Laser Attacks on Aircraft and Some Experiences from the Czech Republic

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***Abstract*— The article deals with the issue of laser attacks directed at aircraft, the incidence of which has been increasing in recent years. Evidence from past events points to the considerable danger of this criminal activity, which can lead to an accident with fatal consequences. This article refers to the recent laser attack that happened near Václav Havel International Airport in Prague. In the discussion, the authors then reflect on the possible risks associated with these attacks and also on how to prevent these incidents.**

Keywords— aircraft, laser attacks, pilot, safety

I. Introduction

The concepts of aviation and security have always been inextricably linked. People's confidence in air transport has always been based on the fact that fatal air accidents happen very rarely. Taking into account the number of passengers transported, or the kilometers travelled, air transport is the safest form of transport without competition [1]. On the other hand, every incident that occurs in aviation is the subject of considerable media attention. Such accidents are investigated in detail, analyzed and their root causes are sought. Thanks to this, we have enough knowledge to prevent these incidents in the future. Human and technical errors are not tolerated in aviation and cannot be covered up for the most part [2]. This is where aviation differs significantly from other types of passenger transport, such as rail or road, where the number of people killed usually correlates on the one hand with the technical condition of the transport links, and on the other hand with the quality of the personnel (drivers, train drivers, technicians, etc.). However, air transport differs from other modes of transport in one way. It is the object of interest of terrorists or other criminal elements. Terrorists try to use airplanes for various attacks, while criminals usually aim to cripple the functioning of the air transport system, cause inconvenience to passengers or financial losses to airlines. But in recent years, there is another phenomenon that has been abundantly present, namely the maliciousness of ordinary people. Specifically, these are attacks carried out with laser beams with the aim of dazzling or paralyzing pilots during flight [1]. While this is certainly nothing new, pilot reports show that the frequency of these attacks has been increasing dramatically in recent years.

II. Laser Attacks

One recent case is the August 12, 2022 incident that happened to the pilots of a Ryanair Boeing 737 on approach to land at Václav Havel International Airport in Prague. There were 126 passengers and seven crew members on board the plane. A green laser beam suddenly entered the cockpit, blinding one of the pilots. He temporarily lost his sight, so he was unable to perform any actions until landing. The second pilot had to manage the landing alone. This incident was subsequently evaluated by the police as a crime of public endangerment. Unfortunately, despite the deployment of a search helicopter and the immediate departure of mobile police patrols, the perpetrators of the attack were not found [3]. Similar events are increasing in the Czech Republic, as well as elsewhere in the world. According to the reports of the Air Traffic Control of the Czech Republic, 27 cases were recorded at the Prague airport until mid-August 2022, while there were 30 in the whole year 2021 and only 19 in 2020 [4].

The frequency of attacks is greatest during the summer months. These incidents most often occur when approaching (72%). Less common is the glare of pilots during the movement of the aircraft on the airport surface (14%), during landing (7%) or takeoff (6%) [1]. Probably the most dangerous attack is during landing. This is because it is the most demanding phase of the flight, during which the pilots must monitor the instruments on the dashboard and be maximally focused. If one of the pilots is dazzled, a situation may arise where he has a reduced ability to correctly perceive important parameters for a few seconds or even minutes. Such a situation can also result in a threat to flight safety, which is the opinion of most pilots who have experienced such an incident themselves [4]. Pilots report that during an attack, a flash is most often seen emanating from one spot on the ground. It is practically never a random phenomenon, but rather a repeated attempt by the perpetrator to hit the cockpit of the aircraft with a beam. If the pilot is hit, he can temporarily lose his sight, but when powerful lasers are used, the pilot's vision can also be permanently damaged. Due to the importance of clear vision in a pilot's duties, an eye injury can potentially also mean the end of his professional career [5]. Should this situation occur, the other pilot must take control of the aircraft, who may be forced by circumstances to make an unplanned landing. Fortunately, so far there has not been a case where both pilots were hit by the beam at the same time [1].

III. Dangerous Laser Devices

Nowadays, it is possible to buy a relatively large number of lasers of various sizes, shapes, colors, powers, etc. A common laser pointer emitting a light beam of green color usually has a power of around 100 mW. However, you can also purchase portable aiming devices with a power of 700 mW and more, which have a standard afterglow of over 5 km, while the divergence of the beam does not exceed 2 mrad at this distance [1]. These are very dangerous devices that can easily cause eye or skin damage. According to the EN 60825-1 standard, the degree of risk to the eye and skin is expressed using the class of lasers. There are classes 1, 1M, 2, 2M, 3R, 3B and 4. Class 3R lasers can cause eye injury only when

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looking directly into the light beam. According to the mentioned standard, their radiant power must not exceed 5 mW. On the other hand, class 3B lasers can be dangerous both when looking directly into the light beam and into its mirror reflection. Their permissible radiant power must not exceed 0.5 W [6].

In addition to the radiant performance of the laser, the following characteristics [1] are important from the point of view of its danger:

- coherence of optical radiation
- monochromatic radiation
- power density of the laser beam
- divergence of the laser beam
- wavelength

The last two characteristics are of main importance, they have a relatively large influence on the visual effect of the light beam used in the laser attack. The divergence of the laser beam in combination with the distance between the laser and the illuminated object (potential attack target) determines the size of the incident laser light on the given object. Meaning it can appear only as a small dot or it can have a much larger dispersion, which can reach several meters. Such a large dispersion represents a relatively big problem in the case of pilot cabin irradiation, as visibility is then almost zero [7].

The second important characteristic is the wavelength. The human eye can see the entire color spectrum of light in the wavelength range from about 400 nm to 750 nm. However, the eye is sensitive to light of different wavelengths. The greatest sensitivity of the human eye is between 500 and 550 nm, which corresponds to the color spectrum from yellow to green. That is why the green laser beam is so dangerous. Previously, red lasers were also used for laser attacks. The wavelength of their light is between 600-650 nm. However, the human eye is much less sensitive to this wavelength, and therefore laser light with this wavelength, even with the same radiant power, does not pose such a danger [1]. The sensitivity of the eye also changes depending on the light environment. In the night environment, the sensitivity of the eye shifts by about 50 nm and is thus in the range of about 400 – 650 nm with the peak of sensitivity at a wavelength of 500 nm [8].

Lasers in the form of pencil laser pointers that emit a beam of green light are most often used for laser attacks on aircraft. Their power ranges from units to hundreds of mW. For example, markers used during conferences, meetings, etc. to highlight points in a presentation have relatively low performance when compared to markers that are used, for example, to show stars in the sky or plant species in nature [1].

IV. Course and Possible Consequences of a Laser Attack

When approaching the landing, the plane is at a relatively large distance from the airport and the height above the ground gradually decreases. The aircraft is therefore relatively well visible from the ground and easily targeted by an attacker. The same is true for landing and takeoff. In such cases, the distance between the plane and the airport is shorter, but the perpetrator is in danger of being discovered and apprehended thanks to the quick response of the security guards guarding the airport perimeter. From the point of view of flight safety, these three phases are considered to be the most risky, as the entire crew must concentrate on individual actions and the pilots' time for a possible reaction is very short. Even the use of an electronic instrument landing system does not mitigate the risk during landing. The latter, combined with the autopilot, can guide the machine to the ideal landing path and essentially guide the machine along that path, but a pilot is always needed to guide the machine to the starting point where this system communicates with the machine. So, the pilot has to correct the instruments and complete the landing maneuvers himself. Moreover, the combination of an electronic instrument landing system and autopilot can only be used under ideal conditions. The instruments cannot deal with, for example, some changes in the weather, such as strong wind shear or evaluate and react to the situation when it is necessary to repeat the landing [1].

The immediate consequences of laser attacks are quite extensive and varied. This is because they not only affect the pilots' sensory abilities, but also their psychological state. This can have far-reaching consequences and extend to longer-term consequences. Thus, a firm boundary between immediate and long-term consequences cannot be firmly established, as one flows into the other and they are highly interconnected. From a psychological point of view, pilots, as well as control center operators, can experience one of the following four states: distraction, agitation, disorientation, and incapacitation, or loss of work ability [1, 2]. As these states escalate from distraction to incapacitation, the pilot gradually loses orientation in space, an overview of the height, speed and direction of the aircraft. If the pilot reaches the third or fourth stage, disorientation, or incapacitation in a critical phase of the flight such as take-off or landing or possibly even during the approach to landing, there is a very high probability of absolute loss of control over the machine and possibly a crash. A second pilot should always be a certain insurance, but it cannot be guaranteed that both pilots will not get into the same state at the same time. However, the first two phases can also be quite serious if the crew is not sufficiently prepared or warned against such a situation and does not know how exactly to react in such a crisis situation [1]. This problem was mainly during the first laser attacks, when the crews were not at all prepared for this possibility and were not even warned by air traffic control [9]. There have been instances where laser light streaks have confused a pilot who thought his path was being crossed by another machine with its landing lights on. Of course, each pilot reacts differently to such a situation, but above all, he loses confidence in the air traffic control dispatcher, believing that he did not alert him to the situation in advance [8]. And just like that, the potential for a domino effect arises, i.e. the chaining of various errors, which in the worst case can result in a crash [2].

From a physiological point of view, the pilot can experience several conditions depending on the distance, intensity, color and power of the laser: irradiation, glare; blindness; afterimages or afterimages. Glare occurs when a distracting object is detected in the person's field, when the vision is exposed to the source of a close, bright light source near the line of sight [10]. Otherwise, this phenomenon is also explained by a change in brightness, i.e. when the retina or part of it is exposed to a significantly greater brightness than it is adapted to at that moment. At low energy values of laser light, eye damage may not occur [8]. Blindness is the result of laser radiation in the visible spectral range, which can also cause longer-term vision loss associated with the formation of spatially defined images or afterimages. Such afterimages are

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similar to those caused by the use of flash in cameras. Images and afterimages remain after the end of the glare and can take different forms. If the glare stimulus was not colored, the images and afterimages resemble a positive black-and-white photograph alternating with the image of its negative. In the event that it was a colored stimulus of glare, subsequent images and afterimages can be either in the same color as the stimulus or in other complementary colors [1].

V. Discussion

Relatively much has been written about laser attacks on aircraft, but there are not many serious scientific works on this topic. Ivan [11] presented the first comprehensive information on accidental laser irradiation of pilots during flight at the Brussels NATO/AGARD conference in 1995. He reported on the results of a screening of visual functions among fighter pilots at an air base near which an amusement park equipped with laser reflectors was built. The immediate impetus for the aforementioned investigation was the blinding of one of the pilots during the last phase of the landing by the beam of a reflector several kilometers away from the threshold of the runway. The pilot suffered permanent loss of central vision in one eye. A subsequent survey of the base's pilots found that 21% of them had already experienced a similar incident. Because their problems quickly subsided, they did not think it was necessary to see a doctor. However, during a detailed ophthalmological examination, persistent color vision defects were found in 8% of them [9]. With respect to the local occurrence of these events, the topic was not later given wide attention. However, similar cases have been increasing in recent years, which is why this topic is starting to come to the forefront of the interests of not only experts, but also politicians and security experts. Eurocontrol and the Organization of Civil Air Navigation Services [12, 13] are understandably aware of the seriousness of the situation, which collects information about the incidents that have occurred. From the available reports, it is clear that laser beam attacks began to appear systematically about twenty years ago, but in the last decade their frequency has increased dramatically, all over the world [14]. At the same time, Nakagawara, Wood and Montgomery strongly drew attention to this problem already in 2008, who described several typical incidents that occurred in the USA during 2004 and 2005 [15].

The increasing incidence of laser attacks on aircraft raises the need to think about three basic questions:

1) What drives attackers to laser attack aircraft?

2) What are the risks associated with laser attacks on aircraft?

3) How can you defend against laser attacks?

Regarding the first question, the investigation of the events that took place showed that these were mostly acts motivated by malice or just for fun. Perpetrators are usually middle-aged men who are often completely unaware of the wrongness of their actions and do not even admit the possible consequences. Sometimes they do so under the influence of alcohol or drugs. The second group of perpetrators are persons who deliberately carry out attacks with the aim of causing problems for air traffic. However, these are not terrorists whose goal would be to cause a plane accident, but rather people who are in principle against air transport, because air traffic bothers them or annoys them for some reason. Although most of the perpetrators cannot be found, quite a few of them have been tracked down by the police. Many of them received high penalties or fines from the court [16].

The second issue was further explored by Schmid and Stanton, who analyzed the risks associated with laser beam attacks using systems theory [17]. They were based on the assumption that flight safety is primarily dependent on the pilot's ability to effectively process the visual scene inside and outside the cockpit while controlling the aircraft. Man is the dominant element in this specific work system, and modern automation has not changed anything about this fact [18]. Even the most advanced aircraft still require pilots to make quick decisions in response to air traffic control instructions and changing weather conditions during flight. Therefore, the only possible defense against the occurrence of an accident due to a laser attack is to train pilots for these situations. It is necessary to ensure that they are not taken by surprise by a potential attack and are able to react appropriately to it. Helicopter pilots are the most vulnerable group. Helicopters fly low above the earth's surface and are therefore relatively easy to target with a laser beam. In addition, these pilots are alone in the cockpit, so a dazzled pilot does not have the opportunity to hand over the controls to a colleague, as is the case with large airliners. The risk of an accident is understandably increased by the way and intensity of the pilot's glare. The ray that enters the pupil of the eye along the axis of vision and when the eye is focused on a distant object can be amplified up to 100,000 times tanks to the lens. Because of this, the green beam of a class 3R laser can cause damage to the retina in about 1 minute, but in the case of a class 3B laser, vision damage can occur after only a few tenths of a second [15]. Hitting the dark-adapted eye is particularly dangerous, as the eye is more sensitive to shorter wavelengths. At the same time, the pupil is maximally dilated and thus much more light can enter the eye. In addition, darkness also limits the pilot's field of vision and can shorten the time the pilot has to react to a critical situation, which can seriously compromise aviation safety [18]. The risk of pilot glare can be effectively reduced by special liquid crystal foils installed on the aircraft windshield, which can absorb or reflect laser light of certain wavelengths.

As for the third question, there are not many options to defend against laser attacks. First of all, it is necessary to eliminate these attacks as much as possible, especially by ensuring that the perpetrators of this crime are quickly tracked down and severely punished [13]. At large international airports, specialized police patrols equipped with aerial search equipment operate - be it helicopters equipped with thermal cameras or remote-controlled drones. At the same time, it is necessary to mediate these events and publicly point out their seriousness. In Western Europe, this trend is beginning to thrive to some extent, as evidenced by recent statistics from the Eurocontrol organization. While in 2015 laser attacks accounted for 7.7% of reported incidents, in 2019 it was only 1.9% [19]. In the Czech Republic, however, we continue to face an increase in these cases, which is why considerable attention is paid to the issue of protection against laser attacks. For this reason, intensive research is also carried out. As part of one of the projects, scientists from the Brno University of Technology are trying to develop a unique optometric system that will make it possible to identify the place where the laser beam originates. This will allow the police to react immediately and catch the perpetrator of the attack [20].

VI. Conclusion

In the Czech Republic, there have not been many laser beam attacks on aircraft for a relatively long time. Until 2008, there were usually 2 to 3 attacks per year, which did not cause the need for increased interest in this matter [1]. The situation has only become more serious in recent years. At Václav Havel Airport in Prague, the number of reports of these incidents ranges from 30 to 40 per year and is gradually increasing [4]. A similar trend is also reported from other countries [16, 17, 21]. Fortunately, so far none of the recorded incidents have been linked to terrorism [13] and no commercial airliner has crashed as a result of a laser attack. In virtually all cases, it was an attack made with a powerful laser pointer emitting a light beam of green color. These devices are commercially available and even children can buy them, even though they are class 3R lasers. There are also rare attacks with powerful laser targeting devices that emit beams of blue light. They can dazzle pilots even in the cockpit of airplanes flying at standard altitude. Research carried out in the Czech Republic by Najman [1] showed that laser attacks most often occur during the landing approach flight phase, in 72% of monitored cases. In 14% these are attacks on aircraft moving along the track and in 7%, respectively 6% were attacks on aircraft during landing, or at take off. Since in 90% of cases the laser attack is conducted against transport aircraft with a maximum take-off weight of over 5700 kg, this is a very dangerous phenomenon [1]. In the Czech Republic, a lot of attention is therefore paid to this issue. Therefore, specific research aimed at developing advanced technologies that will make it possible to identify the place from which the attack is being conducted is also currently being carried out. This will effectively help to catch the perpetrators of this dangerous criminal activity.

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