NLR Air Transport Safety Institute
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Executive summary

Landing Long: Why does it happen?

Problem area
Each year there are on average 40 landing overruns with commercial and executive aircraft worldwide. Analysis of the causes has shown that landing long on the runway was a causal factor in 40% of all landing overruns. Further analysis also showed that the risk of overrunning the runway increases by a factor in the order of 55 when the landing is long.

Description of work
This paper discusses the most important factors that are related to the airborne distance and their relation to long landings. For this purpose an analysis is conducted of both landing overruns in which long landings were a causal factor as well as flight data of day-to-day landings obtained from a number of (mainly) European operators.

Results and conclusions
There are several factors that can be a reason for the aircraft to land long. The most dominate factors are flying too high and too fast during the airborne manoeuvre, significant tailwind, early flares, floating of the aircraft, and use of runway exits far down on a relatively long runway.

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This report is based on a presentation held at the 23rd annual European Aviation Safety Seminar (EASS), Istanbul, Turkey, March 1–3, 2011.

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Summary

Each year there are on average 40 landing overruns with commercial and executive aircraft worldwide. Analysis of the causes has shown that landing long on the runway was a causal factor in 40% of all landing overruns. Further analysis also showed that the risk of overrunning the runway increases by a factor in the order of 55 when the landing is long.

A long landing is clearly unwanted as it increases the required landing distance. As a consequence the available margin in landing distance reduces, increasing the risk of a landing overrun. The airborne distance (from threshold to touchdown) is affected by a number of factors. This paper discusses the most important factors that are related to the airborne distance and their relation to long landings. For this purpose an analysis is conducted of both landing overruns in which long landings were a causal factor as well as flight data of day-to-day landings obtained from a number of (mainly) European operators.

It became clear from the study that that are several factors that can be a reason for the aircraft to land long. The most dominate factors are flying too high and too fast during the airborne manoeuvre, significant tailwind, early flares, floating of the aircraft, and use of runway exits far down on a relatively long runway (it appears that long landings are not strongly correlated to the actual runway length: they occur as frequently on relatively short runways as on long runways with ample landing distance available. The runway exit position has a much stronger influence on the probability of long landings). Some of these factors could occur simultaneously increasing the possibility of a long landing even further. A large number of the factors that contributed to long landings can be traced back to an unstabilised approach.

Contents

1 Introduction

1.1 Background

On May 28, 2005 a Citation V landed at Leeds Bradford Airport. The aircraft was not stopped on the runway and overran the end of the runway by a distance of approximately 160 metres. The approach was unstable however no go-around was initiated by the crew. The aircraft began the landing flare in the region of the touchdown zone at a speed of 155 kt, floated for a considerable distance along the runway and then touched down beyond the runway mid-point at a speed of 121 kt. The commander had in mind that the runway was long (for this aircraft) and so he was very confident that he had plenty of runway available. It was only as he crested the rise of the runway and the far end became visible that he realised he had overestimated the runway remaining. He did not consider that the accident was necessarily as a direct result of the long landing but more the result of his lack of perception of the remaining runway length available. He considered that had he braked immediately upon landing, the aircraft would have had sufficient runway to stop. However the investigation showed that even if he had applied full brake pressure immediately on touchdown, the aircraft would not have stopped on the runway. The long landing the aircraft made, reduced the remaining distance too much to stop the aircraft on the runway. In most cases once the touchdown zone of a runway is behind an aircraft there is normally no direct indication to the pilots what remaining length is available other than what he can see ahead. For this reason, even when there may be excess landing distance available, a landing at the touchdown zone is desirable.

Each year there are on average 40 landing overruns with commercial and executive aircraft worldwide. Analysis of the causes has shown that landing long on the runway was a causal factor in 40% of all landing overruns [Van Es (2010)]. Further analysis also showed that the risk of overrunning the runway increases by a factor in the order of 55 when the landing is long [Van Es (2005)]. Touchdowns of more than 600-700 m from the threshold are typically considered long landings. However there is no formal definition of what a long landing is. In some cases for short runways a value of 25-33% of the runway length is used as the airborne distance from which a landing is considered long.

To a pilot landing 600-700 m from the threshold could be still within the touchdown zone indicated on the runway and could look perfectly correct. However airborne distances of more than 600-700 m are normally much higher than assumed in the landing performance data. Depending on the available runway and the prevailing conditions the remaining runway could not be enough when landing long.

1.2 Objectives

A long landing is clearly unwanted as it increases the required landing distance. As a consequence the available margin in landing distance reduces, increasing the risk of a landing overrun. The airborne distance (from threshold to touchdown) is affected by a number of factors. This paper discusses the most important factors that are related to the airborne distance and their relation to long landings. For this purpose an analysis is conducted of both landing overruns in which long landings were a causal factor as well as flight data of day-to-day landings obtained from a number of (mainly) European operators. More than 211 landing overruns are analysed in which a long landing was cited as a causal factor [data obtained from Van Es (2005)]. Typical factors that are related to long landings are identified from these occurrence data. Flight data obtained from more than 75,000 landings made with commercial jet aircraft are also analysed for factors influencing long landings [Van Es, Van der Geest, (2006)]. The result of the presented analysis should bring some information about the important factors related to long landings. This can result in effective mitigations against long landings and hence reduce the number of landing overruns in the future.

2 Certification, aircraft operating manuals and the airborne distance

In this section a brief summary is given on how the landing airborne distance is treated during certification, and how it is used in performance data available to the pilot.

The Aircraft Flight Manual AFM contains certified information on the landing performance of an aircraft. For many commercial aircraft this landing performance is based on test flights flown by proficient test pilots, using rates of sink and flare not considered acceptable in service for passenger comfort. This is done to reduce test landing variability and give a limiting measure of the actual aircraft performance. A long float prior to touchdown is distance wasted to the manufacturer and will be avoided during test flights. A demonstration of maximum performance in which steep approaches and high touchdown sink rates are permitted, is no longer considered acceptable for newly certified aircraft. AFM landing distance is measured from a screen height (usually 50ft RA), irrespective of whereabouts on the runway this height is achieved. It is then assumed that the airline pilot achieves this screen height over the runway threshold. The assumptions regarding airborne distance will be invalid should the airline pilot not achieve this. A number of aircraft manufactures provide additional landing performance data in the Aircraft Operating Manual (AOM). This information is not certified and the manufacturer provides this as advisory only. These landing performance data are used for in-flight assessment of the required landing distance prior to landing. The airborne distance used in the advisory landing data is not necessarily the same as the value archived the during flight tests. Landing performance data provided by the aircraft manufacturers for in-flight landing distance assessment can assume that the aircraft touches from a certain distance from the threshold (typically in the order of 300-500m depending on aircraft model).

3 Factors influencing airborne distance and long landings

There are a number of factors that influence the airborne distance which can also affect the possibility of a long landing. These factors are discussed now. Both data on landing overruns as well as data from day-to-day landings are used for this analysis [Van Es (2005), Van Es, et. al., (2006)]. The collection and analysis of day-to-day landings was conducted as part of a multi-year project sponsored by the FAA William J. Hughes Technical Center.

3.1 Approach speed

The approach speed has a large influence on the airborne distance. Typically the airborne distance shows a more or less linear relation with the approach speed. Flying too fast can therefore result in longer landings. It can also result in floating as the pilot wants to get rid of the excess speed. Landing overrun accident data showed that excess approach speed was presented in 44% of the cases in which a long landing was also cited. Analysis of flight data showed that during long landings the average speed excess was twice as high compared to normal landings. Note that on average aircraft tend to land at a speed somewhat above the bug speed (=VREF+5kt+wind corrections). High speeds during the airborne manoeuvre are often related to unstabilised approaches.

3.2 Height over threshold

The height at which the aircraft crosses the threshold can have a significant impact on the airborne distance. Flying too high above the threshold can result in a long landing. An aircraft is considered to be high above the threshold when the (radio) altitude at the threshold crossing is roughly 4.5 m (15 ft.) above the normal threshold crossing height. Landing overrun accident data showed that being high above the threshold was presented in 13% of the cases in which a long landing was cited. Flight data on a number of narrow body commercial jet aircraft show that for each meter that the aircraft is too high at threshold the airborne distance increases in order of 15-20 meters (see Figure 1). Analysis of these flight data also showed that in 20% of the long landings the aircraft was too high above the threshold. Flying too high during the airborne manoeuvre can be related to unstabilised approaches. However also approaches that were initially stable could end up in flying too high in the final part of the approach. There are several factors related to this which are discussed later in this paper

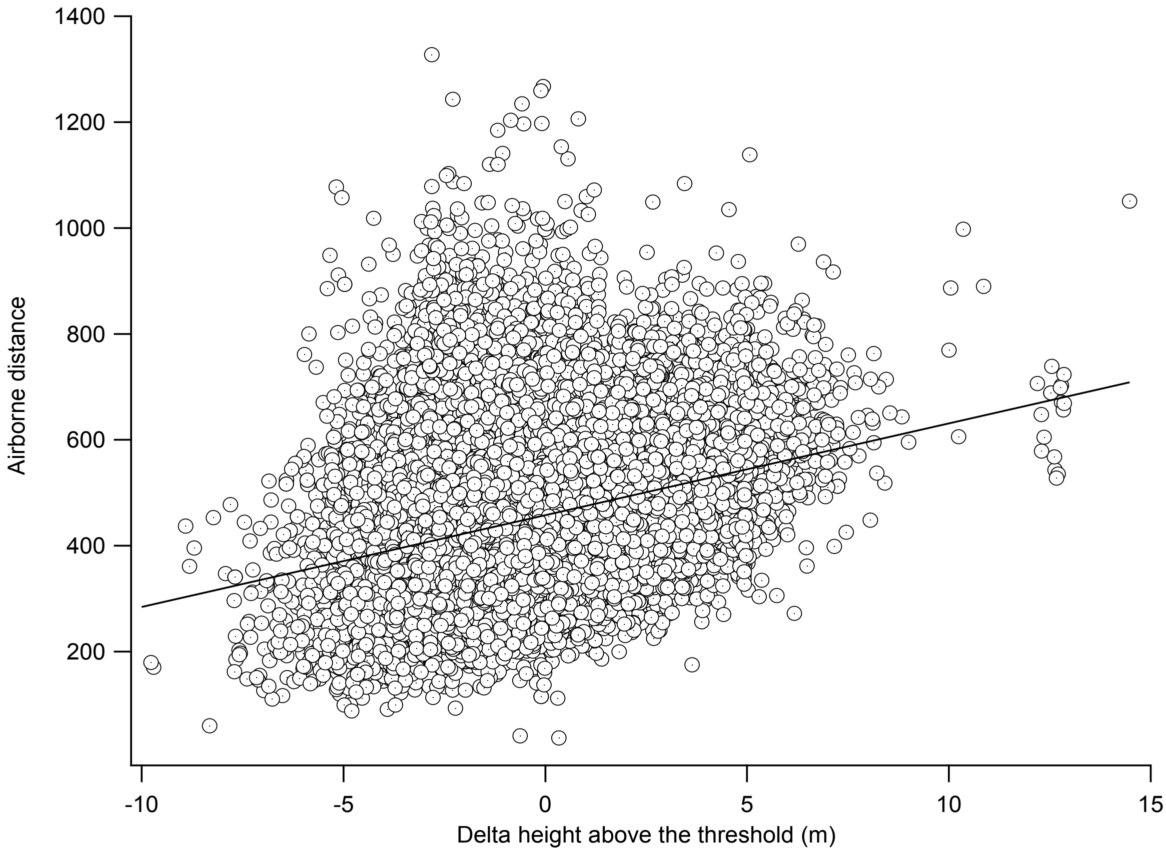

Figure 1: Influence of threshold crossing height deviation on airborne distance

The height of the aircraft at the threshold is also related to the approach guidance being followed. There are two types of approach guidances namely: visual and instrument. Visual approaches are based on visual cues that the pilot can follow that will give information about whether the aircraft is on the glide slope or not. Landing overrun data showed that in 20% of the cases with a long landing such an approach was made. The guidance for visual approach is the Precision Approach Path Indicator (PAPI), Visual Approach Slope Indicator (VASI), and/or the aiming point on the runway (see section on runway markers). The visual aid is typically based on a 3-degree glide path. It is located next to the runway as such that this path intersects the runway at a certain distance from the threshold. This is not always the same position as the aiming point marker (see section on runway markers). Visual aids are set up for the largest regular aircraft type operating into a given runway. Interpretation of visual approach aids therefore depends on aircraft type: smaller aircraft need to adjust their flight path towards the “fly-up” region, which may be counter-intuitive to pilots. During an ILS approach the aircraft follows the ILS until a decision height after which the pilot normally continues the approach using a visual reference. The threshold crossing height is now the height with the aircraft glide slope antenna (which can be located at the radome, the nose gear door or at another location on the aircraft) centred on the glide slope. The ILS glideslope can coincide with the visual references (e.g. PAPI) but this is not always the case.

For approaches without adequate glide path guidance, the pilot should aim to cross the threshold at 50ft. RA. Depending on the location of the radio altimeter antenna, this may mean that such approaches will have a higher airborne distance than during an approach with glide path guidance.

Following an ILS approach to Runway 23 at Coventry, the F27 landed long and fast and subsequently overran the end of the runway. The accident happened in daylight (0608L) but in poor weather with rain. Runway 23 is 1,615m. long. During the approach, the aircraft had been slightly above the glide slope and had maintained a speed of 120kt. (approach target speed 105kt.). At 200ft. the aircraft was still high and fast and the co-pilot 'sought to bring this to the pilot's attention' with a call of 'four whites', indicating that the PAPIs were showing the aircraft to be high. The pilot later stated that he had realised that he was 'slightly steep and slightly fast' and had reduced power in order to reduce the speed. The aircraft touched down in a flat attitude at 114kt. (Vref. plus 19kt.) about 600m. down the runway.

3.3 Flare height and floating

A properly executed flare is essential to avoid a long landing. It is important to flare at the right altitude, and hold the correct pitch attitude through touchdown. When the flare is started the rate of descent is reduced by increase of angle of attack which also results in a decrease of airspeed. The flight-path curvature (or load factor) during the flare may be limited by the pitch control response, by the speed margin above the stall and possibly by the throttle response. Angle of attack limits the extent to which an aircraft may be allowed to float. If the flare begins too early, the airplane may float resulting in an increased landing distance. Ground effect during flare can be pronounced. Once flare has been established any floating tendency can be counteracted by a slight forward motion of the control column. Flight data showed that during long landings the average amount of speed bled off during the flare was some 65% higher than during normal landings. It is not necessary that the aircraft flies too fast to see a high amount of speed being bled off during the flare. However, there is a bit more tendency for pilots doing so when the speed is high. The optimum flare usually only requires increasing pitch attitude by about a few degrees. The actual recommended flare initiation height depends on the aircraft type considered. For commercial jets 20-30 ft. is a typical flare initiation height. Analysis of flight data showed that during long landings the flare initiation height was some 10% higher compared to normal landings. The analysed overrun data indicated that in 20% of the cases the flare was initiated too early.

The aircraft was destroyed when it overran the runway on landing. Following an apparently normal ILS approach in fine weather the 727, possibly due to encountering turbulence as it entered the flare, did not touch-down at the intended point but instead floated a considerable distance down the runway before eventually making contact some 2,500 to 3,000ft beyond the runway threshold. The NTSB determined that the probable cause of the accident was the captain's actions and his judgment following a long touch-down with insufficient runway remaining. The long touch-down was attributed to a deviation from the prescribed landing techniques and an encounter with an adverse wind condition common at the airport.

3.4 Tailwind and wind shear

Tailwind increases ground speed and hence ground distance. The landing overrun data showed that in 15% of the long landings a (significant) tailwind was also present. Flight data showed that in 52% of the long landings a tailwind was present. In 8% of the long landings the tailwind was 10 kts or higher. Tailwind can also result in higher approach path. There are examples that when a headwind turned into a tailwind close to the runway the aircraft started to go above the optimum approach slope (often also related to auto thrust de-selection prior to this event). This could lead to a destabilised approach. If not recognised by the pilots it can result in a long landing.

The landing overrun data revealed that changing winds, wind gusts and wind shear were reported in 8% of all events with a long landing. These winds contributed to longer flares.

During the final stage of a visual approach to Bhojpur, the DHC-6 was reportedly caught by a gust of wind and subsequently 'floated' for some distance. As a result the aircraft touched down some 900ft beyond the normal point and then could not be stopped on the remaining runway length. The aircraft overran and fell into a ditch.

3.5 Touchdown zone markers

The touchdown should take place within the touchdown zone. This area is indicated by touchdown markings. ICAO Annex 14 contains the basic requirements for these runway markings. Touchdown zone markings consist of several pairs of rectangular blocks at fixed intervals from the threshold. They provide reference points for a pilot to assess their progress towards the fixed distance markers. For runways longer than 2,400 meters the touchdown zone has a total length of 900 meters and the so-called aiming point marking is located 400 meters beyond the threshold. Runways with a length between 1,500 m and 2,400 m should have a touchdown zone with a length of 600 m and an aiming point marker 300 meters beyond the threshold. For airports in the US the aiming point is located at 1,000 ft. beyond the threshold. The aiming point marking serves as a visual aiming point for a landing aircraft. It indicates where the aircraft should touchdown. ICAO Annex 14 prescribes the minimum distance from the threshold of the aiming point marker. Surveys of actual markings on runway indicate that in reality things may be quite different. There are many examples of aiming point markers that are much further away from the threshold than recommend by ICAO. This would mean that the aircraft could land much longer than assumed. An example is an airport in Europe where the aiming point was located at almost 500 m from the threshold whereas 300 m was advised by ICAO (runway was 2,200 m long). Analyses of flight data of landings at this particular runway showed a 14% longer airborne distance than the fleet average and a twice as high probability of a long landing. There are many more similar examples for other airports. Touchdown aiming point markers that are further away than recommend can contribute to the occurrence of long landings.

There are pilots that believe that the aiming point marker is always located at the same position for each runway. Clearly this is not the case. Also the fact that the PAPI is not always located next to the aiming point is not considered by every pilot. This could lead to longer landings for smaller aircraft than for which the PAPI was setup.

3.6 RUNWAY LENGTH AND RUNWAY EXITS

Another factor that is believed to have an influence on the airborne distance is the runway length (or landing distance available LDA). In Figure 2 the average airborne distance of a large number of transport aircraft as function of LDA is shown. These data were obtained from analysed flight data and video surveys conducted by the FAA (mainly US runways). The video surveys results (marker by an asterisk) are based on a more limited data set than the flight data derived airborne distances. Although the data show scatter there is some trend visible for runways shorter than 2,400 m. Below this LDA the average airborne distance seems to decrease. This could be partly due to the ICAO aiming point markers located at 300 m instead of 400 m. This also applies to the video results from US airports which have the aiming point located at around 300 m. (1000 ft). The three data points in Figure 2 showing the lowest average airborne distance are for London City airport. This airport has a lower screen height of 35 ft. (steep approach) which results in shorter airborne distances. Also the short runway of this airport makes the pilots to land more on the marks.

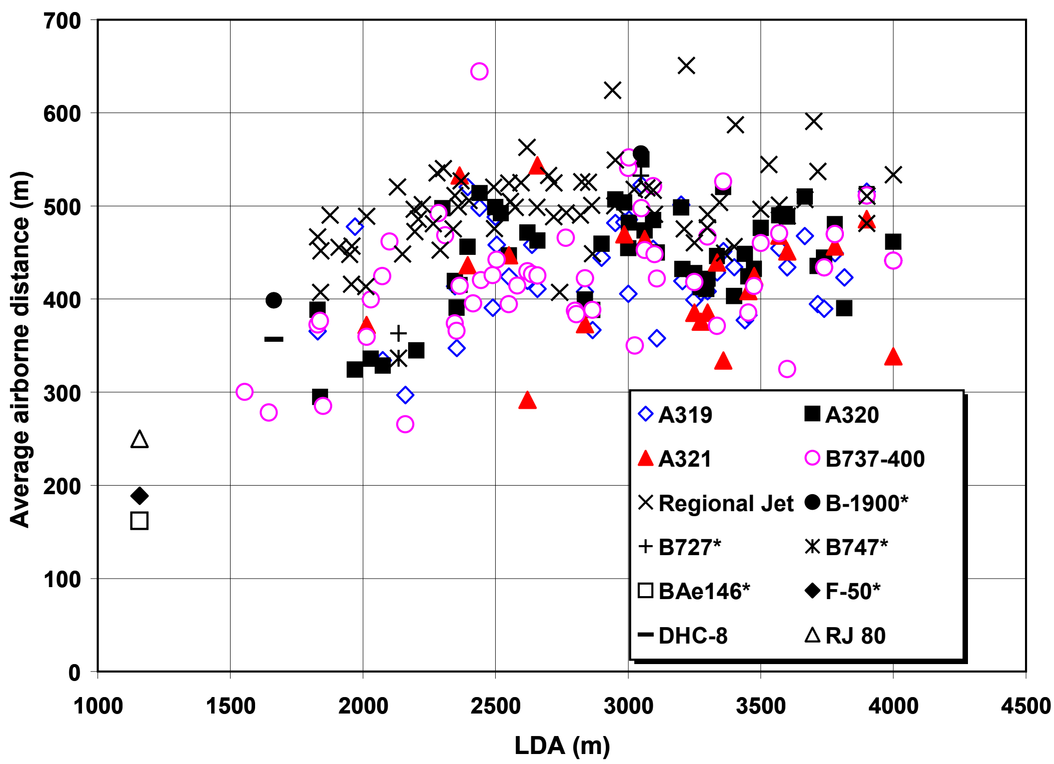

Figure 2: Influence of available landing distance (LDA) on average airborne distance (data obtained from FAA video surveys)*

When looking more closely to the data of Figure 2 it became clear that in only 6% of landings upon the figure was based, the aircraft exited the runway at or near the end of the runway. In all other cases an earlier exit was used. Especially high speed exits that are close to the threshold can have an influence on the airborne distance. The analysed flight data showed a stronger correlation with the location of the runway exits and the airborne distance than with the LDA. On average the airborne distance increases with some 15% when using exits close to the runway end compared to high speed exits. However when looking at long landings the selected runway exit has a much more significant influence. Flight data showed that the probability of a long landing is 15 times higher when using exits near the end compared to using high speed exits.

3.7 Miscellaneous factors

There are a number of miscellaneous factors that can influence the airborne distance. These factors could not always be quantified with the data used in this study. Some of these factors are discussed in this section.

Runway slope

Runway up slope can reduce the airborne distance whereas a down slope does the opposite. This is a pure geometrical effect. Runway slope can also introduce visual illusions which can affect the airborne distance. When there is a downslope in the runway the pilot could experience a below glide path illusion. In this case the reference to the runway gives the illusion that the approach is too shallow and hence the feeling that the aircraft is too low. When correcting for this apparent too low approach the aircraft can land long. There have been a number of landing overruns and long landing incidents in which this factor played a role. The influence of runway slope will be more noticeable for relatively large runway slopes (say 1.5-2%) which are not often found at commercial airports around the world.

On August 6, 1998, a Hawker Siddeley 748 landed at Kasabonika, Ontario, on a freight flight from Pickle Lake, Ontario. During the landing roll, the aircraft could not be stopped and overran the runway. The aircraft landed long and touched at a point from which it could not be stopped under the prevailing conditions. The down-slope of the runway provided misleading visual cues to the crew on approach and may have made it more difficult for them to fly the aircraft on the optimal descent angle.

Visibility

The sudden change of visibility during the final stages of the approach can also influence the airborne distance. This can be due to heavy rain, sun glare, haze, fog or other external factors. Extreme rain showers during the flare have resulted in pilots losing reference with the runway and ending up in a long landing. Heavy rain was present in 16% of the landing overruns in which a long landing also occurred. This gives an indication of the influence of reduced visibility due to heavy rains in long landings. The analysed flight data did not contain many flights that were conducted during heavy rain or low visibility. Therefore no conclusions could be drawn from those data regarding the influence of visibility on long landings.

Flight path angle

In theory the flight path angle at threshold crossing can have an influence on the airborne distance. A very flat approach can result in longer landings. However in only a few cases of the analysed landing overrun data this was quoted as a factor. Analysis of flight data also did not show this to be a major factor to long landings.

Runway width

Wide, long runways can give visual illusions which could result into early flares. This is caused by false angular perception by the pilot resulting in the illusion that the aircraft is lower that in reality. The analysed landing overrun data and flight data do not give an adequate statistical basis to quantify the effect of runway width on long landings.

4 Final remarks and conclusions

In this paper several factors that influence the airborne distance which can also affect the possibility of a long landing are discussed. It is clear that that are several factors that can be a reason for the aircraft to land long. The most dominate factors are flying too high and too fast during the airborne manoeuvre, significant tailwind, early flares, floating of the aircraft, and use of runway exits far down on a relatively long runway (it appears that long landings are not strongly correlated to the actual runway length: they occur as frequently on relatively short runways as on long runways with ample landing distance available. The runway exit position has a much stronger influence on the probability of long landings). Some of these factors could occur simultaneously increasing the possibility of a long landing even further. A large number of the factors that contributed to long landings can be traced back to an unstabilised approach. It is well known that flying a stabilised approach is important to flight safety. Other factors are related to good flying skills, decision making (e.g. decide to go-around) and adequate monitoring by the crew.

5 References

- Van Es, GWH. A Study of Runway Excursions from a European Perspective. NLR-CR-2010-259, 2010 (http://www.nlr-atsi.nl/eCache/ATS/14/919.pdf).

- Van Es, GWH. Running out of runway: Analysis of 35 years of landing overrun accidents. NLR-TP-2005-498, 2005 (http://www.nlr-atsi.nl/eCache/ATS/13/415.pdf).

- Van Es, GWH, Van der Geest, PJ. Cheng. A., Hackler L., Dillar A. A Study of Normal Operational Landing Performance on Subsonic Civil Narrow Body Jet Aircraft during ILS Approaches, Report DOT/FAA/AR-07/7 (also published as NLR-CR-2006-049), 2006. (http://www.tc.faa.gov/its/worldpac/techrpt/ar077.pdf)

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