



Example of risk analysis applied to aircraft landing distance

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EXAMPLE OF RISK ANALYSIS APPLIED TO AIRCRAFT LANDING DISTANCE

CONTENTS

	Page
1. NOTATION AND DEFINITIONS	1
1.1 Notation	1
1.2 Definitions	2
2. INTRODUCTION	3
3. BACKGROUND	3
4. PERFORMANCE ASSUMPTIONS	3
4.1 Pilot Technique	3
4.2 Aircraft Runway Positioning	4
4.3 Wet Runway Braking	4
4.4 Non-limiting Runways	4
5. LANDING DISTANCE DATA	4
5.1 General	4
5.2 Measured Airborne Distance	5
5.3 Airborne Plus Transition Distance	5
5.4 Calculated Braking Distance	6
6. TOTAL LANDING DISTANCE CALCULATIONS AND INFLUENCES	7
6.1 Dry and Wet Runway Data	7
6.2 Comparison with AFM Data	7
6.3 Overrun Safety Statistics	8
7. CONCLUSIONS	8
8. COMMENTS ON CONCLUSIONS	9
9. REFERENCES	10
FIGURES 1 to 7	11 to 14
APPENDIX A – CALCULATION OF BRAKING DISTANCES	15
A.1 Introduction	15
A.2 Calculation Method	15
A.3 Input Data to Calculations	15
FIGURE A1	17

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1. NOTATION AND DEFINITIONS

1.1 Notation

		Units
d	runway water depth	mm
d_{TEX}	runway texture depth	mm
$E[]$	expected (mean) value of quantity in []	—
$M[]$	measured value of quantity in []	—
$N[E[], \sigma[]]$	Normally distributed variable with mean value $E[]$ and standard deviation $\sigma[]$	—
$O[]$	observed value of quantity in []	—
$Pr[]$	probability of event in []	—
p	aircraft mainwheel tyre pressure (gauge)	bar
t_{TRANS}	measured transition time	s
V_{TD}	measured true airspeed at touchdown	knot
W	aircraft weight	N
x	general symbol for landing distance	m
x_A	landing distance available	m
x_{ABN}	airborne distance from threshold to touchdown	m
x_{AFM}	aircraft flight manual scheduled landing distance, which may or may not include an operational factor	m
x_{BRAKE}	landing ground distance covered in braking to full stop	m
x_C	critical landing distance	m
x_{DRY}	value of x for dry runway	m
x_{TOTAL}	total landing distance from threshold to full stop (= $x_{ABN} + x_{TRANS} + x_{BRAKE}$)	m
x_{TRANS}	landing ground-roll distance from touchdown to full braking configuration	m
x_{WET}	value of x for wet runway	m

z	percentage point of Normal distribution	–
$\delta[x]$	difference, $E[x_{AFM}] - O[x_{TOTAL}]$ (see Equation (6.1))	m
$\sigma[]$	standard error (deviation) of quantity in []	–
χ^2	“Chi-squared” test statistic (see Reference 1)	–

1.2 Definitions

Monte-Carlo analysis

An analysis where a limited amount of real data is expanded using either a randomised selection of variables affecting that data, or a simulator or mathematical model, or a combination, to achieve a larger sample of representative data.

Dry Runway

A dry runway is one which is neither wet nor contaminated, and includes those paved runways which have been specially prepared with grooves or porous pavement and maintained to ‘effectively dry’ braking action even when moisture is present (JAR-OPS 1.480 (a) (4), Reference 2).

Damp Runway

A runway is considered damp when the surface is not dry, but when moisture on it does not give it a shiny appearance (JAR-OPS 1.480 (a) (4), Reference 2).

Wet Runway

A runway is considered wet when the runway surface is covered with water, or equivalent, less than specified in JAR-OPS 1.480 (a) (2) (contaminated runway), or when there is sufficient moisture on the runway surface to cause it to appear reflective, but without significant areas of standing water (JAR-OPS 1.480 (a) (10), Reference 2).

Contaminated runway

A runway is considered to be contaminated when more than 25% of the runway surface area (whether in isolated areas or not) within the required length and width being used is covered by the following:

- (i) surface water more than 3mm (0.125 in) deep, or by slush, or loose snow, equivalent to more than 3mm (0.125in) of water,
- (ii) snow which has been compressed into a solid mass which resists further compression and will hold together or break into lumps if picked up (compacted snow),
- (iii) ice, including wet ice (JAR-OPS 1.480 (a) (2), Reference 2).

2. INTRODUCTION

Airworthiness and Operational regulations permit a public transport aircraft to land at its destination when the distance available at that destination equals or exceeds the distance required to land for the aircraft, with an added Operational factor. Whilst the safety record achieved under these regulations can be considered acceptable for Western large jet transport aircraft, no measure of the actual risk at landing for any particular public transport flight is available. This example examines one particular limited set of data for in-service landings in conjunction with the scheduled information, thereby permitting a judgement to be made on the actual achieved level of safety or risk in those landings and hence the adequacy of the Operational factors. This example is based on the outline principles of Reference 3.

3. BACKGROUND

All public transport aircraft operations are governed by performance information contained in the Aircraft Flight Manual (AFM), supplemented by Operational Regulations. In the case of landing an aircraft, this takes the form of an AFM distance (determined in accordance with, for example, CS25, Reference 4, or FAR25, Reference 5,) factored by the Operational Regulation (for example JAR-OPS 1, Reference 2, or FAR121, Reference 6). For large jet transport aircraft landing at their scheduled destination this factor is 1.67, or 1.92 when the runway is wet. These factors are expressed here as simple multiples but inside the Operational Regulations the 1.67 dry runway factor is expressed as 60% of the landing distance available and the 1.92 wet runway factor is 115% of the dry runway landing distance.

In determining the AFM distance and the additional wet runway landing distance factor (+15%), there are a number of implicit assumptions, it being considered that the generosity of the basic 1.67 is sufficient to compensate for any discrepancy arising from errors in these assumptions and variations in flight characteristics that occur in operational conditions. This situation has arisen, largely as a convenience for aircraft manufacturers, borne out by an acceptable safety record in service over 50 years.

4. PERFORMANCE ASSUMPTIONS

Sections 4.1 to 4.4 give a brief explanation of differences between what is either measured or assumed in the determination of an aircraft's landing performance and what is seen in service.

4.1 Pilot Technique

AFM landing performance is measured from test flights flown by proficient test pilots, using rates of sink and flare not considered acceptable in service for passenger comfort. This is done to reduce test landing variability and hence give a limiting measure of the actual aircraft performance. For example, when measuring performance, a long 'float' prior to touchdown is distance wasted to the manufacturer. Further, a test pilot will attempt to shorten the time taken to achieve certain actions, such as brake selection, whereas an airline pilot will attempt to fly more smoothly and not rush such actions. Whilst this procedure may seem unreasonable at first, it does provide a consistent datum. On the other hand the test-pilot uses his own judgement to achieve the test result, whereas the airline pilot generally has approach-path guidance, either an Instrument Landing System (ILS) or Head-Up Display (HUD), plus Precision Approach Position Indicators (PAPIs) to help achieve positioning consistency.

4.2 Aircraft Runway Positioning

During testing, AFM landing distance is measured from a screen height (usually 50ft), irrespective of whereabouts on the runway this height is achieved. Obviously, in service, the airline pilot plans to be at the screen height over the end of the runway, and this is assumed in declaring the landing distance. Should he not achieve this the assumptions regarding distance from the runway end will be invalid.

4.3 Wet Runway Braking

The test pilot will use full, heavy braking on a dry runway to achieve minimum distances for AFM presentation. In service, lesser levels of braking may be used whenever excess runway distance is available and the necessity for heavy braking does not exist. When landing on a wet runway in service, with brakes fully applied by the pilot, maximum achieved braking will be reduced when compared to the levels achievable on a dry runway. However, operational regulations require an additional 15% distance, *applied to both ground and air elements*, to allow for the wet effects. This arbitrary value has no substantive background; it was introduced initially as a response to a spate of jet overruns in the 1950s/1960s.

4.4 Non-limiting Runways

Many aircraft land on runways where the distance available greatly exceeds that required by the AFM and Operational regulation. Consequently the risk associated with landing is reduced in many cases from that for an aircraft landing on a limiting runway. Obviously for operational reasons an airliner must depart the airfield it lands at, so take-off criteria may also influence the length of runway available for landing. However, with ever-increasing commercial constraints, a dedicated operation onto a short runway, where every landing is limiting, can mean that the risk of an overrun will be higher than that given by the current overall safety record.

5. LANDING DISTANCE DATA

5.1 General

For any certificated aircraft there are measured test data that enable a landing distance to be determined. This information has been established without a constraint on the test-pilot flying the tests to fly through a 'window' over the end of the runway and hence is not representative of the task for the in-service airline pilot. A survey has been conducted of airline operations and the actual flight paths achieved, including height over the runway end, comprising 101 landings on a short, 1199 m (3934 ft), runway and these same data are capable of being used to determine the actual risk during landing in service.

Any landing is comprised of three phases, namely:

- (i) the final approach and flare to touchdown from a nominal screen height or end of runway reference point,
 - (ii) the transition distance between touchdown and achieving the full braking configuration
- and (iii) the braking distance to stop.

The subject data set provides information on both the airborne and transition phases, but not the braking phase as the airline pilot, for passenger comfort reasons, used less than full braking. Thus, for the purposes of this example, and to enable a complete landing distance to be determined using maximum braking, that phase has been synthesised from other sources.

The three phases of the landing distance data are further discussed in Sections 5.2 to 5.4.