landing weight is

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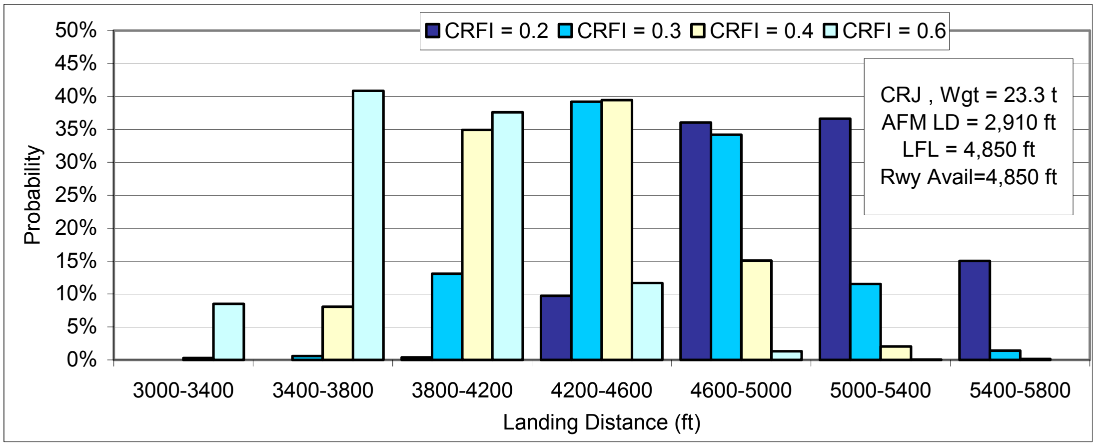
[12] Distance vary by model, distances for contaminated runways are based on factors given in [15].

not restricted and there is excess runway available on which to stop the aircraft above that provided by the regulations.



Source: Sypher Risk Model for Landing on Slippery Runways

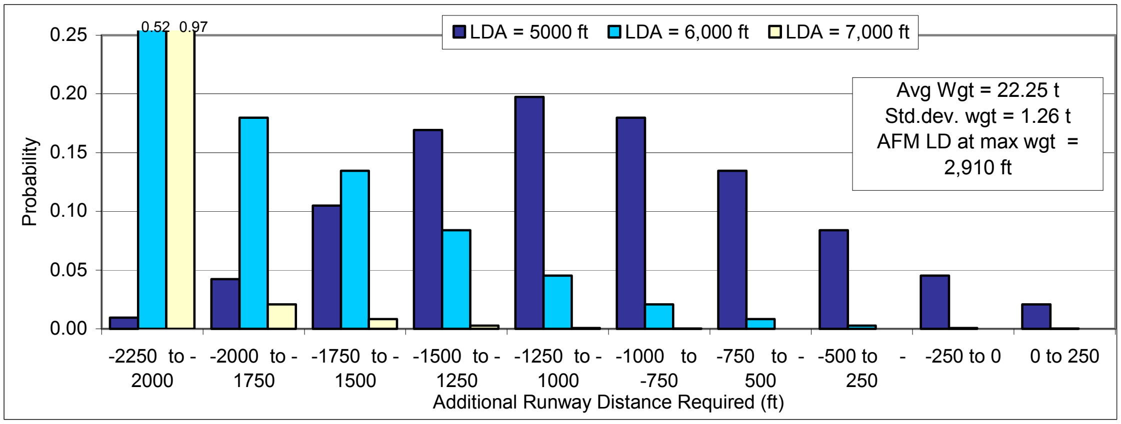
Figure 4.9 Probability Distributions of Landing Distances for a CRJ Aircraft on a Slippery Runway with Landing Weight Restricted Maximum Allowed for 4,850 ft. Runway

Table 4.9 Probability Distribution of Landing Distances for a CRJ with Weight Restricted for Landing on a 4,850 ft. Runway Given CRFI Values of 0.2, 0.3, 0.4 and 0.6

Distance (ft)	Probability LD is in Distance Range Given:			
	CRFI = 0.2	CRFI = 0.3	CRFI = 0.4	CRFI = 0.6
3000-3400	0.0E+00	0.0E+00	3.2E-03	8.5E-02
3400-3800	0.0E+00	5.8E-03	8.1E-02	4.1E-01
3800-4200	3.8E-03	1.3E-01	3.5E-01	3.8E-01
4200-4600	9.7E-02	3.9E-01	3.9E-01	1.2E-01
4600-5000	3.6E-01	3.4E-01	1.5E-01	1.3E-02
5000-5400	3.7E-01	1.2E-01	2.0E-02	7.0E-04
5400-5800	1.5E-01	1.4E-02	1.3E-03	2.8E-05
5800-6200	2.1E-02	7.8E-04	5.3E-05	8.4E-07
6200-6600	1.3E-03	3.2E-05	1.8E-06	1.2E-08
6600-7000	5.4E-05	1.1E-06	3.4E-08	8.6E-11
7000-7400	1.8E-06	1.8E-08	3.4E-10	<1.0E-12
7400-7800	3.5E-08	1.9E-10	2.7E-12	<1.0E-12
7800-8200	4.0E-10	1.5E-12	<1.0E-12	0.0E+00
Over 5,000 ft	5.4E-01	1.3E-01	2.2E-02	7.3E-04
Over 5,750 ft	2.2E-02	8.2E-04	5.5E-05	8.5E-07

Source: Sypher Risk Model for Landing on Slippery Runways

The estimated probability distribution of the additional runway distances required for the CRJ, given that the runway is slippery but making no allowance for the slippery runway (as per current regulations), is illustrated in Figure 4.10 for available runways lengths of 5,000, 6000 and 7,000 ft. Typical distributions of aircraft weights and of CRFI values for slippery runways are allowed for in calculating these risks. The estimated probabilities of a CRJ overrunning the end of the runway due to low runway friction is given in Table 4.10 for landings on runways of 5,000, 6,000 and 7,000 ft., assuming typical runway conditions and aircraft loads.



Source: Sypher Risk Model for Landing on Slippery Runways
Note: Typical range of CRFI values and aircraft loads for landings on runways of 5,000, 6,000 and 7,000 ft. LFL not adjusted for slippery runway.

Figure 4.10 Distribution of the Additional Runway Distance Required for a CRJ Given Runway is Slippery under Current Regulations

Table 4.10 Probabilities of Overrun by Additional Runway Distance Required for a CRJ Due to Slippery Runway under Current Regulations

Additional Runway Distance Required (ft)	Probability Overrun is in Distance Range Given:		
	5,000 ft	6,000 ft	7,000 ft
0 to 250	2.1E-02	1.5E-04	5.3E-08
250 to 500	8.4E-03	2.4E-05	5.3E-09
500 to 750	2.8E-03	3.4E-06	4.4E-10
750 to 1000	7.4E-04	4.5E-07	<1.0E-12
1000 to 1250	1.5E-04	5.3E-08	<1.0E-12
1250 to 1500	1.3E-06	2.9E-10	<1.0E-12
Over 1,500 ft	3.9E-06	4.4E-10	<1.0E-12

Source: Sypher Risk Model for Landing on Slippery Runways
Note: Typical range of CRFI values and aircraft loads for landings on runways of 5,000, 6,000 and 7,000 ft. LFL not adjusted for slippery runway.

Overall – Risks per Million Landings

Most air carriers make some allowance for increased landing distance when the runway is slippery and the risks are therefore less than is indicated in Table 4.10. The survey of airline pilots indicated that 85% of pilots use a 115% or a higher correction factor, the 115% being a requirement for wet runways, when the runway is slippery. The risks of overruns were estimated for CRJ aircraft that only land when they meet the wet field length requirement, and for when they meet the field length requirement for ice-covered runways given in the manufacturer's guidance material. The estimated numbers of overruns, fatalities and value of aircraft damage are given in Table 4.11 for when the additional runway length available above that required for landing at maximum landing weight is zero, 750 ft. and 1,500 ft. The risks are high when no adjustment is made for slippery runways and the field length required is restricted by that available, but are reduced substantially if additional runway is available. Risks are also much lower if the 115% adjustment is made, and are much lower still if the manufacturer's guidance material is used.[13] However, the lower risks are the result of many flights being cancelled, diverted or delayed as is indicated in the table. Based on the frequency of slippery runways described in Section 4.3, approximately 55,000 flights per million would land on slippery runways and a significant proportion of these would be affected, as is shown in the table.

Table 4.11 Estimated Numbers of Overruns, Fatalities and Value of Aircraft Damage per Million Landings for CRJ Aircraft Due to Slippery Runways for Zero, 115% and Manufacturer's Suggested Adjustment, and Various Runway Lengths

	Additional Runway Available at Max. Landing Weight			
	0 or less	750 ft.	1,500 ft.	Est. Overall
Dry Runway Regulations				
No. of Overruns	1,526	60	0.5	2.6
Fatalities	36	0.6	0.002	0.0
Total Cost $Million	$1,994	$42	$0.2	$2.5
Wet Runway Adjustment Used				
No. flights diverted/cancelled	27,488	0	0	27
No. of Overruns	5	34*	0.36	0.7
Fatalities	0.03	0.3*	0.002	0.0
Total Cost $Million	$2.0	$22*	$0.17	$0.4
Manufacturer's Guidance Material				
No. flights diverted/cancelled	27,475	14,528	13,738	13,759
No. of Overruns	0	0.2	0.01	0.01
Fatalities	0	0.001	0.000	0.0
Total Cost $Million	$0	$0.08	$0.01	$0.01

Source: Sypher Risk Model for Landing on Slippery Runways

* Overruns, fatalities and cost are higher with 750 ft. compared to 0 ft. additional runway available due to far fewer flights being diverted/cancelled (6,330 compared to 43,328).

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[13] For the CRJ the risks were insignificant using the adjustment for icy runways, but the adjustment for compact snow was much less and this resulted in the low risks included in the table.

The take-off field length required is longer than the LFL required for almost all aircraft types and since the aircraft must take off after landing, there is almost always additional runway available above the required LFL. At maximum take-off and landing weights, the take-off field length is greater than the LFL by 1,000 ft. for the CRJ, and by 2,000 to 3,300 ft. for all other commercial passenger jet aircraft types in use in Canada, except the BAe 146 for which the difference is zero.

The overall risks can be estimated by combining the risks for the different adjustment factors and additional runway lengths available. The frequencies of these are unknown, but are estimated from the pilot survey and the consultants experience to be:

Regulations		Additional Runway Available	
No Adjustment	15%	0 or less	0.1%
Wet Runway Adjustment	65%	Approx. 750 ft.	0.9%
Manufacturer's Guidance Material	20%	1,500+ ft.	99%

Assuming these percentages, the risks per million landings were estimated to be:

No. of overruns	0.8
No. of fatalities	0.01
Total cost	$0.62 million

Risks are greater for aircraft without reverse thrust. The use of reverse thrust is not accounted for in determining the regulated LFL requirements and its availability adds an additional safety margin that is particularly effective on slippery runways where wheel braking is less effective. The risks were estimated for the F-28 aircraft, which does not have reverse thrust, using the same procedure as was used for the CRJ, and are presented in Table 4.12. The frequency of overruns per million landings is found to be seven times greater than for the CRJ, and the risk of fatalities is estimated to be 60% greater.

Table 4.12 Comparison of Estimated Risks Due to Slippery Runways per Million Landings of a CRJ and an F-28

Aircraft Type	CRJ	F-28	Overall Types
Reverse Thrust	*Yes*	*No*	
No. flights diverted	2,770	8,054	3,298
No. of Overruns	0.8	6	1.3
Consequence			
Fatalities	0.010	0.1	0.04
Total Cost ($million)	$0.62	$1.7	$1.8

Source: Sypher Risk Model for Landing on Slippery Runways

These risks were derived for the CRJ and F-28 aircraft, but were developed in such a way that the frequency of overruns are applicable, at least approximately, to other aircraft types and therefore for the whole fleet. The expected numbers of fatalities and total costs will, however, be greater roughly in proportion to the numbers of passengers onboard and the value of the aircraft. For the fleet as a whole, the expected fatalities and cost would be approximately three times greater. Allowing for the proportion of landings by aircraft without reverse thrust (10% of commercial passenger jet movements), the risks for the whole fleet were estimated and are provided in the right column of Table 4.12. The frequency of overruns when expressed as a rate per million landings on slippery runways is 23.6, which is similar to the rate of 16.6 per million landings found in the accident/incident data (given in Table 4.3). The expected number of fatalities is also consistent with accident data with 0.04 per million landings expected and zero observed. The risk model also predicts that aircraft without reverse thrust should account for about half of the overruns and this compares with 5 of 11 overruns of commercial passenger jet aircraft not having reverse thrust (F-28s and BAe 146). Two of these overruns involved BAe 146 aircraft, which have an airbrake that provides some non-wheel braking, although not as much as reverse thrust.

The risk model therefore produces estimates of the risk that are consistent with past experience.

5. ANALYSIS OF BENEFITS AND COSTS

The following approach was used to determine the benefits and costs of accounting for slippery runways:

- Define the requirements to be evaluated;
- Specify the method used to estimate the benefits and costs for a particular aircraft type and airport;
- Determine the benefits and costs and benefit-cost ratio for each aircraft type and airport;
- Multiply the benefits and costs by the number of landings of each aircraft type at each airport and sum to determine the total benefits and total costs over all aircraft types and airports;
- Include additional costs to air carrier for updating manuals and training;
- Include additional costs and benefits to airport related to any enhanced measurement of CRFI values; and
- Determine the benefit-cost ratios.

The analysis does not consider crosswinds or the possibility of the aircraft going off the side of the runway due to crosswinds as this is outside the scope of this study.

The slippery runway conditions analyzed were as follows:

- Ice, compact snow or frost covering 20% or more of the runway, or
- Loose snow of less than or equal to a depth of 1/8 in. covering 20% or more of the runway.

When runways are extremely slippery, runway operations will cease and the analysis therefore does not need to consider these conditions. It is assumed that no landings currently take place if the CRFI value is less than 0.15.

5.1. Requirements Evaluated

The benefits and costs were estimated for several different approaches to accounting for slippery runways. The means for determining the adjustment are based on:

- CFRI Tables as published in the 2001 AIP; and
- Guidance material for aircraft type.

Both methods for accounting for slippery runways assume that reverse thrust will be used if available for that aircraft type. When using the CRFI Tables, interpolation is used to determine the adjusted landing distance for a given CRFI value and AFM landing distance when the CRFI value and landing distance are not given in the table. Guidance material with adjustments for landing on slippery runways could not be obtained for the F-28, B727 and B757 aircraft. Adjustment factors for these aircraft were estimated based on other aircraft of a similar type or similar characteristics and used in place of the manufacturer's guidance material (values given in Table 5.1).

It was necessary to make a number of simplifying assumptions that could affect the benefits and costs in the practical application of any requirement. These assumptions are as follows.

- The decision on whether to land is made by the pilot just prior to landing based on the most recent RSCR and CRFI value. Costs may be reduced if runway conditions are known accurately prior to departure and other measures could be taken to reduce the costs.
- LFL requirements set at the time of dispatch and departure, as for wet runways, were not examined. Consideration of this type of requirement would greatly complicate the analysis and lead to questionable results. Factors such as changes in CRFI values during the time of the flight, availability for early morning flights, etc. would have to be considered.
- Conditions at alternate airports are not considered, nor are any additional fuel costs associated with alternate airports.

The benefit-cost ratios depend on the base case assumed. As discussed earlier, most pilots make some allowance for slippery runways above the current minimum LFL requirements specified by the regulations. In determining the incremental benefits and costs, three base cases are used:

1. No accounting for slippery (or snow/icy) runways – landing distances based on bare and dry runway;
2. Wet factor of 15% added when runways are slippery (CRFI < 0.6); and
3. Manufacturer's guidance material applicable for landing on slippery runways used (if none available, the estimated value was used as discussed above).

5.2 Aircraft Analyzed

The aircraft types analyzed were the CRJ, A320, B737-200, B727-200, B747-400, B757, B767, B777, F-28, DC9, and BAe-146. Aircraft parameters values used in the analysis are given in Table 5.1. These parameters can vary between aircraft of the same type and the analysis of overall benefits and costs do not take this variation into account. Landing distances for contaminated runways were obtained from an earlier report [15] and from data collected from several additional airlines.

Table 5.1 Aircraft Parameters Used in Benefit-Cost Analysis

Aircraft Type	Reverse Thrust	# Pass. Seats	Max Landing Weight (lb.)	LD* (AFM) (ft)	LFL* Dry (ft)	LFL Adjustment Factor#	
						Compact Snow	Ice .
CRJ	Yes	50	47,000	2,910	4,850	1.18	1.77
A320	Yes	137	150,000	2,880	4,800	na	1.45
B737-200^	Yes	110	103,000	2,640	4,400	na	1.39
B727-200	Yes	145	154,000	3,000	5,000	na	1.45**
B757	Yes	180	209,000	3,060	5,100	na	1.45**
B767	Yes	194	287,000	3,000	5,000	na	1.44
B777^	Yes	280	440,000	3,180	5,300	na	1.79
B747-400^	Yes	392	570,000	4,290	7,150	na	1.45
DC9	Yes	92	101,000	2,520	4,200	na	1.66
BA146	No	77	84,000	2,160	3,600	na	1.79
F28	No	65	60,000	2,340	3,900	na	2.0**

Source: Passenger, weights, LD and LFL – Aviation Week & Space Technology Aerospace Source Book.
Adjustment factors – [15] and several airlines (confidential).

Notes: * LD and LFL for sea level 15°C and zero wind
\# Landing Field Length (LFL) for compact snow and ice based on adjustment factors assuming full reverse thrust used, if available.
^ LFL Ice based on adjustment for "poor" braking
** Factor not available, value estimated from other aircraft with and without reverse thrust.

The numbers of landings of these aircraft at airports in Canada were obtained from the Aviation Statistics section of Statistics Canada and are given in Appendix D.

5.3. Calculation of Benefits

The risk model described in Section 4.5 was used to calculate the expected number and consequences (fatalities, injuries and total cost) of overruns due to landing on slippery runways. These consequences were determined under the base cases described in Section 5.1 and under each of the two methods of accounting for slippery runways being investigated. The benefits of each method are then found by subtracting the consequences for each method from the consequences for each base case.

As discussed previously, the following costs were applied for fatalities and serious injuries:

- Fatality $3.0 million
- Serious injury $850,000

The consequences of overrun accident/incidents, and therefore the benefits of accounting for slippery runways, are dependent on the overrun areas at each airport with jet service. The distances to an embankment, ditch or water required by the model was available for many airports from an earlier study and a default distance of 1,000 ft. was used at the other airports. The airport parameters used in the model are given in Appendix D.

5.4. Calculation of Costs

If the runway is known to be slippery prior to departure and the prospects of it improving sufficiently to allow landing at the planned landing weight are low, there are a number options available to the air carrier:

- Delay departure to allow time for runway friction to improve at destination airport;
- Cancel the flight; or
- Reduce take-off weight by reducing cargo and possibly passengers onboard.

If the carrier chooses to delay or reduce the weight prior to departure, the CRFI may change from that applicable at the time of departure and the runway may still be too slippery to land when the flight arrives at the destination. Alternatively, the runway may have improved and the carrier may have unnecessarily delayed the departure or reduced the take-off weight.

After departure and when en route, the carrier has the following options if the runway is too slippery to land:

- Remain airborne until runway friction improves;
- Dump/burn fuel to reduce landing weight; or
- Divert to another airport.

Due to the complexity of the decision process and the variation with particular circumstances of the weather and possible changes in the friction, the costs were estimated assuming the carrier will choose the least costly option of the following:

- Delay landing at the airport until the CRFI improves sufficiently to land at the planned aircraft weight (i.e., no reduction in cargo or passengers). This delay may occur prior to take-off and/or en route;
- Divert to another airport;
- Cancel the flight prior to take-off; or
- Reduce aircraft weight either by reducing cargo prior to take-off or burning or dumping fuel just prior to landing.

The calculation of the costs associated with each of these options is described below. Parameters related to each aircraft type used in the calculation of these costs are presented in Table 5.2. Landing weights are not reported to TC and were estimated from typical distributions of aircraft take-off weights by aircraft type used in the 1994 evaluation of risks on contaminated runways. The landing weights were used in the analysis expressed weight as the percentage under maximum allowed weight. Average load factors were 68% at the time the data were collected and the most recent load factors (for 2002) for Air Canada and West Jet are 74%. To allow for the higher load factors the average percentage under maximum weight was reduced by 2%. Take-off weights may be under maximum for shorter flights due to lower fuel loads, but since less fuel is burned during the flight, the landing weight will be closer to the maximum. This will result in the average take-off weights being further below their maximum allowed than average landing weights. To allow for this effect, the average percentage under maximum weight was reduced by 3%. Due to the uncertainty in the estimated distribution of weights, the benefit-cost analysis is conducted for both the maximum landing weights and the estimated distribution of landing weights.

Table 5.2 Aircraft Parameters Used in Calculation of Costs of Accounting for Slippery Runways

Aircraft Type	No. of Pass. Seats	Crew cost per hr	Cruise Cost per hr Excl. Crew	No. of Crew	Avg % Under Max Wgt	SD of % Under Max Wgt	Aircraft Replacement Value ($M)
CRJ	50	$588	$1,090	3	7%	4.0%	$17
A320	137	$1,122	$1,302	6	7%	3.0%	$60
B737-200	110	$953	$1,471	5	8%	4.0%	$10
B727-200	145	$1,429	$2,265	6	7%	3.0%	$10
B757	180	$1,555	$1,892	7	7%	3.0%	$45
B767	194	$1,769	$1,870	7	7%	3.0%	$70
B777	280	$2,315	$1,898	9	8%	4.0%	$150
B747-400	392	$4,387	$4,835	11	13%	5.0%	$150
DC9	92	$953	$1,471	5	6%	3.0%	$7
BA146	77	$612	$1,436	4	8%	4.0%	$8
F28	65	$672	$1,376	4	6%	4.0%	$4

Sources: No. of passengers and crew – Airlines Timetables and Web sites.
Crew costs and % Under Maximum Weight – [4] (increased by 20% to account for increases since 1991).
Cruise costs – Nav Canada VOC Database 1999 (costs by aircraft category minus crew costs).
Aircraft Replacement Value – Lloyd's Aviation Aircraft Types and Price Guidelines 1995-6 (average of range of costs) and Nav Canada VOC Database 1999.

Delay Landing at Airport

The required improvement in the CRFI value was determined based on the CRFI value and AFM landing distance using the CRFI Tables. The probability of the CRFI value improving by the required amount for a given flight delay was estimated using the probabilities given in Table 5.3. These probabilities were estimated based on examination of CRFI values from the recent RSFC/CRFI database described in

Section 4.3. All probabilities are less than 0.5 as there is an equal chance of the CRFI deteriorating as improving, and over short time periods there is a good chance of there being little or no change.

Delaying the flight for CRFI to improve will only be feasible for a portion of the flights, even if this is the least costly option. For other flights that would not benefit from a delay, the least costly of other options is used.

Table 5.3 Probabilities of CRFI Improving for Given Flight Delays

Change in CRFI		Probability of Improving in Period		
# of Increments	Example	0.5 hr	1.0 hr	1.5 hrs
1	.18 to .20	0.25	0.35	0.45
2	.18 to .22	0.20	0.29	0.38
3	.18 to .25	0.16	0.24	0.33
4	.18 to .27	0.13	0.20	0.28
5	.18 to .30	0.10	0.17	0.23
6	.18 to .35	0.08	0.14	0.20
7	.18 to .40	0.07	0.11	0.17
8	.18 to .45	0.05	0.09	0.14

Note: CRFI increments are 0.18, 0.2, 0.22, 0.25, 0.27, 0.3, 0.35, 0.4, 0.45, 0.5, 0.55, 0.6.
A change from 0.25 to 0.40 is a change of 5 increments.

The cost of delaying the flight was determined based on the additional crew costs, the costs of downstream delays and the value of passenger delay time. Additional flying costs, excluding crew time, are not considered as there are usually fuel savings by travelling at lower cruise speeds and these will offset other additional flying costs. Also, if the delay occurred prior to departure there would be no additional flying costs (excluding crew time). The relationships used were as follows:

VDELAY = DELAY x CREWCPHR + NSEATS x DSTRMCOST + NSEATS x LF x DELAY x VTIME

where	
VDELAY	Value of the delay
DELAY	Delay time (hrs)
CREWCPHR	Total crew costs per hour
NSEATS	Number of passenger seats
DSTRMFAC	Downstream cost
LF	Passenger load factor
VTIME	Value of time of passengers set to $25 per hr

The downstream cost is the least known of the costs, but for long delays it is the greatest component of the costs. Downstream delays were estimated by summing the delay cost for successive flights following the originally delayed flight, assuming that it is possible to make up 20 minutes on each flight. The 20 minutes is typical for most operations. No additional delay costs are added when the flight is the last flight of the day and it is assumed that by the next morning the flights are back on schedule. An average of six flights per day is assumed and the initially delayed flight could be any one of the six flights. The downstream costs were estimated using this approach, and are illustrated in Figure 5.1 for delays to B767, A320 and CRJ aircraft. These downstream costs do not consider costs to flights by other aircraft that may be affected by the delay and are therefore likely conservative.

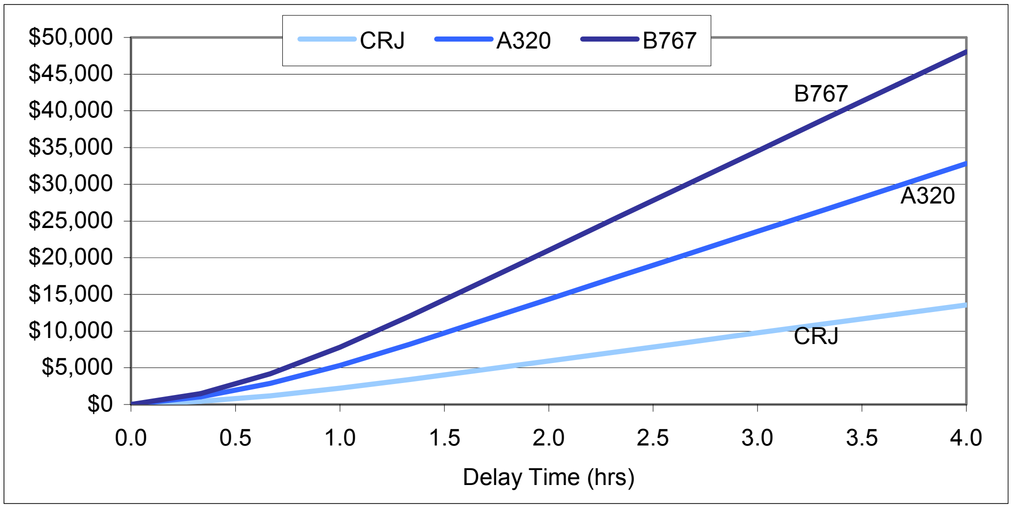

Figure 5.1 Downstream Costs versus Delay Time for B767, A320 and CRJ Aircraft

Diversion to Alternate Airport

The costs for flights diverted to another airport are estimated considering the delays to the passengers and crew and the downstream effects. The additional flight time to an alternate airport will typically be around 20-30 minutes and this represents an additional cost associated with flying the aircraft. On arrival at the alternate airport the aircraft could wait until conditions have improved then go on to the original destination, or make ground travel arrangements for the passengers and return the aircraft to its planned schedule. In the latter case the passengers who would have boarded at the original destination airport will no longer be able to do so. An example of the types of costs that would be involved in both options for a typical short haul flight are given in Table 5.4. It is assumed that there is a total delay of 3 hours when the aircraft diverts and proceeds to the destination once conditions have improved. Where the flight does not continue most of the cost is related to the delay time to passengers (assumed to be 6 hours) and the cost of the alternative transport by bus ($50 each assumed). The costs of the two options are similar and in the analysis only the wait and continue option was modelled.

The cost of a diversion used in this analysis is substantially higher than the costs used by Nav Canada in a recent study [16] evaluating airport weather forecast improvements. The cost of a diversion in the Nav Canada study averaged only $5,285 per diverted flight. This study did not consider any downstream costs and if these are excluded from the costs above, the costs would be similar.

Table 5.4 Example of Costs of Diversion of CRJ Flight for the Two Options Available to Air Carrier on Arrival at Alternate Destination

Option		Time (hrs)	Passengers	Cost/hr	Cost
Wait and continue flight to original destination					
	Additional crew costs	3		$588	$1,764
	Additional flying costs	0.5		$1,090	$545
	Passenger delay time	3	50	$25	$3,125
	Downstream costs	3			$7,717
	Total				$13,151
Discontinue flight					
	Additional crew costs	1		$588	$588
	Additional flying costs	0.5		$1,090	$545
	Passenger delay time	6	50	$25	$5,750
	Alternative transport cost				$1,750
	Downstream costs	1			$1,750
	Passengers at destination airport	2	37	$25	$2,250
	Total				$12,733

Notes: Assumes 70% load factor

Cancelled Flight

The costs for cancelled flights are difficult to estimate. Direct airline operating costs will be less than for diverted flights, but long-term costs related to their reputation for reliability would be affected and this is difficult to quantify. In practice, flights could only be cancelled prior to departure based on CRFI values and would be dependent on many factors that are difficult to model. Airlines indicated they are reluctant to cancel flights if conditions may improve and allow the flight to land. In the analysis it is assumed that flights will only be cancelled if the CRFI value and LFL required make it very unlikely the aircraft will be able to land. The criterion used was that if the LFL required accounting for the slippery runway is 25% greater than the runway length available, then the flight will be cancelled. It is very unlikely that a 25% improvement in the LFL would occur during the course of a flight. For aircraft with reverse thrust this corresponds, for example, to improvements in CRFI from:

- 0.18 to 0.40
- 0.2 to 0.45
- 0.22 to 0.50

- 0.25 to 0.55
- 0.27 to 0.60

It is estimated that the probability of an improvement in CRFI of this magnitude in less than 1.5 hours is about 10% (see Table 5.1).

For cancelled flights it is assumed that the costs to passengers will be double those for a diverted flight (i.e., $150, equivalent to a six hour delay), but that there will be no additional crew and flying costs and little impact on downstream costs (a one hour delay was used). Since the cancellation of the flight would be for factors beyond the carrier's control, there would be no monetary compensation offered to passengers and they would be allowed to travel on a flight at a later time.

Aircraft Weight Reduction

The LFL required can be reduced to allow the flight to land on a slippery runway by reducing the landing weight of the aircraft. The landing weight could be reduced prior to departure by carrying less cargo, fewer passengers, or possibly less fuel. Once airborne, the options are very limited. Excess fuel could possibly be dumped or burned prior to landing. The option of reducing weight is considered by determining the weight reduction necessary for landing on the slippery runway given the CRFI value. It is assumed that the maximum weight reduction is 1% of the landing weight and could be achieved through either reducing the cargo load prior to departure, or reducing the weight of fuel on arrival either by loading less fuel, or by dumping or burning fuel prior to landing. The amount of cargo carried on commercial passenger flights varies from zero to 10% of the landing weight. However, loads are usually very small and 1% of the landing weight represents a typical cargo load level for most jet flights. One percent of the landing weight represents 3% to 5% of the fuel load for a flight.

The average revenue from cargo carried by Canadian air carriers is around $1.40 per kilogram.[14] However, most flights have the capacity to take more cargo and cargo unloaded from one flight can usually be loaded onto a later flight. Only time-sensitive cargo will be greatly affected and this type of cargo is typically carried by integrated courier carriers that operate their own dedicated cargo aircraft. In the analysis, it was therefore assumed that only a third of the revenue from air cargo that is not loaded on a flight due to slippery runways is lost to the carrier. The cost of reduced fuel load is estimated based on a fuel price of $0.35/L, a fuel density of 0.8 kg/L and assuming the fuel is wasted. Since either or both of these methods of reducing weight are possible, but reducing cargo load is more likely, a weighted average of the two costs is used with weights of 67% for cargo and 33% for fuel reductions. The average cost of a weight reduction used in the analysis was $0.41 per kilogram.

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[14] Canadian Civil Aviation 1999, Statistics Canada Catalogue no. 51-206-XIB (revenues from Levels I-IV carriers for transportation of merchandise divided by kg of merchandise carried).

5.5 Benefit-Cost Ratios for Air Carrier Operations

The benefits and costs and the benefit-cost ratio of using the CRFI Tables relative to the three base cases are estimated using the risk model. The benefit-cost ratio varies depending on the aircraft type, landing weight, the length of runway available and the slipperiness of the runway. Use of the CRFI Tables to adjust landing distances may be very cost-effective in particular situations, but when considered over a range of aircraft landings, the adjustments may not be so cost beneficial. Different cases are analyzed in order to provide an appreciation of the cost effectiveness of using the CRFI Table adjustments in specific circumstances, and how this changes as a wider set of landings is considered. The benefit-cost ratios were determined for the following cases:

- Aircraft are at maximum landing weight, the runway length available equals that required under the current regulations, and CRFI = 0.2;
- Aircraft are at maximum landing weight and CRFI = 0.2 at airports where those aircraft types operate;
- Aircraft are at maximum landing weight and CRFI values vary according to the typical distribution for that airport; and
- Aircraft weights vary according to the typical distribution for that aircraft type and CRFI values vary according to the typical distribution for that airport.

The benefits and costs for each of these cases are presented below and detailed listings are given in Appendix E.

Very Slippery and No Additional Safety Margin above Current Regulations

Table 5.5 gives the estimated benefits and costs per 1,000 landings of using the CRFI Tables to determine the allowed LFL for each aircraft type considered where the runway distance available is equal to that required under the current regulations (i.e., with no adjustment) and CRFI is equal to 0.20. In these situations, of each 1,000 landings, about 55 would be on slippery runways and between 13 and 26 of these would result in overruns, depending on aircraft type. Benefits are high in these situations where there is no margin of safety above that provided by the current regulations. The reduction in fatalities and total accident costs are greatest for the B747, partly due to the greater number of passengers on board, and partly due to the greater landing and overrun distance and the greater chance of hitting a ditch, embankment or water for these aircraft. Under the conditions considered in this case, all (approximately 55) landings on slippery runways would be affected by the adjustments in LFL. Most flights would have to be cancelled or diverted and these outcomes account for most of the cost. In the conditions considered, weight reductions would not provide a sufficient reduction in LFL to meet the requirement and were not attributed any costs. The benefits exceeded the costs for each aircraft type and for many the benefit-cost ratio is very high. Clearly under conditions of very slippery runways (CRFI = 0.20) and no additional runway available above that required under the current regulations, the benefits of the CRFI Table adjustment to the LFL far exceed the costs. Similar benefit-cost ratios are found by applying the wet runway adjustment to the LFL and the adjustment based on the manufacturers' guidance material because the flights with landings on slippery runways would be restricted in all cases.

Table 5.5 Benefit-Cost Ratios for Use of CRFI Table Adjustment for Aircraft at Maximum Landing Weight with CRFI = 0.2 and Runway Length Equal to Minimum Allowed under Current Regulations*

Aircraft Type	Expected Overruns per 1000 Landings	Benefits per 1,000 Landings		Costs per 1,000 Landings			Benefit: Cost Ratio
		Fatalities Reduction	Accident Costs Reduction ($000)	Diversions/ Cancellations ($000)	Delays ($000)	Total** ($000)	
DC9	13.4	0.4	$7,469	$223	$11	$234	32
BA146	25.6	4.1	$64,978	$184	$11	$195	334
CRJ	19.1	0.9	$44,098	$121	$6	$127	347
A320	18.9	2.1	$142,992	$332	$16	$348	411
B737-200	15.7	0.8	$15,299	$266	$13	$279	55
B777	22.0	7.1	$578,927	$668	$39	$707	819
B747-400	25.4	57	$1,928,960	$919	$67	$986	1957
F-28	26.3	6.0	$59,680	$155	$9	$164	363
B767	20.4	3.7	$214,990	$470	$23	$493	436
B727-200	20.4	3.0	$40,198	$351	$18	$369	109
B757	20.7	4.1	$159,993	$436	$22	$458	350

Source: Sypher Risk Model

* Altitude = 500 ft. and distance to ditch/embankment = 1,000 ft., zero head & tailwind.

** Weight reduction costs were zero as delay, diversion or cancellation was required in these cases.

Very Slippery and Aircraft at Maximum Weight at Airports at which They Operate

Table 5.6 gives the LFL and benefit-cost ratios for aircraft landing at maximum landing weight with CRFI equal to 0.20 at airports where those aircraft types landed in 2000-01. The table only includes those airport-aircraft with the highest benefit-cost ratios and is sorted by the value of the ratio. For most airport-aircraft pairs (88%), adjustment of the LFL using the CRFI Tables did not result in the LFL being greater than the runway length available, even at low CRFI values. For these airport-aircraft pairs, there are no additional costs or benefits from use of the CFRI Tables. Benefit-cost ratios are greatest for the B747 for the reasons discussed above, and because the additional runway length available above that required by current regulations is typically smaller for B747s than for other aircraft types due to their long landing distances. The benefit-cost ratios of the CRFI Table adjustment relative to the current regulations greater than one for 15 airport-aircraft pairs, but less than one for 15 pairs.

Over all airport-aircraft pairs, and weighting each by the number of landings of that aircraft type at that airport, the benefit-cost ratio of the CRFI Table adjustment is 30 under the conditions that all aircraft were at maximum landing weight and CRFI = 0.2.

Table 5.6 Benefit-Cost Ratios for Use of CRFI Table Adjustment for Aircraft at Maximum Landing Weight with CRFI = 0.2 in Order of B:C Ratio

Airport	Runway Length (ft)	Aircraft Type	LFL (ft) Based on:				Benefit: Cost Ratio Relative to		
			Current Reg.	Wet Adj.	CRFI Table	Manuf. Adj.	Current Reg.	Wet Adj.	Manuf. Adj.
Whitehorse	7,200	B747-400	7,200	8,280	9,474	10,441	>1,000	1.8	0.3
Edmonton Munic.	5,868	B757	5,329	6,129	7,381	7,727	199	0.1	9.8
London	8,800	B747-400	7,215	8,297	9,487	10,463	375	375	0.2
Halifax	8,800	B747-400	7,184	8,262	9,460	10,417	55	55	0.1
St. John's	8,500	B747-400	7,183	8,260	9,459	10,415	127	127	0.4
Quebec	9,000	B747-400	7,167	8,242	9,446	10,393	24	24	0.3
Fredericton	6,000	F-28	3,903	4,488	6,010	7,025	21	21	>1,000
Prince Rupert	6,000	F-28	3,905	4,490	6,013	7,028	16	16	>1,000
Victoria	7,000	B757	5,106	5,872	7,001	7,404	15	15	>1,000
Smithers	5,000	F-28	3,967	4,562	6,127	7,141	15	15	0.1
Sudbury	6,600	A320	4,855	5,583	6,602	7,039	15	15	>1,000
Inuvik	6,000	F-28	3,909	4,495	6,021	7,036	11	11	>1,000
Kuujjuaq	6,000	B757	5,113	5,880	7,013	7,414	6.6	6.6	156
Terrace	6,000	F-28	3,928	4,517	6,056	7,070	5.9	5.9	>1,000
Thunder Bay	6,200	B757	5,166	5,941	7,103	7,491	2.8	2.8	61
Timmins	6,000	A320	4,846	5,573	6,589	7,027	0.7	0.7	54
Rouyn-Noranda	6,500	B757	5,201	5,981	7,162	7,541	0.7	0.7	56
Sudbury	6,600	B757	5,216	5,999	7,189	7,564	0.4	0.4	95
Thompson	5,800	F-28	3,928	4,517	6,056	7,070	0.2	0.2	11
Thunder Bay	6,200	CRJ	4,882	5,614	6,645	8,641	0.1	0.1	19
Fredericton	6,000	B737-200	4,403	5,063	6,017	6,120	0.1	0.1	>1,000
Over All Airports and Jet Aircraft Types in Canada Weighted by # Landings							**30**	**12**	**9.5**

Source: Sypher Risk Model

As many pilots already make some form of adjustment for slippery runways, the benefit-cost ratio of the CRFI Table adjustment was also determined relative to the 115% adjustment applicable for wet runways and to the use of adjustments from the manufacturer's guidance material. The benefits of using the CRFI Tables relative to these base cases are still much greater than the costs, but the ratios are much less, 12 for the 115% wet adjustment, and 9.5 for the manufacturer's adjustment. It should be noted, however, that the manufacturer's adjustment is more conservative than the CRFI Table adjustment and use of the CRFI Tables results in a slightly greater chance of an accident, but significantly reduced costs.

Range of Slippery Runways and Aircraft at Maximum Weight at Airports at which They Operate

Rather than considering the specific case of a very slippery runway with CRFI = 0.2, the benefit-cost ratios over the range of CRFI values typically occurring at each airport are now considered. Table 5.7 presents a summary of the expected overruns and accident costs associated with using each of the possible adjustments for slippery runways, and of the costs associated with each of these adjustments, for aircraft at maximum landing weight. The expected number of overruns due to slippery runways is estimated to be 1.3 per year if no adjustments are made, 1.2 if the 115% wet runway adjustment is used, and 0.35 if the CRFI Tables are used. Average accident costs are about $5.4 million if no adjustment is made, but are less if adjustments are made because the landings that overrun by the greatest amount will be affected by the adjustment (i.e., delayed, diverted, cancelled or weight reduced). Thus, although the number of overruns is only reduced by a factor of 4, the costs are reduced by a factor of 19. The expected number of flights affected by the adjustments range from 1.3 per year for the 115% wet runway adjustment to 755 per year for the manufacturer's adjustment. Costs using the CRFI Table adjustment are lower, as many flights can be delayed by a short time until CRFI has improved sufficiently, but for the manufacturer's adjustment a greater improvement in CRFI was required. The average costs are higher for the 115% adjustment because the aircraft affected happen to be large B747 aircraft.

Table 5.7 Summary of Estimated Annual Accident Costs and Costs of Adjustment for Accounting for Slippery Runways for Aircraft at Maximum Landing Weight

	Current Regs. (No Adjustment)	115% Wet Adjustment	CRFI Table*	Manufacturer Adjustment
# Overruns due to slippery runway	1.3	1.2	0.35	0.001
Expected # Lives Lost	0.26	0.071	0.014	0.000
Expected Total Accident Costs	$7,240,000	$2,375,000	$374,000	$0
Average Accident Cost Using Adj. Factor	$5,417,000	$2,033,000	$1,059,000	
# of Diversions/Delays/Cancellations/ Wgt reductions	0	1.3	55	755
Costs of Diversions	$0	$71,000	$560,000	$15,138,000
Costs of Delays	$0	$0	$130,000	$0
Costs of Weight Reductions	$0	$0	$1,000	$7,000
Total Costs of Accounting for Slippery Rwys	$0	$71,000	$691,000	$15,145,000
Avg. Costs of Accounting for Slippery Rwys		$56,260	$12,561	$20,053
Use of CRFI Table Relative to:				
# Flights Affected	55	54		-700
Benefits	6,866,000	$2,001,000		$14,454,000
Costs	691,000	$620,000		$374,000
B:C Ratio	9.9	3.2		39

Source: Sypher Risk Benefit-Cost Model

* CRFI Table including reverse thrust used if aircraft has reverse thrust

The benefits of using the CRFI Table adjustment relative to the current regulations is estimated to be the accident costs under the current regulations ($7,240,000) less the accident costs using the CRFI adjustment ($374,000). The benefits far exceed the costs and the overall benefit-cost ratio for the CRFI Table adjustment relative to the current regulations is 9.9.

The overall benefit-cost ratios of the CRFI Tables relative to the 115% wet adjustment and the manufacturer's adjustment are 3.2 and 39, respectively. Use of the CRFI Table adjustment becomes much more cost-effective relative to the manufacturer's adjustment when the range of CRFI values is considered. This is because the conservative adjustment from the manufacturer's guidance material is applied whenever the runway has compact snow, ice, frost or loose shallow depth snow, irrespective of the CRFI value. In practice, pilots also make use of PIREP braking reports and consider the CRFI value when deciding whether to apply the manufacturer's adjustment. In many cases where the contaminant type indicates the runway may be slippery, they may decide not to apply the adjustment if reported braking is medium or good and/or the CRFI value is high. Under these circumstances, the benefit-cost ratio for the CRFI Table adjustment relative to the manufacturer's adjustment will be much less than the value of 39 given above, provided the reported braking is highly correlated to the actual braking effectiveness.

Table 5.8 presents the average LFL and benefit-cost ratios for airport-aircraft pairs under typical runway conditions, again with aircraft at maximum landing weight. The benefit-cost ratios are lower when the typical range of CRFI values is considered, but are still greater than one for eight airport-aircraft pairs and equal to 9.9 overall for the CRFI Table adjustment relative to the current regulations.

Range of Slippery Runways and Range of Aircraft at Landing Weights at Airports They Use

Aircraft rarely operate at maximum weight, and at lower weights there is typically a greater margin of safety available for landing. The benefit-cost ratios are further reduced allowing for these lower aircraft weights. The expected numbers of overruns, accident costs, numbers of flights affected by requirements to account for slippery runways, and the costs under the different methods of accounting for slippery runways are summarized in Table 5.9. The benefit-cost ratio of using the CRFI Table adjustment relative to the current regulations, the 115% wet runway adjustment, and the manufacturer's adjustment (given at the bottom of Table 5.5) are 4.7, 1.1 and 158, respectively. These ratios include the benefits and costs to the air carrier and passengers associated with aircraft operations, but exclude other air carrier and airport costs.

Table 5.8 Benefit-Cost Ratios for Use of CRFI Table Adjustment for Aircraft at Maximum Landing Weight over Range of Typical CRFI Values

Airport	Runway Length (ft)	Aircraft Type	Average LFL (ft) Based on:				Benefit: Cost Ratio Relative to		
			Current Reg.	Wet Adj.	CRFI Table	Manuf. Adj.	Current Reg.	Wet Adj.	Manuf. Adj.
Whitehorse	7,200	B747-400	7,200	8,280	8,532	10,441	483	3.7	0.1
London	8,800	B747-400	7,215	8,297	8,544	10,463	134	134	0.9
St. John's	8,500	B747-400	7,183	8,260	8,518	10,415	71	71	1.1
Edmonton City C.	5,868	B757	5,329	6,129	6,661	7,727	40	0.1	4.9
Halifax	8,800	B747-400	7,184	8,262	8,519	10,417	35	35	0.7
Quebec	9,000	B747-400	7,167	8,242	8,506	10,393	21	21	1.7
Smithers	5,000	F-28	3,967	4,562	5,332	7,141	6.7	6.7	0.8
Charlottetown	7,000	B767	5,008	5,759	6,182	7,211	5.2	5.2	>1,000
Thunder Bay	6,200	F-28	3,925	4,514	5,265	7,066	5.1	5.1	>1,000
Kuujjuaq	6,000	B757	5,113	5,880	6,339	7,414	2.1	2.1	143
Thunder Bay	6,200	B757	5,166	5,941	6,418	7,491	1.2	1.2	101
Timmins	6,000	A320	4,846	5,573	5,966	7,027	0.4	0.4	146
Rouyn-Noranda	6,500	B757	5,201	5,981	6,470	7,541	0.4	0.4	170
Sudbury	6,600	B757	5,216	5,999	6,493	7,564	0.2	0.2	279
Thompson	5,800	F-28	3,928	4,517	5,269	7,070	0.2	0.2	68
Terrace	6,000	F-28	3,928	4,517	5,269	7,070	0.1	0.1	278
Fort McMurray	6,000	F-28	3,947	4,539	5,300	7,105	0.1	0.1	178
Inuvik	6,000	F-28	3,909	4,495	5,238	7,036	0.1	0.1	348
Prince Rupert	6,000	F-28	3,905	4,490	5,232	7,028	0.1	0.1	378
Over All Airports and Jet Aircraft Types in Canada Weighted by # Landings							**9.9**	**3.2**	**39**

Source: Sypher Risk Benefit-Cost Model

Table 5.9 Summary of Estimated Annual Accident Costs and Costs of Adjustment for Accounting for Slippery Runways

	Current Regs. (No Adjustment)	115% Wet Adjustment	CRFI Table*	Manufacturer Adjustment
# Overruns due to slippery runway	0.34	0.30	0.10	0.000
Expected # Lives Lost	0.03	0.012	0.003	0.000
Expected Total Accident Costs	$987,000	$256,000	$46,000	$0
Average Accident Cost Using Adj. Factor	$2,939,000	$841,000	$441,000	
# of Diversions/Delays/Cancellations/ Wgt reductions	0	0.4	16	401
Costs of Diversions	$0	$18,000	$162,000	$7,489,000
Costs of Delays	$0	$0	$40,000	$0
Costs of Weight Reductions	$0	$0	$0	$2,000
Total Costs of Accounting for Slippery Rwys	$0	$18,000	$202,000	$7,491,000
Avg. Costs of Accounting for Slippery Rwys		$50,992	$13,024	$18,673
Use of CRFI Table Relative to:				
# Flights Affected	16	15		-386
Benefits	941,000	$210,000		$7,289,000
Costs	202,000	$184,000		$46,000
B:C Ratio	4.7	1.1		158

Source: Sypher Risk Benefit-Cost Model

* CRFI Table including reverse thrust used if aircraft has reverse thrust

The benefit-cost ratios for the airport-aircraft pairs for which flights will be affected by the use of the CRFI adjustment are given in Table 5.10. As before, benefits exceed costs for B747 aircraft landing at airports with runways of 9,000 ft. or less and for several other aircraft types landing on short runways.

Table 5.10 Benefit-Cost Ratios for Use of CRFI Table Adjustment for Aircraft over Range of Landing Weights and Typical CRFI Values

Airport	Runway Length (ft)	Aircraft Type	Average LFL (ft) Based on:				Benefit: Cost Ratio Relative to		
			Current Reg.	Wet Adj.	CRFI Table	Manuf. Adj.	Current Reg.	Wet Adj.	Manuf. Adj.
Whitehorse	7,200	B747-400	6,485	7,457	7,953	9,403	110	0.2	2.1
London	8,800	B747-400	6,395	7,355	7,880	9,274	22	22	23
St. John's	8,500	B747-400	6,367	7,322	7,857	9,232	9.1	9.1	25
Edmonton City C.	5,868	B757	4,988	5,736	6,167	7,232	6.3	2.6	42
Halifax	8,800	B747-400	6,368	7,323	7,858	9,234	6.1	6.1	18
Quebec	9,000	B747-400	6,353	7,306	7,846	9,212	5.2	5.2	31
Charlottetown	7,000	B767	4,546	5,228	5,595	6,547	5.2	5.2	936
Thunder Bay	6,200	F-28	3,726	4,284	4,944	6,706	5.2	5.2	>1,000
Smithers	5,000	F-28	3,765	4,330	5,008	6,777	2.4	2.4	3.2
Kuujjuaq	6,000	B757	4,785	5,503	5,879	6,939	0.4	0.4	352
Thunder Bay	6,200	B757	4,835	5,560	5,950	7,011	0.2	0.2	530
Thompson	5,800	F-28	3,728	4,287	4,948	6,710	0.1	0.1	372
Fort McMurray	6,000	F-28	3,746	4,308	4,978	6,743	0.1	0.1	>1,000
Terrace	6,000	F-28	3,728	4,287	4,948	6,710	0.1	0.1	>1,000
Timmins	6,000	A320	4,388	5,046	5,435	6,363	0.1	0.1	>1,000
Inuvik	6,000	F-28	3,710	4,266	4,919	6,677	0.1	0.1	>1,000
Rouyn-Noranda	6,500	B757	4,867	5,597	5,996	7,058	0.1	0.1	>1,000
Prince Rupert	6,000	F-28	3,706	4,262	4,913	6,670	0.1	0.1	>1,000
Fredericton	6,000	F-28	3,704	4,259	4,910	6,667	0.1	0.1	>1,000
Thunder Bay	6,200	CRJ	4,445	5,112	5,493	7,868	0.1	0.1	>1,000
Over All Airports and Jet Aircraft Types in Canada Weighted by # Landings							**4.7**	**1.1**	**158**

Source: Sypher Risk Benefit-Cost Model

Relative to the 115% wet adjustment, the benefit-cost ratio is 1.1, indicating benefits of using the CRFI Tables are slightly greater than the costs if pilots already use the 115% wet adjustment. This occurs because the LFL for almost all flights can make the 115% adjustment without causing any cancellations, delays or diversions, but in the few cases where the flights are affected, there are large benefits. This shows that at a very minimum, the 115% adjustment should be applicable to slippery runways as well as wet runways. The benefit-cost ratio for application of the 115% adjustment to slippery runways is 40. The benefit-cost ratio of the CRFI Tables relative to the manufacturer's adjustment is extremely high, but as discussed above, is likely lower than this in practice due to the use of PIREP braking reports.

Other Costs to Air Carriers

Costs associated with updating manuals such as the AFM and AOM, to include procedures for accounting for slippery runways are a one-time cost. In the study of benefits and costs for accounting for wet and contaminated runways on take-off, the cost of updating manuals was estimated to be $100,000 per aircraft type. Procedures for accounting for slippery runways on landings are less complicated than for take-offs, and information is available and already included as guidance material for many aircraft types. However, it is only possible to provide approximate costs as the types of changes required have not been specified. The jet aircraft types operated by scheduled air carriers in Canada are:

Air Canada	A340, A330, B747-400, B767-300, B767-200, A320, A319, CRJ
WestJet	B737-200/700
CanJet	B737-100/200
JetsGo	MD-83
Air Transat	A330, B757, L-1011
First Air	B727, B737-100/200
Canadian North	B737-100/200, F-28

Assuming a cost of $50,000 for each aircraft type and model operated by each carrier, the total cost of updating manuals would be approximately $1.2 million. If these costs are spread over a 10 year period, the annual cost would be $120,000.

Additional training of pilots and dispatchers on the use of CRFI for making adjustments to LFL requirements will be required. It is assumed that than additional 30 minutes of classroom training per year will be required and the average hourly rate $175 for non-flying duties. Approximately 3,500 jet aircraft pilots and dispatchers will require training, giving a total annual cost of $306,000.

5.6 Benefits and Costs to Airports

Runway surface condition (RSC) reports and runway friction measures (currently CRFI and previously JBI) have been available at almost all airports with scheduled air carrier service for many years, and TC has published guidance material available for the collection and dissemination of this information. A TC Working Group on Airport Winter Maintenance and Planning is working in parallel with the current study reviewing the winter maintenance requirements and procedures. Generally, the improvements being recommended specify the current procedures and best practices in more detail, and airport operators do not see any significant increases in costs to the changes. The Working Group is considering a recommendation that all airports receiving scheduled air transport services using aircraft with 20 or more passenger seats be required to provide CRFI values. The greatest impact of this the requirement would be providing CRFI values at airports with gravel runways, particularly if the requirement to provide CRFI values were applied to scheduled service of 10-19 seat aircraft. An exemption for airports with gravel runways is being considered.

All airports with paved runways in Canada that have scheduled air carrier service provided by jet aircraft currently measure CRFI values and provide them as part of the RSC reports using TC Guidelines given in ASC 2000-002: Aircraft Movement Surface Condition Reporting (AMSCR) for Winter Operations [9]. There may be some additional costs, depending on the form of the requirements for air operators to account for slippery runways. For example, if CRFI values must be available at the time of dispatch, the time at which collection of CRFI values begins each day may need to be made earlier so that the information is available for early morning flights. The cost to the airport of beginning, say, an hour earlier is not insignificant. Assuming one person is required at a cost of $50 per hour for the 5 months when winter runway conditions occur, the cost for that airport would be $7,500. However, most jet aircraft landings in the early morning occur at a small number of the larger airports and the additional costs at these airports would be minimal. If the requirement to provide CRFI values at the time of dispatch is only for jet aircraft on scheduled service, the overall additional cost should be relatively small, likely less than $75,000 per year.

The survey of airline pilots indicated that improvements in the consistency of reporting of CRFI values are required for them to be used in accounting for slippery runways. Costs of these improvements could not be estimated until the improvements have been specified. However, as the airport operators indicated that they currently follow the TC guidelines regarding CRFI, the improvements will likely be achievable through better and more frequent training and the more diligent application of these procedures. The additional costs are therefore not expected to be great.

Airports with gravel runways that receive scheduled jet service potentially will have the greatest additional costs due to the CRFI requirements. Currently no airports with gravel runways collect CRFI values and Iqaluit is the only one of these airports with scheduled jet service. If gravel runways are not exempt from the requirement to provide CRFI values, the cost to that airport will be significant, as is outlined below.[15]

Initial/Capital Costs	
Cost of one truck	$30,000
Garage	$20,000
CRFI equipment	$ 8,000
Training of staff	$ 6,000
Communication equipment	Cost unknown
Total initial/capital cost	$64,000+

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[15] Costs provided for remote airports in northern Ontario with gravel runways by the Ontario Ministry of Transportation.

Annual/Recurring Costs	
Refresher training/training of replacement staff	$ 2,000 /year
Calibration of CRFI equipment	$ 1,000/year
Vehicle/building operation and maintenance	$ 5,000/year
Two additional staff to provide coverage evenings and weekends	$46,000/year
Total annual/recurring cost	$54,000/year

These costs, although significant for the airport, are relatively small when all costs and benefits of using CRFI values to account for landing on slippery runways are taken into account. Based on conversations with airport operators and the fact that any changes in the collection of CRFI values will be small, benefits to the airports from planned changes in the CRFI are expected to be minimal.

5.7 Overall Benefit-Cost Ratios

The overall estimated annual benefits and costs of using the CRFI Table adjustments for LFL considering all aircraft types and airports for both the air carriers and airports are as follows:

• Benefits –	To air carriers & passengers		$941,000
	To airports		insignificant
• Costs –	To air carriers & passengers	Operational	$202,000
	To air carriers	Manuals	$120,000
		Training	$306,000
	To airports		$129,000
	Total costs		$757,000
• Benefit-Cost Ratio	1.24		

The costs to air carriers do not include any additional costs associated with delays to aircraft on take-off and landing due to more frequent measurement of CRFI values. These could be significant at busy airports.

The overall benefit-cost ratio for application of the 115% adjustment for slippery runways is approximately 4.1, assuming additional costs to the carriers for updating manuals and training of $160,000 per year. The benefit-cost ratio for moving from the 115% adjustment to the use CRFI Tables for slippery runways would then be approximately 0.4.

A number of air carriers operate aircraft at airports where there is sufficient runway available for landing the aircraft after accounting for slippery runways, even for CRFI values as low as 0.18. If this is the case for all airports at which the carrier is approved to operate, then the adjustment for slippery runways would not result in the LFL being greater than the runway available for any landings of that aircraft type by the carrier. In these cases, there would be no operational costs or benefits of accounting for slippery runways for that aircraft type. The costs to the air carrier could be reduced if, for these aircraft types, the air carrier does not have to update the manuals and train the pilots and dispatchers for operations on slippery runways. This could significantly improve the economic case for use of the CRFI Tables.

6. IMPLEMENTATION ISSUES

The benefit-cost ratios given in Section 5 provide an indication of the relative benefits and costs of using the CRFI Tables to adjust LFL for slippery runways. There are, however, implementation issues that should be considered when determining the best approach for accounting for slippery runways on landing.

When Should Adjustment be Made?

The wet runway adjustment is applied at the time the aircraft is dispatched prior to take-off. This adjustment has little impact on the air carriers because the 115% adjustment can be made for most flights with no change in landing weight. However, the adjustments associated with low CRFI values will result in more frequent reductions in weight, delays or cancellations. CRFI values can change significantly over the time between dispatch and landing, and many of the flights may be affected unnecessarily if adjustments are applicable at the time of dispatch. Conversely, if runway friction deteriorates, the aircraft may not be able to land on arrival at the airport.

Use of PIREP Braking Reports

PIREP braking reports provide a valuable source of information on the likely wheel braking effectiveness on landing. The reports are particularly useful when they are very recent and available for landings of similar sized aircraft, which is often the case at large busy airports. The terminology used by some aircraft manufacturers in their guidance material for slippery runways is the same as that used in PIREP braking reports, making application of PIREPs easier than using CRFI values. Many pilots find these reports to be as useful, if not more useful, than the CRFI value for determining the slipperiness of the runway. During busy periods, CRFI values may not be measured as frequently, but the availability of PIREP braking reports keeps pilots informed about the slipperiness of the runway. Even when CRFI values are measured frequently, recent PIREPs will often be more up-to-date than the CRFI value. Any procedure for accounting for slippery runways on landing should allow PIREPs to be taken into account.

The report on the survey of airline pilots [5] provides a discussion of the implementation issues from the pilots' perspective and the form of any regulatory changes for accounting for slippery runways on landing.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

Runways conditions are slippery (i.e., contaminated with ice, compact snow, frost or shallow depth loose snow) for approximately 5.5% of the time at airports serving jet aircraft in Canada. Over a year, the percentage of the time CRFI values are in the specified ranges below are as follows:

• 0.2 or less	0.5%
• 0.21 to 0.3	2.1%
• 0.31 to 0.4	1.7%
• 0.41 to 0.5	0.8%
• 0.51 or greater	94.9%

The risk of a jet aircraft overrunning the end of the runway on landing when the runway is slippery is approximately 13 times greater than when the runway is dry. The risks of overruns on landing for aircraft without reverse thrust are approximately 4 to 7 times greater than for aircraft with reverse thrust.

The overrun accident/incident rate of jet aircraft landing on a slippery runway in Canada over the period 1989 to 2001 was approximately 17 per million landings on slippery runways. For commercial passenger jet aircraft the rate was 13 per million landings. Due to the small proportion of landings on slippery runways, the overrun accident/incident rate due to slippery runways over all landings was 1.3 per million, or 1.0 per million for commercial passenger jet aircraft. The consequences of these overruns also tend to be low, with no fatalities recorded in these types of accidents in the past 25 years in Canada.

The benefits of using the CRFI Tables to adjust LFL exceed the costs of doing so for all aircraft types when the LFL under current regulations equals the runway length available and the runway is very slippery (CRFI approximately 0.2).

For most jet aircraft landings in Canada, the runway length available far exceeds the LFL required, and this provides an additional margin of safety above that provided by the regulations. The risk of an overrun when the runway is slippery is greatly reduced by this additional margin of safety. The additional runway length available will result in extremely few flights (less than 0.01%) being affected by LFL requirements that account for slippery runways using the CRFI Tables.

Considering only the benefits and costs to passenger and air carrier operations, the benefit-cost ratio for use of the CRFI Tables relative to the current regulations over all air carrier jet aircraft landings in Canada, allowing for the range in runway conditions and aircraft weights, is estimated to be approximately 4.7. Much of the benefit is attributed to a small number of landings of B747 aircraft on runways of 9,000 ft. or less.

Considering the benefits and costs to passengers and air carriers of operations, updating manuals and training, and the additional costs to the airport, the benefit-cost ratio for use of the CRFI Tables is estimated to be approximately 1.2.

Costs associated with extending the applicability of the 115% adjustment to LFL to cover slippery runways are low and the benefits for the few landings affected are very high, giving a benefit-cost ratio of over 4. As a minimum, the 115% adjustment should be extended to slippery runways. Many pilots already use an adjustment of 115% or greater. Considering only the operational benefits and costs, the incremental benefits of moving from the 115% adjustment to the use of CRFI Tables for slippery runways are slightly greater than the incremental costs (benefit-cost ratio of 1.1). However, if costs of manual updates and training are considered, costs exceed the benefits.

Application of adjustments in LFL for slippery runways based on manufacturers' guidance material would result in very high costs if applied to all landings on slippery runways, irrespective of the actual CRFI value and PIREP braking reports. Under these conditions, the CRFI Table adjustment provides a very cost-effective alternative for accounting for slippery runways.

7.2 Recommendations

The following recommendations are made:

- The 115% adjustment to the calculation of the required LFL for a wet runway applicable at the time of dispatch be extended to include runway conditions where the CRFI value is 0.5 or less, or where there is ice, compacted snow and/or shallow depth loose snow covering 20% or more of the runway.
- Guidance material be provided for turbo-jet aircraft by the air operator, which will allow the pilot of the aircraft to determine the runway distance required to land the aircraft when the runway is slippery due to ice, compact snow and/or shallow depth loose snow contamination. The guidance material may base the determination of the landing distance on a combination of the CRFI value, PIREP braking reports and the type and extent of snow/ice contamination on the runway, taking into consideration the time of the last reports. Guidance or other material provided by the manufacturer of the aircraft and the CRFI Tables provide acceptable sources of information for developing the guidance material. The procedures for determining landing distance should be easy to use so as to allow pilots to make the calculations while en route, just prior to landings if necessary.
- Consideration be given to allow an air carrier to exclude aircraft types from the above requirement where the adjusted LFL with a CRFI value of 0.18, allowing for the pressure-altitude of the airport, zero headwind and 0°C ambient temperature, is less than the runway length available at all airports where that carrier is approved to operate.

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Appendix A

Sections of Canadian Aviation Regulations for Commercial Air Services on Landing Distance Requirements

CAR Standards

Sections Relevant to Landing Distance Requirements

Part V - Airworthiness

Chapter 525 - Transport Category Aeroplanes

525.125 Landing

(a) The horizontal distance necessary to land and to come to a complete stop (or to a speed of approximately 3 knots of water landings) from a point 50 feet above the landing surface must be determined (for standard temperatures, at each weight, altitude and wind within the operational limits established by the applicant for the aeroplane) as follows:

(1) The aeroplane must be in the landing configuration.

(2) A stabilised approach, with a calibrated airspeed of not less than 1.3 V_S or V_{MCL}, whichever is greater, must be maintained down to the 50 foot height.

(3) Changes in configuration, power or thrust, and speed, must be made in accordance with the established procedures for service operation.

(4) The landing must be made without excessive vertical acceleration, tendency to bounce, nose over, ground loop, porpoise, or water loop.

(5) The landing may not require exceptional piloting skill or alertness.

(b) **[**For landplanes and amphibians, the landing distance on land must be determined on a level, smooth, dry, hard-surfaced runway. In addition:**]**

(1) The pressures on the wheel braking systems may not exceed those specified by the brake manufacturer;

(2) The brakes may not be used so as to cause excessive wear of brakes or tires; and

(3) Means other than wheel brakes may be used if that means:

(i) Is safe and reliable;
(ii) Is used so that consistent results can be expected in service; and
(iii) Is such that exceptional skill is not required to control the aeroplane.

(c) For seaplanes and amphibians, the landing distance on water must be determined on smooth water.

(d) For skiplanes, the landing distance on snow must be determined on smooth, dry snow.

(e) The landing distance data must include correction factors for not more than 50 percent of the nominal wind components along the landing path opposite to the direction of landing, and not less than 150 percent of the nominal wind components along the landing path in the direction of landing.

(f) If any device is used that depends on the operation of any engine, and if the landing distance would be noticeably increased when landing is made with that engine inoperative, the landing distance must be determined with that engine inoperative unless the use of compensating means will result in a landing distance not more than that with each engine operating.

Aeroplane Flight Manual

525.1581 *General*

(g) The Aeroplane Flight Manual shall contain information in the form of approved guidance material for supplementary operating procedures and performance information for operating on contaminated runways.**]**

Part VII - Commercial Air Services

Dispatch Limitations: Landing at Destination and Alternate Aerodromes

705.60 (1) Subject to subsection (3), no person shall dispatch or conduct a take-off in an aeroplane unless

(a) the weight of the aeroplane on landing at the destination aerodrome will allow a full-stop landing

(i) in the case of a turbo-jet-powered aeroplane, within 60 per cent of the landing distance available (LDA), or

(ii) in the case of a propeller-driven aeroplane, within 70 per cent of the landing distance available (LDA); and

(b) the weight of the aeroplane on landing at the alternate aerodrome will allow a full-stop landing

(i) in the case of a turbo-jet-powered aeroplane, within 60 per cent of the landing distance available (LDA), and

(ii) in the case of a propeller-driven aeroplane, within 70 per cent of the landing distance available (LDA).

(2) In determining whether an aeroplane can be dispatched or a take-off can be conducted in accordance with subsection (1), the following shall be taken into account:

(a) the pressure-altitude at the destination aerodrome and at the alternate aerodrome;

(b) not more than 50 per cent of the reported headwind component or not less than 150 per cent of the reported tailwind component; and

(c) that the aeroplane must be landed on a suitable runway, considering the wind speed and direction, the ground handling characteristics of the aeroplane, and other conditions such as landing aids and terrain.

(3) Where conditions at the destination aerodrome at the time of take-off do not permit compliance with paragraph (2)(c), an aeroplane may be dispatched and a take-off conducted if the alternate aerodrome designated in the operational flight plan permits, at the time of take-off, compliance with paragraph (1)(b) and subsection (2).

Dispatch Limitations: Wet Runway - Turbo-jet-powered Aeroplanes

705.61 (1) Subject to subsection (2), when weather reports or forecasts indicate that the runway may be wet at the estimated time of arrival, no air operator shall dispatch or conduct a take-off in a turbo-jet-powered aeroplane unless the landing distance available (LDA) at the destination aerodrome is at least 115 per cent of the landing distance required pursuant to paragraph 705.60(1)(a).

(2) The landing distance available on a wet runway may be shorter than that required by subsection (1), but not shorter than that required by Section 705.60, if the aircraft flight manual includes specific information about landing distances on wet runways.

Appendix B

Analysis of CRFI Tables and their Confidence Intervals

Analysis of CRFI Tables and their Confidence Intervals

The CRFI Tables are based on the analysis of extensive tests conducted as part of the winter runway friction testing program conducted at North Bay [1,2]. An overview of the approach and commentary on the confidence intervals are given below.

Data Used in Determining μB and CRFI Relationship

Relationship between μB and CRFI is derived from 1996 and 1997 data for runways with no, or negligible, contamination drag. Data on similar runways for 1998 were shown to be close to predicted values using that relationship (except test 98/19 with ½ inch of wet snow – discussed below). The relationship was not re-derived using the data for the three years. This will, however, have little or no effect on the final CRFI Table as the recommended landing distance (LD) is based on an empirical 95% confidence limit for that relationship and all points over the three years of testing were used.

The μB – CRFI relationship was derived using data for runways with no, or *negligible*, contamination drag. The changes in requirements being considered will apply to those conditions, i.e., compacted snow and ice patches. However, in determining the recommended LDs, a safety factor is introduced that includes a wide range of contaminated runway conditions from 2 inches of loose dry snow, to ½ inch of wet snow, to slush and standing water. Although the effect of contaminant drag is estimated and accounted for in the estimation of μB, the estimated μB values under these conditions shows greater variation than with no contaminant drag. This results in a larger safety factor.

The changes in requirements for operating on slippery runways being considered have been restricted to where there is no or negligible contaminant drag (compacted snow or ice (frost) on the runway) due to the greater variation under other conditions. If only applied under these conditions, is it overly cautious to base the safety factors on variation that occurs under other conditions? Factors affecting this include:

- How accurately can the CRFI be measured under these conditions?
- How well can the effects of contaminant drag be removed when estimating μB?
- How well does the relationship between μB and CRFI hold in these other conditions?

Safety Factor

A safety factor is applied to the LD given in the AFM to determine the landing field length required. The factor is:

LFL = LD/0.6 for jet aircraft
= LD/0.7 for turboprop aircraft

The LD is determined on a bare and dry runway and, as stated in [1], "is based on the aircraft manufacturer's flight tests using high approach path angle, minimum flare and minimum delay from touchdown to application of full braking. With very aggressive deceleration techniques, the AFM LD probably represents the minimum LD achievable".

The safety factor accounts for variation in pilot technique, aircraft performance and runway conditions from those used in determining the AFM LDs. If the runway conditions are known and included specifically in the LD calculation, one would expect the safety factor required to be less.

If extended back to a CRFI value of 0.8, typical of bare and dry runways, the CRFI Table gives a lower value than the current LFL requirement as would be expected. The proportion of the safety margin included in the LFL that is attributable to runway condition, based on the CRFI Table, is between 9% and 24%. The difference is due to differences in methods of determining the two safety margins. The portion of the safety margin due to runway condition in the current LFL is therefore relatively small.

AFM LD ft.	LFL (LD/0.6)	Recommended LD (CRFI=0.8)	Safety Margin due to Runway Condition*
2,000	3,333	3,220	113 ft. (9%)
3,000	5,000	4,730	270 ft. (14%)
4,000	6,667	6,030	637 ft. (24%)

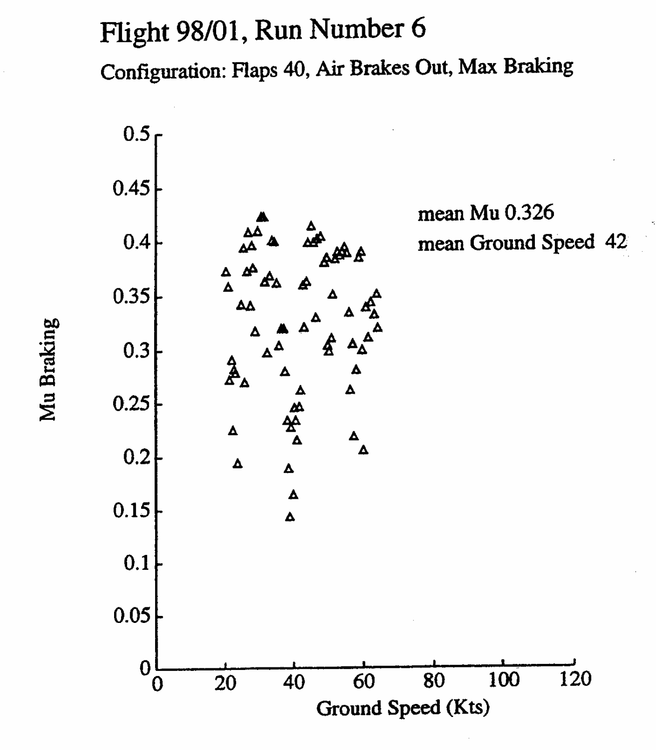
* % of safety margin [LFL – AFMLD]

Calculation of μB

One would expect that if all factors are taken into account in the estimation of μB, then the value for a particular runway conditions should be the same for rejected take-offs as for landings. This, unfortunately, does not appear to be the case, estimated values of μB for landing tends to be higher than for rejected take-offs, although the difference is small.

Variation in μB – CRFI Values

There is considerable scatter in the estimated μB values in a single test run, see Figure B-1. By examining the results of many test runs [1] concluded there is no consistent relationship between ground speed and μB. Each test run makes up only a proportion of a full deceleration from 110 knots, many cover less than a 30 knot range in speeds. The μB values from each of these tests are represented by a single average value, independent of the number of values used to calculate the average and the proportion of the full deceleration covered. Given the scatter in the data, one would expect an average value to be better representative of the true µB value for a full stop if it is based on a larger number of points and a greater portion of the speed range.



Source: [1] (Appendix D, Page D2)

Figure B-1 Estimated Mu Braking Values versus Ground Speed for Single Test Run

The average µB values for each test were used to indicate the variation that could be expected in the estimated µB value for a given CRFI value. We should consider why the average value over the test was used and not the individual µB values in each test. What is the significance of the set of points in a test?

The answer would appear to be that the CFRI value was measured over the test section and a single average value is used to represent the test section as a whole at that time (at least for the purpose of estimating the µB and recommended LD from the CRFI Table). Thus, the average µB over the test section should be related to the average CRFI over the section.

If the test section were longer, more values would be included in the average, and the variation in the average values would be less. If a number of runs are done on the same test section with the same average CRFI values, why would the individual μB values of all these tests not be averaged, especially if the combined set is more representative of a full deceleration?

Questions:

- Why do some tests cover a large range in speeds (35 – 105 knots) and some a very short intervals (30 knots or less)?
- Why do many tests only cover a short part of the test section?
- Why was the density of μB values with speed, high in some tests (typically when speed interval is short), and low in other tests?

Allowance for Variation in μB Values

Figure 7 in [1] shows the μB – CRFI data and the predicted and recommended LDs for given CRFI values, the latter determined by decreasing the deceleration model by one SD[1] (0.0135) and using <u>only 80% of the CRFI value</u>. As noted in [1], four points (overlaid points appearing as two points in the figure) out of the total of 89 points will give about a 95% chance of achieving the predicted μB or higher. An empirical method was used as the prediction errors when all data points are used are not normally distributed. In this situation the approach used appears to be a reasonable. Results will be good if the sources of variation present during the tests will be similar to those present in situations where the estimation procedure will be used. The four points outside the 95% range were all from the same set of test runs, 98/10, with the same runway conditions which were not encountered in other tests. This set of tests has a significant impact on the recommended LD and use of data is discussed below.

As noted above, the changes in requirements being considered will apply to slippery runways with no or negligible contamination drag (i.e., compacted snow and icy runways) and this empirical method based on all data likely results in overly conservative confidence interval.

Where the CRFI values vary along the runway, an average value is used to calculate the predicted LD. If the variation is consistent along the runway (so the average CRFI is representative of the section of the runway where the aircraft is braking), use of an average CRFI value will result in a conservative estimate of the LD. This is due to the concave nature of the LD-CRFI relationship (see Figure 19 of [1]). This will be particularly so when the values vary greatly such as on runways with ice patches that are otherwise bare and dry.

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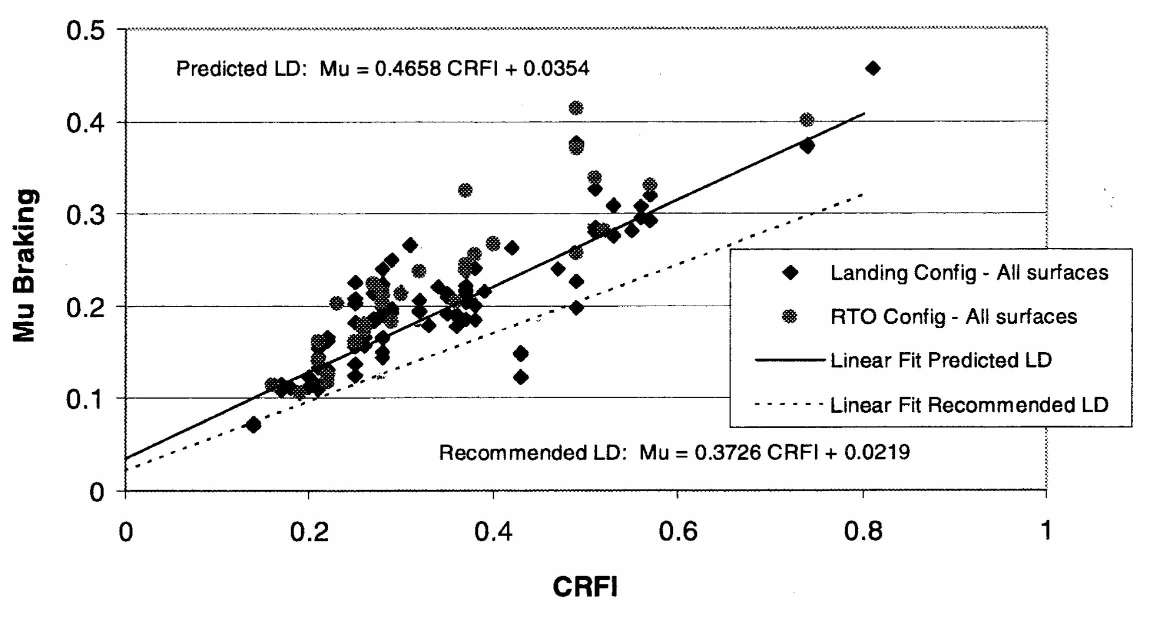
[1] The SD used appears to be the standard error of estimate using the predicted LD equations and only the points where the runway had little or no contamination and conditions did not vary greatly along the runway.



Source: [2] (Figure 7, page 21)

Figure B-2 Falcon 20 Mu Braking versus CRFI, All Data 1996-1999

Rather than using the factor of 80% of the CRFI values for determining recommended LD is all cases, consideration should be given to relating this factor to the uncertainty in the CRFI value. If the measurement of CRFI values is less reliable for runways with particular types of contamination, make the factor less for these conditions. Similarly if weather conditions are such that the friction value may be deteriorating and could be changing quickly, a lower factor should be used than if conditions are stable or likely improving. Note that, if the measured friction values vary along the runway, use of an average value will result in higher recommended landing distances so a lower factor should not be used in these situations, possibly a slightly higher factor should be used.

Inclusion of Data in Test 98/10: Runway ½ Inch Wet Snow

For Test 98/10, runs 2 to 5, the runway varied from: 10% Bare & Wet/ 90% ½ inch wet snow, changing to: 20% Bare & Wet/ 80% ½ inch wet snow. The specific gravity of the snow was not taken, but the temperature was +1°C. The snow was not compacted. Given the temperature and the description as "wet" the specific gravity was likely around 0.2 – 0.3. The contaminant drag would therefore be of a similar magnitude as 1.5 to 2.5 inches of light snow.

In the reporting of runway conditions, when the depth of loose snow is greater than ¼ inch, depth must be reported on the RCI. When depth is less than a ¼ inch it does not need to be reported. The significance of the ¼ inch is primarily related to the presence of contaminant drag above that value.

The changes in requirements being considered would be applicable for slippery runways with no or negligible contaminant drag. The runway conditions during Tests 98/10, runs 2-5, could not be described as slippery with no or negligible contaminant drag. Therefore, it is debatable whether they should be used in determining confidence levels and recommended LDs for slippery runways with no or negligible contaminant drag. Use of this data makes the results very sensitive to the accuracy of calculations removing the effect of contaminant drag when estimating μB.

Exclusion of the four runs in this test significantly alter the apparent accuracy of the μB – CRFI relationship.

Given the comparatively low value of μB for the measured CRFI value, it would be worthwhile exploring possible reasons for the difference and conducting additional tests in these conditions to verify whether the points were outliers, or represent the true aircraft braking behaviour in these conditions.

Calculation of Landing Distance

The method used to calculate LD and the recommended LD is a reasonable approach to setting safety margins. Comparison of the recommended landing distance with the LFL provides a useful method for understanding the safety margin provided by current regulations.

Level of Confidence in Recommended Landing Distances

The LD is found by adding the air distance, D1, delay distance, D2, and the stopping distance, D3. In calculating the recommended LD, a safety factor is applied to each segment as follows:

D1 The standard deviation of D1 from flight test data is calculated (s_{D1}) and twice the SD is added to the average D1 (d_1). The probability that D1 on any given flight is greater than $d_1 + 2\ s_{D1}$ is 0.025 (assuming D1 is normally distributed and 40 tests were conducted)

D2 Similarly, the recommended distance is calculated by the average D2 (d_2) plus twice the SD of D2 (s_{D2}). The probability that D2 on any given flight is greater than $d_2 + 2\ s_{D2}$ is 0.025.

D3 Based on empirical analysis using all data, the recommended stopping distance is calculated from the predicted μ_B using the conservative model chosen so that the probability of the stopping distance on a particular flight being greater than the recommended distance is 0.05.

The probability that the LD (equal to D1+D2+D3), is greater than the recommended distance is not trivial to determine, but is much less than 0.05. To explore the possible level of confidence, some simplifying assumptions are made.

If D1, D2 and D3 were all independent and normally distributed with means $\mu 1$, $\mu 2$ and $\mu 3$ and a variance of σ^2, their sum would also be normally distributed with mean $\mu 1+\mu 2+\mu 3$ and variance $3\sigma^2$. If their variances differ, their sum will only be approximately normally distributed with variance $\sigma_1^2 + \sigma_2^2 + \sigma_3^2$.

$$
\begin{aligned}
&P[\, D1+D2+D3 < (d_1 + 2\, s_{D1}) + (d_2 + 2\, s_{D2}) + (d_3 + 1.65\, s_{D3})\,] \\
&= P[\, \{(D1-d_1) + (D2-d_2) + (D3-d_3)\} / \sqrt{\{\sigma_1^2 + \sigma_2^2 + \sigma_3^2\}} \\
&\qquad < \{(2\, s_{D1}) + (2\, s_{D2}) + (1.65\, s_{D3})\} / \sqrt{\{\sigma_1^2 + \sigma_2^2 + \sigma_3^2\}}\,] \\
&\approx P[\, Z < \{(2\, s_{D1}) + (2\, s_{D2}) + (1.65\, s_{D3})\} / \sqrt{\{\sigma_1^2 + \sigma_2^2 + \sigma_3^2\}}\,]
\end{aligned}
$$

where d_3 is the LD based on μB calculated from the best fit with the CRFI values
σ_3 is the standard deviation of D3
Z has a standard normal distribution

Since s_{D1} , s_{D2} , s_{D3} are estimates of σ_1^2 , σ_2^2 , σ_3^2 and assuming the estimates are good and the three are of similar magnitude, then

$$P[\, Z < \{(2\, s_{D1}) + (2\, s_{D2}) + (1.65\, s_{D3})\} / \sqrt{\{\sigma_1^2 + \sigma_2^2 + \sigma_3^2\}}\,]$$

$$\approx P[\, Z < 5.65 / \sqrt{3}\,]$$

$$= P[\, Z < 3.26\,]$$

$$= 0.9994 \tag{1}$$

If the standard deviation of D3 is greater than D1 and D2, the confidence level would be slightly less. For example, if the standard deviation of D3 is twice that of D1 and D2 ($s_{D3}.= 2\, s_{D1}= s_{D2}$), then equation (1) would be:

$$P[\, Z < 3.12\,] = 0.9991$$

Thus, under the assumption that D1, D2 and D3 are all independent normally distributed random variables, use of the recommended LD provides a confidence level of the order of 99.9%. Stated in another way, the probability of the LD exceeding the recommended landing distance given the CRFI value is roughly 1×10^{-3}. This is much greater than the 95% level of confidence as stated in ref. 1. D1, D2 and D3 are, in practice, likely not independent, but provided the correlations are weak, the above confidence level is still appropriate. For strong dependency between the three variables, the confidence level would approach 0.95.

This estimated confidence level is only rough, but provides a much better value applicable for the Falcon aircraft under the conditions of the tests. Other factors affecting this confidence interval when applied to the changes in requirements being considered include:

- data from other aircraft were not included in setting the μB – CRFI relationship for recommended D3
- data for runway conditions not being considered were included in setting the μB – CRFI relationship for recommended D3
- the CRFI values used in the tests are relatively up-to-date. In practice, CRFI values are sometimes 1 to 2 hours old when used by the pilot and could result in much greater scatter in the μB-CRFI relationship.

If only one point in Figure 20 fell below the lower μB estimate, the confidence level increases to between 99.96% to 99.99% or roughly 1 x 10^{-4}.

References

1. Croll, J.B., Martin, J.C.T., and Bastian, M., *Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the Winter of 1997/1998*, TP 13338E, Transportation Development Centre, Transport Canada, December 1998.
2. Croll, J.B., Martin, J.C.T., and Bastian, M., *Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the Winter of 1998/1999*, TP 13557E, Transportation Development Centre, Transport Canada, December 1999.

Appendix C

Estimation of the Distribution of Actual Landing Distances

Estimation of Distribution Actual Landing Distance

Approach Used

The landing distance is defined as the distance travelled from 50 feet above the runway until the aircraft comes to a complete stop. The landing distance, LD, is initially estimated based on the LD from the AFM adjusted to account for the effect of low runway friction on aircraft braking. Since the use of reverse thrust is not approved for determining the AFM landing distance for any of the aircraft analyzed, but reverse thrust is used in operational conditions by aircraft with reverse thrust, the AFM landing distance is also adjusted for use of reverse thrust. The AFM landing distance is representative of routine landings where everything goes as it should. However, in operational situations there is variation in the landing distances which can be caused by a number of factors. In the current analysis, the variability in the point of touchdown, delay in braking and factors affecting aircraft braking are allowed for in determining a distribution of landing distances.

Following the approach used by Croll, Martin and Bastian [1,2], the landing distance is divided into three segments denoted by D1, D2 and D3:

D1 Air distance – distance travelled from 50 feet above the runway to the point of touchdown;

D2 Delay distance – distance travelled between point of touchdown and application of wheel brakes; and

D3 Stopping distance – distance travelled from application of brakes until aircraft comes to a stop.

Functions developed by [2] from data collected using a Falcon 20 in extensive tests at North Bay were used to estimate the distances D1, D2 and D3. The functions have been shown to provide a good means of estimating the effect of runway friction on aircraft braking and the aircraft landing distances for other aircraft types. The stopping distance, D3, is dependent on the runway friction and the use of reverse thrust (if available), while D1 and D2 are not. The values of D1 and D2 are used to estimate the air and delay distances. The stopping (braking) distance on a bare and dry runway is estimated by the AFM landing distance less the air and delay distances, D1 and D2. It is this segment of the landing distance which is affected by the runway friction and use of reverse thrust. The change in the stopping distance segment of the AFM landing distance is estimated from the change in D3 from a dry runway to a slippery runway and possible use of reverse thrust. The approach used is given below.

Determining AFM Landing Distance Adjusted for Slippery Runway

The following equations for the “predicted” distances from [2] were used to estimate D1, D2 and D3:

$$D1 = 1.55 \times (V_{G50} - 80.0)^{1.35} + 964$$

$$D2 = (V_{G50} - 9.98) \times 1.688 \times 2.96$$

where V_{G50} is the ground speed at 50 feet.

The "predicted" stopping distance, D3, is estimated using the average deceleration over the braking distance from speed V_{EFB} when braking commences to a complete stop as follows:

$$D3 = \{ (V_{GFB} \times 1.688)^2 / (64.348 \times (-ACC)) \} \times REVFAC$$

where V_{GFB} is the ground speed when full deceleration commences;

$$ACC = (600/WGT - Mu_B) + \{ (-4.62/WGT) \times V_{EFB}/\sqrt{2} \} + \{-0.1813 + 0.2087 \times CRFI\}/ WGT \times V_{EFB}^2 /2$$

Mu_B is the aircraft braking coefficient and is estimated from the CRFI by:

$$Mu_B = 0.4658 \times CRFI + 0.0354$$

V_{EFB} is the effective ground speed when full deceleration commences;
$REVFAC$ is the reverse thrust factor and if available is given by:

$$\begin{aligned} REVFAC = \; & 0.65 + 0.6 \times (Mu_B/Mu_{BDRY}) - 0.25 \times \{(Mu_B/Mu_{BDRY})^2 \} \\ & 0.95, \text{ whichever is less} \end{aligned}$$

If reverse thrust is not available, $REVFAC$ is set equal to 1.0; and

Mu_{BDRY} is the aircraft braking coefficient on a bare and dry runway calculated using a CRFI = 0.8.

Values of V_{G50}, V_{GFB} and V_{EFB} vary between aircraft types and from landing to landing. However, for most aircraft V_{G50} ranges between 120 and 150 knots and V_{GFB} is approximately 15 knots less than V_{G50}. With zero headwind, as is assumed in the analysis of the risks, $V_{EFB} = V_{GFB}$. Speeds are less for the short landing distance aircraft and the following speeds were used in the analysis:

Aircraft Type:	CRJ, A320, B737-200, B777, B747-400, B767, DC9	F-28 and BAe-146
V_{G50} (knots)	135	120
V_{GFB} (knots)	120	105
V_{EFB} (knots)	120	105

D1, D2 and D3 are then used to adjust the landing distance from the AFM for the slippery runway, as measured by CRFI, and possible use of reverse thrust. In making the adjustment it is assumed that only the proportion of the AFM landing distance attributable to braking is affected by low runway friction and reverse thrust. Comparisons of the estimated landing distance $D1+D2+D3$ for a CRFI of 0.8 with the AFM distance by

Croll indicated that the estimated distance was 200 to 600 feet longer than the AFM distance. Croll indicated that this difference could be due to longer air and delay distances in operational situations. Another factor could be the use of mid-range autobrake settings rather than maximum manual braking typically used when determining AFM landing distance. So that the estimated actual landing distances are representative of operational conditions, the AFM landing distance was increased by 400 feet. The adjusted AFM landing distance was therefore calculated as follows:

$$LD_{ADJ} = \{ LD_{AFM} + 400 - (D1 + D2) \} \times (D3/D3_{BD}) + (D1 + D2)$$

where LD_{AFM} is the landing distance from the AFM, and

LD_{ADJ} is the landing distance from the AFM adjusted for runway friction and possible use of reverse thrust; and

$D3_{BD}$ is the stopping distance $D3$ on a bare and dry runway (CRFI =0.8).

Allowing for Variation Under Operational Conditions

Variation in the following four factors were allowed for in determining the actual landing distance in operational conditions for use in the risk analysis:

- Aircraft braking coefficient, Mu_B, for a given CRFI value;
- the touchdown point;
- the delay time in applying brakes; and
- the change in Mu_B due to error in setting braking or braking malfunction or due to worn brakes.

The variation in Mu_B with measured CRFI values from tests conducted from 1996 to 1999 at North Bay are given in Figure 7 of [2], a copy which is provided in Appendix B of this report (Figure B-2). Using the variation shown in this figure, probability distributions of Mu_B for given values of CRFI were developed. The distributions are illustrated for CRFI values of 0.2, 0.3 and 0.4 in Figure C1. Probabilities were assigned to 15 possible Mu_B values around the expected value for the given CRFI value. The probabilities follow a normal distribution with the standard deviation, and therefore the spread, increasing as the CRFI value increases.

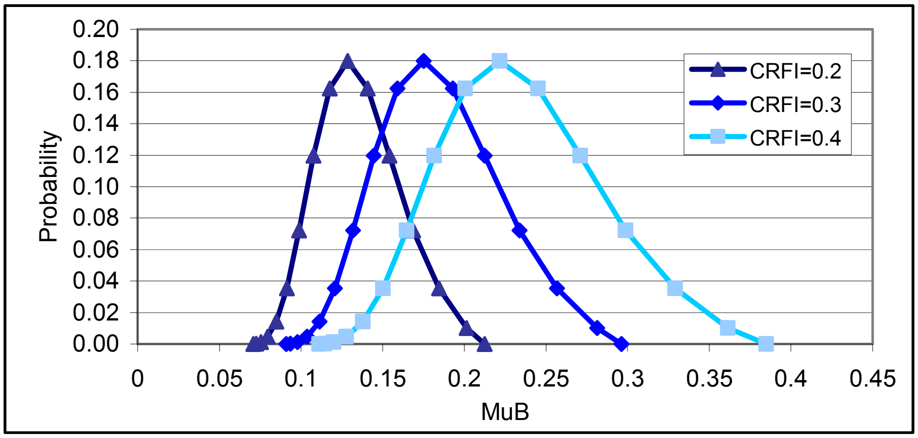


Figure C1 Probability Distribution of Mu Braking for Given CRFI Values

The variation in the touchdown point which affects the air distance, *D1*, was again determined using the variation found by [2]. *D1* values from the North Bay tests [2] were used, but supplemented by information from the accident/incident data. The latter data were used to set the distribution for touchdown points well beyond the target point (i.e., the touchdown point assumed in determining the AFM landing distance typically about 1,500 feet from the runway threshold for jet aircraft) which are the most critical in determining the risks. Croll estimated the standard deviation of the air distance, *SD(D1)* to be a function of V_{G50}.

$$SD(D1) = (V_{G50} - 6.16) \times 1.688 \times 1.72 / 2$$

The distribution of the change in air distance due to the variation in the touchdown point was developed assuming that approximately 95% of the touchdowns would be within two standard deviations of the target and that the remaining 5% would be beyond two standard deviations of the target. The longer distances and their probabilities are based on the long touchdown distances given in the Canadian and international accident/incident data. The distribution of the change in air distance is illustrated in Figure C2. Due to the very low probabilities at the higher distances, an enlargement of the right tail of the distribution is shown in the top right corner of the figure. The distribution indicates that approximately 95% of touchdowns are within 400 feet of the target, but that touchdowns much farther down the runway occur infrequently.

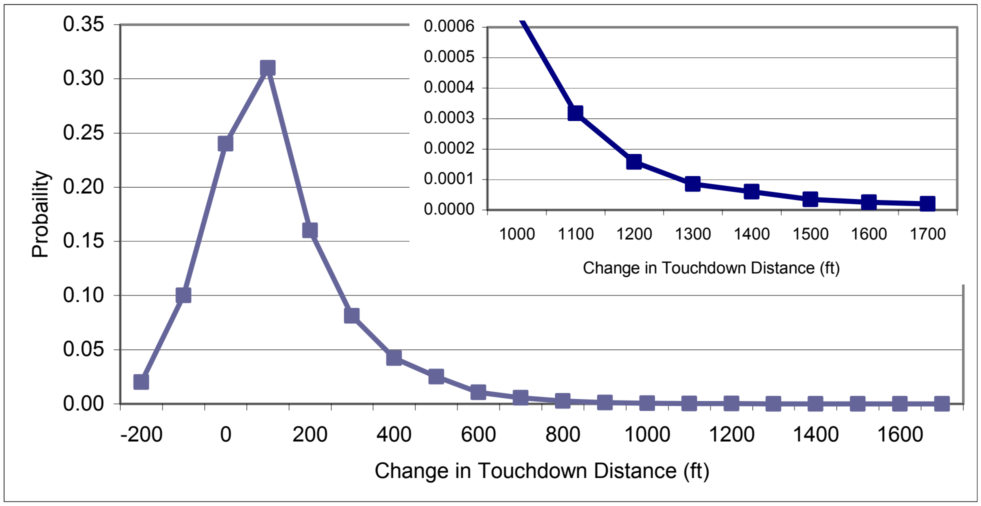


Figure C2 Probability Distribution of Change in Air Distance due to Variation in the Touchdown Point

A similar approach was used for developing the probability distribution of the change in the delay distance due to the variation in time the brakes are applied. The standard deviation of the delay time distance, *SD(D2)*, from the North Bay tests provided by [2] is given by:

$$SD(D2) = (V_{G50} - 13.44) \times 1.688 \times 1.86 / 2$$

The distribution of the change in delay distance was developed assuming that approximately 95% of the delay distances would be within two standard deviations of the target and that the remaining 5% would be beyond the target. The longer distances and their probabilities are based on the long delays in applying brakes as is occasionally is noted in accident/incident reports. The probability distribution of the change in delay distance due to variation in the time of application of the brakes is shown in Figure C3.

Incorrect application or malfunction of brakes is uncommon, but is given as a factor in some overrun accidents/incidents. Little data is available on the frequency of these occurrences and their effect on braking. The distribution shown in Figure C4 was assumed and calibrated so that the frequency of overruns predicted by the model is consistent with the accident/incident history. It was assumed that in 97% of landings the brakes were applied correctly and worked effectively, in 2% of landings the braking is reduced on average by 5%, and that braking is reduced by greater amounts with decreasing probabilities. The insert in Figure C4 shows the assumed proportion of landings with 5%, 10%, 15%, 20% and 25% reductions in braking.

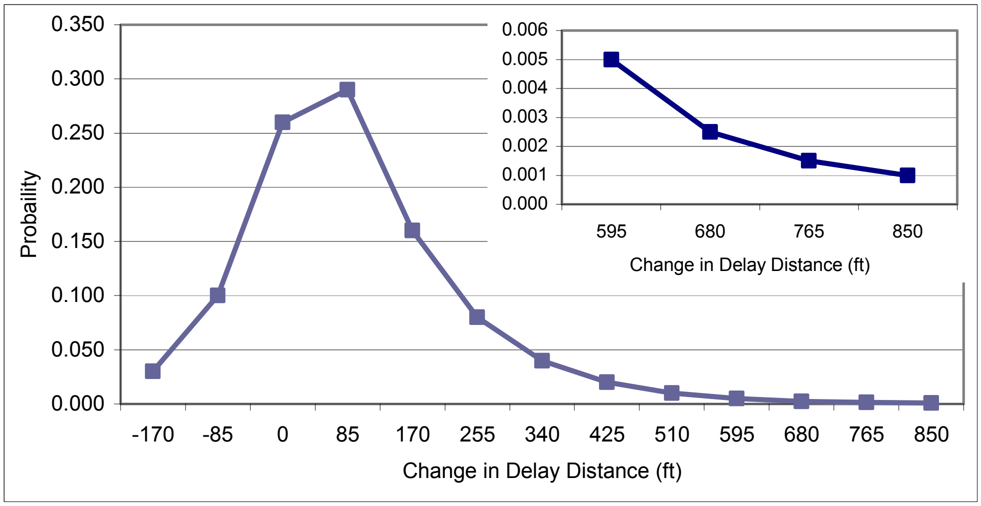


Figure C3 Probability Distribution of Change in Delay Distance due to Variation in Time of Application of Brakes

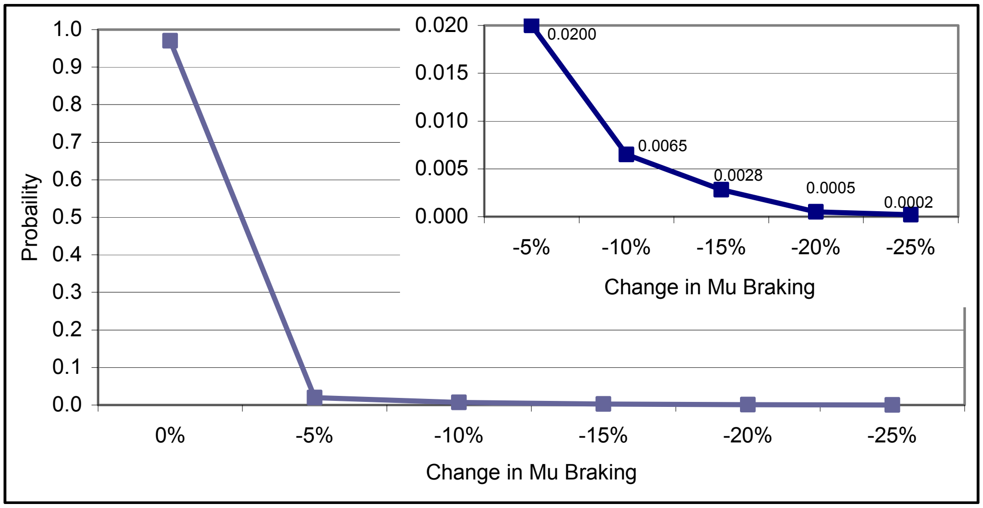


Figure C4 Probability Distribution of Change in Mu Braking due to Incorrect Application or Malfunction of Brakes

The distribution of actual landing distances is found by adding these changes in distance due to variation in Mu_B, touchdown distance and delay time to the AFM landing distance adjusted for CRFI and possible use of reverse thrust (LD_{AFMADJ}) and calculating the probability of that combination of changes. In calculating this probability it is assumed that each of the factors is independent so that the probability of all occurring is equal to the product of the probabilities of each. This assumption is not strictly valid, but the distribution is not sensitive to weak relationships and should allow reasonably good estimates of the distribution of landing distances to be determined.

Allowing for Pilot's Being More Careful When Ice/Snow Contamination Present

The survey of airline pilots indicated that they took a number of measures to reduce the risks when the runway was known to be slippery due to ice and compacted snow contamination. Two of these measures included applying wheel brakes quickly and reverse thrust aggressively, and ensuring the touchdown is close to the threshold. Pilots being aware of the need to have as much runway as possible to decelerate when the runway is slippery will tend to reduce the variation (not the typical value) in the touchdown point and the delay time in applying the brakes. To allow for this reduction in the variation, the changes in the air and delay distance distributions given in Figures C2 and C3 were reduced by 10% for landings on slippery runways.

References

1. Croll, J.B., Martin, J.C.T., and Bastian, M., *Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the Winter of 1997/1998*, TP 13338E, Transportation Development Centre, Transport Canada, December 1998.
2. Croll, J.B., Martin, J.C.T., and Bastian, M., *Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the Winter of 1998/1999*, TP 13557E, Transportation Development Centre, Transport Canada, December 1999.

Appendix D

Airports and Important Characteristics Used in the Analysis

Airport	Runway	Rwy length Available (ft)	Altitude (ft)	Probability of:			Distance (ft) to ditch/ embankment	# of Jet Landings in 12 months
				Ice	Compact Snow	Loose Snow<1/8"		
Abbotsford	07/25	8,000	190	0.002	0.004	0.004	0	3,717
Calgary	16/34	12,675	3,557	0.008	0.005	0.018	1,200	101,793
Charlottetown	03/21	7,000	160	0.039	0.020	0.012		1,260
Deer Lake	07/25	6,000	72	0.039	0.020	0.012	1,000	2,851
Edmonton Intern'l	01/19	11,000	2,373	0.034	0.008	0.010	3,000	54,853
Edmonton City Centre	12/30	5,868	2,220	0.034	0.008	0.010	200	104
Fort McMurray	07/25	6,000	1,211	0.033	0.002	0.028	1,000	1,701
Fort St. John	11/29	6,900	2,280	0.000	0.000	0.000	500	1,719
Fredericton	15/33	6,000	67	0.039	0.020	0.012	1,000	2,369
Gander	04/22	10,500	496	0.039	0.020	0.012		2,695
Grande Prairie	11/29	6,500	2,195	0.034	0.008	0.010		975
Halifax	06/24	8,800	477	0.039	0.020	0.012	500	35,945
Hamilton	12L/30R	8,000	570	0.000	0.000	0.000	1,000	15,183
Inuvik	05/23	6,000	224	0.000	0.000	0.000	1,000	1,098
Iqaluit	17/35	9,000	110	0.000	0.000	0.000	1,000	3,085
Kelowna	15/33	7,300	1,409	0.000	0.000	0.000	1,000	11,986
Kuujjuaq	07/25	6,000	129	0.000	0.000	0.000		1,238
London	15/33	8,800	912	0.002	0.009	0.011		759
Moncton	11/29	8,000	232	0.039	0.020	0.012	1,000	8,141
Montreal Dorval	06/24	11,150	117	0.048	0.005	0.011	1,000	80,616
Montreal Mirabel	06/24	12,000	270	0.048	0.005	0.011	1,000	10,913
Norman Wells	09/27	6,000	241	0.000	0.000	0.000	1,000	1,399
North Bay	08/26	10,000	1,215	0.048	0.005	0.011		29
Ottawa	14/32	9,700	368	0.030	0.005	0.011	2,000	49,183
Prince George	15/33	7,400	2,268	0.033	0.002	0.028	900	7,288
Prince Rupert	13/31	6,000	116	0.000	0.000	0.000	1,000	1,536
Quebec	06/24	9,000	243	0.000	0.000	0.000	2,000	4,130
Rankin Inlet	13/31	6,000	102	0.000	0.000	0.000	1,000	1,469
Regina	12/30	7,900	1,894	0.021	0.010	0.012	2,000	14,659
Rouyn-Noranda	08/26	6,500	988	0.000	0.000	0.000		478
Saint John	05/23	7,000	357	0.039	0.020	0.012	1,000	2,374
Saskatoon	09/27	8,300	1,653	0.021	0.010	0.012	3,000	14,765
Smithers	14/32	5,000	1,712	0.033	0.002	0.028		336
St. John's	11/29	8,500	458	0.039	0.020	0.012	3,000	11,328
Stephenville	09/27	10,000	84	0.039	0.020	0.012		20
Sudbury	04/22	6,600	1,140	0.039	0.020	0.012		26
Sydney	07/25	7,070	203	0.000	0.000	0.000		126
Terrace	15/33	6,000	713	0.033	0.002	0.028	3,000	2,028
Thompson	05/23	5,800	716	0.021	0.010	0.012	1,000	637
Thunder Bay	07/25	6,200	653	0.030	0.005	0.012	2,000	7,112
Timmins	03/21	6,000	967	0.021	0.010	0.012		10
Toronto	15/33	11,050	564	0.002	0.009	0.011	1,000	128,893
Toronto 06R	06L/24R	9,500	564	0.002	0.009	0.011	300	128,893

Airport	Runway	Rwy length Available (ft)	Altitude (ft)	Probability of: Ice	Compact Snow	Loose Snow<1/8"	Distance (ft) to ditch/ embankment	# of Jet Landings in 12 months
Val d'Or	18/36	10,000	1,107	0.000	0.000	0.000		775
Vancouver	08/26	11,000	8	0.001	0.003	0.003	10	121,983
Victoria	09/27	7,000	63	0.001	0.003	0.003	1,000	5,156
Whitehorse	13/31	7,200	2,305	0.000	0.000	0.000	1,000	1,859
Windsor	07/25	7,850	622	0.002	0.009	0.011		269
Winnipeg	18/36	11,000	781	0.021	0.010	0.012	3,000	48,839
Yellowknife	15/33	7,500	674	0.034	0.008	0.010	1,000	7,131

Appendix E

Benefits and Costs by Airport and Aircraft Type

Airport	Aircraft Type	# LDs	# on Slippy Rwys	# Overruns				Expected Total Accident Costs				# of Diversions/Delays/Cancellations/Wgt Reductions			Benefit-Cost Ratio Relative to Current Regulations			Total Costs of Accounting for Slippery Runways		
				Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.
Abbotsford	A320	18	0.228	1.22E-14	1.22E-14	1.22E-14	1.22E-14	9.40E-09	9.40E-09	9.40E-09	9.40E-09	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Abbotsford	B737-200	1589	20.651	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Abbotsford	F-28	253	3.283	8.01E-12	8.01E-12	8.01E-12	8.01E-12	7.23E-07	7.23E-07	7.23E-07	7.23E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	DC9	36	1.207	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0			
Calgary	BA146	469	15.946	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	CRJ	1286	43.707	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	A320	9839	334.51	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	B737-200	23178	788.04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	B777	8	0.255	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	B747-400	22	0.731	8.06E-12	8.06E-12	8.06E-12	8.06E-12	3.58E-05	3.58E-05	3.58E-05	3.58E-05	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	F-28	8639	293.71	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	B767	2195	74.63	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	B727-200	1548	52.615	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Calgary	B757	3681	125.14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Charlottetown	B767	12	0.888	1.32E-07	1.32E-07	7.47E-08	1.55E-08	2.26E-01	2.26E-01	1.18E-01	2.09E-02	0.00E+00	1.13E-03	4.86E-02	0	5.19	0.0002	0.00E+00	2.06E-02	1.03E+03
Charlottetown	DC9	212	15.688	8.74E-14	8.74E-14	8.74E-14	8.74E-14	4.42E-09	4.42E-09	4.42E-09	4.42E-09	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Charlottetown	BA146	171	12.654	7.12E-11	7.12E-11	7.12E-11	7.12E-11	1.03E-05	1.03E-05	1.03E-05	1.03E-05	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Charlottetown	A320	47	3.478	2.29E-08	2.29E-08	2.29E-08	2.29E-08	2.62E-02	2.62E-02	2.62E-02	2.62E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Charlottetown	B737-200	8	0.592	1.47E-12	1.47E-12	1.47E-12	1.47E-12	1.89E-07	1.89E-07	1.89E-07	1.89E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Charlottetown	F-28	180	13.32	6.72E-07	6.72E-07	6.72E-07	1.93E-07	8.17E-02	8.17E-02	8.17E-02	2.17E-02	0.00E+00	0.00E+00	1.53E+00	0	0	0.0008	0.00E+00	0.00E+00	7.50E+01
Deer Lake	B737-200	35	2.59	5.61E-07	5.61E-07	2.38E-07	5.03E-08	1.36E-01	1.36E-01	5.21E-02	9.25E-03	0.00E+00	1.31E-02	1.42E-01	0	0.00057	0.00003	0.00E+00	1.49E+02	4.09E+03
Deer Lake	BA146	1391	102.9	1.54E-05	1.54E-05	1.54E-05	1.19E-08	3.07E+00	3.07E+00	3.07E+00	1.34E-03	0.00E+00	0.00E+00	5.14E+01	0	0	0	0.00E+00	0.00E+00	7.10E+05
Edmonton Internl	DC9	191	10.505	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	BA146	2843	156.37	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	A320	4284	235.62	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	B737-200	13509	743	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	B747-400	13	0.715	1.17E-07	1.17E-07	1.17E-07	1.17E-07	8.20E-01	8.20E-01	8.20E-01	8.20E-01	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	F-28	4080	224.37	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	B767	523	28.738	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	B727-200	489	26.895	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton Internl	B757	1496	82.253	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Edmonton City C.	B757	20	1.072	1.58E-02	6.39E-03	3.29E-04	0.00E+00	9.42E+04	2.39E+04	7.34E+02	0.00E+00	2.27E-01	6.14E-01	1.07E+00	12.2	6.3	2.1	5.79E+03	1.47E+04	4.59E+04
Edmonton City C.	B737-200	33	1.788	4.90E-06	4.90E-06	1.30E-06	1.28E-07	2.24E+00	2.24E+00	5.00E-01	2.96E-02	0.00E+00	3.76E-02	2.06E-01	0	0.00399	0.00037	0.00E+00	4.36E+02	5.92E+03
Fort McMurray	F-28	289	19.19	3.47E-03	3.47E-03	1.77E-03	2.42E-11	6.42E+02	6.42E+02	3.17E+02	1.40E-06	0.00E+00	4.45E-01	1.91E+01	0	0.11	0.0020	0.00E+00	2.92E+03	3.28E+05
Fort McMurray	B737-200	562	37.284	1.45E-05	1.45E-05	5.46E-06	1.44E-06	3.75E+00	3.75E+00	1.31E+00	2.91E-01	0.00E+00	2.72E-01	2.04E+00	0	0.00119	0.00006	0.00E+00	2.05E+03	5.88E+04
Fort St. John	F-28	860	47.272	2.88E-05	2.88E-05	2.88E-05	4.08E-07	4.06E+00	4.06E+00	4.06E+00	4.13E-02	0.00E+00	0.00E+00	1.63E+01	0	0	0.00002	0.00E+00	0.00E+00	1.76E+05
Fredericton	F-28	1091	80.734	8.69E-03	8.69E-03	4.86E-03	4.50E-10	1.47E+03	1.47E+03	7.87E+02	2.71E-05	0.00E+00	1.29E+00	8.00E+01	0	0.069	0.0011	0.00E+00	9.98E+03	1.36E+06
Fredericton	B737-200	6	0.444	9.60E-08	9.60E-08	4.08E-08	8.61E-09	2.33E-02	2.33E-02	8.89E-03	1.58E-03	0.00E+00	2.24E-03	2.43E-02	0	0.00056	0.00003	0.00E+00	2.55E+01	7.01E+02
Fredericton	DC9	8	0.592	7.19E-09	7.19E-09	7.19E-09	0.00E+00	8.46E-04	8.46E-04	8.46E-04	0.00E+00	0.00E+00	0.00E+00	5.92E-01	0	0	0	0.00E+00	0.00E+00	1.43E+04
Fredericton	BA146	80	5.883	8.80E-07	8.80E-07	8.80E-07	6.78E-10	1.75E-01	1.75E-01	1.75E-01	7.63E-05	0.00E+00	0.00E+00	2.94E+00	0	0	0	0.00E+00	0.00E+00	4.06E+04
Gander	DC9	106	7.807	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	BA146	731	54.057	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	CRJ	14	1.036	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	A320	20	1.48	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	B737-200	72	5.328	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00

Airport	Aircraft Type	# LDs	# on Slippy Rwys	# Overruns				Expected Total Accident Costs				# of Diversions/Delays/Cancellations/Wgt Reductions			Benefit-Cost Ratio Relative to Current Regulations			Total Costs of Accounting for Slippery Runways		
				Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.
Gander	B777	12	0.851	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	B747-400	147	10.841	6.67E-06	6.67E-06	6.67E-06	6.67E-06	4.62E+01	4.62E+01	4.62E+01	4.62E+01	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	B767	26	1.924	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	B727-200	73	5.365	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Gander	B757	149	11.026	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Grande Prairie	B737-200	484	26.593	2.31E-07	2.31E-07	2.31E-07	2.31E-07	4.55E-02	4.55E-02	4.55E-02	4.55E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Grande Prairie	F-28	4	0.22	3.03E-06	3.03E-06	3.03E-06	5.53E-10	4.54E-01	4.54E-01	4.54E-01	4.79E-05	0.00E+00	0.00E+00	1.73E-01	0	0	0.00015	0.00E+00	0.00E+00	3.01E+03
Halifax	B747-400	12	0.888	1.34E-03	1.34E-03	3.41E-04	3.03E-07	1.68E+04	1.68E+04	3.22E+03	1.40E+00	0.00E+00	5.41E-02	6.99E-01	0	6.11	0.29	0.00E+00	2.23E+03	5.88E+04
Halifax	DC9	2470	182.74	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	BA146	3014	223	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	CRJ	952	70.411	2.96E-16	2.96E-16	2.96E-16	2.96E-16	9.82E-12	9.82E-12	9.82E-12	9.82E-12	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	A320	3793	280.65	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	B737-200	5059	374.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	B777	10	0.703	2.10E-12	2.10E-12	2.10E-12	7.37E-18	5.23E-06	5.23E-06	5.23E-06	4.14E-12	0.00E+00	0.00E+00	1.49E-01	0	0	0	0.00E+00	0.00E+00	1.07E+04
Halifax	F-28	32	2.368	8.40E-16	8.40E-16	8.40E-16	8.40E-16	3.95E-11	3.95E-11	3.95E-11	3.95E-11	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	B767	1219	90.206	8.12E-14	8.12E-14	8.12E-14	8.12E-14	5.19E-08	5.19E-08	5.19E-08	5.19E-08	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	B727-200	696	51.467	4.63E-14	4.63E-14	4.63E-14	4.63E-14	4.83E-09	4.83E-09	4.83E-09	4.83E-09	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Halifax	B757	719	53.206	1.83E-12	1.83E-12	1.83E-12	1.83E-12	1.11E-06	1.11E-06	1.11E-06	1.11E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Hamilton	DC9	101	5.555	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Hamilton	A320	15	0.798	1.13E-13	1.13E-13	1.13E-13	1.13E-13	8.85E-08	8.85E-08	8.85E-08	8.85E-08	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Hamilton	B737-200	3472	190.96	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Hamilton	B767	3	0.165	2.25E-12	2.25E-12	2.25E-12	2.25E-12	2.78E-06	2.78E-06	2.78E-06	2.78E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Hamilton	B727-200	525	28.875	3.94E-10	3.94E-10	3.94E-10	3.94E-10	8.17E-05	8.17E-05	8.17E-05	8.17E-05	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Hamilton	B757	3476	191.18	4.40E-08	4.40E-08	4.40E-08	4.40E-08	3.84E-02	3.84E-02	3.84E-02	3.84E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Inuvik	F-28	36	1.98	2.21E-04	2.21E-04	1.24E-04	1.28E-11	3.78E+01	3.78E+01	2.02E+01	7.56E-07	0.00E+00	2.98E-02	1.96E+00	0	0.074	0.0011	0.00E+00	2.36E+02	3.33E+04
Inuvik	B737-200	513	28.215	6.30E-06	6.30E-06	2.70E-06	5.85E-07	1.55E+00	1.55E+00	5.94E-01	1.07E-01	0.00E+00	1.33E-01	1.54E+00	0	0.00061	0.00003	0.00E+00	1.57E+03	4.45E+04
Iqaluit	CRJ	10	0.55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Iqaluit	B737-200	704	38.72	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Iqaluit	B757	829	45.568	3.53E-14	3.53E-14	3.53E-14	3.53E-14	1.46E-08	1.46E-08	1.46E-08	1.46E-08	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Kelowna	B757	67	3.658	1.81E-06	1.81E-06	1.51E-06	3.19E-07	2.19E+00	2.19E+00	1.79E+00	3.19E-01	0.00E+00	4.42E-03	4.21E-01	0	0.0032	0.0001	0.00E+00	1.25E+02	1.97E+04
Kelowna	BA146	6	0.33	2.68E-13	2.68E-13	2.68E-13	2.68E-13	3.74E-08	3.74E-08	3.74E-08	3.74E-08	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Kelowna	A320	211	11.578	1.05E-08	1.05E-08	1.05E-08	1.05E-08	1.13E-02	1.13E-02	1.13E-02	1.13E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Kelowna	B737-200	3789	208.4	3.45E-11	3.45E-11	3.45E-11	3.45E-11	4.21E-06	4.21E-06	4.21E-06	4.21E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Kelowna	F-28	1921	105.66	1.20E-06	1.20E-06	1.20E-06	1.20E-06	1.39E-01	1.39E-01	1.39E-01	1.39E-01	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Kuujjuaq	B757	316	17.353	2.31E-02	2.31E-02	1.50E-03	0.00E+00	3.99E+04	3.99E+04	1.96E+03	0.00E+00	0.00E+00	5.01E+00	1.73E+01	0	0.38	0.050	0.00E+00	1.00E+05	7.91E+05
Kuujjuaq	B737-200	304	16.693	3.51E-06	3.51E-06	1.49E-06	3.13E-07	8.58E-01	8.58E-01	3.28E-01	5.87E-02	0.00E+00	7.86E-02	9.14E-01	0	0.00057	0.00003	0.00E+00	9.26E+02	2.63E+04
London	B747-400	2	0.05	5.45E-05	5.45E-05	1.88E-05	1.29E-08	6.26E+02	6.26E+02	1.69E+02	5.99E-02	0.00E+00	1.73E-03	3.93E-02	0	22	0.16	0.00E+00	2.09E+01	3.95E+03
London	DC9	20	0.5	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
London	A320	41	1.025	1.10E-19	1.10E-19	1.10E-19	1.10E-19	8.11E-17	8.11E-17	8.11E-17	8.11E-17	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
London	B737-200	67	1.663	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
London	F-28	6	0.15	6.41E-17	6.41E-17	6.41E-17	6.41E-17	3.02E-12	3.02E-12	3.02E-12	3.02E-12	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
London	B767	14	0.35	3.00E-16	3.00E-16	3.00E-16	3.00E-16	2.13E-10	2.13E-10	2.13E-10	2.13E-10	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
London	B757	230	5.75	3.16E-13	3.16E-13	3.16E-13	3.16E-13	2.05E-07	2.05E-07	2.05E-07	2.05E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Moncton	DC9	470	34.743	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Moncton	BA146	606	44.844	1.94E-16	1.94E-16	1.94E-16	1.94E-16	4.65E-12	4.65E-12	4.65E-12	4.65E-12	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Moncton	A320	64	4.699	4.54E-13	4.54E-13	4.54E-13	4.54E-13	3.55E-07	3.55E-07	3.55E-07	3.55E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Moncton	B737-200	1154	85.396	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Moncton	F-28	324	23.976	1.08E-10	1.08E-10	1.08E-10	1.08E-10	9.87E-06	9.87E-06	9.87E-06	9.87E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Moncton	B767	10	0.74	7.78E-12	7.78E-12	7.78E-12	7.78E-12	9.14E-06	9.14E-06	9.14E-06	9.14E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Moncton	B757	1444	106.82	1.35E-08	1.35E-08	1.35E-08	1.35E-08	1.15E-02	1.15E-02	1.15E-02	1.15E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	DC9	6508	436.04	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00

Airport	Aircraft Type	# LDs	# on Slippy Rwys	# Overruns				Expected Total Accident Costs				# of Diversions/Delays/Cancellations/Wgt Reductions			Benefit-Cost Ratio Relative to Current Regulations			Total Costs of Accounting for Slippery Runways		
				Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.
Montreal Dorval	BA146	2075	138.99	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	CRJ	7061	473.09	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	A320	8235	551.75	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	B737-200	9035	605.31	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	B777	423	28.341	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	B747-400	1057	70.785	1.07E-06	1.07E-06	1.07E-06	1.07E-06	6.35E+00	6.35E+00	6.35E+00	6.35E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	F-28	170	11.39	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	B767	4740	317.55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	B727-200	691	46.297	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Dorval	B757	315	21.105	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	DC9	95	6.332	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	CRJ	529	35.41	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	A320	187	12.495	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	B737-200	674	45.158	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	B777	3	0.168	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	B747-400	52	3.484	2.71E-10	2.71E-10	2.71E-10	2.71E-10	1.21E-03	1.21E-03	1.21E-03	1.21E-03	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	B767	49	3.25	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	B727-200	1477	98.925	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Montreal Mirabel	B757	2394	160.37	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Norman Wells	B737-200	700	38.472	8.69E-06	8.69E-06	3.73E-06	8.04E-07	2.14E+00	2.14E+00	8.21E-01	1.48E-01	0.00E+00	1.81E-01	2.11E+00	0	0.00062	0.00003	0.00E+00	2.14E+03	6.07E+04
North Bay	A320	8	0.502	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
North Bay	B737-200	7	0.469	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	DC9	1028	50.372	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	BA146	465	22.785	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	CRJ	6370	312.13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	A320	6272	307.33	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	B737-200	6452	316.12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	F-28	397	19.428	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	B767	2113	103.51	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	B727-200	158	7.717	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Ottawa	B757	1339	65.587	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Prince George	BA146	105	6.972	4.99E-12	4.99E-12	4.99E-12	4.99E-12	6.95E-07	6.95E-07	6.95E-07	6.95E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Prince George	B737-200	1360	90.304	1.01E-11	1.01E-11	1.01E-11	1.01E-11	1.26E-06	1.26E-06	1.26E-06	1.26E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Prince George	F-28	2179	144.69	1.44E-06	1.44E-06	1.44E-06	1.44E-06	1.69E-01	1.69E-01	1.69E-01	1.69E-01	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Prince Rupert	F-28	768	42.24	4.46E-03	4.46E-03	2.49E-03	2.37E-10	7.50E+02	7.50E+02	4.01E+02	1.42E-05	0.00E+00	6.36E-01	4.19E+01	0	0.069	0.0011	0.00E+00	5.03E+03	7.11E+05
Quebec	B747-400	3	0.138	8.69E-05	8.69E-05	2.80E-05	6.00E-08	9.03E+02	9.03E+02	2.23E+02	2.85E-01	0.00E+00	3.27E-03	9.00E-02	0	5.24	0.13	0.00E+00	1.30E+02	6.99E+03
Quebec	DC9	1161	63.855	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	BA146	5	0.248	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	CRJ	35	1.925	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	A320	113	6.215	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	B737-200	320	17.6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	F-28	376	20.653	1.79E-16	1.79E-16	1.79E-16	1.79E-16	1.33E-12	1.33E-12	1.33E-12	1.33E-12	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	B767	2	0.11	2.09E-18	2.09E-18	2.09E-18	2.09E-18	6.88E-13	6.88E-13	6.88E-13	6.88E-13	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	B727-200	19	1.018	1.93E-17	1.93E-17	1.93E-17	1.93E-17	1.02E-12	1.02E-12	1.02E-12	1.02E-12	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Quebec	B757	33	1.815	2.13E-15	2.13E-15	2.13E-15	2.13E-15	9.47E-10	9.47E-10	9.47E-10	9.47E-10	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Rankin Inlet	B737-200	735	40.397	8.41E-06	8.41E-06	3.57E-06	7.52E-07	2.04E+00	2.04E+00	7.77E-01	1.39E-01	0.00E+00	1.90E-01	2.21E+00	0	0.00056	0.00003	0.00E+00	2.24E+03	6.37E+04
Regina	DC9	707	32.499	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Regina	BA146	6	0.276	2.18E-16	2.18E-16	2.18E-16	2.18E-16	1.68E-11	1.68E-11	1.68E-11	1.68E-11	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00

Airport	Aircraft Type	# LDs	# on Slippy Rwys	# Overruns				Expected Total Accident Costs				# of Diversions/Delays/Cancellations/Wgt Reductions			Benefit-Cost Ratio Relative to Current Regulations			Total Costs of Accounting for Slippery Runways		
				Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.
Regina	A320	434	19.964	3.97E-11	3.97E-11	3.97E-11	3.97E-11	3.69E-05	3.69E-05	3.69E-05	3.69E-05	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Regina	B737-200	2357	108.42	4.55E-16	4.55E-16	4.55E-16	4.55E-16	1.87E-11	1.87E-11	1.87E-11	1.87E-11	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Regina	F-28	3148	144.79	1.01E-08	1.01E-08	1.01E-08	1.01E-08	1.05E-03	1.05E-03	1.05E-03	1.05E-03	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Regina	B727-200	76	3.496	4.81E-10	4.81E-10	4.81E-10	4.81E-10	1.09E-04	1.09E-04	1.09E-04	1.09E-04	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Regina	B757	603	27.715	1.75E-07	1.75E-07	1.75E-07	1.75E-07	1.78E-01	1.78E-01	1.78E-01	1.78E-01	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Rouyn-Noranda	B757	17	0.935	1.16E-04	1.16E-04	2.35E-05	4.38E-10	1.70E+02	1.70E+02	3.02E+01	3.32E-04	0.00E+00	9.74E-02	9.27E-01	0	0.072	0.0041	0.00E+00	1.94E+03	4.17E+04
Rouyn-Noranda	B737-200	222	12.21	3.46E-08	3.46E-08	3.46E-08	3.46E-08	6.42E-03	6.42E-03	6.42E-03	6.42E-03	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saint John	BA146	66	4.847	3.53E-11	3.53E-11	3.53E-11	3.53E-11	5.01E-06	5.01E-06	5.01E-06	5.01E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saint John	B737-200	67	4.921	1.46E-11	1.46E-11	1.46E-11	1.46E-11	2.01E-06	2.01E-06	2.01E-06	2.01E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saint John	F-28	1055	78.07	4.68E-06	4.68E-06	4.68E-06	1.35E-06	5.74E-01	5.74E-01	5.74E-01	1.54E-01	0.00E+00	0.00E+00	8.98E+00	0	0	0.00066	0.00E+00	0.00E+00	6.34E+02
Saskatoon	DC9	695	31.97	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saskatoon	A320	696	31.993	3.66E-13	3.66E-13	3.66E-13	3.66E-13	2.55E-07	2.55E-07	2.55E-07	2.55E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saskatoon	B737-200	2076	95.473	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saskatoon	F-28	3516	161.74	1.73E-10	1.73E-10	1.73E-10	1.73E-10	1.50E-05	1.50E-05	1.50E-05	1.50E-05	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saskatoon	B727-200	59	2.691	4.51E-12	4.51E-12	4.51E-12	4.51E-12	8.88E-07	8.88E-07	8.88E-07	8.88E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Saskatoon	B757	342	15.732	1.43E-09	1.43E-09	1.43E-09	1.43E-09	1.31E-03	1.31E-03	1.31E-03	1.31E-03	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Smithers	F-28	168	11.155	2.37E-01	2.37E-01	8.53E-02	0.00E+00	1.02E+05	1.02E+05	3.14E+04	0.00E+00	0.00E+00	4.07E+00	1.11E+01	0	2.42	0.79	0.00E+00	2.92E+04	1.29E+05
St. John's	B747-400	8	0.592	2.41E-03	2.41E-03	2.49E-04	2.56E-08	3.22E+04	3.22E+04	1.98E+03	1.05E-01	0.00E+00	7.43E-02	5.59E-01	0	9.1	0.61	0.00E+00	3.31E+03	5.23E+04
St. John's	DC9	927	68.561	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
St. John's	BA146	1077	79.661	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
St. John's	A320	812	60.051	4.77E-15	4.77E-15	4.77E-15	4.77E-15	2.02E-09	2.02E-09	2.02E-09	2.02E-09	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
St. John's	B737-200	1821	134.72	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
St. John's	B767	497	36.741	1.67E-12	1.67E-12	1.67E-12	1.67E-12	1.62E-06	1.62E-06	1.62E-06	1.62E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
St. John's	B727-200	138	10.212	4.65E-13	4.65E-13	4.65E-13	4.65E-13	7.46E-08	7.46E-08	7.46E-08	7.46E-08	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
St. John's	B757	387	28.601	3.03E-11	3.03E-11	3.03E-11	3.03E-11	2.24E-05	2.24E-05	2.24E-05	2.24E-05	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Stephenville	A320	10	0.74	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Sudbury	B757	4	0.296	2.30E-05	2.30E-05	3.78E-06	4.76E-10	3.31E+01	3.31E+01	4.76E+00	3.76E-04	0.00E+00	2.57E-02	2.89E-01	0	0.051	0.0026	0.00E+00	5.52E+02	1.28E+04
Sudbury	A320	9	0.666	3.15E-07	3.15E-07	2.12E-07	3.96E-09	4.60E-01	4.60E-01	2.99E-01	3.69E-03	0.00E+00	1.39E-03	1.41E-01	0	0.00904	0.00017	0.00E+00	1.78E+01	2.71E+03
Sydney	BA146	8	0.44	1.13E-12	1.13E-12	1.13E-12	1.13E-12	1.59E-07	1.59E-07	1.59E-07	1.59E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Sydney	B737-200	44	2.42	2.13E-12	2.13E-12	2.13E-12	2.13E-12	2.80E-07	2.80E-07	2.80E-07	2.80E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Sydney	B727-200	11	0.605	4.81E-08	4.81E-08	4.81E-08	5.18E-09	1.37E-02	1.37E-02	1.37E-02	1.13E-03	0.00E+00	0.00E+00	3.31E-02	0	0	0.00002	0.00E+00	0.00E+00	5.33E+02
Terrace	F-28	754	50.066	6.82E-03	6.82E-03	3.46E-03	4.77E-10	1.22E+03	1.22E+03	5.97E+02	3.15E-05	0.00E+00	1.03E+00	4.96E+01	0	0.105	0.0014	0.00E+00	5.92E+03	8.55E+05
Terrace	B737-200	5	0.332	9.42E-08	9.42E-08	4.02E-08	8.94E-09	2.36E-02	2.36E-02	9.10E-03	1.73E-03	0.00E+00	1.42E-03	1.82E-02	0	0.0008	0.00004	0.00E+00	1.83E+01	5.24E+02
Terrace	BA146	255	16.932	3.63E-06	3.63E-06	3.63E-06	3.62E-09	7.52E-01	7.52E-01	7.52E-01	4.18E-04	0.00E+00	0.00E+00	8.46E+00	0	0	0.00001	0.00E+00	0.00E+00	1.17E+05
Thompson	F-28	319	14.651	6.91E-03	6.91E-03	3.30E-03	0.00E+00	1.42E+03	1.42E+03	6.62E+02	0.00E+00	0.00E+00	7.56E-01	1.46E+01	0	0.14	0.0056	0.00E+00	5.36E+03	2.52E+05
Thunder Bay	F-28	80	4	1.61E-04	1.61E-04	8.22E-05	6.90E-10	2.51E+01	2.51E+01	1.20E+01	4.95E-05	0.00E+00	2.68E-02	3.78E+00	0	5.15	0.0004	0.00E+00	2.54E+00	6.52E+04
Thunder Bay	B757	12	0.575	3.83E-04	3.83E-04	3.31E-05	0.00E+00	6.32E+02	6.32E+02	4.27E+01	0.00E+00	0.00E+00	1.25E-01	5.74E-01	0	0.19	0.024	0.00E+00	3.03E+03	2.62E+04
Thunder Bay	CRJ	8	0.375	1.80E-05	1.80E-05	3.65E-06	0.00E+00	8.86E+00	8.86E+00	1.68E+00	0.00E+00	0.00E+00	2.11E-02	3.75E-01	0	0.055	0.0021	0.00E+00	1.30E+02	4.17E+03
Thunder Bay	A320	84	4.175	3.72E-05	3.72E-05	8.56E-06	1.06E-08	5.98E+01	5.98E+01	1.27E+01	8.56E-03	0.00E+00	1.26E-01	2.73E+00	0	0.031	0.00082	0.00E+00	1.53E+03	7.29E+04
Thunder Bay	DC9	1061	53.05	9.55E-08	9.55E-08	9.55E-08	9.23E-17	1.02E-02	1.02E-02	1.02E-02	1.70E-12	0.00E+00	0.00E+00	5.26E+01	0	0	0	0.00E+00	0.00E+00	1.25E+06
Thunder Bay	BA146	5	0.25	9.82E-09	9.82E-09	9.82E-09	1.43E-10	1.88E-03	1.88E-03	1.88E-03	1.88E-05	0.00E+00	0.00E+00	5.29E-02	0	0	0	0.00E+00	0.00E+00	5.83E+02
Thunder Bay	B737-200	2308	115.38	5.70E-06	5.70E-06	5.70E-06	5.70E-06	1.28E+00	1.28E+00	1.28E+00	1.28E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Timmins	A320	5	0.23	1.05E-05	1.05E-05	1.61E-06	1.26E-10	1.82E+01	1.82E+01	2.46E+00	9.10E-05	0.00E+00	1.64E-02	2.03E-01	0	0.081	0.0029	0.00E+00	1.95E+02	6.29E+03
Toronto	DC9	4885	122.11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	CRJ	6806	170.14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	A320	23073	576.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	B737-200	11949	298.73	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	B777	294	7.35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	B747-400	2560	64	1.12E-06	1.12E-06	1.12E-06	1.12E-06	7.00E+00	7.00E+00	7.00E+00	7.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00

Airport	Aircraft Type	# LDs	# on Slippy Rwys	# Overruns				Expected Total Accident Costs				# of Diversions/Delays/Cancellations/Wgt Reductions			Benefit-Cost Ratio Relative to Current Regulations			Total Costs of Accounting for Slippery Runways		
				Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.
Toronto	F-28	2779	69.463	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	B767	9454	236.35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	B727-200	2505	62.625	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto	B757	1424	35.587	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	DC9	4885	122.11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	CRJ	6806	170.14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	A320	23073	576.83	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	B737-200	11949	298.73	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	B777	294	7.35	3.19E-15	3.19E-15	3.19E-15	0.00E+00	3.69E-09	3.69E-09	3.69E-09	0.00E+00	0.00E+00	0.00E+00	4.02E-01	0	0	0	0.00E+00	0.00E+00	3.88E+01
Toronto 06R	F-28	2779	69.463	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	B767	9454	236.35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	B727-200	2505	62.625	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	B757	1424	35.587	3.83E-18	3.83E-18	3.83E-18	3.83E-18	8.13E-14	8.13E-14	8.13E-14	8.13E-14	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Toronto 06R	B747-400																			
Val D'Or	B737-200	130	7.15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Val D'Or	B757	258	14.163	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	DC9	55	0.55	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	BA146	3054	30.84	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	CRJ	557	5.621	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	A320	11741	118.58	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	B737-200	22220	224.42	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	B777	18	0.177	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	B747-400	3938	39.774	6.05E-07	6.05E-07	6.05E-07	6.05E-07	3.89E+01	3.89E+01	3.89E+01	3.89E+01	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	F-28	8218	82.997	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	B767	6851	69.19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	B727-200	1915	19.336	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Vancouver	B757	2428	24.523	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Victoria	B757	44	0.444	2.22E-07	2.22E-07	1.50E-07	7.77E-09	2.60E-01	2.60E-01	1.68E-01	6.62E-03	0.00E+00	8.79E-04	1.52E-01	0	0.028	0.00006	0.00E+00	3.34E+00	4.37E+03
Victoria	A320	615	6.206	2.04E-08	2.04E-08	2.04E-08	2.04E-08	2.34E-02	2.34E-02	2.34E-02	2.34E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Victoria	B737-200	1626	16.418	1.95E-11	1.95E-11	1.95E-11	1.95E-11	2.47E-06	2.47E-06	2.47E-06	2.47E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Victoria	F-28	285	2.878	7.00E-08	7.00E-08	7.00E-08	1.96E-08	8.33E-03	8.33E-03	8.33E-03	2.20E-03	0.00E+00	0.00E+00	3.30E-01	0	0	0.00049	0.00E+00	0.00E+00	1.26E+01
Victoria	B727-200	9	0.091	6.99E-09	6.99E-09	6.99E-09	7.97E-10	2.02E-03	2.02E-03	2.02E-03	1.80E-04	0.00E+00	0.00E+00	4.96E-03	0	0	0.00002	0.00E+00	0.00E+00	8.01E+01
Whitehorse	B747-400	4	0.193	2.46E-02	2.50E-03	3.64E-04	0.00E+00	6.94E+05	3.34E+04	3.31E+03	0.00E+00	1.26E-01	1.41E-01	1.92E-01	52	110	52	1.27E+04	6.29E+03	1.34E+04
Whitehorse	A320	71	3.905	2.02E-08	2.02E-08	2.02E-08	2.02E-08	2.43E-02	2.43E-02	2.43E-02	2.43E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Whitehorse	B737-200	802	44.083	8.88E-11	8.88E-11	8.88E-11	8.88E-11	1.17E-05	1.17E-05	1.17E-05	1.17E-05	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Whitehorse	B767	54	2.943	3.66E-07	3.66E-07	3.66E-07	4.12E-08	6.42E-01	6.42E-01	6.42E-01	5.70E-02	0.00E+00	0.00E+00	1.61E-01	0	0	0.00017	0.00E+00	0.00E+00	3.39E+03
Windsor	DC9	24	0.6	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Windsor	A320	19	0.475	2.36E-13	2.36E-13	2.36E-13	2.36E-13	2.08E-07	2.08E-07	2.08E-07	2.08E-07	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Windsor	B737-200	79	1.975	5.13E-19	5.13E-19	5.13E-19	5.13E-19	1.96E-15	1.96E-15	1.96E-15	1.96E-15	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Windsor	B767	2	0.05	2.03E-12	2.03E-12	2.03E-12	2.03E-12	2.53E-06	2.53E-06	2.53E-06	2.53E-06	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Windsor	B757	11	0.262	1.64E-10	1.64E-10	1.64E-10	1.64E-10	1.51E-04	1.51E-04	1.51E-04	1.51E-04	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	DC9	2545	117.07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	BA146	488	22.448	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	CRJ	1382	63.572	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	A320	4040	185.84	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	B737-200	8646	397.72	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	B777	4	0.184	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	B747-400	7	0.322	1.45E-08	1.45E-08	1.45E-08	1.45E-08	9.46E-02	9.46E-02	9.46E-02	9.46E-02	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	F-28	2720	125.12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	B767	16	0.713	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Winnipeg	B727-200	478	21.965	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00

Airport	Aircraft Type	# LDs	# on Slippy Rwys	# Overruns				Expected Total Accident Costs				# of Diversions/Delays/Cancellations/Wgt Reductions			Benefit-Cost Ratio Relative to Current Regulations			Total Costs of Accounting for Slippery Runways		
				Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Dry Reg.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.	Wet Reg.	CRFI-Table	Manuf.
Winnipeg	B757	4095	188.35	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Yellowknife	B737-200	3313	182.19	5.65E-13	5.65E-13	5.65E-13	5.65E-13	4.93E-08	4.93E-08	4.93E-08	4.93E-08	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Yellowknife	F-28	183	10.065	1.03E-08	1.03E-08	1.03E-08	1.03E-08	1.06E-03	1.06E-03	1.06E-03	1.06E-03	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Yellowknife	B757	70	3.85	1.30E-07	1.30E-07	1.30E-07	1.30E-07	1.37E-01	1.37E-01	1.37E-01	1.37E-01	0.00E+00	0.00E+00	0.00E+00	0	0	0	0.00E+00	0.00E+00	0.00E+00
Total/Overall		452,923	17,723	3.36E-01	3.04E-01	1.04E-01	2.50E-05	9.87E+05	2.56E+05	4.60E+04	1.01E+02	3.53E-01	1.55E+01	4.01E+02	39.51	4.6	0.13.	1.85E+04	2.02E+05	7.49E+06