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Flight Safety During the Aircraft's Motion Along the Runway Line

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Abstract **– The main purpose of this article is to identify and prevent problems related to the flight path diversion on the runway centre line while landing.**

Keywords **– Centre line, deviation, motion trajectory, runway.**

I. INTRODUCTION

Nowadays civil aviation development goes hand in hand with all kinds of infrastructure improvements, which are directly or indirectly related to the air transport industry [1]. In fact, the improvement of aviation passenger service quality and high level of regularity of flights is ensured in every way [2]. The scientific research direction of the study concerns the airplane's motion during the landing phase, when the aircraft deviates away from the runway centre line. Within this scientific direction, some solutions for reducing the number of aviation accidents can be found. These accidents are related to the roll out of the airplane from the runway lane [3].

From the research and calculations of the flight trajectory of touch down and braking phase, it is possible to get new parameters in accordance with the flight path characteristics [4]. These new parameters will place novel demands on airports and runways bands to ensure safety around the braking zone, as well as taxiway positions up to passenger terminals [5]. Aircraft flight path characteristics identify risk factors in addition to the given pulse modulation research data for the aircraft braking system to effectively prevent insufficient adhesion problems [6].

The process of developing, designing and building aviation airport infrastructure takes into account the growth of aviation technologies [7].

This means that designers make estimations in order to prevent the aviation ground infrastructure from slowing down the development of aviation transport system. In fact, constructive resources are calculated in order to support the growth of technical progress [8].

Continuous, consistent and high-quality work of air transport system service is very important, because aircraft spend a considerable part of their operating period on the ground [9]. Airplanes' take off and landing phases are directly associated to the airport area, which is the most important part of the runway lane [10]. It is important that aircraft's motion paths are safe and run in the relevant part of the runway, which ensures safety [11].

The calculations of motion trajectory deviations and critical path probabilities can predict and improve a particular runway zone width and the frequency of accidents on the side of safety zones.

It is important to study the movement of aircraft along the runway lane and determine the mathematical expressions for motion abnormalities, which will make it possible to describe them in a single mathematical model.

Mathematically, the runway lane width could be calculated by analysing the landing of the aircraft [12]. Lane width detection is based on the model aircraft movement along the runway line, with the lateral forces along the runway [13], [14].

After the aircraft's touchdown speed deceleration over the zone, the efficiency of rudder control reduces; on the other hand, the front wheel rack performance increases [15].

After the touchdown, movement occurs through a complex trajectory. The aircraft is exposed to a whole range of negative factors that disturb the uniformity of movement [16]. These adverse factors are associated with different atmospheric conditions, wind strength and side wind direction at different heights.

During the landing phase, pilots, being tired after the long flight, have to carry out a lot of operations.

At the moment of airplane touchdown, the human body relaxes instinctively and the speed of reaction decreases. Directional resistance on the ground with the front landing gear wheel placement manoeuvrability fully depend on the pilots' work.

Such a human body sensor reception area is defined by taking into account the human sense limits, which are attributed to different conditions. For example, a pilot starts to respond only when the parameters of such states become perceived, that is, they enter into the sensory perception area of the human body. However, during the period before the human body senses the perceptual boundaries, aircraft makes distance along the runway.

When the aircraft is moving along the runway, the pilot is unable to detect the deviation between the planned path of movement and the real movement trajectory. It happens if all the variables of the human body's perception phases get into the area known as the human sensory impassibility area. This zone is defined by the threshold values felt by human when distinguish the effect [17]. Pilots begin to respond to the changing perception of the phase when these diversions come out of the impassibility area.

Airplanes have directional resistance to the front landing gear, so the landing phase is limited by a limited range of turning, but the airplane system cannot ensure adequate positioning of wheel direction independently [18].

The human perception in such circumstances is determined by inertia and the pilot's operations follow with a certain delay rather than immediately, which can be called as a pilot reaction time. The fact is that during the reaction time the airplane shifts from the intended landing path to a certain distance.

At this stage, the aircraft is not piloted by the pilot deliberately. At this moment, the deviation N_1 from the centre line occurs (Fig. 1).

Between points 0 and 1 an airplane is actually unmanageable and can already be deviated from the required trajectory N_1. If a pilot initiates the alignment of the airplane to the centre of a runway at the point 2 (where the deviation value is $N_2 > N_1$), he/she has to make stronger manoeuvre to align it in at centre line. But, due to the excessive manoeuvre the plane at point 3 deviates by value N_3 to the other side of the required trajectory.

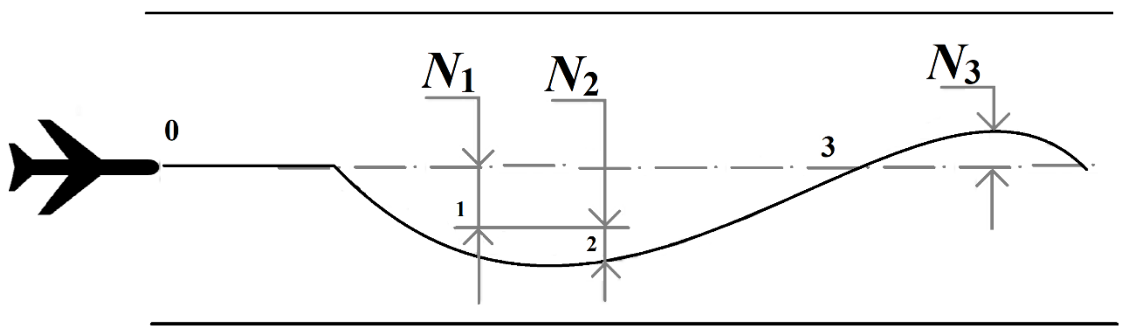

Fig. 1. Trajectory of aircraft movement.

When the pilot starts to manoeuvre the aircraft, he tries to operate the plane close to the centre line. Due to the aircraft inertia motion trajectory does not immediately approach the axis line. At this point, further deviation arises which is $N_1 + N_2 + N_{delta}$, which depends on the real output trajectory to the centre line.

Therefore, to determine the optimal zone width on the runway, it is important to determine the N_1 and N_2 deviation values for the braking regimes/phases. By knowing these values and geometric parameters of the aircraft, as well as the distance margin from the landing gear to the pavement surface, it is possible to determine the details of the necessary lane width.

The calculation method for the determination of the N_1 and N_2 resulting from the set task assignment. At the beginning, the trajectory parameters are determined based on the unmanageable aircraft movement conditions, which are identified by sensitivity threshold levels for pilot sensory organs.

In this case, the evaluation of the pilot and aircraft interaction response time is important. This time is made up of the following values:

1) signal detection time;
2) trajectory parameter decryption time;
3) decision-making time;
4) motion function execution time;
5) airplane reaction time.

The pilot's response time depending on his training and qualifications can vary from 0.1 seconds to 2 seconds. The value N_2 is calculated by taking the aircraft movements at the initial conditions obtained from the calculation of N_1. The unmanageable aircraft movements can be described by differential equations. The aircraft is an absolutely solid body with mass inertia symmetry planes. The equation of motion related projection coordinate axes is formed as follows:

$$\left\{\begin{matrix} m\left(V_x + V_z\omega_y\right) = \Sigma X \\ m\left(V_z + V_x\omega_y\right) = \Sigma Z \\ I_Y\omega_y = \Sigma M \end{matrix}\right\}, \tag{1}$$

where

V_x, V_y are speed vector projection related coordinate axes;
ω_y is angular velocity around the vertical axis;
m is mass of the aircraft;
I_y is a moment of aircraft inertia in relation to the vertical axis;
ΣX, ΣZ, ΣM are forces and moments related to the projection coordinate axes.

Equation (1) must be integrated by Euler methods. For the baseline characteristics of unmanageable movement were selected the following values ($V_{x0} = 55$ m/s; $V_{z0} = 0$ m/s; $\omega_{y0} = 0.05$ rad/s; $\varphi_0 = 0.02$ rad; $x_0 = 0$ m; $z_0 = 1$ m; $t_r = 3$ s), which reflects the pilot sensory sensitivity threshold,
where

V_{x0} initial velocity along the axis Ox;
V_{z0} initial velocity along the axis Oz;
ω_{y0} initial angular speed;
φ_0 initial heading angle;
X_0, Z_0 initial trajectory parameters;
t_r the response time of the pilot operated aircraft.

An important practical significance is the effect of the lateral wind on the changes in the aircraft's trajectory and the bandwidth required to ensure safe movement along the runway area. For this reason, the calculations are done with account of cross-wind effects, $W = 15$ m/s.

When evaluating the above mentioned parameters, a calculation was made for several motions when the aircraft moves along the runway band in braking modes. From the evaluations, the following graphs have been obtained.

Fig. 2 depicts the movement trajectories at different start values of angular speed and the heading angle values. The analysing of the graphs reveals that the major deviations from the centre line are the same as the vector ω and φ directions. The smallest deviation has been observed with different vector ω and φ directions.

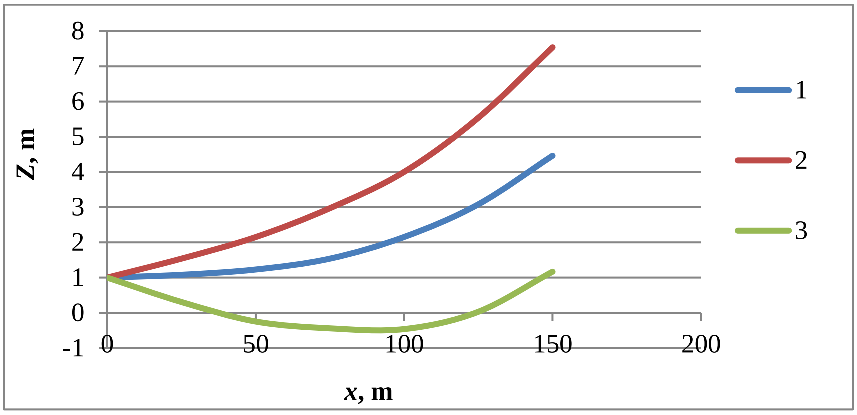

Fig. 2. Motion trajectory of aircraft at various conditions $V_0 = 55$ m/s; $W = 0$ m/s; 1 – trajectory with the initial parameters ω = –0.05 rad/s; φ = 0 rad; 2 – trajectory with the initial parameters ω = –0.05 rad/s; φ = –0.02 rad; 3 – trajectory with the initial parameters ω = –0.05 rad/s; φ = 0.02 rad.

The trajectory is reflected in the graph as a smooth flat exponential type curve.

Fig. 3 depicts the trajectory with allowance for the lateral wind *W*. The greatest deviation from the runway centre line is observed when the following values of the directions ω, φ, and *W* are similar. The smallest deviation is at ω = 0 rad/s, φ = 0 rad and cross wind size *W* = 15 m/s.

Analysing the curve 4, where ω = –0.05 rad/s, φ = 0.02 rad and side wind size *W* = –15 m/s. At time *t* = 1.5 s, a significant deviation from the centre line is observed. At *t* = 3 s the alignment of the trajectory takes place. Actually, some fluctuations occur around the axis of the runway and the greatest amplitude is reached at the moment *t* = 1.5 s.

Curve 5 describes the trajectory of movement at ω = 0.05 rad/s, φ = 0.02 rad, *W* = 15 m/s. Curve 5 trajectory is similar to curve 4, but with a smaller amplitude at the moment *t* = 1.5 s. Curve 3 is characterized by movement at ω = –0.05 rad/s, φ = –0.02 rad, *W* = 15 m/s. Close to the time moment *t* = 1.5 s the trajectory deviation from the centre line exceeds trajectory (curve 2) deviation ω = –0.05 rad/s, φ = –0.02 rad, *W* = –15 m/s, although the further period of time *t* = 3 s deviation becomes smaller than the trajectory (curve 2).

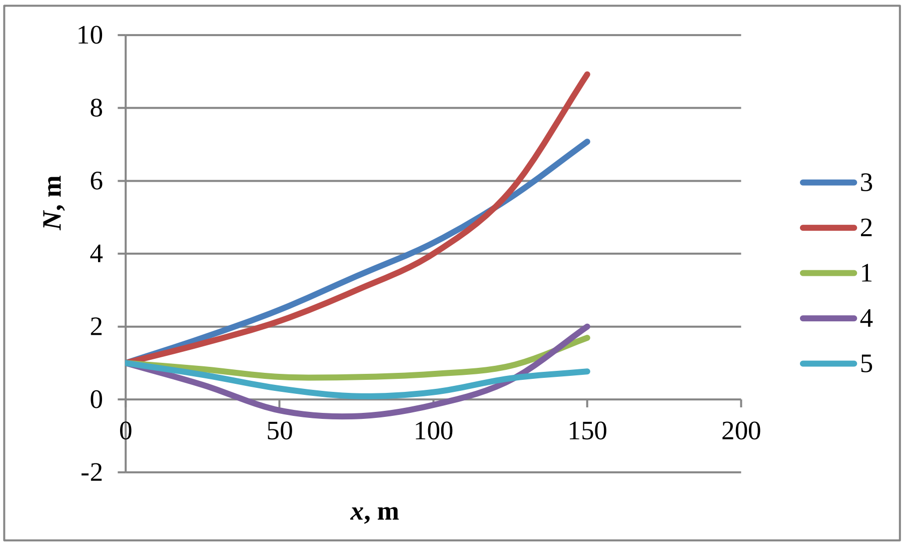

Fig. 3. Aircraft motion trajectory at various conditions $V_0 = 55$ m/s; *W* = 15 m/s; 1– trajectory with parameters ω = 0 rad/s; φ = 0 rad; *W* = –15 m/s; 2 – trajectory with parameters ω = –0.05 rad/s; φ = 0.02 rad; *W* = –15 m/s; 3 – trajectory with parameters ω = –0.05 rad/s; φ = –0.02 rad; *W* = 15 m/s; 4 – trajectory with parameters ω = –0.05 rad/s; φ = 0.02 rad; *W* = –15 m/s; 5 – trajectory with parameters ω = –0.05 rad/s; φ = 0.02 rad; *W* = 15 m/s.

Fig. 4 and Fig. 5 show the path of movement with account of cross winds and initial values ω_0 and φ_0 at different speeds V_0. From the graphs, it is evident that the cross-wind values have influence on the aircraft deviation from the centre line.

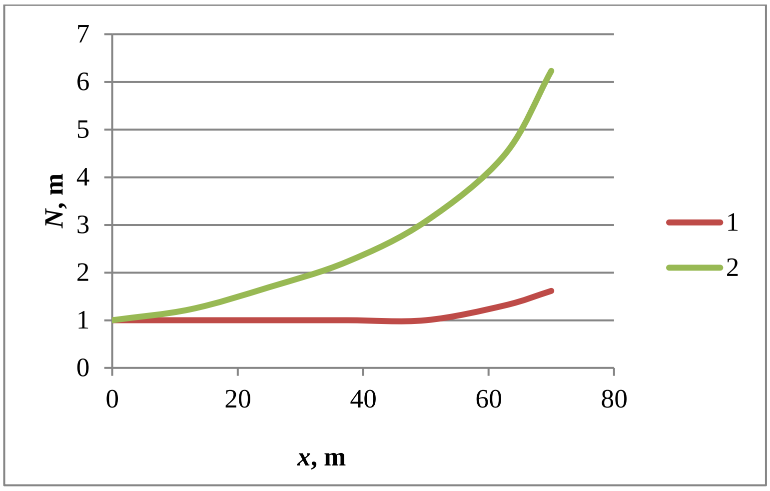

Fig. 4. Aircraft deviation movement trajectory at the beginning of the movement under different conditions $V_0 = 25$ m/s; $W = -15$ m/s; 1 – trajectory with parameters $\omega = 0$ rad/s; $\varphi = 0$ rad; $W = -15$ m/s; 2 – trajectory with parameters $\omega = -0.05$ rad/s; $\varphi = 0.02$ rad; $W = -15$ m/s.

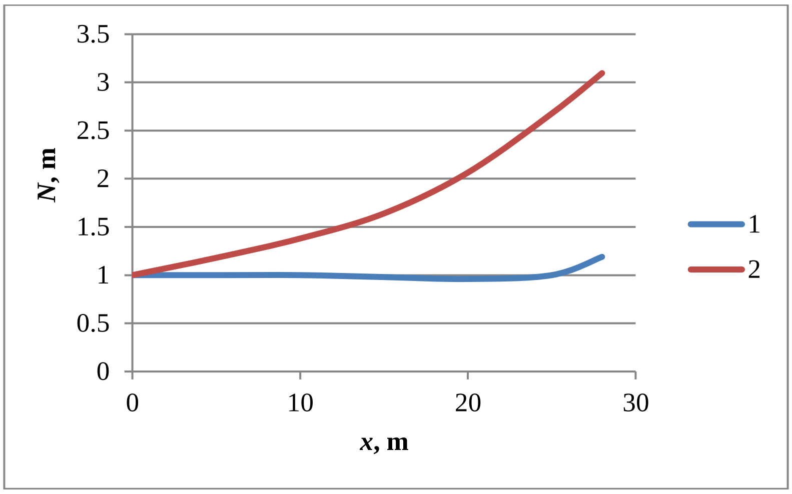

Fig. 5. Aircraft deviation movement trajectory at various conditions $V_0 = 10$ m/s; $W = -15$ m/s; 1 – trajectory with parameters $\omega = 0$ rad/s; $\varphi = 0$ rad; $W = -15$ m/s; 2 – trajectory with parameters $\omega = -0.05$ rad/s; $\varphi = -0.02$ rad; $W = -15$ m/s.

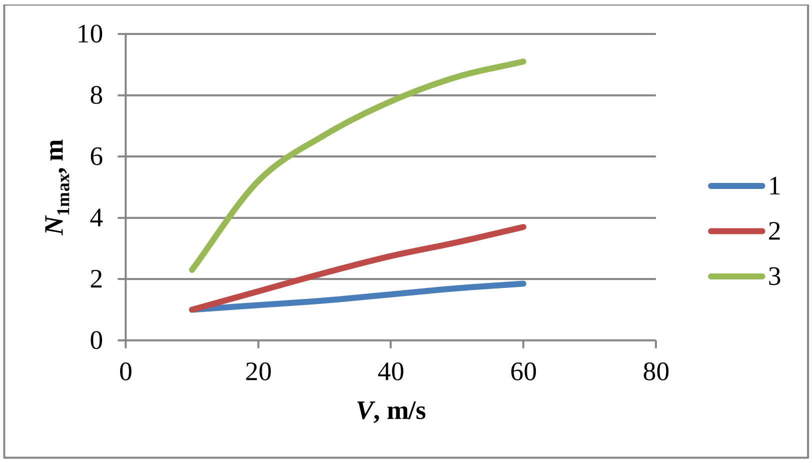

Fig. 6. Dependence of aircraft deviation Z_{1max} on the starting speed V_0 at different reaction speeds 1 – ($t = 0.5$ s); 2 – ($t = 1.5$ s); 3 – ($t = 3$ s).

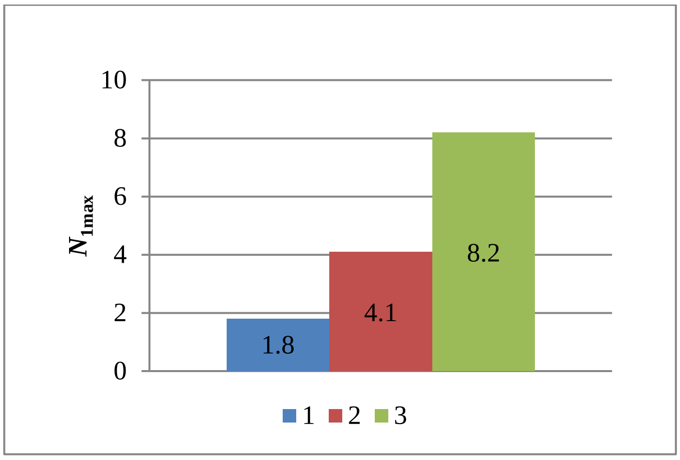

Fig. 7. Dependence of aircraft deviation N_{1max} on the angular velocity ω_0 and heading angle φ_0 at speed V_0 = 55 m/s and cross wind W = 0 m/s, where 1 – at ω = –0.05 rad/s; φ = 0.02 rad; 2 – at ω = –0.05 rad/s; φ = 0 rad; 3 – at ω = –0.05 rad/s; φ = –0.02.

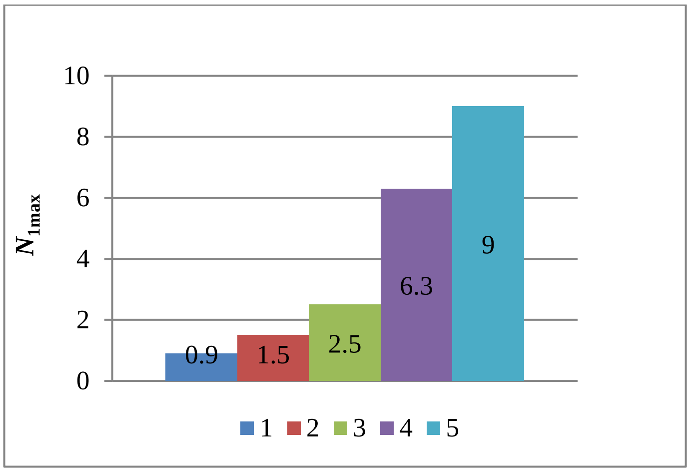

Fig. 8. Dependence of aircraft deviation N_{1max} on the angular velocity ω_0, course φ_0 angle and cross wind W at speed V_0 = 55 m/s, where 1 – at ω = –0.05 rad/s; φ = 0.02 rad; W = 15 m/s; 2 – at ω = 0 rad/s; φ = 0 rad; W= –15 m/s 3 – at ω = –0.05 rad/s; φ = 0.02 rad; W = –15 m/s; 4 – at ω = –0.05 rad/s; φ = –0.02 rad; W = 15 m/s; 5 – at ω = –0.05 rad/s; φ = –0.02 rad; W = –15 m/s.

Fig. 6 displays the N_1 dependence on the initial speed V_0. The largest N_{1max} are at speeds V_0 = 55 m/s. At speeds V_0 = 2 m/s to 5 m/s, the deviation from the centre line will be within the range of 1 m.

Fig. 7 and Fig. 8 show the dependence N_{1max} on different initial parameter combinations. The maximum N_{1max} size is observed when the size of ω, φ, and W vector directions are the same. The approximate calculation of N_2 value at controlled movement, which is based on the analysis of unguided motion, shows that the N_2 value does not exceed 3 m.

II. Conclusion

The following conclusions are drawn from the analysis of the graphs.

1. The largest deviations from the centre line at different circumstances occur at a speed of 55 m/s.
2. The largest deviations from the centre line at different speeds V_0 occur if the original parameters ω_0, φ_0 and W directions are identical.
3. The greatest effect on the deviation from the centre line is caused by the initial angular velocity ω_0 and the initial heading angle φ_0.
4. The effect of cross-wind is only significant at high speeds. At the beginning, the deviation occurs in accordance with the cross-wind direction, but later trajectory deviates against the direction of the cross-wind.

5. At a speed of V_0 = 2 m/s to 5 m/s, the deviation from the centre line will be within the range of 1 m. The pilot cannot notice the deviation from the axis if it is less than 1 meter, but the deviation will be corrected instantly when the aircraft trajectory deviation is more than 1 m.

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