Asesorías y Tutorías para la Investigación Científica en la Educación Puig-Salabarría S.C.
José María Pino Suárez 400-2 esq a Lerdo de Tejada. Toluca, Estado de México. 7223898475
RFC: ATI120618V12

**Revista Dilemas Contemporáneos: Educación, Política y Valores.**
**http://www.dilemascontemporaneoseducacionpoliticayvalores.com/**
**Año: VI Número: Edición Especial Artículo no.:56 Período: Marzo, 2019.**

**TÍTULO:** Una teoría de la cuantificación del efecto de los chorros de aviones sobre la temperatura del curso de la superficie del pavimento de asfalto y concreto del aeródromo.

**AUTORES:**

1. Alexey L. Ramos.
2. Eduard V. Kotlyarsky.
3. Yury E. Vasilev.
4. Vladimir A. Popov.
5. Igor Y. Sarichev.

**RESUMEN:** El presente documento ha intentado justificar teóricamente la necesidad de tener en cuenta el aumento de la temperatura del pavimento del aeródromo de asfalto de hormigón, cuando hay un efecto repetido producido por los chorros de aviones en la superficie del pavimento, en los cálculos de la estabilidad termodinámica del curso de la superficie; no solo en los casos en que la velocidad de chorro del chorro es igual o superior a 100 m/s, sino también en las demás condiciones de operación. Permitirá reducir los riesgos de deformaciones plásticas, la posible erosión por chorro y los baches, incluso en la etapa de diseño, y aplicar mezclas de asfalto con propiedades específicas para el curso de la superficie del pavimento.

**PALABRAS CLAVES:** erosión a chorro, intercambio de calor, campo de temperatura, turbulencia, conductividad térmica.

**TITLE:** A theory of quantifying the effect of jet blasts from aircrafts on temperature of the surface course of asphalt-concrete airfield pavement.

**AUTHORS**:

1. Alexey L. Ramos.

2. Eduard V. Kotlyarsky.

3. Yury E. Vasilev.

4. Vladimir A. Popov.

5. Igor Y. Sarichev.

**ABSTRACT:** This document has attempted to theoretically justify the need to take into account the increase in the pavement temperature of the concrete asphalt airfield, when there is a repeated effect produced by jets of aircraft on the surface of the pavement, in the stability calculations thermodynamics of the course of the surface; not only in cases where the jet velocity of the jet is equal to or greater than 100 m/s, but also in the other operating conditions. It will reduce the risks of plastic deformation, possible jet erosion and potholes, even at the design stage, and apply asphalt mixtures with specific properties for the course of the pavement surface.

**KEY WORDS**: jet erosion, heat exchange, temperature field, turbulence, thermal conductivity.

## INTRODUCTION.

Airfield pavements typically experience heating and power effect of exhaust gas jets of jet aircraft engines, along with power loads from aerial vehicles and effect of natural and climatic factors. Airfield operation experience shows that in certain conditions jet blasts from aircrafts cause erosion of surface, when there is jet impingement on pavement. The depth of organic binder burnout in the layer of asphalt may reach 13mm.

Jet blast causes an abrupt short-time rise in temperature on the surface of pavement. The value of temperature effect dictates whether the surface is burnt out (Leschitskaya & Popov, 2005) or, when the temperature is lower, an organic binder is softened. In the former case, bitumen-unbound mineral constituents of asphalt are blown out from pavement under the effect of air pressure; while in the latter case, structural bonds between asphalt components weaken, and partial blowing out of mineral particles from the pavement surface likewise takes place due to air pressure. If adhesion bonds within asphalt are strong enough to withstand air pressure of jet blast, an integrity of pavement material is retained. However, in this case, when there is a permanent effect of jet blast, organic binder ages more rapidly that contributes to changing physical and mechanical properties of asphalt and facilitates its disintegration over time.

**Fig.1. Asphalt pavement core with jet erosion (core to the left), taken from holding bay, combined with taxiway, and a core taken within apron where there is almost no effect of jet blasts (core to the right). Domodedovo Airport.**


In addition, while operating wide-boded jets with low-jet engines, gas-dynamic effect in the form of separated asphalt layers can occur within those segments of aerodrome pavements that have asphalt strengthening layers with various cracks (Trigony et al,1998; Ivanov, 2005).

The main reasons for destruction of asphalt pavements and strengthening layers exposed to jet blasts lie in inadequacy of the design model and faults in justifying requirements for material, i.e.

composition of asphalt and, first of all, for organic binder, as well as in taking into account condition of the strengthened pavement when building strengthening layers. This is due to non-objective estimation of temperature mode of airfield pavement operation, with no consideration for thermal and force impact of jet blasts upon surface course.

Real temperature conditions of the airfield pavement surface course within segments exposed to jet blasts differ from those, which have currently been taken into consideration in designing the structure of aerodrome pavement and asphalt mix composition that contributes to reduction in pavements' lifecycles.

It is believed that temperature of aerodrome pavement surface depends om thermodynamic characteristics of jet blast and its field, thermotechnical and physical-mechanical properties of the material of the surface course layer of pavement and its temperature prior to exposure to jet blast, specified by local climatic conditions.

The objective of the conducted work is to develop a theoretically justified methodology for determining a design temperature of asphalt pavement heating, taking into account all types of thermal impact on the pavement surface, including that of exhaust gas jet blasts from airplanes. It will allow to more accurately design aerodrome pavements and select compositions of asphalt mixes for surface courses, thereby extending pavement service life. The following problems were solved to attain the above objective:

1. Revising a mechanism of impingement of exhaust gas jet blast from aircrafts on the surface of aerodrome pavement, factors affecting formation of the gas jet field, parameters of jet blast, including temperature and velocity of flow at its various points, and an area of its propagation across the surface.
2. Revising common patterns of heat exchange between jet blast and airfield pavement surface in conditions of forced convection.

3. Developing a theory of computing temperature of asphalt pavement on the surface and distribution of temperature throughout layer depth on exposure to jet blast. Determination of probable depth-wise distance from pavement surface, at which there is an increase in temperature of the layer material.
4. Comparing temperatures of asphalt pavement surface and varying them across the depth of airfield pavement layer, with and without effect of jet blast.

Considering temperature problems as applied to aerodrome pavements, it is necessary to note temperature effects produced by jet blasts from aircrafts that are typical of only aerodrome pavements. This type of thermal effects has a number of specific features: they are spread over not the entire area, but such particular segments of pavements, as launching sections of runways, prelaunch areas, parking aprons, holding positions on taxiways, holding bays, run-up areas, where an aerial vehicle stays immovable some time with engines running, as well as soft shoulders of prelaunch areas and taxiways, unpaved junctions of end-type runway segments. Temperature rises abruptly, and erosion of pavement surface course occurs at those sections, where airplane engines are operated in conditions, close to nominal (N).

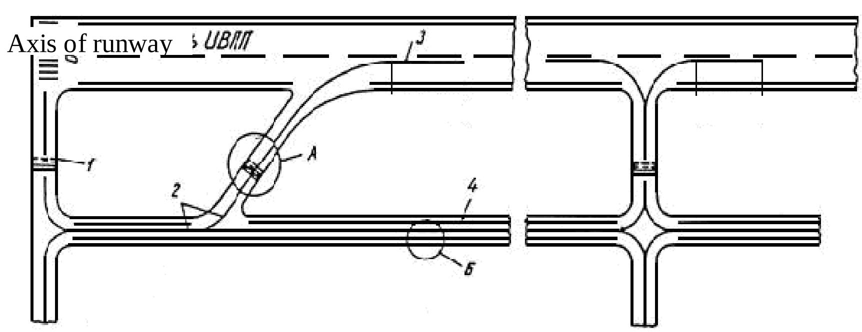
Aircrafts move across aerodrome under their own power in 0.25N operation mode of engines. In this mode, due to short time of impact and low speed, jet erosion of asphalt pavements is usually not seen. At the same time, surface course of pavement periodically absorbs additional non-countable thermal and power load, which may, throughout operation period, change physical and mechanical properties of asphalt-concrete, poured in pavement, and facilitate its destruction. To address the problems of assuring operation of modern jet airplanes at an aerodrome and to increase life cycles of airfield pavements and strengthening layers requires refinement of design characteristics of jet blasts' loads and common patterns of jet heat transfer in conditions of forced convection.

Serviceability of aerodrome complex, including assuring safety of taking off, landing, taxying of modern airplanes in conditions of potential jet erosion of pavements and separation of segments of strengthening surface course asphalt layer when aerodynamic stability is not sufficient, shall be extensively defined by reliability and longevity of particular elements of these pavements.

Step-wise short-time heating of pavement surface in the area of contact with jet is created within some particular sections of aerodrome under the effect of jet blasts. As a result, a non-uniform distribution of temperature occurs across pavement area and structure thickness. Potential jet erosion and separation of asphalt layer for strengthening pavement are most probable in the zone, where maximum effect is produced, i.e. within sections, adjacent to the point of contact between axis of jet blast and pavement surface.

The fragment of aerodrome master layout shows aircrafts' taxi-holding positions, where jet erosion and separation of pavement segment are most probable (Fig.2) (Operation Manual for civil aerodromes of the Russian Federation, 1999).

**Fig. 2. Fragment of aerodrome master layout with indication of taxi-holding positions for receiving permission to lineup airplanes and other commands (Abramovich, 2011).**




**DEVELOPMENT.**

**Materials and methods.**

When there is jet impingement on pavement, jet blasts are spread across the pavement in the form of ellipsoid, producing thereby an intense and unsteady thermal and force effect in the area of contact with its surface. A combined action of velocity and temperature fields takes place here. A jet blast has turbulent structure, characterized with velocity, temperature, pressure, and density of flow. These factors have chaotic oscillations, irregularly changing in space and time. Jet blast from aircraft discharges on aerodrome surface at up to 6° angle to the horizontal in the form of axially symmetrical jet, spreading in relatively stationary air environment, restricted by the surface of airfield pavement on the one side (Trigony, 1981).

In quantifying the effect of jet blasts from aircrafts on temperature of the surface course of asphalt aerodrome pavement, it is initially assumed that the major factors affecting formation of jet blast fields and their parameters are as follows:

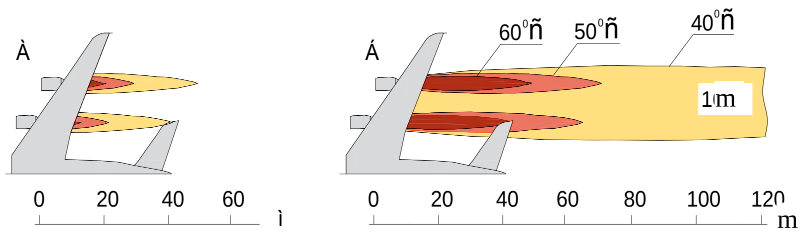
1. Type of aerial vehicle by method of takeoff and landing (vertical, vertical forward, short, shortened, and normal).
2. Details of engines' configuration (their quantity and arrangement) (Fig.2), affecting geometrical dimensions of jet field, temperature, and velocity of gas flow at the level of pavement;
3. Capacity of engine unit that depends on normal operating thrust of power unit. The higher the nozzle-exhaust velocity / temperature and linear dimensions of jet field are, the higher the temperature at the level of pavement is.
4. Mode of engines' operation. When their mode of operation changes, nozzle-exhaust velocity and temperature, linear dimensions of jet field, and maximum velocity and temperature at the level of pavement change as well.
5. The value of initial angle of sloping jet axis to pavement, which depends on design features of aerial vehicles. Temperature of jet at the level of pavement rises under otherwise equal conditions, when an angle of slope towards pavement increases.
6. Height of engines from pavement surface. The more the distance from engine nozzle axis to pavement surface, the lower the temperature and velocity of jet at the level of pavement.

7. Diameter of the engine exhaust nozzle exit. Under otherwise equal conditions, the more the exit diameter of engine nozzle, the higher the temperature, velocity, and geometrical dimensions of jet field. Modern aerial vehicles are usually equipped with power units that contain several engines.

According to studies carried out by ICAO in various airports throughout the world, it was found out that, when there is a close parallel discharge of two and more jets, a role of each particular engine is established in distribution of temperatures and air pressure at up to 70m distance. A unified flow is further formed (ICAO Aerodromes Design guidelines, 2005).

An example of distribution of isotherms in jet blasts of aircraft jet engines, operated in various modes (Fig.3) [26].

**Fig.3 Scheme of distribution of 60°C - 40°C isotherms in jet blasts from Airbus aircraft in taxiing mode – (A) and during takeoff – (B), when ambient temperature is 30°C, and wind velocity is about 1m/sec (isothermal fields of higher temperatures are not shown in the figure).**




(A) (B)

Pursuant to the theory of turbulent jets [1,4], a jet has the highest temperatures on its axis; with distance from the axis sideward, temperature and velocity of jet blast decrease (Abramovich, 2011; Ginevskiy, 1969).

In developing a theory of quantifying changes in pavement temperature due to the effect of exhaust gas jet blasts, common patterns of heat exchange between jet blast and pavement surface were assumed to be the prime postulates.

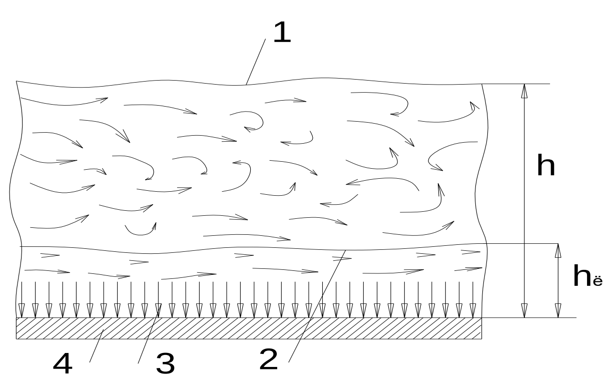
When there is a jet blast airflow about surface, a heat exchange occurs between high-temperature gas flows and surfaces of pavement due to forced convection (Lukanin & Shatrov, 2009; Shatrov et al, 2012).

An intensity of heat transfer depends on the difference between temperatures of gas jet and pavement surface, thermal and physical properties of structural materials of aerodrome pavements, pavement condition and the process time.

In the course of high-temperature jet blast impingement on pavement, friction in boundary layer slows down the jet in multiple points across the entire airflow surface. Movement in these points is totally slowed down that facilitate an increase in temperature in the area of contact with the pavement surface layers.

The structure of jet blast gas flow is of special interest when theoretically solving the problems in question. Fig.4 presents a structure of gas flow in boundary layer in the course of impingement on horizontal surface. As turbulence of impinging flow increases, a boundary turbulent layer quickly appears near the pavement surface. Here, a laminar sublayer is first formed, which is further transformed into a turbulent one (Reynolds number (Re) varies from $10^5$ to $3.5*10^6$) (Operation Manual for civil aerodromes of the Russian Federation, 1999).

**Fig.4. Depth-wise structure of gas flow in boundary layer: 1 – boundary layer edge h; 2 – laminar layer edge $h_л$; 3 – heat flow absorbed by the surface of the top aerodrome pavement layer; 4 – aerodrome pavement.**



Thickness of boundary layer **h** across jet field (along axis X), when Reynolds number $Re \leq 10^7$, shall be defined by formula 1:

$$h = \sqrt[1,25]{0,29 \cdot \left(\frac{\nu}{W_0}\right)^{0,25}} \cdot X \qquad (1)$$

where: $\nu$ – kinematic viscosity;

$W_0$ – velocity of jet core.

Thickness of laminar sublayer in boundary turbulent layer shall be defined by formula:

$$\frac{h_л}{h} = \frac{194}{Re_x^{0,7}} \qquad (2)$$

Unfortunately, few works have been devoted to theoretical studies of heat exchange between jet blasts and aerodrome pavement. They mostly analyze quite conventional schemes, where actual volume of jet flow in the zone of jet contact with pavement is replaced with flat flow that has a non-uniform field of temperatures and velocities of heat exchange. These schemes enable to obtain only approximate solutions.

When temperature and velocity fields are distributed across boundary layer of jet, the process of convection heat exchange is generally described by the Newton equation (Lukanin & Shatrov, 2009), according to which heat flow **Q** from gas jet, moving upwards to the pavement surface, is proportional to the area of heat exchange surface **F** and difference between temperatures of gas jet $T_w$ and pavement surface $T_п$.

$$Q = \alpha F (T_w - T_п) \qquad (3)$$

where α – heat-transfer coefficient that depends on physical properties of pavement surface (density, heat capacity, thermal conductivity), dimensions of surface, nature of medium movement, velocity of movement).

Mathematical tools for describing processes of jet blast heat transfer involve the Fourier equation, which depicts a process of heat transfer at the interface of pavement and jet in the boundary layer, according to which density of heat flow is directly proportional to temperature gradient of gas medium, and a differential equation of continuity (uniformity) of medium (Lukanin & Shatrov, 2009). It is considered that an accurate calculation of temperature fields in aerodrome pavements due to effects produced by jet blasts is currently impossible, since this thermal and physical problem is challenging and requires taking a quantity-related consideration of some specific features of pavement heating conditions:

- Change in boundary conditions over time and across the heated surface;
- Change in thermal and physical properties of the heated surface due to the effect produced by jet blast over time;
- Use of structural pavement layers that are non-uniform through thickness, various types of asphalt concrete, and other factors;
- Coefficients of heat transfer from gas jet to the surface of aerodrome pavement change over time, when an airplane engine starts to be operated in various modes. A variable value of heat transfer coefficient, when thermal and physical properties of materials change, has until recently been taken into account in calculations approximately and neglected in designing asphalt-concrete pavements and assigning the required asphalt-concrete mixes (Lukanin & Shatrov, 2009; Operation Manual for civil aerodromes of the Russian Federation, 1999).

Temperature fields of gas jets are determined on the basis of the theory of gas jet of G.N. Abramovich (Abramovich, 2011). and the theory of heat exchange (Lukanin & Shatrov, 2009), and their quantifying involves solution of the Fourier-Kirchhoff differential equation of heat conductivity with the boundary condition that implies heat balance on the outer surface, and a complete heat isolation on the inner surface.

$$\frac{\partial T}{\partial \tau} = a\frac{\partial^2 T}{\partial z^2} \tag{4}$$

Thermal conductivity of asphalt-concrete is relatively low, and heating due to effect of jet is short-time, gradients of temperatures $\frac{dt}{dx}$ and $\frac{dt}{dy}$ in directions, parallel to the surface of heating, are small as compared to gradients of temperatures $\frac{dt}{dz}$ through thickness of the pavement layer, hence, it is advisable to simplify an equation of thermal conductivity and convert the problem of heat propagation in semi-space to the problem of heat propagation in a semi-bounded body (Lukanin & Shatrov, 2009; Trigony, 1981).

The temperature of aerodrome pavement surface depends on thermal and dynamic characteristics of gas jets and their fields, thermal and technical and physical and mechanical properties of the top structural layer material of pavement, temperature of pavement specified by the effect of nature factors, defined by local conditions and climate.

Heat energy from the environmental exposure, transferred to the pavement surface at the expense of natural convection, further propagates through thickness of the pavement layer by heat transfer due to the material thermal conductivity. In calculating temperature in the surface asphalt layer of aerodrome pavement, the latter can be considered as a semi-bounded solid body with the 1$^{st}$ type boundary conditions.

The temperature on the surface of aerodrome pavement affected by constant but time-varying thermal environmental factors shall be calculated by formula (5); distribution of temperature through thickness of layer may be presented in the form of expression (6), using the Gaussian integral.

$$T_{п} = T_{в} + T_{экв}, \tag{5}$$

$$T(z,\tau) = T_0 + (1 - erf(\frac{z}{2\sqrt{a\tau}})(T_n - T_0) \tag{6}$$

where: $T_п$ – temperature of the pavement surface due to natural and climatic effects;

$T_в$ – ambient temperature;

$T_{экв}$ – equivalent temperature of pavement heating due to solar radiation;

$T_0$ – initial temperature on the lower boundary of the layer;

$T(z,\mathbf{t})$ – temperature of pavement through thickness in point z at the moment in time **t**;

$\alpha$ - coefficient of temperature conductivity of material.

Jet blast, impinging on the pavement surface, has a turbulent structure, therefore, the value of velocity of gas flow propagation, temperature, and pressure at the various points of the jet field and body constantly vary in space and time. Hence, the temperature of the pavement surface in the area of contact with jet blast has various values at different points as well.

Maximum values of temperature and velocity in the field of gas jet are at the point of contact between jet axis and pavement surface. There is a zone, within the field of jet, of maximum effect on pavement, where the central part of the near-wall layer of gas flow with velocity $V_i = (1…0.5)\ V_m$ acts; radius of this zone amounts to 0.441 of radius of jet in the area of contact between jet axis and pavement surface (Trigony, 1981). Temperature of pavement surface heating Tw at any point in the area of contact with gas jet is defined based on the condition that the amount of heat $q_1$, transferred to the surface of pavement from jet blast by forced convection during operation of engine, is equal to the amount of heat $q_2$, transferred from the surface of pavement into the depth of pavement layer over time **t**. Since heating from the effect of jet is short-time, and the depth of the pavement surface course heating is (0.1…. 3.0) cm, it can be assumed that $q_1 = q_2$.

$$q_1 = \alpha_c \cdot F \cdot (T_с - T_п) \cdot \tau \tag{7}$$

$$q_2 = 2\tau(T_w - T_h)\sqrt{\frac{\lambda_n \rho_n c_n}{\pi\tau}} \tag{8}$$

where: $T_п$ – temperature of pavement surface prior to the effect of jet;

$T_c$ – temperature of jet at the point, where there is a contact with pavement;

$\tau$ – time of the jet effect;

F – area of heated surface;

$T_w$ – temperature of pavement surface on exposure to jet blast;

$T_h$ – temperature of pavement at the depth h from the surface prior to the effect of jet (h – thickness of the layer in question); $\sqrt{\frac{\lambda_n \rho_n c_n}{\pi \tau}}$ - heat absorption coefficient of pavement layer;

where: $\lambda_п$ – coefficient of asphalt-concrete heat conductivity;

$\rho_п$ – density of asphalt-concrete;

$c_п$ – heat capacity of asphalt-concrete;

$\alpha_c$ – coefficient of gas jet heat transfer.

Thermal energy from high temperature gas jet, transferred to the pavement surface because of forced convection, further propagates through thickness of pavement layer by heat transfer due to heat conductivity.

Convection heat transfer coefficient of jet $\alpha_c$ shall be defined by formula 9 (Shatrov et al, 2012):

$$\alpha_c = \frac{\lambda}{d_э} N_u \qquad (9)$$

where: l – coefficient of gas jet heat conductivity that depends on its temperature;

Nu – Nusselt criterion defined by formula:

$$N_u = 0{,}023 R_e^{0.8} \qquad (10)$$

Re - Reynolds criterion defined by formula.

$$R_e = V_{.c} \cdot \frac{d_э}{\upsilon} \qquad (11)$$

where **n** – coefficient of jet gas kinematic viscosity, which depends on temperature; $V_c$ – velocity of medium flow; $d_э$ – equivalent hydraulic diameter of gas jet at the level of contact between jet axis and pavement surface, defined by formula:

$$d_э = \frac{4S}{P} = \frac{2\pi r^2}{\pi r + d} \qquad (12)$$

where S – shear area of jet at the point of its axis contact with the pavement surface;

P – perimeter around jet shear area at the point of jet axis contact with the pavement surface;

r – radius of jet cross-section at the point of jet axis contact with the pavement surface;

$d_э$ – diameter of jet cross-section at the point of jet axis contact with the pavement surface.

The temperature of heating of asphalt-concrete pavement surface, considering the effect of jet blasts $T_w$, is defined through method for solving a system of equations $q_1$ and $q_2$.

Thermal energy from high temperature gas jet, transferred to the pavement surface because of forced convection, further propagates through thickness of pavement layer by heat transfer due to heat conductivity. Subsequent distribution of temperature through thickness of pavement shall be described by mathematical relationship (14) using the Gaussian integral.

**Results.**

On the basis of the suggested theoretical postulates, a methodology and a theory were developed to quantify the effect of temperature field of jet blast on the temperature of the surface course of asphalt-concrete aerodrome pavement. It enables to assess the temperature of heating of the material on the pavement surface and at any distance from it, when there is a complex effect of all the main external thermal sources.

A mathematical relationship was obtained between the temperature of heating of the pavement surface at any point of interest in the zone of contact with gas jet and the difference in temperatures of jet and pavement surface prior to the effect of exhaust gases, heat conductivity of gas jet, heat absorption coefficient of pavement layer material, and temperature on the lower boundary of the layer in question prior to the effect of jet.

$$T_w = T_h + \frac{\lambda_c (T_c - T_n)}{2\sqrt{\frac{\lambda_n \rho_n c_n}{\pi\tau}}} \qquad (13)$$

A mathematical relationship was also obtained between a change in temperature through depth of asphalt-concrete pavement layer at any point in the zone of contact with jet blast and the time of the effect produced by jet.

$$T_w(z,\tau) = T_{0.0n} + (1 - erfX)*(Tw - T_{0,0n}) \qquad (14)$$

denote $(\frac{z}{2\sqrt{a\tau}}) = X$

**z** – coordinate across thickness of pavement;

$a$ - coefficient of temperature conductivity of the pavement layer material;

**t**- heating time;

$T_{0,0n}$ – temperature on the lower boundary of the layer in question with no effect of jet blast;

$T_w$ - temperature of pavement surface with the effect of jet blast.

According to the methodology developed, temperature was calculated on the surface of asphalt-concrete pavement and through thickness of layer in moving away from the surface, with the effect of gas jet. There is an opinion that these calculations justify the need for taking into account the effect of jet blasts on pavement to objectively estimate its temperature mode, which affects the life-time of aerodrome complex as a whole.

The calculations made showed that there is a good compliance with multiple performed measurements. The work was carried out using the equipment of the Multiple-access center of MADI (MAC MADI). The temperature of pavement surface heating and distribution of temperature through the depth of layer due to the effect of jet impingement depends on technical characteristics of their source, distance of the point in question from pavement surface, time of jet blast effect, mode of engine operation, ambient temperature. To obtain numerical values of temperatures and depth of thermal effect of gas jets on pavement, an airplane of A-320 type was assumed to be a designed aerial vehicle. Airplanes of such type have widely been used by civil aviation in the Russian Federation and abroad.

Fig. 5, 6, 7 present dependencies of distributing temperature on the surface and through thickness of asphalt-concrete layer on various factors with no account for heat effect of jet blasts and while airplane engine is operated.

**Fig.5. Distribution of temperature across pavement surface and its distribution at various points across depth of the top asphalt-concrete layer without and with effect of jet blasts during 3min, when engine of A-320-type airplane is operated in mode 0.7N and 0.4N of nominal value and 27.5 $^0$C air temperature.**

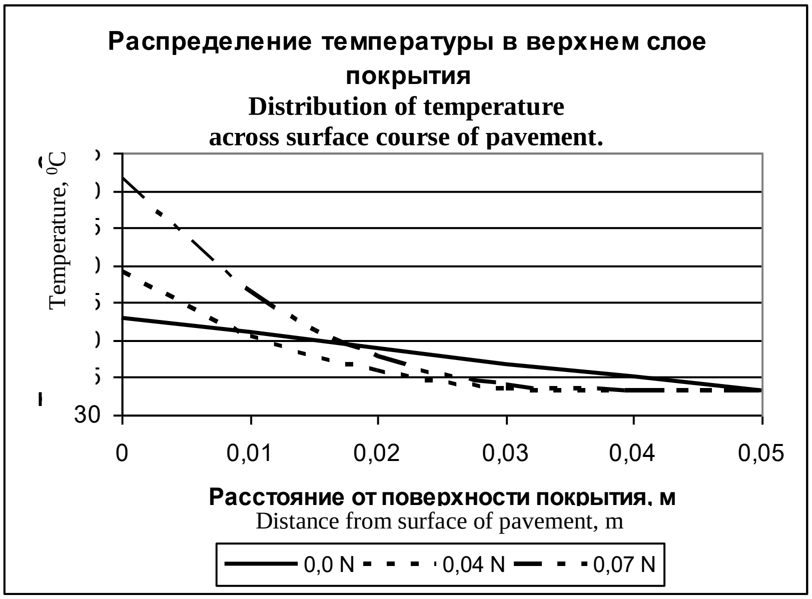
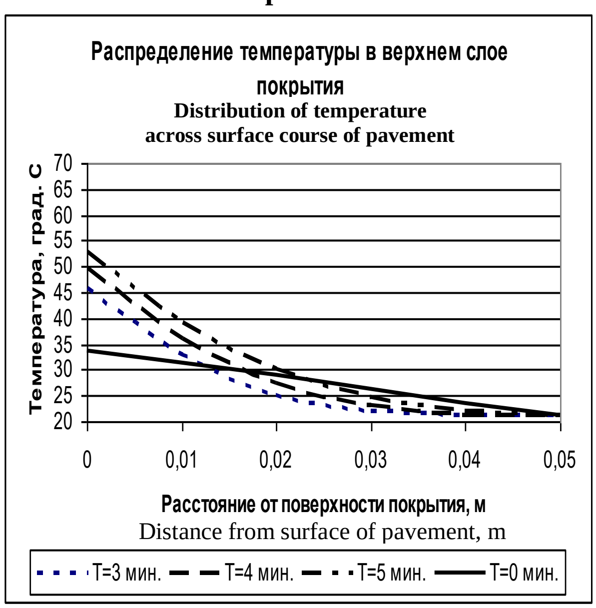
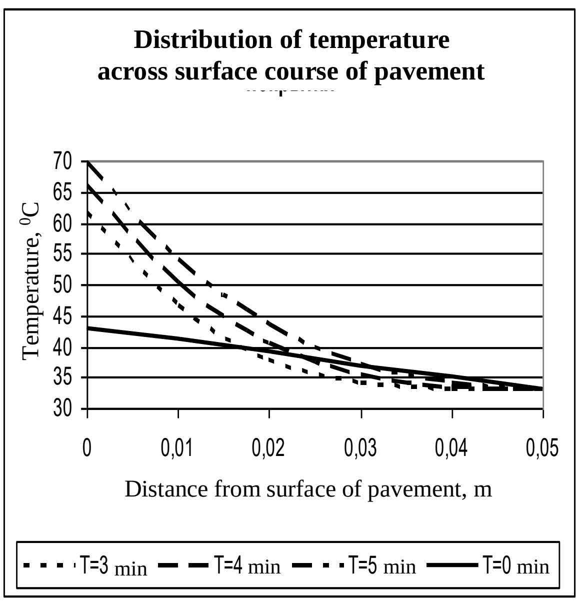



**Fig. 6. Distribution of temperature across pavement surface and at various points across depth of the top asphalt-concrete layer without and with effect of jet blasts during 3, 4 and 5 min, when engine of A-320-type airplane is operated in mode 0.7N of nominal value and 27.5 $^0$C (A) and 15,4$^0$C (B) air temperature.**

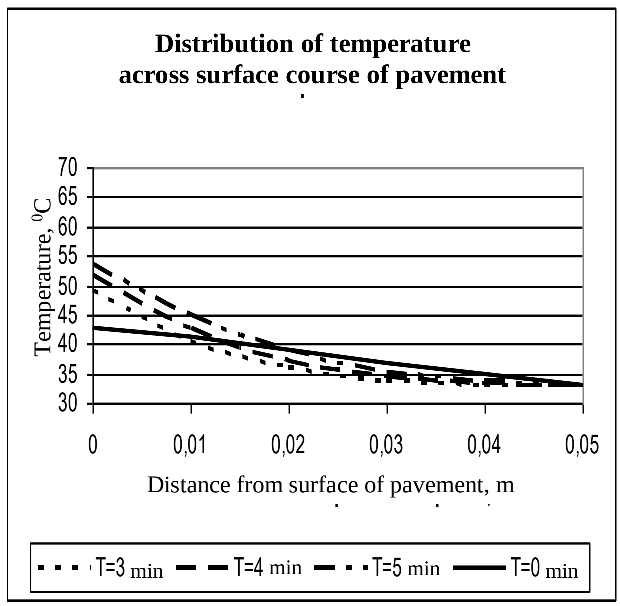


The conducted theoretical study of temperature conditions of the surface asphalt-concrete layer of aerodrome pavement demonstrated that in the process of operation of aerial vehicles with jet engines there is a short-time step-wise increase in temperature on the surface of pavement in the zones of its contact with a jet of exhaust gases, with the subsequent attenuation across the depth of layer (up to 3cm, when the designed engine is working in 0.7N mode during 3-5min) depending on characteristics of jet, mode of effect, and climatic environmental conditions. The most abrupt change in temperature of a layer occurs at up to 1.0cm depth.

**Fig. 6. Distribution of temperature across pavement surface and at various points across depth of the top asphalt-concrete layer without and with effect of jet blasts during 3, 4 and 5 min, when engine of A-320-type airplane is operated in mode 0.7N of nominal value and 27.5 $^{0}$C (A) and 15,4$^{0}$C (B) air temperature.**




(A)




(B)

An intensity of heat transfer occurring when there is an effect of jet blast on the surface, and temperature and depth of heating depend on the difference between temperature of gas jet and pavement surface, thermal and physical properties of material of the pavement surface course, pavement condition, and the process time.

The depth of airfield pavement heating in the zones of contact with jet blast and temperature across the depth of pavement at various distances from the surface under different modes of jet engine operation in diverse climatic zones of Peru, calculated with the use of the developed method, proves the need for comprehensive assessment of temperature conditions of the surface asphalt-concrete layer in designing the pavement and selecting the material of the surface structural layer of pavement.

The developed methods of quantifying the amount of heat energy, obtained by the unit of pavement area, and calculating heat content of mass unit of the pavement surface course material with and without taking into consideration the effect of jet blast effect, enable to assess the change in thermal conditions and physical and mechanical properties of layer material, in the course of jet aircrafts' operation.

To justify theoretical studies and appropriateness of using the developed methods for quantifying temperature and heat content of the top asphalt-concrete layer of pavement considering the effect of all basic heat sources on pavement during operation, it is necessary to carry out laboratory tests for assessing changes in temperature conditions of asphalt-concrete due to the effect of high-temperature jet blast and change in its physical and mechanical properties when time of operation varies. It will further enable to apply asphalt-concretes for aerodrome pavements that have specified properties corresponding to the actual working conditions and, hence, to extend its lifetime.

According to our calculations, a step-wise increase in temperature of asphalt-concrete pavement surface when there is jet blast impingement, may reach 30 $^0$C and more, depending on initial data. All computations in the work were made for A-320-type aircraft and climatic and operation conditions of the Republic of Peru [25-28], therefore, only positive ambient temperatures were taken into consideration (Goretsky, 1965; Escalator Zegarra, 2012; Böhme et al, 2003; Alzahrani, 2017).

**Discussion.**

Studying the effect of jet blasts on the surface of aerodrome pavements started from putting civil jet airplanes into operation and emergence of jet erosion on the surface of newly created pavements, and afterwards a separation of segments of the top asphalt layer during operation of wide-bodies aerial vehicles with low engines.

Effect of jet blasts, characteristics of temperature and velocity field, formed when there are jet flows around horizontal surfaces of aerodrome pavements as well, were studied by G.N.Abramovich [1], L.G.Kovarsky [7], G.E.Khudyakov [22], Goretsky L.I. [24] and more completely by Trigony V.E. [17,20,19,16], who, in addition to experimental works related to measurements of temperature field, developed a methodology of temperature and velocity fields, based on the theory of turbulence of free jets of G.N.Abramovich. V.E.Trigony monography, published in 1981, justifies design ratios to determine temperature stresses and their effect on longevity of rigid aerodrome structures (Abramovich, 2011; Kovarskiy & Kopzon, 1969; Khudyakov & Vas'yanov, 1970; Goretsky, 1965).

The effect of jet blasts of exhaust gases from aircrafts on airfield pavements was studied mostly for cement concrete pavements (Trigony & Kuznetsova, 1970; Trigony et al, 1975; Trigony, 1973). This is with the exception of studies of T.P.Leschitskaya for asphalt-concrete pavements and works, carried out in GPI and NII GA "Aeroproject" in 80's of the previous century under the guidance of V.E.Trigony to quantify and distribute temperatures and velocities in the field of gas jet along its axis, and at the point of its contact with pavement (Leschitskaya, 1978; Trigony et al, 1998).

In 2004, "Aerodrome pavement structure design guidelines" developed by FGUP GPI and NII GA Aeroproject suggests in section "Methods to compute asphalt-concrete layer for aerodynamic stability" an alternative for verifying a condition of asphalt-concrete temperature stability pavement layers. In 2012, SP 121.13330.2012 «Aerodromes. Update revision SNiP 32-03-96» was approved, where the need was specified for calculating asphalt-concrete pavement to absorb aerodynamic loads from gas jets of jet engines, when the velocity of jet in the zone of contact with pavement is equal to or exceeds 100m/sec (Design and Construction Specifications, 2012).

At the same time, there are many scientific and computation works devoted to analyzing temperature conditions of artificial pavements, calculation of temperature on the surface and its distribution through thickness of pavement layers exposed to environmental temperature factors. In domestic and foreign scientific and technical literature, the problem of complex effect produced by thermal sources on aerodrome pavements including jet blasts is covered quite insufficiently (Ladygin & Yatsevich, 1972; Goretskiy et al, 1990; Teltaev & Mynzhasarov, 2010; Chernigov & Teltaev, 1976; Kulchitsky, 2002).

Now, asphalt-concrete has widely been used as the material for strengthening layers of aerodrome pavements both in Russia, and abroad. The review shows that there was no proper attention paid to studying the effect of jet blasts on asphalt-concrete airfield pavements and strengthening layers, and this question is not thoroughly explored

An attempt was made in this work to objectively estimate thermal mode of the pavement surface asphalt layer functioning taking into account impingement of jet blasts; a methodology was developed to quantify the temperature on the surface of asphalt-concrete layer, distribution of temperature through thickness of layer was identified, and a distance from the surface, at which temperature rises, was determined. There exists an opinion that to prevent defects of asphalt-concrete layers of pavements due to the effect of jet blasts and, first of all, to improve stability to jet erosion, more in-depth study of real conditions of asphalt-concrete work in the surface course of pavement is needed. It will allow to reduce the risk of pavement destruction.

**CONCLUSIONS.**

The present work involved:

- Revising a mechanism of interaction between jet blast and aerodrome pavement surface course and factors affecting geometrical, aerodynamic, and thermophysical characteristics of jet blast and its field;
- Revising common patterns of thermal exchange between jet blast and asphalt layer of pavement;
- On the basis of suggested theoretical provisions, a methodology and a theory were developed for quantifying the effect of jet blasts from aircrafts on temperature of the surface course of pavement;
- Data were obtained, and graphs were drawn of relationship between change of temperature on the pavement surface and its depth-wise distribution when exposed to jet blasts and ambient temperature, mode, and running time of engine;
- A comparative analysis was made of surface heating, and distribution of temperatures in asphalt layer of pavement, with and without account for effect of jet blast on pavement.

Operating practice of aerodromes shows that deformations occur and pavements are destroyed mostly not because of exceedance of design power loads, but due to incorrect estimation of actual conditions of pavements' operation. It is, first of all, related to asphalt pavements and strengthening layers, which material is characterized with physical and mechanical properties greatly depending on temperature. It is believed that asphalt mixes that have currently been used, due to insufficient thermal stability of organic binder and relatively low cohesion between mineral particles in asphalt may counteract only short-time effect of gases, discharged from jet engines of airplanes. There is an opinion that one of the reasons is that in choosing a type of organic binder for asphalt mix an increase in temperature of pavement heating from the effect of jet blasts is neglected.

A comprehensive assessment of temperature conditions of pavement operation considering all thermal loads, including those from jet blasts, will contribute to a higher quality of design, improvement of asphalt stability to jet erosion even at the stage of evaluating the structure for pavement and selecting material of layer.

Furthermore, to improve ground support of flights it is necessary to introduce additional technical requirements to design and operation of aerodromes for jet aircrafts, taking into account those already included in SP 121.13330.2012 Aerodromes.

The work done may be of interest to designers and constructors of airfield complexes, repair and operation service departments of airports, and specialists who develop regulatory requirements for construction materials applied in construction of aerodromes. It is considered that further research in this regard will facilitate creation and rational use of asphalt-concretes for surface course of pavements and strengthening layers with the specified parameters, which assure the required strength, thermal and aerodynamic stability, and, hence, safety and longevity of aerodrome pavements.

**BIBLIOGRAPHIC REFERENCES.**


1. Abramovich, G. N. (2011). Theory of turbulent jets. – Phizmatgiz. – M. 715.
2. Goretskiy, L. I., Pecherskiy, M. A., Komchikhina, L. N., Belinskiy, I. A., & Kozodaev, G. A. (1990). Operation of aerodromes, - Transport. – M. 287.
3. Ginevskiy, A. S. (1969). Theory of turbulent jets and traces. – Mashinostroenie. – M.: 234.
4. Ivanov, V. N. (2005). Civil aerodromes. – Air transport. – M. 280.
5. ICAO Aerodromes Design guidelines. (2005). Part 2. Taxiways, aprons, and holding bays. ICAO 999 University Street, Montréal, Quebec, Canada H3C 5H7. 164.
6. Kovarskiy, L. G., & Kopzon, G. I., (1969). Calculation of deviation of axially symmetrical jet with longitudinal flow around planar wall. - Energomachinostroenie. – M. 37-38.
7. Kulchitsky, V. A. (2002). Aerodrome pavements. Modern outlook.- Phizmatlit.- M. 528.

8. Ladygin, B. I., & Yatsevich, I. K. (1972). Strength and longevity of asphalt.- Nauka i tekhnika.- Minsk: - 286.

9. Leschitskaya, T. N. (1978). Thesis: Building up thermal resistance of asphalt-concrete aerodrome pavements – MADI. – M.: - 143.

10. Leschitskaya, T. N., & Popov, V. A. (2005). Modern methods for repairing aerodrome pavements. – MADI. – M.: - 131.

11. Lukanin, V. N., & Shatrov, M. G. (2009). Thermal Engineering. – Vysshaya shkola. - 671.

12. Operation Manual for civil aerodromes of the Russian Federation. (REGA RF-94). (1999). Ministry of Transport of the Russian Federation, Department of Air Transport. - NPF «Besttek-Avia», Novosibirsk: - 233.

13. Design and Construction Specifications (SP) 121.13330. (2012). Aerodromes.- M.: - 63-59.

14. Teltaev, B. B., & Mynzhasarov, N. K. (2010). Methods for accounting temperature mode of asphalt layers in estimating strength of flexible pavements. Vestnik KazdorNII SC "Kazakhstan Road Scientific and Research Institute" Almaty: - 210.

15. Trigony, V. E., Leschitskaya, T. P., & Yurchenko, A. I. (1998). Improvement of longevity of concrete layers for strengthening in reconstruction of aerodromes.- MADI.- M.: - 46.

16. Trigony, V. E. (1981). Jet erosion of aerodromes. – Transport. – M.: -248.

17. Trigony, V. E., & Kuznetsova, T. M. (1970). Thermal stability of cement-concrete aerodrome pavements and the ways to improve it. GPI I NII GA «Aeroproject», 5, 80-94.

18. Trigony, V. E., Kuznetsova, T. M., & Burdin, A. P. (1975). Experimental study of thermal stability of concrete in cyclic heating. GPI I NII GA «Aeroproject», 17, 38.

19. Trigony, V. E. (1973). Accounting of jet effect from jet airplane engines in design of aerodromes. GPI I NII GA «Aeroproject», 48.

20. Chernigov, V. A., & Teltaev, B. B. (1976). Methodological recommendations for computing temperature fields, stresses, and deformations in cement-concrete structures.- SoyuzdorNII.- M.: -24.

21. Khudyakov, G. E., & Vas'yanov, V. D. (1970). Experimental study of propagation of submerged axially symmetrical jet near planar surface. Proceedings of MSU Institute of Mechanics, 62-80.

22. Shatrov, M. G., Ivanov, I. E., & Prishvin, S. A. (2012). Thermal technology. Publ. center Academia, 287.

23. Goretsky, L. I. (1965). Theory and calculation of cement concrete pavements for thermal effects [Text]. M.: Transport, 284.

24. Escalator Zegarra, J. R. (2012). Classification of asphalt binders by desemppeno for the different climatic regions of Peru. Building Camino Revista Especializada en Ingeniería de Pavimentos. Edición- Lima, 5, 32-36

25. Böhme, D. A. L. D. M., Molina, M. F. W. G., Cruzado, C. F. R. C., Salmon, J. Q., Arnao, J. E., & Chamochumbi, F. M. (2003). Atlas of solar energy of Peru.78.

26. Alzahrani, K. S. (2017). Metacognition and Cooperative Learning in the Mathematics Classroom. International Electronic Journal of Mathematics Education, 12(3), 475-491.

**DATA OF THE AUTHORS.**

**1. Alexey L. Ramos.** LLC «Small Innovative Enterprise «Technopark MADI»64, Leningradsky avenue, Moscow, Russia 125319. Igor E. Ivanov· Moscow Automobile and Road Construction State Technical University (MADI). Department of road-building materials64, Leningradsky avenue, Moscow, Russia 125319.

**2. Eduard V. Kotlyarsky.** Moscow Automobile and Road Construction State Technical University (MADI). Department of road-building materials64, Leningradsky avenue, Moscow, Russia 125319.

**3. Yury E. Vasilev.** Moscow Automobile and Road Construction State Technical University (MADI). Department of road-building materials64, Leningradsky avenue, Moscow, Russia 125319.

**4. Vladimir A. Popov.** Federal State Unitary Enterprise «Administration of Civil Airports (Aerodromes)»28, 5$^{th}$ Voikovskiy lane, Moscow, Russia 125171.

**5. Igor Y. Sarichev.** Moscow Automobile and Road Construction State Technical University (MADI). Department of road-building materials64, Leningradsky avenue, Moscow, Russia 125319.

**RECIBIDO**: 6 de febrero del 2019. **APROBADO**: 24 de febrero del 2019.