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AEROPLANE TAKE-OFF RISKS DUE TO WET AND CONTAMINATED RUNWAYS IN CANADA

Prepared by:

David C. Biggs	SYPHER:MUELLER International
Ken D. J. Owen	Airworthiness Specialty Consultants
Gordon B. Hamilton	SYPHER:MUELLER International
Walter McLeish	Aerodevco Consultants Ltd.

SYPHER:MUELLER International Inc.
130 Slater Street, Suite 1025
Ottawa, Ontario, K1P 6E2

Telephone (613) 236-4318
FAX (613) 236-4850

ABSTRACT

This paper gives the results of a study into the risks associated with degraded performance during rejected and continued take-off from wet and contaminated runways. A comprehensive review of world-wide accident and incident data was undertaken to identify the severity of the problem and the factors involved. The effect of runway condition on take-off performance was examined and estimates of the ratios of dry versus wet/contaminated runway take-off and accelerate-stop distances were determined. The frequency of wet and contaminated runways in Canada, the likelihood of critical events on the take-off run and the take-off weight distribution were determined. These and runway, weather and aircraft performance data were utilized in a probabilistic analysis of the risk of take-off accidents. It was found that take-off accident risks on wet and contaminated runways in Canada are twice that of take-offs on dry runways, and that the risks of take-offs on contaminated runways are greater than other published acceptable aircraft accident/incident risks.

AEROPLANE TAKE-OFF RISKS DUE TO WET AND CONTAMINATED RUNWAYS IN CANADA*

David C. Biggs, Ken D. J. Owen, Gordon B. Hamilton and Walter McLeish

INTRODUCTION

Runway condition affects both the acceleration distance required for take-off and the stopping distance in the event of an aborted take-off. However, current Canadian and USA regulations for calculating take-off performance are applicable to dry runway surfaces only, although FAA advisory information is available (FAA, 1987). Regulatory and advisory approaches vary widely among the major aviation countries, and no consensus has yet been achieved on methods to deal with degraded performance on take-off. Of the two civil airworthiness requirements which govern the design standards for most large transport category aeroplanes, USA FAR 25 and the European JAR 25, only JAR 25 includes requirements on contaminated runway take-off performance (JAA, 1988).

Following an accident involving a Boeing 737 at Wabush, Labrador, in 1986, the Transportation Safety Board of Canada recommended that research be undertaken into the risks associated with degraded performance during rejected and continued take-off from wet and contaminated runways. SYPHER:MUELLER International (1991) conducted a study for the Transportation Development Centre, Transport Canada, to identify methods and procedures for including the effects of wet and

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* This research was funded by the Transportation Development Centre, Transport Canada.

contaminated runways in take-off performance calculations, to determine the risks of take-off from wet and contaminated runways in Canada, and to identify counter measures. This paper summarizes the results of that study, focusing on the frequency of wet and contaminated runways and take-off risks.

TAKE-OFF ACCIDENTS

A comprehensive review of world-wide accident data was undertaken to identify the severity of the problem and the factors involved. Take-off accidents were identified as those where the first event, which led to the accident, occurred before the aircraft lifted off the runway. Eighty four take-off accidents involving jet aircraft of first world countries since 1970 were identified in the ICAO accident database. Eighteen (20%) of these accidents were on wet or water covered runways and 12 (13%) were on snow, slush or ice covered runways.

The take-off accidents were divided into 6 types and the frequency of each type of accident on dry, wet and contaminated runways is shown in Figure 1. Two thirds of the take-off accidents were on dry runways, however, this proportion varies with accident type. A good indication of the effect of wet and contaminated runways on the ability of the aircraft to stop on the runway is shown in Figure 1. Almost all of the accidents where the aircraft was able to stop on the runway occurred when the runway was dry. However, just under half of the accidents where the aircraft ran off the runway occurred when the runway was wet or contaminated. This clearly indicates that the factors causing the accidents are different under different runway conditions.

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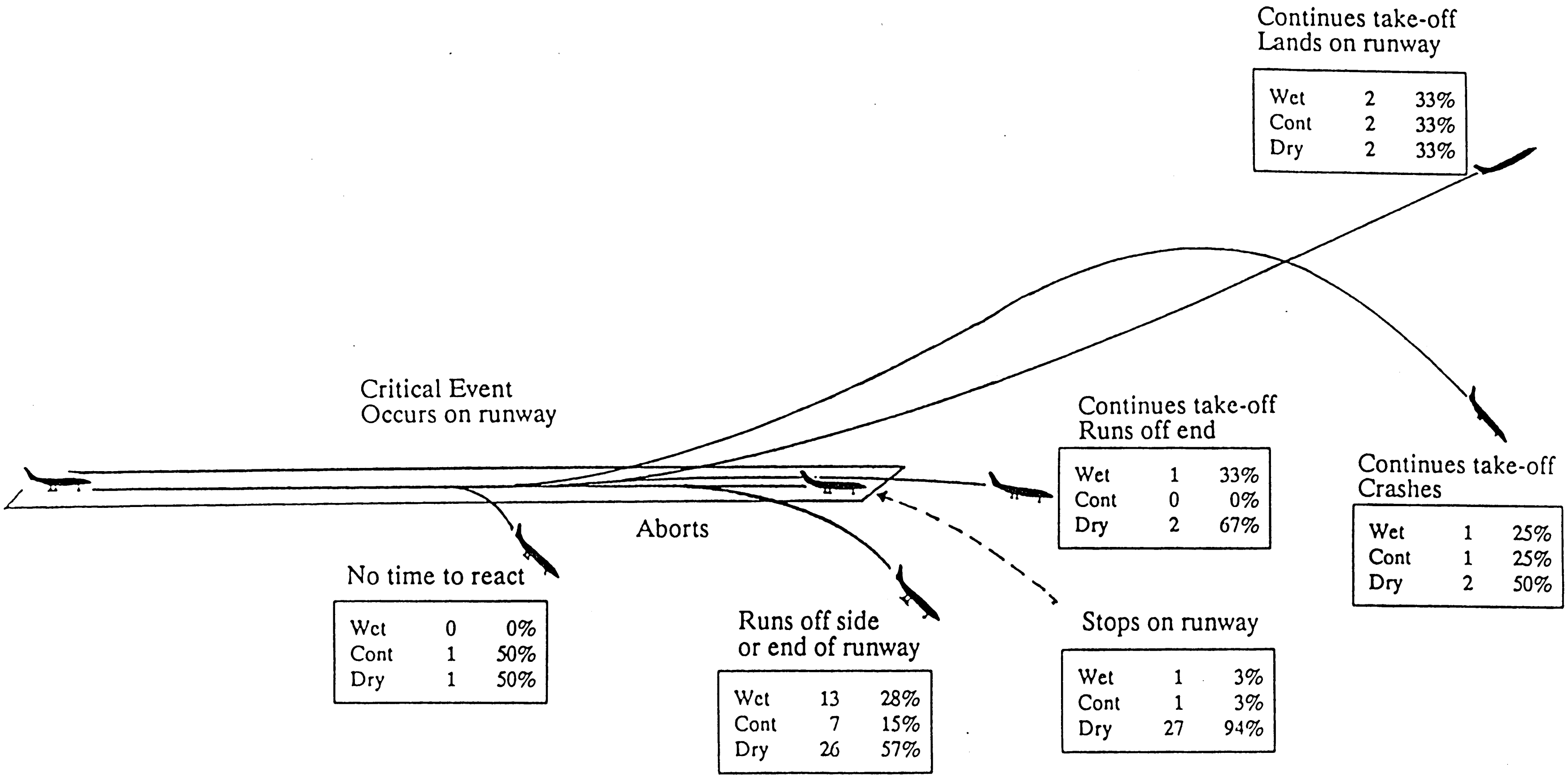


No. of acc. on wet rwys	18	20%
No. of acc. on contam. rwys	12	13%
No. of acc. on dry rwys*	60	67%

* Runway assumed to be dry when contamination not given

Figure 1. Frequency of Take-off Accidents on Dry*, Wet and Contaminated Runways - First World Countries, 1970 to 1989

Most (83%) take-off accidents occur after an aborted take-off. Engine failure is by far the most common critical event on dry and wet runways, while slow acceleration is the most common critical event on contaminated runways. In the abort-run-off-runway accidents, the decision to abort the take-off due to a critical event which occurred after the decisions speed, V_1, is much more common on dry runways than on wet runways. On wet runways, other factors such as runway friction are more common. A late decision to abort is also more common on snow and slush covered runways due to slow acceleration caused by the snow and slush, and thus the longer than expected distance required to reach V_1 and the rotation speed.

Fatalities occurred in 11% of the take-off accidents, the most severe being accidents where the aeroplane continued take-off and crashed. The occurrence of fire usually increases the severity of the accident and fire is common in aborted take-off accidents on dry runways, but is relatively uncommon when the runway is wet or contaminated.

Accidents are rarely the result of a single factor, and a wet or contaminated runway is one factor which reduces the margin of safety and can often lead to an accident when it occurs in combination with other factors.

There have been 3 take-off accidents involving jet aircraft in Canada since 1970 and, similar to the world trend, the runway was wet or contaminated in one of these accidents. As discussed in Section 3, runways in Canada are wet or contaminated about a third of the time during November to March and 11% of the time during April to October; thus over a full year 20% of take-offs are on wet or contaminated runways. Based on these runway condition frequencies and the finding that a third of take-off accidents occur on wet or contaminated runways (both in Canada and in first world countries), the accident risk on a wet/contaminated runway is twice the risk on a dry runway. This relative risk is only approximate as the proportion of take-off accidents on wet/contaminated runways in Canada over a longer time period may differ from the value of a third which was found for Canada and for first world countries over the last 20 years.

RUNWAY CONDITIONS

Winter runway conditions were determined for five Canadian airports based on Transport Canada winter runway condition reports which are filed whenever runway conditions change significantly. The airports studied were Ottawa, Halifax, Calgary, Prince George and Edmonton International. Tables summarizing the runway conditions at three of these airports are given in Table 1.

Table 1. Average Percentage of Time a Section of the Runway is in Each Condition#

(a) OTTAWA

Condition	Nov	Dec	Jan	Feb	Mar
Rwy closed	1.1	0.7	1.7	1.8	0.4
Bare - dry	63.2	59.3	62.4	73.1	75.4
Bare - wet	25.6	11.4	9.0	6.5	14.7
Snow - cover	2.8	11.0	9.4	7.7	2.6
Snow - drift	0.0	0.8	0.5	0.9	0.2
Snow - patch	1.0	2.9	4.9	3.6	0.8
Ice - cover	3.8	12.0	9.3	5.7	5.1
Snow over ice	0.0	0.0	0.0	0.0	0.0
Slush cover	2.5	1.4	0.9	0.6	0.7
Frost	0.1	0.5	1.9	0.1	0.1
Total hours*	1960	2125	2123	1935	2110

Table 1. Average Percentage of Time a Section of the Runway is in Each Condition# (Continued)

(b) HALIFAX

Condition	Nov	Dec	Jan	Feb	Mar
Bare - dry	58.9	51.5	37.3	34.4	56.3
Bare - wet	26.3	15.4	22.8	8.6	15.3
Snow - loose	5.3	10.7	15.2	20.9	8.3
Snow - drift	2.1	4.2	2.5	5.1	1.1
Snow - compt	0.6	1.8	2.3	6.1	0.6
Ice - patch	4.9	11.7	14.1	20.0	13.1
Slush cover	1.9	3.2	2.9	2.7	5.5
Frost	0.0	1.4	3.0	2.2	0.0
Total hours*	1330	1154	1109	651	898

(d) PRINCE GEORGE

Condition	Nov	Dec	Jan	Feb	Mar
Bare - dry	41.0	54.7	42.0	50.2	63.8
Bare - wet	39.7	17.0	10.5	17.5	23.4
Snow - loose	11.9	17.7	26.7	18.3	8.2
Snow - drift	1.7	2.3	2.8	0.2	0.3
Snow - compt	0.2	0.4	1.0	0.6	0.2
Ice - patch	4.2	6.7	13.5	11.9	2.8
Slush cover	1.2	0.7	1.2	1.0	1.3
Frost	0.1	0.5	2.5	0.3	0.0
Total hours*	1514	1580	1582	1445	1568

Probability (expressed as a percentage) that any given patch of runway has the runway condition identified.

* Number of hours on which percentages are based.

Based on the results for the 5 airports studied, runways in Canada during the coldest 5 months are wet or contaminated, on average, a third of the time, but this can vary from 10-65% of the time depending on the airport and month. During December to February the percentage of the time the runways are contaminated are as follows:

- 10-30% snow covered
- 2-20% ice covered
- 2-3% slush covered
- 1-3% frost covered

Typical depths of contaminants in Canada are 0.6 in. of loose snow, 1.5 in. of drifting snow and 0.3 in. of slush. Runway friction measured using ground vehicles varies significantly for the same type of contaminant, but average values are 0.8 for bare and dry, 0.7 for bare and wet, 0.4 for snow, slush or frost and 0.35 for ice patches. Runway friction experienced by the aircraft are significantly less than that measured by ground vehicles (SYPHER (1991) and Yager, Vogler and Baldasare (1990)), typically by 40% to 70%.

Runway conditions in the non-winter months (April to October) are not recorded on a daily basis and weather data on the number of hours when precipitation was recorded for each airport was used to estimate the runway conditions. During the warmer 7 months runways are wet between 5 and 16% of the time at most airports.

EFFECT OF CONTAMINATED RUNWAYS ON TAKE-OFF PERFORMANCE

The impact of runway contamination on aircraft performance has been studied, analyzed and flight tested since the late 1950's (Yager et. al. (1990), Zalovik (1958), NASA (1960), Sommers et.al. (1962), Horne and Leland (1963), Cobb and Horne (1964), Maltby, Slatter and Illingworth (1964), Maltby and Slatter (1969), Herb (1965), Yager, Phillips and Horne (1970), and ESDU (1972)). Take-off performance is affected on contaminated runways in three ways:

- decrease in braking effectiveness due to reduced braking friction between tires and runway;

- increased drag due to displacement of the contaminant by the tires and the impingement of the contaminant on the aeroplane structure; and

- reduction in the directional control of the aircraft due to reduced friction between tires and runway.

Equations for calculating the displacement and impingement drag, the aquaplaning speed, and values of slush drag coefficients for several aircraft types are given in a number of references (Zalovik (1958), NASA (1960) and ESDU (1972)) and are consolidated in the SYPHER report (1991).

The friction between the tire and the ground for both forward and sidewards movement is reduced by any form of contamination, especially as the aeroplane approaches tire hydroplaning speed, and in the presence of a crosswind or engine failure this reduces the pilot's directional control of the aeroplane. Tests using the

UTIAS B747 simulator (SYPHER, 1991) indicated that at a minimum control ground speed (V_{mcg}) appropriate for a 35 knot crosswind on a dry runway, the pilot could not maintain directional control on a wet runway (braking friction coefficient, $\mu=0.3$) with a 25 knot cross wind, and on an icy runway ($\mu=0.1$) could not maintain control in a 10 knot crosswind. Thus, either the minimum control ground speed or the crosswind speed at which it is applicable should be altered in the performance calculations for a contaminated runway.

The performance data for A320, DC10, BA146, F-28, and B747-100 (B747 based on simulator data) clearly indicate that runway conditions significantly affect both the accelerate-stop (ASD) and take-off (TOD) distances. Comparison of the effects of particular types of contamination on the performance of different aircraft types is difficult because of the different methods used to describe and measure runway condition. Consistency in the method used by airports to report runway conditions will be required before the effects of runway conditions on take-off performance can be included in the aircraft flight manual. This is discussed further in SYPHER (1991). Table 2 gives approximate values of the ratio of contaminated to dry values of the ASD and TOD for various typical runway conditions. The ratios for each type of contaminant are fairly similar for the different aircraft types, especially for the B747-100 and A320. Differences between the ratios could be as much due to differences in classifying runway conditions when deriving the data, as actual differences in aircraft performance, especially for the DC10 and F-28. The effect of slush, snow and water on TOD is fairly similar between aircraft types, but the effect of wet, compact snow and ice varies greatly.

Table 2. Ratio of Contaminated to Dry Values of ASD and TOD for Various Typical Runway Conditions

Runway Condition	Friction	Type	Ratio Contaminated/Dry B747[1]	A320[2]	F-28[3]	DC10[4]	BA146
Wet	good-med	ASD	1.18	1.15	1.11	-	-
		TOD	1.02	0.99	-	-	1.00
Water	good-med	TOD	1.70	1.82	1.43	-	-
(6 mm 1/4")			1.06	1.02	-	-	1.11
Slush	med.-poor	ASD	1.51	1.67	1.64	1.48	-
(8mm 1/3")		TOD	1.12	1.14	-	-	1.19
Compact Snow	med.-poor	ASD	1.43	1.46	-	1.28	-
		TOD	1.05	0.92	-	-	1.00
Loose Dry Snow	med.-poor	ASD	1.46	1.65	1.5	1.32	-
(20 mm 3/4")	TOD	1.13	1.13	1.15	-	-	1.10
Ice	poor	ASD	2.07	-	3.35	1.76	-
		TOD	1.04	0.92	-	-	1.00

Notes:

1. Aircraft-runway μ = 0.1 for ice, 0.2 for slush, loose and compact snow, and 0.3 for water and wet conditions for B747.
2. Friction values for A320 implicit when type of contamination is given.
3. Braking coefficient for F-28 assumed to be: good 0.5, good-medium 0.4, medium-poor 0.3 and poor 0.2 based on range of values in Figure 4.21 and table in Figure 4.22 of SYPHER report (1991).
4. Distance corrections for DC10 without reverse thrust.

The effect of runway contamination on the performance of a particular aircraft at a given airport during the winter months was estimated in terms of the ratio of the contaminated to dry value of the ASD and TOD. Figure 2 shows the distribution of these ratios for departures of the B747-100 aircraft at Ottawa airport over the months November to March. For the B747-100 at Ottawa, the runway conditions cause increase in the ASD of up to 50% relatively often, but there are very few times when the effect is greater than 50%. The effect of runway conditions on TOD is much less and is rarely greater than 10% of the runway.

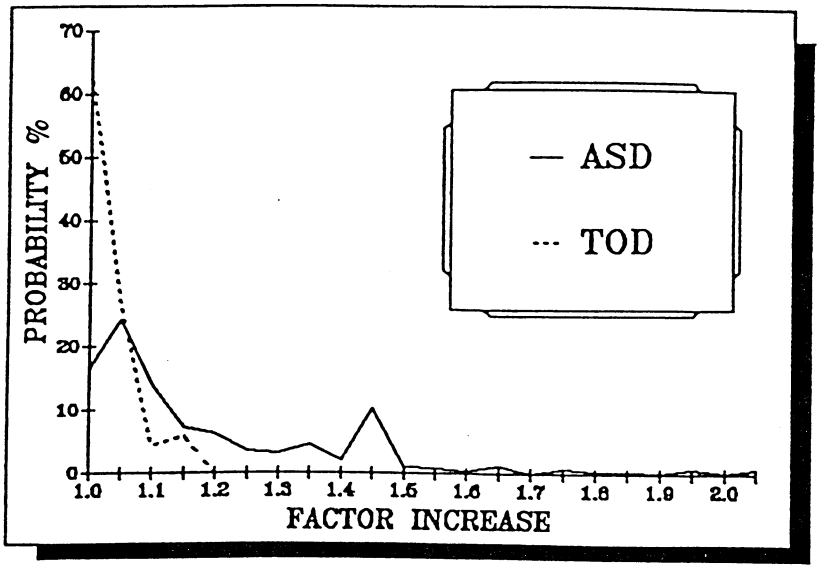


Figure 2. Frequency Distribution of the Ratio of Contaminated to dry Values of ASD and TOD for Departures of B747-100 at Ottawa

MARGIN OF SAFETY ON TAKE-OFF

The margin of safety on take-off can be thought of as the difference between the runway length available and the runway length required for an aborted or continued take-off, given a critical event (such as engine failure) at V_1. On a dry runway the margin of safety, by regulation, should be positive.

Aircraft usually take-off with some margin of safety on dry runways as:

- for many departures the runway length available is greater than that required at maximum take-off weight for that aircraft (e.g., a B737-200 at maximum take-off weight will typically have 2,000 to 4,000 feet of runway to spare if an engine failure occurs at V_1 speed on take-off from Toronto airport), and

- aircraft usually depart only partially loaded and typically have take-off weights 5% to 20% less than the allowed maximum take-off weight (ATOW) of the aircraft from the runway it is taking-off from, and this reduces the required take-off distance by 10% to 35%.

However, if the runway is wet or contaminated, the extra distance required for an accelerate-stop or take-off may result in a negative margin of safety.

A probabilistic model (see SYPHER, 1991) was developed for estimating the margin of safety and the risk of a take-off accident for a particular aircraft type at a given airport allowing for variation in:

- wind direction and speed;
- temperature;
- choice of runway (dependent on wind speed and direction);
- runway condition;
- take-off weight;
- type and time of critical event on take-off run;
- pilot response time; and
- whether reverse thrust was used.

The margin of safety and accident risks are initially calculated assuming reverse thrust is not used as very few aircraft types have been certified with allowance for the use of reverse thrust in the ASD calculations. The effect of reverse thrust is considered in Section 7.

Data for the model were complied for the B747-100, A320 and BA146 aeroplanes and for the Halifax, Ottawa, Toronto and Calgary International airports and Prince George and Edmonton Municipal airports (aircraft and airport characteristics summarized in Appendix B).

The distribution of the margin of safety for B747-100 departures from Toronto airport over a year had the runway been dry (as assumed by the regulation) is given in Figure 3. Distributions are given both for when the aircraft is at ATOW and when at its actual take-off weight. Clearly there is little margin of safety for the B747-100 at ATOW at Toronto, but at actual take-off weights most departures have significant runway to spare in dry conditions.

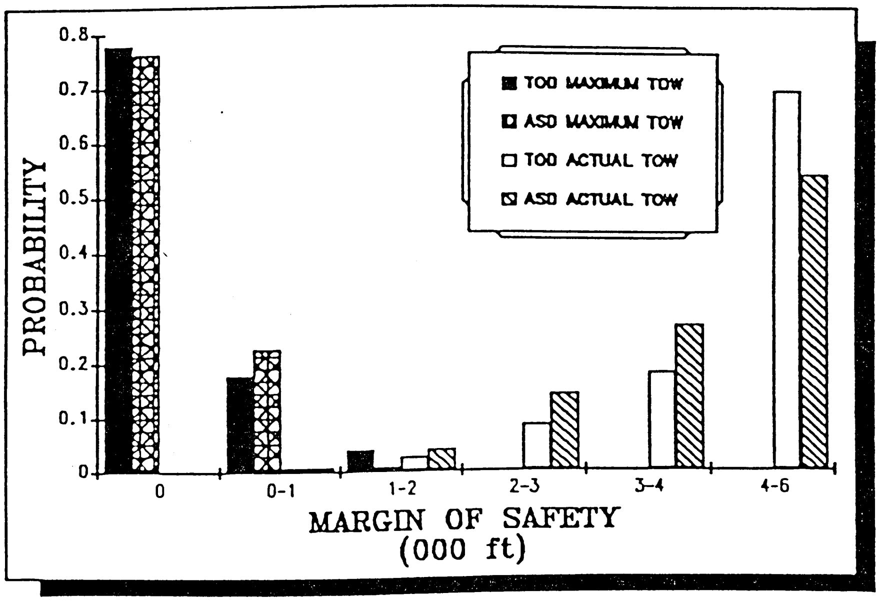


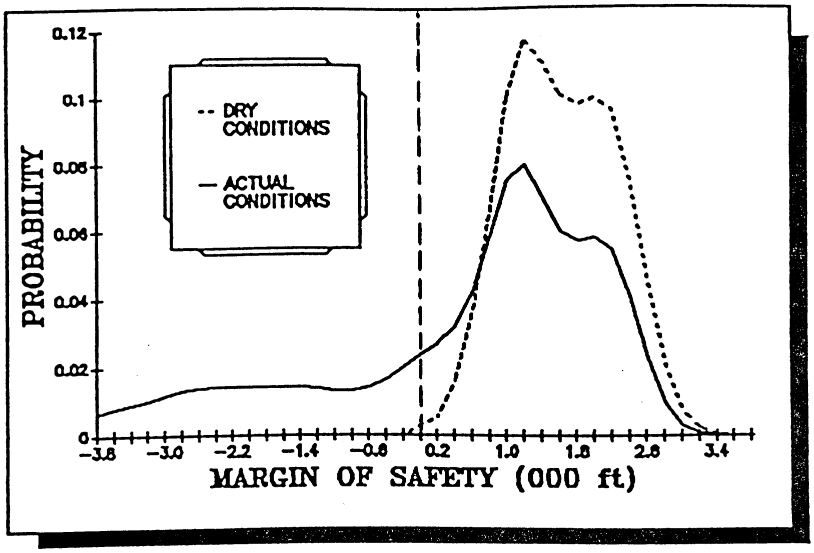
Figure 3. Distribution of the Margin of Safety on Take-off from Dry Runways for the B747-100 at Allowed and Actual Take-off Weight for Departures from Toronto

The percentage of departures where the margin of safety on a dry runway (at actual TOW) is less than 1,000 feet is given in Table 3. Both the B747-100 and A320 have this relatively low margin of safety for a significant percentage of departures at the airports studied, but almost all BA146 departures have at least that safety margin on a dry runway.

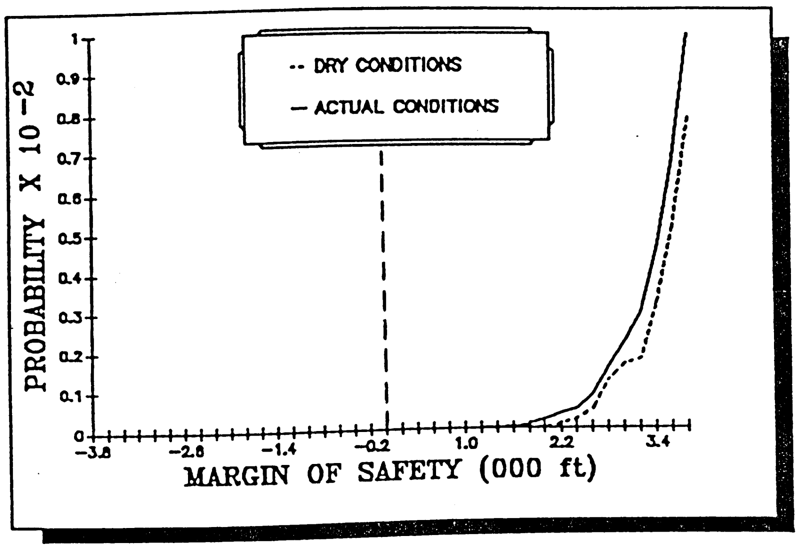
Table 3. Percentage of Take-offs Where Margin of Safety on Dry Runway is Less than 1000 feet

Airport	Aeroplane Type B747-100	A320	BA146
Toronto	1%	0%	0%
Calgary	16%	23%	0%
Ottawa	6%	17%	0%
Halifax	5%	13%	0%
Prince George	-	-	0%
Edmonton Mun.	-	-	0%

The distributions of the margins of safety under dry and actual runway conditions for the A320 from Halifax are given in Figure 4. In the comparison, the same take-off weights under dry and actual conditions are used and in both cases, as specified in the current regulations, the TOW's are less than or equal to the ATOW calculated for dry conditions. The margin of safety is significantly reduced when the effect of runway contamination is included. Under dry conditions there is always additional runway available, but under actual runway conditions the safety margin falls to below zero. Thus, if a critical event occurred at V_1, 28% of aborted take-offs (with reverse thrust not used) for the A320 from Halifax would overrun the runway, but all continued take-offs would clear a 35 ft screen height.



(a) Aborted Take-offs



(a) Continued Take-offs

Figure 4. Distribution of the Margin of Safety Under Dry and Actual* Runway Conditions Given Critical Event at V_1 for the A320 from Halifax

* "Actual" based on percentage under allowed take-off weight for A310 aircraft from Ottawa

ACCIDENT RISK

The risk model was used to estimate the accident/incident risk due to wet or contaminated runways for the three aircraft types at the six airports. An accident/incident is assumed to occur when the aircraft requires more than the available runway length to stop in an aborted take-off, or to clear the 35 foot screen height at the end of the runway in a continued take-off.

The margin of safety and probabilities given in Figure 4 relate to take-offs when a critical event occurs at the decision speed, V_1. The risk of any departure resulting in a take-off accident/incident is much less, as the probability of a critical event occurring near V_1 is very small. For jet aircraft in Canada since 1986, engine failures on the take-off run have occurred once in every 76,000 take-offs and some other type of critical event (e.g., tire failure, warning light) has occurred once in every 40,000 take-offs. The probability of an engine failure, given no engine failure up till that time, was found to be equally likely at any time during the take-off run. The probability of any other critical event was found to be equally likely over any short distance interval during the take-off run. Thus, the probability of a non-engine failure critical event in any small time interval is greater at higher speeds.

An accident/incident is possible without the occurrence of an engine failure on a contaminated runway if the take-off weight is close to the restricted all engine take-off weight and the contaminant increases the all engine take-off distance by more than 15% of the take-off distance on a dry runway (regulated all engine safety margin). This occurs, for example, for the A320 on a runway covered completely with more than 1/2 inch of slush or one inch of snow, or for the BA146 with more than 1/3 inch of water or slush. However, as these types of conditions occur very infrequently (see Section 3) and the runway would usually be closed under these conditions, the risk of an accident/incident not preceded by a critical event was not considered in the risk model.

Risk Given the Runway is Wet or Contaminated

Comparisons of the risk of an accident/incident at times of different runway conditions shows the penalty, in terms of safety, of ignoring runway conditions in the calculation of take-off performance and TOW. Figure 5 gives the risk of an overrun accident/incident for B747-100 departures from Toronto airport (runway used depends on wind conditions) during January for the three cases when the runway is 100% ice patches, loose snow covered (20 mm) or, bare and wet. The corresponding accident/incident probability on a dry runway is zero. On a wet runway the risk is still very low, 10^{-7}, but on snow covered runways this increases to less than 10^{-6}, and on an ice covered runway the chances of a very serious accident (overrun of more than 4000 ft) is 2×10^{-6}. The risk on a runway with 8 mm of slush is very similar to that on 20 mm of snow given in Figure 5. Note that these risks are for aborted take-offs where reverse thrust is not used. The risks of serious take-off accidents on snow and ice covered runways are far greater than other publicized acceptable risks of less serious accidents and incidents (BCAA, 1976).

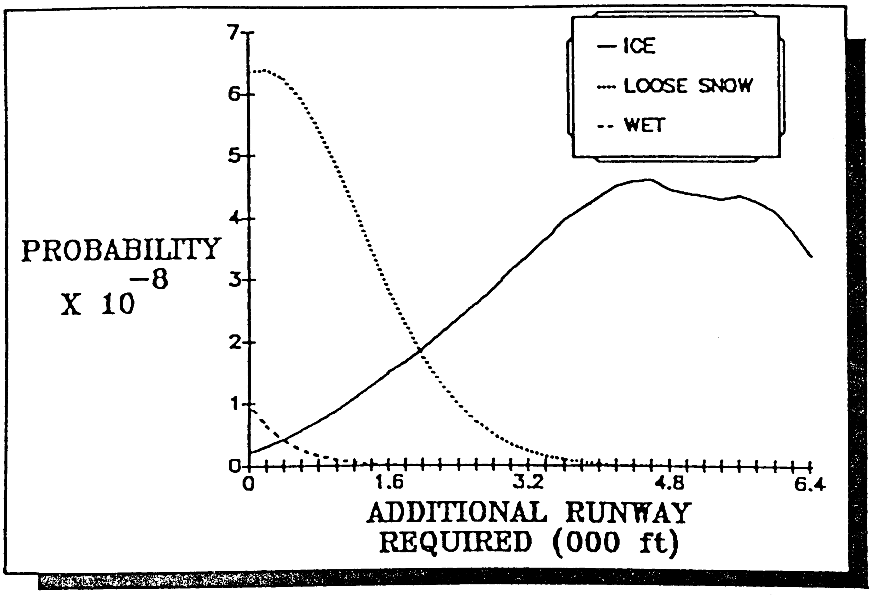


Figure 5. Risk of an Overrun Accident/Incident for a B747-100 from Toronto in January Given Ice, Loose Snow and Wet Runway Conditions*

* Risk equals zero on dry runway; reverse thrust not used.

Overall Risk Allowing for Runway Condition

The accident/incident risk due to wet or contaminated runways and the distribution of the additional runway required over all months of the year and all runway conditions is given in Table 4 for the aircraft and airports considered in the analysis. Again, if runway conditions were always bare and dry, as assumed by the current regulations, the risks would be zero. The distribution of risk for B747-100 departures from Toronto are shown in Figure 6. The risks, as expected, vary greatly with aircraft type and airport and range from 1.5 x 10^{-6} to less than 10^{-9}. The high frequency of poor runway conditions at Halifax airport combined with the short runway length for large jet aircraft result in a relatively high risk for take-offs from Halifax. The accident risk of the small BA146 aircraft is low, even at Edmonton

Municipal airport which has a runway length of 5868 ft at an elevation of 2200 ft (which is roughly equivalent to a 5070 ft runway at sea level). At the larger airports the risk of any form of take-off accident/incident is less than 10^{-9} for the BA146.

Table 4. Accident/Incident Risk and Probability Distribution of Additional Runway Required*

Aircraft /Airport	Probability x 10^{-6} of Additional Distance Required (ft) 0 - 2000 ASD	TOD	2000 - 4000 ASD	TOD	> 4000 ASD	TOD	Accident/ Incident
B747-100							
Toronto	.066	.027	.018	.000	.003	.003	.115
Calgary	.080	.176	.006	.000	.001	.000	.263
Ottawa	.132	.062	.028	.000	.004	.000	.225
Halifax	.296	.034	.052	.000	.004	.000	.387
A320							
Toronto	.163	.007	.050	.002	.007	.001	.229
Calgary	.119	.003	.024	.001	.004	.000	.150
Ottawa	.361	.000	.103	.000	.013	.000	.476
Halifax	1.11	.000	.356	.000	.038	.000	1.500
BA146							
Toronto	.000	.000	.000	.000	.000	.000	.000
Calgary	.000	.000	.000	.000	.000	.000	.000
Ottawa	.000	.000	.000	.000	.000	.000	.000
Halifax	.000	.000	.000	.000	.000	.000	.000
Pr.George	.008	.013	.000	.000	.000	.000	.021
Edm.Mun.	.039	.004	.001	.000	.000	.000	.044

* Risk of less than 10^{-9} given as .000.

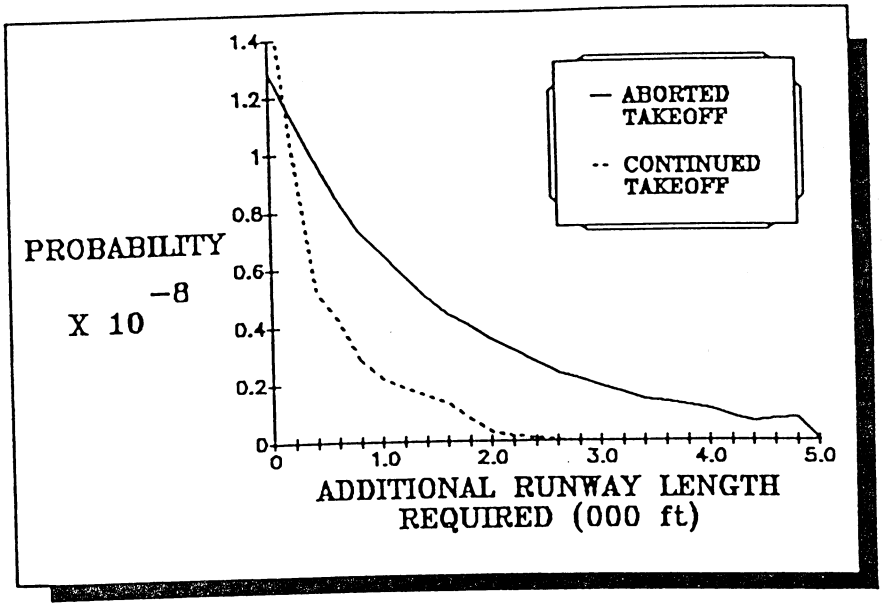


Figure 6. Risk of a Take-off Accident/Incident for B747-100 at Toronto

EFFECT OF REVERSE THRUST ON THE MARGIN OF SAFETY

Currently credit for reverse thrust has not been included in the calculation of the ASD and maximum take-off weight for aircraft in the U.S. and for only the BAC111 in Canada as the aircraft manufacturers have not elected to demonstrate that the aircraft meets the requirements of FAR 25.109. However, reverse thrust is often used in aborted take-offs and can be especially effective when wheel braking is poor due to low friction. Use of reverse thrust can reduce the pilot's ability to control the aircraft during the deceleration, especially if a wing engine has failed and use of reverse thrust in the other wing engine(s) compounds the effect of a cross wind. Therefore, when determining the effect of reverse thrust using the risk model, reverse thrust is assumed to **not** be used when crosswinds are greater than 5 knots and, if it was used in wet or contaminated runway conditions, the aircraft would likely run off the side of the runway.

In estimating the accelerate-stop distance, credit for reverse thrust is given only for those engines which have not failed, a level of approximately 60% of maximum reverse thrust is used and it is assumed to be the last braking device applied.

The effect of reverse thrust on the risk of an overrun accident/incident for aborted take-offs from the V_1 speed is given in Figure 7 for the B747-100 from Toronto. The figure shows that use of reverse thrust reduces the risk for the more serious overruns (more than 4,000 ft) by about 90% and reduces the risk of any overrun accident/incident by almost a half. More generally, use of reverse thrust was found to reduce the risk of serious overruns by a third and of any overrun by 25%. The risk of overrun accidents/incidents could be further reduced by the use of reverse thrust in crosswind situations, but this reduction in risk would be offset by a rise in the risk of "run off side of runway" accidents/incidents.

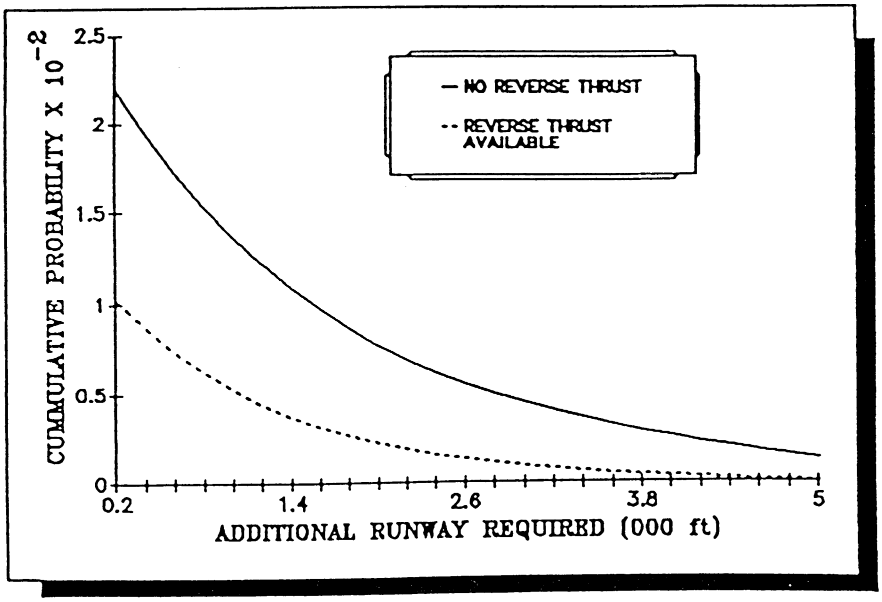


Figure 7. Effect of Reverse Thrust on the Risk of an Overrun Accident/Incident for a B747-100 from Toronto When Critical event Occurs at V_1

FINDINGS AND CONCLUSIONS

The major findings of the analysis of runway conditions and take-off risks are summarized below.

- Wet and contaminated runways are rarely the only cause of take-off accidents, but they reduce margin of safety available so that accidents are more likely under such conditions.

- Runway conditions which significantly affect an aeroplane's take-off performance are relatively common in Canada; approximately 1 in 5 take-off in Canada are from runways which are wet or contaminated, varying from 1 in 3 during the colder 5 months, to 1 in 10 during the warmer 7 months.

- The accelerate-stop distance is increased by approximately 15% on wet runways, 50% on snow, 75% on water deeper than 3 mm and 100% on treated ice; and typical depths of loose snow and slush increase take-off distance by 10%.

- The 15% safety margin for take-offs on dry runways is not sufficient to account for the greater take-off distance (with no engine failure) on runways with more than 13 mm (in.) of slush or 25 mm (1 in.) of loose dry snow for some aircraft types.

- The accident risks in Canada of take-offs from wet or contaminated runways is approximately twice the risk of take-offs from dry runways.

- The combination of a contaminated runway and a critical event, such as engine failure, occurring near the decision speed, V_1, pose a threat to safety under current regulations and the risk is greater than other published acceptable aircraft accident/incident risks.

- The margin of safety on take-off (with critical event at V_1 speed) was found to be less than zero in roughly 1 out of every 1000 departures in Canada due to the non-accountability of runway conditions in the performance calculations.

- Use of reverse thrust in situations where it will not greatly affect the directional control of the aeroplane reduces the risk of a serious accident by about a third.

From these findings it was concluded that currently the risks of take-offs from wet and contaminated runways in Canada are greater than acceptable levels and steps should be taken for including wet and contaminated runway accountability in performance calculations included in the Aircraft Flight Manual.

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