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A Study of Runway Excursions from a European Perspective

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Abstract

This report presents an analysis of runway excursions. Causal and contributory factors that may lead to a runway excursion are identified by analysing data of runway excursions that occurred during the period 1980-2008. The results were used to define preventive measures for runway excursions.

Keywords

Runway excursion	Overrun	RTO	Runway friction
Wet runway	Contaminated runway	Cross- and tailwind	Veeroff
Safety	Runway safety	Aquaplaning/hydroplaning	Takeoff/Landing performance

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Contents

EXECUTIVE SUMMARY

A runway excursion is the event in which an aircraft veers off or overruns the runway surface during either takeoff or landing. Safety statistics show that runway excursions are the most common type of accident reported annually, in the European region and worldwide.

In this report causal and contributory factors that may lead to a runway excursion are identified by analysing data of runway excursions that occurred during the period 1980-2008. The scope of this report includes runway excursions that have taken place globally with a focus on the European context. The study was limited to civil transport type of aircraft (jet and turboprop) involved in commercial or business transport flights. The final results were used to define preventive measures for runway excursions. Post incident / accident recovery after an excursion such as the use of Runway End Safety Areas or arrestor beds are not considered preventive measures, but mitigators of severity after the event and as such are excluded from this study.

The results of the study were discussed with a group of flight operational experts for validation and presented to and discussed with representatives of professional groups and aircraft manufacturers. The outcome of the discussions with the experts, professional associations and industry was used to refine the recommendations on preventive measures.

Based on the analysis of runway excursions the following main conclusions are made:

- The runway excursion rate has not shown significant improvement during the study period 1980-2008;
- Runway excursions that occurred in Europe have very similar causal factors as excursions that occurred elsewhere;
- The four types of runway excursions (takeoff overrun; takeoff veeroff; landing overrun; landing veeroff) show a very similar frequency of occurrence for Europe compared to the rest of the world;
- Landing overruns and veeroffs are the most common type of runway excursion accounting for more than 77% of all excursions;
- 18 causal factors were prominent in all analysed runway excursions.

CHAPTER 1 – Introduction

1.1 Background

A runway excursion is the event in which an aircraft veers off or overruns the runway surface during either takeoff or landing. Safety statistics show that runway excursions are the most common type of accident reported annually, in the European region and worldwide. There are at least two runway excursions each week worldwide. Runway excursions can result in loss of life and/or damage to aircraft, buildings or other items struck by the aircraft. Excursions are estimated to cost the global industry about $900M every year[1]. There have also been a number of fatal runway excursion accidents[2]. These facts bring attention to the need to prioritise measures to prevent runway excursions.

This report identifies causal and contributory factors that may lead to a runway excursion from which preventive measures against runway excursions are formulated.

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[1] Honeywell Aerospace, PARIS AIR SHOW, June 15, 2009.

[2] The fatality rate typically associated with runway excursions is much lower than in other accident types such as Controlled Flight Into Terrain (CFIT). Typically 3% of the occupants are fatally injured in a runway excursion whereas for other accidents this is in the order of 20%.

Landing veeroff after nose gear retraction (Switzerland, January 25th, 2007).

1.2 Objective and scope of the study

The objective of this study was to better understand the causal factors[3] of runway excursions from a European perspective.

The study considered:

a) What is going wrong?
b) Who is involved and how?
c) What are the root factors which were judged to be instrumental in the causal events leading to runway excursions?
d) What do these factors look like according to different views e.g. their importance and interrelations?
e) What measures can mitigate or eliminate runway excursions?
f) How can awareness of excursion hazards best be achieved?
g) Which stakeholder is best placed to implement preventive measures?

The purpose of this study was to identify key preventive actions focused for the relevant stakeholder groups.

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[3] The ICAO ADREP/ECCAIRS taxonomy used in this study does not make a difference between causal and contributing factors. The difference between the both is often subjective and unclear. A factor is defined here as an item, which was judged to be instrumental in the causal events leading to the occurrence. It can be referred to as 'factor' or 'causal factor' in this study.

The scope of this report includes runway excursions that have taken place globally with a focus on the European context. The runway excursions studied in this report occurred during the period 1980-2008. If runway excursions that occurred in Europe include unique causal factors compared to the rest of the world, this has been identified and explained. The study was limited to civil transport type of aircraft (jet and turboprop) involved in commercial or business transport flights.

This study addressed measures to prevent runway excursions only. Contingency/business recovery post accident/incident is not part of the scope (e.g. the presence of the correct runway end safety areas or safety strips around the runway is not considered).

CHAPTER 2 –Methodology

2.1 Data sources

One of the data sources used in this study is the NLR Air Safety database. The NLR Air Safety Database contains detailed information on accidents and (serious) incidents of fixed wing aircraft from 1960 onwards and is updated frequently using reliable sources. For a large number of occurrences the factors which were judged to be instrumental in the causal events are available. These are coded according to the ECCAIRS/ADREP taxonomy[4]. The majority of the occurrences were coded by the reporting organisations (e.g. AIB). The database also contains a large collection of non-accident related data used in the study e.g. airport data, flight exposure data (hours & flights at the level of airlines, aircraft type, and airports), weather data, fleet data, and more.

Data from e.g. Flight Safety Foundation, Boeing and the Australian Transport Safety Board were also considered. In particular these data were used to validate some of the results of this study where possible.

2.2 Data Analysis

The main part of the study comprised of an analysis of available data on runway excursions. These data are described in section 2.1. The basic query was for civil transport type of aircraft (jet and turboprop) operated worldwide (commercial and business transport). The runway excursions studied in this report occurred during the period 1980-2008. This period was considered to be sufficient to obtain statistically relevant results. Both accidents as well as (serious) incidents were considered in the data sample (see ICAO ANNEX 13 for

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[4] See for the latest release www.icao.int/anb/aig/Taxonomy/.

definitions). Note that the difference between a runway excursion *accident* and *(serious) incident* is dictated by the consequences and not by the factors that caused the excursion to happen.

The following analyses were conducted:

- Occurrence data were evaluated through a straightforward single-variable analysis. This includes developing frequency distributions (bar charts) of each factor reported. The occurrence data were analysed from both the global and European perspective. Differences (if any) between both regions were addressed and explained. This analysis considered all possible factors that contributed to runway excursions (e.g. ATM procedures, standard operating procedures, practices at aerodrome etc.). Note that one runway excursion typically has more than one factor assigned.

- The occurrence data from the NLR-ATSI database were used to estimate the runway excursion risk associated with the various operational factors (e.g. excess speed, wind, runway condition etc.). It is therefore essential to understand the prevalence of these individual factors during takeoffs and landings which did *not* end up in an excursion. For instance to estimate the risk associated with long landings it should be known how many long landings took place without resulting in an overrun. Reasonably accurate estimations of the prevalence of a number of risk factors in non-accident flights were made and the number of takeoffs and landings conducted on the different runway surface conditions was used in this study. Some other risk factor data was obtained from Flight Data Monitoring systems from a limited number of operators. These flight data can be used to estimate prevalence of a number of risk factors in non-accident landings. Examples are excess approach speed, long landings, and high approaches. It is realised that this only gives a rough order of magnitude of the prevalence of those risk factors for operations worldwide.

  An estimate of the risk of having a runway excursion with a particular risk factor present is accomplished by calculating a risk ratio. This risk ratio provides insight on the association of a factor on the risk in a runway excursion. The risk ratio is the rate of the occurrence probability with the factor present over the occurrence probability without the factor present. The risk ratio is given by the following formula:

$$Risk\ Ratio = \frac{\left(\dfrac{\text{occurrences with presence of a risk factor}}{\text{normal landings with presence of a risk factor}}\right)}{\left(\dfrac{\text{occurrences without presence of a risk factor}}{\text{normal landings without presence of a risk factor}}\right)}$$

Risk ratio values greater than 1 indicate an increased level of risk due to the presence of a particular factor. For instance a risk ratio of 4 means that the probability of a runway excursion with the risk factor present is 4 time higher than without its presence. Positive associations between a risk factor and landing overruns accidents show that a demonstrated association exists. However it does not proof causation.

- Trends in the data were analysed. In particular changes over time were considered. For this rates of excursions during takeoff and landing for both overruns/veeroffs were determined and analysed.

The results obtained were validated using studies from the Flight Safety Foundation, Boeing and the Australian Transport Safety Board. Discrepancies between the present results and the other studies are explained in this report.

The results from the above mentioned steps were used to answer the following basic questions as set in the objective:

a) What is going wrong?
b) Who is involved and how?
c) What are the root factors which were judged to be instrumental in the causal events leading to runway excursions?
d) What do these factors look like according to different views e.g. their importance and interrelations?
e) What measures can mitigate or eliminate runway excursions?
f) How can awareness of excursion hazards best be achieved?
g) Which stakeholder is best placed to implement preventive measures?

2.3 Consultation with experts and professional associations

The results of the study were discussed with an NLR-ATSI internal group of flight operational experts consisting of engineering test pilots and air traffic controllers for validation.

Furthermore the study results were presented to and discussed with expert groups and representatives of professional groups such as (but not limited to) International Federation of Airline Pilots Association (IFALPA), European Cockpit Association (ECA), International Federation of Air Traffic Controllers' Associations (IFATCA), and Airports Council

International (ACI Europe). Also comments were obtained from aircraft manufacturers (Airbus, Boeing and Embraer) that reviewed the report.

The outcome of the discussions with the experts and professional associations was used to refine the recommendations for preventive actions.

CHAPTER 3 –Big picture

3.1 Data sample description

The complete data sample contained 1732 runway excursions of which 388 (22.4%) occurred in Europe. For 1075 runway excursions causal factors were coded of which 246 occurred in Europe[5]. Out of the 1732 runway excursions 41.7% involved turbo prop aircraft (see Figure 1). The remainder were turbofan/turbojet powered aircraft. This distribution partly reflects the exposure of these aircraft types which is: 32% turbo prop flights; and 68% turbofan/turbojet flights. The majority of runway excursions in the data sample involved passenger operations (66.4%) as shown in Figure 1. Full cargo operations were conducted in 15.2% of the runway excursions in the data sample and business operations in 11.2%. The other types of flights in the data sample were training, and ferry/positioning flights (these are grouped under commercial flights in the ECCAIRS taxonomy). The distribution is partly reflected by the exposure of these operation types which is: 84% passenger, training, and positioning flights; 6% cargo flights, and 10% business flights.

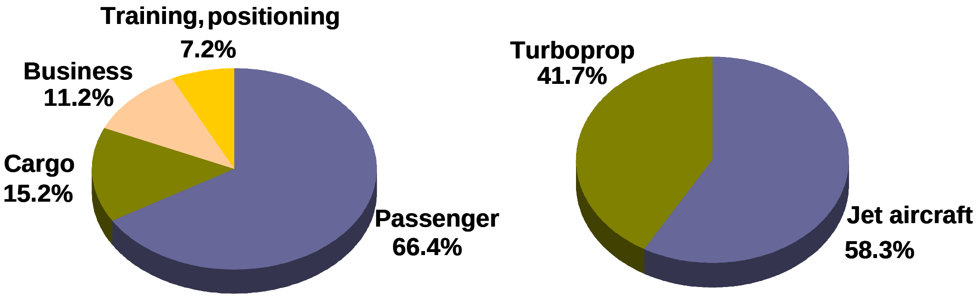

Figure 1: Type of operation and aircraft type distribution.

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[5] These were all coded according to the ECCAIRS/ADREP taxonomy. The majority of the runway excursions were coded by the reporting organisations (e.g. AIB or CAA).

3.2 Comparison between Europe and the rest of the world

An important part of the present study is to compare runway excursions that occurred in Europe to the rest of the world. In Table 1 an overview is given of the frequency of occurrence of the different types of runway excursions for the different flight phases for both Europe and the rest of the world. This table shows that there are only small (statistically not significant) differences in the frequencies in Europe compared to the rest of the world. For both Europe and the rest of the world runway excursions occurred most often during the landing phase with a more or less equal division between landing overruns and veeroffs.

Table 1: Comparison frequency of runway excursion types (includes excursion with and without known causes).

Region	Runway excursion type	Phase of flight	Number of occurrences	Percentage
Worldwide excl. Europe	Overrun	Landing	499	37.1%
	Overrun	Takeoff	144	10.7%
	Veeroff	Landing	535	39.8%
	Veeroff	Takeoff	166	12.4%
Europe	Overrun	Landing	162	41.8%
	Overrun	Takeoff	49	12.6%
	Veeroff	Landing	139	35.8%
	Veeroff	Takeoff	38	9.8%

An important objective of this study was to see if the factors associated with runway excursions that occurred in Europe are any different than of those in the rest of the world. The total data sample contained more than 450 different factors which were judged to be instrumental in the causal events (more than 4800 factors were assigned in total to 1075 runway excursions). Emphasis is given on those factors that occurred the most frequently or those that were related to a high increase of the risk. From a prevention point of view it makes sense to only consider these factors rather than all the 450 different factors indentified.

In Table 2 through Table 5 a comparison is presented of the frequency of the most important factors for runway excursions in Europe and the rest of the world[6]. Data shown are for veeroffs and overruns that occurred during either takeoff or landing. Examination of the data shows that most factors associated with excursions that occurred in Europe have similar frequencies compared to excursions that occurred in the rest of the world. The majority of the differences that are shown in the tables are not statically significant[7]. The

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[6] The factor data presented in this section are in percentage of all corresponding occurrences with known causes. Corresponding occurrences are e.g. the number of landing overruns in Europe, the number of takeoff veeroffs in the rest of the world. The term “insufficient data” applies to those cases where there were not enough data to derive a statistically meaningful frequency. Note that one runway excursion can have more than one causal factor assigned.

[7] At 5% significance level.

only factors that are significantly different in frequency are the wet/contaminated runway factor in landing overruns and veeroffs and the long landing factor in landing overruns. No real explanation could be found for these differences. Although the frequencies of these factors are somewhat lower for excursions in Europe they are still relatively high and show the same order of importance compared the rest of the world.

Table 2: Comparison landing overrun factors.

Landing overruns		
Factor	**Europe**	**Rest of the world**
Wet/Contaminated runway	38.0%	66.7%
Long landing	24.0%	44.5%
Incorrect decision to land	14.9%	16.8%
Speed too high	14.0%	22.1%
Late/incorrect use of brakes	14.0%	10.3%
Late/incorrect use of reverse thrust	14.0%	10.0%
Aquaplaning	7.4%	16.2%
Tailwind	7.4%	15.9%
Too high on approach	3.3%	7.2%

Table 3: Comparison landing veeroff factors.

Landing veeroffs		
Factor	**Europe**	**Rest of the world**
Crosswind	31.6%	25.0%
Wet/Contaminated runway	23.7%	39.9%
Nose wheel steering problems	17.1%	8.5%
Landing gear collapsed	7.9%	5.8%
Hard landing	7.9%	13.1%
Tire failure	7.9%	6.1%
Asymmetric power	2.6%	3.7%

Table 4: Comparison of takeoff overrun factors.

Takeoff overruns		
Factor	**Europe**	**Rest of the world**
Abort/reject - After V1	29.6%	44.1%
Wet/Contaminated runway	11.1%	15.1%
Tire failure	11.1%	12.9%
Takeoff mass too high/incorrect	Insufficient data	9.7%

Table 5: Comparison of takeoff veeroff factors.

Takeoff veeroffs		
Factor	**Europe**	**Rest of the world**
Wet/Contaminated runway	40.9%	41.3%
Nose wheel steering problems	18.2%	17.2%
Inadequate supervision of the flight	13.6%	4.6%
Crosswind	13.6%	19.5%
Asymmetric power	13.6%	8.0%

Based on the analysis made above it is concluded that runway excursions in Europe are very similar to those that have occurred in the rest of the world. From a statistical point of view it therefore makes sense to combine the data for both regions in order to increase the data sample size. For the remainder of this report all data shown refer to runway excursions that occurred worldwide.

3.3 Trends in accident rates

In this section some trends in runway excursion rates are analysed. The annual runway excursion accident rate for commercial and business flights is shown in Figure 2. Only accidents are used in this figure as the number of (serious) incidents in the data sample is not complete and if added could bias trend results. It follows from Figure 2 that the runway excursion accident rate for commercial flights has not changed since 1980. The accident rate for business flights was significantly higher than for commercial flights during the first 5 year of the period. However, after 1985 the runway excursion accident rate for business flights is no longer statistically significant different from the rate of commercial flights.

The annual runway excursion accident rate for both commercial and business operations combined is shown in Figure 3. Again only accidents are used in this figure as the number of (serious) incidents in the data sample is not complete and if added could bias trend results. Figure 3 shows that the overall worldwide runway excursion accident rate has hardly improved. Other accident types like CFIT improved dramatically over the same period. This can be partly explained by the fact that no technical system was available for runway excursions such as the TAWS/EGPWS system for CFIT. Such technical systems proved to be very effective in reducing accidents.

When looking at the different runway excursion categories (see Figure 4and Figure 5) only the takeoff overrun rate has dropped slightly since 1996 from an average of 0.20 to 0.15 per million flights during the last 10 years. The other runway excursion categories showed no or little improvement in the accident rate.

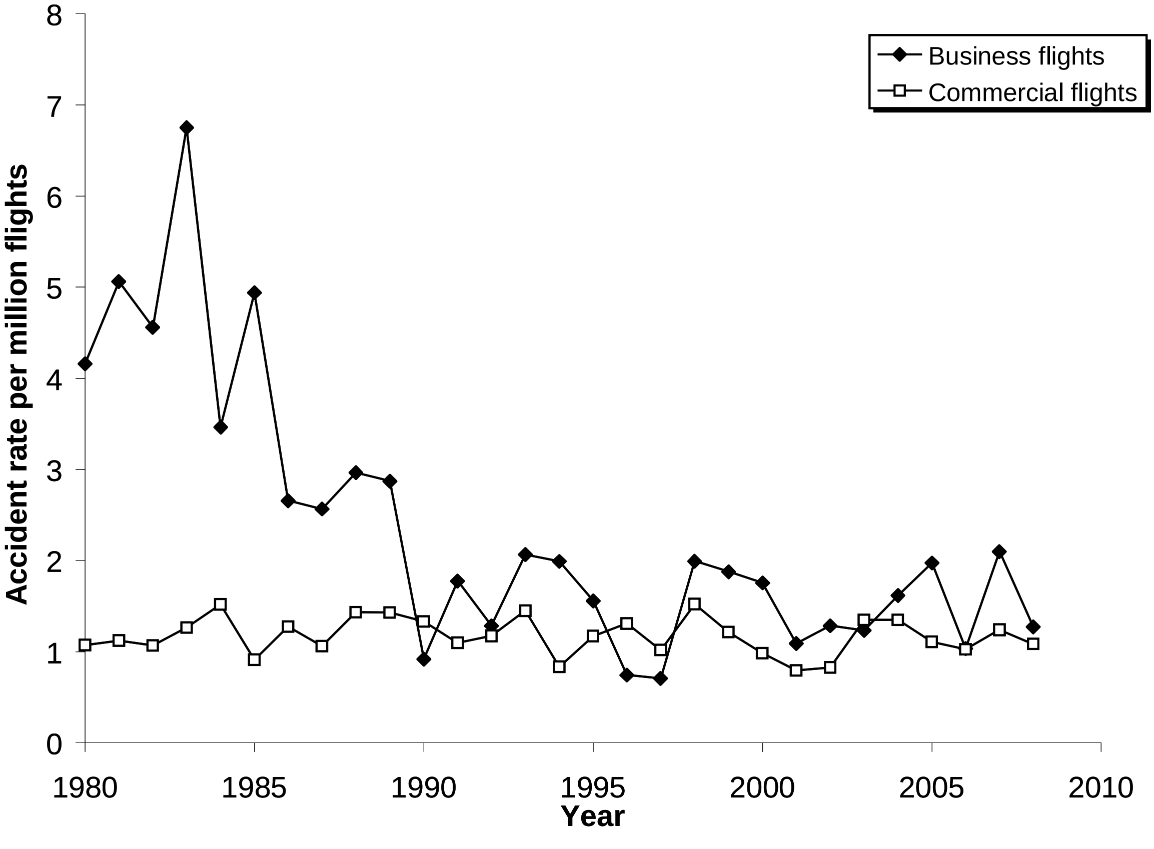

Figure 2: Runway excursion accident rate trend for commercial and business flights (incidents excluded).

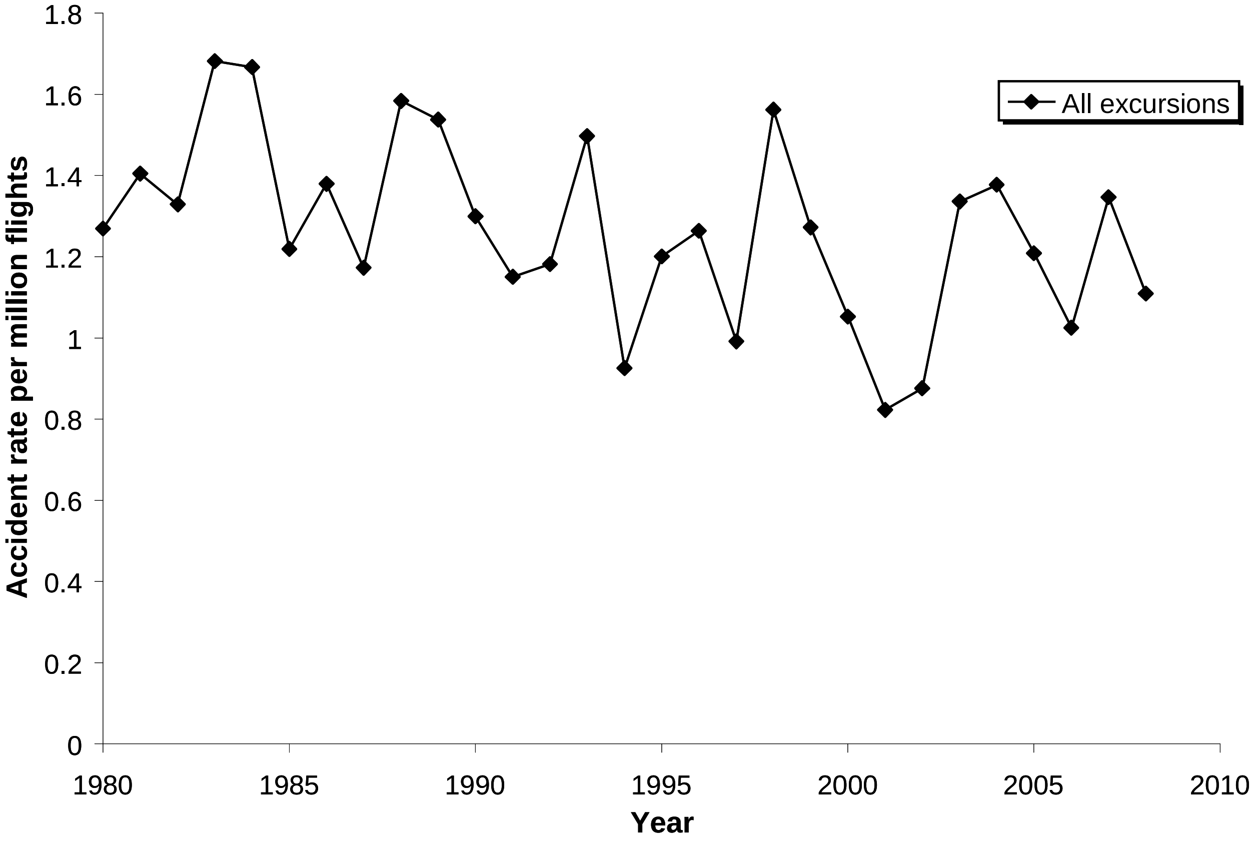

Figure 3: Annual runway excursion accident rate (incidents excluded).

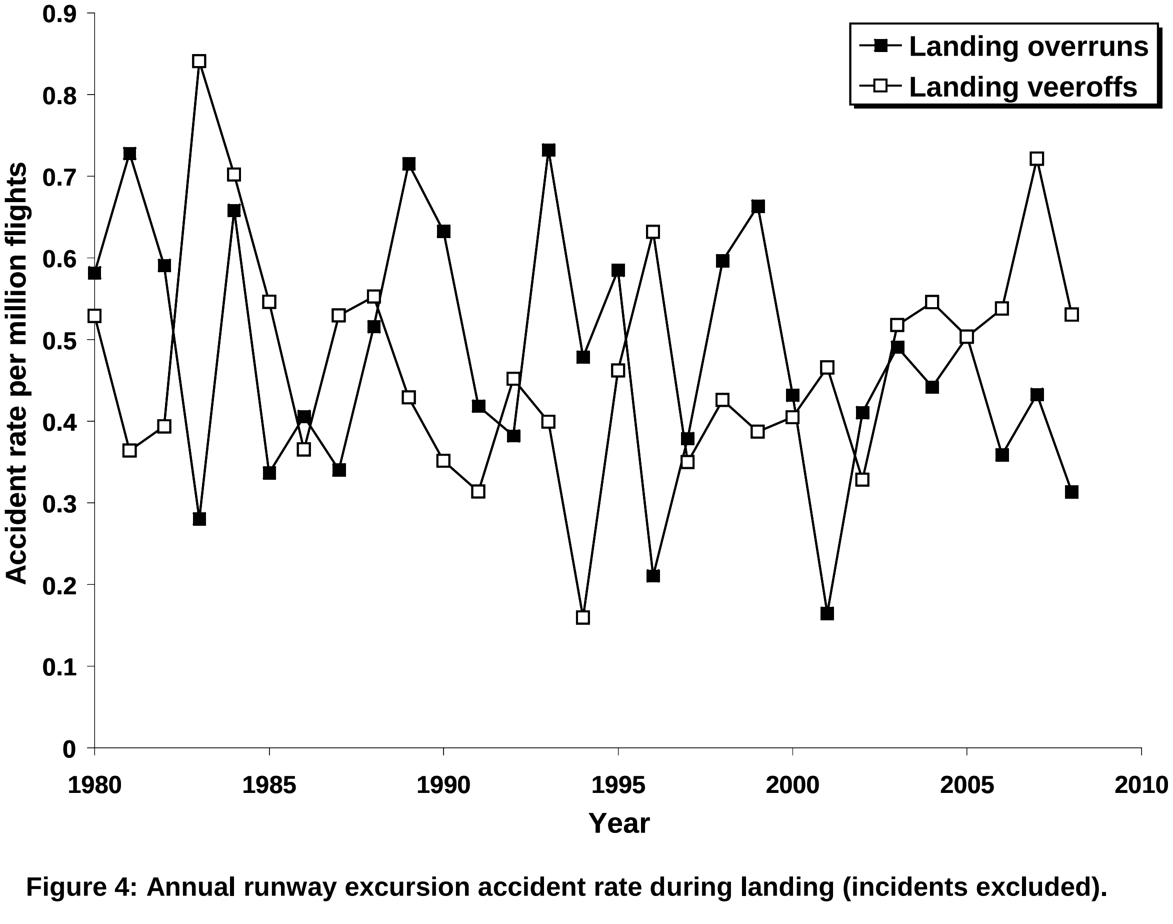

Figure 4: Annual runway excursion accident rate during landing (incidents excluded).

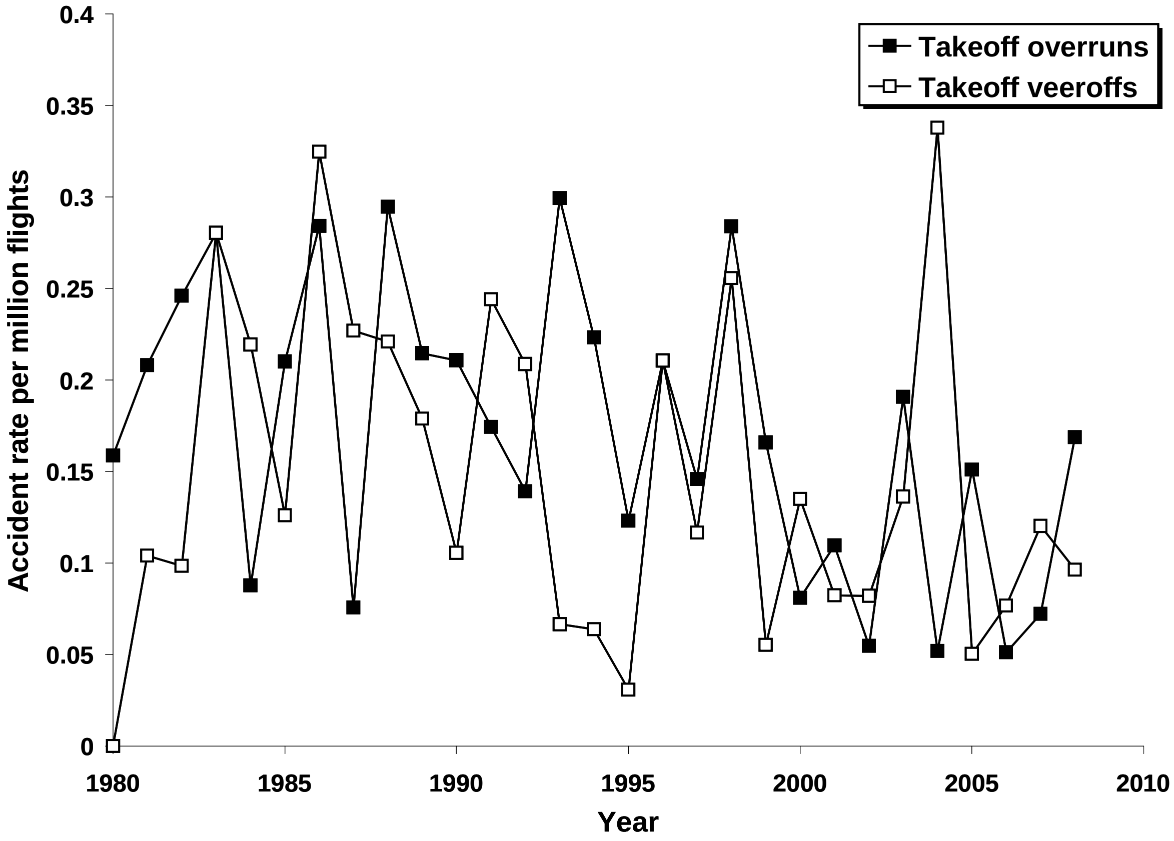

Figure 5: Annual runway excursion accident rate during takeoff (incidents excluded).

CHAPTER 4 –Causal factor analysis

4.1 Landing overruns

Picture of a Fokker F-27 after a landing overrun (2 November 2002, Sligo, Ireland).

A Fokker F-27 carried out a NDB/DME approach to RWY 11 at Sligo Airport (Ireland). The weather during the day of the accident maintained a strong south-easterly wind with pulses of heavy rain. The aircraft carried out a lower and faster approach than normal (due to gusty wind conditions) and touched down further along the runway than normal (almost halfway down the runway). The aircraft skidded along the wet runway and off at its end, coming to a halt with the nose section of the aircraft in the sea, with the main wheels resting on the edge of the embankment leading to the sea.

In this section the frequency of the most important causal factors for landing overruns worldwide are discussed. Table 6 lists these factors for landing overruns as obtained from the data sample. The causal factor data presented in this section is in percentage of all corresponding occurrences with known causes. Corresponding occurrences are the number of landing overruns. Note that one runway excursion typically has more than one factor assigned.

Table 6: Most important causal factors for landing overruns

Landing overruns	
Factor	**Percentage**
Wet/Contaminated runway	58.8%
Long landing	38.9%
Speed too high	19.9%
Incorrect decision to land	16.3%
Aquaplaning	13.8%
Tailwind	13.6%
Late/incorrect use of brakes	11.3%
Late/incorrect use of reverse thrust	11.1%
Too high on approach	6.1%

Runway condition

The most important factor identified is the condition of the runway being wet/contaminated[8]. Such runway conditions are related to a reduction in braking friction between the aircraft tires and the runway compared to a dry runway. Whenever the runway condition wet/contaminated was identified as a factor in an excursion, it was related to a reduction in the runway friction levels. The runway condition (wet/contaminated) itself is not necessarily a causal factor. For instance on a runway with excellent macro- and microtexture[9], the friction levels can be relatively high even if the runway is wet. The

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[8] Contaminated runway: A runway completely or partly covered with standing water (more than 3mm), slush, snow (wet, dry), ice or a combination of these conditions. A runway is considered to be contaminated from a performance point of view if the percentage of the portion intended to be used exceed 25%. However, reporting of contamination could occur before this threshold is reached as is known from operational experience.

[9] The macrotexture encompasses the large-scale roughness of the surface whereas the microtexture is concerned with the

analysed data showed that such occurrences were not limited to airports where wet/contaminated runway operations occurred frequently. Worldwide, approximately 10% of all landings are conducted on a wet/contaminated runway [Van Es, (2005)]. That means that the risk ratio is 13; **hence the risk of a landing overrun is about 13 times higher on a wet/contaminated runway than on a dry runway.**

Crews aware of adverse runway conditions normally account for it when assessing the actual required landing distance. Currently only those operators that fly according to EU-OPS are required to conduct an in-flight assessment of the landing distance using information contained in the operations manual[10]. This assessment should be conducted before commencing an approach to land (see EU-OPS 1.400). This assessment is required to ensure that the landing distance available is sufficient for the specific aircraft, and under the present weather and runway conditions at the airport, to make a safe landing.

There is no simple reason that explains the significant influence of the runway condition in landing overruns. There are several factors that could play a role. Some of the important ones will be discussed now. Aircraft operator manuals can contain landing performance information to account for non-dry runway conditions. The wording used in these operating manuals for describing a particular runway condition is not always aligned with what is reported to the pilots, requiring an interpretation by the crew. The crews are sometimes provided with outdated information or inaccurate information regarding runway conditions and weather in general. Furthermore the methods used to asses the runway condition are not without problems. For instance runway friction devices have been a popular means to determine the braking action of a runway. However many years of research have shown that there is no consistent/reliable correlation between the friction values measured by runway friction devices and the braking friction levels an aircraft can achieve [see e.g. Van Es, Giesberts (2002)]. The “validity’ of the results of operational friction measurements are also limited in time. After a runway friction device is used the conditions on the runway can significantly change and so the measured friction levels change. It is not feasible to use the friction devices frequently during the operational hours of an airport. This can result in the fact that the actual braking action was worse than reported to the pilot based on the friction measurement. There are numerous accident reports that have mentioned these problems[11]. Another popular means to report runway condition is by pilot reports (PIREPS). These are pilot reports of braking action from previous landings. These reports provide the available braking action as perceived by the flight crew. Although these reports are highly appreciated (see e.g. [Comfort et. al., (2010)]) by flight crews they can be misleading. The PIREPS on braking action are affected by the reporting crew’s experience and the aircraft being operated. For instance thrust reversers provide very high deceleration levels irrespective of

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sharpness of the fine grain particles on the individual stone particles of the surface.

[10] FAA recently published Safety Alerts for Operators (SAFO), entitled “Landing Performance Assessments at Time of Arrival (Turbojets)”, The FAA urgently recommends that operators of turbojet airplanes develop procedures for flight crews to assess landing performance based on conditions actually existing at time of arrival, as distinct from conditions presumed at time of dispatch. Those conditions include weather, runway conditions, the airplane’s weight, and braking systems to be used. Once the actual landing distance is determined an additional safety margin of at least 15% should be added to that distance.

[11] See e.g. Statens haverikommission, SHK Report RL 2003:08e, Incident involving aircraft G-FLTA at Arvidsjaur airport, BD County, Sweden, on the 22nd of February 2002.

runway conditions. This can be felt by the pilot as a high braking action leading to false reports on the actual braking action level. Indeed some landing overruns have occurred due to this problem. Also when landing with autobrakes selected the constant level of deceleration generated could provide false indications to the pilots regarding the braking action levels on the runway. Finally the physical description of runway conditions is another means to report runway conditions. Surface condition reports provide an idea of the braking action available. However there are some major drawbacks with surface condition reports. For instance it is not always easy to correctly asses the runway condition by the ground staff. Conditions such as wet snow or slush look very similar to the eye however their impact on braking performance is very different. Along the runway the conditions could be different making it more difficult to report the conditions to the pilot. Another problem is that the conditions on the runway may have changed considerably between the time of the observation of the runway and the actual operation.

Problems with meaningful, consistent, accurate, reliable, and up-to-date information about the runway surface conditions and braking action levels explain to a large extent the strong influence of runway surface condition on landing overruns.

The B747 overran Runway 23L on landing at Dusseldorf. After leaving the runway it impacted the approach lights and ILS installation before coming to rest. The accident happened in darkness (0601L), Wind 330deg./8kt. and visibility 1.5km in snow showers. Runway 23L is 9843 ft in length. The runway braking action shortly before the accident was reported as 'good to medium', however, there was apparently a heavy snow shower just before the aircraft landed and this may have reduced the braking action.

Long landings

Long landings[12] are another important causal factor in landing overruns (see Table 6). Landing performance data provided by the manufacturers (either for dispatch or in-flight methods), assumes that the aircraft touches from a certain distance from the threshold (typically in the order of 1,000 - 1,400 ft.). A long landing is clearly unwanted as it increases the required landing distance. As a consequence the available margin in landing distance reduces. The airborne distance (from threshold to touchdown) is affected by a number of variables including [See Van Es, Van der Geest, (2006)]: speed and height at the threshold, glide path at the threshold, runway slope, amount of floating, speed loss between threshold and touch down, wind along the runway, wing geometry, and flare initiation height. It is important that the aircraft crosses the threshold at the correct height and with the intended glideslope. Excess height at the threshold can increase the landing distance. The same applies when the glideslope is shallower. Some pilots tend to make a so-called duck under manoeuvre when crossing the runway threshold. In this situation the pilot is flying the aircraft below the nominal path with a shallower glideslope. The tendency to do so varies amongst the pilots, aircraft type flown and visual conditions. Such a flying technique can also result in longer landings. During the flare manoeuvre the pilot reduces the rate of descent so that an excessively hard touchdown is avoided. In the execution of the flare the

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[12] There is no common accepted definition of what a long landing (or deep landing) is. Typically, touchdowns of more than 2,000-2,300 ft. from the threshold are considered long landings (Van Es et. al. (2009)]. However sometimes it is related to the available runway length, e.g. 25-33% of the runway length.

pilot relies on his/her experience and judgement. The pilot decides on the moment to initiate the flare and on the amount of elevator input during the flare. On some fly by wire aircraft the flare initiation can be triggered as the fly by wire system begins to reduce the pitch attitude at a predetermined rate when reaching a pre-defined altitude. Consequently, as the speed reduces, the pilot will have to move the stick rearwards to maintain a constant path. The touchdown should follow immediately upon the completion of the flare. However, often the aircraft floats for some time before touchdown. This can take a considerable amount of runway. Deceleration levels during floating can be as much as 5-10 times lower than when braking on the ground [Giesman, (2005)].

The analysed occurrence data showed that 29% of the long landings were in combination with a high speed at the threshold, 14% involved significant tailwind and 9% of the long landing were high over the threshold. Long landings can significantly increase the risk of an overrun [Van Es, (2005)]. Unpublished flight data on day-to-day landings indicated that between 1-2% of all landings are long. Combined with 38.9% share of long landings in landing overruns a risk ratio between 31-63 is calculated. **This means that a long landing increases the risk of a landing overrun by a factor of 31-63**. Combined with other risk factors such as wet/contaminated runways the risk of an overrun increases even more as shown next. The landing overrun data examined showed that in 39% of the landing overruns with a long landing the runway was wet/contaminated. Approximately 10% of all landings are conducted on a wet/contaminated runway [Van Es, (2005)]. Assuming that this number of landings is independent of the number of long landings conducted in day-to-day operations, **it can be estimated that the combination of a wet/contaminated runway and a long landing increases the risk of an overrun with a factor varying between 89 and 178**.

High speed

A speed that was too high was cited 19.9% of landing overruns. The speed flown at the threshold has a dominant influence on the landing distance. Both the airborne distance and ground roll distance increase with the speed at the threshold. If the speed is much higher than the speed assumed for the performance calculations the landing margin will reduce. High speed is a classical factor in unstabilised approaches and if this high speed is continued to the threshold it will influence landing performance.

A METRO III was conducting a ferry flight to Rotterdam Airport (The Netherlands). The aircraft was given runway 24 for landing. The air traffic controller got concerned about the high approach altitude the aircraft was flying. At four nautical miles from touchdown the altitude was approximately 1,600 feet while it should be around 1,200 feet. The air traffic controller asked the crew if they could manage the approach, which was confirmed. The aircraft touched down at about one third of the available runway length with a speed which was 34% higher than the normal landing speed for this aircraft. According to the captain he attempted to stop the aircraft by applying wheel brakes but he had difficulties keeping the aircraft on the centreline. Thrust reverse was applied but this could not prevent that the aircraft ran off the runway. The aircraft was not equipped with an anti-skid system. In a post-incident interview, the captain acknowledged that the approach was not stabilised and he had to nose dive the aircraft to lose altitude.

METRO III Runway excursion event at Rotterdam Airport (December 9, 2005).

Crew decision not to abort landing

The decision to land despite circumstances that indicate not to do so, is another important factor in landing overruns as the data from Table 6 show. The importance of crew decision making to aviation safety has been well known from other types of accidents and incidents. Significant research has been conducted into the crew decision making process and the factors that influence this (e.g. fatigue, poor CRM, get-home-itis). Although factors like fatigue were found in the analysed data sample, none of these factors played a dominant role in landing overruns or in the other excursion types.

Aquaplaning

Aquaplaning (also known as hydroplaning) was reported as a factor in 13.8% of the landing overruns which also corresponded with the number of reported runway conditions standing water or slush in these overruns. When a tire is aquaplaning the footprint of the tire is completely separated from the surface by a film of water. Frictional forces between the tire and the ground are then very low as water cannot develop significant friction forces. The speed at which a tire starts to aquaplane depends on a number of factors such as tire inflation pressure, forward speed of the tire, tire design (radial or cross-ply), etc [Van Es, (2001)]. Friction forces are also needed to get the tire spinning and wheel spin-up can be delayed when landing on flooded runways which can negative outcome on the working of the anti-skid. The anti-skid can prevent wheel lock-up. The tires can become locked if the pilot applies braking before the tires are spinning. As a result the braking forces are significantly lower. **Modern aircraft tires like radial tires can have lower aquaplaning speeds than the older cross-ply tire designs.** This fact is not very well known to the pilot community.

Tailwind

Tailwind is a factor that increases the landing distance (both the airborne as well as the ground roll distance). When the actual tailwind is higher than assumed by the crew, performance calculations will give a too optimistic required landing distance. The combination of a high tailwind with a wet/contaminated runway existed in 53% of all landing overruns in which tailwind was a factor. This is interesting as tailwind limits are normally affected by the runway condition. Most operators for instance do not allow any tailwind operations on contaminated runways.

While inbound to Southampton (UK), the crew of a Cessna Citation had been given the weather as surface wind 040deg./12kt., thunderstorms, the runway is very wet. Ten minutes later they were advised that the visibility was deteriorating - 'now 2,000m., in heavy thunderstorms.' Shortly after this they were advised 'entirely at your discretion you may establish on the ILS localiser for Runway 20 for visual break-off to land on Runway 02.' The captain accepted this offer. He then asked the co-pilot for the surface wind and was told that it was 040deg. but that earlier it had been 020deg./14kt. The flight was then cleared for a visual approach for Runway 02. However, meanwhile, the captain had decided to land on Runway 20 and told the co-pilot this. He later reported that he had decided to land on this runway because he could see the weather at the other end of the runway appeared 'very black' and he had mentally estimated that the tailwind component would be about 10kt. (the operating Manual gives a maximum tailwind component of 10kt.) The co-pilot then advised ATC that they would be landing on Runway 20. The controller replied 'you'll be landing with a fifteen knot tailwind component on a very wet runway.' This message was immediately acknowledged by the co-pilot with the words 'roger, copied, thank you.' However, the co-pilot made no comment to the captain about the tailwind component and did not raise the question of continuing to land on Runway 20 with him. The aircraft touched down normally and within 5kt. of the target speed but, given the tailwind and the wet runway, it was not possible to stop it on the remaining runway length and the aircraft overran the end of the runway. After coming to rest the aircraft caught fire and was destroyed.

Use of brakes and reverse thrust

Late or incorrect use of brakes and reverse thrust was a causal factor in 22.4% of all landing overruns. Landing performance calculation methods assume the proper and timely use of brakes and/or reversers[13]. Deviating from this can significantly reduce the margin that exists between available and required runway length during the landing. The share of late or incorrect use of reverse thrust is actually somewhat higher because not all aircraft in the data sample have the possibility of reversing the thrust. Note that some aircraft are only capable of selecting idle reverser due to problems with rudder effectiveness or structural issues. The timely and correct use of reverse thrust is especially important on slippery

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[13] For dispatch calculations thrust reversers are not considered. However for in-flight landing performance calculations reverser thrust may be used.

runways. Reverse thrust is a very effective stopping device independent of runway conditions.

4.2 Landing veeroffs

A Canadair Regional Jet landed on runway 15 at Fredericton, New Brunswick, Canada. About six minutes before touchdown, the flight crew received the following runway surface condition report: runway 15/33 100-foot centre line, 60% bare and wet, 20% light slush and 20% light snow, outside the centre line one inch of slush and snow mixed. Two minutes before touchdown, the wind was reported to the flight crew as 060° magnetic at 10 knots. Since it was still snowing when the aircraft landed, runway contamination at touchdown would have been greater than reported in the report that was passed to the flight crew. During the after-landing roll, at low speed (40 kt. IAS), the aircraft yawed left. The loss of directional control was initiated by the left crosswind and the slippery runway surface condition. To counteract the yaw, the pilot flying reduced reverse thrust and then stowed the reversers on both engines, while braking and maintaining full right rudder. The reversers were unintentionally stowed before the engines had spooled down to idle reverse. As a result, the aircraft transitioned to forward thrust with a higher than idle thrust setting. The aircraft exited the runway about 5,500 feet beyond the threshold. The aircraft came to a stop when its nose gear sunk into the soft ground adjacent to the runway surface.

The aircraft's maximum demonstrated crosswind component for landing or taking off is 24 knots, which is not considered to be limiting (dry runway). The operator's Airplane Operating Manual (AOM) states that another runway should be considered when the crosswind on a wet or slippery runway exceeds 15 knots. The crosswind component was 10 knots when the aircraft landed. During the investigation, landings were carried out in the flight simulator, with wind and runway conditions approximating those that existed at the time of the occurrence. The left veer off the runway **could not** be duplicated in the simulator.

In this section the frequency of the most important causal factors for landing veeroffs worldwide are discussed. The causal factor data presented in this section is in percentage of all corresponding occurrences with known causes. Corresponding occurrences are the number of landing veeroffs. Note that one runway excursion typically has more than one factor assigned. The most important causal factors in landing veeroffs that occurred worldwide are listed in Table 7.

Table 7: Most important causal factors for landing veeroffs

Landing veeroffs	
Factor	**Percentage**
Wet/Contaminated runway	36.9%
Crosswind	26.2%
Aircraft directional control not maintained	13.9%
Hard landing	12.1%
Nose wheel steering issues	10.1%
Tire failure	6.4%
Landing gear collapsed	6.2%

Runway condition and crosswind

Wet/contaminated runways and crosswind appear to be dominating causal factors. Crosswinds exceeding the capabilities of the aircraft[14] or inadequate compensation by the pilots (see the factor Aircraft directional control not maintained in Table 7) are the reasons for the influence of this factor. The crosswinds during the landing veeroffs analysed in this study varied between minor to strong. In none of the cases analysed in this study the involved aircraft had hard limits regarding the crosswind during landings. In 36% of the landing veeroffs in which crosswind was cited as a causal factor the runway was also wet/contaminated. Analyses of operational data has shown that crosswinds of more than 10 kts. occurred during 15% of all operational landings. Approximately 10% of all landings are conducted on a wet/contaminated runway [Van Es, (2005)]. Assuming that this number of landings is independent of the number of crosswind operations conducted in day-to-day operations, it can be estimated that the **combination of a wet/contaminated runway and a minor to strong crosswind increases the risk of a veeroff with a factor of 7.** Controllability problems during crosswind landings on slippery runways is a well-known issue described in many older studies [Cobb & Horne (1964)].

Only crosswind operations on dry runway conditions are certified. Aircraft manufacturers only give advisory information on crosswind limits for wet/contaminated runways[15]. These advisory crosswinds are often based on engineering models assuming steady (not gusting) wind or piloted simulations combined with engineering analyses. Normally flight tests are not conducted. Engineering simulators or engineering models are not a good tool to explore

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[14] During the combined aircraft braked and yawed rolling (as present in a crosswind landing roll), the braking friction coefficient peak decreases in magnitude and shifts to higher wheel slip ratios as yaw angle increases. This would require an increasing wheel slip ratio as the aircraft yaws in order to maximise aircraft stopping performance. On the other hand, maintenance of maximum tire cornering capability for aircraft directional control requires wheel motion at low slip ratios. Only at low aircraft yaw angles do the aircraft tire requirements merge so that antiskid controls can perform an effective job of preserving both tire braking and cornering capability for aircraft stopping and directional performance. These effects are more critical on wet/contaminated runways on which lower cornering forces can be generated by the tires than on dry runways.

[15] A flight test program devised to explore the limits of aircraft crosswind performance under slippery runway conditions results in placing the safety of both aircraft and flight crew in jeopardy. It is therefore unfeasible to require such tests.

the ground part of a landing or takeoff; this is because the quality of the mathematical ground model in combination with the motion and visual cues of a simulator is usually not high enough to allow sufficient confidence in the evaluation of the results. Therefore limits based on pilot evaluations in a simulator may prove significantly different (optimistic in most cases) from realistic values. This also applies to engineering simulations which uses the same mathematical models as the flight simulators. Because the crosswind limits on wet and contaminated runways are advisory information only, operators can use different crosswind limits for the same aircraft and runway condition. The crosswinds for dry runways are certified. However, there are a number of issues related to these certified crosswinds [Van Es et. al. (2001), Van Es (2006)] such as unclear means of compliance of crosswind certification and wind reporting inaccuracies. Furthermore the certification often gives demonstrated crosswinds rather than crosswind limits. This means that during the certification flights no crosswind was found that was considered limiting for a dry runway. All these above mentioned issues could play a role in the relatively high number of crosswind related veeroffs during landing as found in this study.

An A300-600 made a normal landing on Runway 26L at Charles de Gaulle Airport (France) under gusty windy conditions (190deg/31kt G43). As the aircraft slowed through about 90kt following the cancellation of reverse thrust, it began to drift to the left. The pilot attempted to bring it back to the runway centreline using rudder and differential braking but without success and it ran off the side of the runway at 70kt. After leaving the runway the nose wheel began to dig in the soft ground and it became bogged down. During the landing roll the actual crosswind exceeded the demonstrated value. The investigators concluded that directional control was lost due to sudden increase in crosswind at a speed at which the rudder was no longer effective to counteract the weathervane effect caused by the wind. The investigators concluded also that although the demonstrated crosswind for the A300-600 was not a limit, exceeding this value should be done with great care.

Hard landings and Gear Collapses

Another important causal factor in landing veeroffs is hard landings. These are typically associated with improper flare (late or no flare execution), too high rate of descent, and/or adverse weather conditions. Unpublished occurrence data indicated that on average 0.02% of all landings were classified as hard landings. This means that the risk ratio associated with a hard landing is 690; **hence the risk of a veeroff after a hard landing is 690 times higher than with a normal touchdown**. Hard landings can result in the aircraft bouncing which if not controlled can result in a veeroff. The hard landing itself can also result in a gear collapse. Indeed 48% of landing gear collapses that resulted in a veeroff were related to a hard landing. The remainder of the landing gear collapses were related to mechanical or maintenance issues. Note that such gear collapses occur often and do not necessarily end up in a veeroff.

A Beech 1900D aborted the landing while approaching Samedan Switzerland after the crew did not receive the green indication for the nose gear. The crew performed a low approach to have the tower inspect the landing gear. The tower reported, that all gear struts appeared to be in their correct positions. The crew of the Beech, assuming it was an indication problem, attempted to replace the light bulb of the nose gear indication light, but were unable to do so. Still assuming, that the nose gear was down and locked, the crew decided to land on Samedan's runway 21. The airplane bounced slightly and touched down a second time 180 meters past the first touch down point. The nose gear began to slowly retract and the airplane veered left off the runway, the nose gear retracted fully while the airplane went over the grass adjacent to the runway causing the tips of the propellers to strike the ground destroying the propellers. The airplane subsequently impacted a wall of snow. No injuries occurred, the aircraft received substantial damage.

Nose wheel steering issues

EMB-145 veered off the runway after landing due to nose wheel steering problems (23-9-2003, Luxembourg).

Another important factor in landing veeroffs is nose wheel steering issues. There are several reasons for the nose wheel steering issues however improper maintenance seems the more dominant and also the incorrect use of the steering system[16]. There are a number of ways directional control can be maintained on the ground: rudder deflection (through the rudder pedals), nose wheel steering (through the rudder pedals and/or the nose wheel steering

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[16] Current data sample is too low to justify this as a hard conclusion.

control handle or "tiller"), differential braking and/or through differential (reverse) thrust. However, during a normal landing roll in which the aircraft is decelerated, only the rudder pedals are normally used to steer the aircraft on the runway centreline. The rudder pedals deflect the rudder and, once the nose wheel is on the ground, have limited authority over the nose wheel deflection (a maximum of 5 to 7 degrees nose wheel deflection with maximum rudder pedal deflection is a common value). At lower speeds the rudder becomes ineffective and the tiller is then used e.g. for exiting the runway, for turns during taxiing and for apron movements. The tiller can command a much larger nose wheel deflection than the rudder pedals can (up to 65-75 degrees nose wheel deflection for full tiller deflection is a normal value). Flight crews are advised not to use the nose wheel steering tiller until reaching taxi speed. The use of the nose wheel steering tiller at higher speeds can introduce directional control problems[17]. If the aircraft track deviates from the runway centreline during landing ground roll there are a number of standard actions that can be taken by the flight crew to regain control. The pilot must reduce reverse thrust to reverse idle (if reverse thrust was selected) or even to forward idle, release the (auto-) brakes, use rudder pedals and if necessary use differential braking to correct back to the runway centreline. When re-established and re-aligned on the runway centreline, the pilot should resume normal braking techniques by applying brakes and reverse thrust as required. Figure 6 illustrates how rudder, differential braking and nose wheel steering influence the directional control as function of ground speed from touchdown to a full stop.

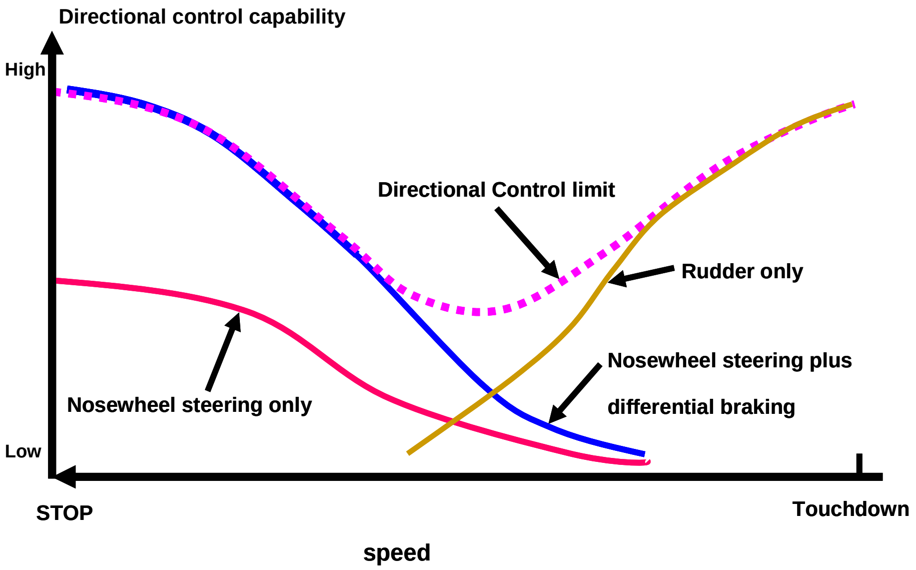

Figure 6: Influence of nose wheel steering, differential braking, and rudder on ground directional control.

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[17] On for instance the Airbus aircraft tiller authority in terms of maximum steering angle is progressively reduced above a groundspeed of around 40kts (to avoid usually unsuccessful attempts of correcting aircraft path with the tiller at high speed), and rudder pedals authority is progressively reduced above 100kts of ground speed (to avoid excessive inputs at high speed).

4.3 Takeoff overruns

A B747-200F took off from runway 20 of Brussels Airport. The initial phase of the take-off run occurred normally. Four seconds after the aircraft reached V1, there was a loud bang, followed by a loss of power from the engine. Two seconds later (six seconds past V1, at V1+12 knots) the crew attempted to abort the take-off. The thrust levers were brought back to idle and braking action was initiated. The thrust reversers were not deployed. The accident investigation could not determine if the spoilers were deployed or not. The aircraft failed to stop in the remaining runway length, travelling 300m beyond the end. The aircraft broke up and was destroyed. The take-off performances were computed for a "wet" runway. Upon lining up, the crew saw the runway, and "it looked dry" to them. The state of the runway may have given the crew the impression they had a better takeoff margin than originally computed. The investigation showed that the aircraft experienced a stall in its inboard right-hand engine after it ingested a kestrel during the take-off roll. It was concluded that the accident was caused by the decision of the crew to abort the takeoff above V1. Contributing factors were amongst others the less than maximum use of deceleration devices and the fact the aircraft lined up at the B1 intersection although the take-off performance was computed assuming the full length of the runway.

Overrun of a B747-200 after a high speed rejected takeoff (Brussels Airport, 25-May-2008).

In this section the frequency of the most important causal factors for takeoff overruns worldwide are discussed. The causal factor data presented in this section is in percentage of all corresponding occurrences with known causes. Corresponding occurrences are the number of takeoff overruns. Note that one runway excursion typically has more than one factor assigned.

Table 8: Most important causal factors for takeoff overruns

Takeoff overruns	
Factor	**Percentage**
Abort/reject - After V1	40.8%
Wet/Contaminated runway	14.2%
Tire failure	12.5%
Takeoff mass too high/incorrect	10.8%
Late/incorrect use of brakes	4.2%

Aborts above V1

In Table 8 the most important causal factors related to takeoff overruns that occurred worldwide are listed. Examination of the list clearly shows that aborting the takeoff above the speed V1[18] is the most important and dominant factor. A pilot may decide to abort a takeoff above V1 only if it is unsafe to continue the flight. The data showed that these involved mainly jet aircraft accounting for 81.6% of all aborts after V1. However this high share is explained by the high utilisation of the jet aircraft in the data sample; jet aircraft accounted for 70% of all takeoffs in the period examined in this study. Wet/contaminated runways and late /incorrect use of brakes also played some role in the aborted takeoffs above V1. A significant part (50%) of the high speed rejected takeoffs above V1 was unwarranted (see also [Van Es, (2010)]. That means that it was not unsafe to fly and the takeoff should have continued.

Wrong takeoff mass

The use of a wrong takeoff mass can result in incorrect V speeds (in particular the rotation speed VR is important). If the assumed takeoff mass used for calculating VR is too low the pilot will rotate at a too low a speed. This can result in the inability to rotate and the pilot could then decide to abort. Incorrect takeoff mass has recently drawn much attention due to the use of electronic means (e.g. laptops and electronic flight bags) to calculate takeoff performance. The current data show that even before the introduction of these means such errors (wrong takeoff mass) were not uncommon. In recent years, accident investigation authorities have investigated several incidents involving incorrect takeoff calculations or errors in the basic data. The investigation authorities have called for regulators to develop safeguards to prevent take-off performance miscalculations. An analysis by IATA also indicated that the rate of incidents involving calculation/Input errors during takeoff is increasing for the last 4 years [IATA, (2009)]. Currently the industry (e.g. aircraft manufacturers, operators) are considering how to address these problems. Wrong takeoff mass can also result in other accident types such as tail strikes.

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[18] V1 has been referred to amongst others as the critical engine failure speed, the engine failure recognition speed, and the takeoff decision speed. To the pilot V1 represents the minimum speed from which the takeoff can be safely continued following an engine failure within the takeoff distance shown in the aircraft flight manual AFM, and the maximum speed from which the aircraft can be stopped within the accelerate-stop distance shown in the AFM. These definitions are not restrictive as other definitions may be outlined in the AFM of a particular aircraft model.

4.4 Takeoff veeroffs

The captain initiated a takeoff on runway 4L with B747-100 at JFK Airport. The runway was covered with patches of ice and snow. The wind was from 330 degrees at 11 knots. Before receiving an 80-knot call from the 1st officer, the airplane began to veer to the left. Subsequently, it went off the left side of the runway and collided with signs and an electric transformer. Investigation revealed evidence that the captain had overcontrolled the nose wheel steering through the tiller, then applied insufficient or untimely right rudder inputs to recover. The captain abandoned an attempt to reject the takeoff, at least temporarily, by restoring forward thrust before the airplane departed the runway. The National Transportation Safety Board determines the probable cause(s) of this accident as follows: the captain's failure to reject the takeoff in a timely manner when excessive nose wheel steering tiller inputs resulted in a loss of directional control on a slippery runway. Inadequate Boeing 747 slippery runway operating procedures developed by Tower Air, Inc., and the Boeing Commercial Airplane Group and the inadequate fidelity of B-747 flight training simulators for slippery runway operations contributed to the cause of this accident. The captain's reapplication of forward thrust before the airplane departed the left side of the runway contributed to the severity of the runway excursion and damage to the airplane.

In this section the frequency of the most important causal factors for takeoff veeroffs worldwide are discussed. The causal factor data presented in this section is in percentage of all corresponding occurrences with known causes. Corresponding occurrences are e.g. the number of takeoff veeroffs. Note that one runway excursion typically has more than one factor assigned.

Table 9: Most important causal factors for takeoff veeroffs.

Takeoff veeroffs	
Factor	**Percentage**
Wet/Contaminated runway	41.3%
Aircraft directional control not maintained	33.9%
Crosswind	18.3%
Nose wheel steering issues	17.4%
Asymmetric power	9.2%

Runway conditions and directional control

Table 9 shows the most important causal factors associated with takeoff veeroffs. Again runway condition is in the top of the list. The wet/contaminated runway factor is often related with other factors such as crosswind (30%) and problems in maintaining direction control (45%). These factors can partly be related to the fact that nose wheel steering should not be used above speeds in the order of 20-30 kts and that the rudder is usually not effective below speeds in the order of 50-60 kts. This leaves a gap between 20-60 kts where is less easy to maintain directional control especially during takeoffs with crosswind and on slippery runways. Indeed a number of takeoff veeroffs occurred in this speed range[19]. However at higher speed controllability problems also occurred especially in crosswind conditions.

Crosswind

Analyses of operational data has shown that minor (more than 10 kts) or stronger crosswinds occur during 15% of all operational takeoffs. This means that the risk ratio of minor or stronger crosswinds is 1.3. Combined with other risk factors such as slippery runways the risk of a veeroff increases. The takeoff veeroff data examined showed that for 12.4% of the veeroffs on a wet/contaminated runway there was a minor to strong crosswind. Approximately 10% of all takeoffs are conducted on a wet/contaminated runway [Van Es, (2005)]. Assuming that this number of takeoffs is independent of the number of crosswind operations conducted in day-to-day operations, it can be estimated that the **combination of a wet/contaminated runway and a minor to strong crosswind increases the risk of a veeroff with a factor of 9.**

The crosswinds during the takeoff veeroffs analysed in this study varied between minor to strong (some exceeding demonstrated values). In none of the cases analysed in this study the involved aircraft had hard limits regarding the crosswind during takeoffs[20]. Only crosswind operations on dry runway conditions are certified. Aircraft manufacturers only give advisory information on crosswind limits for wet/contaminated runways [21]. These advisory crosswinds are often based on engineering models assuming steady (not gusting) wind or piloted simulations combined with engineering analyses. Normally flight tests are not conducted. Engineering simulators or engineering models are not a good tool to explore the ground part of a landing or takeoff. This because the quality of the mathematical ground model in combination with the motion and visual cues of a simulator is usually not high enough to allow sufficient confidence in the evaluation of the results. Therefore limits based on pilot evaluations in a simulator may prove significantly different (optimistic in most cases) from realistic values. This also applies to engineering simulations which uses the same mathematical models as the flight simulators. Because the crosswind limits on wet and contaminated runways are advisory information only, operators can use different crosswind limits for the same aircraft and runway condition. The crosswinds for dry runways are certified. However, there are a number of issues related to these certified crosswinds [Van Es et. al. (2001), Van Es (2006)] such as unclear means of compliance of crosswind certification and wind reporting inaccuracies. Furthermore the certification often gives demonstrated crosswinds rather than crosswind limits. This means that during the certification flights no

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[19] The exact speed at which the aircraft started to deviate was not always known.

[20] Operators can define hard limits themselves often based on the maximum demonstrated crosswinds.

[21] A flight test program devised to explore the limits of aircraft crosswind performance under slippery runway conditions results in placing the safety of both aircraft and flight crew in jeopardy. It is therefore unfeasible to require such tests.

crosswind was found that was considered limiting for a dry runway. All these above mentioned issues could play a role in the relatively high number of crosswind related veeroffs during landing as found in this study.

> The 208 CARAVAN Iwas departing on a scheduled commuter flight. The runway surface had areas of packed snow and ice. A right crosswind was estimated between 15 to 25 knots. About 300 feet after beginning the takeoff roll, between 30 to 50 knots airspeed, the aircraft began to drift to the left, which the pilot was unable to correct. The aircraft departed off the left side of the runway and nosed over. The maximum demonstrated crosswind velocity, takeoff or landing, was 20 knots for this aircraft. Cause: The pilot's inadequate planning and decision to initiate a takeoff into a crosswind that exceeded the demonstrated crosswind component, which resulted in a loss of directional control during the takeoff roll, and subsequent collision with terrain and nose over. Factors contributing to the accident were the crosswind, an icy runway, and the pilot's failure to abort the takeoff.

Nose wheel steering

Nose wheel steering issues are an important causal factor in takeoff veeroffs. The nose wheel steering issues were typically related to malfunctions (30%) or improper use (70%). Pilots must use caution when using the nose wheel steering wheel above 20-30 kts to avoid overcontrolling the nose wheels resulting in possible loss of directional control. This seems to be the most important issue of nose wheel steering related veeroffs during takeoff.

> The B747 initiated a takeoff on a runway which was covered with patches of ice and snow. Before receiving an 80-knot call from the 1st officer, the airplane began to veer to the left. Subsequently, it went off the left side of the runway and collided with signs and an electric transformer. Investigation revealed evidence that the captain had overcontrolled the nosewheel steering through the tiller, then applied insufficient or untimely right rudder inputs to effect a recovery. The captain abandoned an attempt to reject the takeoff, at least temporarily, by restoring forward thrust before the airplane departed the runway.

Asymmetric thrust

Asymmetric thrust is another factor contributing to takeoff veeroffs. Maintaining directional control with asymmetrical thrust can be difficult particularly below certain speeds[22]. Most of the identified events occur at low speeds. Moving throttles to takeoff thrust from asymmetrical thrust at a low power setting can result in significant thrust differences at high power. Therefore pilots should monitor the symmetric build up of power on the engines when applying initial power. Typically the pilots of jet aircraft should advance the thrust levers to just above idle and allow the engines to stabilize momentarily then promptly

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[22] Regulations for large aircraft require the establishment of a minimum control speed on the ground (Vmcg). Vmcg is the calibrated airspeed during the takeoff run at which, when the critical engine is suddenly made inoperative, it is possible to maintain control of the aircraft using the rudder control alone (without the use of nosewheel steering), as limited by 150 pounds of force, and the lateral control to the extent of keeping the wings level to enable the takeoff to be safely continued using normal piloting skill. In the determination of Vmcg, assuming that the path of the airplane accelerating with all engines operating is along the centreline of the runway, its path from the point at which the critical engine is made inoperative to the point at which recovery to a direction parallel to the centreline is completed may not deviate more than 30 feet laterally from the centreline at any point. Vmcg is only determined for dry runways.

advance the thrust levers to takeoff thrust. Asymmetric thrust conditions are particular hazardous in combination with slippery runways however they also occur on dry runways.

The PIC of a B737-800 pressed the TO/GA button to set take-off power when the aircraft was turning onto the runway and still 30 degrees short of the runway heading. The left engine N1 was at 41% RPM and the right engine N1 was at 24% RPM at this time with no stabilisation in engine acceleration at 40%. During this period, the copilot did not observe the engine settings. The thrust levers then moved forward equally toward the take-off thrust setting. However, engine thrust increased more rapidly on the left engine as it had the higher initial N1, and the aircraft continued turning to the right. The PIC applied maximum left rudder input, but was unable to prevent the aircraft from turning past the runway heading. The left engine N1 had reached the take-off setting of 98% RPM and the right engine N1 a maximum of 64% RPM. The aircraft departed runway. The PIC reported that he was not aware of an increasing thrust asymmetry at this time and considered that his difficulty in maintaining directional control was a problem with the nose-wheel steering.

4.5 Role of ATC in runway excursions

From the analysed runway excursions data it became clear that the direct role of Air Traffic Control in runway excursions was relatively small. There were only a limited number of reports in which ATC was actually identified as one of the causal factors leading to an occurrence, in particular the provision of incorrect or late information to the pilot regarding the weather and runway condition. However the role of ATC can be larger than indicated by the data when looking at the number of runway excursions related to unstabilised approaches (high speed and or high over the threshold) and cross-/ tailwind e.g. poor vectoring of the aircraft could result in unstabilised approaches. Airspace design can also increase the likelihood of unstable approaches e.g. tight turn onto base leg of final approach, airspace design that requires tight turns in short timeframe etc. Offering wet/contaminated runways with high cross and or tailwind could increase the risk of runway excursions. It is the pilot’s final responsibility to decide to land the aircraft given the wind & runway conditions, or to recognise an unstable approach. However ATC’s awareness of these risks when assigning runways under critical weather conditions, when vectoring aircraft, and when designing approach procedures is desirable.

LANDING ON THE 3800 FT STRIP THE PILOT LOST DIRECTIONAL CONTROL. THE AIRCRAFT SLID OFF THE SIDE OF THE RUNWAY 160 FT FROM THE END AND COLLAPSED THE NOSE GEAR. PRIOR TO LANDING THE PILOT WAS GIVEN INCORRECT WIND INFORMATION AND HE LANDED WITH A 20 KT TAILWIND COMPONENT. ADDITIONALLY THE RUNWAY CONDITION WAS REPORTED TO BE "GOOD", WHICH THE CONSOLE OPERATORS ASSUMED WOULD BE INTERPRETED BY PILOTS TO MEAN "ICY" DURING THE WINTER MONTHS.

4.6 Comparison of results from other studies

There have been previous studies into runway excursions. The results of some of these studies are briefly presented here and differences with the current study are explained.

4.6.1 Australian Transport Safety Board study

The Australian Transport Safety Board (ATSB) study was limited to runway excursions during landing that occurred with commercial jet aircraft between 1998 and 2007 worldwide [Taylor et.al., (2009)]. ATSB conducted a search of the Ascend World Aircraft Accident Summary (WAAS) which identified 120 landing runway excursion accidents. An in-depth analysis of those 120 accidents was conducted using the narrative information provided in de WAAS database in order to identify the types of flight crew technique and decision-related, flight crew performance-related, weather-related, and systems-related factors that contribute to landing runway excursions. Each accident was analysed to determine probable risk factors. A comparison of the results of the present study with the ATSB study showed very similar top factors that contributed to landing runway excursions. Due to the limited sample used in the ATSB study a comparison of the percentage of a particular factor is not easy and could lead to incorrect conclusions. The use of a limited data sample makes some of the conclusions made in the ATSB study somewhat questionable. Another drawback of the ATSB study is that it partly relied on narrative data from the Ascend WAAS database. Although the quality of the data from Ascend is generally speaking good, these narratives do not always provide a complete picture regarding causal factors. Some factors could therefore be underreported (e.g. crosswind and tailwind seemed to be under reported in the ATSB study). Also some level of subjectivity cannot be ruled out in the assignment of factors based on these narrative data. The present study made use of a much larger data sample and used official AIB/CAA coded reports only.

4.6.2 Flight Safety Foundation study

The Flight Safety Foundation FSF recently completed a study on runway excursions reported in the Runway Excursion Risk Reduction Toolkit [IATA/FSF, (2009)]. The FSF analysed data from commercial aircraft and business jets for the period 1995-2008. The data sample comprised of 536 runway excursions (57 in Europe). FSF used different data sources varying from complete accident reports produced by AIBs to narrative information obtained from the Internet (e.g. ASN), or from insurance claims databases like WAAS. Almost half of the analysed runway excursions in the FSF sample were obtained from the last two sources. As with the ATSB study, a drawback of the FSF study is that it partly relied on narrative data from the Ascend WAAS database and also from information obtained from ASN (Internet). The narratives from these sources do not always provide a complete picture regarding causal factors. Some factors could therefore be underreported in the FSF study. Also some level of subjectivity cannot be ruled out in the assignment of factors based on these narrative data. A comparison of the results of the present study with the FSF study showed similar factors that contributed to runway excursions. However, for instance factors like runway condition, crosswind and tailwind seemed to be underreported in the FSF study when compared to the results in the present study. As the FSF study only had 57 excursions that occurred in Europe a meaningful comparison of the excursions that occurred in Europe with the rest of the world was not possible (nor published in the FSF report).

4.6.3 Boeing study on rejected takeoffs

Boeing made a study on rejected takeoff accidents [(Elliott et. al., (2000), and Root, (2002)]. The time frame of the data analysed was 1959-1999 and it concerned large western-built jet aircraft only. This makes a comparison with the present study somewhat difficult as there is large difference in the type of aircraft and time frame considered. Nevertheless, when doing so it became clear that the Boeing data confirms the significant influence of the causal factor "abort above V1" as identified in this study for takeoff overruns.

4.6.4 NLR study on landing overruns

In 2005 a study was conducted on landing overruns by National Aerospace Laboratory NLR [Van Es, (2005)]. Landing overrun accidents of commercial transport aircraft that took place during the last 35 years were analysed. A total of 400 accidents were identified and analysed. The NLR study considered commercial transports only whereas the present study also included business operations. It was found in the NLR study that on a worldwide basis, there appears to be a significant increase in landing overrun risk when one of the following factors is present during a landing: Non-precision approach, touching down far beyond the threshold (long landing), excess approach speed, visual approach, significant tailwind present, high on approach, wet/flooded runway, and/or snow/ice/slush covered runway. The highest risk increase occurred when the aircraft touched down far beyond the threshold (long landing), followed by excess approach speed. These findings are similar to the results of the present study for landing overruns.

4.6.5 EASA study on runway friction

EASA carried out a study on runway friction characteristics measurement and aircraft braking in 2008-2009 [Comfort et. al. (2009)]. The overall objective of the EASA study was to provide recommendations regarding the assessment of runway friction characteristics and runway condition reporting. Main findings from this study are that:

- A common semantic is necessary to report runway conditions across all aviation domains;
- ICAO Annex 14 needs urgent amendment;
- Friction measuring devices are only one of the tools available to assess runway conditions;
- Training of aerodrome staff is also important;
- The issue of planning pavement maintenance (e.g. "slippery when wet") has to be decoupled from operational risk of runway excursions.

These findings are support by the findings of the present study regarding the issues with runway condition and aircraft braking friction.

4.7 General aviation

The present study was limited to commercial and business operations. Commercial operations cover all types of scheduled and non-scheduled revenue flights. It also covers all ferry/positioning and training/check flight conducted by commercial operators. It should be noted that the type of operation is not related to the type of aircraft. Business flights fall under the general aviation category in the ECCAIRS taxonomy. General aviation operations are those other than a commercial air transport operation and cover a wide variety of operations (e.g. business, pleasure, flight training/instructional, air shows, demonstration flights, ect.). The type of aircraft involved in general aviation also varies significantly. Complete records for general aviation accidents/incidents are difficult to obtain. Especially information regarding accidents/incidents for smaller aircraft (e.g. single engine piston aircraft) is incomplete and often very limited regarding the causes[23]. Also a lot of the general aviation type of operation is done at less equipped and prepared airports (e.g. grass runways). Therefore in the present study only business operations were considered from the general aviation operations category. However, a quick scan of available reports on general aviation runway excursion suggested that the causal factors looked similar to the ones identified in this study for commercial and business operations.

The pilot of a Cessna 182 reported that while en route on the cross-country flight he observed the alternator's voltage degrading, which prompted him to divert to an alternate airport. The pilot stated that he was "hot and fast" on final approach, which resulted in the airplane touching down long and overrunning the end of the runway. The airplane subsequently impacted a fence before coming to rest upright. An examination of the airplane by a certificated FAA airframe and powerplant mechanic confirmed that the airplane had sustained substantial damage to its left wing and aft fuselage area.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows: The pilot's misjudgement of distance/speed and his failure to attain the proper touchdown point during landing, which resulted in a runway overrun during the landing roll.

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[23] However the US NTSB is an exception to this observation. The public database of the NTSB gives a very complete record of accidents with smaller piston type GA aircraft that occurred in the US. The ATSB of Australia, AAIB UK and TSB of Canada also have good public records in GA aircraft.

CHAPTER 5 –Preventive measures

5.1 Introduction

Based on the results from the analysis presented in the previous section, preventing actions were defined for minimising the likelihood of excursions. In particular measures and actions were formulated which apply to the European situation. Existing and proposed technology was considered in this work as well as existing action plans and training aids.

The study results were presented to and discussed with expert groups and representatives of professional groups such as (but not limited to) European Cockpit Association (ECA), International Federation of Air Traffic Controllers' Associations (IFATCA), and Airports Council International (ACI Europe). Also comments were obtained from aircraft manufacturers (Airbus, Boeing and Embraer) that reviewed the report.

The outcome of the discussions with the experts, professional associations and industry was used to refine the recommendations on preventive actions.

5.2 Landing overruns

5.2.1 Long landings

A long landing is an important factor that increases the risk of a landing overrun. It is not easy to identify the exact reasons of pilots to make long landings. A correct landing in the touchdown zone is part of the basic flying skills of a pilot. It has been suggested that pilots make long landings when a runway is very long and the exits are near the end of the runway. However, analysis of flight data did not give consistent results to support this thought. Some (unpublished) flight data did show a correlation between airborne distance and runway length while other flight data did not. Pilots should be made aware of the risks of landing long on a runway. Pilots should always aim to land within the assigned touchdown zone (for every landing even on runways that are very long, or if it could help runway capacity) and should conduct ‘firm’ landings to avoid possible floating[24]. If a landing cannot be assured within the predetermined touchdown zone and the conditions (slippery, short runway, tailwind etc.) are critical the best option seem to be to go-around. However, it is realised that a go-around at low attitude is an untrained manoeuvre. In the case where such action is required, pilots should be aware that ground contact is likely and any attempt to commence a climb before the engines have achieved go-around thrust may result in a stall especially on turbofan engined aircraft. There can also be a reluctance to discontinue the approach at altitude especially after the flare. As go-arounds after flare initiation are normally not trained, the level of confidence and skill for the manoeuvre may be lacking. Furthermore it is not taken into account when determining the obstacle free zones that an aircraft lands long and hence it can no longer be guaranteed that a collision with an obstacle will not occur.

Pilots should be made aware of the risks of making long landings.

Pilots should always aim to land within the assigned touchdown zone (for every landing even on runways that are very long, or if it could help runway capacity to land longer) and should avoid ‘soft’ landings. Airlines should have standard operating procedures that outline procedures for the flare and touchdown to ensure a landing in the touchdown zone.

Pilot should be trained for making go-arounds at low altitude with the thrust/power lever at or near idle.

Runway touchdown markings can be of great help to the pilot to avoid a long landing. However these touchdown markings should be designed according to the appropriate standards (ICAO ANNEX 14) in order to avoid confusion and to be effective.

Aerodromes should have touchdown markings according to ICAO provisions.

5.2.2 Landing performance assessment

Currently only those operators that fly according to EU-OPS are actually required to conduct an in-flight assessment of the landing distance using information contained in the operations manual. This assessment should be conducted before commencing an approach to land (see EU-OPS 1.400). This assessment is required to ensure that the landing distance available is sufficient for the specific aircraft, and under the present weather and runway conditions at the airport, to make a safe landing. According to EU-OPS the assessment should be made with regard to the performance information contained in the Operations Manual.

There is however no requirement in EU-OPS for any safety factor that should be applied to this assessment. Some commercial operators have therefore introduced safety margins by

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[24] Firm landings also promote wheel spin-up which is needed for the proper functioning of the anti-skid system.

themselves which are expressed in a fixed distance increment or a percentage increase beyond the actual landing distance required. Such safety margins are applied to the unfactored landing performance data of the aircraft. Examples of such factors are a 15% increase of the calculated (actual) landing distance, or a fixed margin of 200 meters between the calculated distance and the landing distance available. The use of such margins is highly recommended to account for deviations from the normal landing (e.g. faster, longer landings etc.). The information regarding landing performance contained in the operations manual is normally not certified and is advisory only. Furthermore this information is not always provided in the aircraft operations manual (especially for executive jet type of aircraft). This leaves the crew with only landing distance data from the certified aircraft flight manual which is not representative for actual landings and should only be used for dispatch calculations with the appropriated dispatch factors[25].

It is recommended that operators always conduct an in-flight assessment of the landing performance prior to landing using realistic landing performance data provided by the aircraft manufacturers and also apply a safety margin to these results.

It is recommended that operators always conduct an in-flight assessment of the landing performance prior to landing using realistic landing performance data and also apply a safety margin to these results. This recommendation is **not** limited to jet aircraft, to EU-OPS operators or to JAR/FAR/CS 25 certified aircraft only.

Although many commercial aircraft manufacturers do provide information for in-flight assessment of the landing distance not all manufacturers do so. It is therefore recommended that all aircraft manufacturers should provide information for an in-flight assessment of the landing performance based on assumptions reflecting the day-to-day operation.

5.2.3 Use of available stopping devices

To stop the aircraft the pilot should use all means available in an effective and timely manner. These include the use of reverse thrust (incl. propeller reverse), airbrakes, ground spoilers/lift dumps, and wheel brakes.

The use of full reverse thrust is a powerful way to stop an aircraft. The use of idle or partial reverse thrust as dictated by noise restrictions or fuel savings instead of full reverse thrust should be avoided as much as possible. When the runway is wet/contaminated and/or the stopping margins are low the use of full reverse thrust is always recommended[26].

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[25] The certified landing distance provided in the Aircraft Flight Manual is not representative for day-to-day landings. It is only used for dispatch purposes using correction factors e.g. 1.67 (jets) or 1.43 (turboprop) for dry runways, plus 1.15 for wet surfaces.

[26] On aircraft with rear fuselage mounted engines full reverse thrust is normally not allowed. This could cause directional control problems as the flow could blank out the rudder affecting rudder efficiency. Especially with operations on wet/contaminated runways under crosswind condition this is very critical.

Pilots should always consider the use of full reverse thrust especially on wet/contaminated runways. Noise restrictions should not hamper the use of full reverse thrust on wet/contaminated runways or when the stopping margins are minimal.

It is important that right after touchdown the available stopping devices are used as soon as possible.

Airline training curricula should emphasise that after touchdown the pilots should not delay any of the following: lowering the nose (no aerodynamic braking), application of ground spoilers/lift dumps, application of reverse thrust, and application of appropriate braking (e.g. auto brakes or manual braking).

Auto brake systems are often more effective in producing consistent deceleration levels than manual braking by the pilots. When the deceleration levels are lower than expected the pilot should first select a higher auto brake setting before applying manual braking[27].

Airline training curricula should emphasise that pilots should consider selecting a higher auto brake setting first before applying manual braking if deceleration levels are not as expected.

5.2.4 Runway condition and braking friction

Runway conditions (e.g. wet or contaminated by slush, standing water etc.) play a significant role in landing overruns. There are different ways to inform the pilots about the runway conditions and braking friction levels. These ways and their relation to landing performance assessment as discussed in the previous section have a strong influence on the landing overrun risk.

Following the overrun of a Boeing 737 at Midway in December of 2005 the FAA found that the current state of the industry practices did not have adequate guidance and regulation addressing the operation and non-dry, non-wet runways, i.e., contaminated runways. As such the FAA chartered an Aviation Rulemaking Committee (ARC) to address Takeoff and Landing Performance Assessment (TALPA) requirements for the operation and certification of aircraft in the U.S. The TALPA ARC found that the ability to communicate actual runway conditions to the pilots in real time and in terms that relate to aircraft stopping performance was critical to the success of the project. Numerous significant short comings were discovered by the TALPA ARC in the current (United States) NOTAM processes that hampered this communication effort. TALPA ARC has formulated recommendations and reporting procedures that could resolve the identified short comings. TALPA ARC also recommended that aircraft performance data are calculated and presented in a way consistent with the required runway reports. At the core of this recommendation is the concept of using the

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[27] On some aircraft the activation of the braking is delayed somewhat when the lowest auto brake setting is selected. Pilots sometimes react to this by applying manual braking before the auto brake system activates.

Paved Runway Condition Assessment Table as the basis for performing runway condition assessments by airport operators. The Paved Runway Condition Assessment Table uses the description of the runway condition, percentage of runway coverage, and contaminant depth to assign a code to the runway representing the braking friction level an aircraft can encounter. Results from braking friction vehicles and PIREPS are only used to downgrade to a lower runway condition code. The results from the Paved Runway Condition Assessment Table can be used by pilots for interpreting the reported runway conditions in a standardised format based on airplane performance data supplied by airplane manufacturers for each of the stated contaminant types and depths.

The TALPA ARC method for paved runway condition assessment is a promising alternative for the current practices of reporting which is know to be subjective and inaccurate. Before this new method can be introduced testing is recommended. In particular the TALPA ARC method results should be compared to the actual braking friction levels an aircraft encounters. For this analyses flight data from quick access recorders (QAR) can be analysed for landings and compared with the paved runway condition assessment matrix results for those landings. There are plans to do such an analysis. Before introducing of the TALPA retraining of e.g. pilots, airports personnel etc. is required. Currently the TALPA ARC method is only considered for operations in the U.S. It is recommended that EASA should consider introducing the TALPA ARC paved runway condition assessment method in Europe if the outcome of evaluation of the method is positive. A common semantic for reporting runway conditions is necessary, to be used by aerodrome observers, ATC, and pilots. This common semantic has to be consistent with the semantics used in the Approved Flight Manual. Friction measuring devices may be one of the inputs to be considered. Note that EASA and FAA are supporting the ICAO Aerodrome Panel to develop appropriate recommendations to amend ICAO Annex 14.

It is recognised that EASA and FAA are working together to harmonise the runway condition and braking friction measures based upon the TALPA ARC paved runway condition assessment method. The findings of this study support this activity. Further validation of the TALPA ARC method is however advised before introducing it in Europe.

The conditions along the runway may vary. From a number of landing overruns analysed in this study it became clear that full braking was not always commenced on the first part of the runway. As the end of the runway approached the pilots did not anticipate a significant reduction in the braking actions levels and were not able to stop the aircraft on the runway. Pilots should be made aware that runway friction levels may vary along the runway even if this was not reported to them. It is therefore important that the application of all stopping should be done immediately after touchdown without any delay.

Pilots should be made aware that runway friction levels may vary along the runway even if this was not reported to them. It is therefore important that all stopping devices should be used immediately after touchdown without any delay.

5.2.5 Aquaplaning

Aquaplaning is a well-known factor in landing overruns. However what is not realised by the aviation community (e.g. pilots, airports, accident investigators) is that modern aircraft tires such as radial ply and H-type, aquaplane at lower speeds than the classical cross-ply tires.

It is recommended to raise the awareness of the aviation community about the lower aquaplane speeds of modern aircraft tires.

It is recommended that EASA considers the lower aquaplaning speed of modern tires in aircraft contaminated runway certification.

5.2.6 Unstabilised approaches

Unstabilised approaches are indentified as a factor in a number of landing overruns. As the problem of unstabilised approaches has already been addressed in other safety action plans (e.g. FSF ALAR tool kit) no separate recommendations are given in this study regarding its prevention. However regarding ATC three issues related to unstable approaches are emphasised here.

ATC should vector aircraft according to ICAO guidelines (see ICAO Doc 4444)[28].

ANSPs should carefully design airspace to avoid unstable approaches.

ATCos and airspace designers should be made aware of how ATC can influence unstable approaches (See FSF ALAR tool kit).

5.2.7 Technical solutions

Both Honeywell and Airbus have developed onboard technical solutions to reduce the landing overrun risk. Both systems are briefly discussed in this section. Note that other systems have been developed which until now have not been put into commercially available products (e.g. the “Aircraft stop-to-position autobrake control system”, developed by Boeing).

The Airbus system is known as ROW/ROP or ROPS (Runway Overrun Protection System)[29]. The system has recently been certified by EASA. This system is the safety net for the brake-

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[28] When vectoring to intercept the ILS localizer course or MLS final approach track, the final vector shall enable the aircraft to intercept the ILS localizer course or MLS final approach track at an angle not greater than 30 degrees and to provide at least 2 km (1.0 NM) straight and level flight prior to ILS localizer course or MLS final approach track intercept. The vector shall also enable the aircraft to be established on the ILS localizer course or MLS final approach track in level flight for at least 3.7 km (2.0 NM) prior to intercepting the ILS glide path or specified MLS elevation angle.

[29] Information regarding ROW/ROP or ROPS was obtained from several sources including presentations and articles.

to-vacate system developed by Airbus. The ROPS system works during the approach as a warning system and during the ground roll as a protection system. Below 500 ft. the system continuously calculates and displays on the Navigation Display (ND) the realistic operational landing distance and compares it with the landing distance available for the selected runway. The computed landing distances are updated continuously with actual flight conditions. The system takes into account several elements such as the aircraft's speed, position, temperature, wind and runway elevation. Visual (below 500 ft.) or aural messages (below 200 ft.) are given when the required distances (dry and wet runways are computed) exceed the available landing distance. Based on the information provided by the system the pilot can decide to go-around if the system determines that the runway is too short. The system also accounts for long landings as it continuously monitors the landing up to touchdown. After touchdown the protection system monitors the actual deceleration of the aircraft. This deceleration is used to estimate the remaining stopping distance needed. This information is again displayed on the ND. The computed stopping distance is continuously compared to the remaining runway length. If the computed distance is higher than the available distance the maximum autobrake setting is applied for a certain period of time and continued if the remaining distance is still less than the required stopping distance. If maximum reverse is not selected the system will also give a call out to select this. This can be done below speeds at which maximum reverse thrust should not normally be used. The pilot has the authority to disengage the runway overrun protection at any time. The Airbus ROPS system is a dynamic system which monitors different parameters throughout the landing. As it helps pilots in there decision to make a go-around and helps to obtain optimum deceleration during the ground roll it can be very effective in reducing landing overruns.

Honeywell developed a system called Smartlanding[30]. The SmartLanding system is a software upgrade to the enhanced ground-proximity warning system (EGPWS). The Smartlanding system scans the reference approach airspeed and the nominal approach angle to a particular runway and if prescribed values are exceeded, an aural/visual advisory can be given. The Smartlanding system also includes callouts for long landing if the aircraft extends beyond a predetermined touchdown zone (customer defined), together with callouts of runway distance remaining during landing and rollout. This could be limited to the last part of the runway when the aircraft is above a certain speed. The Smartlanding system addresses a number of important factors in landing overruns and can therefore help in reducing landing overruns. The current Smartlanding system does not yet use the actual deceleration levels during ground roll. However Honeywell is considering extending the Smartlanding system with this feature in which the remaining runway distance is compared to actual deceleration of the aircraft, and if insufficient warns the pilot about this[31].

Both systems (ROPS and Smartlanding) can be effective means for reducing landing overruns. At the time of writing this report both systems are planned to be used. For instance Lufthansa and Air France are set to introduce the ROPS landing system on the Airbus A380.

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[30] Information regarding Smartlanding was obtained from official brochures and presentations.

[31] The basic concept was originally looked at by Honeywell in 2000 (US Patents 7,132,960 & 7,068,187).

Emirates is to be the first airline to install Honeywell's new landing aid. Furthermore Boeing is to offer Smartlanding as an option on the B747-8, the B777 and the B737 in early 2010.

Both the Airbus ROPS and Honeywell Smartlanding are the first available systems developed to prevent landing overruns. These systems (and others that might be developed in the future) could have a large influence on improving landing overrun safety. Operators should therefore seriously consider such systems in future fleet development and upgrades.

5.3 Landing veeroffs

5.3.1 Crosswind and wet/contaminated runways

The provision of operational crosswind on wet/contaminated runways provided in the aircraft operating manuals is believed to play an important role in landing veeroffs. Many pilots are not aware how these crosswinds have been established. Pilots should be made aware of the limitation of the advisory crosswind limits for wet/contaminated runways. Furthermore more guidance is needed on how such crosswind limits can be established by the manufacturer[32]. In this guidance the use of engineering models, simulators etc. for establishing crosswind wind limits on non-dry runways should be addressed.

Pilots should be made aware of the limitations of the advisory crosswind limits given in the operating manual.

Pilots should be made aware of associated risks of landing on wet/contaminated runway in combination with crosswind during landing.

EASA (and other regulators) should draft guidance material how to determine crosswind limits on wet/contaminated runways when using engineering models and/or simulators.

There is often confusion among pilots how to interpret the maximum demonstrated crosswind component as given in the aircraft flight manual and in the aircraft operating manual. A recent survey amongst 81 airline pilots of 5 operators done by the Germany accident investigation board BFU gave some interesting facts about this problem. When the BFU gave the scenario of a maximum demonstrated crosswind component of 33 kts. gusting 38 with a actual wind gusting up to 40 kts., 40% of the pilots replied that landing is permitted if gusts were not perceived as operationally relevant, 36% replied landing is not permitted because the gust would exceed operational limits of the aircraft, 20% said landing is permitted because gusts are irrelevant for crosswind computations as only steady wind counted, and 4% had no idea[33]. On the question what is the practical meaning in normal

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[32] During the EASA workshop “Workshop Runway Friction and Aircraft Braking- The way forward”, simailir suggestions were made by airline operators (March 2010).

[33] Unterschungsbericht, 5x003-0/08, March 2010.

flight operations of the term "demonstrated crosswind" in the aircraft operating manual, 50% replied that it is a limit, 47% replied it is guidance, and 3% did not know.

Operators should have unambiguous procedures regarding allowable crosswinds. The crosswind limits in the operating manual should include gusts. The gust should be assumed omnidirectional when deriving crosswind components

Another issue regarding crosswind (and also tailwind) are the existing requirements for how the wind should be measured and reported. A number of the perceived shortcomings and issues were addressed in previous studies [Van Es et. al., (2001)]. An example of a shortcoming is the fact that in the current way of reporting wind speed as required by ICAO, gusts are not always reported (when they are less than 10 kt.). This may result in substantial discrepancies between reported wind direction and wind speed and actually encountered crosswind. Consequently, this may lead to reduced safety margins when operating under relatively high crosswind or tailwind conditions. The discrepancies between current requirements for wind reporting, the absence of a methodology to derive wind components and today's operations should be eliminated whenever possible.

Pilots should be made aware of the limitations of the current wind reporting practice to determine crosswind (and also tailwind) components.

EASA (and other regulators) should eliminate the discrepancies between current requirements for wind reporting as much as possible by drafting guidance material or submit to the appropriate standardisation bodies improved standards for wind reporting and methodologies to derive wind components, whichever is more appropriate.

5.3.2 Hard landings

The data showed that hard landings are an important factor in landing veeroffs. Hard landings are typically caused by things like unstable approaches, destabilisation of the approach in the last 200-100 ft ("duck under"), and improper flare technique. These factors are addressed in other action plans (See e.g. FSF ALAR tool kit).

Besides the avoidance of a hard landing itself also the recovery of a consequential bounce should be addressed. Crew should be made aware of the bounced landing recovery techniques and operators should have procedures and training for bounced landing recovery. Note that bounced landing recovery procedures cannot be adequately trained in a flight simulator. While bounce recovery procedures are often described in aircraft manuals provided by the manufacturers there are still operators that do not instruct their pilots on the bounced landing procedure.

Pilots should be made aware of recovery techniques from hard and bounced landings. Operators should have procedures and training for bounced landing recovery.

5.4 Takeoff overruns

5.4.1 High speed aborts

The present study showed that the biggest problems regarding takeoff overrun lie with high speed rejected takeoffs (above V1). This problem has been investigated many times in the past. In 1993 a group of airlines, manufacturers, pilot groups, and government agencies presented the Takeoff Safety Training Aid[34]. The educational material and the recommendations provided in the Takeoff Safety Training Aid were developed through an extensive review process to achieve consensus of the air transport industry. The goal of the training aid was to reduce the number of RTO related accidents by improving the pilot's decision making and associated procedural accomplishment through increased knowledge and awareness of the factors affecting the successful outcome of the "Go/No Go" decision. From Figure 3 it becomes clear that the takeoff overrun excursion rate has dropped slightly since 1996 from an average of 0.20 to 0.15 per million flights during the last 10 years. It is difficult to prove that this is due to the Takeoff Safety Training Aid. It is not unlikely however that material of the training aid has helped to increase the knowledge and awareness amongst pilots of the factors affecting the successful outcome of the "Go/No Go" decision. A brief survey amongst a number of European pilots suggested that the existence of the Takeoff Safety Training Aid is fading. Furthermore the training aid was not aimed at business jets and turbo prop aircraft and therefore probably not well-known amongst their users. As the Takeoff Safety Training Aid provides a tool for mitigating rejected takeoff related overruns it is recommended to bring this material back under the attention of the aviation community (not limited to the large commercial operators only). It is believed that the content of the training aid is as valid today as it was upon initial publication. However this should be checked. Some topics might need a revision (e.g. more attention should be given on how to recognise unsafe flight conditions). Also manufacturers of business jets and turbo prop aircraft should examine the content of the training aid and provide additional information if needed.

It is recommended to bring the Takeoff Safety Training Aid back to the attention of the aviation community and update its contents if necessary. This should cover commercial operators and business/executive operators of both turbo fan/jet and turbo prop powered aircraft.

A significant part (80%) of the high speed rejected takeoffs were not engine related. Currently pilot simulator training often presents RTOs as engine-related events while the Takeoff Safety Training Aid gives recommendations about other failure conditions to consider. As already noted, the majority of all RTO accidents were not related to engine problems. In these cases it is possible that the pilots were not fully prepared to recognise cues of other anomalies during takeoff. The data indicate that pilots often interpret these

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[34] In 1989 the U.S. Federal Aviation Administration (FAA) urged the aviation industry to take steps to reduce the number of overrun accidents and incidents resulting from high-speed rejected takeoffs (RTO). This led to the formation of an international takeoff safety task force, with members from airlines, regulatory agencies, pilot unions, and manufacturers.

other anomalies (like a tire burst) as events that threaten the safety of flight and (often incorrectly) decide to reject the takeoff at any speed.

It is recommended to train non-engine related RTO events as recommended by the Takeoff Safety Training Aid. More attention should be given on how to recognise unsafe flight conditions. An update of the Takeoff Safety Training Aid might be necessary for this.

5.4.2 Takeoff performance monitoring systems

A takeoff performance monitoring (TOPM) system TOPM system monitors the progress of the takeoff and can provide advisory information which the crew can use to decide to continue or to abort the takeoff. Today no commercial TOPM system is available despite the significant research conducted in the world. Although a TOPM system could reduce the number of takeoff overruns (and even some takeoff veeroffs) there were some reservations regarding the TOPM system. For instance a TOPM system may increase the number of aborted takeoffs. The hazards introduced by these might outweigh any benefit. Furthermore it is difficult to define an acceptable level of deceleration (the primary parameter a TOPM system looks at). Current aircraft are equipped with GPS systems and have databases with accurate information on the runways. These could by used by modern TOPM systems. Airbus is currently again looking into the possibilities of introducing a TOPM system[35]. It was not known at the time of writing this report if other manufacturers were considering TOPM systems for their products in the near future.

The aviation industry is encouraged to look into the next generation TOPM systems using currently available technology such as GPS and airport databases

5.4.3 Incorrect takeoff mass

The use of laptops and electronic flight bags has introduced the possibility that incorrect rotation speeds are calculated by using wrong takeoff mass data. Currently the industry (e.g. aircraft manufacturers, operators) are considering these problems. For instance Airbus has developed the Take-Off Securing function (TOS), which automatically checks the entered data for consistency. Pilots should be more aware of these risks when using laptops and electronic flight bags for takeoff performance calculations.

Pilots should be made more aware of the risks of using wrong takeoff masses when using laptops and electronic flight bags for takeoff performance calculations. During recurrent training these problems should be addressed.

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[35] Statement made Capt. Claude LeLaie from Airbus S.A.S. at the International Air Safety Seminar 2009.

Aircraft manufacturers, operators should enhance the laptop and electronic flight bag HMI to ensure a user friendly output that allows V speeds to be calculated by using correct takeoff mass data and cross checked by the human eye.

5.5 Takeoff veeroffs

The problems of crosswind limits on wet/contaminated runways provided in the aircraft operating manuals are believed to play an important role in takeoff veeroffs similar to landing veeroffs. Many pilots are not aware how these crosswind limits for wet/contaminated runways have been established. Pilots should be made aware of the limitation of the advisory crosswind limits. More guidance is needed on how such crosswind limits can be established. In this guidance the use of engineering models, simulators etc. for establishing crosswind wind limits on non-dry runways should be addressed.

Pilots should be made aware of the risks of taking off on wet/contaminated runway in combination with crosswind during takeoff.

Regulators (EASA, FAA, TC etc.) should draft guidance material how to determine crosswind limits on wet/contaminated runways using engineering models and/or simulators.

The incorrect use of nose wheel steering is also a factor in takeoff veeroffs. Pilots must use caution when using the nose wheel steering tiller above 20-30 kts to avoid overcontrolling the nose wheels resulting in possible loss of directional control. The operating manual and the training curricula should address this properly.

Pilots must use caution when using the nose wheel steering tiller above 20-30 kts to avoid overcontrolling the nose wheels resulting in possible loss of directional control. The operating manual and the training curricula should address this properly.

5.6 Flight Data Monitoring

Flight data monitoring (FDM) is a valuable method to improve flight safety. This method can also help to prevent runway excursions within an operator. Standard FDM software will normally already monitor a number of parameters related to runway excursions e.g. unstable approaches (speed, glide slope deviations etc.). However there are more parameters that can be monitored than are related to runway excursions.

Aircraft operators should monitor parameters that are closely related to runway excursions. Flight Data monitoring software suppliers should make provisions in their products for this.

Below are some suggestions of parameters that could be monitored for each type of runway excursion.

Landing overruns

The following parameters can be monitored using FDM:

- **Unstable approaches.** Note that care should be taken how the different approach elements of unstable approaches are identified in the FDM software. This is not always similar to the unstable approach criteria provided in the flight crew operating manual.
- **Long landings** (see example Figure 7). Typically a landing is considered to be long when the distance from the threshold to the touchdown point is more than 610-700 m (2,000-2,300 ft.). However this is not a generally accepted definition for a long landing. Some operators use different thresholds. Some use a relation between the maximum airborne distance and available runway length. Other definitions relate it to the approach speed (e.g. airborne distance longer than 7 times Vapp). The algorithms used by standard flight data monitoring software are often not very accurate in calculating the airborne distance which could give an over- or underestimation of the airborne distance. For instance the threshold is sometimes set to be the point where the aircraft is at 50 ft. AGL. This is of course not always correct as the aircraft can be higher or lower at the threshold or the threshold crossing height itself could differ from 50 ft. if the glide slope is not equal to 3 degrees. Furthermore the air-ground switch is often used to estimate the touchdown point. The sample rate for the air-ground switch recordings on the QAR is often low (say 1 per sec.). This can lead to inaccuracies of up to 300-500 ft. in the airborne distance as derived by the FDM software. See for an accurate estimate of the airborne distance using quick access recorder data the study into landing distance performance by Van Es and Van der Geest [Van Es et. al., (2006)].
- **Actual tailwind during landing.** The tailwind can be calculated from the quick access recorder data by subtracting the recorded ground speed and true air speed from each other. This should be done for a height around 10 m (33 ft.) AGL as this height reflects the certification standards.
- **Threshold crossing height.** An aircraft can be considered to be high above the threshold when the altitude at the threshold crossing is 4.5 m (15 ft.) above the prescribed threshold crossing height (normally the threshold crossing height is 15.2 m. or 50 ft.). The GPS recorded position could be used to the determine the threshold crossing time however it should be realised that often the sampling rate and the number digits of the quick access recorded GPS position is insufficient to do so.
- **Speed loss between threshold and touchdown** (gives an indication of floating). Aircraft manufacturers give guidelines on the speed loss between threshold and touchdown. These guidelines can be used in the FDM analysis.
- **Time between flare initiation and touchdown** (indication of floating). Flare initiation can be approximated by selecting a fixed altitude at which the aircraft should normally start the flare.
- **De-rotation time after main gear touchdown** (indication of aerodynamic braking). A target could be a de-rotation time of less than 4 seconds.

- **Time of application of brakes** (manual) and/or **thrust reverse** after touchdown. See example in Figure 8 for the time from touchdown to thrust reverser engagement on a very long runway and short runway as derived from flight data.
- **Autobrake settings** in relation to runway length and weather conditions (derived from METAR).

Landing excursions

The following parameters can be monitored using FDM:

- **Lateral deviation** during the ground roll as function of crosswind. Crosswind should be derived from the METAR data and not from the FMS wind data[36]. Lateral deviation can be derived from GPS or LOC deviation data.
- **Use of nose wheel steering** at speeds above 20-30 kts.
- **Hard landings**.
- **Rate of descent** during the flare.

Takeoff overruns

- There are no obvious parameters related to rejected takeoffs that could be monitored.

Takeoff veeroffs

- **Lateral deviation** during the ground roll as function of crosswind. Crosswind should be derived from the METAR data and not from the FMS wind data. Note that although the METAR wind data are subjected to the same problems as e.g. tower wind, it is by far more accurate than FMS wind data recorded during the landing. Lateral deviation can be derived from GPS or LOC deviation data.
- **Use of nose wheel steering** at speeds above 20-30 kts.
- **Thrust build-up** prior to selecting takeoff power (asymmetric power application).

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[36] First the FMS wind is not what it appears to be, in particular during takeoff and landing. First, the FMS wind is not corrected to a height of 10 meters. At 500 ft. AGL the wind is about 50% higher than at a height of 10 meters. Second, internal FMS calculation of the wind during approach is filtered, delayed and very sensitive for small errors in track or heading measurement. Furthermore, the FMS wind is not corrected for sideslip. Note that the FMS tailwind component is relatively insensitive to FMS errors in the determination of the drift angle.

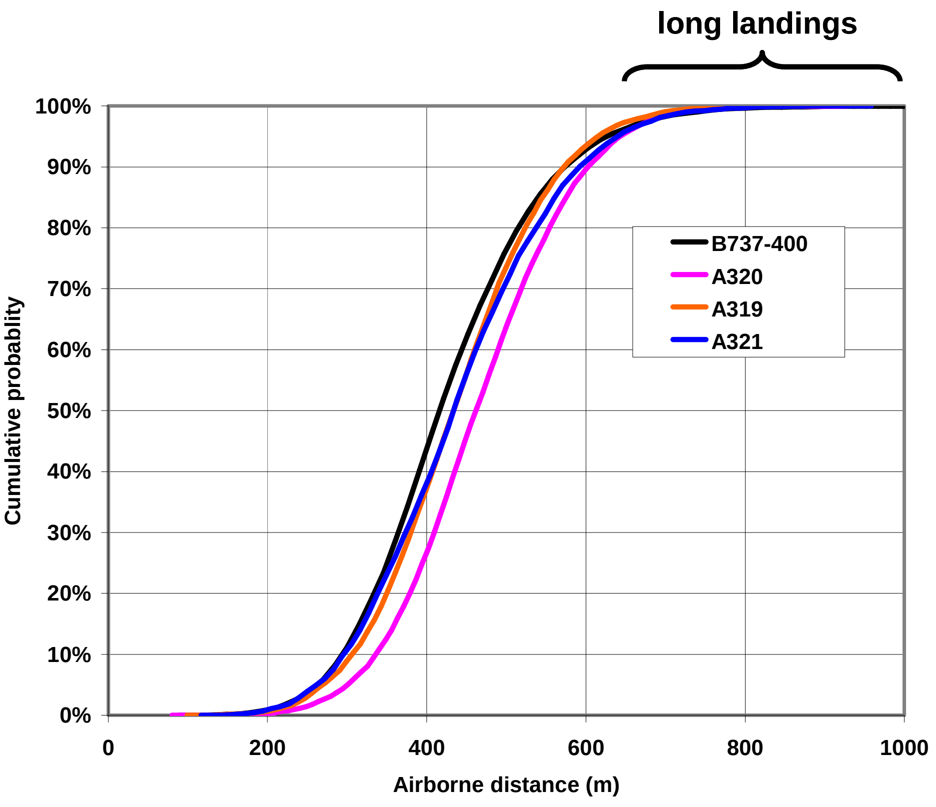

Figure 7: Example airborne distance and long landing analysis [Van Es et. al, (2006)].

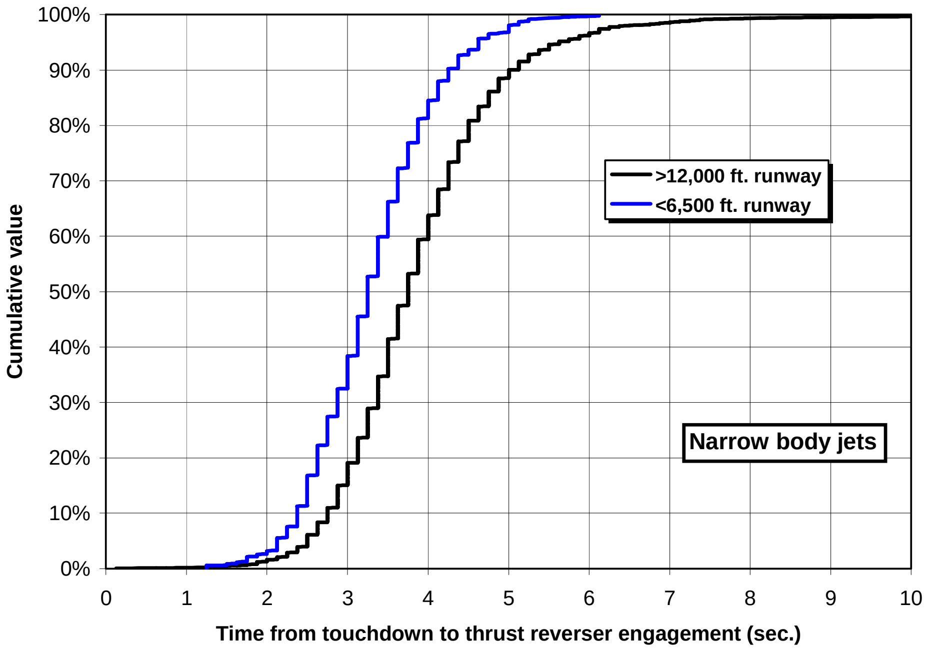

Figure 8: Example of time from touchdown to thrust reverser engagement analysis.

CHAPTER 6 –Conclusions and recommendations

6.1 Conclusions

This study presents an analysis of runway excursions that occurred worldwide during 1980-2008. Based on this analysis the following main conclusions are made:

- The runway excursion rate has not shown significant improvement during the period 1980-2008;
- Runway excursions that occurred in Europe have very similar causal factors as excursions that occurred elsewhere;
- The four types of runway excursions (takeoff overrun; takeoff veeroff; landing overrun; landing veeroff) show a very similar frequency of occurrence for Europe compared to the rest of the world;
- Landing overruns and veeroffs are the most common type of runway excursion accounting for more than 77% of all excursions;
- Over 450 different factors which were judged to be instrumental in the causal events leading to runway excursions have been identified. However 18 causal factors were prominent in all analysed runway excursions.

6.2 Recommendations

6.2.1 Preventive measures

While a part of the following recommendations concern the voluntary dissemination of best practices (e.g. operators), a number of recommendations are also addressed to the regulatory authorities (e.g. EASA within the European Union).

6.2.2 Landing Safety Training Aid

As a large number of the proposed preventive measures are related to training and educating of pilots it is recommended to consider the development of Landing Safety Training Aid similar to the Takeoff Safety Training Aid.

On 13 December 2002, a McDonnell Douglas DC-8-62 freighter overran Runway 20R while landing at Singapore Changi Airport. The overrun occurred after the aircraft landed long (by about 1,300 metres) on the runway in heavy rain. The aircraft sustained substantial damage during the overrun. None of the four persons on board was injured.

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