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Influence of unevenness of airport pavements on technical condition and safety of air operations

Abstract: The publication presents the requirements for airport pavements for the assessment of the evenness of airport pavements, including the methodology of testing unevenness. On the basis of the selected aircraft type, the impact of unevenness on the dynamic interaction of the plane - pavement was determined, and the vertical displacements occurring at the edges of concrete slabs were taken for analysis. The paper presents the influence of operational procedures in the form of pavement grooving and local surface repairs on the results of unevenness measurements and improvement of the technical condition of the pavement, as well as on the safety of air operations.

Keywords: Pavement unevenness; Evaluation criteria; Dynamic action plane - surface; Grooving pavement; Maintenance treatments; The functional element of the airport

Introduction

The process of diagnosing the structural systems of airport pavements is primarily associated with the need to obtain the necessary information about the technical condition of individual functional elements of the airport (EFL). Therefore, there is a need for continuous monitoring of the technical condition, the beginning of which is initiated by tests related to putting the facility into operation. Assessment of the evenness of airport pavements is one thing of the basic diagnostic parameters. Changes in the evenness of the pavement as a result of its operation are a significant problem in the assessment of the condition of the structure. The requirements for evenness relate mainly to the proper drainage of the pavement and the dynamic interaction between the aircraft and the pavement. The limitations of inclination that occur on airport pavements, even with slight unevenness, create stagnant water, leading to aquaplaning. In winter conditions, this results in the formation of a surface ice mirror, which affects the safety of air operations. In order to improve the drainage conditions of the runway surface, especially with its one-sided transverse slope, grooving is used, i.e. grooving of the surface.

An important factor determining the safety of air operations is the impact of unevenness on the dynamic interaction between the aircraft and the surface. The vibrations of the wheels of the braking aircraft cause a temporary decrease in their grip on the surface. Threshold-type unevenness has a particularly adverse effect on grip, affecting the length of the braking distance. Surface unevenness causes vertical vibrations in the aircraft, causing additional forces to affect the airport pavement. The magnitude of these dynamic effects is a function of the aircraft's weight and the damping properties of the aircraft's landing gear.

Methodology for measuring the evenness of airfield pavements

The evenness of airport pavements is assessed in accordance with the standard NO-17-A502:2015 Airport Pavements. Equality Test [2]. The standard specifies the requirements for testing evenness, the requirements for equipment used to measure airfield pavements in field conditions, and the criteria for assessing the state of evenness of airfield pavements. Measurements are made in the longitudinal and transverse direction using the P-3z planograph, modernized at the Air Force Institute of Technology, 4 m or 3 m long, shown in Fig. **1**. Measurements of unevenness can also be performed using a staff and a wedge [4, 7, 8, 9]. The assessment of the state of equality is carried out following the criterion of defectiveness [1].

1. The planograph P-3z during evenness measurements

Measurements of unevenness are recorded in the form of a digital record with a frequency of every 10 cm of the tested route [1]. The evenness of airfield pavements, as defined by the NO-17-A502:2015 standard, is expressed by the degree of defect W. This term is understood as the percentage share of the number of 5 m-long route sections where at least one limit value was exceeded between the theoretical connecting line formed by the points of contact between the planograph wheels and the upper surface of the pavement. The object in terms of equality is assessed by analyzing the average value of defectiveness W, which is determined from the relationship [2, 9]:

$$W = \frac{\sum_{i=1}^{n} w_i \cdot F_i}{\sum_{i=1}^{n} F_i} \quad (1)$$

where:

W – defectiveness of the assessed area or zone [%],

w_i – defectiveness of the "i" assessed research area [%],

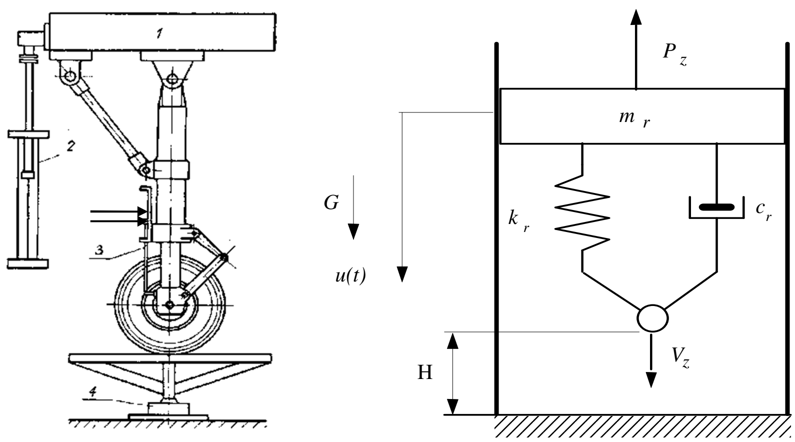
F_i – the length of the assessed section of the route (research area) accepted for assessment [m].

The referenced standard [2] defines: the method of assessing the levelness of airport pavements on individual functional elements of the airport, the assessment criteria, and the method of presenting the results obtained from field tests [2, 4, 9]. In order to be able to track changes in the state of evenness during the operation of the pavement, as well as to determine areas where degradation progresses faster, it is necessary to know the state of evenness before putting it into operation and to systematically subject it to periodic control tests during the further use process. Sample analyses of measurement results are discussed and presented in [4,9].

The impact of unevenness (threshold type) on the dynamic interaction between the plane and the pavement

The state of evenness determines not only the comfort of movement on the airport pavement but also affects the magnitude of dynamic impacts on the pavement. The impact of threshold irregularities resulting from vertical displacements occurring at the border of expansion joints (at joints of slabs made of cement concrete) or cracks on the dynamic impact on the pavement from aircraft taking off or landing was analyzed.

For the dynamic interactions originating from the threshold inequalities for the selected type of aircraft, it was necessary to determine the elastic-damping parameters of the landing gear. For this purpose, the results of the chassis tests were used, which were the initial parameters for the analysis carried out according to the computer simulation process. The tests and simulation of the process were carried out according to the idea presented in Figure **2**.



The actual layout   Layout scheme

where
P_z - lift,
m_r - reduced weight,
c_r - damping coefficient [Ns/m],
k_r - stiffness modulus [N/m],
V_z - the vertical speed of the aircraft at the time of contact with the apron [m/s]
1 - load,
2 - SC displacement measuring line,
3 - shock absorber stroke measuring line,
4 - thrust plate.

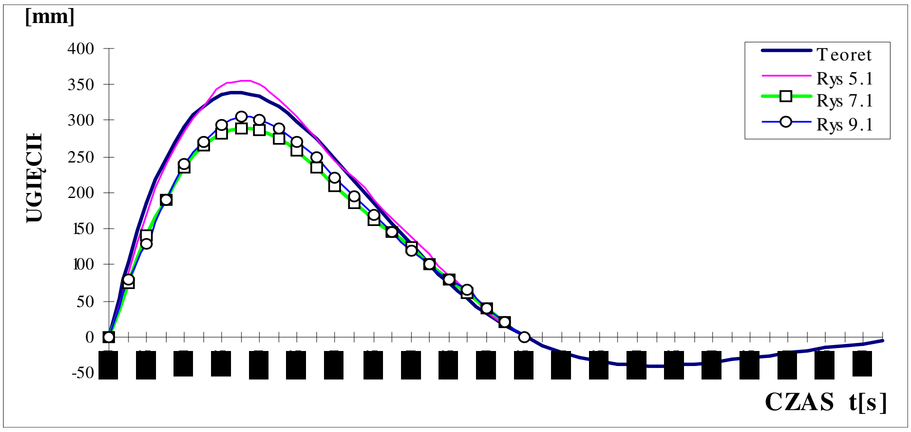
2. Experimental setup for testing the characteristics of the aircraft landing gear

The mass m_r together with the elastic-damping system described by the parameters k_r and c_r is dropped from the height H and hits the plate of high rigidity with the velocity V_z. During the contact of the system with the plate, the course of mass movement u(t) in relation to the static deflection U_s is registered in time. The velocity V_z is the value of the vertical component of the motion of the aircraft during landing. The loading of the system includes the unloading of the total weight by the lifting force Pz occurring at the moment of landing.

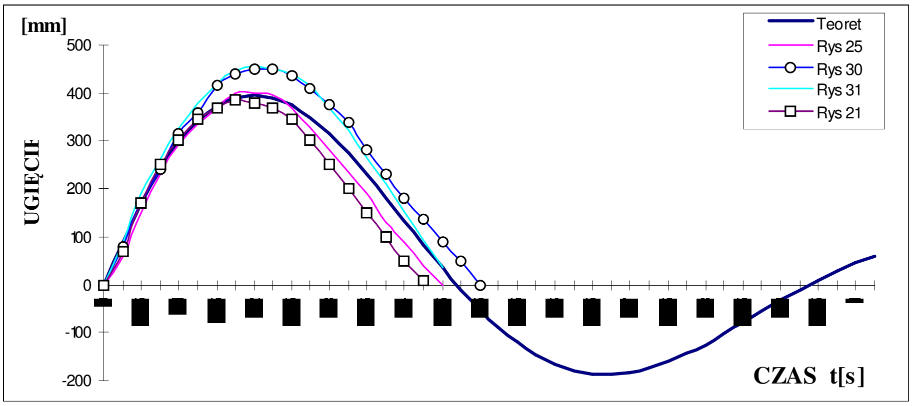
A computer simulation of this process was carried out with the experimental characteristics of the landing gear and the theoretical solution of the model adopted for testing. As a result of the simulation, the characteristic parameters of the chassis were adjusted, i.e.:

- coefficient of elasticity k_r,
- damping coefficient c_r.

For the process carried out in this way, the experimental characteristics and the theoretical solutions related to the elastic and damping units of the aircraft used in the experiment were fully consistent. This agreement is expressed by the correlation coefficient R > 0.95. Examples of simulation test results are shown in Figures **3** and **4**.

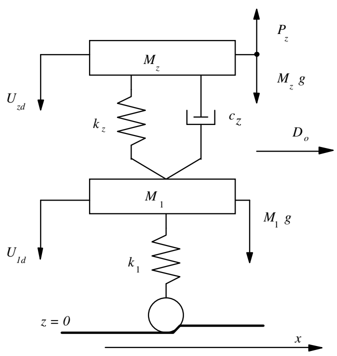


3. Deflection characteristics of the nose landing gear



4. Deflection characteristics of the aircraft main landing gear

For the non-stationary impact of the aircraft on the pavement with threshold unevenness, a modified equivalent system of the aircraft was adopted to study the vibrating motion while moving along the assumed unevenness. This arrangement is shown in Figure **5**.



5. Modified equivalent aircraft system for testing the oscillating motion while moving over a threshold-type unevenness

The equation of motion for the adopted model is as follows:

$$\left.\begin{aligned}&(M_1+M_z)\ddot{y}_1+M_z\ddot{y}_z+k_1y_1=k_1z(x)\\&M_z\ddot{y}_1+M_z\ddot{y}_z+c_z\dot{y}_z+k_zy_z=0\end{aligned}\right\}\qquad(2)$$

where, after transformations, was marked:

$$\left.\begin{aligned} y_1 &= u_{1d} \\ y_z &= u_{zd} - u_{1d} \end{aligned}\right\} \qquad (3)$$

z(x) - function describing the inequality profile,
x = x(t) - function describing the distance traveled by the plane over time.
The initial conditions are homogeneous:

$$y_1 = \dot{y}_1 = y_z = \dot{y}_z = 0 \qquad (4)$$

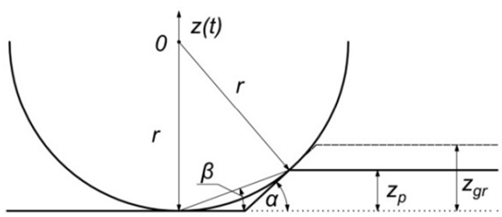
Equation (2) can be transformed to the form

$$\left.\begin{aligned} &(\mu+1)\ddot{y}_1 + \ddot{y}_z + \omega_1^2 \mu y_1 = \omega_1^2 \mu z \\ &\ddot{y}_1 + \ddot{y}_z + 2h_z \dot{y}_z + \omega_z^2 y_z = 0 \end{aligned}\right\} \qquad (5)$$

where:

$$\mu = \frac{M_1}{M_z}, \quad \omega_1^2 = \frac{k_1}{M_1}, \quad \omega_z^2 = \frac{k_z}{M_z}, \quad h_z = \frac{c_z}{2M_z}.$$

In order to determine the form of function *z(t)*, the kinematics of the wheel approaching the threshold presented in Fig. **6** were considered.



6. Scheme of the threshold-type pavement unevenness

From the analysis carried out for $\frac{z_p}{r} \langle 1$ we obtain:

$$z(t) = \begin{cases} v_p t & dla \ \ 0 \le t \le t_0, \\ z_p & dla \ \ t > t_0, \end{cases} \qquad (6)$$

where:

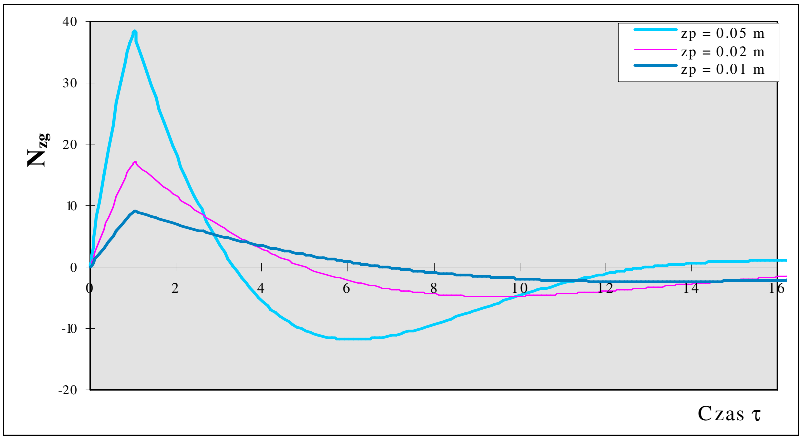
$$v_p = D_o \sqrt{\frac{z_p}{2r}}, \qquad t_o = \frac{\sqrt{2 z_p r}}{D_o}, \qquad (7)$$

and:

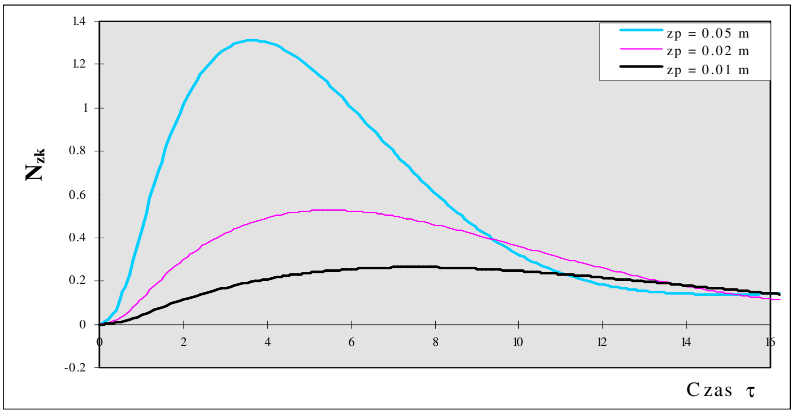
t_o - the time of entry of the aircraft wheel over the obstacle,
r - airplane wheel radius,
D_o - speed,
z_p - inequality height.

The examined case concerns a situation in which the plane connecting the fault is not tangential to the circle of the aircraft wheel. The boundary condition z_{gr} that determines such a case can be called a geometric criterion that connects the radius of the circle with the profile of the threshold. Detailed descriptions and transformations of formulas are presented in [1, 5].

For the scheme (model) adopted in this way, calculations were made for specific (exemplary) parameters. Exemplary results of the numerical analysis are presented in graphs for the wheel (N_{zg}) and fuselage (N_{zk}) overloads and the course of the reaction as a function of time with changing values of the threshold height z_p and the aircraft speed D_o. Calculations were made for the adopted damping parameter h_z = 2,6 [1/s] and wheel diameter 2r = 0,7 m, as shown in Figures **7** and **8**.



7. Values of wheel overload coefficients as a function of time, for different threshold heights, at the speed of the aircraft D_o = 50 m/s



8. The values of the fuselage overload coefficient as a function of time, for different threshold heights at the aircraft speed D_o = 50 m/s

From the calculations presented, e.g., Figures **8** and **9**, it is clear that the wheel and fuselage overload coefficients increase proportionally to the function of the threshold height. On the other hand, an increase in the speed of the aircraft causes an increase in the positive wheel overload coefficient while maintaining its constant negative value. The hull overload coefficient has a constant positive maximum value and shows a shift in time with increasing speed. The reaction of the aircraft's impact on the pavement shows a strong tendency to increase with the increase in sill height. Maximum values occur at the moment of entering the threshold and reaching values from 40 to 180% of the static load. The speed of the aircraft slightly causes an increase in the reaction, which reaches a value of about 35% of the static load and occurs at the moment the wheel hits the threshold.

The results of the numerical calculations show a large variety of ways in which the individual parameters characterizing the surface and the aircraft affect the values of the analyzed overloads. Changing the damping parameter has little effect on overloading and the size of the impact reaction on the pavement. The tire elasticity parameter k_1, which depends on the tire pressure, significantly influences the overload values. Doubling k_1 also doubles the overload. The dynamic reaction of the aircraft's impact on the pavement also doubles in this case.

The impact of exploitation procedures in the form of grooving of the pavement and local surface repairs on the results of unevenness measurements

In order to obtain the best anti-slip parameters by ensuring the proper coefficient of friction (especially during rainfall), grooving was performed on one of the airport facilities on the runway with a cement concrete surface. This method consists of making cuts (grooves) in the pavement in a direction transverse to the runway axis. The standard groove spacing was 38 mm, and the width and depth of the grooves were 6 mm. The texture reduces the phenomenon of aquaplaning and enables faster drainage of water after rainfall. The view of the grooved surface is shown in Figure **9**.

9. Texture of the pavement as a result of grooving

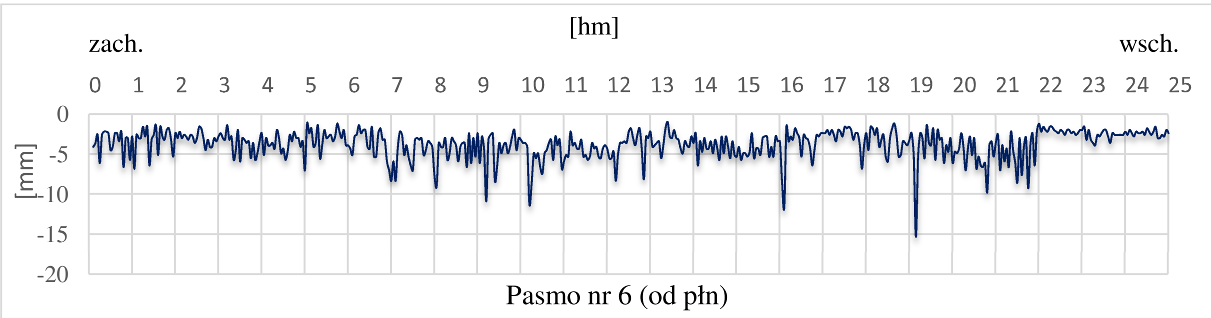
The primary purpose of the runway surface grooving is to drain water from the surface and reduce the risk of aquaplaning. The grooving of runway surfaces has been recognized as an effective surface treatment to reduce the risk of aircraft skidding when landing on a wet runway surface. In addition, with a grooved surface, isolated ponds of water that may form due to an uneven surface are usually reduced or eliminated.

In order to check the impact of grooving on the evenness of the surface, measurements of the evenness of the laid surface before and after grooving were carried out using a modernized planograph. The assessment of the evenness of the pavement was carried out based on the defect criterion, following NO-17-A502: 2015 Airport Pavements. Equality study. Measurements were made in the longitudinal direction. Measurements of the unevenness of the assessed pavement were carried out in the central part of the slabs (strips) on individual routes (rows) accepted for assessment. After the measurements, an analysis was carried out, the result of which was the determination of the degree of the defect - **W** [%], which is its assessment. The average number of defects exceeding the permissible irregularities in the longitudinal direction before grooving was 2.3%, with an average value of unevenness of 2.5 mm and a standard deviation of 0.9 mm, while the average number of defects exceeding the permissible irregularities after grooving was 2.5%, with a mean unevenness of 3.1 mm and a standard deviation of 1.0 mm. The differences in the unevenness resulting from the grooving procedure compared to the state before grooving are insignificant and do not have a significant impact on the evenness of the surface.

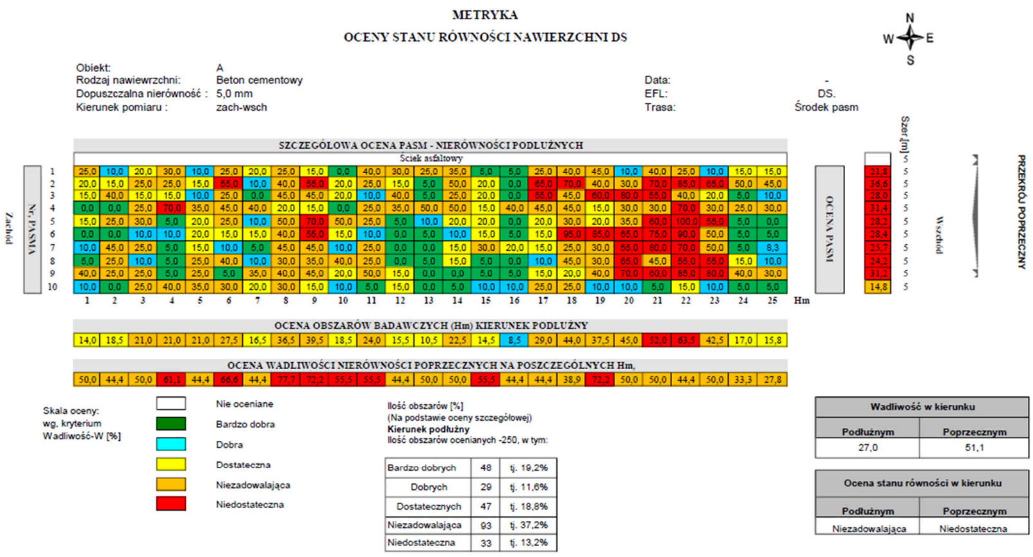
For exploited pavements, operational parameters are regularly monitored, including the assessment of pavement evenness. In the event of exceeding the permissible unevenness, and in particular, exceeding the limits of the quantities adopted for the assessment of the "defectiveness" parameter, preventive actions are taken in the form of repairs of surfaces with irregularities that significantly affect the assessed parameter.

On one of the objects, after the tests were carried out and the measurement results were presented (according to [2]), 36% of areas exceeded the permissible requirements. On this object, point-exploitation procedures were performed, to a minimum extent, on the bands where the permissible irregularities were significantly exceeded. After the next measurements, the evenness was significantly improved, including: the number of areas that did not meet the requirements decreasing to 21% and the defectiveness decreasing from 24.1% to 11.7%. Presenting information on the condition of the surface obtained from measurements is very important for the facility manager, who, thanks to this information, can take action to determine the causes of their formation through accurate diagnostics and thus reduce the rate of degradation by selecting the appropriate repair technology.

An exemplary graphic record and a metric for evaluating the state of equality from the measurements taken are shown in Figures **10-11**.



10. Maximum unevenness recorded by the planograph



11. Equity status assessment metric

Summary and Conclusions

The analysis carried out in the article leads to the following conclusions:

1. For proper monitoring of the technical condition of airfield pavements, devices guaranteeing the repeatability of results and appropriate test and assessment methodologies are required. The adopted requirements contained in [2, 10] make it possible to track changes in the state of evenness, to determine the surfaces where these changes are the largest and which require maintenance operations,
2. The presentation of the results of the measurements in the form of profiles enables visual analysis of the size of the unevenness and the location of its occurrence, and the prepared metric for assessing the evenness of the runway surface indicates places that may affect the safety of air operations. For a correct analysis of changes in the state of evenness, it is necessary to present the state at the time of commencement of operation of the pavement, which will also allow, after subsequent monitoring, to make appropriate operational decisions to ensure the safety of air operations.
3. Operational procedures performed in the form of grooving the surface, improving the speed of rainwater drainage, and the adhesion of the wheel with the surface, do not have a significant impact on the size of the unevenness and thus do not affect the evenness of the surface.
4. The presented numerical analysis of the impact of inequalities (of the threshold type) on the dynamic interaction between the plane and the road showed that:
   - The maximum overload of the aircraft wheel reaches a value of about 9 times the acceleration of gravity at the height threshold of 0.01 m and increases with its increase. A similar tendency was obtained with the increase in the aircraft speed.
   - The maximum dynamic value of the aircraft's reaction to the pavement is greater by about 40% of the static load value,
   - The wheel and fuselage overload coefficients increase proportionally to the aircraft wheel spring coefficient parameter, while the increase in the damping parameter has a smaller effect. A similar tendency is shown by the reaction of the aircraft to the pavement.

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