Airmen with 912th Aircraft Maintenance Squadron line up AGM-183A Air-Launched Rapid Response Weapon Instrumented Measurement Vehicle 2 as it is loaded under wing of B-52H Stratofortress at Edwards Air Force Base, California, August 6, 2020 (U.S. Air Force/Giancarlo Casem)

Analyzing the Potential Disruptive Effects of Hypersonic Missiles on Strategy and Joint Warfighting

By Bruce M. Sugden

Will the potential widespread deployment and employment of hypersonic missiles be a disruptive development for strategy and military operations? That is, will a competitor's use of hypersonic missiles undermine assumptions underlying the Department of Defense (DOD)'s emerging global and regional concepts for joint warfighting, as well as undermine widely held beliefs about strategic stability and how to deter threats to America's most vital interests?[1] Will U.S. hypersonic missiles undermine the assumptions behind Russia's and China's warfighting concepts and beliefs about deterrence, possibly allowing U.S. forces to enhance extant, or obtain new, warfighting advantages?

There are conflicting assertions about the implications of the United States, Russia, and China developing and deploying high-speed maneuvering weapons delivery systems—more commonly referred to as hypersonic missiles (for the remainder of this article, *hypersonic*

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missiles will be used as a generic term) to conduct warfare. The often hyped and much-anticipated technical promise of hypersonic missiles raises questions that go to the heart of long-held U.S. operational and strategic assumptions. Issues about deterrence, offense-defense balance, basing and posture, and command and control (C2) are not likely to be found or analyzed in a program office or laboratory or on a test range.[2]

To better understand military operations featuring hypersonic missiles, and well before the executive and legislative branches debate the affordability of procuring such missiles, DOD should initiate a campaign of experimentation, "a process of discovery about new military operational concepts and capabilities."[3] The underlying purpose of military experimentation is to acquire "knowledge to guide decisions about an uncertain future."[4] Relatedly, as Robert Angevine has noted, the newly acquired knowledge can

> *reduce risk when acquiring new military capabilities or developing new tactics, techniques, and procedures with existing capabilities. In the absence of an effective joint experimentation program, future combatant commands will most likely face the task of figuring out . . . how newly developed Service capabilities are stitched together at the operational level to achieve effective unified action.*[5]

To support such a campaign, a coherent body of research that seeks to understand how the three major military competitors envision deploying and employing hypersonic missiles is required.

This article argues that wargaming, informed by new research, should be at the vanguard of the campaign that explores the implications of the proliferation of hypersonic missiles. This is not to say that wargaming should be conducted at the expense of other tools of experimentation, but that wargaming is a cost-effective way to identify and develop the cognitive and analytic frameworks that could then be explored in more thorough and comprehensive analyses.[6] In the absence of disconfirming evidence from either wartime experience featuring the use of hypersonic missiles or a campaign of experimentation centered on understanding the possible effects of hypersonic missiles on strategy and military operations, DOD and Congress should accept the null hypothesis: the widespread deployment and use of hypersonic missiles by the United States, Russia, and China will not produce strategic and operational effects that diverge from those associated with extant ballistic and cruise missiles.[7] Correspondingly, the United States should not procure and deploy hypersonic missiles as a higher priority than other missile systems.

The article unfolds in eight steps. First, it describes the two types of hypersonic missiles that the Great Powers are developing and the capabilities that distinguish hypersonic missiles from other kinds of missiles. Second, it identifies the major competitors' developmental and current hypersonic missiles. Third, the article sketches the key assertions and issues in the debate about the implications of hypersonic missiles for military operations and defense strategies. Fourth, it explores U.S., Russian, and Chinese warfighting concepts and military doctrines that each will incorporate into its near-term hypersonic missiles. Fifth, the article discusses several broad ways in which hypersonic missiles might be employed in a future U.S.-Russia or a U.S.-China conflict. Sixth, the article unpacks several issues pertaining to defense against hypersonic missiles. Seventh, it makes the case that a campaign of wargames at the frontline of a military experimentation effort could make significant headway in determining whether hypersonic missiles will produce any disruptive effects for strategy and military operations. It also proposes a set of candidate research questions for a campaign of wargames to investigate the array of issues raised in the preceding sections of the article. Finally, the article discusses how the outputs of military experimentation, if they show that hypersonic missiles would indeed produce disruptive effects and could provide an opportunity for the U.S. military to enhance its operational advantages against Russian and Chinese forces, could help DOD develop competitive strategies centered on hypersonic missiles against Russia and China.

Background

A hypersonic missile has two key capabilities: flying at a speed of or above Mach 5.0 and flying at least half its range in aerodynamic flight (that is, as an airplane can rotate in the dimensions of yaw, pitch, and roll). Individually, these capabilities are not novel; it is their combination that makes hypersonic missiles a potentially disruptive innovation.

Discussions of hypersonic missiles usually place them in one of two categories: hypersonic glide vehicles (HGVs) or hypersonic cruise missiles. HGVs are launched into their flights using traditional missile boosters. When separated from their boosters, they begin to glide in the upper atmosphere without motor assistance.[8] Hypersonic cruise missiles are powered by an air-breathing engine.[9] To get these missiles to hypersonic speeds, designers have been working on scramjet engines—a beefed-up version of ramjet engines. In ramjet engines, the air flow through the engine is subsonic. In a scramjet engine, the air flows through the engine at supersonic speed.[10]

The Major Competitors and Developments

The United States, Russia, and China are developing technologies for HGVs and hypersonic cruise missiles. U.S. research and development efforts are looking at hypersonic missiles in both categories that could be launched from the ground, sea, or air and carry conventional payloads. As of late 2020, according to publicly available information, the United States had six lines of effort to develop operational prototypes of hypersonic missiles: one each in the Air Force, Army, and Navy and three in the Defense Advanced Research Projects Agency (DARPA).[11]

The Air Force hypersonic development effort is the AGM-183 Air-Launched Rapid Response Weapon (ARRW), which is an air-launched HGV designed to strike ground targets as far away as 1,600 kilometers within 10 to 12 minutes.

Delivery of first prototype hypersonic hardware to Soldiers of 5th Battalion, 3rd Field Artillery Regiment, 17th Field Artillery Brigade, is completed on October 7, 2021, with ceremony at Joint Base Lewis-McChord, Washington (U.S. Army/Karleshia Gater)

The B-52H is expected to be the primary launch platform for the ARRW.[12] The Army's effort is the Long-Range Hypersonic Weapon. The missile will use the same Common-Hypersonic Glide Body as the Air Force's and Navy's efforts and will first be boosted by a ground-launched two-stage rocket. The missile is intended to have a range greater than 2,775 kilometers and be employed against ground targets.[13] The Navy's Conventional Prompt Strike (CPS) uses the Common-Hypersonic Glide Body mated with a submarine-launched booster system. CPS might achieve initial operational capability on a *Virginia*-class submarine with a Virginia Payload Module in fiscal year 2028.[14] It is being designed for employment against ground targets.

Meanwhile, DARPA is working to develop and demonstrate critical technologies to enable future air- and ground-launched hypersonic weapon systems. Working with the Air Force, one system is the Tactical Boost Glide, which might also be compatible with the Navy's vertical launch system found on a variety of its ships. DARPA's Operational Fires program is another effort that might eventually transition to the Army. Lastly, the Hypersonic Air-Breathing Weapon Concept (HAWC) is a joint effort with the Air Force to develop an air-launched hypersonic cruise missile. Considering HAWC's smaller size relative to other developmental vehicles, it might be compatible with several launch platforms.[15]

Unlike the United States, China and Russia have not declared that they will abstain from deploying nuclear payloads with their systems.[16] In fact, Russia's first SS-19 intercontinental ballistic missile (ICBM) unit equipped with the Avangard HGV, armed with a nuclear warhead, entered combat duty in December 2019.[17] Russia is also developing the Tsirkon hypersonic cruise missile. It is a ship-launched system that may be capable of striking ground targets and naval ships.[18]

Reports suggest that China has several hypersonic missile programs.[19] One is the ground-launched DF-17 medium-range system (flight range of roughly 1,800–2,500 kilometers) designed to carry HGVs for use against ground targets. It might already be operational. A second system is the DF-ZF HGV, which was previously known as the WU-14. It may have a range of roughly 1,930 kilometers. China has also flight tested a third system, the Starry Sky–2 (or Xingkong-2), which might be capable of carrying a nuclear payload. In contrast to HGV designs, the Starry Sky–2 employs powered flight more like a hypersonic cruise missile design. Because it achieves aerodynamic lift from its own shockwaves, the Starry Sky–2 might be considered a hybrid

hypersonic missile design. Finally, China might also deploy intercontinental-range hypersonic missiles to threaten the U.S. homeland, as General Terrence O'Shaughnessy, then commander of U.S. Northern Command and North American Aerospace Defense Command, suggested in testimony before Congress early in 2020.[20] However, the open-source literature does not identify a specific intercontinental-range hypersonic vehicle program.

The Debate

Compared to maneuverable subsonic cruise missiles and nonmaneuvering ballistic missiles with reentry vehicles, the capabilities of hypersonic missiles will improve the ability to elude detection and tracking sensors, penetrate an opponent's air and missile defenses, and strike their targets.[21] As a result, hypersonic missiles could possibly strike targets with little warning and catch an opponent off guard. In fact, Vice Chairman of the Joint Chiefs of Staff (and former commander of U.S. Strategic Command) General John Hyten has stated that conventional hypersonic missiles could "provide responsive, long-range, strike options against distant, defended, and/or time-critical threats when other forces are unavailable, denied access, or not preferred. While conventional hypersonic weapons are not a replacement for nuclear weapons, their unique attributes will increase traditional warfighting advantages and bolster conventional and strategic deterrence."[22] But just how significant will the effects of the deployment and employment of hypersonic missiles actually be relative to extant warfighting advantages and concepts of deterrence?

On one side of the debate, a former National Security Council staff member asserts that "hypersonic weapons, at long last, appear poised to fulfill the promise of air power"—the prompt, accurate, and unstoppable delivery of weapons on an opponent's critical national assets to compel it to give up the fight without the use of ground troops, which have "proved costly, unpopular and generally ineffective."[23] Extending this theoretical vision into U.S. strategy, Michael Griffin, who was the Under Secretary of Defense for Research and Engineering from 2018 to 2020, asserts that an asymmetry in hypersonic missiles that favors America's competitors could, during wartime, result in the United States having to choose nuclear escalation to prevent its adversaries from achieving their war aims. He further suggests that nuclear adversaries may doubt the credibility of a U.S. nuclear threat in response to their use of conventionally armed hypersonic missiles.[24] It is a new twist on a Cold War–era question: Would the United States risk nuclear escalation, including against the homeland, in a response to conventional strikes in a distant theater?

On another side of the debate is the belief that deploying hypersonic missiles will not overturn the logics of deterrence and strategy that have characterized relationships among the United States and its nuclear-armed Great Power competitors for years.[25] Even without hypersonic missiles in its arsenal, the United States will retain an array of effective military responses to China's or Russia's use of hypersonic missiles. Though not explicit, this view might hinge on what Thomas Schelling referred to as "the threat that leaves something to chance"—that is, the inescapable risk of escalating to large-scale, counter-homeland nuclear strikes will make a nuclear adversary's military threat against U.S. allies unlikely in the first place.[26]

Finally, there is a third facet of the debate. Dean Wilkening suggests that hypersonic missiles "could have a profound effect on strategic stability" in two ways.[27] Strategic stability usually encompasses two categories. The first, *crisis stability*, is a situation in which two nuclear competitors cannot limit the damage they might incur in a war by conducting a preemptive counterforce attack, thereby militating against the temptation to strike first to avoid suffering the other's counterforce attack. The second is *arms race stability*—a situation in which the survivability and assured retaliatory capabilities of the competitors' nuclear forces are highly insensitive, or are robust, to qualitative or quantitative changes in each other's nuclear force structure.[28] The first potential effect on strategic stability, according to Wilkening, involves the defender's attack assessment challenge vis-à-vis high-speed maneuvering delivery vehicles. The difficulty of correctly assessing the inbound missiles' likely targets could undermine crisis stability by rendering nuclear escalation "difficult to control."[29] The defender's uncertainty about whether the payloads on the inbound missiles are nuclear or conventional would further reduce crisis stability.

The second potential effect is that a competitor's deployment of a substantial number of hypersonic missiles could increase the risk that a portion of the other's nuclear retaliatory force would suffer a surprise counterforce attack, thereby decreasing arms race stability. The elevated sense of vulnerability could compel a competitor to enhance the capabilities of its nuclear forces or to change their readiness posture, or both.[30]

Competitors' Approaches to Large-Scale Combat Operations

This section briefly examines U.S., Russian, and Chinese warfighting concepts and military doctrines that each will incorporate into its near-term hypersonic missiles. Its purpose is to establish the strategic and operational contexts for the subsequent discussion on the competitors' possible employment concepts for hypersonic missiles.

The United States. The National Defense Strategy calls for the joint force to deter aggression in key regions—the Indo-Pacific, Europe, and the Middle East—and to deter nuclear and nonnuclear strategic attacks and defend the homeland. Among many capabilities required to accomplish these missions, the joint force must be capable of striking a diverse array of targets inside adversary defensive layers to destroy mobile power-projection platforms.[31]

The U.S. military has a well-demonstrated playbook of achieving conventional advantage in large-scale combat operations: to degrade, disrupt, or destroy enemy command, control, and communications (C3) capabilities and to gain air superiority over the theater of operations.[32] Though

U.S. maritime superiority has been a regional battlespace fact at the outset of conflicts since the end of the Cold War, U.S. air superiority—the sine qua non of successful land operations—has had to be achieved in several conflicts beginning with Operation *Desert Storm* in 1991.

Current doctrine states that the joint force commander "must overcome the enemy's A2/AD [antiaccess/area-denial] capabilities to establish and maintain access to OAs [operational areas] where they are likely to operate."[33] The upcoming Joint Warfighting Concept, ostensibly founded on a new American way of war known as All Domain Operations, will possibly echo aspects of current doctrine in calling for an integrated joint force that can deny an adversary's ability to dominate on the land, sea, in the air, space, and cyber domains—and support its own ability to dominate in the same.[34] In light of the breadth and depth of improving Russian and Chinese A2/AD layers extending from the competitors' home territories, the joint force might have to substitute temporary moments of defense penetration and freedom of maneuver utilizing joint all-domain capabilities for widespread and prolonged rollback of A2/AD capabilities that occurred in conflicts over the past 20 to 30 years involving the United States and far less capable military powers.[35] Small numbers of U.S. hypersonic missiles could play a role in producing the temporary moments in which less survivable U.S. platforms and delivery vehicles could penetrate adversary defensive layers and conduct strikes, while larger numbers of hypersonic missiles could possibly help the joint force achieve an outcome closer to the long-lasting rollback of adversary A2/AD capabilities.

Russia. Should war break out, Russia would rely on imposing a level of damage upon its opponent calculated to control escalation and compel its acquiescence to Russia's demands.[36] Assuming that a conflict against the United States originates in a region bordering Russia, Russia would lean on its perceived advantage in the balance of resolve—the willingness to impose and suffer damage to win or safeguard a disputed stake.[37] Should wartime conditions warrant, the ideal Russian strategy would be to conduct conventional precision strikes, while preferably withholding nuclear strikes to deter U.S. nuclear escalation.[38]

Russian strategists understand that deterrence plays out in the perceptions of the adversary's society and its decision-makers and that each set of perceptions can influence the other and in turn constrain an adversary's strategy. To manipulate the adversary's perception of risk, impose costs, and threaten additional costs, the Russian military literature for years has confirmed that the Russian military wants to be able to employ to varying degrees nonstrategic nuclear weapons, strategic nuclear weapons, and long-range conventional precision-strike weapons (not necessarily in this order). The military envisions some or all military tools being employed in conjunction with the Russian government's diplomatic, political, and informational tools.[39]

Russian nuclear weapons are the most numerous and most destructive options. However, Russia has been expanding the size and quality of its conventional precision-strike weapon arsenal to provide more nonnuclear options to control escalation and achieve strategic objectives in regional conflicts. Russian writings discuss using conventional strike forces in the "threatened period of war" and in the early phases of conflict.[40] At the same time, many of Russia's theater-range missiles are dual-capable, meaning the same missile body can carry either a conventional or nuclear warhead. Russia's Tsirkon hypersonic missile program, if deployed, might be a dual-capable system.

The Russian military envisions employing conventional precision-strike weapons in attacks of varying scale and severity: from demonstration or single strikes to "strategic operations for the destruction of critically important targets" (SODCIT).[41] Dave Johnson suggests that what a critically important target is in the context of SODCIT is reflected in Russian government documents on civil defense. Those documents point to a critically important target being an asset that "the destruction or suspension of functionality of which would lead to loss of control of the economy of the Russian Federation, or of the territorial unity of the Russian Federation, her unrecoverable negative change (destruction) or a substantial lowering of the security of the vital functions of the population."[42]

Russian military writings also point to operational and strategic target categories for SODCIT. The operational targets include C2, aerial ports of debarkation, seaports of debarkation, major assembly and staging areas for military forces, and chokepoints along lines of communications. Strategic targets include national C2, strategic strike capabilities, munitions stockpiles, government control centers at national and regional levels, war-supporting industry, and aerial ports and seaports of embarkation.[43]

China. Many China watchers consider that the doctrinal writings of China's military forces (chiefly the People's Liberation Army Rocket Force [PLARF], formerly the Second Artillery Corps) call for using conventional missiles in missions to support combat operations by Chinese ground, air, naval, and information operations units around and near China's periphery. As of 2021, China has deployed missile forces suitable for conducting conventional precision-strike operations against targets in India, East Asia, and the western Pacific Ocean. As Chinese missile capabilities and associated employment concepts evolve, a missile campaign could be designed to conduct strikes against more distant critical targets, such as U.S. military bases in the eastern Pacific and along the west coast that would support a surge of forces to fend off Chinese aggression against U.S. allies and partners.[44]

According to Michael Chase, the 2004 edition of the *Science of Second Artillery Campaigns*, which even in the 2010s China watchers considered essential to understanding PLARF doctrine, recognizes the following potential target types for conventional missile strikes: strategic- and campaign-level C3 centers, radar installations, information-related hubs, missile and air force bases, naval facilities, logistics hubs, chokepoints in lines of communications, energy

infrastructure, and aircraft carrier strike groups. The *Science of Second Artillery Campaigns* describes the missile strike campaign's intent as "paralyzing the enemy's command system; weakening the enemy's military strength and its ability to continue operations; creating psychological shock in the enemy and shaking its operational resolve; and checking the powerful enemy's military intervention activities." Chase observes that Chinese military writings accentuate the importance of achieving surprise in conventional missile strike campaigns and, therefore, seem to see military utility in preempting the enemy.[45]

Possible Employment Concepts

It is quite possible that the three competitors would adopt different hypersonic technologies and procure different numbers of systems, deploy them differently, and incorporate—or perhaps even integrate—them differently into operational plans. The discussion so far suggests five broad ways in which hypersonic missiles might be employed in a future U.S.-Russia or a U.S.-China conflict and highlights possibly different operational and strategic implications of varying arsenal sizes and warfighting approaches for a campaign of wargaming to address.

First, preceding a missile raid, hypersonic missiles might be used to knock out specific missile defense radars or batteries to reduce defense capabilities to ensure that the follow-up missiles reach their targets. Over the past two decades, Russia, for example, has been building up layers of multidomain and dual-capable defenses against perceived military threats around its periphery.[46] In a hypothetical conflict in the Baltic states, Russia's deployment of hypersonic missiles like the Tsirkon could raise the possibility of Russia employing hypersonic antiship conventional or nuclear missiles against a ballistic missile defense

Damage control sailors aboard USS *Gridley*, flagship of North Atlantic Treaty Organization's Standing Maritime Group 1, respond to simulated cruise missile strike during Alliance's Naval Electro-Magnetic Operations 19 exercise, October 31, 2019 (NATO)

University of Maryland Department of Aerospace Engineering doctoral candidate Laura Paquin takes apart High-Speed Aerodynamics and Propulsion Laboratory's hypersonic wind tunnel at University of Maryland, College Park, November 16, 2020 (U.S. Air Force/Perry Aston)

ship, such as an *Arleigh Burke*–class destroyer, or against a U.S. Terminal High Altitude Area Defense missile defense battery defending an aerial port of debarkation for U.S. military reinforcements to the European theater. Likewise, China could employ the DF-17 system against missile defense assets arrayed to defend Kadena Air Base on Okinawa to open the door for less-capable missiles to conduct follow-on strikes against the base. This type of precursor strike might be the most likely use of hypersonic missiles when a competitor has a limited number of them in its arsenal compared to the numbers of more traditional ballistic and cruise missiles.

Second, because both Russia and China see U.S. and allied missile defenses protecting land- and sea-based assets as a formidable obstacle to their nonhypersonic offensive missiles, they might employ hypersonic missiles as part of small missile raids against heavily defended U.S. assets based along their peripheries. Larger numbers of hypersonic missiles available for use might supplant traditional ballistic and cruise missiles and enable competitors to strike key targets without using saturation tactics.

Third, corresponding with General Hyten's views of the roles of hypersonic missiles, U.S. forces could use them to strike time-sensitive, relocatable targets, such as mobile launchers for advanced air-missile defense systems or long-range offensive missiles that are believed to be armed with weapons of mass destruction. However, such U.S. strikes against targets in the homeland of either Russia or China, as Wilkening noted, could lead to nuclear escalation.

Fourth, also in line with Wilkening's concern about crisis stability, hypersonic missiles' ability to complicate and reduce an opponent's missile attack warning assessment and response timeline means that Russia or China could attempt to preemptively decapitate senior leadership. This is one possible use for Russia's Avangard HGV. Even if Russia armed Avangard with a conventional warhead, U.S. decisionmakers might interpret the inbound HGV as a nuclear threat and begin the process of launching a nuclear retaliatory strike.

At the same time, it is important to remember that while hypersonic missiles might reduce an opponent's missile attack warning time, they will not necessarily eliminate it. Sensors in geosynchronous orbit around the earth might still detect the initial boost phase of a HGV's booster rocket, thereby providing sufficient time for dispersal of senior leaders and relocatable critical assets, such as on-alert bombers.[47] The greater risk, and one that wargames could investigate further, is that an adversary would orchestrate a hypersonic missile attack in conjunction with a counterspace campaign directed against sensors in geosynchronous orbit to deny an opponent critical information to further reduce or eliminate its warning time of a missile attack.

Fifth, possibly in a more distant future, perhaps even with a larger footprint of operational U.S. missile defenses, Russia or China could use large numbers of hypersonic missiles in deep conventional strikes against U.S.-based rear-area logistics, transportation chokepoints, space-launch facilities, counterspace assets, C3 and intelligence-gathering assets, or war-supporting industry to reduce the U.S. ability to sustain overseas military operations and to impose psychological shock on the American public and leadership. For Russia, these types of strikes using hypersonic missiles would fit squarely within its SODCIT concept and could elicit a U.S. launch-on-warning nuclear response.

Interestingly, some of the hypothetical operational approaches point to the threat of large-scale, conventionally armed hypersonic missile strikes—on the order of several hundred hypersonic missiles—leading to nuclear escalation. In a regional conflict, such as in Europe or the East China Sea, the potential effectiveness of large-scale use of conventional hypersonic missiles in preventing a state from achieving its war aims could drive it to employ nuclear weapons as a last-ditch attempt to turn the tide of the war to its favor. Such a scenario seems consistent with Russia's thinking about nuclear escalation stemming from a regional conventional conflict. In addition, perhaps depending on the conditions and effectiveness of missile defense architectures, large-scale, counter-homeland conventional hypersonic missile strikes could generate a nuclear first-strike incentive between nuclear-armed Great Powers, thereby undermining crisis stability. It is conceivable, though, that the threat of a large-scale hypersonic missile attack between the United States and one of its major competitors will not be seen differently than the threat of large-scale attacks involving traditional ballistic and cruise missiles. As discussed below, wargaming could help identify and characterize the conditions surrounding different hypothetical deployment and employment schemes of hypersonic missiles that are more likely to generate nuclear first-strike incentives across the three major military competitors.

Playing Defense Against Hypersonic Missiles

Proponents and opponents of U.S. hypersonic missiles expect this new technology will exacerbate a defender's task of shooting down an attacker's missiles. It remains true that missiles in boost phase (including missiles carrying HGVs) are more vulnerable to detection and tracking than in other phases of flight. However, boost-phase intercept requires the defender's sensors and interceptor launchers to be located near the attacker's launch sites. Geography and the current state of A2/AD threats have so far precluded the United States from pursuing this intercept option in its terrestrial form. As a result, to defend forward-deployed U.S. forces and regional bases from missile attack, the U.S. military relies primarily on conducting kinetic energy, or hit-to-kill, intercepts in the midcourse (between booster burnout and the beginning of terminal phase) and terminal phases of missile flight.[48] Even U.S. homeland missile defense relies on midcourse kinetic intercept, and it is designed for limited ICBM attacks from North Korea and potentially Iran.[49]

Evasive maneuvers are one of the most effective defense penetration features that could be used on offensive missiles. If designed properly, an evasive maneuver could render the entire defense system ineffective even if all the other defense system elements perform optimally.[50]

High-speed maneuvering delivery systems (like maneuvering reentry vehicles and hypersonic missiles) could wreak havoc for a kinetic missile defense system.[51] First, in some cases, the defense interceptor might be launched before the target vehicle begins to maneuver. If the maneuver is significant enough, the target vehicle could maneuver completely outside the intercept envelope for the defense interceptor. Second, if the intercept were to be attempted while the target vehicle is maneuvering, the defense interceptor must have the kinematic capability to outmaneuver it.

Because of the technical challenges associated with active defense against hypersonic missiles, the proliferation of hypersonic missiles might persuade the United States to reconsider its declaratory policy regarding an adversary's preparations to conduct offensive strikes using hypersonic missiles, especially in the case of long-range hypersonic missiles capable of striking the U.S. homeland. For example, to deter an attack, the United States could declare that if such preparations were detected, then U.S. forces would conduct preemptive strikes to prevent the launch of the hypersonic missiles. One risk of this approach, in an ironic twist, is that the United States misjudges the intelligence on the adversary's activities and becomes the first competitor to use hypersonic missiles in an act of war against a nuclear adversary's homeland, thereby opening the door to retaliation against the U.S. homeland. The consequences of acting on flawed intelligence assessments against a nuclear adversary might preclude the United States from adopting a policy of preemptive attack.

Instead of revising its policy, the United States could pursue potential technological countermeasures to hypersonic missiles, but they are not without their drawbacks. One option for missile defense is directed-energy weapons (DEWs). To successfully engage inbound hypersonic missiles with DEWs, the defender needs to place as much energy on the target as it can for the longest period. For obvious reasons this means the DEW must be sited as far away from the defended asset as possible to maximize the engagement window. Because the surfaces of the target missile were designed to withstand extremely high temperatures, the DEW would likely need more time to engage the target than if it were an aircraft or a low-flying subsonic cruise missile. Furthermore, atmospheric conditions will likely reduce the lethality of DEWs in all but the shortest ranges, which further compresses the potential engagement windows.[52]

Electronic warfare (EW) defenses have the potential to be a long-term solution to the active defense problem. The defender needs to know the frequencies used in the target vehicle's terminal guidance system or arming, fusing, and firing system, for example. But as with DEWs, the EW solution will require enough time to degrade the vehicle's subsystems.

Army Space and Missile Defense Command/Army Forces Strategic Command conducted first flight of Advanced Hypersonic Weapon concept in November 2011 (U.S. Army)

Finally, nuclear-tipped interceptors might be the most effective option for defeating hypersonic missiles. Specifically, the blast wave or radiation output of a tailored nuclear weapon or a low-yield nuclear weapon might produce a lethal radius exceeding that of conventional weapons.[53] The larger lethal radius increases the chance of disabling an incoming maneuvering delivery vehicle without the interceptor scoring a direct hit.[54] This was the basic concept underlying U.S. deployment of nuclear-tipped air and missile defense interceptors from the 1950s through the 1970s. Interestingly, there have been no reports that DOD is considering tailored nuclear weapon designs over nonnuclear intercept technologies for dealing with hypersonic delivery systems, but perhaps it should.[55] The DOD inhibition might be due to the belief that negative political consequences would result from exploring nuclear-armed interceptors. Granted, adversaries could respond to the deployment of U.S. nuclear-tipped interceptors in several ways to mitigate their effectiveness, and the design of U.S. interceptors would have to compensate for such countermeasures.[56]

Even if the United States did not return to nuclear-tipped missile interceptors, Russia is on course to maintain nuclear weapons for select antiair and missile defense systems.[57] Such payloads might be used with Russia's developmental S-500 surface-to-air missile, an interceptor that might be capable against some types of hypersonic missiles.[58] Thus, the design of U.S. hypersonic missiles would need to consider enemy defenses utilizing nuclear weapon effects.

The upshot is that the proliferation of hypersonic missiles might compel the United States to revisit how and where it deploys missile defense interceptors and sensors across space and terrestrial domains. The hypersonic missile threat has already catalyzed the United States to begin investing in a space-based component of its expanding missile defense capabilities aimed at the boost, midcourse, and terminal phases of HGVs and other hypersonic missiles.[59] The Space Development Agency (SDA) has proposed the National Defense Space Architecture (NDSA), consisting of several different layers of satellite constellations to fulfill different mission sets. Two layers would be designed with hypersonic missile defense in mind: the tracking layer, which would "provide global indications, warning, tracking, and targeting of advanced missile threats, including hypersonic missile system"; and the transport layer, which would connect the tracking layer to terrestrial-based interceptor networks.[60] The Missile Defense Agency (MDA) and U.S. Space Force are working with the SDA to develop the Hypersonic and Ballistic Tracking Space Sensor that will populate the tracking layer. Alongside development of the NDSA, MDA and DARPA are exploring new interceptor options that could outmatch the kinematic capabilities of offensive hypersonic missiles in their terminal phases of flight to perform successful intercepts.[61]

U.S. plans for enhanced missile defenses against hypersonic missiles suggest two areas of inquiry for a wargaming campaign. First, as of 2021, U.S.-planned defenses against hypersonic missiles are focused on regional threats to forward-deployed U.S. forces and bases, but China and Russia have always suspected that the ultimate objective behind U.S. advances in missile defense technologies is to deploy a global missile defense architecture that would negate a Chinese or Russian nuclear second-strike against the United States.[62] Thus, according to Chinese and Russian criticisms, U.S. missile defense efforts are sources of instability that could generate nuclear first-strike incentives.

Second, the rise of enhanced space-based missile defense capabilities, possibly across the three major military competitors over the long term, could spawn a more intense offense-defense competition in space. The NDSA's tracking and transport layers might consist of approximately 90 satellites, a number that may not be large enough to deter a competitor from engaging in kinetic or nonkinetic counterspace operations to degrade or destroy the NDSA's ability to provide missile warning and interceptor engagement information.

The issues of nuclear first-strike incentives and counterspace operations directed against the NDSA highlight the need to conduct a campaign of wargames focused on hypersonic missiles that includes multidomain supporting or enabling operations as well as different assumptions about the effectiveness of missile defense systems that have yet to be tested against realistic targets and offensive missile tactics. Wargames could also investigate the use of U.S. hypersonic missiles against the Intelligence Community's estimates of future Chinese and Russian missile defense architectures and systems, including nuclear-armed interceptors. In addition, different missile defense architectures and different numbers of deployed hypersonic missiles could be used in wargames to analyze how the interactions between the two sets of forces might result in different incentives and operational concepts for the three major military competitors, possibly undermining the deterrence beliefs of one or more of the nuclear competitors.

Research Agenda with Wargaming as a Key Analytic Tool

The introduction of arsenals of hypersonic missiles in a future military environment creates an imprecise and complex problem set, which is ideal for wargames to tackle. Wargames can produce knowledge that is indicative: "at its best [wargames] can indicate the possibilities of a projected warfare situation and certain potential cause-and-effect linkages."[63]

Wargaming in general, and a campaign of wargames in particular, offers at least six analytic benefits to understanding a future joint operational environment featuring hypersonic missiles. These benefits make a campaign of wargames an ideal tool to put at the forefront of an experimentation effort that explores the implications of the proliferation of hypersonic missiles. First, populated with technologists, operators, and planners, a wargame would be ideal for generating useful insights into what the proliferation

of hypersonic missiles would mean for a regional conflict and the potential for escalation against homelands.

Relatedly, working with missile defense technologists, wargame designers could posit more effective missile defense systems in a regional or homeland setting to learn about how the competitors might employ their hypersonic missiles and conduct operations differently. For example, would more effective defenses compel competitors to use more hypersonic missiles as part of a strike package to saturate the defense? Or would they turn to more aggressive counterspace operations to degrade space-based missile defense sensors? Game designers and analysts could glean useful insights into how changes in missile defense architectures and technologies could change competitors' approaches to deploying and employing hypersonic missiles as well as how they might think about other military capabilities.

Second, having a live red team that interacts with the blue team could produce insights into the dynamic dimensions of the research issues at hand. That dynamic interaction could expose previously unseen flaws in team analysis and plans. Moreover, the existence of a human "adversary" raises the competitive nature of the wargame, making players work harder to produce products that "beat" their adversary and "win" the war. The advantages live red teams provide, therefore, place a premium on finding good red team players who not only understand the hypersonic missiles and related technologies a particular adversary may possess but also, perhaps more important, understand how they might be employed in the context of the overall campaign and to what end.

Third, the issues surrounding the employment of hypersonic missiles that wargames should address are complex and dense and need analysis and focus to properly address them. Constraints on time and participant interest and energy make it difficult—if not impossible—to adequately address the research questions in a single game. However, wargames are inexpensive compared to field exercises and could thus be repeated more inexpensively to explore different dimensions of the issues. Compounding the analytic difficulties, the issues related to employing hypersonic missiles exist in a setting of *strategic indeterminacy*, meaning that outcomes are determined to a great degree by the interaction of team members and teams' courses of action, much like actual combat operations.[64] A campaign of wargames would also help sort out the problem of strategic indeterminacy.

Fourth, by conducting a campaign of wargames, analysts could adapt future games to consider new issues raised in prior games or to reconsider issues that did not receive enough attention in prior games, resulting in broader and deeper analysis of how employing hypersonic missiles might generate novel operational and strategic issues.[65] Such game evolutions could act as parametric analysis to investigate how military operations might change with modifications to particular offensive and defensive variables, such as a hypothetical rise in effective point-defense technologies against hypersonic missiles.

Fifth, conducting a campaign of wargames also improves the quality of the participants. Good players—those comfortable with "beyond the horizon" scenarios and who think creatively—tend to perform even better after playing several games because they will have learned from previous games and become increasingly familiar with the scenarios, concepts, forces, and game objectives. One possible drawback that should be guarded against, however, is that some repeat participants will attempt to "game" the game.

Finally, wargames could illuminate previously unseen operational issues, complex combat interactions, or strategic dilemmas that result from the employment of hypersonic missiles. Some of these concerns could also result from the combination of hypersonic missiles with other emerging technologies, such as artificial intelligence (AI).[66] Perhaps AI-enabled hypersonic missiles would be used in tandem with other weapons delivery systems in swarming or "cooperative behavior in which uninhabited vehicles autonomously coordinate to achieve a task."[67] One example of such a task might be to strike a group of naval combatants or supply ships dispersed across a large area that has sailed several miles away from the hypersonic missiles' original aimpoint. Such new questions and issues may require other tools of experimentation—perhaps modeling and simulation, workshops, or field exercises and experiments—to yield better insights into how they might affect U.S. operations and strategy.

There are a few research questions around which to organize a wargaming campaign. Candidate questions include:

- How might the competitors deploy hypersonic systems, including the delivery systems, payloads, and launch platforms, as well as their basing modes?
- How might the competitors conduct operations using hypersonic vehicles to achieve war aims? What types of targets, operating concepts, and desired effects will they choose, and why? How might their operations change if the quantities of hypersonic vehicles in their arsenals change?
- What types of active and passive defensive measures might competitors employ to protect their high-value assets against hypersonic missile attack? What level of autonomy might they grant to AI-enabled active defenses against missile attack? How might these defensive measures affect an adversary's deployment and employment of hypersonic vehicles?
- How might the competitors integrate hypersonic vehicles with other kinetic and nonkinetic operations?
- How might deployment and employment of hypersonic vehicles affect competitors' nuclear policies and postures? Will they take measures to enhance their nuclear forces' survivability during different phases of a competition that vary from a world without hypersonic vehicles? What types of hypersonic missile deployments, and on what numerical scales, are more likely to undermine U.S., Chinese, and Russian beliefs about homeland

Paratrooper assigned to 54th Brigade Engineer Battalion, 173rd Airborne Brigade, participates in development of electronic warfare training at Grafenwoehr Training Area, Germany, July 28, 2020 (U.S. Army/Mathew Pous)

deterrence or to generate nuclear first-strike incentives? How would the numbers and types of Chinese and Russian hypersonic missiles affect U.S. beliefs about extended deterrence to allies and partners?

- In what ways, if any, might unique attributes of hypersonic missiles, or characteristics of missile operations featuring hypersonic missiles alongside ballistic and cruise missiles, prompt nuclear escalation in a regional conflict? How might possible changes in U.S. nuclear policy or posture affect nuclear escalatory pressures that China or Russia might perceive in a regional conflict?
- How might competitors integrate hypersonic vehicles with, or use the vehicles to exploit, emerging technologies or enablers for command, control, communications, computers, intelligence, surveillance, and reconnaissance, such as AI and machine learning? How might deployment and employment of hypersonic vehicles affect each competitor's C2 relationships? What strengths or weaknesses of extant C2 relationships will the proliferation of hypersonic vehicles expose? Which of their command echelons do the competitors believe should exercise C2 of hypersonic vehicles? In the case of U.S. operations, for example, how might U.S. Strategic Command's C2 of hypersonic missile operations affect the mission command of U.S. Army units that have their own hypersonic missiles forward deployed if they must reach back across the Atlantic or Pacific Ocean for release authority against a time-sensitive target? What might be the effects of pre-delegating these authorities?[68]
- How might competitors' threats of hypersonic vehicle use affect power projection and other concepts of operations? How might the threat of widespread use of hypersonic vehicles affect the U.S. approach to forward basing and theater force laydown?
- Which potential characteristics of hypersonic vehicles do operators and planners value most and why (for example, speed, precision guidance, range, defense penetration)?

Due to the constraints on time and participant interest, a single wargame should not and could not generate useful answers to all the research questions. The variety of the questions, as well as the complexity of issues they are bound to surface, not only illustrates the value of iterative wargaming but also suggests that at least several wargames that are part of a larger campaign series should be designed as force planning exercises, while others could be designed to focus on joint warfighting. In addition, wargame designers could

structure a game to shed light on how lessons learned from an operational setting could be applied retrospectively to the force-planning phase by including a "move zero." In other words, after wargame participants complete moves one through three, for example, of an operational level wargame, game control could rewind the wargame to a peacetime context where the participants could discuss, with the benefit of hindsight, how they should have designed their forces, posture, and concepts of operations to mitigate the weaknesses and enhance the strengths they observed in moves one through three. Of course, many of the questions and issues that would surface in such a wargame would be amenable to further investigation through other tools of experimentation.

Finally, a word of caution regarding a desire to "impose some order and sequencing" on a multigame campaign focused on fostering better understanding of the implications of hypersonic missiles. Rather than pursue a fool's errand of establishing order and sequencing with the research questions and wargame designs prior to initiating what would likely be a multiyear research project, the wargaming campaign would be more effective for potential DOD sponsor(s) if the sponsor(s) and wargame designers collaborated at each step in the campaign. Such collaboration would entail identifying a sponsor's high-interest research questions and determining the levels of game design and execution complexity required to analyze the questions. At that point, the sponsor would be better positioned to select the first set of questions for the initial tranche of wargames. Further collaboration would involve identifying key insights and observations that came out of a recently completed wargame and figuring out whether the wargame brought to the surface previously unforeseen issues and questions that warrant immediate analysis in the follow-up wargame. Slavish adherence to an early imposition of order and

Members of AGM-183A Air-Launched Rapid Response Weapon Instrumented Measurement Vehicle 2 test team make final preparations prior to captive-carry test flight of prototype hypersonic weapon at Edwards Air Force Base, California, August 8, 2020 (U.S. Air Force/Kyle Brasier)

sequencing would rule out inter-wargame flexibility and rob DOD of immediate learning opportunities on its most pressing areas of research and analysis. This is especially true for hypersonic missiles considering the near-term DOD procurement timeline for the weapon systems.

Conclusion: An Opportunity to Shape Competitors' Choices?

Wargaming, at the frontline of a campaign of military experimentation, could shed light on whether hypersonic missiles would disrupt assumptions underlying the major competitors' strategies and warfighting concepts. Unless DOD establishes a wargaming campaign (where hypersonic weapons are considered as part of a larger military campaign) to investigate the implications of the proliferation of hypersonic missiles, the defense analytic community will probably remain unsure during peacetime about how different the effects of hypersonic missiles would be on combatants' decision timelines, the survivability of their forces, and other aspects of their operations compared to the effects of traditional ballistic missiles and subsonic cruise missiles.

If wargaming were to indicate that hypersonic missiles could produce disruptive effects in warfare, then analyzing their role in military competitions using wargames and other tools of experimentation could help DOD develop a competitive strategy. A competitive strategy is designed to use real and latent military power to purposely shape a competitor's choices and relatively inefficient use of resources in ways that favor U.S. objectives in a protracted peacetime competition.[69] At the DOD level, a competitive strategy would accentuate areas of competitive advantage for the United States that are enduring or could be "made enduring through appropriate research and development, investment, training, etc."[70]

Furthermore, such a strategy would focus on the "interaction among and between defense establishments."[71] As a result of the interaction, the competition might evolve across several decades.

A competitive strategy would establish the bounds and parameters within which DOD decides on its investments in offensive hypersonic systems and associated defenses vis-à-vis particular competitors.[72] It would address how the U.S. military could build or sustain advantages over one or more competitors. Developing the strategy would entail the Intelligence Community focusing collection and analysis to help DOD better understand competitors' decisionmaking processes, procurement, and doctrine; to anticipate adversary responses and long-term investments; and to shape the competition to sustain or enhance the U.S. global strike advantage. JFQ

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