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The Concept of the UAS Utilization to Identify Aerodrome Traffic Safety Hazards

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ABSTRACT
Aircraft operations performed in aerodrome traffic are characterized by special aerodynamic, navigational and operational conditions. According to statistical analysis of aircraft accidents and incidents, take-off and departure as well as approach and landing operations are particularly dangerous. One of the serious hazards, whose scale of occurrence has recently significantly increased, are the events of dazzling pilots with the laser beam. In this article, the identification of these hazards and the analysis of the safety risk was performed. Then a study of legal regulations concerning the protection of the aerodrome surroundings area against the laser emission was carried out. Based on the obtained results, the necessity to increase the effectiveness of practical laser beam sources identification was stated. For this purpose, utilization of unmanned aerial vehicle (UAV), which, when properly equipped in telematic devices, will be an unmanned aerial system (UAS) for detecting laser beam sources, was proposed. In the following part, analysis and research on practical aspects of the proposed concept's implementation were carried out, specifying potential chances and threats of their implementation.

KEYWORDS: aerodrome traffic safety, unmanned aerial vehicle, laser emission

1. Introduction – aircrafts operations and aerodrome surrounding protection zones

"Aerodrome traffic" is defined as all traffic on the manoeuvring area of an aerodrome and all aircraft flying in the vicinity of an aerodrome [6]. In practice it means that final approach, landing, taxiing, take-off and initial climbing operations are performed as its part. Listed operations are performed in the aerodrome traffic circuit - the specified path to be flown by aircraft operating in the vicinity of an aerodrome [6], or on the manoeuvring area - part of an aerodrome to be used for the take-off, landing and taxiing of aircraft, excluding aprons [3], with the use of CNS (Communication, Navigation and Surveillance) systems. Those aircrafts' operations are characterised by special conditions' and aerodynamical parameters' changes as well as significant pilot load due to simultaneous operations in the areas of: pilotage, navigation and air traffic control procedures' performance. As its consequence, mentioned flight phases in the aerodrome traffic, except from taxiing, should be treated as particularly dangerous.

The identified high level of safety risk enforces the necessity of special measures application to ensure the safety of aircrafts' operations in the aerodrome traffic. This is, among other, put into practice by designation of the obstacle limitation surfaces, obstacle free zones, obstacle limitation requirements as well as, what seems crucial in this article, by designation of the protected flight zones. The protected flight zones, defined as the airspace specifically designated to mitigate the hazardous effects of laser radiation [3], are established in order to mitigate the risk of operating laser emitters in the vicinity of aerodromes and may be divided into:

- laser-beam free flight zone – LFFZ,
- laser-beam critical flight zone – LCFZ,

- laser-beam sensitive flight zone – LSFZ,
- normal flight zone – NFZ.

The restrictions on the use of laser beams in the three protected flight zones: LCFZ, LFFZ and LSFZ, refer to visible laser beams only.

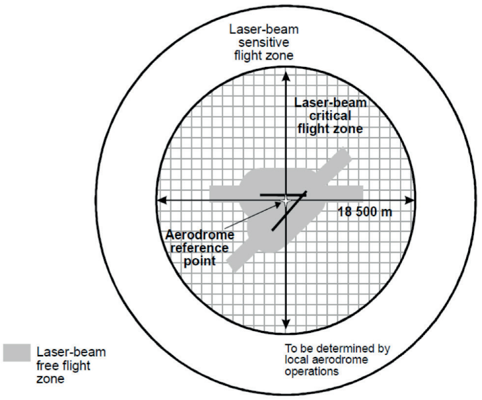

Fig. 1. Protected flight zones (The dimensions indicated are given only as example) [own study based on [3]]

In all navigable airspace, the irradiance level of any laser beam, visible or invisible, is expected to be less than or equal to the maximum permissible exposure - MPE i.e. the internationally accepted maximum level of laser radiation to which human beings may be exposed without risk of biological damage to the eye or skin, unless such emission has been notified to the authority and permission obtained. In other words the MPE is that level of laser beam energy below which exposure to a laser beam is not expected to produce adverse biological damage. There are differences in MPE calculations depending on whether the laser beam is pulsed or continuous. MPEs for the skin and eye for any laser beam and exposure condition are available in the American National Standards Institute ANSI Z136.1-2000 the International Electrotechnical Commission (IEC) 60825-1:19983 and other related international documents [8].

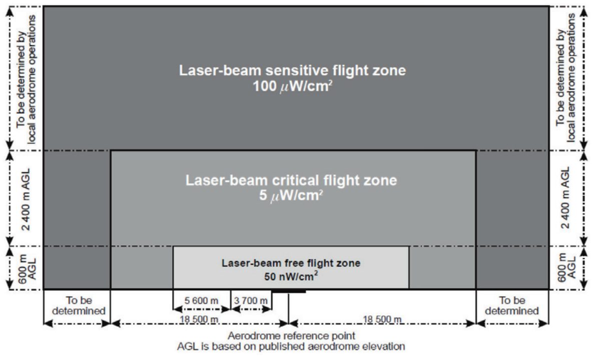

Fig. 2. Protected flight zones with indication of maximum irradiance levels for visible laser beams [own study based on [8]]

As practical experience shows, these formal regulations are not effective. The majority of cockpit illuminations occur at LFFZ - ca. 30% and LCFZ - ca. 81%, and their number grows almost twice a year [14]. The number of laser attack incidents on aircrafts and pilots as well as aerodrome control towers (TWR) is constantly growing. According to statistics, the most affected is the approach phase (see Fig. 3).

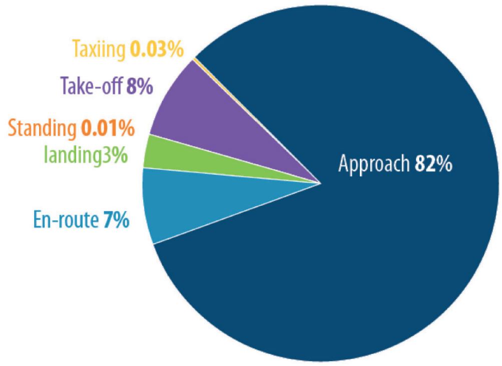

Fig. 3. Laser threat, phase of flight: summer seasons 2012-2016 [own study based on [2]]

All these events, in the causal sense, can be considered as safety threats [3, 5] or acts of unlawful interference [4, 11]. However, regardless of the reason, laser attacks pose significant threats to the safety of aircraft operations as well as aircraft's crew and aerodrome traffic controllers' (TWR) health.

2. Analysed issue

2.1. Statistical analysis and formal aspects

The problem of laser attacks in aviation is global and known world widely. In 2010 in Europe 4266 laser-aircraft incidents were reported (which is a significant increase compared to year 2008 – 1048 reported incidents). In several cases, pilots who were temporarily blinded were forced to pass control of the aircraft to the co-pilot. There have also been cases in which lasers were aimed at airport control towers [12].

Laser incidents have till now been identified at 74 different locations within 24 European States. More than 100.000.000 laser pointers are estimated to exist world-wide. Lasers come in a multitude of colours: red, green, blue, yellow, violet and infra-red (invisible). All these types of lasers, particularly the green, blue and infra-red ones, are capable of causing permanent damage to the eye. Physical consequences of laser exposure include:

- flash blindness (the flashbulb effect),
- glare (such as when driving on a sunny day),
- loss of dark adaptation (similar to being in a dark room and turning the lights on then off),
- glare discomfort and afterimages (the "blue dots" one might see after a camera flash).

In UE this problem has already been formally pointed out in 2011 [11], stating that "[…] laser emitters pose a significant threat to aviation safety and security. The recent alarming growth of laser incidents triggers an industry-wide response to raise awareness and a call to Regulators to recognize laser attacks as an act of unlawful interference with operations and develop adequate and harmonised countermeasures. The aviation industry is highly committed to a safe and secure air transport." Although laser attacks are not a new phenomenon, the growth of reported incidents in the recent years is striking. Laser attacks undermine the safety and security of flight operations. In reference to aircrafts' operations in aerodrome traffic they can interfere with the pilot´s vision and limit the crew´s ability to perform its duties. Consequently this can force pilots to abort landing, degrade flight performance, disrupt cockpit procedures, crew coordination and air traffic control communication. Similar effects also strike air traffic controllers in the provision of services, particularly in Air Traffic Control Towers, and may cause operational problems.

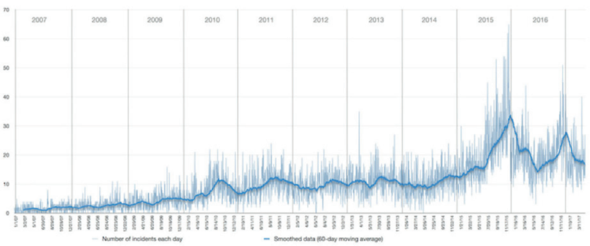

Fig. 4. Laser attacks reported to FAA each day, January 1st 2007 – April 29nd 2017 [own study based on [12]]

The absence in many countries of clear regulation with regard to the purchase, possession and use of lasers that could potentially harm aircraft operations, ask for adequate countermeasures to mitigate this threat to aviation safety. In Europe there is no Community legislation that would regulate the use of laser pointers. Some European Member States have reacted quickly to the increased number of laser attacks either by using existing legislation (i.e. aeronautical codes, penal code, criminal code, etc.) or by creating specific legislation. This has led to a situation in which in some European countries laser attacks against aircrafts are not punished and in others offenders may be condemned to a jail sentence and/or be subject to heavy fines.

A similar situation can be observed in the United States, where as a consequence of shortages in Federal Law, laser attack offences were subject to the jurisdiction of individual States legislation. Since June 2011 the US Federal Aviation Administration is using a new legal interpretation of existing regulations that prohibits interferences with aircraft operations. Also Eurocontrol has taken the initiative to organise a very first workshop about this serious safety issue. It gathered all stakeholders with a vested interest to consider adopting a collective approach towards reducing the growing threat of unauthorized laser interference in aviation. The aviation stakeholders in Europe fully support this initiative and at the same time pointed out that rapid action is needed. That is why they called upon the European Commission and its Member States to:

- recognise laser attacks as acts of unlawful interference (as an legislative amendment to the EU law [15]);
- harmonise legal actions against those found guilty of targeting aircraft and thus endangering aviation safety including aircraft, crews, ATC, ground staff, everything on the ground etc.;
- ensure the European harmonized implementation of ICAO Doc 9815 Manual [8];
- regulate the trade of laser emitters of 5 mW or bigger;
- promote public awareness (including adequate labelling of emitters and information);
- the EU-wide adoption of laser attacks as a mandatory reporting item with regard to Occurrence Reporting in Aviation.

For the third succeeding year, EVAIR (Eurocontrol Voluntary ATM Incident Reporting) recorded a decrease in laser reports (see Fig. 5). This reduction, throughout the period monitored (years 2012 – 2016), was complemented by a reduction in the number of locations and air operators affected (Fig. 6). In most events pilots reported that they informed ATC and did their best not to look at the position from where the laser illumination was coming, hence following the main recommendation on laser interference. However, in the majority of cases, reports prepared by the stakeholders do not show the same outcomes as the EVAIR ones. Cross checks of both show that in some geographical regions there is still an increase in laser interference, regardless whether or not the adequate regulation is in place.

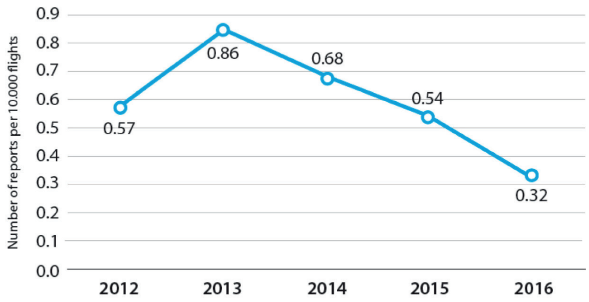

Fig. 5. Laser reports in summer seasons of the years 2012-2016 [own study based on [2]]

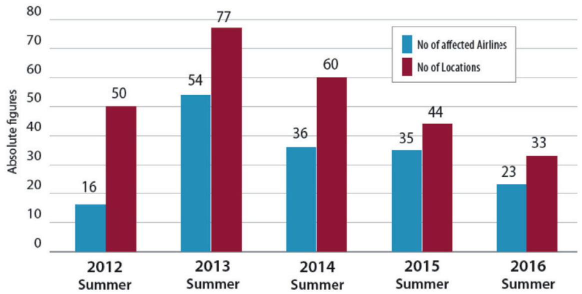

Fig. 6. Laser interference values based on No of locations and No of affected carriers in summer seasons of the years 2012-2016 [own study based on [2]]

In other words, practice shows that the absence of harmonized European regulation reduces the effect of national regulations addressing the problem of the use of lasers against aircraft. The absence of harmonized regulation means that equipment bought within countries without regulation can be transferred legally across Europe. States, ANSPs (Air Navigation Service Providers), and air carriers expect support from EASA to push for European regulation and to improve the situation regarding the illegal use of laser devises against aviation [2].

2.2. Health risk analysis

Hazards caused by laser radiation result from the interaction of highly concentrated and highly energetic radiation on biological tissues. This applies to all soft tissues and internal human organs, in particular to the skin and eyes. In the analysed problem the considerations were focused on the danger for people eyes, for which the impact of the laser beam is particularly dangerous. This is due to the characteristics of the optical radiation interaction and the particular susceptibility of the eye to radiation within the wavelengths emitted by some types of lasers. This impact is considered in relation to physico-chemical damaging factors and can be:

- thermal (photocoagulative) - causing tissues damage as a result of temperature growth, being a consequence of radiation absorption;
- acoustico-mechanical, causing impetuous pressure changes in the eyeball;
- photochemical (photolytic), causing chemical and structural changes of the eyesight organ tissues.

However, the potential for any given laser beam to induce damaging effects or bioeffects is not only a function of the physical characteristics of the laser beam itself, but also of assorted environmental or atmospheric conditions present at the time. Which means in practice that for the pilot or ATC/TWR controller, the bioeffects of laser attack may include [8]:

- distraction,
- glare (also referred to as dazzle),
- flash-blindness,
- after-images,
- scotomas,
- retinal burns,
- retinal haemorrhages,
- globe rupture,
- and other dangerous.

The analysis presented above revealed that the threat of laser beam attacks may be analysed in a wide spectrum of consequences and hazards, starting with direct health threats (resulting in non-compliance with medical requirements for pilot licence preservation [10]) as well as resulting from them visual and psychological effects [8], causing danger to aircrafts' operation safety [9].

In the following part of the article attention was paid to aviation operations' safety risk analysis applying guidelines [8] and the method [9] defined by ICAO as well as utilizing generalized data published by Eurocontrol [1, 2] and FAA [12]. The obtained results (Table 1) are therefore of a general nature, but nevertheless they properly reflect the essence of the examined problem.

Table 1. Laser attack risk analysis [own study]

Phase of aircraft's operation threatened by a laser attack	Likelihood	Severity	Level of safety risk tolerability
Approach	Frequent (5)	Catastrophic (A)	Unacceptable under the existing circumstances
Landing	Frequent (5)	Catastrophic (A)	Unacceptable under the existing circumstances
Taxiing	Remote (3)	Minor (D)	Acceptable based on risk mitigation
Take-off	Frequent (5)	Hazardous (B)	Unacceptable under the existing circumstances
Climbing or descent	Occasional (4)	Major (C)	Acceptable based on risk mitigation
Over flight	Remote (3)	Minor (D)	Acceptable based on risk mitigation

The obtained risk analysis results show that in each phase of the flight operation the risk of a laser attack is outside the acceptable level and that the threats with the highest severity are also characterized by the highest likelihood and they indeed occur in aerodrome traffic. That is why it is necessary to introduce appropriate safety and preventive measures. Currently, work is undertaken on the use of special glasses by pilots and ATC/TWR controllers or sticking to the aircrafts' windshield or aerodrome traffic control towers (TWR) a protective film, with a specified optical density and damping lengths conformable with visible laser beam. Although these solutions may be helpful, they will not prevent laser attacks and the resulting aviation accidents and serious incidents and are therefore not sufficient in aerodrome traffic. It is necessary to look for solutions reducing the probability of laser attacks, which are predominantly caused by perpetrators who are often even not aware of their potential consequences and criminal responsibility.

3. The concept of the method allowing identification of laser radiation sources

3.1. Theoretical concept

Effective prevention of the laser attacks threat requires early detection and determination of the laser radiation sources' location in the aerodrome's surrounding, in particular within the aerodrome control zone - CTR, but also in a certain part of the terminal control area - TMA[1]. Laser radiation source's detection

[1] Terminal Control Area – TMA, i.e. a control area normally established at the confluence of ATS routes in the vicinity of one or more major aerodromes [6]

and location determination will enable effective actions to be taken to apprehend the perpetrator and eliminate the threat, as well as to issue a warning to the aircraft's crews. The large area that should be monitored inclines the Authors to propose the use of unmanned aerial system - UAS consisting of an unmanned aerial vehicle - UAV equipped with remote sensing and telematic systems that will detect and locate the laser radiation source and send information to the control tower and Airport Duty Officer.

The proposed operation rule is based on the measurement of the received laser beam intensity – I [8, 10]:

$$I = I_0 e^{-\mu r} \tag{1}$$

where:

I_0 – the initial intensity,

μ – the atmospheric attenuation coefficient,

r – the distance from the laser source.

The Authors propose that in practice the values of:

I_0 should be adopted in accordance with the ICAO Annex 14 [1] specifications, i.e.:

$$I_0^{LFFZ} = 50\left[\frac{\text{nW}}{\text{cm}^2}\right] \tag{2}$$

$$I_0^{LCFZ} = 5\left[\frac{\mu\text{W}}{\text{cm}^2}\right] \tag{3}$$

$$I_0^{LSFZ} = 100\left[\frac{\mu\text{W}}{\text{cm}^2}\right] \tag{4}$$

μ should be adopted based on the actual RVR - runway visual range value, according to Allard's law (i.e. an equation relating illuminance (E) produced by a point source of light of intensity (I) on a plane normal to the line of sight, at distance (x) from the source, in an atmosphere having a transmissivity (T) [7]), according to the equation [13]:

$$\mu = 0{,}05^{\frac{1}{RVR}}\left[\text{km}^{-1}\right] \tag{5}$$

When measuring the intensity of three UASs with fixed position coordinates such as:

$$UAS_1\left(x_1, y_1, z_1\right)$$
$$UAS_2\left(x_2, y_2, z_2\right)$$
$$UAS_3\left(x_3, y_3, z_3\right)$$

three measurements of the laser radiation intensity I_1, I_2, I_3 will be obtained from the source with coordinates (x, y, z):

$$I_1 = I_0 e^{-\mu r_1} \tag{6}$$

$$I_2 = I_0 e^{-\mu r_2} \tag{7}$$

$$I_3 = I_0 e^{-\mu r_3} \tag{8}$$

dependent from the distances r_1 , r_2 , r_3, where:

$$\begin{cases} r_1 = \sqrt{\left(x_1 - x\right)^2 + \left(y_1 - y\right)^2 + \left(z_1 - z\right)^2} \\ r_2 = \sqrt{\left(x_2 - x\right)^2 + \left(y_2 - y\right)^2 + \left(z_2 - z\right)^2} \\ r_3 = \sqrt{\left(x_3 - x\right)^2 + \left(y_3 - y\right)^2 + \left(z_3 - z\right)^2} \end{cases} \tag{9}$$

For fixed UAS positions defining a rectangular coordinate system in space: $\left(\underset{x}{\rightarrow}, \underset{y}{\rightarrow}, \underset{z}{\rightarrow}\right)$ measurement of angles created by vectors: $\left\{\underset{r_1}{\rightarrow}, \underset{r_2}{\rightarrow}, \underset{r_3}{\rightarrow}\right\}$ with the versors allows presentation of the system of equations, which solution will determine the wanted coordinates of the laser source $L(x,y,z)$:

$$\begin{cases} \cos\left(\vec{r}, \vec{x}\right) = \dfrac{x}{\sqrt{x^2 + y^2 + z^2}} \\ \cos\left(\vec{r}, \vec{y}\right) = \dfrac{y}{\sqrt{x^2 + y^2 + z^2}} \rightarrow L\left(x, y, z\right) \\ \cos\left(\vec{r}, \vec{z}\right) = \dfrac{z}{\sqrt{x^2 + y^2 + z^2}} \end{cases} \tag{10}$$

The determined in such a way (and as assumed with some approximation) laser radiation source's location should be notified to the appropriate unit of the Police or other authorized service, whose officers should immediately go to the indicated area, locate the actual radiation spot, determine its actual intensity I_0 and on this basis take adequate measures to eliminate or reduce the I_0 intensity, and in any case provide instructions and inform about safe and legal conditions for the laser radiation emission. At the same time, the appropriate air traffic services unit should immediately issue a warning to the aircraft crews as well as carry out a risk assessment to decide whether to suspend or introduce restrictions on the performance of aerodrome operations until the threat is eliminated.

3.2. Concept of the practical implementation

The concept of preventive detection and control of laser radiation sources in the vicinity of the aerodromes, presented in the previous part of the article, requires continuous observation. For this purpose, the Authors propose to use UAS equipped with cameras and laser radiation detectors. The analysis carried out by the Authors in the discussed field shows that on the market there are many devices available, which parameters meet the requirements, in particular regarding sensitivity and scope of measurement as well as small weight and long working time. These devices should be built on an UAS of a medium range class, characterised by the following parameters:

- range - ca. 200 km,
- flight operation time - ca. 8 hour,
- flight ceiling - ca. 250 m,
- lifting capacity - 2 kg,

- equipped with the supervision and control system - AHRS (Altitude and Heading Reference System) as well as GPS navigation,
- with the position self-monitoring system, performing non-visual flights BVLOS (Beyond Visual Line of Sight) with the autonomous positioning system according to the flight plan.

In case of laser radiation source identification the UAS notifies the ground station operator, who manually changes the parameters and flight route in order to accurately recognize the source and determine its position.

Another important issue is to ensure safety of the UAS operation in the aspect of preventing its collisions with the aircrafts performing flight operations in aerodrome traffic. This may be achieved by designating UAS flights routes in CTR below the surface limiting the aircraft obstacles - OLS and at the minimum safe distances defined in ICAO Annex 14 [3].

The required supervision should be carried out using 3 UASs, which detectors in a coordinated manner will "observe" the aerodrome's surroundings, in particular within the CTR limits. This will require the establishment of UAS operation procedures agreed with the air traffic services unit.

4. Conclusion

The threat of aircraft pilots', performing operations in aerodrome traffic, dazzle with a laser beam is significant, both in terms of frequency and potential effects. The legal regulations concerning this matter and being in force currently are not a sufficient protection. As indicated in the article and based on the mentioned hazards' characteristics it is necessary to early identify and assess the risk and take effective preventive actions. For this purpose the Authors proposed the use of 3 UAS equipped with detection, registration and control systems, forming a "constellation" of UAS, conducting a continuous supervision of the selected aerodrome's area and in case of laser signal detection making the necessary measurements and determining the location of the laser radiation source.

Assumed opportunities and expected benefits:

- continuous CTR monitoring,
- low costs,
- high efficiency,
- designation of areas with the increased incidence of laser radiation emission, which may be called "laser attack hazard map",
- increase of social awareness.

Expected constraints and threats:

- the risk of collision with an aircraft,
- the risk of autopilot failure,
- the risk of losing control from the ground station,
- susceptibility to wind,
- "false alarms",
- errors in mission plans and UAS coordination.

The presented concept, as each technical solution, has its advantages as well as disadvantages. However, even if the proposed unmanned aerial system - UAS will not be useful in all weather conditions, the described CTR supervision and possible creation of the laser attack hazard map seems worth trying as it gives a good chance of eliminating repetitive laser threats' locations at aerodrome traffic.

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