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CHAPTER 2

Hypersonic Weapons: Emerging, Disruptive, Political

Dominika Kunertova

Hypersonic weapons can travel at extreme speeds in the earth's atmosphere and maneuver along an unpredictable trajectory. They are also overhyped. This chapter explains how three trends – unsubstantiated claims about the effectiveness of hypersonic weapons in development, politicized technological competition, and a widening spectrum of missile threats – obscure our understanding of the hypersonic military capability. The hype about hypersonic weapon programs is more dangerous than hypersonic technology itself.

Military vehicles carrying hypersonic missiles DF-17 drive past Tiananmen Square during the military parade, October 1, 2019. *Thomas Peter / Reuters*

Hypersonic weapons will transform the global security environment and disrupt the strategic balance, or so goes the dominant public narrative, as the three peer competitors in this field – the United States, China, and Russia – continue developing hypersonic offensive capabilities. But then physics gets in the way by showing that hypersonic weapons are neither as fast nor as agile as advertised. This chapter contributes to ongoing debates about the hypersonic threat to global stability and European security. From a military-technical and a socio-political perspective, the chapter looks at recent developments in weapon systems labeled as "hypersonic" and examines the hype surrounding these new weapons to gain a better understanding of their potential geopolitical impact in the short to medium terms. The chapter identifies the following three trends.

First, many claims about the military effectiveness of hypersonic weapons are premature. Hypersonic weapons are technically feasible and may become fully operational by 2030–2040. However, the hype surrounding these weapons exaggerates their current offensive and defensive capabilities and their short-term prospects. Hypersonic weapons have yet to reach maturity in terms of materials, propulsion, and control. Whether relying on a boost-glide system or an air-breathing engine, these weapons are still largely in development and prototype testing phases. Countries developing these weapons are yet to overcome thermal and aerodynamic obstacles that occur during hypersonic flight in the atmosphere.

Second, technological competition has become politicized**.** Investing in the research and development of new emerging technologies has become part of the toolkit of great powers in their rivalry for primacy. Their hypersonic weapons development and testing serve as a political tool for demonstrating technological prowess and great-power status. In this technological competition, the main selling pitch is that hypersonic weapons are fast, low-flying, and highly maneuverable weapons that are designed to be too agile for existing missile defense systems. Reportedly, Russia deployed its first hypersonic weapon system, the Avangard, in December 2019 and China its hypersonic glider, the DF-ZF, in 2020, while the United States is likely to field its own hypersonic weapons by 2023. China appears to be ahead of the United States and Russia in the development and testing of such weapons, yet none of the great powers is expected to field any significant number of hypersonic weapons in the short to medium terms. The unconfirmed first battle use of a Russian hypersonic missile during the war in Ukraine further demonstrates the propaganda potential of these weapons.[1]

Third, the spectrum of missile threats has been widening. The hypersonic hype obscures our understanding of the emerging variety of high-speed, maneuverable threats from the sky. The language of hypersonics diverts attention toward the extreme speed of the weapons, while in most cases their maneuverability is the crucial factor. This trend suggests that although a growing number of countries are labeling their new weapon programs as hypersonic, they are actually more interested in extending the range of existing ballasting missiles along an unpredictable trajectory in the form of new unpropelled maneuverable re-entry vehicles (MARVs) than in increasing their speed. To save energy, new hypersonic gliders maneuver less in their midcourse flight than might be expected of a highly maneuverable weapon. Indeed, they maneuver no more during this phase of flight than traditional MARVs. Thus, their advantage compared to traditional MARVs is unclear.

Based on the observed trends, the condition of research in hypersonic technology raises questions about the maturity of deployed systems and indicates that hypersonic weapons will remain a niche capability until at least 2030, when boost-glide technology is expected to become operational. Thus, it is unrealistic to anticipate that national arsenals of hypersonic cruise missiles will emerge before 2040. However, the hypersonic threat could grow qualitatively greater in conjunction with the effects of Artificial Intelligence (AI) and advancements in space technology.

Hypersonic technology itself is not a game-changer. However, set in the geopolitical context of great-power rivalry, it could prompt technological competition to spiral into costly and dangerous arms races and further nuclear build-up. Paradoxically, the military added value of hypersonic weapons vis-à-vis existing systems remains unclear. In reality, hypersonic weapons at strategic ranges have existed for decades. They have just been called intercontinental ballistic missiles (ICBMs). Therefore, the development of new hypersonic weapons to strengthen strategic deterrence and second-strike capabilities would seem to be either redundant or merely a hedging strategy. However, hypersonic weapons could generate military effects at theater ranges in naval warfare and by limiting regional missile defenses.

Lastly, hypervelocity is only one of the features that will shape future warfare in the air and space domains. This needs to be reflected in thinking about a future air and missile defense architecture that would be flexible enough to defend against the whole spectrum of missile threats (hypersonic weapons; ballistic, cruise, and aeroballistic missiles; orbital rockets; and drones).

The objective of this chapter is twofold. The first aim is to provide a better understanding of hypersonic weapon systems. The second is to explain the potential geostrategic implications of these weapons for the global security environment. The chapter starts by outlining the basics of hypersonic technology and presents the major weaponizers. It subsequently examines not only what this technology can do, but also what it could mean for global security in the short to medium terms. From a military-technical perspective, the chapter contrasts political declarations with the scientific reality and, based on available technical assessments of hypersonic technology, details some of the most pressing problems that countries wishing to go hypersonic must solve, as well as the requirements for hypersonic defense. From a social-political perspective, the chapter evaluates the extent to which new hypersonic weapon systems are a matter of hyped expectations. By using the hype cycle concept, it examines the negative effects of the hype around hypersonic technology on our understanding of missile threats. It also investigates the added value of new hypersonic weapons in terms of both offense and defense. The chapter concludes by situating the hypersonic hype within the context of great-power competition and other so-called emerging and disruptive technologies (EDTs) and with a projection of trends beyond 2040.

A Hypersonic Primer

Hypersonic weapons are platforms that can travel at extreme speeds in the earth's atmosphere and have an outstanding ability to maneuver. As their name indicates, hypersonic systems can travel at a sustained speed of Mach 5 (that is, five times the speed of sound, or around 6,125 kilometers per hour in standard atmospheric conditions) or greater. The high speed is not the only standout feature of hypersonic weapon systems. The new generation of hypersonic weapons combines the main advantages of both ballistic and cruise missiles: extreme speed and superior maneuverability.

Hypersonic weapons can create a moment of surprise, as they can change flight direction and fly at unusual altitudes within the atmosphere.

Technically all ballistic missiles with a range longer than a few hundred kilometers are hypersonic because they can fly faster than Mach 5. However, while ballistic missiles are fast, they travel along a trajectory that is predictable, bullet-like, and easily calculated. Standard cruise missiles can navigate to the target more accurately than ballistic missiles. However, they are relatively slow, travelling at less than Mach 1 right before impact.

Hypersonic weapon systems can be divided into two main types. First are those using air-breathing engines, such as single-use hypersonic cruise missiles (HCM) and reusable aircraft, also referred to as post-stealth reconnaissance and strike aircraft. Second are those using the boost-glide system, combining a boost rocket and unpropelled hypersonic glide vehicles (HGV).[2]

HCMs, which fly at altitudes of 20–30 kilometers, are a faster version of existing cruise missiles. They are propelled by air-breathing supersonic combustion ramjet engines, also called scramjets. These engines compress incoming air in a short funnel before the combustion phase, allowing operation at high speeds. As they get the oxygen they need directly from the atmosphere, missiles using scramjets are smaller than ones using common jet engines. Scramjets operate under extreme conditions, which significantly increases the difficulty of developing an engine that would work at a hypersonic speed. Efforts to achieve this feat, which rely on advances in heat-resistant materials and other enabling technologies, have been under way for several decades. The first successful test of a vehicle using hypersonic air-breathing propulsion occurred in 2004, when NASA, under its Hyper-X program, flew an X-43 demonstrator at a speed close to Mach 10, though only for a few seconds.[3] Given the technical challenges of air-breathing engines that are necessary for hypersonic propulsion, no deployed systems currently use scramjets.[4]

In contrast, HGVs are unpropelled and rely on a rocket for their lift into the atmosphere. Whereas ballistic missiles fly high into space in an arc like a bullet to reach their target, gliders are lifted into the atmosphere and released early in their flight at altitudes between 40 and 100 kilometers (much lower than ICBMs). They then descend unpowered at hypersonic speeds to strike targets on the ground. The boost-glide concept involves the ability to maneuver along convoluted routes and the unpredictability of re-entry at different altitudes. This enables gliders to evade missile defenses and makes it harder to track and defend against them. In addition to their high speed and ability to maneuver, HGVs operate across and within the air and space domains, which can have a significant impact on the effectiveness of air and missile defense systems.

Most HGVs in development and testing rely on ballistic missiles during the boost phase. However, China recently mounted a hypersonic glider on an orbiting rocket. This hypersonic weapon system combines orbital weapons technology, inspired by the Soviet Fractional Orbital Bombardment System (FOBS),[5] and glider technology, which provides local maneuverability. "Orbital" here means that this system can circle around the earth until the weapon's operator determines that it should stop orbiting and fly down. The novelty of this system does not lie in the combination of an orbiter and a hypersonic glider, but rather in China's alleged attachment of a nuclear warhead to it.[6] This type of hypersonic system has been around for some time and is well known in the form of a rocket-powered space shuttle–that is, as a vehicle that is lifted by a rocket, goes into an orbital flight mode, and then glides back to the earth.

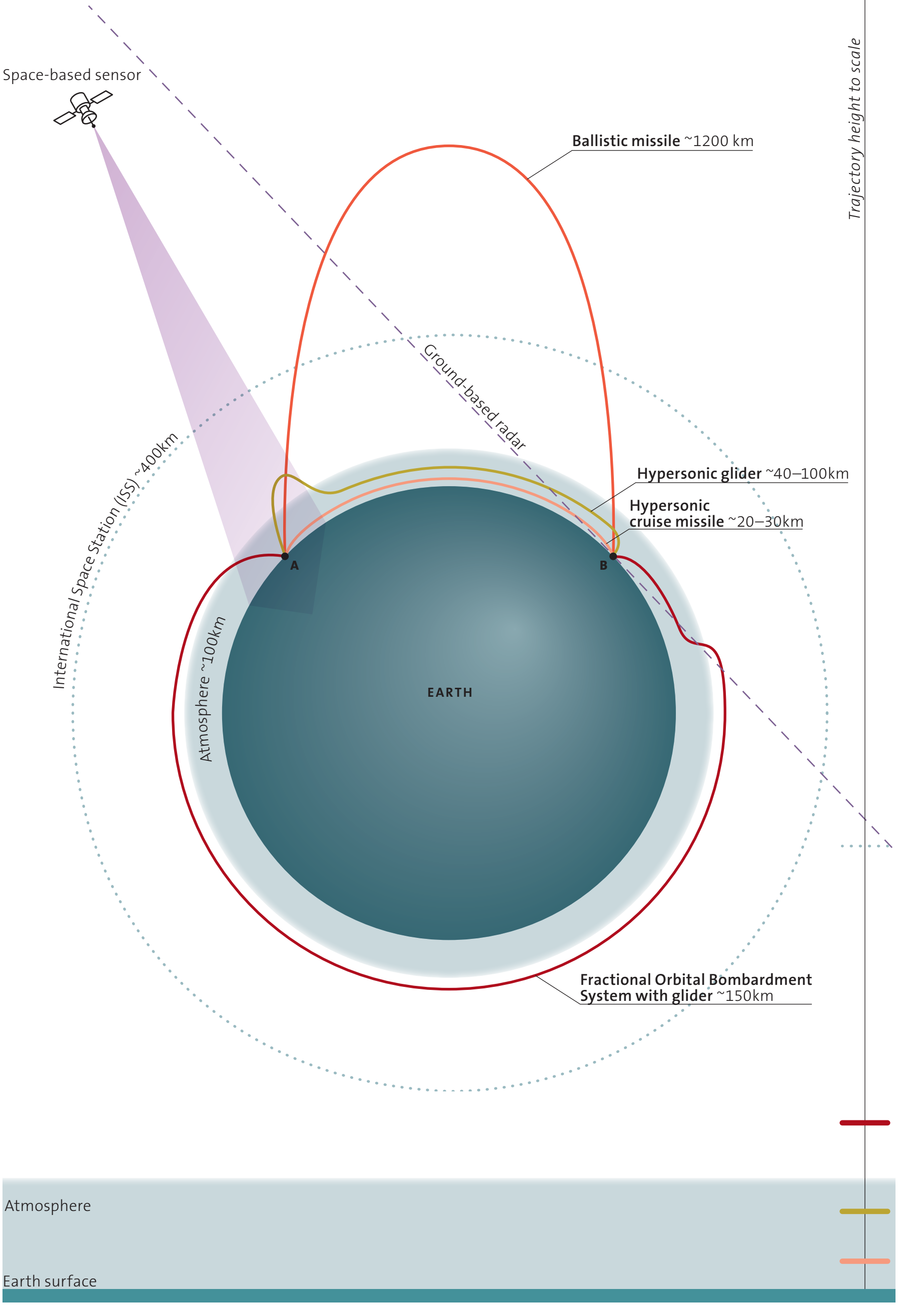
Hypersonic weapon systems introduce several new threats to the stability of the security environment. First, incoming weapons flying at hypersonic speeds leave defenders with as little as a few minutes to react, determine the target, identify the type of warhead, consider possible responses, and assess the potential damage that will result from any chosen course of action. The extreme speed of hypersonic systems reduces engagement opportunities and makes kinetic intercept very difficult.

Second, the ability of hypersonic weapon systems to maneuver can deceive the defender about which target the weapon will strike. Maneuverability creates ambiguity regarding the target and, together with the unusual flight altitude, makes it difficult for existing missile defenses to detect and stop hypersonic threats. Gliders, unlike ballistic missiles, spend most of their time within the atmosphere, hiding behind the curvature of the earth. This decreases the time between detection and interception by ground-based defense systems. Further, the superior maneuverability of hypersonic weapons allows them to access undefended altitudes and to shrink the defender's area of defense.

Third, although hypersonic weapons can rely on their high speed and accuracy to destroy the target with the kinetic energy impact alone, they can also carry supplemental warheads. The ability of dual-capable hypersonic

Flying Hypersonic

Hypersonic trajectories in a comparative perspective



weapons to carry either conventional or nuclear warheads, compounded by the defender's lack of clarity about the target, can significantly reduce the predictability of the security environment.

These advantages suggest that hypersonic weapons may have high military relevance. For instance, they could assure greater survivability against an enemy's integrated missile defenses; extremely rapid strikes against high-value, time-sensitive targets; and long-range airborne reconnaissance that is more flexible than satellites and less endangered by air defenses than drones.

Hypersonic Tech Racing

Russia, China, and the United States are the three most advanced developers of hypersonic weapons. Faster cruise missiles, maneuvering gliders, and orbiting vehicles that can evade missile defenses promise new methods of weapon delivery and ways to strengthen second-strike capabilities. They also send a powerful signal to audiences abroad. This is why open-source information about these weapons is often littered with state propaganda, while actual technological progress is kept secret.

Russia. After having announced its first hypersonic weapon systems in 2018, Russia has prided itself on leading the deployment of an entire new class of weapons.[7] For some time, Russia has been interested in acquiring nuclear-capable hypersonic delivery systems to strengthen its nuclear deterrence posture, which Moscow believes was undermined by Washington's withdrawal from the Anti-Ballistic Missile Treaty in 2002.

Russia has publicly disclosed three hypersonic weapon systems. First is the nuclear-capable HGV Avangard, which is boosted by an ICBM (likely the new Sarmat ICBM) before it glides at speeds exceeding Mach 20 toward its target. Second is a ship-launched HCM 3M22 Tsirkon, which has a range of 500 kilometers and may become a key Russian naval strike capability. Third is the maneuvering air-launched ballistic missile Kh47M2 Kinzhal. Although this is neither an HGV nor an HCM, Russia reports it among its hypersonic weapons, since it can reach Mach 10 within a range of 2,000 kilometers. This is because Kinzhal can be launched from a modified supersonic MiG-31 interceptor jet, which gives the missile a boost to reach higher speeds at unusual altitudes and extend its range. However, this does not say anything about any alleged superior maneuverability and accuracy of Kinzhal missiles.

Russia has built a large network of research and testing facilities, such as

National Hypersonic Weapon Programs

	Hypersonic Weapon System	*Range (km)*	*Status*
UNITED STATES			
Navy			
	Conventional Prompt Strike (ship or submarine launched HGV)	> 2800	Initial Operational Capability (IOC) in 2025 and deployment in 2028
	Offensive Anti-Surface Warfare (OASuW) Increment 2 (anti-ship HCM)	(?)	(?)
Army			
	Long-Range Hypersonic Weapon (HGV)	> 2,800	Prototype flight testing until 2023
Air Force			
	Hypersonic Attack Cruise Missile	(?)	Critical design review in 2023
	AGM-183 Air-Launched Rapid Response Weapon (HGV)	< 1,600	IOC in 2022
DARPA			
	Tactical Boost Glide (air-launched HGV with a tactical range)	(?)	Flight testing through 2022
	Operational Fires (ground-launched HGV)	< 5,400	Critical design review in 2022
	Hypersonic Air-breathing Weapon Concept (air-to-air HCM)	(?)	Final program review in 2022
RUSSIA			
	Avangard (nuclear-capable HGV)	> 5,500	IOC in 2019 (?); IOC of its Sarmat ICBM component in 2022
	3M22 Tsirkon (ship-launched HCM)	< 1,000	IOC in 2023
	Kh-47M2 Kinzhal (maneuvering air-launched ballistic missile)	< 2,000	IOC in 2021
CHINA			
	DF-17 (medium-range ballistic missile to carry HGVs)	< 2,500	Entering service (IOC in 2019?)
	DF-41 (dual-capable ICBM to carry HGVs)	> 5,500	Entering service (IOC in 2019?)
	DF-ZF HGV	< 2,400	Entering service (IOC in 2020?)
	Starry Sky-2 / Xing-King 2 (nuclear-capable HCM)	< 800	IOC in 2025
	Hypersonic fractional orbital bombardment system using a Long March rocket (a space-launched HGV)	> 5,500	Tested in August 2021

wind tunnels in Zhukovsky and Novosibirsk, as well as launch sites such as Dombarovsky Air Base and the Baykonur Cosmodrome. Yet many observers remain skeptical about the readiness of these weapons, as evidence indicates that the Russian hypersonic industrial base is under-resourced.[8] It is plausible that none of the Russian hypersonic cruise missiles and gliders will be fully operational for at least a decade.[9]

China. Following years of effort, China is leading the development and testing of hypersonic weapons. The fear of a pre-emptive US strike that would disable China's nuclear force and deprive it of its ability to retaliate appears to be motivating Beijing to invest heavily in hypersonic research and development. Some reports suggest that China has the most robust infrastructure for testing hypersonic weapons – the China Aerodynamics Research and Development Center alone claims to have 18 wind tunnels – that allows it to conduct "20 times as many hypersonic tests as the United States."[10] Some researchers in China even consider hypersonics a distinct operational domain.[11]

These geostrategic concerns prompted China to fit DF-41 ICBMs with multiple HGVs that are supposedly able to carry conventional or nuclear warheads.[12] China has also been developing hypersonic weapons to further project its power in the South China Sea and over Taiwan, while increasing its chances of circumventing US missile defenses in the Indo-Pacific. In this respect, China has tested a medium-range ballistic DF-17 missile designed to launch up to eight independently guided HGVs. Further, Starry Sky-2, a tactical nuclear-capable HCM that uses a waverider design that can derive lift from its own shock waves, could become a core feature of China's future anti-ship missiles. China may also fit conventionally armed HGVs onto DF-21 and DF-26 ballistic missiles to improve its anti-access/area denial (A2/AD) capability. All of the DFs mentioned here are supposedly already operational.

Lastly, in 2021, China demonstrated its innovative hypersonic research. In contrast to previous HGV tests using ballistic missiles, China attached a nuclear-capable hypersonic glider HGV92 onto an orbital Long March rocket, which resembles a fractional orbital bombardment system. In the test, the glider flew in the near space around the earth before speeding down toward its target.[13] This means that China is the first country that is moving towards acquiring a nuclear-armed orbital HGV that is capable of circumventing US missile defenses and warning stations spread over the Northern Hemisphere.

United States. Although the Unites States has been researching hypersonic technology for decades, its recent budget boost for military hypersonics has been a reaction to Russia and China's advances in the field.[14] Unlike China and Russia, the United States has publicly ruled out acquiring nuclear-capable hypersonic weapons.

Until recently, the United States was developing and testing only experimental prototypes and had no weapons procurement program on record. The situation changed when the US Air Force requested 12 HGVs for 2022, a product of its AGM-183 Air-Launched Rapid Response Weapon (ARRW) program. However, this procurement plan has been delayed due to three failed booster flight tests in 2021.[15] In addition to its two development programs, the US Air Force is also consulting industry on "Project Mayhem," which seeks to design a longer-range hypersonic cruise missile. The US Navy's flagship hypersonic program is a submarine-launched glider, which is to be deployed on Zumwalt-class destroyers by 2025 and Virginia-class submarines by 2028. Very little is known about another of the Navy's hypersonic weapon systems, the Offensive Anti-Surface Warfare Increment 2. It is likely to be an air-launched, anti-ship HCM mounted on carrier-based fighters. The US Army is expecting to field its mobile ground-launched Long-Range Hypersonic Weapon in 2023. Finally, the Defense Advanced Research Projects Agency is developing several boost-glide and air-breathing weapon concepts.[16]

Other countries. The interest in hypersonic technology is not limited to great powers. Several Western countries have been researching hypersonic propulsion systems and even hypersonic offensive and defensive capabilities. France appears set to become the first European country to develop its own hypersonic weapons. Launched in 2019, its Project V-MaX (Experimental Maneuvering Vehicle) aims to create an HGV by 2022. This project, a joint venture between Airbus and France's Safran, is meant to improve the French nuclear deterrent by modifying its air-to-surface ASN4G supersonic missile for hypersonic speeds. However, it can also enhance France's arsenal of conventional cruise missiles. France is not shying away from the prospect of developing a nuclear-capable hypersonic missile.

Elsewhere in Europe, Norway has been developing advanced solid fuel ramjet technologies together with the United States. These could be applied to feed into future hypersonic missiles for the US Army and Navy. At the EU level, member states are paying attention to potential defenses against hypersonic threats. In 2021, the European Defence Agency published a call for research projects on advanced over-the-horizon radars and endo-atmospheric interceptors.

In the Indo-Pacific, Australia continues to work with the United States on hypersonic air-breathing technologies. India has been working with Russia on the BrahMos II, a Mach 7 HCM similar to the Russian Zirkon, and testing a dual-capable HCM. Japan is developing a scramjet, the Hypervelocity Gliding Projectile, and a hypersonic anti-ship missile for its defenses in the East China Sea. Japan's strengthened security alliance with the United States additionally involves the development of hypersonic countermeasures. South Korea has also been researching the military applications of hypersonic technologies, as China is not the only source of hypersonic threats in the region. North Korea has recently tested what it calls a hypersonic weapon. It very likely fired a new ballistic missile from the Hwasong family with a range of 500 kilometers. In an effort to fool recently reinforced US and South Korean missile defense shields, North Korea extended this missile's range to 700 kilometers by having it release a maneuvering glider.

Where Is the Catch?

Extreme speed and maneuverability top the shopping list of requirements for hypersonic weapons. Hypersonic weapons are expected to be difficult for defenders to detect, track, and intercept, as they leave very little time for defenders to react to them and determine their intended targets. This feeds into their reputation of being frightening, unstoppable, and disruptive. Nevertheless, mastering hypersonic capability – the ability to fly fast and far within the atmosphere, while retaining navigability – is literally a matter of rocket science.

The technological requirements include not only those comparable to spacecraft re-entry but also additional needs dictated by military missions.[17] The ability to fly at great speeds and maneuver requires the overcoming of significant complications that result from physical limitations imposed by atmospheric flight. This involves aerothermodynamics, signature management, sensors, communication, control, and navigation.[18] The manufacturers of hypersonic weapons still need to engineer their way out of some persisting shortcomings to find the right balance among speed, flight altitude, maneuverability, and accuracy. These trade-offs imply performance limitations that await further evaluation, especially in terms of the development of possible defenses against a hypersonic threat.[19]

Manufacturing hypersonic flight. Several engineering challenges are apparent in this area. First, scramjets and gliders flying at hypersonic speeds operate under extreme conditions with high stagnation point temperatures. This necessitates the use of heat-resistant materials that prevent the weapons from melting away before they reach their target. The friction from the compression of air in front of the vehicle as it travels through the dense atmosphere heats its surface to levels exceeding 1,600 degrees Celsius. Hypersonic weapons need to be built from thick, dense materials that capture and emit the heat, use heat sinks to absorb and re-radiate the heat, or rely on heat shields made of ablative materials that gradually wear away. Also, blunt conical or wedge-shaped designs are better at keeping the vehicle cool, as they create a shock wave that insulates it while providing a greater surface area for the heat to spread across. However, this creates the challenge of how to prevent shock waves from disrupting the vehicle's trajectory. Importantly, hypersonic flights are a delicate affair, as the fast-flying vehicle is sensitive to surface imperfections. For instance, a single crack in the carbon panel on the outer skin of the Columbia space shuttle, by definition a hypersonic glider, caused the vehicle to disintegrate in 2003.

Second, hypersonic flight is a very fuel-demanding and thus costly affair. At such great speeds, air resistance is extremely high. Even if manufacturers can design the vehicle to prevent it from melting or falling apart, it still requires vast amounts of fuel to make it fly that fast to counter the pressure of the atmosphere.

Third, the maneuverability of hypersonic weapons, which increases accuracy and defense system evasion, is a less reliable feature than usually assumed. The extreme surface temperature that a hypersonic vehicle must deal with creates a line of ionized gas that can disrupt navigation signals. Even a small deviation from a given route can add up to a significant change in course over longer distances. Further, the potential for signal disruption suggests that hypersonic weapons need to travel more slowly during their terminal phases, when external guidance and communication with GPS satellites are likely to be most important. However, reduced speeds diminish the potential lethality of the missile that could be caused by its kinetic energy.

Fourth, high-temperature surfaces produce infrared signatures. The plasma that a hypersonic vehicle produces can make it visible to heat-seeking sensors based in space. Hypersonic weapons may thus be betrayed by the heat they produce for much of their atmospheric flight, which was thought to help them hide from ground-based radars behind the curvature of the earth. The side effects of flying low in the atmosphere can thus include negative consequences for a vehicle's performance and exposure to missile defenses.

Missile defense is hard, but hypersonic defense is harder. Hypersonic weapons can be stopped. However, the building of effective defenses against them would require major improvements to the space sensor architecture. It would also necessitate new interceptor capabilities to counter such weapons' near-space operating altitude (20–60 kilometers), unpredictable trajectory, and speed. Such defense systems will need to be layered and more integrated than ballistic missile defenses alone.[20] This will involve seamlessly connecting space-based sensors with upper layer intercept capabilities outside the atmosphere and lower layer intercept capabilities within the atmosphere.

Since the mid-2010s, the US Missile Defense Agency (MDA) has been researching hypersonic missile defense options, including interceptor missiles, hypervelocity projectiles, laser guns, and electronic attack systems. MDA and the Space Development Agency (SDA) are presently developing layers of sensor satellites to be used for hypersonic missile launch indication, warning, and tracking. MDA has also been looking into a glide phase interceptor and alternative mechanisms to destroy incoming hypersonic weapons. MDA believes that the time to engage hypersonic weapons is during their earlier glide phase of flight, as this is when they maneuver less, are more fragile, and are easier to destabilize.[21] Exploiting the weaknesses of hypersonic flight in the atmosphere, namely heat and drag, will be key for longer-range interceptors. Such interceptors could force hypersonic weapons to expend energy on extra maneuvers, slowing the threat down to diminish its performance. It is worth noting that engaging hypersonic weapons earlier in their flight will be necessary for area-wide defense rather than point defense. Further, hit-to-kill interceptors could be supplemented with area-wide mechanisms, including electromagnetic microwaves that damage a missile's internal electronics and cyber jamming countermeasures. Due to the high surface temperature of hypersonic vehicles, it is doubtful whether lasers could act as effective countermeasures.

Even though China is not building any missile defense systems against hypersonic weapons, its extensive research provides fertile ground for doing so.[22] For instance, a 2012 proposal by the China Aerospace Science and Industry Corporation Academy of Defense outlined a defense architecture composed of a sensor detection network, a high-speed information center to process data in real time, a command-and-control system, and a set of fast response, air-to-air space-based interceptors. Similarly, the Aerospace Engineering University in Beijing explored the use of existing surveillance assets, such as early warning aircraft and ground radars, for early detection of hypersonic missiles. China's Air Force Engineering University is also examining the feasibility of deploying high-altitude, long-endurance drones to intercept hostile hypersonic strikes.

Two problems with hypersonic defense remain. First, as to detection, most countries rely on ground- and sea-based radars for early warning. These are not equipped for the persistent tracking of hypersonic weapons after launch or when flying at lower altitudes. In other words, this means below the altitude of ballistic missile interceptors and above the altitude of the lower layer air defenses. Effective defense systems would need to connect layers of terrestrial radars with space-based sensors for a global detection and tracking capability to spot an incoming hypersonic threat. Second, as to interception, although existing defense systems could be adapted to intercept hypersonic weapons, they can cover only small areas and would be prohibitively expensive to use for continental defense.[23] In the European context, any effective defense against fast-flying and maneuvering missiles will need to be continent-wide and thus require international cooperation with allies. Ultimately, such a defense system would also need to employ AI, as it would require new software tools to process intelligence fast enough to detect and track missile launches.

The Patriot and the Terminal High Altitude Area Defense (THAAD) systems may already be able to detect hypersonic weapons during the glide or terminal phases, when such weapons operate within the atmosphere and at lower speeds. However, existing interceptors that would be able to tackle hypersonic weapons during their terminal phase of flight are designed to engage missiles in the vacuum of space, not in the dense atmosphere. Nevertheless, software and propulsion modifications for the Patriot and THAAD systems may offer a capability for shorter-range glide-phase intercept.[24]

More Hype, Less Sonic

The idea of flying at hypersonic speeds has been around for some time.

Although the theoretical foundations were laid down in the 1960s, the lack of suitable manufacturing processes hindered the development of hypersonic systems. In addition, air-breathing engines for space shuttles were judged too heavy and costly. Today, spurred by great-power rivalry, recent scientific advances have brought these systems within reach, as they have allowed prototypes to be constructed and tested. This has sparked hype and impatience among trendspotters about whether hypersonic technology will unleash a new industrial and/or military revolution.

The hype is not unique to hypersonic weapons. The phenomenon of emerging and disruptive technologies (EDTs) is plagued with a lack of understanding of the time it takes for a given technology to mature, innovation and adoption challenges, and its real-world effects in both the short and long runs. According to a 2020 NATO Science and Technology Organization report, the EDTs include data, AI, autonomy, space, hypersonics, quantum technologies, biotechnology, and materials. The report suggests that all of these are either currently in nascent stages of development or are undergoing rapid development.[25]

Technology is labeled as “emerging” when it is coming to maturity. At this stage, the use of such technologies is not widespread, nor are their effects and functions fully known. Although a technology maturity timeline is often difficult to determine, emerging technologies make policymakers reconsider the status quo and ponder their implications for future warfare.

Technologies considered “disruptive” are those that are expected to have major or even revolutionary effects, but have yet to be exploited. For example, they could undermine nuclear deterrence, increase risk of a nuclear first strike, expand opportunities for crisis escalation, and heighten insecurity caused by some form of duality in a technology. Dual-purpose technologies having both civilian and military uses or application in both the conventional and nuclear realms can be destabilizing.[26] In contrast, some experts point out that disruptive technologies can also have stabilizing effects. For instance, this could occur if a technology were to improve early warning and detection mechanisms or enable new arms control verification measures.[27]

Other researchers disagree in principle, arguing that a technology itself cannot be disruptive, stabilizing, or game-changing. This view emphasizes the importance of technology adoption processes. For example, here, the success of armed forces in using open architecture and modular systems to absorb fast-paced technological changes is vitally important. Ultimately, the military technology represents the means to the political ends; only the ways in which the latter are achieved can be disruptive.

Insights from the sociology of technology adoption can help in understanding the hype surrounding hypersonic weapon systems and temper unrealistic expectations. In the early 1990s, Howard Fosdick outlined the stages of technological development through scientific discovery, innovation, and increased public awareness, but also through failures and efforts along ultimately unproductive avenues. He noted that the greatest amount of discussion about many technologies takes place before they reach maturity, prior to their real use. In doing so, he suggested that usability of a technology and its publicity are inversely correlated.[28]

According to the Gartner Hype Cycle, the most well-known cycle of technological progress built upon Fosdick's work on technology adoption, a trending technology goes through five key phases, each of which describes a state of attention towards the technology: 1) the Innovation Trigger, marking a new technology or scientific discovery; 2) the Peak of Inflated Expectations, when the technology gains publicity; 3) the Trough of Disillusionment, when the limitations of the technology come to the fore; 4) the Slope of Enlightenment, which comes with a better understanding of the technology's utility; and 5) the Plateau of Productivity, the stage of a mature application of the "unhyped" technology.

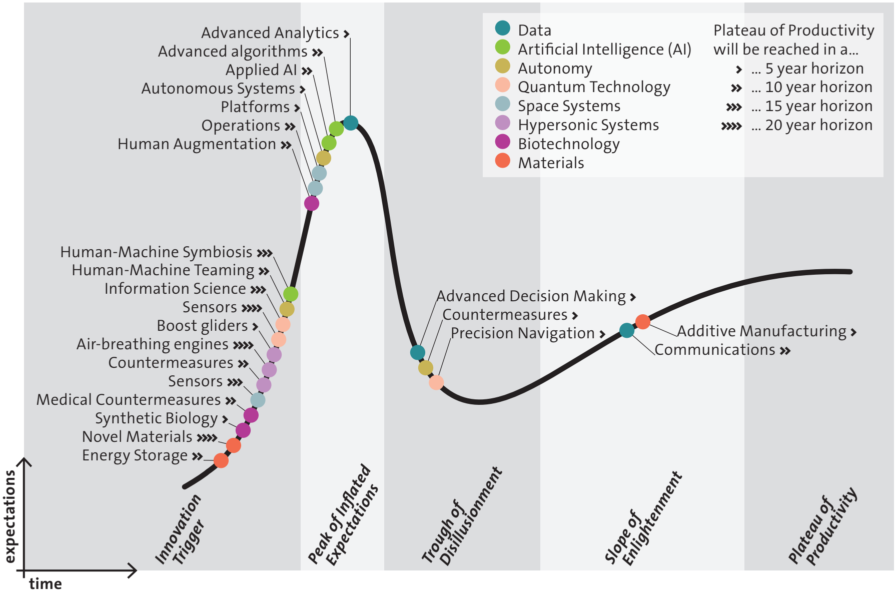
Based on these criteria, data, AI, autonomy, space, and hypersonics will produce significant or disruptive impacts on military capabilities over the next five to 10 years, while quantum technology, biotechnology and materials are still emerging and will need 10–20 years to produce their disruptive effects (see figure).[29]

This hype cycle shows that the attention does not represent a technical assessment. Instead, it often reflects the interests of political actors and profit-oriented industries. It also highlights the role that media play in promoting the impatient expectation of an impending industrial-military revolution. All technologies face the test of proving their usefulness and viability, but this is something that usually happens only after the hype fizzles out.

International security scholars and tech experts who look beyond the

Emerging and Disruptive Technologies Hype Cycle

Technology adoption process in a time perspective



Source: NATO Science and Technology Organization, 2020, Science and Technology Trends: 2020–2040

allure of wonder weapons question the technical feasibility and military effectiveness of hypersonic weapon systems.[30] They warn that these systems have yet to reach maturity in terms of materials, propulsion, and control. Indeed, even though unpropelled hypersonic gliders use existing ballistic missile technology for their boost, such gliders may only become fully operational by 2030 at the earliest.

Likely advancements before 2030 may include air-launched tactical boost-glide vehicles. However, longer-range gliders will only be developed by countries that already have ICBMs. Further, propelled hypersonic cruise missiles, such as the Boeing X-51 Waverider, BrahMos II, and Tsirkon, will take longer to achieve maturity because of the complex air-breathing technology they use for reaching hypersonic speeds. As the advanced technology required for a functional scramjet represents a major obstacle, reusable hypersonic aircraft and the dawn of a post-stealth world loom beyond the horizon of 2040.[31]

The impact of hypersonic technology will likely be enhanced in combination with other EDTs. For instance, the conjunction of space, hypersonic, and material technologies could reduce manufacturing costs, increase reliability, and facilitate the spread of new systems such as long-range hypersonic surveillance and reconnaissance drones. Moreover, effective countermeasures against these systems will likely require AI-enhanced performance support to improve situational awareness. Current defense systems will not be able to process data quickly enough to respond to incoming hypersonic weapons.

What if it is not the speed that counts? The hype has brought about a tendency to apply the label "hypersonic" to any system that is able to maneuver at high speeds. Few observers realize that all ballistic missiles with a range longer than a few hundred kilometers fly faster than Mach 5 and thus are, by definition, hypersonic missiles. For instance, ballistic missiles with a range of 500 kilometers can already reach Mach 6, those of 1,000 kilometers Mach 8.7, and so on.

Recent studies based on computational modeling point out that the longer and farther an HGV glides, the slower it approaches its target flying at a lower speed than a ballistic missile of the same range.[32] Any maneuver by a vehicle results in increased drag, which requires additional thrust to maintain a given speed. However, scramjet engines are unable to compensate for this, and gliders have no engine at all. This suggests that countries developing hypersonic weapons are interested in improving the ability of their missiles to maneuver rather than in how fast they fly.

Labeling gliders as a new hypersonic capability can be misleading in this respect. Current gliders are usually fitted to regular ballistic missiles. However, to improve their ability to maneuver to their target, some ballistic missiles have already been equipped with a MARV, which is a type of ballistic missile warhead capable of shifting trajectory in flight and autonomously tracking ground targets. The North Korean missile launch in January 2022 is a case in point. Although Pyongyang claimed that this was a hypersonic missile, in reality it was a test of a regular shorter-range missile that travelled along a ballistic trajectory and then dropped below the radar to glide down, conducting a 120-kilometer cross range maneuver in the process.[33]

This shows that talking about a hypersonic threat by referring solely to speed misses the point: Hypersonic weapon systems are slower than typical ballistic missiles of a similar range. However, they are dangerous because of their ability to maneuver at high speed. Importantly, different types of re-entry vehicles have different degrees of maneuverability.[34] This degree depends on where the glider detaches from its booster and where the maneuvers begin. Hypersonic gliders currently in development should be considered an improvement over the design of multiphase ballistic missiles in the form of a new type of unpropelled MARV.

What problem are hypersonic weapons trying to solve? The expert community is split about the strategic implications of hypersonic weapons.[35] On the one hand, such weapons can enhance deterrence by improving second-strike capabilities. On the other, they could erode deterrence, for example if they could enable a country to take out an opponent's second-strike capability.

The strategic advantage of hypersonic weapons is likely to be minimal. This is because the speed and range of hypersonic systems, even if they are nuclear-capable, are comparable to existing ICBMs and submarine-launched ballistic missiles.[36] This means that since the United States, Russia, and China already have this "hypersonic" capability, the development of new hypersonic weapons is a waste of money. It can be argued, however, that new hypersonic weapons could reinstate mutually assured destruction between two nuclear-armed countries. For instance, this could be the case if a country were to build advanced ballistic missile defenses that would diminish the nuclear threat of the other.

Even though the advantage of hypersonic weapons might be the weakest at intercontinental ranges, for Russia they represent a hedging strategy. They offer a new way of overcoming US missile defenses and signaling the reinforcement of Russia's strategic posture. However, considering that European capabilities to defend against a full-scale attack using nuclear ICBMs are non-existent, the introduction of hypersonic weapons into the Russian arsenal on top of existing nuclear-capable missiles does not qualitatively worsen the threat picture.

Similarly, China hopes to counter a US strike that could wipe out Chinese missiles by building additional second-strike capability. Importantly, conventionally armed hypersonic weapons could upset strategic stability by offering a way to keep conflict escalation below the nuclear threshold.[37] US nuclear deterrence against a Chinese non-nuclear hypersonic attack may not be credible; such a threat may influence US willingness to defend its Indo-Pacific allies.[38] However, it is not entirely clear whether hypersonic weapons can add any strategic value to China's existing roughly 100 ICBMs that can target the United States or to the second-strike capability provided by its six Type 094 Jin-class nuclear-powered ballistic missile submarines.[39]

A more plausible explanation, therefore, is that hypersonic weapons have acquired an illusion of strategic importance in the public discourse, and the development of these weapons has become politicized. Regardless of the actual strategic military effectiveness of hypersonic weapons, the hype alone could create instability between nuclear-armed countries. For instance, this could be done by raising fears of a disarming attack or – in a situation where deterrence was based on the unverified performance of weapons systems – by creating the illusion of an effective deterrent capability. Hypersonic weapons can contribute to conflict escalation through their established reputation for ambiguity concerning the warheads they carry and their targets. This is on top of their high speeds that reduce a defender's response time. Hypersonic weapons could also contribute to the risks posed by other advancing or emerging technologies, such as space and cyber capabilities.[40]

While not exactly a Sputnik moment, the Chinese test of a hypersonic FOBS-glider weapon prototype testifies to the broader military buildup in China, which is expanding into the space and cyber realms. It also confirms China's entry into geopolitical and military competition with the United States. Existing Russian and Chinese ICBMs would travel to the North American continent over the North Pole, high in space, and would thus be visible to radar based in this region. However, China has found a way to evade radars in the Northern Hemisphere by taking a route over the South Pole, where there is no "SOUAD," a southern equivalent to the North American Aerospace Defense Command (NORAD). In the context of China's rapid development of strategic nuclear weapons, its testing of hypersonic weapon systems is a source of concern and dispels any doubts about China being a strategic rival.

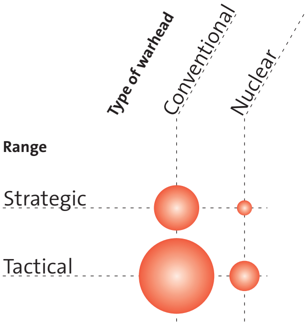
Hypersonic weapons will have their most significant impact on a sub-strategic level due to their ability to frustrate regional missile defenses and endanger locally deployed armed forces (see figure). Their military application at shorter, tactical ranges could include engaging high-value and time-sensitive targets, rapid re-targeting during flight, and creating impermeable advanced A2/AD capabilities. For instance, Chinese high kinetic strikes could place US battle groups and forward deployed forces at risk, and even make aircraft carriers more vulnerable. This could cause military operations to disintegrate from the outset.[41] If hypersonic weapons target sensors, communication channels, and radars, they could disable ships equipped with missile defenses and disrupt naval operations.[42] In this sense, China's FOBS-glider test was just a distraction. Tactical hypersonic systems with strategic implications are the next weapons to watch closely.

The Future: Same but Different

This chapter has looked beyond the headlines and argued that the hype about hypersonic weapons is more disruptive than the technology itself. Gliders will not be fully operational before 2030. Missiles using air-breathing technology will not reach maturity before 2040, though some may be deployed prematurely. However, the chapter has also argued that great powers instrumentalize the reputation of hypersonic weapons in their status-seeking efforts.

Hypersonic weapons are not as fast or as agile (yet) as advertised. It is improbable that such weapons will become more than just a niche capability due to their high level of sophistication and costly development. Indeed, this makes them unaffordable when compared to other weapon platforms with similar military effects. This is far from saying that hypersonic weapons are not troubling. A nuclear-capable glider is still a weapon system that is able to deliver nuclear warheads.

Hypersonic Effects



Hypersonic weapons are not unstoppable. The most likely short-term impact of hypersonic weapons will be on defense. Countries will accelerate their work towards upgrading and multilayering their air and missile defenses, ensuring above all a persistent wide area coverage with a solid space-based sensor architecture. Although the offense-defense dynamic will intensify, it remains to be seen whether the pace of technological change will dictate the nature of interactions between countries: in particular, whether such interactions will feature cooperative arms control dialogue or conflictual arms racing.

This chapter has identified a different kind of danger: labelling anything that is able to maneuver at high speeds as a new hypersonic weapon. This aspect of the hype around the term ignores the existence of a whole spectrum of weapons that feature differences in their operational altitudes, duration of hypersonic flight, timing, and degree of maneuverability. Hypervelocity is not new, and it is only one of the characteristics that will define the future of missile warfare.[43] Although at first glance it may seem puzzling, using the label hypersonic for every high-speed weapon program in development is misleading. For instance, this would obscure the fact that many countries are fitting standard ballistic missiles with maneuverable add-ons to make their theater-range missiles a war-winning capability that is more agile and able to fly farther.

Hypersonic weapons are dangerous, but they are not revolutionary. To portray them as such is irresponsible, as it feeds into wishful thinking about a capability that would make a decisive victory possible. This can encourage reckless behavior, alter the perception of one's own vulnerability, and lead to escalation among adversaries confident about their chances of success when they have such weapons in their arsenals. A high-tech silver bullet that could remove the fog of war and guarantee victory in one surprise blow has always been a fantasy among strategists in their brainstorming of new warfighting concepts.[44] It is no surprise that hypersonic weapons generated promises of fast and efficient victories before anyone had even demonstrated their potential for destruction or surprise.

Although it looks like China is getting "FOBSsessed" about evading US missile defenses, and Russia keeps polishing its Avangard glider, what we observe is not an arms race but a competition to master technologies that will define the future of warfare. Indeed, great powers are engaged in a multi-domain technological race that includes quantum technology, AI, autonomy, space, and other EDTs. To exercise caution regarding the fearmongering discourse surrounding EDTs, policymakers and defense planners should not ask what kind of wonders a new system can work but whether it is the optimal and desirable way to achieve political and military objectives. Several important questions regarding hypersonic technology still await convincing answers. Above all, what added value can the new-generation hypersonic technology deliver, and which policies, concepts, and doctrines should govern its use?

The existing scientific research suggests maintaining a healthy skepticism about the potential military applications of hypersonic technology. Hypersonics are most likely to find their primary application far from the military realm, such as in the form of reusable space transport vehicles that make access to space easier. Indeed, fully functioning air-breathing engines would be a notable breakthrough in propulsion technology and a major step forward in efforts to build efficient space infrastructure.

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