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History of military laser technology development in military applications

Abstract. *The aim of this research is to study the development as well as the known cases of military applications of laser technologies – from the first lasers employed in auxiliary systems to modern complex independent laser systems. For better understanding and systematization of knowledge about development of historical applications in the military field, an analysis of publicly known knowledge about their historical applications in the leading world countries was conducted. The study focuses on development that was carried out by the superpowers of the Cold War and the present era, namely the United States, the Soviet Union and the Peoples Republic of China, and were built in metal. Multiple avenues of various applications of laser technology in military applications were studied, namely: military laser rangefinders; ground and aviation target designators; precision ammunition guidance systems; non-lethal anti-personnel systems; systems, designed to disable optoelectronics of military vehicles; as well as strategic and tactical anti-air and missile defense systems. To summarize and compare the results, an analysis of a number of previous works was considered, which considered the historical development, prospects and problems of the laser weaponry development. The issues of ethical use of laser weapons and the risks of their use in armed conflicts, which led to an international consensus in the form of conventions of the United Nations and the International Committee of the Red Cross, were also considered. As a result of the analysis, a systematic approach to the classification of applications of laser technology in military products by three main areas of development was proposed: ancillary applications, non-lethal direct action on the human body and optical devices of military equipment, and anti-aircraft and anti-missile defensive systems. Due to the constant comprehensive modernization of laser technology systems in use, it was decided not to use the periodic classification* *model, but to indicate important and key events that indicated the main directions of further developmental work. However, it is important to note that the main focus of historical development of laser weapons depended not only on the technological limitations of the time, but also on the military-geopolitical situation in the world.*

Keywords: *laser weaponry; laser rangefinders; target designators; non-lethal laser weapons; anti-ballistic missile laser weaponry; historical review*

Introduction.

The first mentions of focused light usage as a weapon can be traced back to Hippocrates (not to be confused with the Hippocrates the Physician), the Greek commander of the Syracusan forces in 212 BC. According to ancient documents, his troops set fire to the sails of the Roman fleet, focusing sunlight with copper mirrors – a system proposed by Archimedes, the world-famous mathematician and inventor (Olson, 2012). Weapon systems that worked on principles, close to those of lasers, such as "beam guns" have long been one of the staples of science fiction authors, gathering the attention of people around the world. Various concepts of "death rays" appeared in fiction more than a hundred years ago in Wells' 1897 novel "The War of the Worlds", later appearing in A. F.Ossendovsky's "Brig Horror" (1913), as "death rays" in Dominic's "Rays of Death" novel (1921), as "purple rays" in "Erendorf Island" by V. P. Kataev (1924), in the story of Bulgakov's "Fatal Eggs" (1924) in the form of "red ray of life", in O. M. Tolstoy's "Hyperboloid of Engineer Garin" (1926–1927) and others. It should be noted that in all these literary works, directed heat or light rays played an extremely negative role in the development of mankind and civilization. This view has advanced along the path of modern research and discovery in the field of science and technology: laser weapons in the world were developed as weapons of mass destruction of the future wars. In the Soviet press, they were dubbed "the devil's rays". However, in the A. F. Paley "Golfström" (1927), an "orange ray" was shown as a "miracle of Soviet science", although no practical work in this area was carried out in the USSR.

The first practical steps towards the creation of lasers were made by Albert Einstein in 1916 (Hecht, 2010), with subsequent breakthroughs in the interwar period. The first working laser with a ruby active element was developed in 1957 by Professors Gould and Towns, with the start of their production in the 1960s (Hecht, 2009). They also approved the definition of "LASER" – light amplification by stimulated emission of radiation or "amplification of light by stimulated (forced) radiation". Just a few years later, in 1964, the first yttrium–aluminum grenade lasers were developed. At the same time, the end of process of development of the first laser designs coincided with the beginning of drastic changes in the vision of the future of armed conflict (Hecht, 2010).

With the development of real laser designs, science fiction has caught on this direction of development, constantly showing laser weapons as the basis of all weapons systems in future intergalactic wars. Thus, in the world-famous Star Wars movies, battles between spaceships take place with the help of "turbolasers", imperial stormtroopers fight with the Jedi with the help of "laser guns"; the concept of which is also found in the "Warhammer 40,000" world as well as other science fiction universes. Of course, humanity is still far from developing working "laser rifles". However, with the constant progress in the laser development over the past 60 years, laser weapons are slowly becoming a reality.

Research methodology and it's description. Theoretical basis of the study.

In the early years of the "Cold War", the vast majority of studies on the use of lasers as weapons were extremely classified, so much so that it is quite difficult to assess the direction of theoretical work of that era even today; most reliable sources come from in the forms of unofficial stories and memoirs, published by the scientists. However, this trend began to decline in the second half of the 1970s, and short articles on the use of lasers for military purposes, such as the enrichment of military plutonium-238, began to appear in publications such as Nature (Dickson, 1981). Another article in Scientific American (Tsipis, 1981) described the possibility of using gas-discharge lasers to intercept missiles from space. These and other works were directly related to the US Strategic Defense Initiative program (SDI), which aimed to develop both laser weapons as well as other means to destroy the relative military-technological parity between the United States and the Soviet Union. Nevertheless, most of the available theoretical and practical principles on the use of laser radiation as a weapon were written after the SDI program and the Cold War itself, focusing on the development of the concepts about the usage of the laser weapons in their modern form, as well as specific issues, inherent to laser technological applications (Horowitz, 2014).

For example, in April 1997, the US Air Force Secretary, Mr. Widnall, said: *"It isn't very often an innovation comes along that revolutionizes our operational concepts, tactics and strategies. You can probably name them on one hand - the atomic bomb, the satellite, the jet engine, stealth, and the microchip. It's possible the airborne laser is in this league"* (Perram, Marciniak, & Goda, 2004).

Modern theoretical research examines possible principal laser schemes for individual applications (Zejin, Weiqiang, Kai, & Xiaojun, 2021; Yun, Song, & Pei, 2020; Cunha, Giacomelli, Kaufman, Brajer, & Pereira, 2021), while current studies such as Nature (Extance, 2015) and the work of Danson, et al. (2021) analyze problems, inherent to the long-distance usage of lasers.

Nevertheless, by reviewing the practical applications of lasers on military equipment of the past, as well as test data of various prototypes of laser weapons, it is possible to acquire a general picture of the main efforts on the technological development of laser weaponry (Lazov, Teirumnieks, & Ghalot, 2021; Ji, Zong, & Yang, 2020). Such an analysis can provide us an opportunity to find and understand various principles of interaction between scientific progress and its integration into military affairs (Jianli et al., 2022; Zhihe, Jianqiu, & Jinbao, 2021; Kombarov, Sorokin, Tsegelnyk, Plankovskyy, Aksonov, & Fojtů, 2021; Strelko, Pylypchuk, Berdnychenko, Hurinchuk, Korobchenko, & Martyian, 2019; Babyak, Neduzha, & Keršys, 2020; Tao, & Feng, 2020; Romanova et al., 2021; Bernatskyi & Khaskin, 2021).

The purpose of this work is to identify the principles of interaction of scientific progress and its integration into military affairs over time through a multifaceted analysis of the practical military applications of laser technology in the world. This analysis will be divided into several categories, each of which will focus on the chronology of a particular area of usage of the laser technology in military equipment.

Auxiliary uses of laser technology in military applications.

The first practical uses of laser technology in the military were ancillary applications such as laser rangefinders, as well as guidance and targeting systems for guided munitions.

The first laser rangefinders appeared in the Soviet Union between 1963 and 1964, developed by specialists of the Vavilov's Institute of Optics located in Leningrad, USSR (Molebny, McManamon, Steinvall, Kobayashi, & Chen, 2016). However, the first practical application of this technology is attributed to Sweden and Great Britain, which between 1968 and 1970 created several models of laser rangefinders and installed them on armored vehicles. In both cases, the rangefinders were based on a solid-state laser with a ruby active medium, which allowed them to accurately measure the range (Danson, et al., 2021). Of the earliest rangefinders, the British Barr and Stroud LRF (1969) should be singled out as the first documented laser rangefinder, that was installed onto armored vehicles as the part of their production process (Barr, 1999, p. 257).

In the 1970s, laser rangefinders became the norm for large armored vehicles such as tanks, completely replacing stadiometric as well as other forms of optical rangefinders. Each country-manufacturer of military equipment has created its own types of such laser devices, mainly based on solid-state lasers with different active media. In the case of the Soviet Union, these were the 1G42, 1G46 and 1G46M gunner's sights. All three systems use solid-state lasers based on quartz active medium; however, modern Ukrainian developments based on these sights explore the possibility of replacing such obsolete systems with diode lasers.

At the same time, lasers began to be used to "paint" targets of various munitions dropped from aircraft. The first laser-equipped targeting pod for the aircraft, the AN/AVQ-10 (Fig. 1), was adopted in 1969 as a part of the "Pave Knife" laser targeting pod bomb system, later being adapted for targeting of various air-to-ground missiles (van Geffen, 2020). The advent of these technologies has revolutionized the tactics of using aviation in the field, as such laser-guided munitions dramatically reduce the required amount of munitions to destroy the designated target, while also allowing such weapons to achieve consistency, accuracy and cost-effectiveness that was impossible to receive when using conventional weapons. NATO forces have used such munitions during the wars in the Middle East and former Yugoslavia, resulting in a general increase in accuracy, as well as a relative reduction of collateral damage to civilian structures (Flemming, Flower, Huantes, & Kennedy, 2017).

Figure 1. AN/AVQ-10 laser targeting pod "Pave Knife" (Bell, 1984, p. 34.)

Soviet developments in this area led to the development of the "Klen-PS" targeting system in 1975, which is still heavily used on close-support aircraft of the post-Soviet states (Rakhmanov, Paltsev, Kibovskiy, & Devisilov, 2014). It should be noted that in contrast to solid-state lasers used in Western designs, the Soviet guidance systems used a semiconductor heterolaser - a rarely used type of laser technology due to its limitations and specifics. Special lasers for aiming and tracking targets are still used today as parts of modern targeting pods such as Litening III, LANTIRN (Fig. 2) and ATLIS II, which use different kinds of lasers - from solid-state to diode lasers, while the most modern systems (such as Sniper ATP) use multimode lasers with different wavelengths to improve their guidance capabilities (Gaitanakis, Vlastaras, Vassos, Limnaios, & Zikidis, 2019).

Figure 2. LANTIRN targeting pod, equipped with a laser (Lockheed Martin, n. d.).

Over time, the lasers used as means of guidance for guided ammunition became small enough to make their usage on the ground feasible. When the reduction in the size of both laser guidance and receiving systems allowed for their use in ground weapons, laser guidance of ground anti-tank guided missiles (or ATGMs) has become one of the most widespread areas of the laser technology usage in weaponry. The pioneers in this field are considered to be the Soviet guidance systems for “Kobra”, “Agona” and “Refleks” gun-launched anti-tank guided missiles (GLATGM’s), which were implemented in 1976 T-64B tank, and began to be widely used in all Soviet tanks of the 1980s. This guidance principle has since been widely used in anti-tank weapons and is still used for such anti-tank systems as the Ukrainian “Kombat” (Zaloga, 2011, p. 42). As an example, the Ukrainian-made 1G46M “Promin’” tank sight provides the capability for guidance of “Kombat” gun-launched anti-tank guided missiles (Fig. 3).

With the development of laser technology, laser target designators have become compact enough to be used by individual people. Although the first individual guidance systems were extremely cumbersome, the further development of laser technology has allowed for the development of lasers target designators of sizes, sufficient for comfortable use (Lamb, 2018). The first of such laser units was the AN/PEQ-1 SOFLAM, developed in 1996, using a solid-state Nd:YAG laser (Fig. 4). It saw widespread use by US Army special forces in Iraq, Afghanistan, later seeing service with other countries (Rahmani, 2018; Pushies, 2003, pp. 98–99; Neville, 2016, p. 28). Today, laser “pointers” (the moniker for personal laser aiming devices) have become compact enough to be mounted directly on the assault rifles and machineguns of regular army soldiers (Dyer, Smith, & McClure, 1995, p. 4; Gardony & Horner, 2020; Çelik, 2020) – from the US “AN/PEQ-15” (Jevtić, 2020) to the russian “Perst-4”.

Figure 3. General view of the "Kombat" GLATGM with it's laser guidance system installed (Ukroboronservice, 2018).

Figure 4. General view of an AN/PEQ-1C SOFLAM (Shepherd, 2007).

Non-lethal direct application of lasers on the battlefield.

One of the first laser systems designed for direct use in combat operations as an independent combat unit was the Soviet 1K17 "Szhatie" (Fig. 5) complex, developed in 1982–1992 – a laser system designed to counter optoelectronic spotting devices of enemy vehicles. Structurally, the laser complex represented a powerful solid-state laser, with the active medium used being a 30 kg artificial ruby crystal.

Figure 5. 1K17 "Szhatie" complex, Military Technical Museum, Ivanovskoye (Halak, 2013).

The 1K17 complex was designed to suppress electron-optical surveillance systems and fire control systems of armored vehicles in harsh climatic and operational conditions. In 1992, the complex was adopted, but only a few were made, as the price of vehicles equipped with 30-kilogram rubies was simply unaffordable for post-Soviet Russia. Additionally, the laser required a lot of energy to work. To power it, a powerful generator, powered by an autonomous auxiliary power plant was installed, which led to the size of the laser system exceeding the dimensions of the main battle tanks of the period (Rakhmanov, Paltsev, Kibovskiy, & Devisilov, 2014).

In military analytical circles, the People's Republic of China is widely known as being one of the first countries to create and use portable laser systems to blind personnel and disable sensitive electro-optical sensors of vehicles. In 1987 and subsequently, in 1995, Norinco showcased the ZM-87 Portable Laser Disturber at arms shows in the United Arab Emirates and later, the Philippines (Roblin, 2018). The

15 MW neodymium solid-state laser that is able to discharge five laser pulses every second, has been specifically designed to be able to inflict permanent eye damage to human eyes at a range of three to five kilometers, along with an additional ability to inflict temporary blindness to a range of up to 10 km. However, due to changes in the international law, only up to 30 weapons have been produced, with their sporadic public appearances until the early 2000s.

Continuation of the development of such technologies in the PRC is represented by the development of a series of laser "dazzlers" – laser systems designed to disable enemy optics and radars, where temporary blindness is only perceived as a side effect, leading to its use to disperse mass gatherings. Thus, the more modern WJG-2002 emits a green laser, which is more harmful to eyesight than the lasers emitting the red spectre. Emitting the laser emission three times per second, the system is reported to be able to cause temporary dizziness and blindness. Manufactured using nylon injection molding technology, WJG-2002 (Fig. 6) has a range of only fifty meters, its built-in battery being able to sustain twenty minutes of continuous emission (Roblin, 2018).

Figure 6. General view of WJG-2002 laser dazzler. (Nathaniel, 2015).

Personnel Halting and Stimulation Response (PHaSR) is a rifle-sized laser weapon system (Fig. 7), developed in 2003–2006 for use in the US military and law enforcement agencies by ScorpWorks, a research contractor in the Laser Division of the Laboratory's Directed Energy Department. U.S. Air Force Air Force Research in Kirtland, New Mexico (Sirak, 2005). This system used two diode lasers that emit in the non-lethal part of the wavelength spectrum: one in the visible wavelength in the green part of the spectrum and one with the wavelength in the infrared part of the spectrum. The laser light generated by this weapon, temporarily blinds them and reducing their ability to effectively resist (Davison, 2009).

Figure 7. Personnel halting and stimulation response dual-laser weapon (Kumar & Dixit, 2019).

Usage of the laser technology in air-defense and missile defense systems:

One of the most important tasks, that laser weapon development aimed to achieve is to protect against missile attacks, caused by the continuous development and improvement of missile technology. The development of high-power laser emitters has opened up new opportunities for combating certain types of missiles, as effective countermeasures against them became problematic to develop using traditional air defense and anti-missile principles.

The USSR was the first country to achieve significant results in this area of research (Shelyagin et al., 2021). The first work in this direction was carried out at the Terra-3 facility, built-in Kazakhstan in 1966–1968. 19 solid-state ruby lasers, one gas photodissociation and one fiber (3D–01) liquid oxygen laser were created at the site. (Demin, 2010) Many works were carried out on the site, such as:

- a pulse laser with a power of radiation equal to 300 kJ was developed;
- the experimental laser locator LE-1 (Fig. 8) was developed and tested;
- an electro-ionization CO_2 laser with 500 kW power capacity was developed and built;
- "explosive" lasers with a pulse power of up to 1 MJ were developed.

The creation of laser weapons, capable of missile defense while covering strategic importance objects from a possible attack by various weapons, including intercontinental ballistic missiles with nuclear warheads was the main goal of the "Terra-3" program (Zemskov, 2012). The task was not completed successfully, as even the construction of the prototype laser point defense system could not be completed. For this reason, in 1978, further research works at the "Terra-3" facility were suspended

(Demin, 2010). However, research and development, carried out in the "Terra-3" complex significantly advanced soviet science and technology on subjects, related to the program. A significant part of the developments on "Terra-3" subsequently found application in other laser system projects of various purposes.

Figure 8. TG-1 telescope of the LE-1 laser locator, built for the "Terra-3" complex, Sary-Shagan test site (Zarubin & Pol'skikh, 2011).

One such application was a complex of studies, carried out aboard the "1A" flying laboratory (also known as A-60) (Fig. 9), built by the G. M. Beriev Design Bureau in early 1977. Onboard this aircraft, a laser system, designed to study the specifics of laser beams propagation in the upper atmosphere, was installed. According to available information, the research in this direction was carried out in broad cooperation of various design bureaus with enterprises and scientific organizations throughout the USSR, the main of which was Central Marine Design Bureau "Almaz", at the time headed by B. V. Bunkin. The IL-76MD plane, chosen as the base aircraft for the creation of the A-60 flying laboratory, underwent significant changes that altered its appearance. Two generators with a summary power capacity of 2.1 MW were installed onboard the aircraft, but unfortunately, the only additional information available about the laser system is that it utilized a CO_2 laser (Apollonov, 2016).

Figure 9. Beriev A-60 “1A” flying laboratory, 1980s (Cenciotti, 2016).

It is known that during the 1984 tests, a series of test fires against air targets ranging from balloons to old La-17 fighters was carried out (Apollonov, 2016). However, according to some reports, the “1A” flying laboratory has burnt down in 1986, while its descendant, the “1A2” flying laboratory, has been used as a transport aircraft for a long period of time; although it is now known that in 2012-2016 the aircraft was refitted with a new set of lasers, with further work in this direction being carried out under the leadership of prof. Stepanov. The possibility of using airborne laser systems to disable satellites is also being considered.

The next project (Pascallon & Dossé, 2012) of Soviet scientists was the creation of 17F19DM “Skif-DM” (Fig. 10) – a truly gigantic space-based CO_2 laser, created in response to a statement by the US Air Force on the planned deployment of nuclear weapons in space (Sönnichsen & Lambach, 2020). Contrary to popular belief at the time, the statement, despite being a part of a purely hypothetical proposal, was purposefully created to misinform the Soviet leadership for the purposes of facilitating wasteful spending of the Soviet defense budget. According to the designers (Merzhanov, 2016), the incredibly heavy 80-ton module designed by “Salyut” was not able to be launched into space for political reasons, while its design solutions that allow the laser to be stable and efficient in space still impress the minds of engineers with their complexity.

Figure 10. 17F19DM "Skif-DM" (Ignatiev, 2007).

Very little is known about the time-equivalent American analogue of the A-60, the Boeing flying laboratory, based on the Boeing NKC-135A: it was used to study the possible application of airborne use of lasers during the Cold War, utilizing a CO_2 laser with a wavelength of 10.6 μm in a series of undisclosed tests (Rogers, 2001).

Much more is known about its descendant – Boeing YAL–1 flying laboratory (Fig. 11), which was revealed to the public in 2003, although its development is told to have begun in 1996. Initially, the laser installation on board of the aircraft consisted of six chemical oxygen-iodine lasers (Fig. 12) with a wavelength of 1.315 μm and a power of up to 1 MW. From 2007 to 2010, a series of successful missile interception tests were conducted, after which it was announced that the tests of this system had been successfully completed (Ganeev, 2014). However, in 2010, due to the reduction of the departmental budget, the project was stopped. The aircraft was finally dismantled in 2014.

Figure 11. Boeing YAL–1 focusing unit (Rubial & Berges, 2012).

An indirect descendant of these developments is the AN/SEQ-3 LaWS: a solid-state laser (Fig. 13) with a 30–150 kW variable power, emitting in the infrared spectrum, designed to combat unmanned aerial vehicles and small ships such as Somali pirate boats. This system was installed on the US Navy destroyer USS Ponce in 2014 (Strecker, 2018; Hecht, 2018), where it tested positive during the annual test, remaining installed on the ship until its departure from the Navy registers in 2018. The 150 kW weapon was installed onboard USS PORTLAND (LPD 27) in 2019 and has successfully disabled a UAV during an at-sea test in 2020 (Hood, 2021, p. 38).

Perspectives of the usage of laser weapons in such applications are confirmed by the fact that the US Army plans to test laser-only systems in the lower levels of the air defense network with the introduction of DE M-SHORAD systems (Fig. 14), equipped with high-energy (HEL) laser with emission power of up to 50 kW (Feickert, 2018, p. 12), for experimental use in the US Army in the latter half of 2022 (Obering, 2019).

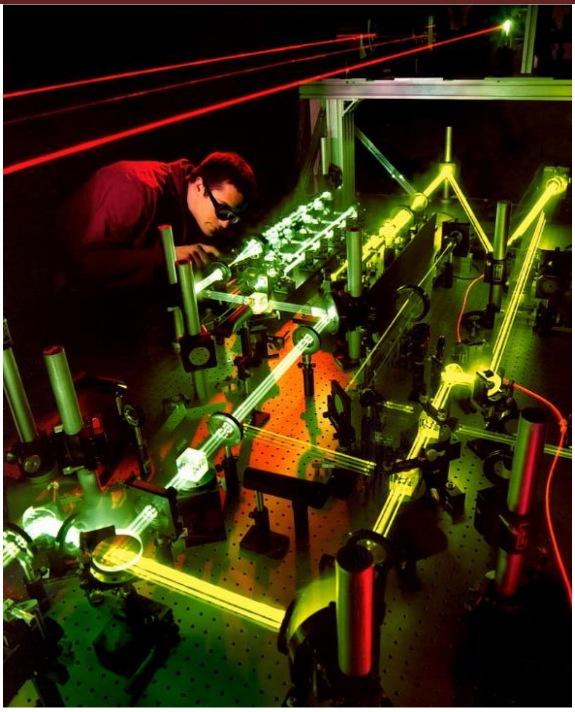

Figure 12. Maintenance of the laser complex mounted abroad the Boeing YAL–1 flying laboratory (Scannell, 2007).

Figure 13. AN/SEQ-3 LaWS aboard USS Ponce (Zabunov & Mardirossian, 2020).

The Ethics of laser weaponry usage.

The use of laser weapons raises many questions not only among scientists, but also in international legal entities, because, according to theoretical estimates, gathered from data about the conflict in Afghanistan (1979–1989), as well as the first Gulf War (1991), widespread use of laser weapons would result in 25 to 50 percent of all human casualties being blinded (Stylianou & Talias, 2014). On the one hand, blindness is considered a “lesser evil” compared to death, however, such permanent trauma changes a person's life forever, severely hampering its capabilities and freedoms.

Figure 14. Raytheon DE M-SHORAD air-defense system on trials (Suits, 2021).

The unconfirmed rumors about the usage of experimental laser weapons by the British Navy during the 1982 Falklands conflict (McCall Jr, 1997; Lazov, Kondratieva, & Dolchinkov, 2019), as well as breakthroughs in laser weapons technology, have led to a number of UN conventions on conventional weapons being held in 1985 and 1995 (Doswald-Beck, 1996). The effectiveness of these resolutions was surprising, as the adoption of these conventions stopped the development and production of several models of laser weapons, the most striking example of which was the Chinese ZM-87, stopping its production entirely, as well as tightening standards for legally acceptable laser weaponry. These moves shifted further developments in this type of weaponry to systems that only temporarily blind enemies, while some other systems were redefined, finding a new application against unmanned aerial vehicles and anti-tank missiles.

Discussion.

In general, all reviews positively consider the prospects for the use of laser weaponry. The Perram, Marciniak, Goda (2004) review stated: *“High energy laser (HEL) weapons are ready for some of today’s most challenging military applications. For example, the Airborne Laser (ABL) program is designed to defend against Theater Ballistic Missiles in a tactical war scenario. Similarly, the Tactical High Energy Laser (THEL) program is currently testing a laser to defend against rockets and other tactical weapons. The Space Based Laser (SBL), Advanced Tactical Laser (ATL) and Large Aircraft Infrared Countermeasures (LAIRCM) programs promise even greater* *applications for laser weapons."* The view of this review is supported by the more recent work of Ahmed, Mohsin and Zubar Ali (2021), who believes that: *"Laser weapons have many advantages over traditional weapons. First, the transmission at the speed of light allows laser-based weapons to engage distant targets immediately after detection. Second, the directed laser energy provides less collateral damage and low-profile and covert operations capabilities… Today many types of lasers are available having different power ranges, wavelengths, operating efficacies, spectral bandwidths, and other features. The increase in the maturity of compact optical and laser devices have improved their abilities for military purposes. Consequently, laser technologies have changed the paradigm of modern warfare, by serving in diverse roles, such as indicators & target designators, sensing devices, data relays, active lighting, rangefinders, weather regulators, and directed energy weapons"*. However, judging by the experience of recent research, such as the closure of the YAL–1 program, as well as publicly known recent developments, we can say that these estimates were quite optimistic. This can be attributed to many economic and scientific factors, as well as shifting the focus of work towards the use of laser weapons from strategic to more operational and tactical goals. It is also necessary to mention a large number of problems in the development and production of lasers that need to be addressed, as well as the problems of cooperation between civil and military industries. This is the need for deep cooperation between the civilian and military development process in the Brazilian work by Roso, Moreira and Oliveira, (2014), which stated: *"…according to the evidence of operational applications with laser weapons systems in many conflict situations, a new age in military and civilian cooperation is possible…"*. Hecht (2009) wrote about these same issues: *"Big challenges remain in making high-energy lasers that can fire reliably on the battlefield, with key issues including keeping the optics clean, avoiding optical damage, building durable cooling systems, and making the lasers reliable and affordable. But the task is also vastly easier than SDI's (Ronald Reagan's 1980s program – auth.) goal of building orbiting battle stations capable of blocking a massive Soviet nuclear attack (using lasers – auth.) …"*. However, broadly speaking, there has been significant progress in laser technology, as well as progress in its use as weaponry.

The review shows how laser technology first was used for ancillary purposes (distance measurement and targeting) in the 1960s and 1970s, later the work shifted to a strategic dimension: heavy air defense and anti-missile systems on both sides (USSR and USA) due to military-political opposition to the Cold War period (Terra-3, Skif-DM and SDI), flying laboratories (ALL and A-60) to intercept enemy aircraft and missiles. And only at the end of the Cold War, as well as in the modern era, the focus shifted to improving ergonomics, autonomy and ease of individual use with a comprehensive expansion of laser weapons in search of opportunities for partial replacement of lethal weapons. This makes it possible to point out a few certain key events in the history of laser weapons development, which set the main trends in the development of laser weapons for further development:

1. The first successful installation of a laser rangefinder on a military vehicle (1965) – laser technology is used for auxiliary purposes: range finding, target designation and munition guidance. Solid-state lasers with ruby and glass active media were the main types of lasers used;
2. First successful experiments at the "Terra-3" facility and start of studies that led to the creation of "1A" flying laser laboratory (1973–1975) – laser technology started to be seen as a possible way to form a "missile shield" of the world's superpowers to protect them against the possible nuclear exchange. The overall dimensions of laser complexes used in these applications rose substantially, with a more widespread usage of CO_2 and chemical lasers;
3. The demonstration of ZM–87 at the arms expo in Abu Dhabi (1987) shows that the laser weapons development has shifted to promote its more low–level tactical usage; more and more states have started local developments of laser weaponry for various purposes, including as non-lethal weapons. Various newer laser designs – both diode and fiber – are seeing more widespread adoption.

This method of periodization is considered optimal, because it is difficult to show separate developmental periods of individual areas of technology, because, even as the main developmental focuses shift, the process of continuous modernization and improvement of existing laser systems has never stopped.

Conclusions.

In 55 years, the use of laser technology for military purposes has radically changed the methods of combat operations, becoming an integral part of military affairs. In the process of analysis of the available information on the development of laser weapons, a proposed system to identify turning points in the development of laser technological applications in military equipment, namely – the first installations of lasers in military applications through the installation of auxiliary laser units into military vehicles, studies on the practical possibilities of using lasers as parts of anti-ballistic missile defense systems of superpowers, as well as shift of the focus of development of laser technology towards the small unit tactics and individual use of lasers. It was noted that the changes in the main focus of the laser weapon development are caused not only by the technological progress, but also the changes in the attitude to the possibility of usage of lasers as a possible weapon, as well as the military and geopolitical situation in the world.

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Історія розвитку лазерних технологій у військовому застосуванні

Анотація. *Дана робота посвячена вивченню прогресу та відомих використань лазерних технологій у військовій продукції – від перших спроб в допоміжних застосуваннях до сучасних комплексних систем. Для кращого розуміння та систематизації знань про розвиток застосувань лазерів у військовій галузі було проведено аналіз публічно відомих знань щодо їх історичних застосувань у провідних країнах світу. Дослідження фокусувалось на розробках, що проводились супердержавами ери "Холодної війни" та сучасності, а саме США, СРСР та КНР та були побудовані в металі. Було розглянуто багато напрацювань з різних застосувань лазерних технологій у військовій продукції, а саме: військові лазерні далекоміри; наземні та авіаційні цілевказівники; системи наведення керованих боєприпасів; нелетальні системи придушення ворожої живої сили; системи, призначені для виведення з ладу оптико-електронних приладів військової техніки; а також системи протиповітряної та протиракетної оборони стратегічного та тактичного рівня. Для підведення висновків та порівняння результатів було проведено аналіз ряду попередніх праць, які розглядали історичний розвиток, перспективи та проблеми прогресу лазерного озброєння. При цьому було розглянуто питання етичного використання лазерного озброєння та ризики його використання у збройних протистояннях, що призвели до міжнародного консенсусу у вигляді конвенцій ООН та Міжнародного Комітету Червоного Хреста. У результаті проведеного аналізу було запропоновано систематизований підхід до класифікації застосувань лазерних технологій у військовій продукції за трьома основними напрямками розробки: допоміжні застосування, нелетальна пряма дія на організм людини та оптичні пристрої військової техніки, а також протиповітряні та протиракетні лазерні комплекси. Через постійну всебічну модернізацію систем, де використовуються лазерні технології, вирішено не використовувати періодичну модель класифікації, а зазначити важливі та ключові події, які вказали на напрямок подальшого розвитку. При цьому важливо зазначити, що напрямок розвитку лазерного озброєння залежав не тільки від технологічних обмежень того часу, але й від військово-геополітичної ситуації у світі.*

Ключові слова: *лазерне озброєння; лазерні далекоміри; лазерні цілевказівники; нелетальне лазерне озброєння; протиракетне стратегічне лазерне озброєння; історичний огляд*

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