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MODERN LASER COMBAT SYSTEMS FOR DESTROYING UNMANNED AERIAL VEHICLES AND EVALUATION OF THEIR EFFECTIVENESS IN DEFEATING UNMANNED AERIAL VEHICLES

1. Development of modern technologies to combat UAVs

The rise of unmanned aerial vehicles (UAVs), or drones, has brought significant benefits across various sectors, from agriculture to entertainment. However, they also pose security risks, especially when used for espionage, smuggling, or military purposes. As a result, advanced anti-drone technologies have been developed to counter UAV threats. Military UAVs pose significant threats to various objects and infrastructure[1], as their capabilities expand from surveillance to direct attack roles[2]. Here are some key targets military UAVs can threaten and countermeasures to mitigate their impact:

1. Critical Infrastructure. UAVs can attack power plants[3], oil refineries[4], water treatment facilities, and communication hubs. A successful attack could cause widespread outages, disrupt essential services, or create environmental hazards.
2. Military Bases and Personnel[5]. UAVs can be used for reconnaissance or launching missile strikes against troops, equipment, and military installations. They can carry bombs, missiles, or act as kamikaze drones, directly targeting high-value military assets.
3. Government Buildings. UAVs can be deployed for espionage, capturing sensitive information, or even direct attacks on key government sites such as command centers, embassies, or defense ministries.
4. Transportation Infrastructure. UAVs pose threats to airports, ports, bridges, and highways. Attacks on these facilities can paralyze logistics, hinder troop movements, and disrupt supply chains.
5. Nuclear Facilities. UAVs can be used to attack nuclear power plants or weapons facilities, risking catastrophic consequences like radiation leaks or the destruction of nuclear materials.
6. Civilian Population and Public Events. UAVs can target densely populated areas or major public events, resulting in mass casualties and creating widespread panic, especially in cases of terror attacks.
7. Industrial and Economic Targets[6]. UAVs can disrupt factories, financial centers, or major corporations, causing economic instability by damaging production lines, data centers, or financial infrastructure.

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1 Kim, J., Choi, J., & Kwon, H. (2024). A study on the development directions of a smart counter-drone defense system based on the future technological environment. *KSII Transactions on Internet & Information Systems, 18*(7), 1929-1952. URL : http://doi.org/10.3837/tiis.2024.07.011

2 Liu, W., Zhang, L., Wang, D., Meng, X., & Zhang, B. (2024). Application and key technologies of laser weapons in anti-UAV swarm operations. *Hangkong Xuebao/Acta Aeronautica et Astronautica Sinica, 45*(12), 329457. URL : https://doi.org/10.7527/S1000-6893.2023.29457

3 Mohsan, S. A. H., Khan, M. A., Noor, F., Ullah, I., & Alsharif, M. H. (2022). Towards the unmanned aerial vehicles (UAVs): A comprehensive review. *Drones, 6*(6), 147. URL : https://doi.org/10.3390/drones6060147

4 Chamola, V., Kotesh, P., Agarwal, A., Gupta, N., & Guizani, M. (2021). A comprehensive review of unmanned aerial vehicle attacks and neutralization techniques. *Ad hoc networks, 111*, 102324. URL : https://doi.org/10.1016/j.adhoc.2020.102324

5 Kratky, M., Minařík, V., Šustr, V., & Ivan, J. (2020). Electronic Warfare Methods Combatting UAVs. *Advances in Science, Technology and Engineering Systems Journal, 5*(6), 447-454. URL: http://dx.doi.org/10.25046/aj050653

6 Lykou, G., Moustakas, D., & Gritzalis, D. (2020). Defending airports from UAS: A survey on cyber-attacks and counter-drone sensing technologies. *Sensors, 20*(12), 3537. URL : https://doi.org/10.3390/s20123537

8. Naval and Maritime Assets. Drones can threaten ships, ports, or offshore oil rigs, using surveillance to monitor naval movements or deploying explosives to cause physical damage.

Countermeasures to mitigate UAV threats:

1. Electronic Warfare (EW) Systems[7]. Disrupting the communication between UAVs and their operators by interfering with radio frequencies and GPS signals[8]. This causes the UAV to lose control, either forcing it to crash or return to its base. Advanced EW systems can intercept and decode UAV signals to determine its purpose and neutralize its mission, either by hacking the communication or shutting down the control system.
2. Anti-UAV Lasers[9]. High-energy lasers can rapidly engage and destroy UAVs by heating and damaging their components, making them non-operational.
3. Kinetic Defenses. These systems can detect, track, and destroy larger military UAVs at long ranges. They're especially effective for high-altitude UAVs used in combat and surveillance missions.
4. Interceptor Drones[10]. Specialized anti-drone drones can be launched to capture or neutralize enemy UAVs in mid-air using nets or jamming systems. These systems are flexible and can target UAVs across different terrains and environments.
5. Artificial Intelligence (AI)-Driven Detection Systems[11]. Advanced radar systems can detect small UAVs, while infrared sensors track UAV heat signatures. AI-based systems can predict the UAV's flight path and analyze threat levels.
6. Hardened Structures. Essential infrastructure, such as government buildings or military installations, can be hardened with physical barriers, reinforced shields, or underground bunkers to minimize damage from drone strikes[12].

7 Kratky, M., & Minarik, V. (2017, May). The non-destructive methods of fight against UAVs. In *2017 International conference on military technologies (ICMT)* (pp. 690-694). IEEE. URL : https://doi.org/10.1109/MILTECHS.2017.7988845

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9 Zheng, C., Liu, L., Xu, C., Wang, J., Huang, D., Yang, K., ... & Guo, J. (2024). Research on damage characteristics of UAV flight control system irradiated by continuous laser. *Preprints.Opticaopen.Org*. Retrieved from. URL : https://preprints.opticaopen.org/ndownloader/files/48326686

10 Król, M., Koperski, W., Błaszczyk, J., Woźniak, R. B., & Błaszczyk, P. M. (2017). San: an integrated unmanned air vehicles interdictor system concept. *Problemy Mechatroniki. Uzbrojenie, lotnictwo, inżynieria bezpieczeństwa, 8*(4), 79-94. URL : http://dx.doi.org/10.5604/01.3001.0010.7319

11 Tlili, F., Ayed, S., & Fourati, L. C. (2024). Advancing UAV security with artificial intelligence: A comprehensive survey of techniques and future directions. *Internet of Things, 27,* 101281. URL : https://doi.org/10.1016/j.iot.2024.101281

12 Hao, Q., Li, W. Z., Qiu, Z. K., & Zhang, J. L. (2020). Research on anti UAV swarm system in prevention of the important place. *Journal of Physics: Conference Series, 1507*(5), 052020. URL : http://dx.doi.org/10.1088/1742-6596/1507/5/052020

7. Drone Detection Networks[13]. Multiple sensors deployed over large areas create an early-warning network that tracks UAVs entering restricted airspace. These networks can coordinate with response teams to intercept the UAV before it reaches critical areas.
8. Decoy Systems[14]. By sending false GPS data, decoy systems can redirect drones away from their intended targets, forcing them to land or crash at controlled locations. Decoy emitters can mimic valuable targets, drawing UAVs away from real infrastructure or assets. This works particularly well with drones relying on signal or radar guidance for targeting.
9. Cybersecurity Measures[15]. Strengthening cybersecurity measures around drone command and control networks can prevent hacking attempts or cyberattacks from adversarial drones. Through advanced cyber tools, friendly forces can hack into enemy drones, taking control or neutralizing them mid-flight. This prevents them from completing their missions without causing physical damage.
10. Regulatory and Legal Approaches (Geofencing). Implementing no-fly zones for drones[16], enforced by built-in restrictions in UAV software[17]. Unauthorized drones can be blocked from entering these areas through legal and technical means[18]. Mandatory registration of military UAVs[19], along with real-time tracking systems[20], can help authorities monitor UAV movements and distinguish between authorized and unauthorized flights[21].

13 Yin, X., Jin, R., & Lin, D. (2024). Efficient Air-to-Air Drone Detection with Composite Multi-Dimensional Attention. In *2024 IEEE 18th International Conference on Control & Automation (ICCA)* (pp. 725-730). IEEE. https://doi.org/10.1109/ICCA62789.2024.10591905

14 Jin, W. C., Kim, K., & Choi, J. W. (2023). Adaptive Beam Control Considering Location Inaccuracy for Anti-UAV Systems. *IEEE Transactions on Vehicular Technology, 73*(2), 2320-2331. URL : https://doi.org/10.1109/TVT.2023.3320176

15 Wang, Z., Li, Y., Wu, S., Zhou, Y., Yang, L., Xu, Y., ... & Pan, Q. (2023). A survey on cybersecurity attacks and defenses for unmanned aerial systems. *Journal of Systems Architecture, 138*, 102870. URL : https://doi.org/10.1016/j.sysarc.2023.102870

16 Lei, Y., Yao, H., Jiang, B., Tian, T., & Xing, P. (2022). Anti-UAV High-Performance Computing Early Warning Neural Network Based on PSO Algorithm. *Scientific Programming, 2022*(1), 7150128. URL : https://doi.org/10.1155/2022/7150128

17 Wang, C., Wang, T., Wang, E., Sun, E., & Luo, Z. (2019). Flying small target detection for anti-UAV based on a Gaussian mixture model in a compressive sensing domain. *Sensors, 19*(9), 2168. URL : https://doi.org/10.3390/s19092168

18 Ferreira, R., Gaspar, J., Sebastião, P., & Souto, N. (2022). A software defined radio based anti-UAV mobile system with jamming and spoofing capabilities. *Sensors, 22*(4), 1487. URL : https://doi.org/10.3390/s22041487

19 Roder, A., & Choo, K. K. R. (2020). Unmanned aerial vehicles (uavs) threat analysis and a routine activity theory based mitigation approach. In *National Cyber Summit (NCS) Research Track* (pp. 99-115). Springer International Publishing. URL : https://doi.org/10.1007/978-3-030-31239-8_9

20 Zhao, J., Zhang, J., Li, D., & Wang, D. (2022). Vision-based anti-uav detection and tracking. *IEEE Transactions on Intelligent Transportation Systems, 23*(12), 25323-25334. URL : https://doi.org/10.1109/TITS.2022.3177627

21 Dewedar, M. A., Kamel, A. M., Hassan, M. A., & Elhalwagy, Y. Z. (2022, March). Real-Time Arial Targets Tracking for Anti-UAV Systems Using OpenCV. In *2022 13th International Conference on Electrical Engineering (ICEENG)* (pp. 1-4). IEEE. URL : https://doi.org/10.1109/ICEENG49683.2022.9781864

By combining these defensive measures, nations and organizations can effectively counter the threats posed by military UAVs, ensuring the protection of both critical infrastructure and civilian populations. As UAV technology advances, so too must the tactics and technologies designed to combat them.

The purpose of this work is to study modern laser systems for combating UAVs and to evaluate the effectiveness of their use in affecting the materials from which UAVs are made.

2. Study of modern laser systems for combating UAVs

The U.S. Department of Defense (DoD) classifies UAVs into «Groups» according to their size and capability, a joint system that replaced the service branches' separate categorization schemes in 2011[22]. The «Group» system has five categories, whose capabilities increase with the number (see Table 1).

Table 1

The «Group» system has five categories, whose capabilities increase with the number[23]

<table>
<tr><th>Group</th><th>Maximum weight (lb) (MGTOW)</th><th>Nominal operating altitude (ft)</th><th>Speed (kn)</th><th>Examples</th></tr>
<tr><td>1</td><td>0–20</td><td>< 1,200 AGL</td><td>100</td><td>RQ-11 Raven, WASP, Puma</td></tr>
<tr><td>2</td><td>21–55</td><td>< 3,500 AGL</td><td rowspan="2">< 250</td><td>ScanEagle, Flexrotor, SIC5 , PDW C100</td></tr>
<tr><td>3</td><td>< 1,320</td><td rowspan="2">< FL 180</td><td>Shield AI V-BAT, RQ-7B Shadow, RQ-21 Blackjack, Navmar RQ-23 Tigershark, Arcturus-UAV Jump 20, Arcturus T-20, SIC25, Resolute ISR Resolute Eagle, Vanilla Unmanned</td></tr>
<tr><td>4</td><td rowspan="2">> 1,320</td><td rowspan="2">Any</td><td>MQ-8B Fire Scout, MQ-1A/B Predator, MQ-1C Gray Eagle</td></tr>
<tr><td>5</td><td>> FL 180</td><td>MQ-9 Reaper, RQ-4 Global Hawk, MQ-4C Triton, Skydweller Aero (former Solar Impulse airframe)</td></tr>
</table>

An analysis of open sources was conducted to classify and categorize anti-UAV laser systems depending on the type and technical characteristics of the UAV. According to the UAV classification in Table 1, it is possible to divide anti-UAV laser systems into 2 main categories.

22 Unmanned Aircraft System Airspace Integration Plan. *Acq.Osd.Mil.* Retrieved from URL : http://www.acq.osd.mil/sts/docs/DoD_UAS_Airspace_Integ_Plan_v2_ %28signed %29.pdf

23 UAS groups of the United States military. *Wikipedia.Org.* Retrieved from URL : https://en.wikipedia.org/wiki/UAS_groups_of_the_United_States_military

1) *Anti-UAV laser systems for destruction of quadcopter and barrage munitions type UAVs (Mavic, Lancet, FPV, etc.) (Group 1-2)*

Let us consider the features of such laser systems on the example of the French anti-UAV laser system HELMA-P. The HELMA-P laser weapon system was successfully tested aboard French Navy (Marine Nationale) Horizon type Air Defense destroyer Forbin (D620) between June 12 and 14, 2023[24]. The HELMA-P system was developed in collaboration between CILAS and Ariane Group. The development took place from 2017 to 2019. The system consists of a 2-axis turret with an array of optical sensors and the laser weapon itself, which has a power of 2 kilowatts (see Figure 1).

Figure 1. French anti-UAV laser system HELMA-P[25]

This turret is controlled by a single operator via a human-machine interface. It can reach targets up to 1 kilometer away, which is 3 to 4 times more compared to competing anti-drone technologies, according to the director of CILAS' innovation department. Let's look at the technical features of the HELMA-P system. Fiber laser with a power of 2 kW, focal spot at a distance of 1 km – 2 cm^2, disables targets at distances of 100-1000 meters in about 10 seconds. It is used in conjunction with a laser target designation system (LIDAR). There is a variant using multiple fiber lasers simultaneously to increase the power and range of the weapon.

24 French Navy tests HELMA-P Laser Weapon from Horizon Destroyer – Naval News. *Navalnews.Com* . Retrieved from URL : https://www.navalnews.com/naval-news/2023/06/french-navy-tests-helma-p-laser-weapon-from-horizon-destroyer/

25 The French Navy tested the combat laser HELMA-P – Military. *NGO «Ukrainian Military Center"*. Retrieved from URL : https://mil.in.ua/uk/news/vms-frantsiyi-vyprobuvaly-bojovyj-lazer-helma-p/

The next anti-UAV laser system of this class is Raytheon HELWS[26]. Designed to stop aerial threats such as unmanned aerial vehicles (UAVs), this 15-kilowatt laser is the latest development in the UK Ministry of Defence's Land Demonstrator programme[27]. Raytheon UK was contracted in 2021 to develop and install the laser system on a UK Wolfhound armored vehicle (see Figure 2).

Figure 2. British anti-UAV laser system Raytheon HELWS[28]

The Wolfhound is a six-wheeled variant of the well-known Mastiff and offers troops extra security while assisting missions in dangerous regions. In addition to serving as a gun tractor and gun limber for the Royal Artillery's 105 light cannon, it offers a highly protected load-carrying vehicle for various tasks. Raytheon UK is building on the success of U.S. investment, where a total of eight high-energy laser weapons have been delivered to the U.S.

26 Lyu, C., & Zhan, R. (2022). Global analysis of active defense technologies for unmanned aerial vehicle. *IEEE Aerospace and Electronic Systems Magazine, 37*(1), 6-31. URL : https://doi.org/10.1109/MAES.2021.3115205

27 Raytheon UK set to receive and integrate UK's first laser weapon system in October. *Rtx.Com.* Retrieved from URL : https://www.rtx.com/news/news-center/2023/09/13/raytheon-uk-set-to-receive-and-integrate-uks-first-laser-weapon-system-in-octobe

28 Groundbreaking Milestone! UK's 1st Laser Weapon System To Be Integrated Into British Military Vehicles By Raytheon. *The EurAsian Times*. Retrieved from URL : https://www.eurasiantimes.com/groundbreaking-milestone-uks-1st-laser-weapon-system/

military[29]. These systems have defeated more than 400 targets over 25,000 operational hours.

The next machine of this class under consideration is the American Raytheon H4[30]. Raytheon's H4, its latest 10 kilowatt (10 kW) high-energy laser (HEL) weapon system, is designed for the U.S. Air Force to be easily portable and protect against short-range aerial threats (see Figure 3).

Figure 3. American anti-UAV laser system Raytheon H4[31]

It can target, track, and destroy Class 1 or Class 2 small- to medium-sized drones in not only short- and long-range attacks, but also swarm attacks[32]. Small enough to fit in the bed of a pickup truck, Raytheon's H4 laser weapon system comprises a high-energy laser weapon module, a long-range EO/IR sensor that also serves as the beam director, thermal control, internal electrical power, and

29 Lyu, C. Y., & Zhan, R. J. (2020, December). Research on the cutting-edge application of high energy laser C-UAS technology. In *International Conference on Optoelectronic and Microelectronic Technology and Application* (Vol. 11617, pp. 291-304). SPIE. URL : https://doi.org/10.1117/12.2585023

30 High-Energy Lasers. *Rtx.Com*. Retrieved from URL : https://www.rtx.com/raytheon/what-we-do/integrated-air-and-missile-defense/lasers

31 Raytheon Technologies delivers 4th combat-ready 10kW air defense laser weapon to US Air Force. (2023, June 13). *Armyrecognition.Com*. Retrieved from URL : https://www.armyrecognition.com/news/army-news/2023/raytheon-technologies-delivers-4th-combat-ready-10kw-air-defense-laser-weapon-to-us-air-force

32 Johnson, S. C. (2023, July 12). *Laser Focus World*. 'On-the-go' high-energy laser weapon system counters drone threats. Retrieved from URL : https://www.laserfocusworld.com/lasers-sources/article/14296218/on-the-go-high-energy-laser-weapon-system-counters-drone-threats

targeting software (see Figure 3). Raytheon's strategy is to minimize the cost and increase the production capability of HELs, so their beam directors are built at their facility in McKinney, TX, where they build all of their EO/IR sensors of the same architecture.

After integration of the laser weapon demonstrator (LWD) onboard the German frigate «SACHSEN»in June 2022, the trials of the LWD at sea have successfully been completed (see Figure 4).

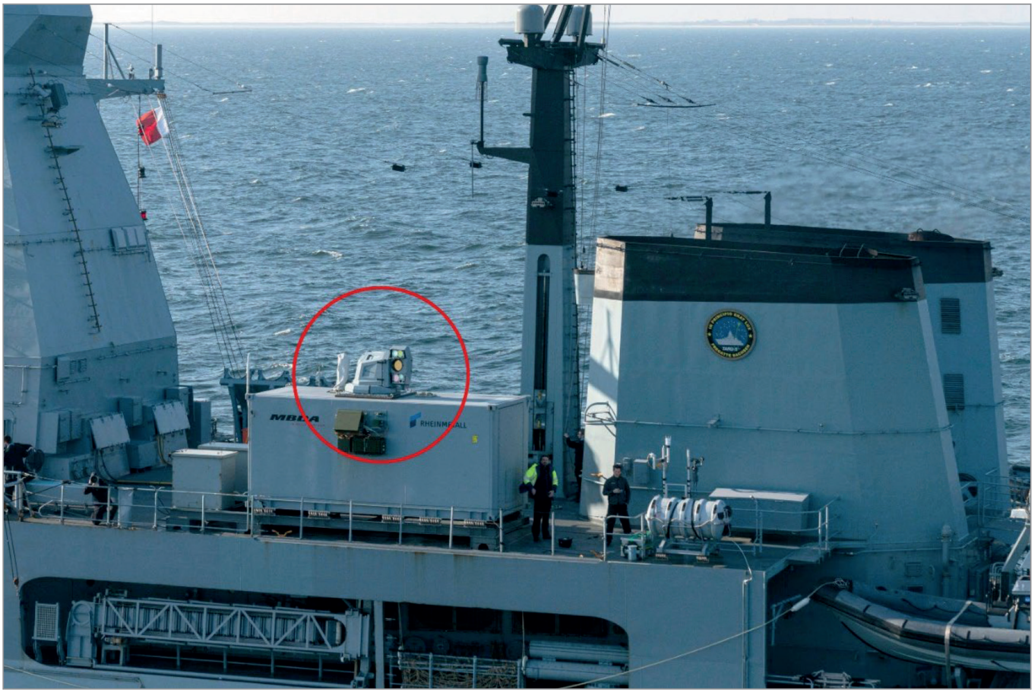

Figure 4. German anti-UAV laser system LWD[33]

Responsible for development and construction as well as the support during the trials that have been planned and organised by the Federal Office of Bundeswehr Equipment, Information Technology and In-Service Support (BAAINBw), is the High-Energy Laser Naval Demonstrator Working Group, or ARGE, consisting of MBDA Deutschland GmbH and Rheinmetall. During the trials with overall six campaigns lasting nearly a year, the combat effectiveness of the laser weapon demonstrator, or LWD, has been proven in increasingly complex scenarios under realistic operating conditions against different target types. This included all aspects from

33 Murray, D. (2023, September 29). German Navy fleet may soon be armed with combat-ready lasers. *Independent.Co.Uk*. URL : https://www.independent.co.uk/news/world/europe/german-navy-fleet-armed-combat-lasers-b2421107.html

detection and tracking (including highly agile targets); the interplay of sensors, command and weapon engagement systems and effectors; possible rules of engagement; and of course the successful engagement of targets with a high-energy laser beam[34].

The project is based on spectrum communication technology. It is known that the output power of the demonstrator's beam can reach 20 kW at high beam density[35]. Like other powerful lasers, the German demonstrator consists of 12 almost identical fiber laser modules with a diffraction-limited beam of 2 kW each. Small laser beams are combined into one using dielectric grating technology, which allows for a homogeneous beam of high power. This spectral coupling technology has a number of advantages over other methods of combining laser beams. It is simpler to manufacture, has a modular design, and allows for power increases of up to 100 kW without large-scale interventions. MBDA Deutschland is responsible for target detection and tracking, the operator's console, and the connection of the laser weapon demonstrator to the control system. Rheinmetall is responsible for the rotation system, laser beam guidance, the demonstrator container, as well as the mechanical and electrical integration of the demonstrator on the deck of the Sachsen frigate, and the high-energy laser source, including its peripherals.

Category summary. Power used is mostly less than 30 kW (mostly 2-15 kW), focal spot size is about 2cm^2, range depends on power, ranging from 1-1.5 km for 2 kW to 4-5 km for 30 kW. A large share of fiber lasers.

2) *Anti-UAV laser systems for destroying UAVs such as «Shahed-131\136", «Orlan-10", etc. (Group 3-5)*

The next class of anti-UAV laser devices has a much larger power range of 30-100 kW. Among the most significant representatives of this class is DE M-SHORAD[36]. Laser of power of 50 kW (see Figure 5). The downing of a Class 3 UAV has been documented. The damage distance is «beyond the field of view»(more than 1-2 km).

34 Hoffmann, O. (2023, September 22). Bundeswehr successfully concludes laser weapon trials at sea. *Rheinmetall AG*. URL : https://www.rheinmetall.com/en/media/news-watch/news/2023/9/2023-09-22-laser-weapon-trials-at-sea

35 The Sachsen frigate of the German Navy tested laser weapons. NGO «Ukrainian Military Center". Retrieved from URL : https://mil.in.ua/uk/news/fregat-sachsen-vms-nimechchyny-vyprobuvav-lazernu-zbroyu/

36 Bernatskyi, A., & Sokolovskyi, M. (2022). History of military laser technology development in military applications. *History of Science and Technology, 12*(1), 88-113. URL : https://doi.org/10.32703/2415-7422-2022-12-1-88-113

Figure 5. Raytheon DE M-SHORAD air-defense system on trials[37]

Another representative of this class of systems is the Chinese Silent Hunter (see Figure 6). Based on 30 kW LASS. Power in the range of 30-100 kW. The laser is probably based on a smaller anti-drone laser, the Low Altitude Guard. That's enough to knock out automobiles by burning out their engines from over a mile away, as the 30-kilowatt Lockheed Martin ATHENA laser demonstrated in 2015. The Silent Hunter uses fibre optic lasers (fibre optics doped with rare earth minerals), which provide weight savings over chemical lasers through increasing optical gain by kilometers of coiled fibre optics (as opposed to bulky chemical lasers). The Silent Hunter is likely to be scaled up and equipped with radars to complement its optical/infrared tracking system, making it a capable close range defense system against enemy missiles, artillery, drones and aircraft. Documented «instantaneous»defeat of a quadcopter-type target from a distance of 300 meters. The ability to penetrate 5 sheets of 2 mm thick steel from 800 meters or one sheet of 5 mm thick steel from a distance of 1000 meters has been documented. The maximum damage distance is 4-5 km. The focal spot is several 2-5 square centimeters in area.

37 Suits, D. L. (2021, August 20). Army to field laser-equipped Stryker prototypes in FY 2022. *US Army News Service.* Retrieved from URL : https://www.army.mil/article/249549/army_to_field_laser_equipped_stryker_prototypes_in_fy_2022

Figure 6. Silent Hunter laser systems[38]

Category summary. The most relevant capacities vary in the range of 30-100 kW. The strike distance is 5-7 km.

3. Study of the effectiveness of laser systems on the materials from which UAVs are made

As part of the project «Study of the effect of a laser beam on the materials of UAV parts and substantiation of the technical parameters of the laser equipment of the mobile complex to combat them", the authors identified the materials most commonly used to make parts of various UAVs. In particular, it was found that parts of the hull of attack UAVs can be made of hetinax. This research was funded by the National Research Foundation of Ukraine under the project No. 2023.04/0166 « Study of the effect of a laser beam on the materials of UAV parts and substantiation of the technical parameters of the laser equipment of the mobile complex to combat them".

The purpose of the work at this stage of the project was to answer the following questions:

38 Saudi Arabia Deploys China-made Laser-firing Anti-drone System against Houthi UAVs. *Defensemirror.Com* Retrieved from URL : https://www.defensemirror.com/news/32959/Saudi_Arabia_Deploys_China_made_Laser_firing_Anti_drone_System_against_Houthi_UAVs

1.1. How does laser radiation interact with the material of a UAV part made of hetinax (absorbs / reflects / partially absorbs and partially reflects and scatters)?

1.2. What is the required laser radiation power density for the destruction of the material of the UAV part made of hetinax (how many watts of laser radiation power must be applied per unit area to start the destruction, W/cm^2), under conditions when the laser beam and the sample simulating Part 1 are stationary relative to each other?

1.3. What should be the energy exposure of a beam of a certain laser radiation power density to destroy the material of a UAV part made of hetinax of a certain thickness, under conditions when the laser beam and the workpiece are stationary relative to each other (how long (in seconds) should a beam of a certain laser radiation power density (W/cm^2) affect the material of a UAV part made of hetinax of a certain thickness to destroy a UAV part made of hetinax)?

The research was carried out using the laser equipment available at the E.O. Paton Electric Welding Institute (laser DY044) and a three-axis manipulator. The parameters that varied during the experiments were: laser power (0.5–4.0 kW); laser beam size on the sample surface (5.0–20.0 mm); time of interaction of laser radiation with the sample material (goethanax) (0.25-20.0 s). All tests were performed at an angle of incidence of laser radiation on the workpiece material of 90 degrees. The following results were obtained (see Figure 7–10).

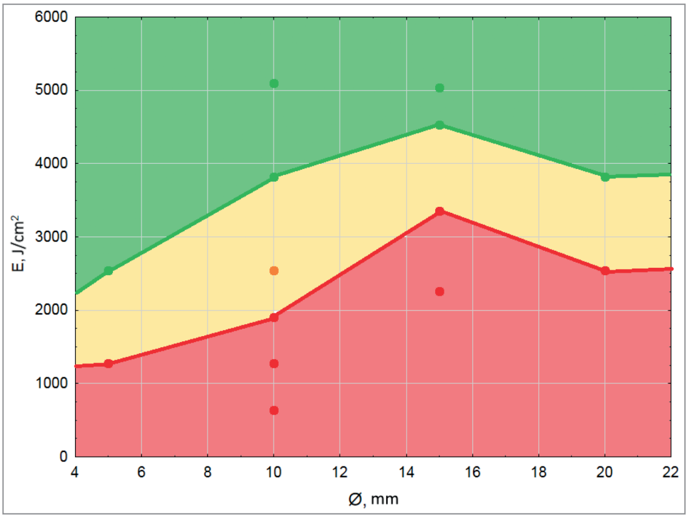

Figure 7. Graph of the dependence of processing results on the values of radiant exposure and beam diameter

The arcuate nature of the reference line of guaranteed penetration should be noted, as well as the stabilization of the radiant exposure required for penetration at the level of 3800–4500 J/cm².

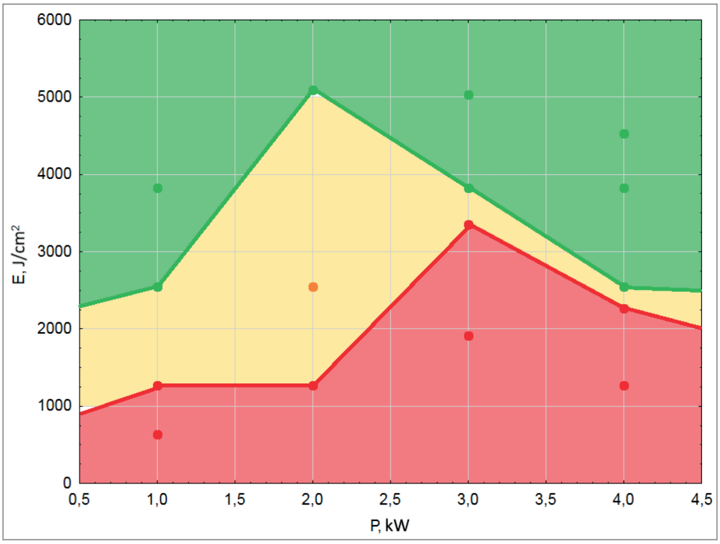

Figure 8. Graph of the ratio of processing results to the values of the radiant exposure and laser power

On this graph, it can be noted that there is a rather large «zone of uncertainty» in the interval between the powers of 1 and 2.5 kW, after which the reference lines converge.

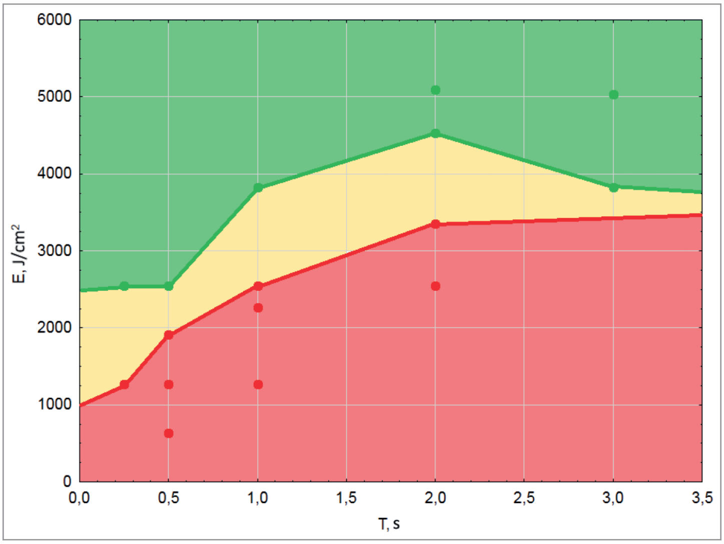

Figure 9. Diagram of the dependence of the penetration results on the radiant exposure value as well as the laser processing time

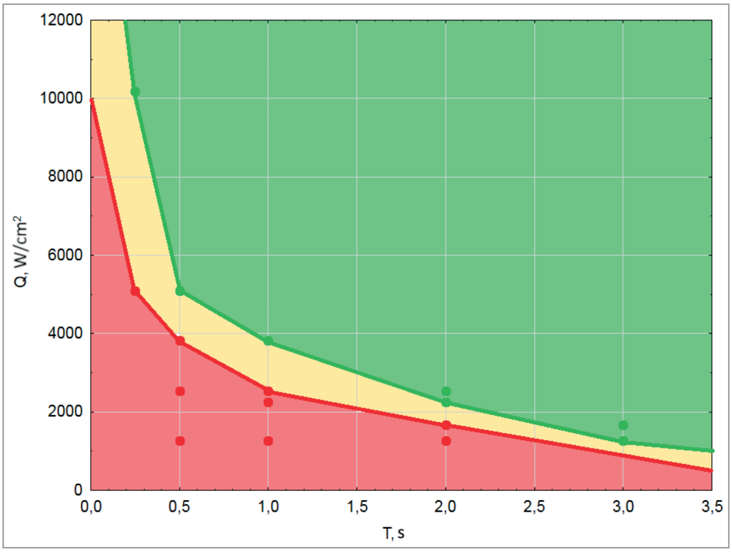

Figure 10. Diagram of the dependence of the experimental results on the power density and processing time

This graph shows dependence of the experimental results on the power density and processing time. It should be noted that there is virtually no «zone of uncertainty»where penetration is not guaranteed. This indicates that the material accepts laser radiation well over a longer period of time.

FUNDING.

This research was funded by the National Research Foundation of Ukraine under the project No. 2023.04/0166 «Study of the effect of a laser beam on the materials of UAV parts and substantiation of the technical parameters of the laser equipment of the mobile complex to combat them».

DOI: 10.51587/9798-9895-14663-2024-119-146-160