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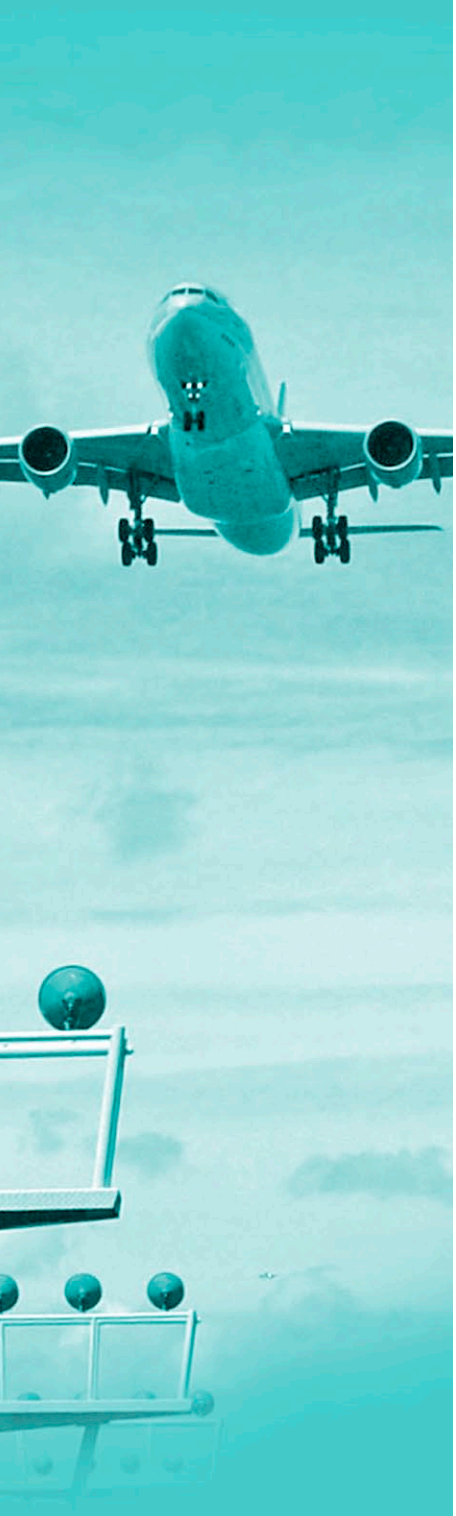

NLR-CR-2014-030

SAFETY ASSESSMENT OF LANDING PERFORMANCE FACTORS OF BUSINESS TYPE OF AIRCRAFT

G.W.H. van Es
J.N.M. van Eekeren

Executive summary

SAFETY ASSESSMENT OF LANDING PERFORMANCE FACTORS OF BUSINESS TYPE OF AIRCRAFT

Problem area

EASA Landing distance limitations oblige operators to calculate the landing mass at the destination airport in such a way a full stop is achieved at 60% of the Landing Distance Available for a turbo-jet aircraft and 70% of the Landing Distance Available for a turbo-propeller aircraft. This regulation originally applied to commercial air carriers only. However, it can now also apply to business aircraft operators. This limits the destinations that can be selected during dispatch.

Description of work

EBAA, in co-operation with GAMA and ERAC, intends to present a Safety Case that analysis the possibility of higher runway landing factors similar to the US. As a key input to this safety case the EBAA requires a safety assessment that investigates what risk reducing measures would be required to achieve an equivalent level of safety with landing factors higher than those stated by EASA.

Results and conclusions

A safety assessment is done for four different business aircraft types that are representative to the aircraft used by European business aircraft operators. Different mitigating measures are identified and their impact on the landing performance is determined. The impact of the identified mitigating measures is quantified using a landing distance simulation model. This shows that an equivalent level of safety with landing dispatch factors higher than those stated by EASA is achievable.

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SAFETY ASSESSMENT OF LANDING PERFORMANCE FACTORS OF BUSINESS TYPE OF AIRCRAFT

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SUMMARY

EASA Landing distance limitations as prescribed by CAT.POL.A.230 Landing — dry runways – of Annex IV [Part-CAT] of the Cover Regulation on Air operations [Reg. (EC) 965/2012] oblige operators to calculate the landing mass at the destination airport in such a way a full stop is achieved at 60% of the Landing Distance Available for a turbo-jet aircraft and 70% of the Landing Distance Available for a turbo-propeller aircraft. This regulation originally applied to commercial air carriers only. However, it can now also apply to business aircraft operators. This limits the destinations that can be selected during dispatch.

In the US, the FAA approved a change of the landing factor form 60% into 80% for business operators under certain conditions. Contrary to the FAA the EASA regulations do not (yet) provide a possibility for a relaxation of the landing factor. Since present EASA regulations are the most limiting, the EBAA claims that a situation “fair market distortion and unfair competition” occurs to business aircraft operators. Therefore EBAA, in co-operation with GAMA and ERAC, intends to present a Safety Case that analysis the possibility of higher runway landing factors similar to the US. As a key input to this safety case the EBAA requires a safety assessment that investigates what risk reducing measures would be required to achieve an equivalent level of safety with landing factors higher than those stated in EASA CAT.POL.A.230. The present report presents the results of this safety assessment. The assessment is done for four different business aircraft types that are representative to the aircraft used by European business aircraft operators. Different mitigating measures are identified and their impact on the landing performance is determined. The impact of the identified mitigating measures is quantified using a landing distance simulation model. This shows that an equivalent level of safety with landing dispatch factors higher than those stated in EASA CAT.POL.A.230 is achievable. The actual increase of the landing dispatch factors varies between the different aircraft types analysed.

CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

Commercial air carriers cannot take off for a destination airport unless the Airplane Flight Manual indicates that the jet aircraft is capable of a full stop landing at that airport within 60% of the effective length of the runway. The original 60% rule reflects the inability to accurately predict aircraft landing performance for aircraft that existed during the 1940s and provided a safety margin against landing overruns. During this period, performance variations existed among aircraft of the same model produced by the same manufacturer, and these differences were often significant. Also the ability to accurately forecast weather conditions at the planned airport destination was not available. Although the typical problems of the 1940s that justified the use of the 60% rule were resolved in the years after, the rule is still in use today. This is mainly because the certified landing distances do not always represent the landing performance that can be achieved during day-to-day operations. The dispatch factor now accounts for the deviate from the conditions during certification flight test (e.g. longer flares, longer transition times from touchdown to braking, lower deceleration values, and higher approach speeds). The landing dispatch factor itself was never formally changed despite many changes in operations and certification of commercial aircraft. Also other improvements like better weather forecasts, better pilot training, and improvements in aircraft systems like brakes, and anti-skid systems have also not been considered. Today the landing dispatch factor developed in the 1940s is still applied for jet aircraft operations (for turbo propeller aircraft a factor of 70% is used).

In 2000, the Fractional Ownership Aviation Rulemaking Committee proposed to the US Federal Aviation Authorities FAA that for certain business jet operations the 60% rule should be changed into 85%. The FAA finally agreed with a change of the landing factor into 80% however only under certain conditions. Operators using this higher landing factor must meet certain requirements identified in FAA 14 Code of Federal Regulation (CFR) Part 135.4 including two-pilot crew and specific additional flight crew experience and crew pairing requirements. Also the operator must have a Destination Airport Analysis Program (DAAP) to keep an acceptable level of safety for landing. The landing factor of 80% was to the knowledge of the present authors not determined by a formal quantitative safety assessment.

EASA has also regulations on landing factors that an operator needs to apply during dispatch which are similar to the FAA regulations. EASA Landing distance limitations as prescribed by CAT.POL.A.230 Landing — dry runways – of Annex IV [Part-CAT] of the Cover Regulation on Air operations [Reg. (EC) 965/2012] oblige operators to calculate the landing mass at the destination airport in such a way a full stop is achieved at 60% of the Landing Distance Available for a turbo-jet aircraft and 70% of the Landing Distance Available for a turbo-propeller aircraft. Contrary to the FAA the EASA regulations do not (yet) provide a possibility for a relaxation of the landing factor. Since present EASA regulations are the most limiting, the EBAA claims that a situation "fair market distortion and unfair competition" occurs to business aircraft operators. Therefore EBAA, in co-operation with GAMA and ERAC, intends to present a Safety Case that analysis the possibility of higher runway landing factors similar to the US. This is done in advance of the proposed rulemaking tasks RMT.0296 (OPS.008 a) & RMT.0297 (OPS.008 b) producing Opinion and Decision for Aeroplane CAT performance taking into account the European Action Plan for Prevention of Runway Excursion [EAPRE, (2013)]. As a key input to this safety case the EBAA requires a safety assessment that investigates what risk reducing measures would be required to achieve an equivalent level of safety with landing factors higher than those stated in CAT.POL.A.230. The present report presents this safety assessment.

1.2 PROJECT OBJECTIVES AND SCOPE

The objectives of the presented study are to:

- To determine if a level of safety equivalent to that implied by the runway factors in CAT.POL.A.230 can be achieved using higher runway factors and additional risk reducing measures;

- To conduct sensitivity tests to investigate how robust the conclusions of the risk assessment are and to determine what range of runway factors could be considered acceptably safe;

- To provide documented evidence that can support the arguments to be developed within the EBAA Safety Case;

- To determine, for certain types of business aircraft, how many runways/airports in Europe such a change in allowed landing distance would correspond to.

The safety assessment is conducted for performance class A, business operated aircraft with a takeoff mass of no more than 45,000 kg and a maximum seat capability of 19 seats or less (reflecting the largest business aircraft currently operated). Under EASA regulations performance Class A aircraft include multi-engine turboprop aircraft with more than 9 seats *or* a maximum takeoff mass exceeding 5700 kilograms, and all multi-engine turbojet powered aircraft.

2 PROJECT APPROACH AND PROPOSED METHODOLOGY

The proposed methodology for the safety assessment of runway landing factors of business type aircraft is discussed in this section.

2.1 OVERALL SAFETY ASSESSMENT APPROACH

The main objectives of the present study is to determine if a level of safety equivalent to that implied by the runway factors in CAT.POL.A.230 can be achieved using higher runway factors and additional risk reducing measures. In aviation, the level of safety is often defined in terms of the probability of an aircraft accident or incident occurring. In some cases the term risk is also used which refers to the combination of probability of an occurrence and the associated consequences. In this last case an equivalent level of safety can be achieved by reducing the probability of an occurrence and/or by reducing the consequences of the occurrence. In the present study the safety level is defined as the probability of a landing overrun. The consequences of a landing overrun are mainly influenced by the surface on which the aircraft runs on after leaving the runway and/or obstacles surrounding the runway end. The landing factors will primarily influence the landing overrun probability. In the present assessment consequences of landing overruns are therefore not taken into account.

The selected approach here is to calculate the landing overrun probability for a given runway length, landing factor and aircraft type under a wide variety of operational conditions (e.g. runway conditions, tailwind, etc.). The reference case which determines the level of safety to be achieved is defined here as the landing overrun probability with a 60% landing factor. Overrun probabilities for higher landing factors are then determined and compared to the reference case. Mitigating measures that could reduce the landing overrun probability are defined and the impact on the landing overrun probability is quantified.

2.1.1 LANDING OVERRUN PROBABILITY MODEL

In order to determine the safety level associated with a certain value of the landing dispatch factor, the landing overrun probability should be quantified.

Landings overruns are normally always caused by a combination of different factors. Typical important causal factors are: excess speed, long landings, late application of brakes, slippery runways, and strong tailwind [Van Es (2013), Van Es (2010)]. These types of causal factors have a direct influence on the landing stopping performance. Basically the energy during landing is too high (e.g. due to an unstable approach or tailwind) and/or the energy not reduced quickly enough during the landing resulting in an inability to stop the aircraft on the runway (e.g. due to slippery runways, late application of stopping devices etc.).

There are several ways to quantify the landing overrun probability. First of all statistical data on landing overruns obtained from worldwide or European operations could be used. This approach can give a good indication of the average probability. However a major drawback is that it is difficult to accurately account for airport and aircraft specific factors like runway length and landing performance characteristics with this pure statistical approach. Furthermore there are several interdependencies between factors that can't be easily quantified using statistical data only. In normal landing operations there is always randomness in the value of parameters such as pilot reaction times, speed deviations, aircraft weight variations etc. These factors play an important role that is difficult to assess using only statistical data. Therefore an alternative approach using simulations to quantify the landing overrun probabilities is used for the present study. NLR-ATSI has developed engineering aircraft performance models according to industry standards which accurately describe the landing performance of an aircraft. The landing performance models account for variations in environmental factors such as wind and runway contamination. Other factors like runway slope are also taken into account by the model. A schematic overview of the landing distance model is shown in Figure 1. The landing distance is calculated in distinct segments comprised of the air distance, the transition distance and the braking distance.

A number of factors in landing performance are not constant and can vary. To analyse the effects of these random and varying factors, a simulations are conducted using the Monte Carlo method. This allows simulating millions of landings under a wide variation of conditions in a reasonable amount of time[1]. For a given runway length it is then possible to calculate the probability that an aircraft cannot be stopped on the runway during a landing. In the Monte Carlo method, a landing distance model is used which includes (most of) the variables

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[1] The principal feature of a Monte Carlo simulation is that a large number of input random variables represented by probability distributions are utilised. The parameter values of the functions are randomly selected using a random number generator.

that could affect the landing distance. Independent random values of each significant operational variable are selected from estimates of the statistical distribution of the variable, and the resulting landing distance is determined. The estimates of the statistical distribution of the variables (such as deviation from target approach speed, significant floating during flare, time from touchdown to braking etc.) are based as much as possible on available operational landing data for business aircraft obtained from flight data monitoring programmes. A number of such data for business jet operations are available to NLR-ATSI. These data have been extended with additional data of EBAA members that have a Flight Data Monitoring (FDM) programme.

The Monte Carlo approach used here has also been successfully used to analyse landing dispatch factors in relation to EASA NPA 14/2004 [Transport Canada (2005)]. The method used here has been used successfully to change proposed regulation on landing performance in the past.

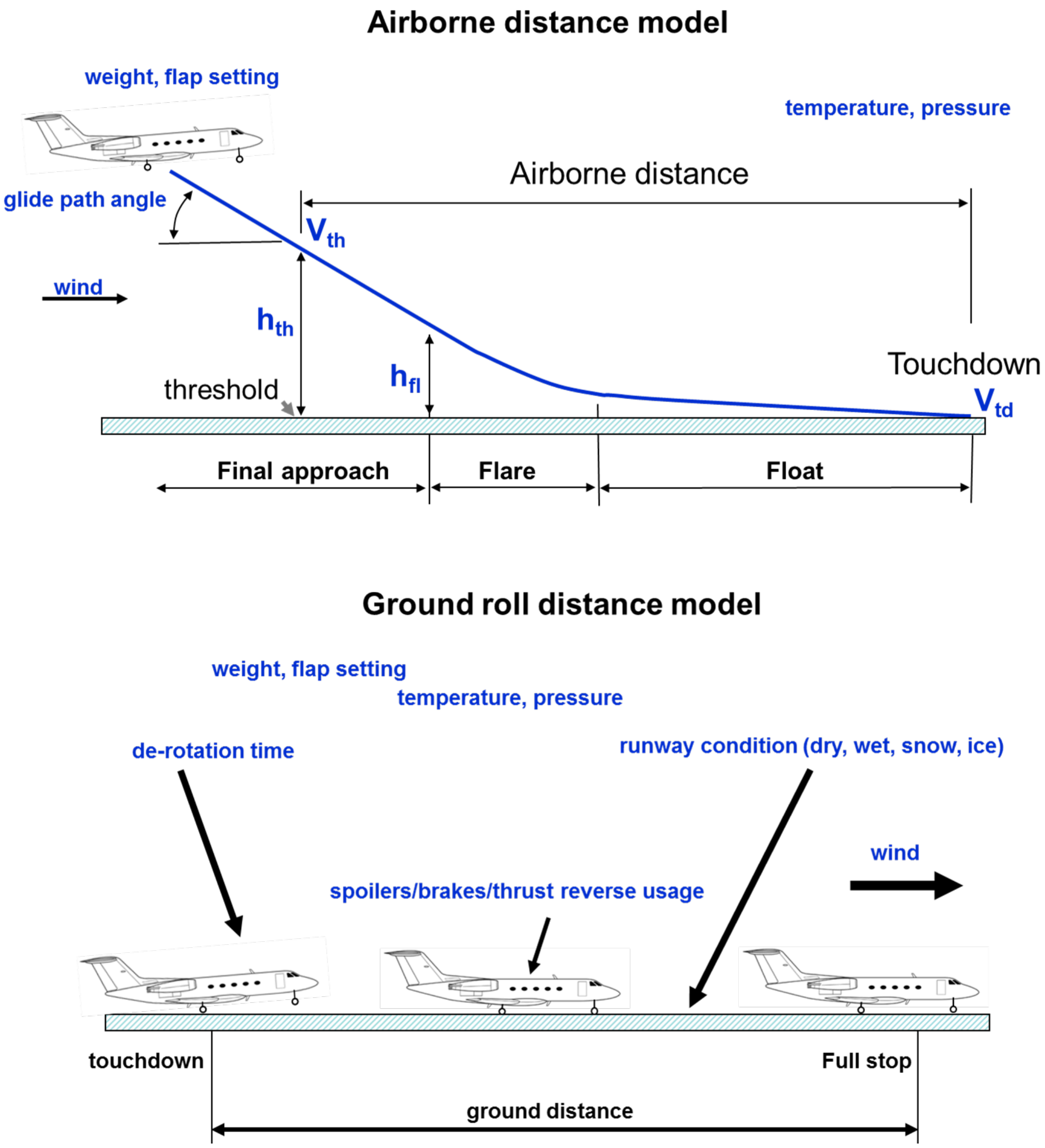

Figure 1: Schematic overview of the landing performance simulation model.

2.1.2 APPLICATION OF THE LANDING OVERRUN MODEL

The simulation model described in section 2.1.1 is applied to a limited number of business type of aircraft considered to be representative for their category. The assessment is done for EASA performance class A, business operated aircraft as defined in the project scope. Performance Class A aircraft include multi-engine turboprop aircraft with more than 9 seats or a maximum takeoff mass exceeding 5700 kilograms, and all multi-engine turbojet powered aircraft. The present assessment is limited to 3 business jet aircraft and 1 business twin turboprop aircraft. Based on ownership and usage data of business aircraft operators in

EASA countries (see e.g. Figure 2) the following four aircraft categories are used for the safety assessment:

- 13-19 passenger jet aircraft (like the Gulfstream G550/G650, Dassault Falcon 2000, Dassault Falcon 900, CL-600) ;
- 9-12 passenger jet aircraft: (like the Citation Excel, Hawker Horizon, Learjet 45) ;
- 6-8 passenger jet aircraft: (like Cessna CJ3, Cessna mustang, BEECHJET, BAE-125, Premier, MU-300);
- 14 passenger turbo prop: (like the Beech king Air series);

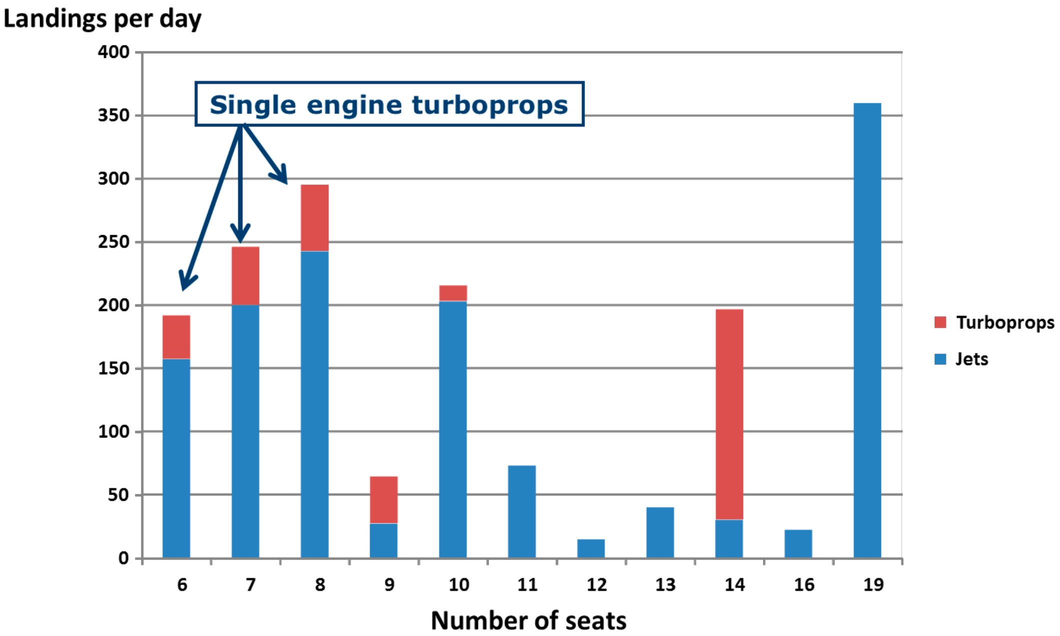

Figure 2: Activity data of business operated aircraft in Europe (source Eurocontrol STATFOR, 2012).

For each category a model of a representative aircraft is selected and used for the simulations.

For the selected aircraft types Monte Carlo simulations on landing distance are performed. The main result of these simulations is a range of actual landing distances that are compared to the available runway length (LDA). From that a landing overrun probability can be calculated. As a first step an assessment is done for a 60% landing factor for jets and 70% factor for turboprops assuming the normal dispatch requirements. For those individual cases where the aircraft cannot comply with the dispatch landing distance requirement the result is disregarded from the simulation. The landing overrun probability associated with the landing factor of 60 or 70% is assumed to be a value for the level safety that needs to be achieved. In the next step the assessment is done for higher landing factors. This increase of the landing factor will automatically be associated with an increase in landing overrun probability compared to the lower values as the runway margins become less (shorter runways become available to land on). To account for the increase in landing overrun probability mitigating measures are identified and the impact of the measure on the operation is determined. For each mitigating measure and combinations of measures the assessment is done for a range of landing factors. This is repeated until an overrun probability is found that is equal to the reference value for a landing factor of 60/70%. Note that the reference case does not include any of the mitigating measures identified. Figure 3 illustrates the overall safety assessment process.

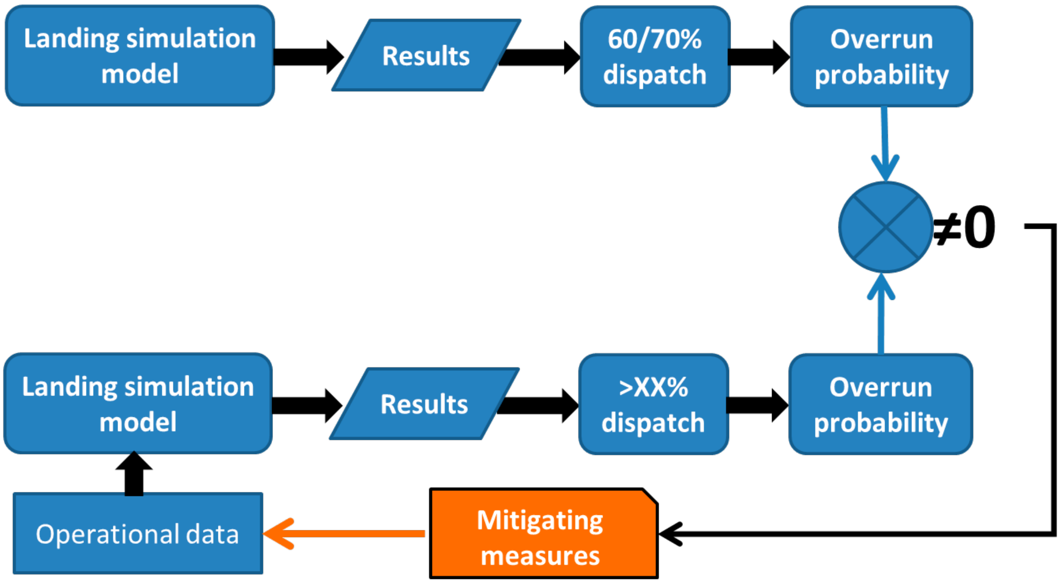

Figure 3: Illustration of steps taken in safety assessment.

The landing factors discussed so far are for dry runways. However changing these dry runway factors could also affect the safety when landing on none-dry runways. In the landing distance simulations wet and contaminated runways are also considered through a reduction in deceleration during the ground roll. Regulations require during dispatch an additional landing distance factor of 1.15 to be used on top of the dry runway factor when the runway is forecasted to be wet or contaminated[2]. Changes to this additional non-dry runway landing factor are not considered in the present study. All dispatch calculations conducted in the present assessment assume a factor of 1.15 for wet/contaminated runways on top of a dry runway landing factor.

2.1.3 LANDING DISTANCE MODEL

Aircraft performance models are used here developed according to industry standards and practices. These models accurately describe the landing stopping performance of an aircraft. The landing performance models account for the aircraft characteristics, variations in environmental factors such as wind, runway contamination and other factors like runway slope are also taken into account by the model. A schematic overview of the landing distance model is shown in Figure 1. The landing distance is calculated in distinct segments comprised of the air distance, the transition distance and the braking distance. For each segment engineering models are used. The first segment is calculated using the method developed by ESDU [Mitchel (1991)]. This gives a detailed engineering model for estimating airborne distance for fixed-wing aircraft. The method is based on energy considerations. It is based on analyses of measured performance for a wide range of aircraft types including business jets and business propeller-powered aircraft. It accounts for factors like different styles of landing flares (e.g. floating), influence of speed losses, approach speed variation, wind and runway slope. The second segment in the landing distance is calculated using the touchdown speed (as determined in the first segment calculations), wind speed, and transition time. Finally the third segment is calculated using the e.g. the speed after transition ending, wind speed, time of use of thrust reversers, runway slope, and runway condition [see e.g. Boeing (2009), ESDU (2006)].

Models are developed for 4 classes of business aircraft as described in section 2.1.2. For each class data for an existing aircraft was used and a landing distance model was developed using the characteristics of this aircraft (e.g. wing area, maximum lift coefficients, wing aspect ratio, declarations capabilities, influence of thrust reverser etc.). The results obtained with the landing distance performance models are compared to the published landing performance data of the actual aircraft. Appendix A shows some comparisons of the landing distance

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[2] If the computed landing distance on a contaminated runway (calculated according to EASA CS 25.1591 or other advisory data provided by the manufacturer) plus a 15% safety margin is less than the factored wet runway landing distance, the factored wet runway landing distance prevails. This is taken into account in the landing simulations.

as calculated by the NLR engineering model and published performance data. Typically the average difference between the landing distance model and the published manufacturer data is less than 1.5% which is more than acceptable for the present study. Note that in the present assessment the 19 and 12 passenger jets and the 14 passenger turbo prop aircraft are equipped with thrust/propeller reversers, whereas the 8 passenger jet has no thrust reverser installed. This reflects the typical standards of aircraft in these categories.

The distributions of the variable parameters affecting the landing distance used in the Monte Carlo Statistical Analysis are obtained from operational flight data of a number of business aircraft operators and other data sources available to NLR [FDM (2013)]. Frequency distributions are determined for parameters like head-tailwind during landing, flare characteristics, pilot reaction times, reverse thrust usage, glide slope deviations, runway conditions, speed deviations, runway slope, temperature etc. During each run in the landing simulation a runway length (LDA) is randomly selected. The distribution of this runway length is based on the frequency of airports used in Europe for the 4 different business aircraft categories considered in this study. These data were obtained from the Eurocontrol Statistics and Forecast Service, STATFOR[3].

A large number of runs is required to establish a reliable estimate of model uncertainties. The total number of runs used here is based on a standard error of less than 1% of the mean statistic defined as the ratio of the standard deviation of the calculated landing distance and the square root of the number of trials in the simulation. According to this measure the minimum required number of runs is in the order of 350 million. Most of the simulations were conducted with more than 350 million.

A number of metrics can be considered to validate the Monte Carlo simulation model results. The ultimate metric is the landing overrun probability. However a direct comparison of the model predicted and historical landing overrun probabilities is not straightforward. Historical data on landing overruns need to be assessed over some time to obtain statically accurate rates (say 10-20 years). During such a period many changes could have occurred in the operational characteristics and technical developments which cannot always correctly be assessed within the model. Also the historical data are mainly recorded for accidents and serious incidents whereas the model results are for all types of overruns irrespectively of the consequences. The historical data therefore could

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[3] The Central Route Charges Office of EUROCONTROL is a key data source to STATFOR. It includes all IFR flights and only those VFR (Visual Flight Rules) flights which are chargeable.

result in lower overrun rates than calculated. Furthermore the Monte Carlo landing model is run for certain aircraft type whereas the historical data normally covers a wide range of different aircraft types. Nevertheless the probabilities calculated by the model have been compared to some historical data. It was found that these are in the same order of magnitude as historical rates or somewhat higher[4]. A second way of validation of the Monte Carlo model is done by looking how strongly model parameters influence the landing distance (and hence the landing overrun probability) and compare these with causal factors in landing overruns as an equivalent. Figure 4 shows how strongly different parameters in the model correlate with the calculated landing distance by the simulation model. The closer the correlation coefficient is to ±1 the stronger the correlation between the parameter and the landing distance is. A positive value of the coefficient relates to an increase in landing distance. For instance a non-dry runway will significantly affect the landing distance (increase) whereas a headwind (as opposite to a tailwind) significantly reduces[5] the landing distance. This is reflected by the model as shown in Figure 4.

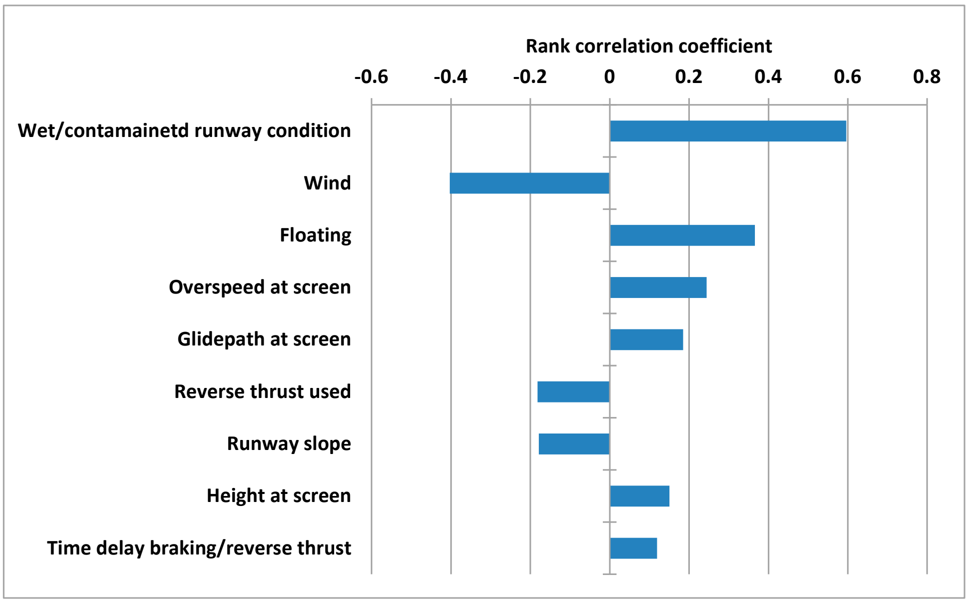

Figure 4: Correlation of model parameters with landing distance in Monte Carlo simulation.

When compared to the major causal factors in landing overruns with business aircraft (see Figure 5), the model parameters show a very similar pattern in terms importance. This is also an indication that the model produces validate results.

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[4] It can be expected that the model would be slightly more conservative (identifying more landing overruns).

[5] As more landings are made wind a headwind rather than a tailwind, the correlation coefficient shown is negative. The results show a strong influence of wind.

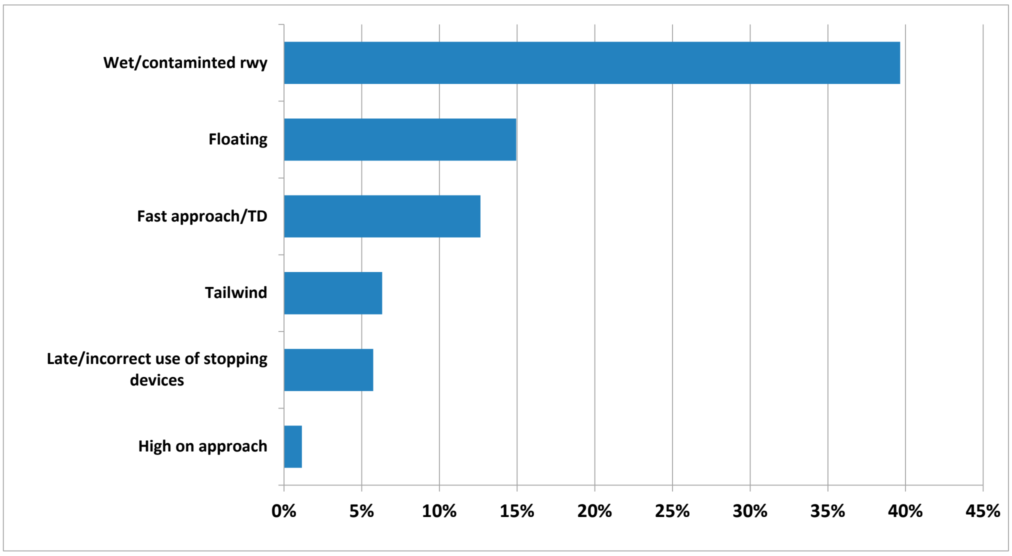

Figure 5: Causal factors in landing overruns with business aircraft as percent of overruns with known causes ([Van Es (2013)].

2.1.4 IMPORTANT ASSUMPTIONS IN LANDING DISTANCE SIMULATIONS

It is assumed in all calculations that any installed equipment that would influence the landing distance is serviceable. It is therefore assumed that no MEL dispatch occurs with inoperative systems such as ground spoilers (if installed), anti-skid systems, brakes, thrust reversers (if installed), and flaps[6]. Malfunctions of these systems can have a significantly greater impact on the actual landing distance and hence on the landing overrun probability than changes in the landing dispatch factors. Table 1 gives an overview of typical increases in landing distance for a number of system malfunctions for executive type of aircraft as found in flight manuals. Finally it should be noted that the failure rates of aircraft systems are not affected by the landing dispatch factor itself.

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[6] This means that during dispatch with higher landing factors these systems should be available.

Table 1: Typical values for landing distance increase for different system malfunctions.

Malfunction	*Typical increase in landing distance (dry runway)*
No ground spoilers	150-170%
No anti-skid	160-200%
No brakes	200-300%
No flaps	130-150%

There are different types of runway contaminates all with their specific impact on stopping performance. For the present study the braking characteristics associated with a flooded runway are used without any kind of contamination drag to account for the effect of contaminated runways on landing stopping performance. This gives a good average representation of impact of the different types of contaminated runways.

All Monte Carlo simulations are conducted with a so-called fixed seed value[7]. This means that the results from simulation will not change each time it is run. As the present study looks at the impact of different mitigating measures it is important that the changes in the simulation results are not caused by the different seed values used to generate random numbers.

It is assumed for all calculations that the conditions at the destination airport have not changed while flying the mission[8]. This means that the weather and runway conditions known during dispatch are assumed to be same when landing at the destination airport.

During each run in the simulation a runway length is randomly selected. The distribution of the runway length is based on the frequency of airports used in Europe for the 4 different business aircraft categories. These data are obtained from Eurocontrol. Both a minimum and maximum runway length is used in the

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[7] Starting off with a seed value generates a particular sequence in the simulation. A different seed value will result in another sequence and hence other results if insufficient simulations are conducted.

[8] In reality the conditions forecasted for the destination airport can change. The accuracy of a forecast (e.g. wind and runway condition) depends on a number of factors such as the quality of the local met office, regional influences, and the overall time for which the forecast is valid. By assuming unchanged conditions at the destination airport some error is introduced. However, it is believed that this error will be small as the actual conditions could be worse or better than forecasted. Also it is imperative that crews will perform an inflight weather check to assess if a safe landing can be performed.

simulation reflecting the actual limits in runway length at the European airports used by the involved business aircraft category.

All simulations are done for airports with normal approach angles (2.5-3.5 degrees). Some airports require steep approaches. Some business aircraft have been certified to conduct such steep approaches. Steep approach procedures at airports could require lowering the threshold crossing height to e.g. 35 feet, allowing for an early touchdown. It is accepted that these types of operation allow less margin for error and that steep approaches require special training and procedures. Special procedures, such as steep approaches are outside the scope of this analysis. It is sometimes suggested that operations on very short runways will increase pilot’s alert levels. Psychological effects on pilot reaction times during operations on e.g. short runways; adverse weather operations; mountainous terrain etc. are also outside the scope of this analysis. Finally all special operating conditions such as MMEL; low visibility; special approach procedures (e.g. leading to go outside the stabilized approach criteria), etc. are not considered in the analysis.

3 RESULTS

3.1.1 IDENTIFICATION OF MITIGATING MEASURES

Mitigating measures are identified that could bring the level of safety for operations with the higher landing factors to the same level as for 60% or 70% landing factors. These mitigating measures were defined using available information from the literature e.g. European Action Plan for the Prevention of Runway Excursions, items covered in a Destination Airport Analysis Program used by some US business aircraft operators, runway excursion safety studies, and assessments done by operational experts. The actual influence of some of the mitigating measures on related landing parameters⁹⁾ (e.g. tendency to floating, deviation from target speed at threshold etc.) had to be estimated through engineering judgement and/or known results from best practices from commercial airlines.

After a careful analysis of the available information and expert knowledge the following mitigating measures are considered in the present analysis:

- Avoidance of continuation of unstable approaches;
- Avoidance of long landings (floating);
- Use of reverse thrust or propeller reverse on each landing (if installed);
- No landings on a runway that is forecasted to be contaminated or with a braking action of less than GOOD[10];
- No landings on a runway forecasted to have a tailwind;
- No MEL dispatch is allowed with inoperative systems such as ground spoilers, anti-skid systems, brakes, thrust reversers and flaps.

3.1.2 BACKGROUND ON MITIGATING MEASURES

This chapter identifies reasoning behind the various factors leading to an increased overrun risk for business type aircraft operators which are used for defining mitigating measures. The next section, 3.1.3 addresses the mitigation measures that operators could implement.

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9) NLR-ATSI has access to a large collection of operational landing flight data from commercial airlines from which this can be estimated.

[10] Currently a new classification is being explored for runway friction classification (TALPA ARC Runway Condition Assessment Matrix). This will have a different classification for runways using numbers instead of braking action.

Stabilised approaches

Flight data from business operators show that compared to commercial operators a larger percentage of unstabilised approaches are continued [FDM (2013), Van Es (2013)][11]. Flight data from business operators show that there are significantly more overspeed events at the threshold during unstable approaches than during stable approaches and that the threshold crossing height distribution is similar for both unstable and stable approaches. The flight data also show that for business aircraft the speed deviations at the threshold are much higher than with landings of commercial airlines. It should be possible for business operators to obtain similar speed deviations at the threshold as the commercial airlines with the appropriate measures. For this flight crews of business operators should conduct a stabilised approach according to published criteria by the operator so as to cross the threshold at 50 feet and calculated speed in the intended landing configuration. Any approach which is not stabilised should result in executing the published missed approach procedure and no attempt should be made to continue the landing.

Long landings/floating

Flight data from business operators show that compared to commercial operators long landings occur more often within the business aircraft operations [FDM (2013), Van Es (2013)]. This is illustrated in Figure 6. It should be possible for business operators to reduce the amount of landings with significant floating to the same level as commercial operators. Flight crews should therefore aim to touchdown within the first 1000-1200 feet, avoiding floating as a mitigating measure.

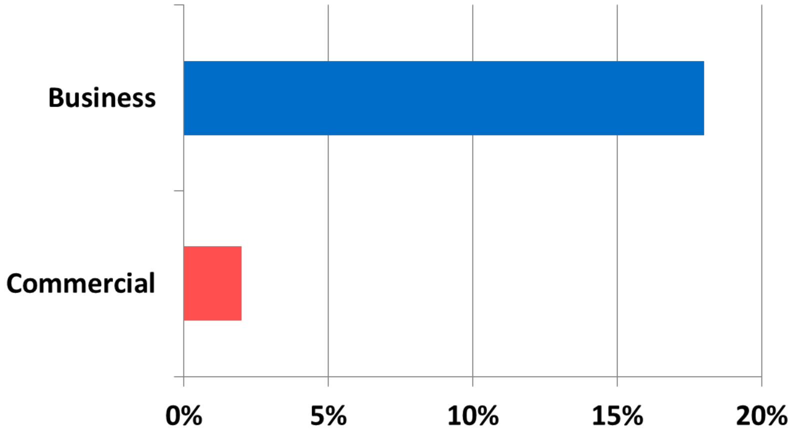

Figure 6: Comparison long landing rate [Van Es, (2013)].

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[11] Commercial operations have an unstabilised approach rate in the order of 1-8% and business operations have a rate in the order of 4-14%. Only 1-2 % of unstabilised approaches resulted in a go-around.

Maximum reverse thrust

Late or incorrect use of reverse thrust is a contributing factor in landing overruns. Reverse thrust is especially effective on slippery runways. EAPRE recommendation 3.4.24 explicitly recommends the use of immediate full reverse on wet contaminated runways irrespective of any noise related restrictions.

No tailwind landings

Data show (refer to figure 3 and 4 of paragraph 2.1.3) that the Landing overrun risk is considerably increased in tailwind conditions. Variations of the forecasted wind with the actual wind cannot be avoided. However the probability of large deviations can be reduced by limiting the planned mean forecasted wind and by a forecast with high accuracy. Weather reports should therefore always come from a formally approved source and no forecasted tailwind should exist.

No landings on contaminated runways

Data show (refer to figure 3 and 4 of paragraph 2.1.3) landing overrun risk is considerably increased on contaminated runway operations. Although at the moment the interpretation of contaminated runway is changing; this analysis refers to the EASA definition. Reducing the landing overrun risk could therefore also be achieved by not considering operations on runways forecasted to be contaminated during dispatch. It is also important that the weather forecasts and possible runway reports are of high accuracy. Weather and runway reports should therefore always come from a formally approved source.

Dispatch items

It is assumed for all calculations that any installed equipment that would influence the landing distance is serviceable. This means that no MEL dispatch is allowed with inoperative systems such as ground spoilers, anti-skid systems, brakes, thrust reversers and flaps when using a higher landing factor than 60% for jets or 70% for turbo props.

3.1.3 IMPLEMENTATION OF THE MITIGATING MEASURES

In this section details are provided how operators can achieve a successful implementation of the different mitigating measures.

Operational restrictions

The operational restrictions to destinations such a contaminated runways, no tailwind, or no MEL dispatch with inoperative systems such as ground spoilers (if installed), anti-skid systems, brakes, thrust reversers (if installed), and flaps, can be covered in a dispatch checklist. The only extra provision here would be to assure that the data for the wind and runway reports are from an approved and reliable source. These limitations could reasonably simple be implemented at dispatch.

It will prove more challenging to implement stabilized approaches, go-arounds, correct 50' height crossing speed, avoiding floating, fast or long landings, timely use of brakes and reverse etc. as mitigating measures. All these items are dependent on human, crew performance. Only stating in an operational manual that e.g. "a correct approach and landing must be applied when using a higher landing factor" would be correct but at the same time be insufficient. Thus getting grip and improving crew performance is needed. A traditional method trying to quantify crew's performance is to refer to flight hours. Apparently it is assumed that more flight hours will provide a certain guarantee that approaches are flown stable and landings are conducted normal.

The FAA requires that when operators would like to plan with higher landing factors (EOD)[12], their pilots are trained in accordance with an approved Destination Airport Analysis Program (DAAP). The crew shall consist of minimal 2 qualified pilots; the PIC should have an ATPL, type rating and minimal1500 hours. The SEC should have a CPL IR with minimal 500 hours and either one must have minimal 75 hours on type for operations under the DAAP. Basically tries this traditional method based on flying hours to assure that operations with a higher landing factor would be flown accurate enough. However it might be expected that e.g. 1000 hours/ year on long haul flights only will be of far less significance than 50 landings/year on short runways. Thus regular exposure to short or critical runway operations could be regarded as a mitigating factor. Especially during operations with higher landing factors the combination of exposure, training and monitoring could prove to be of higher value than a flight hours alone criteria in assuring that the crew as mitigating element is acceptable.

The EAPRE provides evolved recommendations on improving crew performance.[13]. Adopting these EAPRE recommendations would enable accepting crew performance as mitigating measure with reference to stabilized approaches, avoiding floating, long or fast landings, immediate use of braking devices. Experience by the large commercial aircraft operators learned that a combination

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[12] The Eligible On Demand operator must meet certain requirements identified in FAA 14 Code of Federal Regulation (CFR) Part 135.4

[13] (EAPRE 3.4.3; 3.4.15;)

of regular exposure, continuous training (theoretical and practical), checking and monitoring proved to be a successful method to achieve the desired crew performance.

Stabilised approach

Especially during operations with an increased landing factor the crews mind set should be that the approach would result in a go-around except when all parameters of the stabilized approach are met[14]. This mind set can only be achieved if promoted by the operator and trained as such. Experience by large commercial operators and business aircraft operators show that a non-punitive FDM program not only enhances crew's awareness, but also provide operators a good method of improving specific training and or operations. Another element of avoiding un-stabilised approaches is technology. Presently special on-board warning equipment is available warning the pilot when an unstabilised approach is flown. Such stabilised approach monitor systems offer a supplement to the flight crew awareness of unstabilised approaches. Such systems automatically issue advisories if the pre-defined stabilised approach criteria for e.g. flaps, speed, and approach profile are not met.

Long landings / floating

For operations with the increased landing factor are correct landings at the correct speed and touchdown point more important since the margin for error is proportionally reduced with the increased landing factor. A stabilised approach helps achieving this, but is no a guarantee. During these types of operation a firm and correct touchdown is preferable over a smooth, soft, and long landing. Operators should provide adequate training, passengers should be briefed and the crew should be aware of the aiming point and ultimate touchdown point[15]. A non-punitive FDM program will help reducing the long landing / floating factor. Currently special on-board warning equipment is available for some aircraft that helps to warn the pilot when a long landing occurs. If the aircraft has not touched down before a pre-defined threshold, the system will activate an aural (caution) message upon the crew can react (e.g. balked landing).

Immediate use of all braking devices

Data show that too late using full reverse thrust (if installed) or too late wheel braking are a causal factor in landing overruns (see e.g. Figure 5). Especially low speed overruns occur often after late application of wheel brakes and finding out

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[14] EAPRE 3.4.16; 3.4.18; 3.4.19

[15] EAPRE 3.4.21; 3.4.22;

too late that the deceleration is not what is expected to be. Immediate use of all available stopping devices is not only necessary on wet runways but is also required when operating under the increase Landing Factor.[16] This element should be adequately trained and monitored as well.

Flight Data monitoring

EAPRE 3.4.2 recommends that operators should include and monitor aircraft parameters related to potential runway excursions in their FDM program. Flight Data Monitoring is the pro-active use of digital flight data from routine operations to improve aviation safety and is mandatory for aircraft with a maximum certificated take-off mass (MCTOM) in excess of 27 000 kg. FDM is now being used by aircraft operators throughout the world to inform and facilitate corrective actions in a range of operational areas. It offers the ability to track and evaluate operational safety trends, identify risk precursors, and take the appropriate remedial action. These actions include, but are not limited to, specific training, improved operations and addressing identified potential safety risks.

Typical parameters would be related to the stabilized approach, touchdown point, touchdown speed and the moment of using the various braking devices. Data from various operators (airline and business) show that approach and landing deviations have been reduced considerably after implementing a non-punitive FDM program[17]. The European Authorities coordination Group on Flight Data Monitoring provides material on implementing FDM programs and standardised FDM based indicators.

The main goals of a FDM program should be to recognise trends in unstabilised approaches, long landings, fast landings and / or late application of braking devices. It could also serve in a non-punitive environment as a specific crew awareness method. It is recognised that FDM is in general not obliged for business type operators and also not all business type operators would be in a position to set-up an own FDM. Nevertheless is it expected that a voluntarily FDM would enhance the possibility of regarding crews as a solid mitigating factor during increased landing factor operations.

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[16] EAPRE 3.4.24; 3.4.25;

[17] The European Aviation Safety Plan addresses specifically the role of FDM in the risk of runway excursions.

Other factors

Visual clues

Especially during the final approach phase could visual clues influence the perception of pilots. Factors that are mentioned [18] to increase the possibility of the overrun risk are wide, short runways, downslope, low intensity lighting and haze. These items should be addressed in crew training but should not be a regarded as limiting factors for planning with higher landing factors.

Threshold crossing height

It is generally accepted that each deviation of + 50 ft threshold crossing height, typically increases the landing distance by 300 meter. Crossing the threshold too low, increases the risk of an undershoot and decreases the margin for error. Planned deviations from the threshold crossing height are not considered in this analysis.

Conclusion on realism of mitigating measures.

It is reasonable to expect that the mentioned operational limits (contaminated runways, no tailwind, or no MEL dispatch with inoperative systems such as ground spoilers (if installed), anti-skid systems, brakes, thrust reversers (if installed), and flaps) can be adhered to during dispatch.

Crew related items require a more comprehensive approach. First of all is adequate training essential, second a reasonable amount of exposure and finally an (voluntarily) implemented FDM program would be beneficial.

3.1.4 IMPACT OF MITIGATING MEASURES ON LANDING OVERRUN PROBABILITY

In this section the influence of the identified mitigating measures on the overrun probability for higher landing factors is presented and discussed. First Figure 7 shows the influence of different landing dispatch factors on the overrun probability relative to the reference case of each of the four aircraft types considered without any mitigating measures[19]. As shown increasing the landing factor without any mitigating measures will increase the landing overrun probability. The influence of the landing factor on the overrun probability differs for the different aircraft types. The lowest influence in noticeable for the 14 passenger turbo prop aircraft and the highest for the 12 passenger jet. During each run in the landing simulation a runway length (LDA) is randomly selected.

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[18] Airbus getting to grips ALAR.

[19] Shown is the ratio between the overrun probability for a given landing factor and the probability for the reference case.

The distribution of this runway length is based on the frequency of airports used in Europe for the 4 different business aircraft categories. The frequency distributions of the LDA vary for the four aircraft which to some extend explains the differences between the aircraft shown in Figure 7. The rather low change of probability with increasing landing factor for the 14 passenger turbo prop can be explained by the fact that this type of aircraft is not frequently used at airports with short runways according to the Eurocontrol operational data. Therefore increasing the landing factor (which provides the opportunity to land at shorter runways) has not a strong influence.

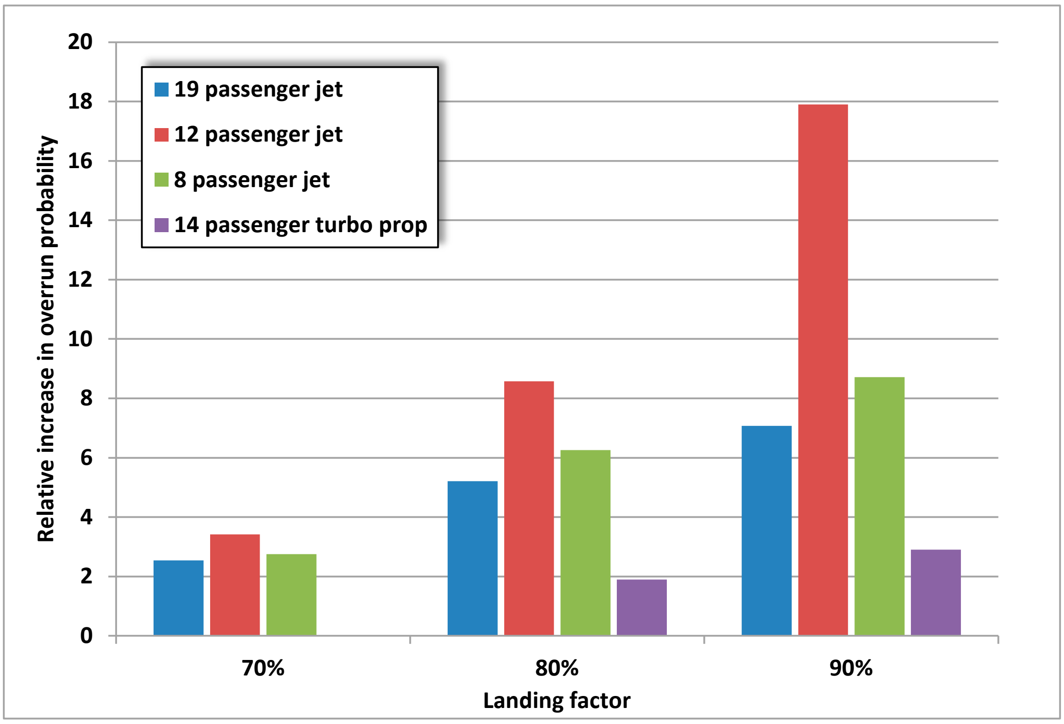

Figure 7: Influence of landing factor on the relative overrun probability (relative to the 60% or 70% factor for jets and turbo props respectively).

Next the influence of mitigating measures on the overrun probability (as discussed in the previous section) on the landing overrun probability is discussed. The analysis was conducted with those measures and combinations of measures that were considered to be the most promising ones which also could be introduced without great difficulties or effort. For all cases it is assumed that systems such as ground spoilers, anti-skid systems, brakes, thrust reversers and flaps are operative at the landing. For combinations of mitigating measures the landing factor was determined which would provide an equivalent level of safety to the reference case with a 60% or 70% landing factor (for jets and turbo props respectively). The overall process is illustrated in Figure 8. The simulation is rerun with small increments of the landing dispatch factor until an equivalent level of safety is found.

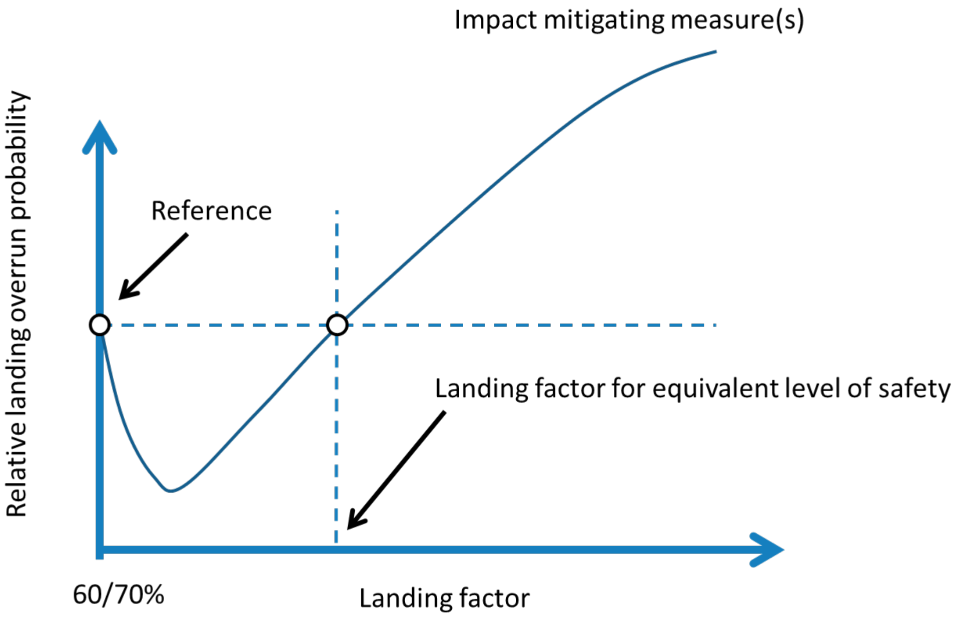

Figure 8: Illustration of the process for determining an equivalent level of safety for a given (set of) mitigating measure(s).

It should be noted again that the reference cases do not include any of the mitigating measures. The results of the safety analysis are shown in Table 2. The combination of mitigating measures shown in this table were chosen as such that they provided the most effective influence in reducing the overrun probability compared to the reference case. The analysis started with the restriction of landings on contaminated runways as initial analysis indicated that this provided the most significant reduction of landing overrun probability of all mitigating measures identified. The results show that the restriction of landings on contaminated runways[20] provides an additional 8-12% landing factor for the business jets. The turbo prop aircraft only gained 1% in landing factor with this measure[21]. Restricting tailwind landings together with no landings on contaminated runways provides an additional 11-14% landing factor for the business jets. The effect of these combined measures for the turbo prop aircraft is small again as only 2% is gained in the landing factor. The addition of the

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[20] This is equivalent to a reported braking action less than GOOD.

[21] As propeller reverse is highly effective and can be used down to much lower speeds than reverse thrust on jet aircraft the influence of restricting contaminated runway landings does not have a significant effect on the landing overrun probability of the 14 passenger turbo prop aircraft analysed here.

100% use of reverse thrust or propeller reverse (if installed) on each landing to the previous measures provides an absolute increase in the landing factor of 12-18% for the business jets and 8% for the turbo prop aircraft[22]. Reverser thrust is most effective in reducing stopping distance on contaminated runways. As contaminated runways are already excluded as a mitigating measure the impact of a 100% use of reverser thrust is now mainly for wet runway landings which is normally much less than for contaminated runways. Finally use of all mitigating measures considered provides an absolute increase in the landing factor of 18-22% for the business jets and 11% for the turbo prop aircraft on top of the reference landing factor of 60% and 70% respectively.

Table 2: Landing factors with an equivalent safety level for different mitigating measures.

Mitigating measure(s)*	**13-19 passenger jet**	**9-12 passenger jet**	**6-8 passenger jet**	**14 passenger turbo prop**
No landings on contaminated runways	69%	72%	68%	71%
No tailwind landings, no landings on contaminated runways	71%	74%	71%	72%
No tailwind landings, no landings on contaminated runways, 100% reverse thrust	72%	78%	N/A**	78%
No tailwind landings, no landings on contaminated runways, 100% reverse thrust, reduced unstable approaches, limited floating	78%	82%	74%	81%

** It is assumed that systems such as ground spoilers, anti-skid systems, brakes, thrust reversers and flaps are operative.*

***Aircraft type does not have thrust reversers installed.*

It can be concluded that when the identified mitigating measures (no tailwind landings, no landings on contaminated runways, 100% reverse thrust, reduced unstable approaches, limited floating) are all applied, an equivalent level of safety compared to the landing factor of 60% /70% is achieved at a landing factor of 78% (13-19 passenger jet); 82% (9-12 passenger jet); 74% (6-8 passenger jet) and 81% (14 passenger turbo prop). With the exemption of the 8-passenger jet the figures are close to the FAA 14 CFR part 135.4 of 80%.

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[22] Analysis of flight data of business aircraft operators indicated that reverse thrust is normally used during 90-99% of all landings. An average of 95% utilisation is assumed in the reference case.

3.2 IMPACT OF LANDING FACTOR ON RUNWAYS/AIRPORTS IN EUROPE

For a number of business aircraft it is determined how many additional runways (in Europe) a change in the landing factor would provide at dispatch. For this the NLR-ATSI airport database is used which contains detailed information on Landing distance Available LDA of all runways in Europe. Only those European airports are considered that according to Eurocontrol STATFOR data were used at least once a day on average by business aircraft in 2013. Landing distances for the different aircraft types considered are obtained from the official flight manuals of these aircraft. The assessment is conducted for still air conditions and a maximum landing mass. Only the most commonly used aircraft for business operations in Europe[23] are considered. The results are shown in Table 3. The percentages in this table show the increase in the number of runways available during dispatch relative to a landing factor of 60% for jets and 70% for turbo props.

For jets a landing factor of 70% the number of available runways increases between 5 and 20% with an average of 9%. For a landing factor of 80% this ranges from 10-31% with an average of 15%. For the turbo props little is to gain with an increasing landing factor as the airports used by these aircraft have runways that are much longer than required during dispatch for these aircraft.

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[23] The most commonly used twin turboprop aircraft in an executive role are the Beech King Air 200 and the King Air 90 accounting for more than 75% of all aircraft activity in Europe (source: STATFOR Eurocontrol).

Table 3: Impact of higher landing factors on the increase in available runways for dispatch in Europe.

Aircraft type	**70% landing distance factor**	**80% landing distance factor**
F900EX	17.1%	25.3%
F2000EX	11.9%	20.6%
7X	8.6%	14.3%
G550	6.0%	10.3%
LR60	19.7%	30.6%
MU-300	6.3%	10.8%
Beechjet 400	8.1%	15.1%
HS-125-800	5.4%	10.7%
Mustang	6.0%	11.2%
CJ1	6.8%	11.2%
XLS	9.2%	14.5%
CJ2	7.1%	13.5%
CJ3	6.1%	10.6%
King Air 200	N/A	2.3%
King Air 90	N/A	0.0%

4 CONCLUSIONS

The present report presents the results of a safety assessment that investigates what risk reducing measures would be required to achieve an equivalent level of safety with landing dispatch factors higher than those stated in EASA CAT.POL.A.230. The assessment is done for four different business aircraft types that are representative to the aircraft used by European business aircraft operators. Different mitigating measures are identified and their impact on the landing performance is determined using e.g. operational flight data. The impact of the identified mitigating measures is quantified using a landing distance simulation model. This shows that an equivalent level of safety with landing dispatch factors higher than those stated in EASA CAT.POL.A.230 can be achieved. It is concluded that when the mitigating measures no tailwind landings, no landings on contaminated runways, 100% reverse thrust, reduced unstable approaches, and limited floating are all applied, an equivalent level of safety compared to the landing factor of 60% /70% is achieved at a landing factor of 78% (13-19 passenger jet); 82% (9-12 passenger jet); 74% (6-8 passenger jet) and 81% (14 passenger turbo prop). With the exemption of the 8-passenger business jet the figures are close to the FAA 14 CFR part 135.4 of 80%.

It is shown that higher landing factors will increase the number of runways (and hence airports) available during dispatch. This applies to all business jet aircraft analysed. However, turbo prop business aircraft show hardly any increase of available runways with increasing dispatch factor.

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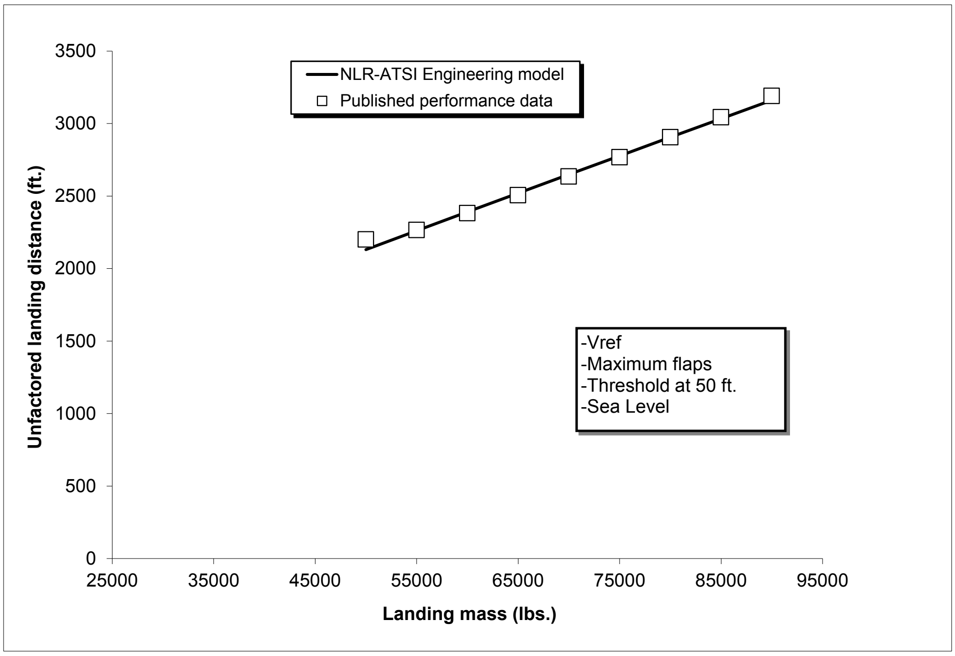
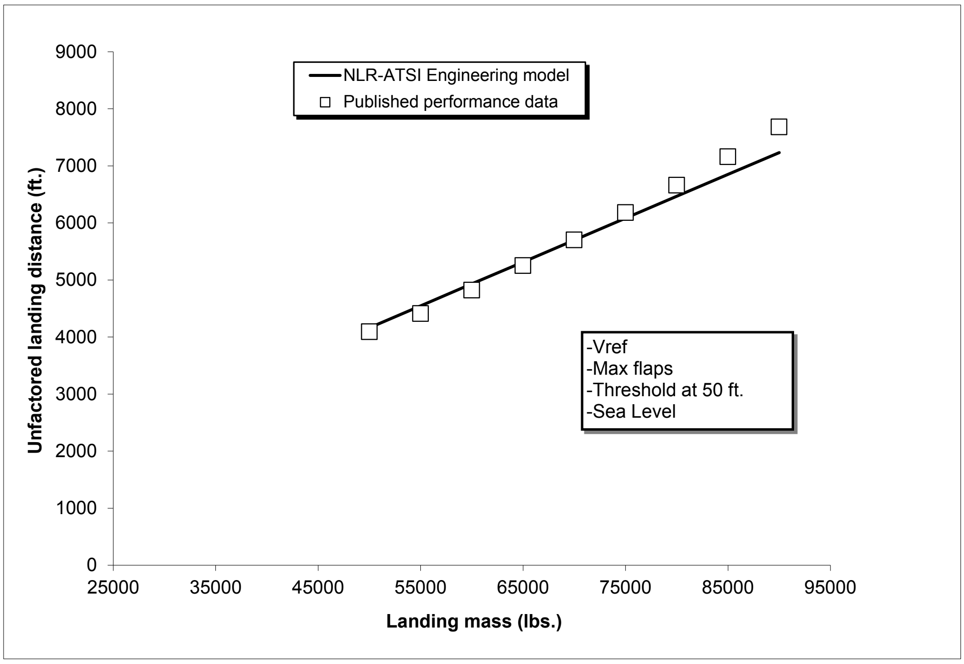
Van Es, G.W.H (2010)	A Study of Runway Excursions from a European Perspective, NLR CR-2010-259
Transport Canada (2005)	EASA NPA 14/2004 landing distance on contaminated runways, discussion paper no. 35, Transport Canada aircraft certification flight test division
EAPRE	European Action Plan for the Prevention of Runway Excursions. Edition 1.0, 2013.

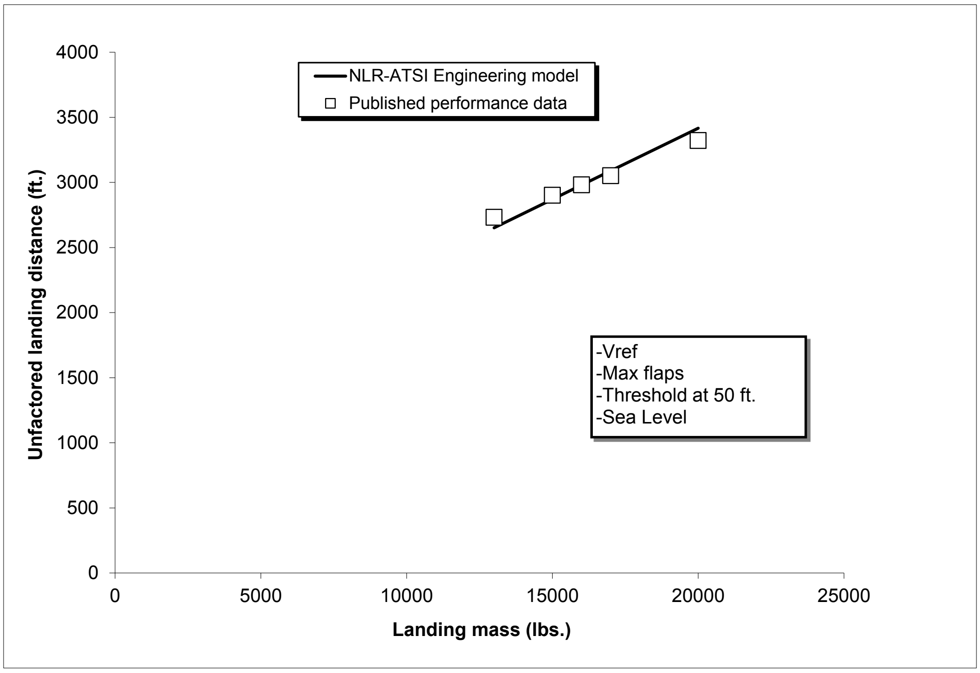
Appendix A EXAMPLES LANDING PERFORMANCE MODEL VERIFICATION



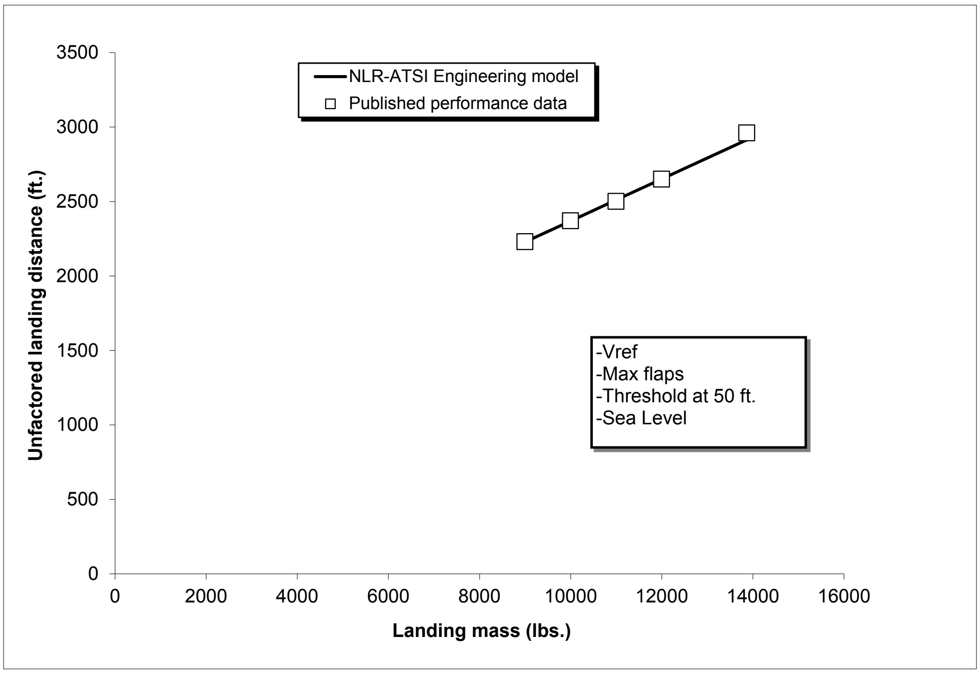
19 passenger jet business, dry runway no reverse thrust.



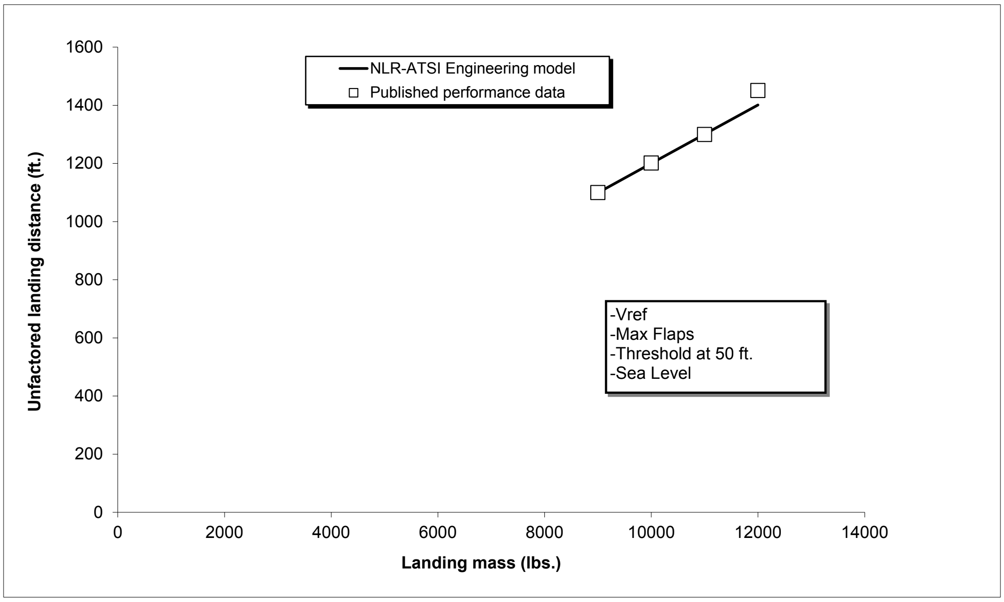
19 passenger business jet, dry runway, no braking, reverse thrust.



12 passenger business jet, dry runway, no reverse thrust.



8 passenger business jet, dry runway, no reverse thrust.



14 passenger turbo prop, no propeller reverse.