

Harnessing Artificial Intelligence for Countering Hypersonic Weapons: A New Frontier in Battlefield Offense and Defense (A Short Review)

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Abstract: The rise of hypersonic weapons, capable of traveling at speeds exceeding Mach 5 with unparalleled maneuverability, represents a transformative shift in modern warfare. These weapons, including HGVs (hypersonic glide vehicles) and HCMs (hypersonic cruise missiles), challenge traditional defense systems due to their stealth-like speed, unpredictable flight paths, and low-altitude trajectories. Their ability to compress decision-making windows and evade conventional radar systems has sparked a global arms race, creating a critical need for advanced countermeasures. AI (artificial intelligence) emerges as a revolutionary solution to counter the stealth and speed of hypersonic threats. By leveraging AI-driven detection, tracking, and interception systems, defense mechanisms can overcome the limitations of conventional technology. AI enhances early detection through multi-sensor fusion, real-time data processing, and predictive modeling of hypersonic trajectories. It also facilitates the development of precision-guided interceptors and advanced systems like DEWs (directed energy weapons), offering effective avenues for neutralizing these fast-moving threats. Despite its promise, AI integration into hypersonic defense systems faces challenges, including data bias, cybersecurity risks, and potential escalation of conflicts. Ethical considerations and global collaboration are essential to address these concerns and ensure responsible deployment. As hypersonic weapons redefine the battlefield, AI stands as the linchpin for a robust, resilient, and future-proof defense strategy. This article explores the intersection of hypersonic technologies and AI, providing insights into how intelligent systems can safeguard global security against these next-generation threats.

Key words: Hypersonic weapons, AI, HGVs, HCMs, stealth and speed, multi-sensor fusion, DEWs, real-time data processing, predictive modeling, missile defense systems.

1. Introduction

The advent of hypersonic weapons, traveling at speeds greater than Mach 5 and capable of maneuvering unpredictably, has redefined modern warfare. These advanced systems pose a significant challenge to traditional defense mechanisms due to their stealth-like speed and ability to evade radar detection. As the global arms race intensifies, AI (artificial intelligence) is emerging as a critical enabler for countering the unprecedented challenges posed by hypersonic velocity. This article explores how AI-driven technologies can overcome the stealth and speed of hypersonic weapons,

providing actionable insights into detection, tracking, and interception. See Fig. 1 which is presentation of missile pushing Mach 5 hypersonic ramjet technology as scramjet stopgap.

The pace of technological advancements in military weaponry has led to the emergence of hypersonic weapons, often described as the most transformative innovation in modern warfare. Hypersonic systems, capable of traveling at speeds exceeding Mach 5 (around 6,000 km/h), have introduced an entirely new category of challenges for defense systems worldwide. Unlike traditional ballistic missiles, hypersonic weapons

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Propulsion Performance

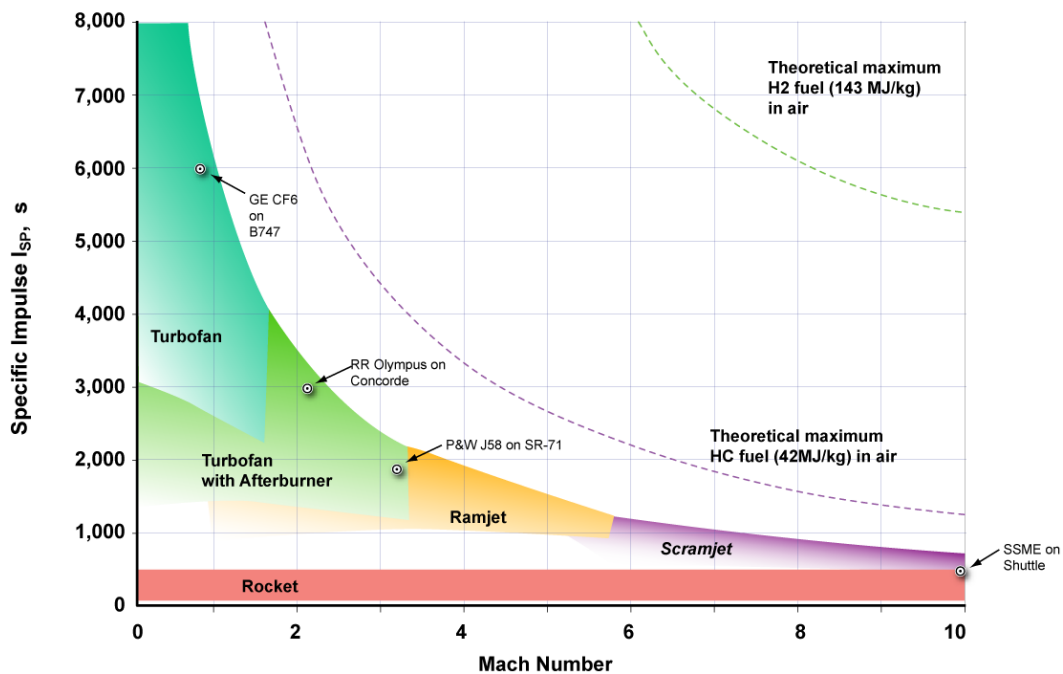


Fig. 1 Missile pushing Mach 5 hypersonic technology [1].

combine extreme speed with maneuverability, enabling them to evade radar detection and interceptors with ease. These characteristics make them a formidable weapon on tomorrow's battlefield, posing a threat not only to national security but also to global stability.

Hypersonic weapons are broadly categorized into two types: HGVs (hypersonic glide vehicles) and HCMs (hypersonic cruise missiles). HGVs are launched on a ballistic missile before detaching and gliding at hypersonic speeds along unpredictable trajectories. HCMs, on the other hand, are powered by advanced scramjet engines, allowing them to sustain hypersonic speeds during flight. Both types are engineered to outpace traditional defense mechanisms, exploiting gaps in existing detection and interception systems.

The stealth of hypersonic weapons is not merely a result of their speed but also their ability to fly at lower altitudes and adjust their trajectories mid-flight as illustrated in Fig. 2. Traditional radar systems, optimized for detecting high-altitude ballistic missiles or subsonic aircraft, struggle to track these weapons consistently. Furthermore, the compressed reaction

time associated with hypersonic velocities reduces decision-making windows for defense operators from minutes to mere seconds, compounding the difficulty of countering such threats [2].

The implications of hypersonic weapons extend beyond the battlefield. Their potential to carry conventional or nuclear warheads makes them strategic tools for coercion and deterrence, disrupting the delicate balance of global power. Adversarial nations are investing heavily in developing hypersonic arsenals, escalating an arms race that compels other nations to prioritize countermeasures.



Fig. 2 A powerful hypersonic flying objects.

Source: Raytheon Corporation.

This is where AI steps in as a game-changer. AI has the potential to revolutionize defense systems by addressing the critical gaps in detecting, tracking, and intercepting hypersonic weapons. Through its ability to process massive datasets in real time, predict complex flight patterns, and optimize resource allocation, AI is emerging as the linchpin for countering hypersonic threats. As the speed and stealth of hypersonic systems redefine the dynamics of warfare, leveraging AI-driven solutions is not just an option but a necessity for ensuring the security of tomorrow’s battlefield.

The remainder of this article explores the intersection of AI and hypersonic defense, focusing on how intelligent systems can overcome the stealth of speed to detect, track, and neutralize these next-generation weapons effectively.

2. The Threat of Hypersonic Weapons

Hypersonic weapons, such as glide vehicles (HGVs) and cruise missiles, represent a leap in offensive capabilities.

Their distinguishing features include:

- Extreme Speed: Hypersonic weapons travel at speeds exceeding 6,000 km/h, roughly speaking 3,800 miles/h, compressing decision-making windows.
- High Maneuverability: Unlike ballistic missiles, they follow non-linear trajectories, making them harder to predict.

- Stealth: Their ability to evade radar detection due to low-altitude flight paths and speed-induced radar blackout zones. Although the usage of material and special painting of manufacturing of them has been reduced their RCS (Radra Cross-Section) way below radar detection as well [3].

These attributes make hypersonic systems difficult to detect, track, and intercept using traditional radar and missile defense systems, thus a new innovative technology and assist from AI come to play an effective rule. See Fig. 3, which is illustrating proposed AI-driven detection technology [4-6].

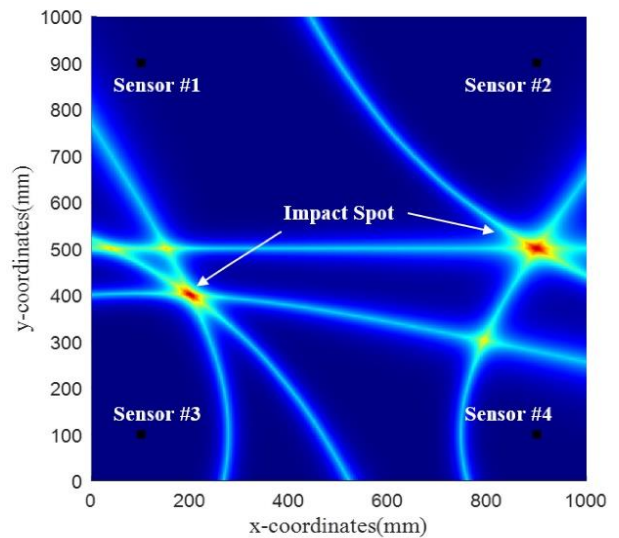


Fig. 3 AI-driven hypervelocity detection technology. Source: www.wikipedia.org.

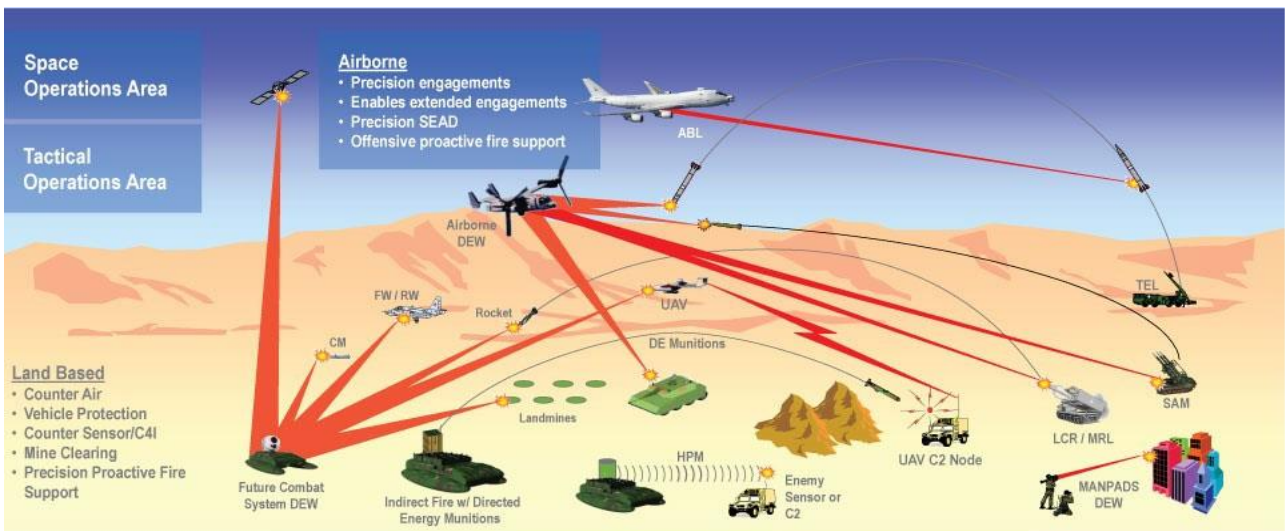


Fig. 4 Theater of tomorrow’s battlefield. Source: www.wikipedia.org.

In summary, AI offers transformative potential for overcoming the stealth and speed of hypersonic threats through advanced data analytics, real-time processing, and decision-making capabilities.

3. The Threat of DEWs (Directed Energy Weapons)

Their scalability further enhances their utility; operators can adjust power levels to incapacitate or destroy targets based on the mission's requirements. However, this unprecedented combination of speed, precision, and adaptability also introduces new threats, as DEWs can bypass conventional defenses, disrupt command systems, and destroy incoming hypersonic or ballistic missiles with minimal warning. Their potential to undermine existing military strategies underscores the urgent need for advanced countermeasures [7-18]. See Fig. 4 as it illustrates the battle management of tomorrow's new battlefield theater, that gets fought at speed of light.

3.1 Key Features of DEWs

- **Speed of Light Engagement:** DEWs deliver energy to targets at the speed of light, ensuring instantaneous impact and eliminating delays associated with conventional projectiles.
- **Pinpoint Precision:** These weapons can target specific components or systems (e.g., sensors, electronics) with extreme accuracy, minimizing collateral damage.
- **Stealth Capability:** DEWs operate silently and invisibly, making them difficult to detect during an attack and ideal for covert operations.
- **Low Cost per Shot:** Once deployed, DEWs offer a low-cost-per-use model compared to traditional ammunition-based systems, relying only on a power source for operation.
- **Scalability and Flexibility:** Energy output can be adjusted to disable, damage, or destroy targets, allowing versatility in their application.
- **Multi-Domain Utility:** Effective for countering a

range of threats, including drones, missiles (ballistic and hypersonic), and even manned aircraft or vehicles.

- **Electronic Disruption:** High-power microwaves can disable enemy communication and navigation systems without physically destroying them.
- **Unlimited Ammunition Potential:** As long as a power source is available, DEWs can continue to operate, unlike kinetic weapons that rely on finite stockpiles.
- **Integration into Modern Platforms:** DEWs can be mounted on a variety of systems, including aircraft, naval ships, ground vehicles, and satellites, enabling wide-ranging applications.
- **Anti-Missile Capability:** DEWs are particularly effective against high-speed threats, such as hypersonic missiles, intercepting them by overheating or damaging critical components.

In summary, DEWs offer unparalleled speed, precision, stealth, and cost efficiency, making them versatile tools for countering diverse threats while challenging traditional defense systems with their adaptability and near-unlimited operational potential.

4. AI as a Force Multiplier in Countering Hypersonic Weapons

AI offers transformative potential for overcoming the stealth and speed of hypersonic threats through advanced data analytics, real-time processing, and decision-making capabilities.

4.1 Enhanced Early Detection and Tracking

- **AI-Driven Sensors:** AI algorithms can process data from next-generation sensors, such as space-based IR (infrared) detectors and over-the-horizon radars, to identify hypersonic threats earlier in their flight.
- **Multi-Sensor Fusion:** Combining data from multiple sources using AI enhances detection accuracy, compensating for the evasive maneuvers of hypersonic systems.
- **Predictive Modeling:** Machine learning models trained on trajectory patterns can predict possible flight paths, even for highly maneuverable systems.

4.2 Real-Time Data Processing

- **High-Velocity Data Streams:** AI systems can analyze terabytes of sensor data in real time, filtering noise and extracting actionable intelligence faster than human operators.
- **Dynamic Resource Allocation:** AI can prioritize sensor focus and recalibrate detection systems dynamically to track fast-moving threats across multiple domains.

4.3 Hypersonic Interception Systems

- **AI-Guided Interceptors:** Leveraging AI in missile guidance systems enables precise targeting of hypersonic threats, compensating for their high-speed evasive maneuvers.
- **DEWs:** AI enhances the targeting and operation of DEWs, such as high-powered lasers, offering a viable alternative for intercepting hypersonic weapons.

4.4 Resilience against EW (Electronic Warfare)

- Hypersonic systems often employ EW techniques to jam radars. AI-based algorithms can identify and counter EW tactics, ensuring uninterrupted detection and tracking.

In summary, AI serves as a critical force multiplier in countering hypersonic weapons by enabling real-time detection, tracking, predictive modeling, and precision interception to address their speed and maneuverability challenges.

5. Case Studies in AI-Driven Hypersonic Defense

Case studies in AI-driven hypersonic defense highlight innovative applications of AI, such as predictive trajectory modeling, sensor fusion, and autonomous interceptors, demonstrating its potential to neutralize hypersonic threats effectively.

- **DARPA's Glide Breaker Program:** DARPA's Glide Breaker initiative uses AI to develop interceptors capable of neutralizing HGVs. AI facilitates precision in mid-course corrections to engage fast-moving targets.

- **Joint AI-Space Integration:** Collaborative efforts between AI-driven technologies and space-based platforms, such as satellites with advanced infrared imaging, are revolutionizing hypersonic detection at global scales.

- **AI-Enhanced Wargaming Simulations:** Defense organizations are employing AI-powered simulations to train systems against hypersonic threats, fine-tuning algorithms for real-world applications.

AI-driven hypersonic defense case studies showcase the transformative role of AI in enhancing detection, tracking, and interception capabilities against hypersonic threats.

6. Challenges and Ethical Considerations

While AI holds immense promise in countering hypersonic weapons, it also presents challenges:

- **Data Bias and False Positives:** AI models may struggle with accuracy in ambiguous scenarios.
- **Cybersecurity Threats:** Adversaries could exploit vulnerabilities in AI systems.
- **Escalation Risks:** Autonomous systems may inadvertently escalate conflicts due to misinterpretations of threats.

These challenges necessitate rigorous testing, ethical oversight, and robust cybersecurity measures.

7. Future Directions

To stay ahead of the hypersonic threat, defense systems must embrace a layered and integrated approach:

- **Quantum AI:** Combining quantum computing with AI for faster threat analysis.
- **Autonomous Swarm Defenses:** AI-controlled drone swarms that dynamically intercept hypersonic systems.
- **Global Collaborations:** Sharing AI-driven insights across allied nations to create a comprehensive defense ecosystem.

In summary, future directions emphasize integrating AI, quantum computing, and autonomous systems to

create advanced, collaborative defense networks capable of countering evolving hypersonic and next-generation threats.

8. Conclusion

Hypersonic weapons have ushered in a new era of warfare, challenging conventional defense paradigms. However, AI's unparalleled ability to analyze data, predict trajectories, and optimize responses provides a promising avenue for countering these formidable threats. By integrating AI into detection and interception systems, nations can develop resilient defenses capable of neutralizing hypersonic weapons' stealth and speed, ensuring the safety of tomorrow's battlefields.

In overall conclusion context, we state that, the rapid advancements in hypersonic and DEWs have transformed the landscape of modern warfare, posing unprecedented challenges to traditional defense systems. These technologies, characterized by extreme speed, stealth, precision, and adaptability, demand innovative solutions to ensure global security and strategic stability. AI emerges as a pivotal tool in this context, offering real-time detection, predictive analytics, and enhanced interception capabilities that can overcome the limitations of existing systems.

From tracking hypervelocity threats to enabling precision in directed energy systems, AI-driven solutions have proven indispensable in addressing the complexities of these next-generation weapons. Case studies demonstrate how AI can fuse multi-sensor data, predict evasive trajectories, and optimize defense mechanisms, while future directions highlight the integration of quantum AI and autonomous systems for even greater resilience.

However, these advancements also bring ethical and security challenges, necessitating robust testing, cybersecurity measures, and global cooperation. As the speed and stealth of hypersonic and light-speed weapons redefine the battlefield, embracing AI-driven innovations will be crucial to maintaining a strategic

edge, ensuring that nations are prepared for the emerging threats of tomorrow.

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