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EXPERIMENTAL STUDY OF FIBERGLASS COMPOSITE DEGRADATION
UNDER HIGH-POWER LASER RADIATION
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This study focuses on the role of glass-based composite plastics, especially FR-4 fiberglass composite, in the design of modern unmanned aerial vehicles (UAVs) and on how these materials degrade when exposed to high-power laser radiation in counter-UAV operations. Over the last decade, UAVs have become widely used due to their low cost, versatility, and proven effectiveness in combat. Their importance became especially clear during Russia's full-scale war against Ukraine, where cheap, small drones have been heavily used for reconnaissance, artillery targeting, and direct strikes. Because these UAVs are often produced in large numbers with limited resources, manufacturers rely on inexpensive and easily available materials like FR-4, valued for its strength, light weight, and insulating properties. However, this widespread use also creates a significant weakness: FR-4 is highly susceptible to damage from directed energy weapons, particularly high-power lasers.

The main goal of this research was to study how FR-4 degrades and ultimately fails when exposed to laser radiation. The study focused on identifying the key laser parameters – power, angle, exposure time, and beam diameter – that cause serious structural damage or complete penetration of UAV parts made from FR-4, including both the airframe and electronic components. By combining literature analysis with experiments, the research aimed to provide a solid scientific basis for improving laser weapon tactics and to reveal the fundamental weaknesses of FR-4-based UAV designs.

The research was carried out in two stages. First, a detailed review of open-source literature was conducted to understand trends in UAV construction, the growing reliance on FR-4, and the existing models describing how laser energy interacts with this type of material. This step helped identify the most important factors affecting FR-4 vulnerability. In the second stage, experiments were performed to determine the exact conditions under which lasers cause critical damage. Tests were conducted using a fiber

laser MAX MFSC-6000M (Maxphotonics, China) with a maximum power output of 6.0 kW and a wavelength of 1070 nm. Variables included laser power levels (1.0, 2.0, and 3.0 kW), beam angles (30°, 45°, 60°, and 90°), exposure times (0.25 to 3.0 seconds), and beam diameters (5.0 to 20.0 mm). The samples were 2.0 mm thick FR-4 sheets, representative of materials commonly used in UAV bodies and circuit boards.

The experiments showed that exposure time is the most important factor influencing laser effectiveness. It was found that to completely pierce a 2.0 mm FR-4 sheet, the laser must remain focused on the target for at least 0.5 seconds. Even with lower power densities (around 1000 W/cm²) and wide beams (15–20 mm), exposure beyond this threshold reliably caused full penetration. This proves that UAVs built from FR-4 are highly vulnerable to sustained laser fire, making lasers a practical solution for neutralizing such drones.

From a practical standpoint, these results are valuable for two groups. For developers of laser-based counter-UAV systems, the data help in refining operational parameters such as dwell time and targeting precision. For UAV manufacturers, the study highlights the serious risks associated with using FR-4 and points to possible design improvements, though these may increase cost and weight.

The novelty of this work lies in combining theoretical analysis with direct experimental evidence. This provides a rare, data-driven understanding of how high-power lasers affect FR-4 composites and contributes to both the development of more effective counter-UAV weapons and the broader knowledge of material survivability in modern drone warfare.

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