National Security Update

Hypersonic Missiles and U.S. Security

This eleventh *IFPA National Security Update* examines hypersonic weapons; their unique capabilities and characteristics; their military and strategic implications; U.S., Chinese, and Russian efforts to develop hypersonic weapons; technical challenges; and the urgent need to develop missile defenses to counter the threat posed to the United States by hypersonic weapons.

Previous *National Security Updates* have examined topics including U.S. missile defense priorities, nuclear modernization issues, U.S. options to counter the electromagnetic pulse (EMP) threat, the status of the U.S. Space Force, China's actions in the South China Sea and U.S. options, and the military applications of artificial intelligence. They may be accessed on the IFPA website at www.ifpa.org/.

Key Conclusions and Findings

- The United States, China, and Russia are developing hypersonic missiles (HMs) that will become increasingly important components of their arsenals in the coming decade.

- The speed (greater than Mach 5 or ~3836 mph), maneuverability, and accuracy of HMs, coupled with the impediments to detect and track them, will provide unique strategic and tactical advantages:
    - Increased targeting options including more accurate and much speedier interdiction of time-sensitive and mobile targets;
    - Greatly reduced adversary decision-making time;
    - Difficulty to defend against;
    - Can carry both conventional and nuclear payloads; and,
    - Could be utilized in a reconnaissance/surveillance configuration.

- Two main types of HMs are under development: hypersonic glide vehicles and hypersonic cruise missiles.
    - Russian and Chinese HMs are likely to house nuclear weapons;
    - U.S. HMs will carry conventional warheads, representing a greater technical challenge requiring sophisticated precision guidance and maneuvering capabilities to destroy targets.

- Technological hurdles that must be surmounted before operational U.S. HMs can be fielded include:
    - Managing the intense heat produced in hypersonic flight which could erode the vehicle's protective coating and destroy onboard electronics;

- Developing guidance systems that deliver needed accuracy and ability to withstand the aerodynamic forces pounding the vehicle during hypersonic flight;
    - Completing development of scramjet engines and other technologies needed to field an operational hypersonic cruise missile; and,
    - Constructing the requisite infrastructure such as wind-tunnel facilities to test HMs in Mach 5+ simulated conditions.

- Current U.S. missile defenses cannot provide effective protection against HMs principally because:
    - U.S. missile defenses designed to intercept RVs in space during their midcourse phase of flight would have far less utility in interdicting Chinese or Russian HGVs likely housing nuclear warheads because the bulk of their flight is within the atmosphere; and,
    - HMs can evade detection and tracking by U.S. ground-based radars early in their flight trajectory making their targeting problematic.

- The United States cannot be kept in the dark, not knowing where and when – and in some cases how many – HMs may impact the U.S. homeland and/or its forward-deployed forces and allies.

- It is crucial that U.S. decision makers fully understand the importance of the hypersonic threat and the role HMs plays in the strategic and military calculations of both China and Russia. This becomes an even greater imperative because, unlike the United States, Beijing and Moscow see HMs as an effective and promising means to deliver nuclear weapons.
    - For a variety of reasons, Russia and China may also decide to provide hypersonic systems or HM-technological know-how to U.S. adversaries such as Iran and North Korea, a consequence that would increase the HM – and likely nuclear – threat facing the United States even further.

- As a result, development of effective defenses against hypersonic missiles must become a U.S. national priority. This concerted effort requires augmented defense funding for defense capabilities including:
    - A space-sensor layer to detect and track HMs and guide U.S. interceptors to destroy them;
    - Improvements/modifications to existing U.S. interceptors;
    - Enhanced cyber- and electronic-warfare/jamming capabilities;
    - Capabilities for left-of-launch interdiction;
    - Improved battle management, command, control, and communications; and,
    - Boost-phase intercept (BPI) capabilities.

- By far, the most effective BPI approach would be a space-based intercept system based on the *Brilliant Pebbles* concept of the 1980s. A 21st-century *Brilliant Pebbles* network would provide a cost-effective defense solution to the Chinese and Russian hypersonic nuclear threat as well as to traditional ballistic missile threats including electromagnetic pulse (EMP) attacks. It would enable destruction of such threats during the boost-phase of flight prior to the release of nuclear payloads and possible decoys.

- The fact that current U.S. midcourse defenses, designed for interdiction in space, would not be capable against HMs whose flight is almost exclusively within the atmosphere and that U.S. terminal missile defenses can protect only a very limited area, further underscores the need for a space-based, BPI network such as *Brilliant Pebbles*.

- A current-day *Brilliant Pebbles* system would also bolster deterrence by denial, expand escalation control options, and help reverse the offense/defense cost-exchange ratio that now favors the offense.

Introduction

Hypersonics are a potentially game-changing military technology. The United States, China, and Russia are at the forefront of the development of hypersonic missiles. Both China and Russia, which the Trump Administration's 2017 National Security Strategy and 2018 National Defense Strategy[i] identify as the primary threats facing the United States, are testing hypersonic weapons of various types that will house nuclear warheads and have made substantial progress toward their goal of deploying operational systems in the very near future.

Offensive hypersonic missiles (HMs), when fully integrated into weapon arsenals and linked with command and control, communications and intelligence, surveillance and reconnaissance (ISR) networks, will give the nations possessing them distinct strategic and tactical advantages by providing more and faster targeting options on a global scale.

A wider array of targeting options will enable HM strikes against time-sensitive and moving targets previously not achievable because of the time it took a missile to arrive there. Hypersonic missiles can also generate dislocating effects on an adversary by collapsing the "decision space" thereby reducing his time to make necessary decisions.

Moreover, HMs will pose considerable difficulties for missile defenses because of their unique features including speed, ability to maneuver, and unpredictability. HMs will substantially reduce the time available to detect, assess, track, and engage the incoming missile.

Improved missile defenses will therefore be needed to address the HM threat. This would include upgrades to current defenses and the development of new systems such as a space-sensor layer to detect/track HMs and cue interceptors, as well as boost-phase intercept capabilities to destroy HMs before their hypersonic payloads are released. The fact that China and Russia are expected to field operational HMs shortly – Russia claims it has already done so – and that they are most likely to carry nuclear payloads, requires that defense against the hypersonic threat becomes a U.S. national priority.

Hypersonic Weapons Explained

Hypersonic missiles represent a new category of weapons. The term hypersonic refers to missiles, rockets, air, and spacecraft that can reach speeds within the atmosphere greater than Mach 5 (five times the speed of sound), i.e., > 3836 mph or 6174 km/h (actual Mach 5 speeds can vary depending on the altitude, local weather conditions, and temperature). HMs could be launched from a variety of air, sea, or land platforms.

Even though they can travel at higher speeds than HMs and thus can reach a target quicker, traditional ballistic missiles such as intercontinental ballistic missiles (ICBMs) – and their payloads – are not commonly classified as hypersonic weapons because they have little to no ability to maneuver. What sets HMs apart from traditional types of ballistic missiles and makes them strategically significant is that they offer a combination of speed, range, maneuverability, and precision accuracy. In comparison to current military systems, HMs would enable military operations from longer ranges with shorter response times and greater effectiveness.

Importantly, maneuverability also delivers a significant capability to elude missile defense systems. As will be discussed in greater detail in a subsequent section of this *Update*, given the fact that our two primary adversaries, China and Russia, are at the forefront of HM development, the United States needs to focus far greater attention on the development and fielding of defenses to counter HMs.

There are two primary types of hypersonic missiles: hypersonic glide vehicles (HGVs) – also called boost glide vehicles or BGVs – and hypersonic cruise missiles (HCMs). Both types of HMs could carry either conventional or nuclear warheads.

Similar to a traditional re-entry vehicle (RV) boosted by a ballistic missile, an HGV sits atop a ballistic missile and achieves hypersonic speeds following launch; after separation from the missile it returns to earth in unpowered flight and maneuvers to its target. However, an HGV does not follow a predictable, parabolic arc like a regular ballistic-missile RV which spends most of its flight trajectory in space.

In stark contrast, soon after separation from the still-rising ballistic missile at altitudes ranging from 25 miles to over 62 miles the HGV reenters the atmosphere and can maneuver to glide along the upper atmosphere or change direction and race through the atmosphere for hundreds or possibly thousands of miles before homing in on its target. HGVs combine the best features of ballistic missiles and cruise missiles: the Mach 5+ speeds and range of the former together with the maneuverability and accuracy of the latter.

To illustrate, the mainstay of the U.S. land-based nuclear deterrent, the *Minuteman* III ICBM, has an accuracy – i.e., circular error probable (CEP) in Department of Defense (DOD) parlance – of approximately 120 meters which signifies that half the RVs launched are projected to strike within 120 meters of their intended targets; its range is 8,078 miles[ii] and travels at speeds approaching 15,000mph.[iii] On the other hand, the *Tomahawk*, the most advanced cruise missile in the U.S. inventory, has a CEP of 10 meters giving it far greater accuracy than the *Minuteman* III, but flies at subsonic speeds (defined as between 350 and 750mph) with a range of only 1,036 miles.[iv]

In sum, HGVs offer unique features to military planners: speeds unmatched by other kinetic weapons apart from ballistic missiles; potentially longer ranges than ballistic missiles; greater payload capability over a given range; midcourse maneuvering; low-altitude flight; and great accuracy.

Hypersonic cruise missiles would fly many times faster but be equally as accurate as today's air-, sea-, or land-launched cruise missiles. Unlike hypersonic glide vehicles, however, HCMs are powered throughout their full flight, staying aloft by aerodynamic lift like an airplane. For example, HCMs achieve hypersonic speeds by a rocket but then change over to an internal scramjet (supersonic combustion ramjet engine) flying thereafter on their own power. When HCMs become operational, their speed and maneuverability will make them extremely difficult to interdict even though they fly within the altitude range of current air defenses.[v]

In addition, HMs could be reconfigured to be outfitted with sensors and communication equipment to act as an intelligence, surveillance, and reconnaissance (ISR) platform. Travelling at Mach 5+ speeds, a hypersonic ISR platform could in some cases reach and overfly an area of interest, with a high level of survivability, faster than repositioning an ISR satellite.

Hypersonic System and Technology Challenges

Several technological obstacles must be addressed before a viable HGV capability can be realized. This includes ensuring that the structural integrity of the hypersonic vehicle remains intact and the onboard instrumentation and payload continue to function properly.

Specifically, this includes the need to: manage the extreme heat generated during hypersonic flight within the atmosphere which could peel off an HGV's protective coatings and destroy onboard electronics; develop guidance systems that can deliver sufficient accuracy during maneuvering hypersonic flight; and, withstand the enormous aerodynamic forces buffeting the vehicle during flight. Additional wind-tunnel facilities to test HMs in simulated flight must also be built.[vi]

The development of scramjet engines for HCMs present particular challenges. A scramjet must function at speeds that would rip standard jet engines apart. The U.S. Air Force has developed a scramjet engine that was flight tested four times between 2010 and 2013 on the X-51 *Waverider* demonstrator program. These tests validated the feasibility of a scramjet-powered vehicle for weapon applications but more development needs to be undertaken.

According to Dr. Thomas Bussing, Vice President of Advanced Missile Systems at Raytheon, a leader in the development of hypersonic systems, over the past decade significant progress has been made to surmount some of these technical challenges including advances in computational fluid dynamics, new materials and electronics, and guidance systems better able to endure the harsh environment of hypersonic flight.[vii] To underscore this fact, and as will be described in greater detail below, the United States, China, and Russia are expected to deploy operational HMs soon. In fact, Russia claims it has already fielded a hypersonic missile system.

A Brief History of U.S. Hypersonic Efforts

The ambition to achieve hypersonic flight is not new. Research into systems resembling the HGVs under development today dates back to the late 1920s when the first rocket-boosted glider flew in Germany in 1928.[viii] After the allied D-Day landing in 1944, German missile engineers added wings to the V-2 rocket in an effort to extend the missile's range by enabling it to glide. This attempt was largely unsuccessful, however.

Following the war, both the United States and Soviet Union seized German rocket technologies and enlisted German scientists (the most notable, Wernher von Braun, surrendered to the United States) leading to significant advances in HGV systems. For example, in the 1950s the United States used Germany's failed HGV effort during World War II as the foundation for the development of the Alpha Draco HGV. It was flight-tested three times and reached hypersonic speeds, proving the feasibility of the hypersonic glide-vehicle concept. The tests also yielded essential data on the aerodynamics of hypersonic flight.[ix]

In the mid-1980s, the U.S. National Aerospace Plane (NASP) program was initiated. It was a DOD and NASA project to develop a manned, single-stage-to-orbit, horizontal takeoff/horizontal landing vehicle powered by an air-breathing scramjet engine designed to reach speeds of Mach 25.

Although it was never fielded (the obstacles to manned hypersonic flight were too difficult to solve at the time and DOD funding ended in 1995), the NASP program advanced many hypersonic technologies, including computational fluid dynamics, scramjet air-breathing propulsion, and high-temperature structures and materials that have contributed to current U.S. hypersonic efforts.[x] The U.S. space shuttle (in operation by NASA between 1981–2011) was also a type of hypersonic glider which provided important data on hypersonic flight.

The current U.S. effort to develop hypersonic systems, however, generally dates to the early 2000s and the George W. Bush Administration. At that time the United States began a steady pursuit to develop hypersonic missiles as part of DOD's conventional Prompt Global Strike (PGS) program (more in the next section).

Not surprisingly, the development of hypersonic technologies/systems is primarily occurring within the militaries of the United States, China, and Russia, although some civilian governmental and commercial space technology development is also relevant to hypersonics.

Current U.S., Chinese, and Russian Hypersonic Programs[xi]

As noted above, the primary catalyst for the development of a U.S. hypersonic missile capability has been the Prompt Global Strike mission. The objective of the PGS is to develop the ability to strike any target on Earth within an hour.[xii] An HM capability is viewed by U.S. defense officials as the means to project power and counter the multi-layered anti-access/area-denial (A2/AD) networks deployed by China, Russia, and increasingly by Iran. HMs would enhance U.S. power projection enabling the capability to attack high-value targets at the beginning of a conflict and throughout its duration.

According to Mike White, DOD's Assistant Director for Hypersonics, the Pentagon envisions a three-step plan for hypersonics: first, invest heavily in offensive capabilities; develop defenses against HWs next; and lastly, at least ten years in the future, develop/field reusable airborne hypersonic vehicles.[xiii]

Pentagon leaders have refrained from a joint-service HM effort as occurred with the F-35 fighter because they want several programs to solve technological challenges common to a range of service requirements without negatively impacting individual programs. For example, addressing the requirements for a submarine-launched HM could compromise and delay the development of an HM able to be launched from an aircraft.[xiv]

The United States has stated that it is focusing on HMs armed only with conventional warheads that could be utilized during conflict in regional theaters and as part of the PGS mission. Their development, therefore, is far more difficult because it entails greater effort and technical sophistication to achieve the requisite precision and accuracy to interdict targets with conventionally-armed HMs than with nuclear-armed HMs. The U.S. payload approach differs significantly with that of both China and Russia which view HMs as an effective and promising means to deliver nuclear weapons.

Although there is much debate about the validity of Chinese and Russian assertions of progress in their hypersonic programs, several U.S. defense officials say that it would be a critical blunder to ignore the evidence of their advances, particularly with regard to China. For example, former Vice Chairman of the Joint Chiefs of Staff General Paul J. Selva stated that "China has made it a national program, so China's willing to spend tens to up to hundreds of billions to solve the problem of hypersonic flight, hypersonic target designation, and then ultimately engagement."[xv]

A key motivation of the Chinese hypersonic weapon program is to enhance the capability of China to hold at risk high-value U.S. targets. Michael D. Griffin, the Pentagon's Undersecretary of Defense for Research and Engineering (USD/R&E), is also troubled by Chinese advances in hypersonic research. Leaving the Chinese unchallenged in hypersonics, he states, could allow them to "hold at risk our carrier battle groups … our forward-deployed forces and land-based forces."[xvi]

Russia is pursuing the development of hypersonic weapons primarily to overcome U.S. current missile defense systems and expected future advances which it fears could negate the utility of its strategic nuclear deterrent forces. Moscow's HMs, particularly those with intercontinental ranges, are therefore designed to penetrate and overwhelm U.S. defenses. Shorter-range HMs are also being developed by Russia which would impact U.S./NATO operations in Europe.

Russian President Vladimir Putin has boasted that his nation has developed and tested HMs capable of speeds in excess of Mach 10 which can evade existing or potential air and missile defenses and carry either conventional or nuclear warheads.

U.S. Hypersonic Programs

The U.S. Army is developing the Alternate Re-entry System (ARS) which was previously called the Advanced Hypersonic Weapon. The ARS is a precision-guided HGV with a range of 3,730 to 4,970 miles. Successful ARS tests took place in November 2011, August 2014, and October 2017. Initially, the ARS was the backup for the FALCON Hypersonic Technology Vehicle-2 (HTV-2) program, a joint Air Force-Defense Advanced Research Projects Agency (DARPA) efforts. However, after the HTV-2 suffered two failed tests it was cancelled and the ARS is now the common HGV for the U.S. Army, Navy, and Air Force. Deployment of the ARS is expected in the early 2020s.

The U.S. Air Force (USAF) Air-Launched Rapid-Response Weapon (ARRW) – sometimes called *Arrow* – is an advanced design, air-launched HGV. The ARRW reportedly could achieve speeds of Mach 20 during its glide phase or some four times faster than comparable Russian and Chinese HMs under development. In June 2019, a flight test of the ARRW was performed with a missile carried by a B-52 bomber.

In contrast to the technological-envelope-pushing ARRW, the USAF Hypersonic Conventional Strike Weapon (HCSW) is an air-launched cruise missile incorporating hypersonic technologies already established in its design. The USAF is utilizing rapid-prototyping authorities to speed development of the ARRW.

The U.S. Navy is developing the intermediate-range Conventional Prompt Strike (CPS) system. It is an HGV similar to the Army's Alternate Re-entry System but providing a sea-based launch option. The Navy has not made a final decision on the CPS' launch platform, i.e., either a submarine or a surface vessel. In 2017, the initial CPS test flight was launched from an Ohio-class submarine; another test is slated for 2020.

In 2014, the USAF and DARPA initiated a joint program called the Hypersonic Air-Breathing Weapon Concept (HAWC). It focuses on a number of technologies that would enable air-launched, jet-propelled hypersonic cruise missiles but particularly the development of scramjet engines. Instead of carrying separate oxygen tanks, a scramjet engine would use oxygen from the atmosphere and funnel it inside the engine enabling the HGV to attain hypersonic speeds using its own power. It would also allow the HGV to be lighter and faster than current HM options.

The Tactical Boost Glide (TBG) program is another joint USAF-DARPA hypersonic effort. The objective of TBG is to advance the technologies necessary for future air-launched glide systems. Many of the program's primary goals emerged from the aforementioned FALCON HTV-2 program. These include the ability of the TBG vehicle to achieve Mach 5, launch within two hours, strike targets in under one hour, and following separation from its booster missile, sustain a maneuverable flight trajectory. Unlike the U.S. hypersonic programs noted above which are designed for global strike missions, the air-launched TBG vehicle is slated for tactical offensive use in theater operations. (See Chart 1 for a list of U.S. hypersonic programs.)

Chart 1
U.S. Hypersonic Weapon Programs/Efforts

U.S. Army
- Land-Based Hypersonic Missile*

U.S. Navy
- Intermediate Range Conventional Prompt Strike Weapon (IR CPS)

U.S. Air Force
- Hypersonic Conventional Strike Weapon (HCSW)
- AGM-183A Air-launched Rapid Response Weapon (ARRW)

Defense Advanced Research Projects Agency (DARPA)
- Hypersonic Air-Breathing Weapon Concept (HAWC)
- Tactical Boost Glide (TBG)
- Advanced Full-Range Engine (AFRE)
- Operational Fires (OpFires)

*Also called the Long-Range Hypersonic Weapon

China's Hypersonic Activities

China has several HMs under development. They include the *Xing Kong*-2 (*Starry Sky* 2), a multi-stage, maneuverable, and nuclear-capable hypersonic missile with speeds estimated between Mach 5.5 and Mach 6.

The DF-ZF (the WU-14 in DOD nomenclature), is a medium-range HGV capable of maneuvering at speeds between Mach 5 and Mach 10. The DF-ZF has been tested as many as nine times since 2014 and in 2017 was flown atop the DH-17 ballistic missile. Consequently, it may be nearer to deployment than HGVs being developed in the United States.

The *Dongfeng* (DF)-26 is an intermediate-range (1,860 to 3,420 miles) HGV. It is sometimes called the "Guam Killer" because it has the range to target the joint U.S. military base in Guam which also houses THAAD missile defenses.

China has also developed the CM-401 anti-ship cruise missile (ASCM), described by its Chinese manufacturer as the first hypersonic ASCM in production. If true, the CM-401 would put U.S. forward deployed sea, air, and land forces at risk.

Russian Hypersonic Programs

The *Avangard* is an intercontinental-range HGV designed to ensure the capability of Russia's strategic nuclear deterrent to penetrate U.S. missile defense systems. It is expected to be deployed on SS-19 *Stiletto* ICBMS. The *Avangard* is currently in production with initial operational capability planned for 2020. However, a U.S. official states that only 60 *Avangards* will be produced because of their difficulty and cost to manufacture.[xvii]

In his March 2018 State of the Nation address, President Putin listed the *Kinzhal* medium-range HM (KH-47M2) as one of Russia's five nuclear superweapons. The Russian military characterizes the *Kinzhal* as stealthy and highly maneuverable. The *Kinzhal* reportedly possesses a range of 1,240 miles and could be carried on Russian bomber aircraft.

The following year, during President Putin's February 2019 State of the Nation address, he confirmed the development of the *Tsirkon* short-range HCM. The *Tsirkon* is powered by a scramjet engine and according to President Putin, can reach speeds of Mach 9 with a range of 620 miles, can be fired from ships or submarines, and is capable of striking land or sea targets. It likely will be capable of housing nuclear or conventional payloads.

Hypersonic Research and Development by Other Nations

Apart from the activities of the three nations surveyed above, other nations including Australia, France, India and Japan have conducted some HGV research. (See Chart 2 for a full list of additional nations conducting hypersonic research.)

Chart 2
Other Nation Hypersonic Weapons Programs and Research

China
- *Dongfeng* (DF)-ZF ballistic missile to launch hypersonic glide vehicle*
- DF-26 HGV
- *Xing Kong*-2 nuclear-capable hypersonic vehicle**

Russia
- *Avangard* hypersonic glide vehicle launched from an ICBM
- *Kinzhal* air-launched hypersonic missile
- *Tsirkon* ship-launched hypersonic cruise missile***
- *BrahMos*-II hypersonic cruise missile (co-development with India)

Additional Nations
- Australia, France, Germany, Japan, and India (with Russia) are also developing hypersonic weapon technologies.
- Iran, Israel, and South Korea have conducted basic research on hypersonic aerodynamics and propulsion systems but do not appear currently to be pursuing a hypersonic weapon capability.

* Designated the WU-14 by the Pentagon
** Also called *Starry Sky*-2
*** Often called *Zircon*

Defense Against the Hypersonic Threat

The likely near-term introduction of maneuvering hypersonic missiles into the arsenals of China and Russia poses a significant challenge for current U.S. missile defenses, both for protecting the homeland and defending U.S. and allied deployed forces. The flight profile of HGVs will make their interception extremely difficult for the current U.S. missile defense architecture.

For example, as noted earlier, an HGV spends little time in space, rather the bulk of its journey is flown on a depressed and unpredictable trajectory within the atmosphere meaning its intended target and the path it will follow getting to it would remain largely unknown. This contrasts with the predictable, parabolic trajectories in space that traditional ballistic missiles and their RVs follow which can be calculated soon after launch and hence tracked and targeted.

An HGV boosted by a ballistic missile would be detected at launch by space-based early-warning satellites but U.S. ground-based radar would subsequently have difficulty detecting/tracking the HGV. Present U.S. missile defense sensors, primarily ground-based radars, are not designed to track systems with an HGV's unique characteristics. An HGV's unpredictability enabled by its Mach 5+ speeds, maneuverability, and atmosphere trajectory mean that because of the Earth's curvature, U.S. line-of-sight radars may not be able to detect and track it until much later in flight. In other words, current U.S. sensor systems would lose track of an HGV soon after its launch.

For example, a 2017 RAND report quantified the problem this situation presents U.S. missile defenses in terms of timely detection. Given a traditional RV and an HGV of comparable ranges, the RAND analysis determined that a ground-based radar would detect the RV about 12 minutes before impact but only six minutes before impact of the HGV.[xviii] This would significantly abbreviate the already short engagement timeline available to U.S. missile defenders.

Consequently, U.S. missile defenses designed to intercept RVs in space during their midcourse phase of flight would have far less utility in interdicting Chinese or Russian HGVs likely containing a nuclear payload. Their unpredictable flight path and late detection by radars would appreciably curtail the reaction/response times of U.S. missile defenders and senior decision makers in the event of a crisis involving an HGV.

That said, effective defense against the hypersonic threat, while difficult, is not insurmountable. Hypersonic missiles have limitations making them vulnerable to interdiction. For example, HGVs are traveling slower when they reenter the atmosphere than are traditional ballistic-missile RVs. It is also not yet clear whether an HGV will be able to execute the rapid terminal maneuvers necessary to elude interceptors homing in on it.

This may make interdiction of HGVs achievable by existing U.S. defenses such as THAAD, the most advanced *Patriot* system, and perhaps, with modifications, the U.S. Navy's *Standard Missile*-3. In addition, because an HGV stays within the atmosphere for most of its flight, the daunting challenge of discrimination, i.e., identifying and targeting the actual warhead as opposed to the accompanying decoys and associated ballistic-missile debris in space, is eliminated. In essence, the defense against hypersonic systems is an advanced form of air defense.[xix]

However, THAAD and *Patriot* interceptors can only defend small portions of the United States in a terminal defense configuration. For example, protecting all of the United States would entail deployments of numerous THAAD/*Patriot* batteries across the country at an exorbitant and likely unaffordable cost.

The mission of the Ground-Based Midcourse System (GMD) deployed in Alaska and California is to defend all of the United States against ICBMs. But because GMD interceptors are designed to destroy threat RVs in space during the midcourse phase, they would have little to no capability to counter HGVs that soon after launch fly only within the atmosphere.[xx]

As a result, developing an effective missile defense to defend the United States, its allies, and forward-deployed forces, against hypersonic missiles must become a U.S. national priority. It is strategically untenable for the United States to be in a situation in which it does not know precisely the location and trajectories of attacking HMs likely to be armed with nuclear payloads, the number of HMs speeding toward the U.S. homeland and/or its forward-deployed forces and allies, and when and where they will impact.

It is vital that U.S. decision makers grasp the significance of the hypersonic threat and the role HMs plays in the strategic plans of China and Russia. It takes on even greater significance given that the cargo carried on Chinese and Russian HMs is likely to be nuclear weapons. As has happened previously with other Russian and Chinese weapon systems, both Moscow and Beijing may also be motivated by military, strategic, and economic reasons to provide/sell hypersonic systems or technologies/know-how to U.S. adversaries including Iran and North Korea. This would augment even further the threat posed to the United States by HMs as well as, given that North Korea already possess them and Iran may soon, HMs toting nuclear weapons.

Addressing this situation will require solutions comprising a combination of current and newly-developed missile defense systems and innovative technologies in several areas. This includes a low-earth orbit (LEO) space-sensor layer (SSL), improvements/modifications to the current interceptors noted above, development of new interceptors, enhanced cyber- and electronic-warfare/jamming capabilities, assets/capabilities for left-of-launch interdiction, and improved battle management, command, control and communications.

A new SSL is a critical component to counter the hypersonic missile threat. As noted, U.S. ground-based radars would have trouble tracking HGVs given their line-of-sight limitations caused by the horizon and curvature of the Earth.

The SSL is envisioned as a constellation of many low-cost satellites deployed in LEO where they would be better able to detect and track the threat because of their proximity to the HGVs skimming along the edges of the atmosphere. It would provide birth-to-death tracking, discrimination, and fire-control data and kill assessment for ballistic missiles as well as the burgeoning Russian and Chinese hypersonic missile threats. A new space-sensor network would also increase the range/accuracy of current U.S. interceptors.

Several defense officials have voiced support for augmented efforts to defend against hypersonic threats, including Mark Esper, the new Secretary of Defense.[xxi] USD/R&E Griffin is a particularly vocal advocate of the SSL. He is concerned by the hypersonic threat which he states has “a much reduced signature, by a factor of 10 or 20 times less than the strategic missile threat with which we’ve dealt in the past.”

Griffin believes the United States should develop a LEO-sensor network because “we need to proliferate our capabilities there” to address the hypersonic threat” and be in closer proximity for tracking and interception. He is also on record stating that deploying space sensors is feasible and affordable.[xxii]

Capitol Hill also supports expanding efforts to counter the hypersonic threat. In the Fiscal Year 2020 defense authorization and appropriation bills now winding their way through Congress, there have been reports that members plan to boost funding for space sensors by approximately $108 million. Total spending on hypersonics programs is expected to exceed the $2.6 billion requested by the Trump Administration in March 2019.

However, as noted in previous IFPA *Updates*,[xxiii] interception of threat missiles during the boost-phase affords the defender numerous advantages unavailable in the subsequent flight phases of an HGV or traditional ballistic missile. The benefits of boost-phase intercept (BPI) include: relative ease of interdiction because the ballistic missile is moving slowly and producing an enormous infra-red signature facilitating detection and targeting; the missile has not released its warheads/decoys allowing a far easier engagement opportunity; all or most of the debris from the intercepted missile would fall back on the territory of the launching nation; it would lessen the defense burden on U.S. midcourse- and terminal-phase missile defense systems; and it reduces the offensive/defensive cost-exchange gap that now favors the offense.

In regard to defense against an HGV, a BPI capability would negate its unique characteristics and troublesome capabilities (i.e., speed, maneuverability, and difficulty of detection/tracking) because the booster missile and the HGV it houses would be destroyed before the HGV payload is released. The authors of the 2017 RAND study cited above in this section confirm that a BPI defense would counter the HGV threat: "We note that potential defensive systems that intend to intercept incoming ballistic missiles before they deploy their payload, e.g., in the boost phase, would retain their effectiveness against HGV weapons."[xxiv]

Brilliant Pebbles: The Solution to the HM Threat and More

The optimum approach to BPI is a network of space-based interceptors (SBI) which would provide significantly increased defense coverage and HGV intercept capabilities. An SBI network should be modeled on the most promising, viable SBI option: the 1980s *Brilliant Pebbles* space-intercept concept. This concept was developed during the Reagan Administration within the Strategic Defense Initiative Organization but never brought to fruition.

Brilliant Pebbles consisted of a constellation of 1,000 interceptors that combined their own early-warning and tracking capability with high maneuverability to engage attacking ballistic missiles in all phases of their flight trajectory. This concept was based on a robust, operational capability that survived numerous scientific, engineering, and budget peer reviews in the 1989-90 timeframe.

The estimated cost for *Brilliant Pebbles* was $11 billion in 1989 dollars. In 2019 dollars, a constellation of 1000 *Brilliant Pebbles* would cost $23.09 billion spread over a twenty-year period. The cost of a 21st-century *Brilliant Pebbles* program could be less – and its capabilities greater – given the current advancements in the commercial sector in computing and other critical technologies, miniaturization, and reduced launch costs. USDR&E Griffin has stated that an SBI layer is both technically achievable and affordable.[xxv]

A 21st-century *Brilliant Pebbles* network would provide the solution to the hypersonic nuclear threat posed by China and Russia as well as to traditional ballistic missile threats including electromagnetic pulse (EMP) attacks.[xxvi] It would enable destruction of such threats during the boost-phase of flight prior to the release of nuclear payloads and possible decoys.

The need to develop and field a space-based, BPI network such as *Brilliant Pebbles* is further highlighted by the inadequacies of current U.S. missile defense elements. For example, U.S. midcourse defenses, i.e., primarily the aforementioned GMD system but also the Navy's *Aegis Standard Missile*-3, are configured to destroy missiles and RVs in space and thus would possess little, if any, capability to counter HMs whose flight is almost exclusively within the atmosphere. Moreover, as noted U.S. terminal missile defenses can protect only a very restricted geographic area.

A contemporary *Brilliant Pebbles* system would significantly strengthen U.S. deterrence posture by complementing “deterrence by punishment” or retaliation with “deterrence by denial.” Deterrence by denial provides the ability to defend vitally important targets. It forecloses or significantly complicates the capacity of an adversary to carry out a successful attack and achieve his goals thereby making an attack less likely. Deterrence by denial represents an indispensable element of escalation control which provides U.S. decision makers escalatory and deterrence options in addition to those based solely on retaliation.

Finally, a present-day *Brilliant Pebbles* constellation would also help reverse the offense-defense cost-exchange dynamic that now significantly favors the offense.

Conclusions

The United States, China, and Russia are developing HMs that will become increasingly critical assets when integrated into their inventories throughout the next decade. The speed (greater than Mach 5 or ~3836 mph), maneuverability, and accuracy of HMs, combined with the difficulty to detect and track them, will provide unique strategic and tactical advantages.

These include increased targeting options and more accurate and speedier interdiction of time-sensitive and mobile targets; a significant reduction in the time an enemy would have to make decisions; defending against HMs is extremely difficult; they can be outfitted with either conventional or nuclear warheads; and, they could be configured for different missions, e.g., for intelligence, reconnaissance, and surveillance operations.

Two primary categories of HMs are being developed: hypersonic glide vehicles and hypersonic cruise missiles. Russian and Chinese HMs are likely to house nuclear weapons while the United States has stated that its HMs will carry conventional warheads. The U.S. approach represents a greater technical challenge because, unlike HMs equipped with nuclear payloads, the precision accuracy needed to make conventionally-armed HMs effective requires sophisticated guidance and maneuvering capabilities.

A number of technological hurdles must be overcome before operational U.S. HMs can be fielded. These include managing the intense heat produced in hypersonic flight which could erode the vehicle’s protective coating and destroy onboard electronics; developing guidance systems that deliver needed accuracy and are able to endure the aerodynamic forces hammering the HM while in hypersonic flight; completing development of scramjet engines needed to field an operational hypersonic cruise missile; and, building the infrastructure such as wind-tunnel facilities necessary to test HMs in Mach 5+ simulated conditions.

Current U.S. missile defenses cannot provide effective protection against HMs, chiefly because they can elude detection and tracking by U.S. ground-based radars early in their flight trajectory making their targeting extremely problematic. The United States cannot be in a situation where it does not know where, when, and how many HMs may impact the U.S. homeland and/or its forward-deployed forces and allies.

It is critical that U.S. defense decision makers grasp and understand the hypersonic threat and the role HMs plays in the strategic plans of China and Russia. This is all the more vital because, unlike the United States, Beijing and Moscow see HMs as an effective and promising means to deliver nuclear weapons. Moreover, for several reasons both nations could be motivated to provide HMs to U.S. adversaries such as North Korea and Iran further exacerbating the threat facing the United States from HMs, and likely from nuclear weapons.

Consequently, development of a defense against hypersonic missiles must be become a U.S. national priority. Such an undertaking involves enhanced missile defense capabilities including:

- A space-sensor layer to detect and track HMs and guide U.S. interceptors to destroy them;
- Improvements/modifications to existing U.S. interceptors;
- Enhanced cyber- and electronic-warfare/jamming capabilities;
- Capabilities for left-of-launch interdiction;
- Improved battle management, command, control and communications; and,
- Boost-phase intercept capabilities.

Far and away, the most effective BPI approach would be a space-based intercept system based on the 1980s *Brilliant Pebbles* concept. A 21st-century *Brilliant Pebbles* network would provide a cost-effective defense solution (i.e., $23.09 billion in 2019 dollars spread over a twenty-year period) to the Chinese and Russian hypersonic nuclear threat as well as to traditional ballistic missile threats including electromagnetic pulse (EMP) attacks. It would enable destruction of such threats during the boost-phase of flight prior to the release of nuclear payloads and possible decoys.

Further underscoring the need for a space-based, BPI network such as *Brilliant Pebbles* is the fact that: present U.S. midcourse defenses are configured to destroy missiles and RVs in space and thus would possess little to no capability to counter HMs whose flight is almost exclusively within the atmosphere; and U.S. terminal missile defenses can protect only a very limited area.

In addition, a present-day *Brilliant Pebbles* space-intercept system would strengthen deterrence by denial, augment escalation control options, and help reverse the offense/defense cost-exchange ratio that now favors the offense.

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