Open Journal of Applied Sciences, 2023, 13, 1246-1256
https://www.scirp.org/journal/ojapps
ISSN Online: 2165-3925
ISSN Print: 2165-3917

Risk Assessment of Aircraft's Lateral Veer-Off the Runway Surface during Landing

Victor V. Stolyarov, Allam Jamal-Eddine

Faculty of Transport Construction, Yuri Gagarin State Technical University of Saratov, Saratov City, The Russian Federation
Email: allamlar@hotmail.com

How to cite this paper: Stolyarov, V.V. and Jamal-Eddine, A. (2023) Risk Assessment of Aircraft's Lateral Veer-Off the Runway Surface during Landing. *Open Journal of Applied Sciences*, **13**, 1246-1256.
https://doi.org/10.4236/ojapps.2023.138098

Received: June 25, 2023
Accepted: August 13, 2023
Published: August 16, 2023

Abstract

This article presents a methodology to determine the risk of aircrafts lateral runway excursion during landing via mathematical risk modeling. In addition, the methodology is demonstrated by means of detailed calculation of the lateral runway excursion risk value during the landing of the aircraft Airbus A310-200, in view of the maximum landing weight and the appropriate range of landing velocities according to the International Civil Aviation Organization specification. Obviously, the calculation demonstrates that the developed math solutions and equations presented herein are powerful tools to evaluate the risk of lateral runway excursion of the majority of aircrafts and for any airport. The method is also applicable to assess the residual level of risk at any specific airport and its deviation compared to the recommended safety level. Consequently, the presented mathematical solutions to determine the risk rate of lateral runway excursion during landing offers airports' operational and safety management departments a viable tool so that appropriate measurements could be adopted. Finally, it is a methodology not only to assess the risk but also to determine the appropriate runway width.

Keywords

Risk, Runways, Veer-Off, Aircraft, Design

1. Introduction

According to the latest statistics from the International Civil Aviation Organization (ICAO), the global accident rate is 2.9 accidents per million departures for the year 2019 [1], whereas most frequent accidents occur during the landing phase. The Airport Corporative Research Program (ACRAP) identifies 5 levels of accident probability based on quantitative criteria: frequent, probable, small, extremely small, and extremely unlikely. At the same time, the acceptable risk value of the risk category identified as "small" is 1×10^{-6}, in other words, one out of a million operations [2]. According to the statistics of the lateral runway excursion (known as aircrafts landing veer-off) in the USA the actual frequency of veer-offs for USA sample airports is 1.38×10^{-6} [3]. Thus the acceptable risk cannot be higher than the value of 1×10^{-6} since the present risk value in the United States is already close or equal to this value. Therefore, the value of the residual risk that has been determined to be acceptable is one incident or accident per million flights.

1.1. Mathematical Models of Risk Assessments

Mathematical modeling of risk assessments is divided into general solutions and particular or individual solutions. General solutions can be used in any area of human activity and in any system having the risk of an undesirable event. It is only necessary to settle in input variables affecting our specific task into the general mathematical apparatus, which changes depending on the appropriate distribution law (according to which the input parameters of our variable are distributed) and on what ratio between the average value of the specified parameter (A_{cp}) and its critical value ($A_{кр}$) corresponds to the set of assigned requirements ($A_{cp} \gg A_{кр}$) or ($A_{cp} \ll A_{кр}$). Particular or individual mathematical solutions are mathematical models of risk assessments applied exclusively to particular or precise dangerous situations, for example, to assess and reduce the risk of vehicles crashes on two-lane roads.

Indeed, a general mathematical model of risk assessments is a general solution that is used in any hazardous situation and in any specific task, for example, applying the general solution of risk assessments to the specific risk situation mentioned above. Nevertheless, the final results of both solutions have the same outcome.

1.2. Determination of the Risk of Aircraft Landing Veer-Off Using a Particular Mathematical Model

During takeoff and landing, an aircraft tends to move within a dynamic width called the dynamic corridor. When developing the mathematical model of the dynamic width of the aircraft movement, to determine the danger of aircraft veer-off, the following parameters should be taken into consideration:

- the distance from the outer edge to the outer edge of the widest set of main gear tires (S);
- the landing speed of the aircraft (V);
- and the length of the aircraft (D).

It is obvious that the critical width of the runway, at which the risk of the outer wheel departs the physical edges of the runway pavement to the shoulder located on both sides, will be equal to 50% risk if the runway width is designed according to the overall parameters of the aircraft and based on the standard landing conditions.

Examining at the beginning the critical road width, at which the risk is 50% of two vehicles having design speeds V_1 and V_2 departs the physical edges of the road. The critical road width can be found using the equation: [4]

$$B_{KP}=\frac{D_1\times V_1}{720}+\frac{a_1+c_1}{2}+\frac{D_2\times V_2}{720}+\frac{a_2+c_2}{2}$$

where:

a_1 and a_2 are the widths of the first and second vehicle respectively;

c_1 and c_2 are the tracks of the first and second vehicle respectively;

D_1 and D_2 are lengths of the first and second vehicle respectively;

V_1 and V_2 are speeds of the first and second vehicle respectively.

Given that it's just a single transport in motion, an aircraft during landing, and the distance between the outer edges of the outer wheels of the aircraft corresponds to the track measurement, the risk of aircraft landing veer-off is determined according to the equation:

$$B_{кр}=\frac{D\times V}{720}+\frac{S+S}{2}=\frac{D\times V}{720}+S \tag{1}$$

where:

($B_{кр}$) is the critical width of the runway, at which the risk of the outer wheel going off the runway is 50% ($r = 0.5$), m;

(D) is the length of the aircraft, m;

(V) is the aircraft landing speed at the moment of touching the surface, km/h;

(S) is the distance between the outer edges of outer wheels, m.

It is very important to bear in mind that this equation is true for no wind condition.

The risk of occurrence of an interval between the mathematical expectations of the calculated parameter that reflects the actual situation (or design value) and the parameter corresponding to 50% risk can be determined using the equitation: [4]

$$r=0.5-f\left[\frac{A_{CP}-A_{KP}}{\sqrt{\sigma_{A_{CP}}^2+\sigma_{A_{KP}}^2}}\right] \tag{2}$$

where:

(r) is the risk of an undesirable event;

(A_{cp}) is the mathematical expectation or average value of the actual or design parameter;

($\sigma_{A_{cp}}$) is the standard deviation of the actual or design parameter normally distributed with respect to probability;

($A_{кр}$) is the mathematical expectation of the critical parameter;

($\sigma_{A_{кр}}$) is the standard deviation of the critical parameter.

Thus, the risk of the aircraft wheels leaving the runway edge to the shoulder during the landing of the aircraft is expressed as:

$$r=0.5-f\left[\frac{B_{cp}-B_{KP}}{\sqrt{\sigma_{B_{cp}}^2+\sigma_{B_{KP}}^2}}\right] \tag{3}$$

This relationship is true when respecting the condition $B_{cp} \gg B_{\kappa p}$.

where:

(B_{cp}) is the design (regulatory as stipulated in the applicable norms) runway width, m;

($B_{\kappa p}$) is the critical runway width at which the risk of outer aircraft wheel (S) going off the runway is 50%;

($\sigma_{B_{CP}}$) is the admissible standard deviation of the design width of the runway pavement during its construction or the actual standard deviation of the width of the existing runway (named also as built value), in m;

($\sigma_{B_{KP}}$) is the standard deviation of the critical width of the runway, m;

The probability integration of Laplace distribution or the Laplace function $f(u)$ that could be determined directly from the table given on appendix in Ref. [4] depending on the calculated value of the quintile (u) or by integration.

$$F(u) = f\left[\frac{B_{CP} - B_{KP}}{\sqrt{\sigma_{B_{CP}}^2 + \sigma_{B_{KP}}^2}}\right],$$

$$u = \frac{B_{CP} - B_{KP}}{\sqrt{\sigma_{B_{CP}}^2 + \sigma_{B_{KP}}^2}}.$$

When designing, as well as developing standard parameters, the admissible value of the standard deviation of the pavement width, the tolerance, is set via the equation: [4]

$$\sigma_{Bcp} = C_v^{Bper} \times B_{CP} \tag{4}$$

where:

(B_{cp}) is the design width (standard as stipulated in the applicable runways norms), which during construction should be implemented as an average runway value (taking into consideration that deviations are unavoidable, but, remain within the admissible range);

(C_v^{Bper}) is the admissible value of the coefficient of variation of the runway pavement width due to the construction works. This value hovers around 0.05% of the design value of the pavement width and is equal to 0.075. Indeed, when commissioning a runway for exploitation or examining an existing runway, the average value of the pavement and the standard deviation of the runway width are determined using mathematical statistics methods (survey). However, under all circumstances, the maximum tolerance value must be considered. In reality, there are different ways to extract the maximum tolerance value. The Federal Aviation Administration (FAA) specified that from the center line of the runway to the row of lights alignment located on the runway center line, the horizontal tolerance is 0.15 m or 0.075 m on each side [5]. In reality, this value reflects the real operational tolerance. Thus, the maximum admissible value of the coefficient of variation of the runway pavement width due to the construction works of runways is 0.075.

Knowing that the root-mean-square deviation of the critical width of two-lane road during the design phase could be determined using the equation [4]:

$$\sigma_{B_{KP}} = \frac{\sqrt{(D_1 \times V_1)^2 + (D_2 \times V_2)^2}}{2160}$$

Hence, with D_2 and $V_2 = 0$, the standard deviation of the critical runway width equation is determined as follows:

$$\sigma_{B_{KP}} = \frac{D \times V}{2160} \quad (5)$$

where:

(D) is the length of the aircraft, m;

(V) is the landing speed of the aircraft at the moment the outer wheels of the aircraft when touching the runway surface, km/h.

So, the coefficient of variation of the critical width of the runway in the particular mathematical model can now be expressed as:

$$C_v^{B_{KP}} = \frac{\sigma_{B_{KP}}}{B_{KP}} \quad (6)$$

where:

($\sigma_{B_{KP}}$) is the standard deviation of the critical width of the pavement, established in Equation (5);

($B_{\kappa p}$) is the critical runway width determined in Equation (1).

Typically, when developing roads standards, the admissible deviations for road width or the tolerance for the standard deviation is calculated by means of equation: [4]

$$\sigma_B^{ad} = \Delta_{ad} \left(\frac{B_{cp}}{d} \right)^2$$

where:

(Δ_{ad}) is the admissible deviation of the pavement width relative to the design width, (m). The value of this parameter during the construction of the road is predetermined as: $\Delta_{ad} = 0.06$ m;

(B_{cp}) is the design width or the as-built width of the pavement, m;

(d) is the regulated (as required by the applicable norms) admissible distance between the design cross-sections (m), whereby the measured deviation during the acceptance of the road for exploitation (Δ_i) should not exceed the admissible deviation value of the pavement width;

The (d) parameter is determined according to the equation dedicated to road design [4]. $d = 0.104\ V$, where V is the estimated speed according to the category of road in question, km/h. For the runway the value of the parameter (d) varies from 10 to 30 meters depending on the project, the design standard and the owner's requirements, typically this value is around 20 meters. This indicates that the value of (d) can be calculated depending on the estimated speed of the aircraft, but must remain below 30 meters.

Thus, the value of the parameter (d) for runways (m) is calculated according to the dependence:

$$d = 0.104V_p,$$

where (V_p) is the landing speed (at the moment the outer wheels touch the runway pavement), km/h.

Finally, given the operational characteristics (one aircraft and one direction), the tolerance of the standard deviation of the runway pavement width is:

$$\sigma_B^{ad} = \Delta_{ad}\left(\frac{B}{d}\right)^2 = 0.075\left(\frac{B}{d}\right)^2, \quad (7)$$

1.3. Modeling the Risk of Aircraft Landing Veer-Off Using the General Mathematical Model

The zero incident risk condition satisfies the conversion of Laplace function into the number $f(u) = 0.5$ with the quintile $(u) = 5$.

$$u = \frac{B_{cp} - B_{KP}}{\sqrt{\sigma_{B_{CP}}^2 + \sigma_{B_{KP}}^2}} = 5,$$

hence, $B_{KP} = B_{CP} - 5\sqrt{\sigma_{B_{CP}}^2 + \sigma_{B_{KP}}^2}$

from the Equation (6) $\sigma_{B_{KP}} = C_v^{B_{KP}} \times B_{KP}$

Solving the equation for ($B_{кр}$), both the mean value and the standard deviation of the critical parameters are calculated. The mean value and the standard deviation of the critical parameters (in the density of the normal distribution), respecting the same condition given in the particular solution ($A_{cp} \gg A_{кр}$), in the general mathematical model are determined by means of the followings:

for

$$C_v^{B_{KP}} \neq 0.2; \quad B_{KP} = \frac{\sqrt{B_{CP}^2 + \left[25\left(C_v^{B_{KP}}\right)^2 - 1\right]\left(B_{CP}^2 - 25\sigma_{B_{CP}}^2\right)} - B_{CP}}{25\left(C_v^{B_{KP}}\right)^2 - 1}; \quad (8)$$

for

$$C_v^{B_{KP}} = 0.2; \quad B_{KP} = \frac{B_{CP}^2 - 25\sigma_{B_{CP}}^2}{2B_{CP}}; \quad (9)$$

Equation (9) is obtained by disclosing the uncertainty of the form 0/0 in the event that in Equation (8) $C_v^{B_{KP}} = 0.2$.

The coefficient of variation of the critical pavement width ($C_v^{B_{KP}}$) in Equation (8) is taken equal to the coefficient of variation of the real runway pavement width ($C_v^{B_{CP}}$). Thus, it guarantees the respect of the condition that the distribution law of the critical variable (B_{kp}) must have homogeneity with the distribution law of the design or actual variable (B_{CP}).

To this extent, with this decision, indicators B_{CP} B_{KP}, $\sigma_{B_{CP}}$ and $\sigma_{B_{KP}}$ will belong to the same set (they are coherent).

So that the particular and general mathematical models provide coherent calculation, it is necessary to apply in the general solution the coefficient of variation of the critical width of the runway established through Equation (6). Hence, the initial data of both models will be comparable. If the coefficient of variation of the runway width is not equal to 0.2, then its value is substituted into Equation (8) and the (B_{kP}) parameter is determined. Otherwise, if $C_v^{B_{KP}} = 0.2$ parameter (B_{kP}) is calculated according to Equation (9).

During the design phase, the admissible value of the standard deviation of the runway width is set either using Equation (7) or through the equation below:

$$\sigma_{B_{CP}} = C_v^{B_{CP}} \times B_{PR}, \tag{10}$$

where:

(B_{PR}) is the design or the regulated (as required by the applicable runways norms) width that during construction should be realized as the average value of the runway width (taking into consideration that deviation is expected, but must be within tolerance), m;

($C_v^{B_{CP}}$) is the admissible value of the coefficient of variation of the runway pavement width.

After determining the required parameters of the designed or operated runway, the risk assessment is performed for both mathematical models according to Equation (3).

1.4. Example of Computing the Risk of Aircraft Landing Veer-Off

The following example provides details of the risk calculation of the Airbus A310-200 landing veer-off.

Initial data: Aircraft type Airbus A310-200; Aircraft length D = 46.68 m; The distance between the outer edges of the aircraft's outer wheels. S = 10.97 m; Landing speed V = 257.5 km/h considering standard conditions and maximum landing weight; Runway width B = 45 m as stipulated in the applicable norms, reference code letter and number (4D) [6].

1.5. Calculation Procedure Based on the Particular Mathematical Model

1) The critical width of the runway, upon landing on which an AirbusA310-200 aircraft outer wheel may veer-off the exiting runway with a probability of r = 0.5 (50%), is determined using Equation (1):

$$B_{KP} = \frac{D \times V}{720} + S = \frac{46.68 \times 257.5}{720} + 10.97 = 16.70 + 10.97 = 27.668\ \text{m}$$

where:

(D) is the length of the aircraft, m;

(V) is the landing speed of the aircraft at the moment the outer wheels of the aircraft when touching the runway surface, km/h.

2) The admissible value of the standard deviation of the runway width is computed according to the Equation (7) where d = 0.104. V = 0.104 × 257.5 = 26.78 m:

$$\sigma_{Bcp} = \Delta_{ad}\left(\frac{B_{cp}}{d}\right)^2 = 0.075\left(\frac{45}{26.78}\right)^2 = 0.212 \text{ m}$$

where:

(Δ_{ad}) is the deviation's tolerance of the runway width compared to the design width (m);

(B_{cp}) is the design or the as-built value of the runway width, (m);

(d) is the design or the standard (as required by the applicable norms) distance between the cross-sections (m), through which the measured deviation of the pavement width (Δ_{ad}) must not exceed the limit deviation.

3) Substituting specified values into Equation (5), the standard deviation of the critical width of the runway is determined:

$$\sigma_{B_{KP}} = \frac{D \times V}{2160} = \frac{46.68 \times 257.5}{2160} = 5.565 \text{ m}$$

4) The coefficient of variation of the critical width of the runway is determined from Equation (6):

$$C_v^{B_{KP}} = \frac{\sigma_{B_{KP}}}{B_{KP}} = \frac{5.565}{27.668} = 0.201$$

5) According to Equation (3), knowing the quintile of Laplace function, Laplace distribution or Laplace function $f(u)$ is determined from appendix in Ref. [4]. Hence, we determine the risk of the outer wheel of the aircraft coming off the runway edge:

$$r = 0.5 - f\left[\frac{B_{CP} - B_{KP}}{\sqrt{\sigma_{B_{CP}}^2 + \sigma_{B_{KP}}^2}}\right] = 0.5 - f\left[\frac{45 - 27.668}{\sqrt{0.212^2 + 5.565^2}}\right]$$
$$= 0.5 - f\left(3.112053209\right) = 0.5 - 0.49907846 = 9.22 \times 10^{-4}$$

2. Method Validation

A standard 45-meter runway width, category 4D runway, does not meet the required maximum admissible risk value of the Airbus A310-200 veer-off, since for one million landings probably 922 plane coming off the runway edge, whereas, the acceptable risk corresponds to the value of 1×10^{-6} (one out of million landings).

If the runway width is increased to a value of 55 meters, then the admissible standard deviation of the new width according to formula (7) turns out to be:

$$\sigma_{Bcp} = \Delta_{ad}\left(\frac{B_{cp}}{d}\right)^2 = 0.075\left(\frac{55}{26.78}\right)^2 = 0.316348 \text{ m}$$

Consequently, the resulting risk corresponds to the admissible value. In other words, the probability or the risk value of the aircraft wheels leaving the runway edge to the shoulder during the landing is acceptable as the risk value turns out to be 1×10^{-6} (one incident per one million landings).

Demonstrating the new numerical risk value:

$$r = 0.5 - f\left[\frac{B_{CP} - B_{KP(1)}}{\sqrt{\sigma_{B_{CP}}^2 + \sigma_{B_{KP}}^2}}\right] = 0.5 - f\left[\frac{55 - 27.668}{\sqrt{0.316^2 + 5.565^2}}\right]$$
$$= 0.5 - f(4.903278) = 0.5 - 0.49999894 = 1.06 \times 10^{-6}$$

Thus, 55-meter runway width meets the maximum admissible probability of the Airbus A310-200 landing veer off at 257.5 km/h speed, given that for million landings, probably one plane's wheel leaves the runway edge and that value corresponds to the admissible one.

2.1. Calculation Sequence Based on the General Mathematical Model

According to the value of the coefficient of variation of the critical runway width, first of all, we compute the required runway width based on the general mathematical model (when $A_{CP} \gg A_{KP}$) using one of the equations below:
for

$$C_v^{B_{KP}} \neq 0.2; \quad B_{KP} = \frac{\sqrt{B_{CP}^2 + \left[25 \times \left(C_v^{B_{KP}}\right)^2 - 1\right]\left(B_{CP}^2 - 25 \times \sigma_{B_{CP}}^2\right)} - B_{CP}}{25\left(C_v^{B_{KP}}\right)^2 - 1}; \quad (8)$$

for

$$C_v^{B_{KP}} = 0.2; \quad B_{KP} = \frac{B_{CP}^2 - 25 \times \sigma_{B_{CP}}^2}{2 \times B_{CP}}; \quad (9)$$

The admissible standard deviation according to Equation (7)

$$\sigma_{Bcp} = \Delta_{ad}\left(\frac{B_{cp}}{d}\right)^2 = 0.075\left(\frac{55}{26.78}\right)^2 = 0.316348 \text{ m}.$$

The coefficient of variation of the critical width of the runway should be the same as in the previous calculation so that both mathematical models belong to the same set (have comparable and matching benchmark input data). Indeed, this is the only way to compare the calculation results of both mathematical solutions. Thereby, this coefficient was computed earlier in paragraph 4 of the previous solution:

$$C_v^{B_{KP}} = \frac{\sigma_{B_{KP}}}{B_{KP}} = \frac{5.565}{27.668} = 0.201$$

Since the coefficient of variation of the critical width corresponds to the condition $C_v^{B_{KP}} \neq 0.2$, then we apply Equation (8) to the calculation:

$$B_{KP} = \frac{\sqrt{B_{CP}^2 + \left[25\left(C_v^{B_{KP}}\right)^2 - 1\right]\left(B_{CP}^2 - 25\sigma_{B_{CP}}^2\right)} - B_{CP}}{25\left(C_v^{B_{KP}}\right)^2 - 1}$$

$$B_{KP} = \frac{\sqrt{55^2 + \left[25(0.201)^2 - 1\right]\left(55^2 - 25 \times 0.316^2\right)} - 55}{25(0.201)^2 - 1} = 27.399 \text{ m}$$

We obtained very close values of the parameter (B_{KP}) (27.668 ≈ 27.399), despite the fact that a smaller number of input data was used in the general solution.

Both solutions yield to almost the same risk value as the discrepancy is almost zero, which validates the calculation and at the end the methodology.

2.2. The Landing Veer-Off Risk Variance of the Aircraft Airbus A310-200

According to ICAO, during the approach phase, the speed range for a category 4D aircraft to which Airbus A310-200 belongs is between 240 and 340 km/h [7], with a likely speed of 257.5 km/h considering the maximum landing weight and standard conditions with no wind. Hence, the range of these specified speeds yields to corresponding veer-off risk values. Resulting risk values are plotted in the Figure 1 below. As a result, the risk of the aircraft A310-200 veer-off when landing on a 45 meters wide runway considering the expected speed velocities range during landing, can be calculated using the following Equation (10)

$$r = 4.448663 \times 10^{-8} \times V^3 - 3.291456 \times 10^{-5} \times V^2 + 8.141086 \times 10^{-3} \times V - 0.6729219$$

where V is the landing velocity Km/h.

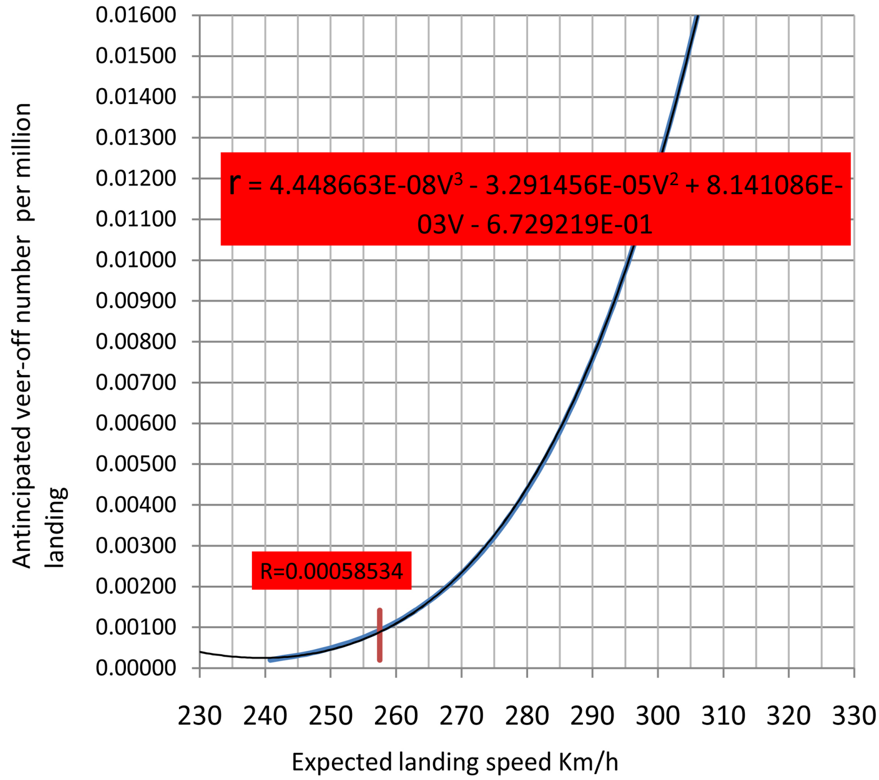

Figure 1. Risk of veer-off of Airbus 310-200 when landing on 45 m runway width.

3. Conclusions

Obviously, linear increase in landing speed results in an exponential increase in the risk of veer-off during landing. Thus, special attention should be paid during the design phase and during the operation by assessing the anticipated operational landing speed that is expected for each airport individually.

The mathematical risk assessment presented herein for aircraft veer-off is not just a powerful tool and research technique. Indeed it is a methodology that claims priorities in both, runway design and risk assessment.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] International Civil Aviation Organization Montréal, Canada ICAO Safety Report (2020). 5-64.
https://www.icao.int/safety/Documents/ICAO_SR_2020_final_web.pdf

[2] Manuel Ayres Jr., *et al*. (2015) A Guidebook for Safety Risk Management for Airports. ACRP Report 131. Transportation Research Board, Washington, DC.142-145.
https://skybrary.aero/sites/default/files/bookshelf/3520.pdf

[3] Manuel Ayres Jr., *et al*. (2014) Development of a Runway Veer-off Location Distribution Risk Assessment and Reporting Template. ACRP Report 107. Transportation Research Board, Washington, D.C .38-121.
https://nap.nationalacademies.org/catalog/22411/development-of-a-runway-veer-off-location-distribution-risk-assessment-and-reporting-template

[4] Stolyarov V., *et al*. (2017) Calculation Examples of Highways' Geometric, Transport-Operational and Strength Parameters Based on the Theory of Risk. I, Design, Saratov State Technical University, City of Saratov, The Russian Federation, SSTU, 156-270p+18+262+154+88+262.
https://www.studmed.ru/stolyarov-vv-proektirovanie-avtodorog-s-uchetom-teorii-riska-chast-i_f89645f4e40.html

[5] Design and Installation Details for Airport Visual (2018) FAA Advisory Circular. AC No. 150/5340-30J, A-35P.
https://www.faa.gov/documentLibrary/media/Advisory_Circular/150-5340-30J.pdf

[6] Aerodrome Design Manual (2020). Part 1, Runways, Fourth Edition. ICAO Doc 9157, ISBN 978-92-9265-232-6, A1-5, 86p.
https://standart.aero/en/icao/book/doc-9157-p-1-aerodrome-design-manual-part-1-runways-en-cons

[7] Aerodrome Design Manual (2005) Part 2, Taxiways, Aprons and Holding Bays, Fourth Edition. ICAO Doc 9157, ISBN 978-92-9265-232-6, 39, 157p.
https://standart.aero/en/icao/book/doc-9157-p-2-amendment-no-1-ed-4-en-9010