DIMENSIONING OF ZONES OF LASER THREATENING TO AIRCRAFTS

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ABSTRACT

Issues of blinding of pilots of aircrafts with laser items have been discussed for some years. In many countries legal regulations stipulate arraignment for offenses of that kind. And the article put forward a problem: what are the geometric parameters (dimensions) of the region of space surrounding the aircraft in which laser products can actually pose a real threat to flight safety? The article assesses methods of determining a size of areas of possible blinding and possible eye damage of a pilot, as well as minimal risk height of the aircraft, where temporary blinding of a pilot or damage to the retina of his eyes become possible. The results of the analysis suggest conducting organizational and technical measures, enabling to reduce the laser threat to flight safety. The authors considered examples of expert assessment of «laser hooliganism» cases, recorded in the first half of 2014. A methodology to estimate a degree of a real laser hazard to flight safety described in this paper can serve as an effective tool in determining legal liability for laser hooliganism.

Keywords: aviation, aircraft, flight safety, «laser hooliganism», zone of probable blindness of a pilot, zone of probable damage to eyes, minimum dangerous flight altitude, expert evaluation, laser dosimetry.

Background. *In [1, 2] the legal issues of laser safety (hereinafter-LS) of vehicles are considered and it is noted that in order to ensure it for aircrafts government resolution № 735 dated July 19, 2012 «Federal rules for the use of the airspace of the Russian Federation» [3] (hereinafter-FRUAR) are supplemented with paragraph 56.1: «The use of lasers and laser-based products in the direction of aircraft while taxiing, taking off, landing and flying is prohibited».*

In our view, paragraph 56.1 is formulated very unsuccessfully, because the authors of the wording did not consider existing legal documents on LS [4–8], determining which lasers and laser products (hereinafter-LP) pose a danger to people, and which are quite safe including for pilots and aircrafts.

After the introduction of par. 56.1 a situation arises in which any activity in the airspace with the use of lasers emitting open laser beams (hereinafter-LB) is prohibited. For example, it becomes impossible to use ground-based laser distance meters to the aircraft running on a completely invisible to the eye safe wavelength of 1540 nm («eye safety» – laser distance meters of LDM-7 type, EG-LRF type et al., measuring the distance up to 20 km). In addition, officials applying advanced landing laser system of «Glissade-M» type [9], that is engaged in «the use of products based on lasers in the direction of aircraft while landing» [3], de facto violate the requirements of par. 56.1 and thus may be subject to a formal administrative proceedings under article 11.4 of the Code of Administrative Offences «Violation of the rules for the use of airspace».

The authors of par. 56.1, formally fending threats to air transport because of multiple cases of «laser hooliganism», went on a simple way – a complete prohibition on the use of LP with open LB in the airspace, ignoring the fact that the laser radiation unlike other physical factors of impact on a person (for example, electromagnetic fields or ionizing radiation) has very space- limited area of localization of power (energy) of radiation in the form of a divergent laser beam. The degree of risk from the LP does not remain constant over the entire distance of its expansion and decreases depending on the distance to the law of «inverse squares».

Hence, in fact, a natural question arises: what are the geometric parameters (dimensions) of the region of space surrounding the aircraft in which laser products can actually pose a real threat to flight safety?

Objective. *The objective of the authors is to analyze methods for determining the size of the area of possible blinding and area of possible eye damage of a pilot, as well as minimal risk height of the aircraft, where temporary blinding of a pilot or damage to the retina of his eyes can occur.*

Methods. *The authors use legal and content analysis, evaluation method, comparative method.*

Results.

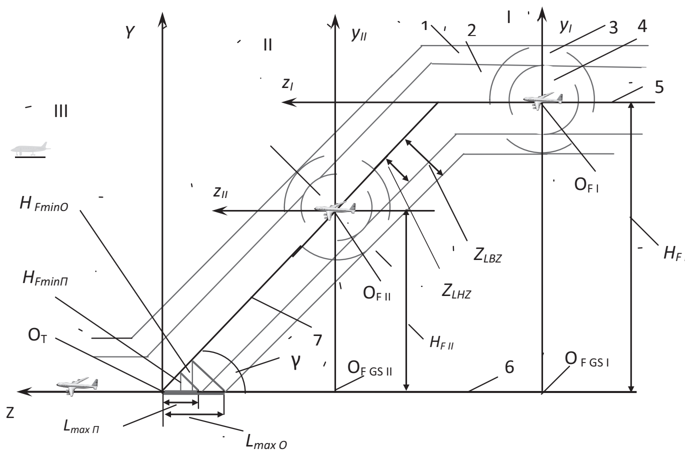
Spatial parameters of danger

There are computational methods of laser dosimetry in open spaces [10, 11], enabling to adequately estimate the size of spheres and zones of probable adverse effects of laser radiation on eyes of a pilot during takeoff, flight and landing. These parameters together with minimal dangerous flight altitude H_{Fmin}, above which there is a threat to get under radiation of LP located on the ground surface will be called spatial parameters of laser hazards to aircraft (hereinafter- PLHA). The knowledge of PLH allows for organizational and technical measures to ensure the laser safety of aircraft during their operation, as well as to develop reliable criteria for the applicability of legal sanctions against those who violate the rules of LS relative to the aircraft.

Pic. 1 shows a schematic diagram of a generalized flight and landing of an aircraft, which is in three consecutive phases of movement: I – horizontal flight parallel to the ground surface plane (hereinafter-GSP) (flight phase); II – a smooth descent and landing (landing phase); III – motion with braking on the runway (landing phase). The scheme is given in the projection on a vertical plane passing through the line 5 (flight course) and line 7 (direction of landing, glissade). For simplicity, we assume that throughout Phase II movement on the glissade is carried out in the same vertical plane (without turns) at a constant glide slope angle γ (°, rad) to GSP.

The position of the aircraft in space is characterized by point of flight O_FP. Pic. 1 uses two rectangular coordinate systems: the system XYZ, associated with GSP and the system xyz, associated with the aircraft. Beginning of XYZ coordinate system is at the touchdown point of O_T of the aircraft, and the beginning of the coordinate system xyz is at O_F. The Y-axis is perpendicular upward of the O_T; axis y is along the line connecting the point O_F with GSP. Axis Z, z are directed forward on the flight path, and Z is along the projection of the flight and glide to GSP, and z is along the projection of the flight path and glide on a flight's plane passing through the point O_F parallel to GSP. The vertical coordinate of the point O_F in the system XYZ is equal to flight altitude H_F (m). Projections of points O_F on GSP are identified as $O_{F\,GS}$.

For each point O_F there are two spatial spherical areas of possible impact of laser radiation (hereinafter- ALRI) on a pilot of an aircraft:



Pic. 1. Generalized scheme of assessment of spatial parameters of possible laser hazard area for the aircraft in phases of flight, takeoff and landing.
1 – cylindrical ALRI B;
2 – cylindrical ALRI D;
3 – spherical ALRI B; 4 – spherical ALRI D;
5 – flight path; 6 – ground surface plane (GSP); 7 – glide path.

– The area of possible impact of laser radiation on the criterion of short-term blinding of the pilot (ALRI B) 3, limited by a corresponding sphere SLRI B, shown in cross-section by a dashed line;

– The area of possible impact of laser radiation by the criterion of retinal damage to pilot's eyes (ALRI D) 4, limited by a corresponding sphere of SLRI D, shown in cross-section by a dashed line.

Radius of SLRI B is the maximum distance from the radiator to the border of laser blinding zone Z_{LBZ} (m), and the radius of SLRI D is the maximum distance from the radiator to the border of laser hazardous zone Z_{LHZ} (m) [10, 11].

In [11], formulas are given for calculating the coefficients of the danger degree of LR by criterion of retinal damage R_D and criterion of blinding of a person R_B (e. g., pilot). On the basis of these estimates for the conditions $R_D = 1$ and $R_B = 1$ values of Z_{LHZ} and Z_{LBZ} are calculated for LP operating at different wavelengths λ (nm) and having different radiation power P (W, mW) and the divergence angles Θ (rad). Table of values of R_D, R_B, Z_{LHZ} and Z_{LBZ} for $\Theta = 5 \cdot 10^{-4}$ rad are given in [11].

On the basis of the principle of the highest risk, we take into account the likelihood of use of dangerous laser designators (hereinafter- LD), which are commercially available (in daily use – «laser pointer»). Analysis of advertising material published on the Internet shows that by the criterion of damaging effects (i. e., the highest radiation power P) and the criterion of probable sales the greatest threat to safety belongs to LD having λ = 445 nm and P = 1W. By the way, a laser beam of such a designator ignites paper easily and burns cardboard at a distance of more than 10 m.

Recently, on the Internet has appeared the advertisement of significantly more severe LD with power of LB up to P = 30 W (for example, «laser pointers' series «Blaster» and «Zver» [12]). LD series «Blaster» are particularly dangerous, primarily because of the extremely high output power of LR, not required for normal needs, including identification of distant objects.

The word «Blaster», denoting a favorite «beam weapon» of heroes of «Star Wars», attracts young people, trading companies speculate on them. But this is not a harmless product of «mass market». The simultaneous use of at least ten LD with P = 30 W, laser beams of which are collected together by a simple optical device, will mean the use of laser weapons of close operating range with power P ≈ 300 W prohibited by international «Protocol on blinding laser weapons' (Vienna 13.10.1995) [13]. Focus of this beam at a distance of about 50 meters makes it possible to burn not only cardboard and plastic, but the dark metal lining of the fuel tank of a car or wheel tires.

Free sale of such LD means not only the emergence of a hooligan threat to safety of life (as we have previously mentioned [1, 3, 5, 14]), but the real threat of terrorism [12]. In this regard, we would like to reiterate that the free sale of LD with a radiation power of 100 mW or more should be strictly prohibited, as well as advertising of these LP.

In further calculations, we still focus on the highest power of LD available today P = 1 W, assuming that sales of high power-samples is still insignificant due to relatively high prices of products. At the same time, we also consider possible cost of providing protective measures to reduce the potential threat of a laser threat, which essentially depends on value of predicted maximum power of source of adverse effects.

In the area of direct threats

Accounting of physiological characteristics of human retina [11, 12] shows that the most unfavorable «laser» wavelength on the criterion of temporary blindness of a person is λ = 532 nm. On the Internet there are advertisements of several types of LD with λ = 532 nm and P = 500 mW. They have a divergence angle of the laser beam $\Theta = 10^{-3}$ rad.

According to the formulas given in [11] for the selected LD we get:

$Z_{LHZ} \approx 1000$ m, $Z_{LBZ} \approx 1100$m – for LD with λ = 445 nm, P = 1 W;

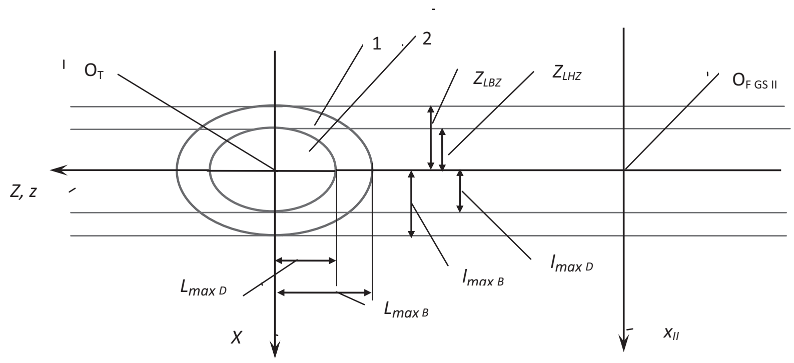
$Z_{LHZ} \approx 700$ m, $Z_{LBZ} \approx 1200$ m – for LD with λ = 532 nm, P = 0,5 W.

To assess PLH A we consider as the maximum distance to the border of laser blinding zone Z_{LBZ} = 1200 m, and as the maximum distance to the border of laser hazardous zone Z_{LHZ} = 1000 m.

When the aircraft moves, spheres SLRI B and SLRI D form in the space corresponding cylindrical areas of possible laser impact ALRI B (1) and ALRI D (2), limited by cylindrical surfaces CLRI B and CLRI D shown in Pic. 1 by solid lines in the cross section.

On the basis of this scheme, we can conclude that any LP with radiation power not exceeding 1 W (at λ = 445 nm) and 0,5 W (at λ = 532 nm), which is beyond CLRI B, do not pose any danger to flight crew, wherever this LP was located – in the environment or on the ground surface. Since the radius of CLRI B is 1200 m, any LP (with radiation power not exceeding 1 W at λ = 445 nm and 0,5 W at λ = 532 nm), which directs the laser beam from the ground surface on an aircraft in flight phase or in a part of landing phase at an alti-

Pic. 2. Generalized scheme of estimating parameters of zones of possible laser hazard to the aircraft, which is in landing phases in the projection onto the ground surface plane. 1 – ZLRI B; 2 – ZLRI D



tude above 1500 m, cannot even lead to temporary blinding of pilots and is safe. Naturally, the pilots will clearly see the laser beam of a particular color in the environment that may have some distracting effect, but this is unlikely to pose a threat to flight. A completely different situation may arise in the final stage of landing phase, which we consider in more detail.

When CLRI B and CLRI D cross with the ground surface plane, flat shapes in the form of an ellipse are formed (Pic. 2). Sites, located within these ellipses, will be called zones of possible laser radiation impact (hereinafter- ZLRI) by the criterion of blinding of the pilot (ZLRI B) (1, Pic. 2) and the criterion of retinal damage to pilot's eyes (ZLRI D) (2, Pic. 2).

Distances $L_{max\,B}$ (m, km) and $L_{max\,D}$ (m, km) from the touchdown point O_T to the most distant points of the boundaries ZLRI B and ZLRI D are equal to lengths of major semi- axes of the ellipses limiting ZLRI B and ZLRI D. In accordance with Pic. 1, we get: $L_{max\,B} = Z_{LBZ} / \sin\gamma$, $L_{max\,D} = Z_{LHZ} / \sin\gamma$. For aircraft of airplane type (e. g., airliners) glide path angles have small values, and it is possible to apply simplified formulas $L_{max\,B} = \gamma^{-1} Z_{LBZ}$, $L_{max\,D} = \gamma^{-1} Z_{LHZ}$. For example, for civil aircrafts the typical value is $\gamma \approx 3° = 0,05$ rad. For a considered generalized model of point like aircraft, vulnerable from all sides to the laser beam, we get $L_{max\,B} = 24$ km and $L_{max\,D} = 20$ km.

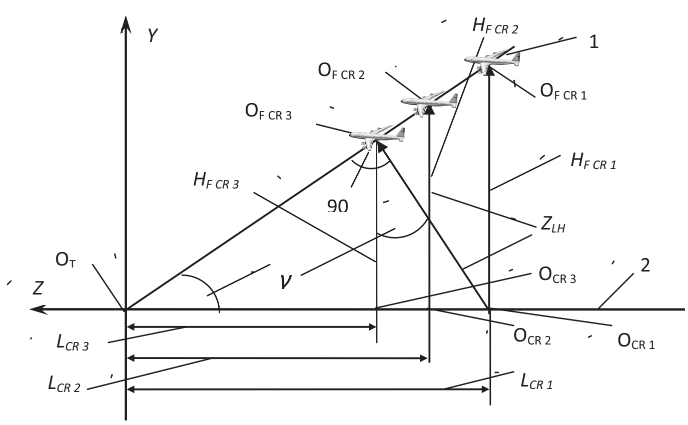
For the aircraft with large glide path angles, for example, helicopters or aircraft of vertical takeoff (landing), the parameters $L_{max\,B}$ and $L_{max\,D}$ have significantly lower values. Thus, for $\gamma = 60°$ we get $L_{max\,B} \approx 1,4$ km и $L_{max\,D} \approx 1,2$ km.

Transverse dimensions ZLRI B and ZLRI D $l_{max\,B}$ (m) and $l_{max\,D}$ (m) (Pic. 2) are equal to lengths of small semi-axis of ellipses bounding ZLRI B and ZLRI D, i. e. $l_{max\,B} = Z_{LBZ} = 1,2$ km; $l_{max\,D} = Z_{LHZ} = 1$ km.

In the future, when assessing PLH A we will take into account only LP located on the ground surface plane. For possible LP located at a certain height h (m) above GSP (for example, on the upper floors of the houses or on the hills in relative proximity to the edge of the runway), we should simply take into account an amendment to the values of PLH A, obtained for LP, located on GSP.

For a more accurate estimation of the parameter $H_{F\,min}$ we consider Pic. 3, which shows in a greater scale as compared with Pic. 1, a generalized diagram of the final section of the landing of the aircraft. When entering this section the aircraft, moving downwards on the glide path 1 is consistently at the critical points of flight $O_{F\,CR1}$, $O_{F\,CR2}$ and $O_{F\,CR3}$, corresponding to the height of flight $H_{F\,CR1}$, $H_{F\,CR2}$ and $H_{F\,CR3}$. The question arises, what point of the flight (flight altitude) should be considered as point where arises a hazard of blinding or damage with laser beam, i. e., what should be assumed as $H_{F\,min}$?

Point $O_{F\,CR1}$ is located at the most remote at the distance L_{CR1} from O_T by the point O_{CR1} of elliptical ZLRI (ZLRI B or ZLRI D), i. e., L_{CR1} is equal to either $L_{max\,B}$ or $L_{max\,D}$. The point $O_{F\,CR2}$ is located at the distance (height) of laser hazard Z_{LH} from GSP (2), where Z_{LH} is equal to either Z_{LBZ}, or Z_{LHZ}, i. e. $H_{F\,CR2} = Z_{LH}$. The point $O_{F\,CR3}$ is a glide path point, for which the length of the normal to the glide path is equal



Pic. 3. General scheme of the final stage of landing for the aircraft entering the zone of possible impact of blinding or damaging laser radiation.
1 – glide path; 2 – ground surface plane (GSP)

to Z_{LH}. Since $H_{F\,CR1} > Z_{LH}$, the most dangerous LB directed towards the aircraft with GSP along the line $O_{CR1}O_{F\,CR1}$, will not yet pose a danger to the aircraft by the criterion corresponding to this ZLRI. For example, for ZLRI B this beam still will not have a blinding effect. The real danger arises only at the point $O_{F\,CR2}$ at a flight altitude Z_{LH}. From Pic. 3, it follows that the distance L_{CR2} is less than the distance L_{CR1}, but this point O_{CR1} should be considered when assessing the length of ZLRI as LP, located at this point, will pose a danger to the aircraft, which has passed $O_{F\,CR2}$ and has got in $O_{F\,CR3}$.

These considerations can be neglected for the aircraft with a small glide angle and it is assumed that for a point line aircraft, vulnerable from all sides to the laser beam, it is permissible to take the following list of PLH A: $H_{F\,min\,B} = Z_{LBZ} = 1{,}2$ km, $H_{F\,min\,D} = Z_{LHZ} = 1$ km, $L_{max\,B} = 24$ km and $L_{max\,D} = 20$ km.

Terms of the cockpit

Modern civil aviation aircrafts have a cockpit at the top of the fuselage, and a review of the surrounding space is carried out through a viewing window in front of the pilot at a certain height above the floor (Pic. 4). When moving on the glide path in the starting area of elliptical ZLRI B this aircraft is located in the zone of inaccessibility (dead zone) for any LP located on GSP. Laser beams have sufficiently large angles of inclination α to GSP (angles goal) and cannot get into the cockpit to endanger the safety of the flight.

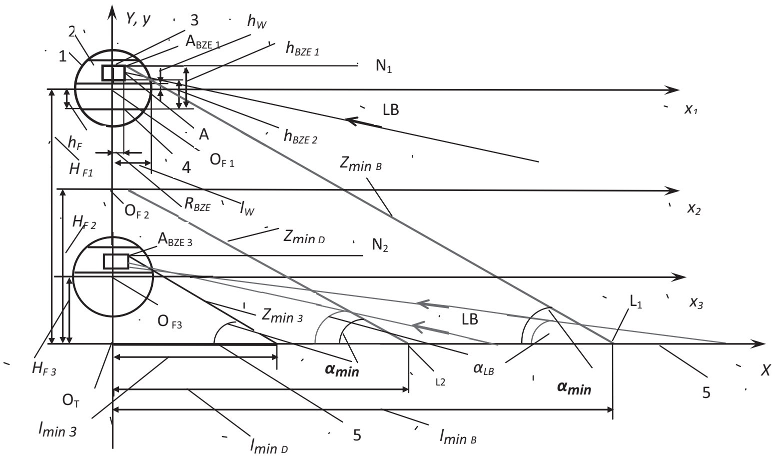
Let's define at what altitudes $H_{F\,min}$ and α_{min} target

Pic. 4. View of the cockpit of civil aviation aircraft.

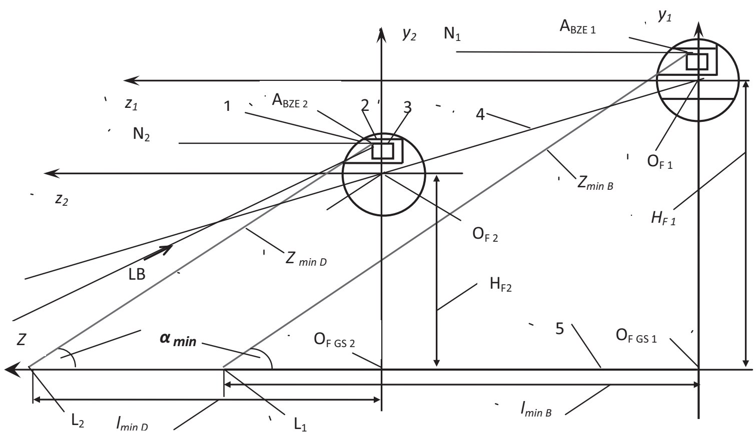
angles there is a real threat to the safety of the aircraft, i. e. at what values of these parameters LB can enter the eyes of the pilot, sitting at the workplace.

Pic. 5, 6 show schemes for evaluation of PLH A for the aircraft with the cockpit, covered on the side of the lower hemisphere. Pic. 5 shows a scheme in vertical projection on the plane XO_TY, Pic. 6 – on the plane ZO_TY.

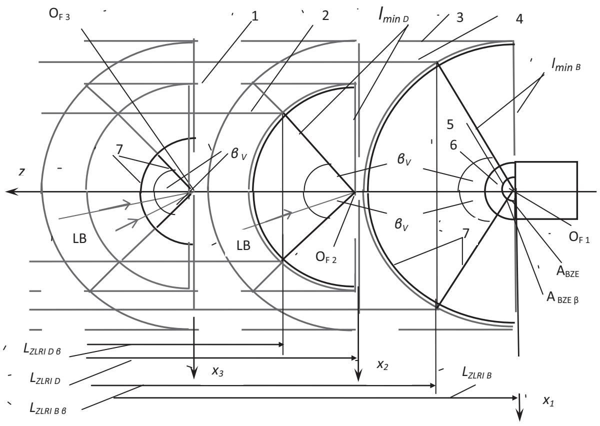
Cross section of the cockpit 1 are represented as circles with centers at the flight points O_F. Inside the cockpit above the floor 4 (Pic. 5) a pilot's workplace is located. To determine PLH A we will use spatial averaging parameters for a workplace of laser system



Pic. 5. Scheme for evaluation of parameters of possible laser hazard for the aircraft, having the cockpit, covered on the side of the lower hemisphere, in the vertical projection on the plane XOTY.
1 – cockpit; 2 – viewing window; 3 – BZE; 4 – cockpit's floor; 5 – GSP



Pic. 6. Scheme for evaluation of parameters of possible laser hazard for the aircraft, having the cockpit, covered on the side of the lower hemisphere, in the vertical projection on the plane ZO_TY.
1 – cockpit; 2 – viewing window; 3 – BZE; 4 – glide path; 5 – GSP



Pic. 7. Scheme of evaluation of parameters of possible laser hazard for an aircraft with account of a full vision angle $2\beta_V$ of a pilot in the horizontal projection on the plane ZO_1X.
1 – border of ZLRI D excluding $2\beta_V$ angle; 2 – border of ZLRI D including $2\beta_V$ angle; 3 – border of ZLRI B excluding $2\beta_V$ angle; 4 – border of ZLRI B including $2\beta_V$ angle; 5 – BZE; 6 – cockpit; 7 – border of a dead zone

operator used in GOST R 12.1.031–2010 [6]. In particular, we assume that the region of space in which the pilot's head can be during the performance of work operations is limited by the border of zone of possible eye damage (hereinafter- BZE).

BZE (3) is a schematic vertically disposed cylindrical surface of radius R_{BZE} (m), limited by upper and lower planes at a distance of $h_{BZE\,1}$ (m) and $h_{BZE\,2}$ (m) above the plane of the floor 4 of the cockpit. The lower edge of the viewing window 2 is located at an altitude of h_w (m) above the horizontal axis of symmetry x of the cockpit. The half-width of the lower window edge has a length l_w (m).

The first position of the cockpit in Pic. 5, corresponding to the point of flight O_{F1}, characterized in that LB with a minimum length of $Z_{min\,B}$, already dangerous by the criterion of blinding, reaches BZE at the critical control point A_{BZE}. This laser beam from the point L_1 to GSP is shown by the solid line. Another LB directed from the ground surface to the aircraft and crossing BZE at any point, is in the sector of space, limited by segments A_{BZE}.N_1 and A_{BZE}.L_1.Naturally, the length of this LB is more than $Z_{min\,B}$, and it still does not pose a danger on the criterion of blinding the pilot.

The second position of the cockpit (not shown in Pic. 5), corresponding to the flight point O_{F2} is characterized in that LB with the minimum length $Z_{min\,D}$, already dangerous by the criterion of retinal damage reaches BZE at the critical control point A_{BZE}.

The third most dangerous position of the cockpit (Pic. 5) corresponds to the flight point O_{F3}, the aircraft is both in the area of blinding and area of eye damage of the pilot. In this case, the aircraft is vulnerable to a laser beam with a length not exceeding $Z_{min\,B}$ or $Z_{min\,D}$ and having a target angle $\alpha_{LB} < \alpha_{min}$. A point L of location of LP, generating such a LB, should naturally be within ellipses limiting ZLRI B and ZLRI D. Such laser beams dangerous for the pilot are indicated in Pic. 5 by thin solid lines. In this case, the laser beams with the length of less than $Z_{min\,3}$ and target angles of more than α_{min} do not pose a threat to the pilot, as corresponding LP are in a dead zone with respect to the aircraft. The radius of the dead zone is shown in Pic. 5 by a thick line.

To calculate PLH A we use a formula for calculation of a minimal hazardous flight altitude when entering ZLRI B.

$$H_{min\,B} + h_{A\,BZE} = Z_{min\,B} \sin \alpha_{min}, \quad (1)$$

where $h_{A\,BZE}$ (m) = $h_{BZE\,1} - h_F$ is an altitude of a critical control point A_{BZE} above the horizontal axis of symmetry x of the cockpit.

To determine α_{min} we take a formula

$$h_{BZE\,1} - h_F - h_W = (l_W - R_{BZE})\ \mathrm{tg}\ \alpha_{min}. \quad (2)$$

From the formula (2) we get

$$\alpha_{min} = \mathrm{arc\ tg} k, \quad (3)$$

where $k = (h_{BZE\,1} - h_F - h_W) / (l_W - R_{BZE})$; $h_{BZE\,1} = h_{BZE\,2} + \Delta h_{BZE}$;

Δh_{BZE} is an altitude of BZE.

According to GOST [6]: R_{BZE} = 20 cm; $h_{BZE\,2}$ = 0,6 h_P (h_P is average height of a pilot). We take: Δh_{BZE} = 30 cm; h_P = 180 cm; h_F = 30 cm; h_W = 60 cm; l_W = 150 cm. Then we get: $h_{BZE\,2}$ = 108 cm; $h_{BZE\,1}$ = 138 cm; α_{min} = arc tg 0,36;

$\alpha_{\mathbf{min}}$ = 0,35 rad = 20°.

We take $Z_{min\,B} = Z_{LBZ}$ = 1200 m. With formula (1) we get $H_{min\,B} \approx 410$ m. Excluding R_{BZE} we get $l_{min\,B} = Z_{min\,B} \cos \alpha_{min} \approx 1130$ m.

Applying the formula (1) and assuming $Z_{min\,D} = Z_{LHZ}$ = 1000 m, we get: $H_{\mathbf{min\,D}} \approx 340$ m. Excluding R_{BZE} we have $l_{min\,D} = Z_{min\,D} \cos \alpha_{max} \approx 940$ m.

Distances $L_{max\,B}$ and $L_{max\,D}$ are determined by formulas: $L_{max\,B} = H_{min\,B}\ \mathrm{ctg}\gamma \approx \gamma^{-1} \cdot H_{min\,B}$; $L_{max\,D} = H_{min\,D}\ \mathrm{ctg}\,\gamma \approx \gamma^{-1} \cdot H_{min\,D}$. For the chosen values Z_{LBZ} and Z_{LHZ} and γ = 3 ang. deg we get $L_{max\,B}$ = 8,2 km; $L_{max\,D}$ = 6,8 km.

The values of the parameters of possible laser hazard, obtained with account of the structural features of the aircraft cockpit and working environment of the pilot, have significantly lower values in comparison with the data obtained from the model of the point like aircraft, vulnerable to LB from all sides.

Accounting of a vision field

Pic. 4 demonstrates that when the pilot operates the aircraft in the most crucial phase of the movement – landing on the runway, the pilot's glance is directed straight ahead on the course. Turns of his head or body in extreme lateral directions at normal landing are hardly expected. Full angle of vision of the pilot $2\beta_V$ in this position is less than 180°, which we have taken into account. Accounting for the actual value of the angle of vision results in an additional reduction in values of PLH A.

The scheme of calculating the parameters of laser hazards, taking into account the angle of the pilot's vision field is shown in Pic. 7. The actual border of ZLRI B and ZLRI D given a vision angle $2\beta_V$ are shown by solid lines, the same borders without $2\beta_V$ are marked by dashed lines.

Distances $L_{ZLRI\,B\,\beta}$ and $L_{ZLRI\,D\,\beta}$ as shown in Pic. 7 are determined by formulas: $L_{ZLRI\,B\,\beta} = L_{max\,B} - l_{min\,B} \cos \beta_V$; $L_{ZLRI\,D\,\beta} = L_{max\,D} - l_{min\,D} \cos \beta_V$. Taking β_V = 60° ($2\beta_V$ = 120°) and using the obtained values of the parameters we have $L_{ZLRI\,B\,\beta}$ = 7,6 km; $L_{ZLRI\,D\,\beta}$ = 6,3 km.

Transverse dimensions of ZLRI B and ZLRI D with account of angle of vision $2\beta_V$ $l_{ZLRI\,B\,\beta}$ and $l_{ZLRI\,D\,\beta}$ are calculated by formulas $l_{ZLRI\,B\,\beta} = l_{min\,B} \sin \beta_V$; $l_{ZLRI\,D\,\beta} = l_{min\,D} \sin \beta V$. Taking β_V = 60° and using above mentioned settings, we have $l_{ZLRI\,B\,\beta}$ = 1040 m; $l_{ZLRI\,D\,\beta}$ = 870 m.

Summing up both types of adverse effects (temporary blindness and retinal damage) and rounding up the results, we assume that the distance L_{ZLRI} from the edge of the runway to the border of zone of possible adverse impact of laser radiation on the civil aircraft by the ground LP, threatening flight safety, is 8 km and cross-sectional dimensions of this zone l_{ZLRI} are 1 km on each side of the runway axis.

In the previous chapter it was found that the minimum flight altitude of a landing aircraft, when there is a threat of temporarily blinding the pilot, is 410 m and the minimum height for the threat of damage to retina is 340 m. Summarizing both types of adverse effects, and introducing some reserve coefficient for safety, we assume that the minimum flight altitude of a civil aircraft, when there is a threat to the flight safety H_{Fmin}, is 500 m.

In order to ensure the laser safety of flight it is possible to offer the following ground precautionary measures:

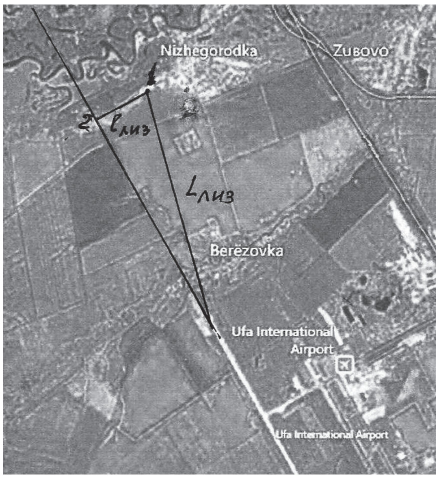
– To organize a special monitoring (including the use of video surveillance) of the area inside the rectangle with sides 8 at 2 km, adjacent to the edge of the runway, in order to identify possible sources of laser hazards (e. g., location of youth groups, using lighting effects for entertainment, etc.)

– To ensure the widest possible fencing of the area adjacent to the edge of the runway, preventing the entry of unauthorized persons in the area of potential risk.

In addition, it is proposed on board of the aircraft:

– to set special signaling devices in the cockpit, warning the crew of entering the zone of possible laser hazard when the altitude is 500 m; in this case it is advisable to

Pic. 8. The sign «Danger, laser radiation».



Pic. 9. Scheme of definition of parameters L_{LP}, l_{LP} on map for the incident near the airport «Ufa» (incident № 1 on Table 1).

Table 1

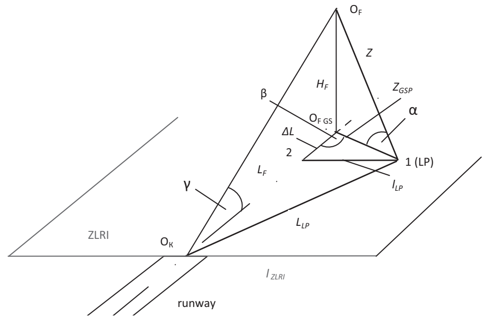
Data on expert assessment of degree of laser hazard to the flight of the aircraft

№	Date of the incident (publication of information)	Aircraft type, flight route, flight phase *	H_F (m) *, L_F (km) *. Location of LD: L_{LP}** (km), l_{LP} ** (m)	Results of comparison of H_F, L_F, L_{LP}, l_{LP} with PLH A. Conclusion on the points of location of the aircraft and LP with respect to ZLRI	Preliminary conclusion on the threat of NLRI of the aircraft for the pilot of the aircraft	The final conclusion on the threat of NLRI of the aircraft for the pilot of the aircraft
1	05.03. 2014 (06.03. 2014)	Boeing –737–500, Moscow-**Ufa**, landing	Village Nizhegorodka, H_F = 400 m L_F = 2,5 km, L_{LP} = 3,7 km, l_{LP} = 800 m	$H_F < \mathbf{H_{Fmin}}$ (500 m), $L_F < \mathbf{L_{ZLRI}}$ (8 km), $L_F < \mathbf{L_{ZLRI\,D}}$ (6,3 km) $L_{LP} < \mathbf{L_{ZLRI}}$ (8 km), $l_{LP} < \mathbf{l_{ZLRI}}$ (1 km). The flight point of the aircraft is located inside ZLRI. Point of location of LP is located inside ZLRI (ZLRI D)	Danger of blinding and eye damage is possible	**A real hazard in the point of the incident did not arise**.*** At points of the glide path at distances from 4,2 to 4,5 km from the runway there is a hazard of **blinding** of the pilot.***
2	15.04. 2014	CRJ-100, Moscow-**Saransk**, landing	Village Lukhovka, L_{LP} = 2,3 km, l_{LP} = 280 m	$L_{LP} < \mathbf{L_{ZLRI}}$ (8 km), $L_{LP} < \mathbf{L_{ZLRI\,D}}$ (6,3 km), $l_{LP} < \mathbf{l_{ZLRI}}$ (1 km). The flight point of the aircraft is located inside ZLRI. Point of location of LP is located inside ZLRI	Danger of blinding and eye damage is possible	At points of the glide path at distances from 2,5 to 3,5 km from the runway there is a hazard of **blinding** of the pilot.***
3	26.04. 2014 (30.04. 2014)	Challenger 604, Karlovy Vary -**Kazan**, landing	Settlement Teteevo, Laishevsky district, L_{LP} = (36–38) km	L_{LP} >> 8 km. Point of location of LP is located outside ZLRI	Safe	Safe
4	18.05. 2014	A-319, Moscow-**Rostov-on-Don**, landing	Theater square of Rostov-on-Don, L_{LP} = 5,3 km, l_{LP} = 800 m	$L_{LP} < \mathbf{L_{ZLRI}}$ (8 km), $L_{LP} < \mathbf{L_{ZLRI\,D}}$ (6,3 km), $l_{LP} < \mathbf{l_{ZLRI}}$ (1 km). The flight point of the aircraft is located inside ZLRI. Point of location of LP is located inside ZLRI	Danger of blinding and eye damage is possible	At points of the glide path at distances from 5,7 to 6 km from the runway there is a hazard of **blinding** of the pilot.***
5	02.06. 2014	AN-148–100V, Moscow-**Kazan**, landing	Village Borovoe Matyushino, L_F = 20 km, L_{LP} = (17–20) km	$L_F >> \mathbf{L_{ZLRI}}$ (8 km), $L_{LP} >> \mathbf{L_{ZLRI}}$ (8 km). Point of location of LP is located outside ZLRI	Safe	Safe

* Data from the information source

** The values of parameters obtained by the use of mapping tools

*** The conclusion obtained by additional calculations



Pic. 10. The scheme of determining the distance Z from the flight point OF to the point1 of LP location and determination of angles α and β.

use a light panel, highlighting a sign of laser hazard in accordance with GOST R 12.4.026–2001 [12] (Pic. 8);

To fix on the front side of the area of the cockpit's viewing window on both sides of the horizontal axis two laser threshold dosimeter (GOST R 12.1.031–2010 [6]) with a total vision angle of 120˚, beeping when laser beam with power exceeding a maximum permissible level by the blinding criterion gets in their pupil.

Naturally, the information on triggering of the dosimeter should be transmitted to the control station, which will enable to determine the sector of location of the radiation source and to take prompt measures.

Examples of assessing the real threat

The article [1] contains the results of a preliminary assessment of the degree of laser hazard to flight safety of the aircraft for some incidents, occurred from January to August of 2013. Henceforth cases of «laser hooliganism» were re-marked in relation to the aircraft. We have information on seven such facts from January to June 2014. Data on five of them are listed in Table 1. Internet sites give information about flight altitude H_F (m) and distance of the aircraft from the edge of the runway L_F (km), there is also addition of results of assessment of distances L_{LP} (km) from the intended location of LP (1) to the edge of the runway and evaluation of distances l_{LP} (m) from the intended location of LP to the runway access, made with the use of mapping tools (Pic. 9). In addition, Table 1 shows the results of comparisons of these parameters with the values of PLH A, received earlier, and the conclusion about the location of the aircraft and a LR source with respect to the border of ZLRI.

Incidents for which a conclusion on the location of the aircraft and LP within ZLRI, should be subjected to additional expert analysis in order to clarify presence or absence of a hazardous situation. For a more accurate assessment of the hazard degree we apply of the following criteria of hazards:

$Z \le Z_{LHZ}$ or $Z_{LHZ} < Z \le Z_{LBZ}$; $\alpha_{LB} \le \alpha_{min}$; $\beta \le \beta_V$, (4)

where Z (m) is a distance from the intended point of LP location (Table 1, Pic. 9) to the intended flight point O_F during radiation;

β (˚, rad) – the angle between the projection of the axis of LB on GSP and the projection of the glide path to GSP.

In assessing the parameters Z, α_{LB}, β we take the scheme of Pic. 10. In order to simplify we assume that the touchdown point O_T is located on the edge of the runway. We determine Z using a system of equations:

$Z = (H_F^2 + Z_{GSP}^2)^{1/2}$; $Z_{GSP} = (\Delta L^2 + l_{LP}^2)^{1/2}$;
$\Delta L = L_F - (L_{LP}^2 - l_{LP}^2)^{1/2}$. (5)

We use criteria (4) for α_{LB} and β as follows:

$\alpha_{LB} \le 0{,}35\ (20˚)$; $\alpha_{LB} = \arccos (Z_{GSP}/Z)$ (rad);
$\beta \le 1{,}05\ (60˚)$; $\beta = \mathrm{arc\,tg}\, (l_{LP}/\Delta L)$ (rad).

In accordance with the conclusions given in the fifth column of Table 1, the incidents № № 1, 2, 4 should be subjected to further expert analysis.

<u>The incident № 1</u> (Ufa airport). Substituting into the equation for ΔL (5) values of parameters L_{LP} and l_{LP} from the Table 1 for the incident № 1, we get: ΔL = – 1100 m. The negative value of ΔL says that the point 2 (Pic.10) is located further than the point $O_{F\,GS}$. In turn, this means that the laser beam emitted from the point 1, was sent to the aircraft on the scheme «upwards, sidewise and at the rear», i. e. in pursuit of the overflying aircraft. This LB could not get to the workplace of the pilot.

However, it is doubtful accuracy of the information about the parameters of the H_F and L_F. If the value of L_F is taken as 2,5 km, then at the standard glide path angle $\gamma \approx 3˚$ (0,05 rad) we get $H_F \approx 0{,}05\ L_F = 125$ m, while in the source of information it is stated that the flight altitude was 400 m. If we assume that the value $H_F = 400$ m is significant, the $L_F = 20\ H_F = 8$ km (and not 2,5 km, as indicated in the source). If we assume $L_F = 8$ km, we find that the radial flow was directed in the front field of view and could get into the cockpit. Indeed, we have β = 0,18 (<1,05) = 10˚, Z = 4400 m, i. e. $Z > Z_{LBZ} = 1200$ m.

The overall conclusion of the examination, based on data from the Internet shows that in the incident № 1 a real threat to the flight did not arise. However, this does not mean that such a threat does not exist elsewhere at other flight points located towards the runway. It is easy to identify near-border zone to the runway of distances L_{F1}, where the laser beam will be already out of sight of the pilot. Taking $\beta = \beta_V = 60$ ang. deg, we get $L_{F1} = 4{,}2$ km. For a flight point, located at a distance L_{F2}, for which while descending the aircraft the following conditions are met $Z = Z_{LBZ} = 1200$ m, $L_{F2} = 4{,}5$ km. Thus, near the village Nizhegorodka there is a section of a glide path vulnerable for LB directed from GSP. This site is located between flight points, located at distances from 4,2 to 4,5 km from the edge of the runway.

<u>The incident № 2</u> (Saransk airport). In this case we do not have data on the values of H_F and L_F, and therefore it is impossible to measure the degree of threat posed at the time of the incident. Applying the method described above for calculating distances L_{F1}, L_{F2}, we get $L_{F1} = 2{,}4$ km, $L_{F2} = 3{,}4$ km. That is, we can only say that near the village Lukhovka there is a section of a glide path, vulnerable to LB. It is located between the flight points, located at distances from 2,4 to 3,4 km from the edge of the runway. For more specific assessment of the possible threat we should calculate the hazard ratio R_D, R_B for a flight point, located at a distance L_{F1} from the edge of the runway. On formulas (5) it is Z = 930 m. On the formulas given in [10], we get $R_D = 1{,}1$ (λ = 445 nm, P = 1 W, $\Theta = 10^{-3}$ rad), $R_B = 1{,}4$ (λ = 532 nm, P = 0,5 W, $\Theta = 10^{-3}$ rad). Thus, at the flight point at a distance L_{F1} from the edge of the runway temporary blinding of a pilot is possible.

<u>The incident № 3</u> (Rostov-on-Don airport). The situation is similar to the previous one. The corre-

sponding values of the boundaries of the danger zone: L_{F1} = 5,7 km, L_{F2} = 6 km. Values of the coefficients R_D and R_B are approximately equal to them, since, as in the previous case, at the flight point at a distance L_{F1} from the edge of the runway temporary blinding of the pilot of the aircraft is possible.

These examples show that the presence of the aircraft and LP within ZLRI still cannot serve as a basis for the final conclusion of the reality of the laser hazard to the flight. For the final output it is necessary to know specific numerical values of H_F and L_F as well as sufficiently reliable values of L_{LP} and l_{LP}. If the reception of the information about the values of H_F and L_F does not present any difficulties, then the task of obtaining information about more or less exact values of the parameters L_{LP} and l_{LP} as well as information about the characteristics of the used LP causes certain difficulties. Its solution rests entirely on workers of flying safety service, along with representatives of public security services.

Conclusion.

In conclusion, we note that the methodology to estimate a degree of a real laser hazard to flight safety described in this paper can serve as an effective tool in determining legal liability for «laser hooligans».

With regard to paragraph 56.1 FRUAR demonstrated approaches and calculations prove conclusively that it is pointless to prohibit the use of laser beams in the air, in the sky, if the aircraft is at an altitude above 1,5 km. Paragraph 56.1 should be amended firstly by introducing clarification about the varieties of laser products prohibited for use in the direction of flying aircraft, and secondly, by extending this ban only to the area Endangering. World of Transport and Transportation, 2014, Vol.12, Iss . 1, pp.146–155. the runway.

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