STRATEGIC STUDIES QUARTERLY - PERSPECTIVE

Nuclear-Armed Hypersonic Weapons and Nuclear Deterrence

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Abstract

Nuclear-armed hypersonic weapons, with their ballistic missile defense (BMD) penetrating capability, will provide an overall strategically stabilizing effect in the global arena but will further destabilize regional competitions. Development and deployment of BMD is a strategically destabilizing agent since adversaries perceive that they can no longer hold each other at risk of a retaliatory nuclear strike. Nuclear hypersonic weapons, with their promised capability to defeat missile defenses, will bolster expectations of reciprocal nuclear strikes. When this capability to provide retaliation is undermined, strategic instability ensues and manifests as arms races, aggressive posturing, and bellicose rhetoric. Therefore, global nuclear powers, with their robust counterforce capabilities, should develop nuclear-armed hypersonic weapons to return deterrence to an era of assured vulnerability that keeps nuclear weapons holstered. However, introducing hypersonics, with first-strike counterforce and decapitation capabilities, to regional nuclear power competitions will have the opposite effect, further destabilizing an already uneasy peace. In both cases, some period of greater strategic instability will exist as nuclear-armed hypersonic weapons become operational in an unbalanced manner. That is, as one nuclear power attains BMD-defeating capability, opposing powers will perceive that they are at a disadvantage. To mitigate this transition period of instability, global powers should proceed in developing hypersonic weapons but counter regional instability by banning regional development and curtailing hypersonic technology proliferation.

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Over two decades ago, Keith Payne wrote in *Deterrence in the Second Nuclear Age* on the challenges of the changing dynamics of nuclear deterrence in the era following the bipolar Cold War. He cautions, with near clairvoyance, that the US needs to balance assured nuclear retaliation against the Russian Federation while hedging protection against rogue states with ballistic missile defense (BMD) development.[1] In other words, the US must consider the second- and third-order effects of its missile defense policies and capabilities on strategic stability. Taking Payne's argument one step further confirms that US development of ballistic missile defenses has upset great power strategic stability by violating the key nuclear deterrent principle of assured vulnerability. Essentially, there are two nuclear arenas to explore regarding the effects of hypersonic nuclear weapons: global nuclear powers (e.g., US, China, and Russia) and regional nuclear powers (e.g., India, Pakistan, and North Korea). In the context of global deterrence stability, countries seek equilibrium, and in doing so, they pursue nuclear-armed hypersonic missiles with their high-speed, maneuverable, missile defense–defeating capabilities to bolster counterforce options and return stability to strategic deterrence. The consequences of this pursuit are now materializing as China and Russia accelerate programs in hypersonics. China is considering changes in its nuclear alert posture.[2] It has been less direct about confirming research in nuclear-armed hypersonic weapons. However, intelligence indicates Chinese hypersonic capabilities heading in the nuclear-armed direction for similar missile-defense-penetrating reasons.[3] Russia is racing to develop hypersonic nuclear weapons to defeat ballistic missile defenses.[4] It has stated intentions to mate nuclear warheads to these hyper-fast, maneuverable weapons to counter US missile defenses against nuclear attack.[5] A hypersonics competition is also being sought regionally for defense-penetrating capabilities, increasing instability in regional nuclear standoffs as seen in the Pakistan-India conflict. These competitions will have destabilizing effects due to the respective weak counterforce postures and capabilities combined with the first-strike and decapitation potential that nuclear hypersonics may bring.

Today, most hypersonic weapons research globally is focused on conventional arms primarily for the potential value of these weapons in penetrating anti-access environments.[6] Yet some authors fear that the development of hypersonic nuclear missiles will bring us closer to nuclear holocaust. This logic is not universally applicable across global and regional areas and is not grounded in sound deterrence theory.[7] For global nuclear powers, the anticlimactic good news is that if nuclear-armed, non-ballistic hypersonic missiles become a staple of their military arsenals, the long-term deterrent effect will manifest as greater strategic stability. In other words, nuclear-armed hypersonic missiles, with the promised capability to defeat missile defenses, will usher in a return to assured nuclear vulnerability among the global nuclear powers. However, the unsettling news is that as nuclear hypersonics infiltrate regional nuclear power arsenals, strategic instability will increase. In both cases, the path to this new era of stability is fraught with tension and uncertainty. The world will likely experience times of greater strategic instability as nuclear hypersonic missiles become operational in an unbalanced manner. As one nuclear power attains BMD-defeating capability, opposing powers will perceive they are at a counterforce capability disadvantage against ever-advancing, increasingly affordable, and proliferating missile defenses.

To buttress these arguments, this article first reviews how introducing new technology may create deterrence instability. It then examines hypersonic capabilities and the effects of these weapons on nuclear deterrence. Finally, it uses Albert Wohlstetter's attributes of stable nuclear deterrence to demonstrate the implications of nuclear-armed hypersonic missiles for strategic stability. This article makes the case that dismantling missile defenses and adding hypersonic technology to a nonproliferation ban may be the best approach to avoid global transition instability periods and overall regional instability. These policy proposals will seem counterintuitive, but they appear logical and necessary to stabilize the changing nuclear deterrence environment.

Strategic Stability and Nuclear Deterrence Instability

A stable nuclear deterrence environment, as described by Wohlstetter and Thomas Schelling, is underwritten by each country's credible second-strike capability to levy extraordinary punitive costs against adversaries.[8] In essence, stability contains two parts: the belief that a target adversary has the capability and the political will to deliver a punishing counterstrike, ensuring any first strike would fail to dismantle the opponent's capability to counterstrike. Specifically, Wohlstetter outlines six attributes of a credible (as believed by a nuclear country and its adversary) second-strike deterrent system: It must (1) be reliable, affordable, and sustainable; (2) survive enemy attack; (3) make and communicate the decision to retaliate; (4) reach enemy territory with enough fuel to complete the mission; (5) penetrate the enemy's active defenses; and (6) destroy the target despite passive defenses.[9]

When this retaliatory capability is no longer perceived to be credible (violates one of the six Wohlstetter stability attributes) and is profoundly costly, then instability ripples throughout nuclear and nonnuclear nations, manifesting as arms races, bellicose rhetoric, force posturing, and universal unease.[10] Thomas Schelling similarly wrote, "It is not the 'balance'—the sheer equity or symmetry in the situation—that constitutes mutual deterrence; it is the stability of the balance. The balance is stable only when neither, in striking first, can destroy the other's ability to strike back."[11] The importance of Schelling's statement cannot be underscored enough: a nuclear stalemate requires that all nuclear parties have an invulnerable second-strike capability to provide optimal stability. A nuclear-armed country that fields technology either mitigating its opponent's capability to impose cost or enhancing its own benefit for initiating a nuclear first strike (an enhanced preemptive strike weapon) leads other nations to question their capability and/or credibility, upsetting the status quo. For deterrence to be effective, nuclear powers must thoroughly evaluate the effect of technology insertion into the nuclear arena on deterrent stability.

The first example highlighting deterrence-destabilizing technological advantages can be found in the USSR launch of *Sputnik*. The orbiting sphere showcased a first-strike nuclear attack capability of the USSR, upset the perception of a nuclear stalemate, fed the US's fear of a missile gap, and spurred the intercontinental ballistic missile arms race.[12] Prior to the 1957 launch of *Sputnik*, the only intercontinental nuclear delivery capability that existed was long-range bombers. Nuclear-tipped intermediate range ballistic missiles (IRBM) did exist at the time and were deployed throughout the European theater, threatening the USSR, but there were no comparable opposing missile deployments that directly threatened the North American continent. Using a fleet of bombers against the US entailed a cascade of warnings and hours of flight time that made a surprise attack unlikely.

Further, the US established Air Defense Command to intercept and mitigate any bomber-borne nuclear threat the USSR could impose. At the time, defenses against airborne ballistic missiles did not exist, let alone defenses against intercontinental ballistic missiles. With IRBMs deployed along the borders of the USSR and threatening Soviet targets, the USSR was spurred to develop an ICBM force to hold the US at similar risk.[13] As one can imagine, a Soviet satellite shot into space and allowed to fly over the US without challenge fueled a sense of naked vulnerability among strategic nuclear thinkers, politicians, and average civilians.

Looking at the *Sputnik* situation through Wohlstetter's stability lens, the USSR's perceived capability to obliterate the US with virtual impunity upended the nuclear deterrent environment. This instability was further exacerbated by the limited survivability of a US retaliatory force of long-range bombers (a nuclear force susceptible to a preemptive ICBM strike). Altogether, the perception of a missile gap—driven home by the Soviet radio beacon flying above—introduced an instability into nuclear deterrence that manifested as an ICBM arms race.

Another example of this instability-inducing technology is the advent of antiballistic missile (ABM) systems or ballistic missile defense efforts by the US in 1967. Touted to deny an adversary's advantage to impose cost by claiming the capability to intercept inbound nuclear warheads, US BMD programs naturally alarmed the USSR. Looking at Wohlstetter's stability attributes, a BMD capability violates an adversary's "penetrate enemy active defense" characteristic and diminishes the possibility of ensuring a costly retaliation. Against a US BMD, the USSR perceived its missiles to be less likely to provide a credible retaliatory punch, fundamentally undermining the assured vulnerability concept essential to stable nuclear deterrence. This capability-limiting perception spurred the USSR to develop its own BMD program and pushed both superpowers into a counter-BMD arms race. This arms race manifested in the development of multiple independently targetable reentry vehicles (MIRV) capable of defeating BMD systems. [14] The BMD race spurred the MIRV race, which fundamentally was an attempt to return the nuclear deterrence environment back toward strategic stability between the US and USSR.[15] Distressed by this BMD arms race and its promise to intercept nuclear warheads, the Nixon administration and Soviet leadership signed the ABM treaty, halting any real deployment of a BMD umbrella over the US and USSR.[16]

Understanding nuclear deterrence, the elements of nuclear deterrence stability, and the symptoms of instability underpins the key elements for analyzing new capabilities into the nuclear deterrence arena. The desirable stable nuclear deterrence environment, as defined by Wohlstetter's six criteria to credibly guarantee a costly retaliatory response, underwrites the modern US nuclear deterrence strategy. The symptoms of volatility—including nuclear arms races, bellicose rhetoric, and general international unease—are highlighted as nuclear deterrence instability indicators. Altogether, they serve as the foundation to measure modern BMD and the effects of nuclear-armed hypersonic missiles on global and regional nuclear deterrence.

Capabilities and Effects of Hypersonic Weapons

There has been a tremendous amount of concern about introducing nuclear-armed hypersonic missiles over the past decade. Across the internet and in the press, words like "hypersonic arms race," "hypersonic weapons," and "hyper escalation" are making headlines.[17] These manuscripts attribute to hypersonic vehicles the capability to penetrate BMD and air defenses with impunity, reach targets with absolute precision and accomplish all of these with tactical surprise. However, many of these statements are speculative and are not grounded in physics or even the realm of the possible.

In reviewing literature regarding hypersonics, there seems to be an almost mystical admiration and a general misunderstanding of vehicles traveling in this speed regime. The reality is that hypersonic speed has existed since 12 April 1961 when Russian cosmonaut Yuri Gagarin reentered Earth's atmosphere, traveling at speeds fast enough to ionize air into plasma. US hypersonic testing began with the manned X-15 rocket plane that surpassed the hypersonic speed of Mach 5 in June 1961. Today, weapons that travel at hypersonic speeds are already in the inventories (mostly as part of air and BMD systems) of many nations and are on a trajectory to become mainstream in commercial space travel and military applications in the near future. The world is on the brink of a breakout in hypersonic technology use and employment. This makes it essential for readers to have a basic understanding of the hypersonic flight regime as well as hypersonic missiles and their capabilities. Toward that end, this section defines *hypersonic*, discusses the engineering challenges of traveling at this speed, and addresses types of hypersonic assets and their competencies. Such a fundamental appreciation for these super-fast capabilities will complement the deterrence argument.

The National Aeronautics and Space Administration (NASA) defines *hypersonic* as the atmospheric speed regime greater than or equal to five times the speed of sound.[18] While hypersonic speed is not a new achievement, it is not a ubiquitously traveled speed realm. Every space reentry vehicle—from Mercury-Redstone space capsules and ICBM reentry vehicles to the space shuttle—traverses the hypersonic regime, sometimes entering the atmosphere in excess of Mach 25.[19] Further, modern military surface-to-air missiles, such as the SA-21 Growler (S-400 as named by the Russian developers), streak to their targets at speeds up to Mach 12.[20] In each hypersonic case mentioned, the technological hurdles were (and still are) quite extreme. Until the recent emergence of commercial space programs, this realm was limited to a few state-sponsored programs using national resources to solve the significant engineering challenges.

All hypersonic literature agrees that heat is the most challenging engineering problem facing hypersonic flight. Figure 1 illustrates the stagnate point temperature calculations at the skin of hypersonic vessels. At hypersonic speeds, the punishing temperatures experienced disassociate and ionize the air, resulting in chemically reactive airflows and plasma.[21] These reactions and plasma-inducing temperatures also produce communication barriers that block reception and transmission of radio signals.[22] Finally—but not least of the problems of hypersonic speed—is shockwave impingement. In certain situations, shockwaves produced by hypersonic flight can act like a blowtorch wherever they contact the aerospace vehicle frame, burning through the skin and further compounding temperature-related problems.[23]

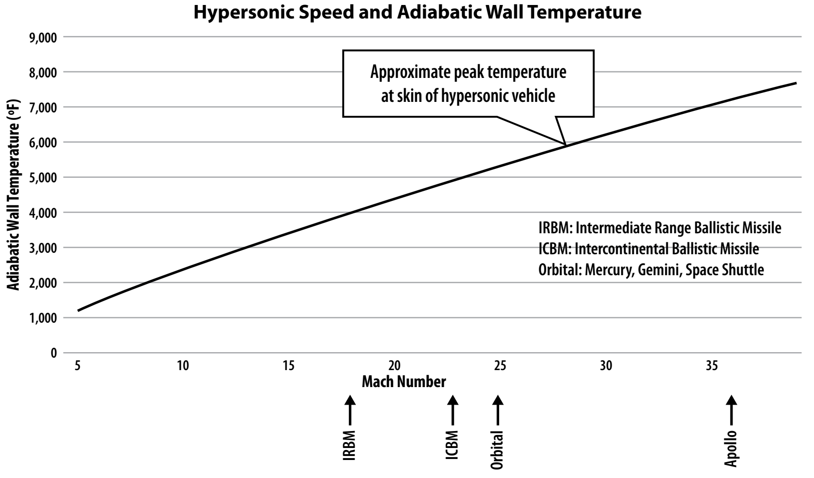

Figure 1. Hypersonic speed versus skin temperature

Note: Mach speeds and temperatures were calculated using a 170,600 (52 km) altitude, a radius of 1 ft, and material emissivity of 0.8. Mach temperature calculator was provided by Mr. Barry Hellman, Air Force Research Laboratory.

(*Source*: For IRBM, ICBM, orbital, and Apollo speeds, see John D. Anderson, Jr., *Modern Compressible Flow:With Historical Perspective*, 3rd ed. [Boston: McGraw-Hill, 2003], 18.)

Despite these extreme difficulties, humans have entered the realm of hypersonic speed with advancements in material, propulsion, and understanding. In vehicles like space capsules, space shuttles, the X-15 and other reentry vehicles, the thermal problems of hypersonic travel have been managed using a combination of ablation heat shields, silicon tiles, carbon composites, zirconia, and high-temperature nickel and titanium alloys.[24] However, these before-mentioned hypersonic vehicles also mitigated heat problems with relatively short durations of exposure to high temperatures. Reduced time exposure lessens the impact of convective heating.

Using these engineering leaps in hypersonics, two basic types of hypersonic vehicles have received most of the attention in military research and application: the boost-glide vehicle and the powered-cruise vehicle (cruise missile). At this time, both vehicle classes require the boost of a large rocket motor to reach hypersonic performance. A boost-glide vehicle is launched using rocket boost systems and glides, much like the space shuttle, to a target. The air-breathing hypersonic cruise vehicle can be launched from ground or airborne assets using a rocket motor boost to achieve hypersonic speeds fast enough to ignite a scramjet[25] (an engine designed to operate at hypersonic speeds) and power the flying vehicle to a target.

Figure 2 compares the flight profiles of a hypersonic cruise missile, hypersonic boost-glide machine, and ballistic missiles. Hypersonic cruise missiles typically travel between ~70,000 to ~120,000 feet above sea level. These altitudes ensure that there are enough oxygen, air volume, and pressure to support combustion for a scramjet engine while mitigating heat-inducing and dynamic pressure properties of lower altitude, higher air densities. Boost-glide vehicles are launched to high altitudes (sometimes leaving the atmosphere), pitch over, and establish a descending glide to a target at hypersonic speeds.[26] As they approach their ground target, both vehicle classes perform a slowing descent to lower Mach numbers for thermal and dynamic pressure management.[27] Lower altitudes also allow for an increase in maneuverability in the terminal phase of flight.[28] Figure 2 depicts the depressed trajectories of glide and cruise missiles as compared to ballistic parabolas. The importance of depressed trajectory and maneuverability attributes are discussed later.

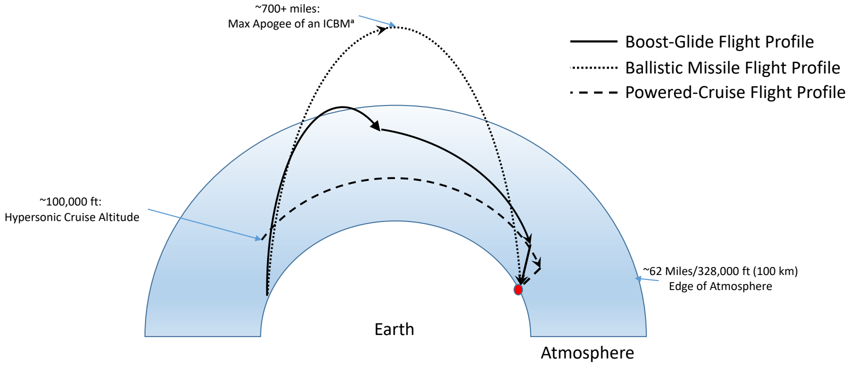

Figure 2. Nominal flight paths of ballistic missiles, boost-glide vehicles, and cruise vehicles

[a]ICBM apogee obtained from Federation of American Scientists, "LGM-30 Minuteman III," accessed 18 January 2017, https://fas.org/.

The different flight profiles are a result of different airframe designs. Hypersonic boost-glide vehicle wedge design generally maximizes glide range and can allow relatively large payload capacities, carrying several thousand pounds of cargo or weapons. The load capacity and size are limited only to the power of the boost vehicle (i.e., more boost = more weight and size available for the glide vehicle).[29] Boost-glide hypersonic vehicles are expected to have a global range comparable to that of intercontinental ballistic missiles (equal to or greater than 5,500 km).[30]

Besides having a boost phase, hypersonic, air-breathing cruise missiles have a different aerodynamic design than boost-glide vehicles. These missiles are engineered to have a sleek, narrow, futuristic bullet shape that manipulates the shockwave for scramjet operation and limits the amount of drag for maximum speed and range.[31] Although hypersonic cruise missiles can technically be launched from ground-based sites, most US efforts have focused on air-launched hypersonic cruise vehicles, likely in compliance with the former Intermediate Nuclear Force Treaty that banned ground-launched cruise missiles.[32] These cruise missile prototypes are currently launched by bomber-size aircraft due to their relatively large size and weight. Consequently, the air-launched configuration will limit expected ranges (currently 200 to 850+ miles), comparable to short- and intermediate-range ballistic missiles (short missile range: <620 miles; IRBM: 1,800 to 3,400 miles).[33] The reason for these shorter ranges is the payload capacity limits of the combined weight of the booster and a fully fueled hypersonic vehicle. (Recall that the hypersonic vehicle size limit directly relates to the size of the rocket motor that propels it to hyper speed. ICBM-size boosters are generally used for larger boost-glide vehicles while smaller rocket boosters are used for launches from airborne platforms).[34] However, weaponized hypersonic cruise missiles are expected to get smaller as the technology matures to enable higher speeds and launch from smaller, possibly fighter-size, aircraft.[35]

Defense Penetrating Panacea?

The widely touted, missile-defense-defeating capability of hypersonics is triggering speculation and instability in the world. Despite this hype, the reality is that while hypersonic weapons will be better at defeating robust defenses than what is available today, they will not be a panacea against missile and ballistic missile defenses. Physics is the largest limiting factor in the capability of hypersonic flying; understanding these limits is important when judging the true impact hypersonics will have on the nuclear deterrence landscape. When hypersonics are matched against the latest missile defenses of today and tomorrow, the fast-flying projectiles will not be impervious to counter-systems with equal speed and maneuverability capabilities.

Before proceeding, it is helpful to review the hypersonic weapon concepts most of the literature seems to be using. To begin, the promised hypersonic capabilities are a combination of speed, range, accuracy, and maneuverability. With these combined capabilities, hypersonic weapons would conceptually be used for global strike (e.g., a boost-glide vehicle), reaching any target within minutes and penetrating defenses with immunity through a combination of tactical surprise (detected later due to lower altitude flight path when compared to a ballistic missile—see fig. 3) and maneuverability. Additionally, a hypersonic cruise missile could be launched at standoff ranges and penetrate dense and deadly defensive systems, thereby striking targets with impunity.

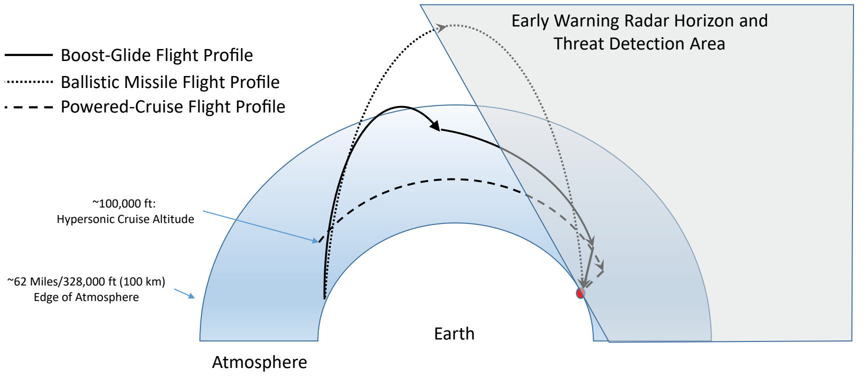

Figure 3. Flight profiles and early-warning radar threat detection

The real characteristics of hypersonic vehicle speed and flight profiles still make these weapons vulnerable to today's modern defense weapons, being only marginally more survivable and effective than ballistic missile–deployed weapons.[36] Reviewing the flight profiles of hypersonic boost-glide and cruise missiles, they must fly at high altitudes (70,000 ft or higher) for aerodynamic load and dynamic pressure limitations (fig. 2). These high-altitude profiles leave them detectable at longer ranges than if they flew at lower altitudes where traditional radar-evading cruise missiles fly.[37] Also, hypersonic boost-glide and cruise vehicles do not move faster than reentering ICBM-launched MIRVs, the very objects some missile defenses are designed to counter. [38] Further, the descending, decelerating end-game profile required of hypersonic vehicles to hit ground targets puts them at greater risk of engagement.

Pitting hypersonics against modern and soon-to-be-fielded advanced anti-missile systems is sobering. James Acton's report *Silver Bullet?* points out that hypersonic cruise and boost-glide weapons can theoretically be detected and engaged by Russian-made S-300 (SA-20 Gargoyle) surface-to-air missile systems' antiballistic missile capability.[39] Furthermore, current antiballistic missile systems, such as the Russian-made S-400 Triumfator (SA-21 Growler), specifically boast the capability to engage hypersonic cruise missiles with an interceptor that can maneuver at 20 times the force of gravity (g) at 100,000 feet. This maneuverability promises to mitigate the advantages of an inbound hypersonic weapon.[40] Also, the soon-to-be-fielded S-500 Triumfator-M advertises advanced air and space defense capabilities and anti-hypersonic warhead ability, further grounding hypersonic speculation.[41] Of course, it is hard to make specific comparisons against the anti-missile systems and hypersonic flyers without detailed information on the hypersonic vehicles themselves. The point is that anti-missile systems are continually advancing and proliferating.[42] They are already quite lethal to equally fast-flying ballistic missiles and have hypersonic interceptors that are quite maneuverable at high altitudes. Together, these evolving capabilities mean that hypersonic weapons will likely face a formidable challenge around densely defended targets (the very same targets hypersonics are designed against).

The best attribute a hypersonic weapon has is its speed. Using the hypersonic concepts of global strike and defense penetration, speed will likely be used to achieve tactical surprise and compress the timeline required to counter this inbound threat.[43] Therefore, to truly attain tactical surprise against a modern antiballistic and anti-hypersonic missile system, an inbound hypersonic missile would have to fly at an altitude low enough to avoid detection long enough so that by the time it is detected, there is not enough time to defend against it (see table 1). Again, lower altitudes are problematic for hypersonic flight because the lower altitudes overpressure hypersonic engines and prolonged flight creates extreme thermal management issues.[44]

Table 1. Estimated warning times of different hypersonic systems

		Global Boost Glide System (Mach 10–25)	Intermediate-Range Ballistic Missile (~ Mach 15)	Mach 5 Hypersonic Cruise Missile
Strike Range (Miles)		6,800	2,200	930
Warning Time (Minutes)	Early Warning Satellite	33	19	16
	Early Warning Radar	4	14	11
	Air Defense Radar	3	0	8

Source: Table modified from *James M. Acton, Silver Bullet? Asking the Right Questions about Conventional Prompt Global Strike* (Washington, D.C.: Carnegie Endowment for International Peace, 2013), 70, https://carnegieendowment.org/.

Other attributes that put hypersonic vehicles at a further disadvantage are their significant heat signature and relatively limited maneuvering capability. The heat signature produced at hypersonic speeds makes these vehicles very detectable, even visible to the human eye (as hot as 2,000 degrees Celsius [3,600 degrees Fahrenheit] at Mach 10 for the X-43. This is the same temperature as jet engine exhaust identifiable by existing infrared detectors and heat-seeking missiles.[45] Maneuverability, cited as a key survivability attribute of hypersonic weapons, will make them more difficult to engage. However, this maneuvering attribute will likely make hypersonic vehicles only marginally more effective since turning at hypersonic speed is problematic. High-speed turns generate giant turn radii and loss of energy (resulting in slower speed), requiring increased maneuvering space and decreased range. Taking evasive action at these high-speed ranges has a high potential to throw these swift vehicles miles off course in a fraction of a second. Timed at the right ranges, engaging an inbound hypersonic weapon can force survivability maneuvering, instantly turning the missile far enough off course as to make the weapon miss the intended target. Evasive actions at hypersonic speed will also slow down the missile and/or require more fuel, reducing its range and survivability. Further, anti-ballistic missile interceptors use a combination of thrusters and aerodynamic devices at high altitudes to achieve high maneuverability—methods that hypersonic vehicles can also use to defeat defenses.[46] As mentioned before, if anti-missile systems are already employing these maneuvering capabilities, then hypersonic weapons' main advantage is speed to delay detection until it is too late for an effective defense. Finally, this hypersonic maneuverability characteristic has been around since the late 1970s with the advent of the Advanced Maneuverable Reentry Vehicle (AMaRV). This warhead was designed to defeat BMDs through maneuvers during reentry and the terminal phase of flight—a stark departure from normal ballistic trajectories.[47] Novel at that time, the AMaRV was declared operational for the Minuteman III in 1982.[48] Over three decades have passed since warhead maneuvering was introduced to the nuclear arena, allowing missile defense system development to mature to the point they can counter trajectory-changing reentry vehicles.

The Nuclear Hypersonic Effect

Despite the reality of hypersonic capabilities, China and Russia have announced they are developing hypersonic boost-glide vehicles and hypersonic cruise missiles to penetrate US antiballistic missile defenses.[49] Furthermore, there is speculation that both countries are developing conventional and nuclear variants of these weapons.[50] India, in a joint venture with Russia, is also developing hypersonic technology as a response to robust air and sea defenses.[51] However, India seems focused on multi-mission (indications are primarily an anti-ship) hypersonic cruise missiles with ranges around 290 km (180 miles) and has not indicated plans to produce a nuclear variant.[52] Altogether, four nations (US, China, Russia, and India) are developing hypersonic technology in response to sophisticated anti-access and BMD systems.

BMD systems are not new to the realm of nuclear deterrence and have existed in various US and Russian (USSR) forms since the 1950s. Whether hypersonics can penetrate BMD defense or not, the ubiquitous belief that the fast-fling systems can defeat missile defenses is what matters in a strategic environment. Relying on this defense-penetrating belief and reflecting on Wohlstetter's stability attributes of penetrating enemy active defenses, it is easy to understand the USSR's staunch resistance to US development of nationwide ballistic missile–defeating systems. With the USSR perception that its strategic nuclear arsenal could be made partly or completely impotent, it came to the treaty table to dismantle any US ABM effort. The US Arms Control and Disarmament Agency indicated the ABM Treaty would "decrease the pressures of technological change and its unsettling impact on the strategic balance."[53]

Similar perceptions exist today concerning US missile defense systems. The US has stated that the deployment of BMDs is, according to the 2014 *Quadrennial Defense Review* (QDR) and the 2019 *Missile Defense Review* (MDR), to protect the homeland and its allies from regional actors, namely North Korea and Iran, from limited ballistic missile attack.[54] This position to build strategic missile defenses, according to well-known nuclear deterrent theorist Herman Kahn, is the moral obligation of a country to save lives (saving some is better than saving none), even if the system is not foolproof.[55] Additionally, the QDR and MDR rationale is grounded in the philosophy that BMDs be built to deter "smaller" countries. This argument appears based on the assumption that such a system would be more effective against fewer warheads, rendering a country's small nuclear arsenal impotent.[56] However, what the QDR, MDR, and Kahn fail to adequately address are the second-order effects of developing such defensive systems, specifically, how other global nuclear powers may view and respond to these defenses and how these systems would affect regional nuclear standoffs.

We are presently seeing the second-order effects of such defenses manifest as nuclear deterrence instability and hypersonic arms races.[57] Thomas Schelling predicted this dilemma when he wrote, "ABM systems deployed in both countries would make preemptive war more likely, and the arms race more expensive."[58] Consequently, due to the impression a BMD system can diminish or neuter the effectiveness of a nuclear attack, the MDR, experts, and scholars alike believe Russia and China are developing nuclear-armed hypersonic weapons designed to render these defenses futile.[59]

It is no surprise that several nations are enamored with hypersonic capabilities. After all, the potential of moving military operations at speeds above two miles per second has a tremendous appeal. Militaries that can move weapons or cargo at these speeds will set a tempo of conflict that no adversary can currently match. However, the conclusion regarding hypersonic capability is that rhetoric is proceeding actual capability. The speed, range, and maneuverability of hypersonics are all attributes that will make them preeminent weapons, but that capability will likely not culminate in the penetrating defense panacea some literature speculates. The engineering problems these speedy vehicles face are titanic and require not only unique material and design solutions but must fly high altitude profiles; both attributes which degrade the promised defense-penetrating capabilities. Understanding these fast-aero vehicle characteristics is fundamental to gaging the effects they will have on nuclear deterrence. Hypersonics will be another arrow in an array of capabilities that, when used, will be part of a holistic force concept to produce desired military effects. In other words, hypersonics are certainly an evolution in weapons technology, not a revolution. It will provide only modest defense-penetrating capability.

Implications for Deterrence: Global and Regional

The development of nuclear-tipped hypersonic missiles is the deterrence "environment" attempting to return the nuclear order to a state of stability. As Wohlstetter implies in "The Delicate Balance of Terror," the international nuclear deterrence system is a balancing act of attributes. As he states, "To deter attack means being able to strike back in spite of it."[60] When the counterstrike option is diminished, as a BMD system has the ability to do—whether actually or perceptually—the deterrent system is shaken and becomes unbalanced and unstable. Russia and China naturally feel disadvantaged by the US development of a credible, albeit limited, ICBM defense capability. However, given the limited number of US BMD defenses, they can easily be overwhelmed.[61] This limited missile defense capability restricts options for a counterstrike, assuming an adversary's doctrine had a spectrum of counterstrike choices versus just massive retaliation (the only way to defeat this limited ballistic missile defense capability is with an overwhelming strike). Also, the deployment of the missile defense system may embolden adversaries: what is to deter them from firing nuclear warning shots if they will be shot down? Again, while the US asserts that the deployment of terminal interceptors in Europe cannot physically challenge Russian missiles and that the deployment of THADD in South Korea cannot surveil all of China, what really matters is the perception of Russian and Chinese leaders that these defenses could mitigate their nuclear missiles.[62]

Conversely, in accordance with Wohlstetter's stability attributes to ensure a costly counterstrike, nuclear-tipped hypersonic missiles will return the nuclear deterrent system between Russia, China, and the US to a condition of higher stability. Even with the additional first-strike and decapitation bolt-from-the-blue capability that hypersonics may be able to provide, the other Wohlstetter attributes remain in play: a costly counter-strike guaranteed by submarine-launched nuclear weapons, airborne command posts, and possibly air-alerted nuclear-carrying bombers are hardly likely to be simultaneously destroyed provided a counterforce posture is maintained and deployed. See tables 2, 3, and 4 below to compare US, China, and Russian counterforce and stability attributes. (Note that the current state of stability can be uprooted by other technologies outside of BMD and hypersonic nuclear weapons that this article does not consider, which makes it of utmost importance to continue to modernize, conceal, and deploy robust counterforces.[63]) In other words, hypersonics, with their capability to defeat missile defense systems (whether perceived or actual), will return the US-Russia-China nuclear relationship to a state of assured vulnerability and a more stable strategic deterrence environment.

Table 2. US nuclear attributes

Nuclear Weapon System	Reliable, Affordable, Sustainable	Survivable	Credible Perception of Retaliation	Capable of Reaching Adversary	Penetrate Active Defenses	Destroy Target w/ Passive Defenses
ICBM	Positive	Positive	Positive	Positive	Positive	Positive
SLBM	Positive	Positive	Positive	Positive	Positive	Positive
Bombers	Positive	Negative	Positive	Positive	Positive	Positive

Table 3. Russia nuclear attributes

Nuclear Weapon System	Reliable, Affordable, Sustainable	Survivable	Credible Perception of Retaliation	Capable of Reaching Adversary	Penetrate Active Defenses	Destroy Target w/ Passive Defenses
ICBM	Positive	Positive	Positive	Positive	Positive	Positive
SLBM	Positive	Positive	Positive	Positive	Positive	Positive
Bombers	Positive	Negative	Positive	Positive	Negative	Positive

Table 4. China nuclear attributes

Nuclear Weapon System	Reliable, Affordable, Sustainable	Survivable	Credible Perception of Retaliation	Capable of Reaching Adversary	Penetrate Active Defenses	Destroy Target w/ Passive Defenses
ICBM	Positive	Positive	Positive	Positive	Positive	Positive
SLBM	Positive	Positive	Positive	Positive	Positive	Positive
Bombers	Positive	Negative	Positive	Positive	Negative	Positive

Notes: Nuclear attribute table design explanation: deterrence stability tables were developed using Wohlstetter's criteria when compared to each other, with each attribute scored on a basic scale: positive and negative. Positive scores are given for the regional system with attributes that add to deterrent stability. A negative score is given to an attribute based on evidence, logic, or questionable theory that detracts from stability when compared to its adversary. Each attribute is evaluated by itself (i.e., if the system was not found survivable, it may still possess attributes that allow it to penetrate defenses like stealth and be awarded "positive" for the penetrate defenses attribute). See appendix A (online at https://www.airuniversity.af.edu/) for a detailed overview of each county's nuclear capability in relation to Wohlstetter's attributes.

Table 5 matches nuclear countries with and without ballistic missile defense against nuclear countries with and without nuclear (N) hypersonic missiles. This table specifically addresses the Wohlstetter stability attribute of a country's ability to penetrate enemy defenses. It highlights that if a country cannot penetrate defenses or perceives that it cannot), then the rest of the attributes are largely nullified, and the overall deterrent system is unstable. The fundamental calculation used to determine whether a deterrent system was stable or unstable was whether the opposing countries could penetrate each other's defenses. If defenses for both County A and Country B could be penetrated, then the overall system is stable. If defenses could not be penetrated by either country—one country possessed a ballistic missile defense, and the opposing country did not have defense-penetrating nuclear hypersonic missiles in its inventory—then the overall system trends unstable since the guarantee of assured vulnerability is in doubt. Note that a country possessing nuclear hypersonic missiles is alone not a determining factor of whether a system is stable. Countries can possess hypersonic capabilities without upsetting the stability of the deterrent system. If anything, assured vulnerability is bolstered when both nuclear powers have nuclear-capable hypersonic missiles since these weapons have better capability to defeat defenses. The determining factor for stability is whether defenses can be penetrated and opposing countries can hold each other at risk with a robust counterforce capability, underwriting assured vulnerability.

Table 5. Strategic deterrent environment stability scenarios

		Nuclear Country B			
		Ballistic Missile Defense & No N-Hypersonic Missiles	**Ballistic Missile Defense & N-Hypersonic Missiles**	**No Ballistic Missile Defense & N-Hypersonic Missiles**	**No Ballistic Missile Defense & N-Hypersonic Missiles**
Nuclear Country A	No Ballistic Missile Defense & No N-Hypersonic Missiles	Situation G Increases Stability	Situation A Decreases Stability	Situation D Decreases Stability	Situation F Increases Stability
	Ballistic Missile Defense & No N-Hypersonic Missiles	Situation A Decreases Stability	Situation B Decreases Stability	Situation C Decreases Stability	Situation H Increases Stability
	Ballistic Missile Defense & N-Hypersonic Missiles	Situation D Decreases Stability	Situation C Decreases Stability	Situation E Increases Stability	Situation I Increases Stability
	No Ballistic Missile Defense & N-Hypersonic Missiles	Situation F Increases Stability	Situation H Increases Stability	Situation I Increases Stability	Situation J Increases Stability

The assumption in developing table 5 is that hypothetical countries A and B have a robust nuclear capability that satisfies Wohlstetter's other five attributes of reliability/affordability/sustainability and the ability to survive an enemy attack, reach enemy targets with enough fuel, destroy the target, and have effective retaliatory communication. Some may argue that nuclear-tipped hypersonic missiles could be used as a first-strike capability to nullify an opponent's counterstrike force, making situations F and J unstable. However, the assumption used in table 1 for hypersonic capability is much like ballistic missile submarines capability: both these systems could effectively be used in a first strike scenario against a country's nuclear capability, but each country's nuclear strike capability will still maintain an overwhelming counterstrike capability (sea, ground, and/or air) to validate Wohlstetter's stability attributes. This assumption is not valid in regional nuclear stability cases, addressed later in this article, where nuclear forces are relatively small and potentially vulnerable.

Situation A is unstable because one opponent has BMD while the other does not. Fundamentally, this situation violates the "assured vulnerability" criteria for Country B, putting Country A in a precarious position of returning the deterrent system to stability (arms race) or considering a first strike (nuclear or nonnuclear) to nullify the BMD.

Situation B is likely the most unstable of all the scenarios. In this case, both countries have BMDs and no hypersonic missiles to counter such defenses, putting both country's assured vulnerability in question. Both countries are questioning whether their nuclear strike capability is adequate to ensure a powerful counterstrike, with both considering a first strike to nullify each other's defenses and return the deterrent system to a more stable state.

Situations C and D are unstable since one country does not have nuclear hypersonics to nullify the opposing country's BMD. Again, assured vulnerability is not guaranteed in these scenarios.

Situations E, F, G, H, and I all are stable deterrent environments since one or the other country has a counter to BMDs. Further, in situations E, I, and J, both countries possessing nuclear hypersonic missiles keep the deterrent system in an "assured vulnerability" stable state whether BMDs are involved or not.

Nuclear Hypersonics—Regional Deterrence Implications

On the flip side of nuclear deterrence considerations, hypersonic missiles—nuclear or not—will have a destabilizing impact among regional nuclear powers. Fundamentally, this technology will exacerbate the existing regional nuclear imbalances in Wohlstetter's six attributes of stability. Situation A in table 5 capsulizes this current regional deterrent environment: India has a strong ballistic missile defense capability when compared to Pakistan's nuclear strike capability. However, the underlying assumptions from table 2 are not all applicable since both regional nuclear powers have caveats to their nuclear strike capability when compared to Wohlstetter's stability attributes and require further investigation (see tables 3 and 4). Nuclear deterrence between the regional powers of India and Pakistan relies largely on posture (keeping nuclear warheads disassembled[64] from their launchers and India's no-first-use policy[65]) rather than true Wohlstetter stability in their bilateral relationship. India clearly has a robust and resilient force with solid-fueled missiles (allowing for indefinite alert postures), BMDs, and a nuclear-capable ballistic missile submarine.[66] Further, India's nuclear force attributes, as outlined in table 6, clearly add to deterrent stability.

Table 6. India – Wohlstetter's nuclear attributes

Nuclear Weapon System	Reliable, Affordable, Sustainable	Survivable	Credible Perception of Retaliation	Capable of Reaching Adversary	Penetrate Active Defenses	Destroy Target w/ Passive Defenses
IRBM	Positive	Negative	Negative	Positive	Positive	Positive
SLBM	Positive	Positive	Positive	Positive	Positive	Positive
Bombers	Positive	Negative	Negative	Positive	Negative	Positive

Pakistan, on the other hand, relies primarily on the mobility of its nuclear-capable ballistic missiles for survivability and lacks a submersible, hard-to-locate nuclear capability. Using Wohlstetter's stability attributes, it is evident that this deterrent situation is unstable (table 7). India, with its missile defense system and maturing nuclear triad, can unmistakably weather a first strike from Pakistan and produce a crushing retaliatory nuclear response.[67] Without a credible air and ballistic defense combined with exposed nuclear delivery systems, the same cannot be said for Pakistan following a hypothetical nuclear first strike from India.

Table 7. Pakistan – Wohlstetter's nuclear attributes

Nuclear Weapon System	Reliable, Affordable, Sustainable	Survivable	Credible Perception of Retaliation	Capable of Reaching Adversary	Penetrate Active Defenses	Destroy Target w/ Passive Defenses
MRBM	Positive	Negative	Positive	Negative	Negative	Positive
SLCM	n/a	n/a	n/a	n/a	n/a	n/a
Bombers	Positive	Negative	Positive	Negative	Negative	Positive

India's development of hypersonic cruise or boost-glide missiles is only adding to the instability of the regional deterrent situation, pushing the environment into a situation D (table 5) scenario. Nuclear or not, an arsenal of perceived defense-defeating, first-strike capabilities can theoretically penetrate and eliminate much of Pakistan's nuclear force. However, in addition to Pakistan maturing its nuclear force to include SLBMs and solid-fuel rockets, deterrence stability would improve if Pakistan and India were to develop and procure hypersonic boost-glide or cruise missile capability. This increased stability correlates with Wohlstetter's penetrate-defense attribute. Ideally, it provides both Pakistan and India the capability to defeat antiballistic missile systems, putting both opponents in a stronger assured vulnerability state. Pakistan attaining hypersonic technology is not out of the question; the technology may be available for purchase from a current hypersonic producer, or Pakistan may develop it. In this regional situation, a potential proliferator of hypersonic technology is China because it sees Pakistan as a counterbalance to the India-US strategic relationship.[68]

Another hypothetical regional scenario to consider is the introduction of hypersonics to the Korean peninsula. There is no evidence to indicate that North Korea has a hypersonic missile program. Further, it does not possess a credible anti-BMD system that would require the use of the penetrating attributes of hypersonic missiles (likened to table 4, situation A) where the US is the opponent. North Korea does operate a dense, robust, aging (1960s–1970s era) air defense system, which would complicate fourth-generation warplane access in the event of a conflict.[69] However, this formidable but defeatable air defense system has little to no capability against a hypersonic glide vehicle that the US would likely use to target North Korea's emerging nuclear weapons program. A hypersonic first-strike attack is unlikely since stealth bombers and fighters can easily penetrate such air defenses at less expense than a $10 million hypersonic missile.[70] Regardless, due to the already profound asymmetric match of North Korea's nascent nuclear weapon systems when compared to US mature nuclear capabilities—to include the extended nuclear umbrella over Japan and South Korea—hypothetical nuclear-armed US hypersonic weapons are unlikely to alter this region's current nuclear deterrent dynamic (table 8).

Table 8. North Korea – Wohlstetter's nuclear attributes

Nuclear Weapon System	Reliable, Affordable, Sustainable	Survivable	Credible Perception of Retaliation	Capable of Reaching Adversary	Penetrate Active Defenses	Destroy Target w/ Passive Defenses
ICBM/ IRBM	Negative	Positive	Positive	Positive	Negative	Positive
SLCM	n/a	n/a	n/a	n/a	n/a	n/a
Bomber	n/a	n/a	n/a	n/a	n/a	n/a

Note: North Korea's deterrence stability table was developed using Wohlstetter's criteria when compared to the US, with each attribute scored on a basic scale: positive and negative. Positive scores are given for the regional system with attributes that add to deterrent stability. A negative score is given to an attribute based on evidence, logic, or questionable theory that detracts from stability when compared to its adversary. Each attribute is evaluated by itself (i.e., if the system was not found survivable, it may still possess attributes that allow it to penetrate defenses like stealth and be awarded "positive" for the penetrate defenses attribute). See appendix A (online at https://www.airuniversity.af.edu/) for a detailed overview of North Korea's nuclear capability in relation to Wohlstetter's attributes.

The dynamic changes considerably if North Korea acquired a nuclear hypersonic glide or cruise missile. The 2014 *Quadrennial Defense Review* names North Korea as one of two regional actors that missile defense is designed to deter and defeat.[71] A North Korea hypersonic capability would certainly erode any sense of protection a now operational US missile defense system is providing the West Coast. However, given the theoretical acquisition of nuclear-capable hypersonic weapons, the North Korea-US situation would turn more stable since North Korea could assure the vulnerability of the US and its allies. The assumption underpinning this statement is if North Korea's nuclear arsenal could somehow attain all six Wohlstetter attributes to truly realize this potential deterrent stability. However, North Korea has a long way to go in meeting Wohlstetter's stability attributes.

Another hypothetical case to consider is hypersonic weapons in the Middle East. If the undeclared nuclear power of Israel were to procure hypersonic capability (nuclear or conventional), the instability would remain the same since there are no other opposing nuclear powers in the region (table 4, situations A to D). However, if Iran obtained a nuclear hypersonic missile capability, the deterrent environment would turn more stable (situation H) (assuming Israel only possesses BMD and Iran refrains from proliferating this theoretical acquisition of nuclear hypersonic technology to its proxy forces and terrorists in the region). This newly acquired Iranian capability would increase stability since Iran could theoretically penetrate Israeli missile defenses, putting some of Israel's nuclear capability, conventional forces, and general population at a perceived higher risk, achieving assured vulnerability, fundamentally deterring Israel from striking Iran.[72]

Transition Instability

A period of increased instability will occur during the phase in which nuclear hypersonics become operational. This turbulence will peak as one nuclear country deploys hypersonic weapons while others are still in developmental stages. Once this occurs, nuclear powers without hypersonic capability will perceive a disadvantage and be more vulnerable to a strike from the nation with the defense-penetrating capability. During this time, the disadvantaged power will contemplate and recalculate its options, deciding whether a first strike is warranted because of its perceived vulnerability. As Thomas Schelling stated, "Vulnerable strategic weapons not only invite attack but in a crisis could coerce the . . . government into attacking when it might prefer to wait."[73] Therefore, until opposing powers share the same vulnerabilities and/or comply with Wohlstetter's stability criteria, the mismatch in nuclear attributes will promote instability. Additionally, when competing countries possess ballistic missile defenses and no defense-penetrating capabilities (table 4, situation B), instability will rumble through the nuclear deterrent paradigm: assured vulnerability is completely undermined with neither country convinced it could launch a credible counterstrike. Therefore, as a counter to ballistic missile defenses, hypersonic weapons are a natural evolution in nuclear deterrent systems; they should be anticipated and expected to bring back true assured vulnerability. The danger lies during the transition to assured vulnerability and should be managed in a manner that minimizes risk from the absence of BMD and hypersonics.

Conclusion and Policy Considerations

Two solutions exist to mitigate the impending problems of nuclear hypersonic missiles: dismantle the ground-based missile defense program and add hypersonic specific technology to a nonproliferation ban. As identified here, missile defense is the primary reason for increased nuclear instability and the impetus for the development of nuclear-tipped hypersonic weapons. Specifically, the ground-based midcourse defense system established in Alaska and the West Coast of the US has undermined assured vulnerability by degrading Russia's and China's ability to hold targets in the Western Hemisphere at risk. As Wohlstetter asserts, mutual assured vulnerability is critical to a stable nuclear stalemate. Therefore, the best policy to stabilize the nuclear deterrence environment among the three great nuclear powers (China, Russia, and the US) is to dismantle continental missile defenses and discontinue further development since missile defense is underwriting the emerging hypersonic arms race.

Stabilizing regional nuclear deterrence is a more difficult problem. Many of the regional nuclear powers possess a form of BMD that has at least some capability against each other's nuclear delivery systems. As stated earlier, the natural evolution of these regional nuclear standoffs is to develop nuclear weapon systems that can defeat missile defenses. Consequently, opposing regional nuclear powers will want to develop hypersonic weapons. The dangerous transition periods will emerge during the unbalance of capability—when only one opposing nuclear power attains this hyper-fast, defense-penetrating weapons. During this window, tensions will heighten while adversaries weigh their options, including a preemptive strike to remove this hyper capability from their foe, a heightened nuclear alert posture that sows seeds for a crisis, and/or an increase in bellicose rhetoric. There may well be two options to prevent the regional hypersonics dilemma: quickly proliferate hypersonic technology to all nuclear powers, or add hypersonic technology to the Hague Code of Conduct against Ballistic Missile Proliferation and/or the Missile Technology Control Regime to halt hypersonic proliferation. One option is highly improbable and laced with danger (exporting high-tech weapons to adversaries). The other requires action before the window of technology maturation closes and it is too late to prevent calamity.

After unpackaging hypersonic capabilities and deterrence theory, it should be apparent how maturing hypersonics technology will impact nuclear deterrence. Mature nuclear powers will experience an era of greater strategic stability since each will be more vulnerable to each other's hypercapability, solidifying the desired nuclear stalemate. Regional nuclear powers that develop nuclear hypersonic capability will incite regional instability since one power will have the advantage of the first strike to disable/destroy its opponents' retaliatory nuclear capability. In the long term, regional stability should increase—assuming hypersonic technology proliferates quickly among these nascent nuclear powers and their respective nuclear capability matures to provide a guaranteed costly, retaliatory strike. Overall, the period when this technology is not evenly distributed among nuclear powers will be the highest period of instability. The world is at a crossroads: it can stand by and let the introduction of hypersonic technology sneak in and induce nuclear instability, or it can take action by limiting the export of hypersonic technology and eliminating missile defense. SSQ

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Notes

1. Keith B. Payne, *Deterrence in the Second Nuclear Age* (Lexington: The University Press of Kentucky, 1996), 148.

2. Gregory Kulacki, *China's Military Calls for Putting Its Nuclear Forces on Alert* (Cambridge, MA: Union of Concerned Scientists, January 2016), https://www.ucsusa.org/.

3. Congressional Research Service (CRS), *Hypersonic Weapons: Background and Issues for Congress* (Washington, D.C.: CRS, 17 March 2020), updated 27 August 2020, https://crsreports.congress.gov/, 17.

4. Andrew Osborn, "Putin, before Vote, Unveils 'Invincible' Nuclear Weapons to Counter West," 1 March 2018, Reuters, https://www.reuters.com/.

5. Richard Stone, " 'National Pride Is at Stake': Russia, China, United States Race to Build Hypersonic Weapons," *Science Magazine*, 8 January 2020, https://www.sciencemag.org/.

6. Congressional Research Service, *Hypersonic Weapons*, 1.

7. Kyle Mizokami, "Could Hypersonic Weapons Make Nuclear War More Likely?," *Popular Mechanics*, 12 October 2017, https://www.popularmechanics.com/.

8. While the brief citations of Schelling's work in this article may miss some of the nuance of his ideas, the author chose Wohlstetter's six attributes as the best possible criteria to judge the effects and implications of new technology on deterrence. Obviously, many other nuclear deterrence scholars, including Colin Gray and Herman Kahn, have profound ideas on deterrence that are outside the scope of this argument.

9. Albert J. Wohlstetter, "The Delicate Balance of Terror," *Foreign Affairs* 37, no. 2 (1959): 216.

10. Lawrence Freedman, *The Evolution of Nuclear Strategy*, 3rd ed. (New York: Palgrave Macmillan), 245, 255. Freedman describes in his lesson for arms control the cause and effect of improved defenses or offenses, how it spurs instability and an arms race. He states, "The lesson drawn for arms control was that, as every improvement on one side's defense provided no extra security but merely a spurt to the offence of the other, once both sides ceased making defensive moves forces could stabilize at current levels" (245). He also describes how, once the USSR realized the strategic upper hand of the US in nuclear capability, the USSR aggressively pursued a "major military build-up" to catch up with the US (255).

11. Thomas C. Schelling, *The Strategy of Conflict* (New York: Oxford University Press, 1973), 232.

12. Fred M. Kaplan, *The Wizards of Armageddon* (Stanford: Stanford University Press, 1991). In chaps. 9 and 10, Kaplan points out how the 1957 launch of *Sputnik* stoked the already existing fears of a missile gap. Kaplan argues that these fears were largely founded in faulty intelligence reports that supported a general intellectual consensus (fed by the Gaither Report and Wohlstetter's R-290 report) that the USSR was gaining on the US with superior nuclear deterrence technology, numbers of bombers, and estimates they would have hundreds of ICBMs by 1960. Along with these reports, Sputnik's launch reinforced justification for accelerated procurement if US ICBMs.

13. Kaplan, 160.

14. Stephan Kieninger, "Diverting the Arms Race into the Permitted Channels: The Nixon Administration, the MIRV-Mistake and the SALT Negotiations," Nuclear Proliferation International History Project (NPIHP) Working Paper No. 9, The Woodrow Wilson International Center for Scholars, November 2016, https://www.wilsoncenter.org/. MIRVs essentially would overwhelm any defensive system with thousands of individual nuclear warheads.

15. Kieninger.

16. Kieninger.

17. See Lt Col Nathan B. Terry, USAF, and Paige Price Cone, "Hypersonic Technology: An Evolution in Nuclear Weapons?," *Strategic Studies Quarterly* 14, no. 2 (Summer 2020): 76, https://www.airuniversity.af.edu/.

18. Tom Benson, "Speed Regimes: Low Hypersonic," Glenn Research Center, US National Aeronautics and Space Administration, accessed 9 January 2017, https://www.grc.nasa.gov/.

19. Tom Benson, "Speed Regimes: Hypersonic Re-Entry," Glenn Research Center, US National Aeronautics and Space Administration, accessed 9 January 2017, https://www.grc.nasa.gov/.

20. John D. Gresham, "S-400 Triumf/SA-21 Growler: New Threat Emerging," Defense Media Network, 8 April 2011, http://www.defensemedianetwork.com/.

21. John D. Anderson, Jr., *Modern Compressible Flow: With Historical Perspective*, 3rd ed. (Boston: McGraw-Hill, 2003), 19.

22. Anderson, 19.

23. William H. Mason, professor, Virginia Tech, "Hypersonic Aerodynamics," chap. 11 in "Configuration Aerodynamics," self-developed textbook for course AOE 4124, accessed 20 January 2017, http://www.dept.aoe.vt.edu/.

24. NASA, "Speed Regimes: Hypersonic Re-Entry." Zirconia was used in the heat shield of the X-43A. T. A. Heppenheimer, *Facing the Heat Barrier: A History of Hypersonic Flight* (Washington, D.C.: National Aeronautics and Space Administration, 2007), 269.

25. Luu Hong Quan et al., "Analysis and Design of a Scramjet Engine Inlet Operating from Mach 5 to Mach 10," *International Journal of Mechanical Engineering and Applications* 4, no. 1 (2016): 11–23. This article describes a *scramjet* as a "supersonic combustion ramjet, a variant of the ramjet engine cycle. Different from other types of air breathing engine like turbojet and turbofan, [the] ramjet engine doesn't rely on turbo machinery but shockwave for compression." For a scramjet, supersonic air is compressed by shockwave "before entering the combustor where fuel is injected and burnt. Air is then accelerated through a nozzle to create thrust." Quan et al., 11–23.

26. The US Army's Advanced Hypersonic Weapon, a hypersonic boost-glide vehicle, has been launched without leaving the atmosphere. The point here is that a hypersonic boost-glide weapon does not have to leave the atmosphere, but longer ranges (intercontinental) will likely require higher exoatmospheric boosts. John Reed, "Army Successfully Tests Hypersonic Weapon Design," *DefenseTech*, 17 November 2011, http://defensetech.org/.

27. James M. Acton, *Silver Bullet? Asking the Right Questions about Conventional Prompt Global Strike* (Washington, D.C.: Carnegie Endowment for International Peace, 2013), 35, https://carnegieendowment.org/. This slowing descent is indicative of the severe aerodynamic loading experienced at lower altitudes primarily due to higher air densities at lower altitude. High-altitude hypersonic flight is desired to limit these loads (pressures) and simplify design efforts to focus on the extreme thermal management issues. Barry Hellman, Air Force Research Laboratory, Aerospace Systems High-Speed Division engineer (interview by the author, 10 February 2017).

28. Acton, *Silver Bullet?*

29. The Minotaur IV Lite boost vehicle (formerly the booster for the Peacekeeper ICBM) was used by Hypersonic Test Vehicle 2, which could carry up to 1,730 kg and produces 500,000 lbs of thrust at launch. "Minotaur IV," GlobalSecurity.org, accessed 23 January 2017, http://www.globalsecurity.org/. The space shuttle (74,800 kg) used two solid-rocket boosters, each producing 3.3 million pounds of thrust at launch. NASA, Kennedy Space Center, "Solid Rocket Boosters," accessed 23 January 2017, https://science.ksc.nasa.gov/. Excerpted from National Space Transportation System (NSTS) News Reference Manual handed out to the press in September 1988. Logic follows that larger booster equals larger hypersonic aircraft, but the limiting factor will likely be cost, which gives the Minotaur (50 or so available in US stock, per "Minotaur IV," GlobalSecurity.org) the edge in being the hypersonic booster of choice due to its ready availability.

30. Acton, *Silver Bullet?*, 80.

31. Mason, "Hypersonic Aerodynamics," 25.

32. Arms Control Association, "The Intermediate-Range Nuclear Forces (INF) Treaty at a Glance," fact sheet, accessed 25 January 2017, https://www.armscontrol.org/. The INF Treaty specifically banned "ground-launched ballistic and cruise missiles with ranges of 500 to 5,500 kilometers." Arms Control Association, fact sheet. Australian researchers, however, have ground-launched hypersonic air-breathing vehicles (with the point being that this mode of launch is possible. Heppenheimer, *Facing the Heat Barrier*, 275.

33. Joseph Cirincione, *The Ballistic Missile Threat*, testimony (Washington, D.C.: Carnegie Endowment for International Peace, 2001), http://carnegieendowment.org/.

34. US hypersonic programs launch air-breathing hypersonic vehicles from a B-52 bomber or L-1011 via boosters are advertised to carry approximately 1,000–1,240 lbs of payload. NASA Armstrong, "Hyper-X Program," fact sheet, 28 February 2014, https://www.nasa.gov/; Orbital ATK, "Pegasus Patented Air Launch System," fact sheet, 2017, https://satsearch.co/; and Florian Ion Petrescu and Relly Victoria Petrescu, *New Aircraft II* (Norderstedt, Germany: Books on Demand GmbH, 2012), 110, http://dx.doi.org/10.13140/RG.2.1.2584.6480. The X-51A Waverider and booster weigh approximately 4,000 lbs (1,800 kg) (the MGM-140 Army Tactical Missile System [ATACMS] booster weighs 2,900–3,600 lbs [1,300 – 1,670 kg] alone), with a scramjet fuel capacity of ~270 lbs (122 kg). When readied for launch, the full stack (booster and vehicle) is 25 feet in length. Andreas Parsch, "MGM-140," in *Directory of U.S. Military Rockets and Missiles*, accessed October 2020, http://www.designation-systems.net/; and US Air Force, "X-51A Waverider," fact sheet, 2 March 2011, https://www.af.mil/. In this configuration, the Waverider advertises a 240-second scramjet burn at Mach 5.1 (~4,000 miles per hour), giving it a range of ~266 miles (428 km). Assuming the same flight time at Mach 10 (~7,610 mph), this would equate to range of 507 miles (815 km). These powered-cuise distances do not include boost and glide time. Assuming expected glide characteristics of a boost-glide vehicle (likely much less due to low lift/drag design of the hypersonic cruise vehicles), I use the 4 to 1 ratio mentioned earlier), assuming 100,000 feet operating altitude, to calculate an X-51 glide range of 75 miles (120 km)—which brings a max range of ~582 miles (936 km). James Acton, "Hypersonic Boost-Glide Weapons," *Science and Global Security* 23, no. 3 (September 2015): 191–219, https://doi.org/10.1080/08929882.2015.1087242. With boost phase included, the X-43 yper-X has an expected range of 850 miles (1,367 km). NASA, "Hyper-X Program."

35. Air Force acquisition official (interview by the author, January 2017).

36. Acton, *Silver Bullet?*, 65.

37. Acton, 156. Review "How a Missile Only Becomes Visible to a Powerful Radar Once It Has Passed through the Radar's Horizon" for a description of missile detection.

38. John D. Anderson, *Hypersonic and High Temperature Gas Dynamics*, 2d ed. (Reston, VA: American Institute of Aeronautics and Astronautics, Inc., 2006), 18.

39. Anderson, 73. Additionally, Dr. Kopp addressed an upgraded S-300 system that boosted tactical antiballistic missile capability comparable to early models of the Patriot system. Carlo Kopp, *Almaz S-300P/PT/PS/PMU/PMU1/PMU2 Almaz-Antey S-400 Triumf SA-10/20/21 Grumble/Gargoyle*, Technical Report APA-TR-2006-1201, Air Power Australia, December 2006, http://www.ausairpower.net/.

40. Carlo Kopp, *Almaz-Antey 40R6 / S-400 Triumf: Self Propelled Air Defence System / SA-21*, Technical Report APA-TR-2009-0503, Air Power Australia, May 2009, http://www.ausairpower.net/.

41. Aerospace Daily & Defense Report, "S-300 Surface-To-Air Missile Systems," *Aviation Week*, 6 August 2015, 6–10; and Carlo Kopp, *Almaz-Antey S-500 Triumfator M Self Propelled Air / Missile Defence System* / SA-X-NN, Technical Report APA-TR-2011-0602, Air Power Australia, June 2011, www.ausairpower.net/.

42. Mark Episkopos, "Introducing Russia's S-500: Can It Take Out an F-22 or F-35?," *The National Interest*, 18 May 2019, https://nationalinterest.org/. Episkopos speculates that the S-500 will proliferate through China and Russia sales.

43. Acton, *Silver Bullet?*, 67.

44. Hellman, interview. Mr. Hellman explained how the air density at lower altitudes creates high dynamic pressures that lead to overpressures in the scramjet, ultimately rendering it inoperative.

45. Charles R. McClinton, "X-43–Scramjet Power Breaks the Hypersonic Barrier: Dryden Lectureship in Research for 2006," 44th American Institute of Aeronautics and Astronautics (AIAA) Aerospace Sciences Meeting and Exhibit, Reno, Nevada, 9–12 January 2006, published online 21 June 2012, https://doi.org/10.2514/6.2006-1; and Acton, *Silver Bullet?*, 77. Acton states

about a video of an HTV-2 test that "the HTV-2 produced so much heat that it is actually visible to the naked eye." Acton, *Silver Bullet?*, 77.

46. Kopp, *Almaz-Antey 40R6 / S-400 Triumf*. Dr. Kopp notes that the S-400 interceptor employs "canards and thrusters to achieve extremely high G and angular rate capability throughout the engagement envelope."

47. William Yengst, *Lightning Bolts: First Maneuvering Reentry Vehicles* (Mustang, OK: Tate Publishing & Enterprises, LLC, 2010), 159–67.

48. Yengst, 167.

49. National Air and Space Intelligence Center (NASIC), *Ballistic & Cruise Missile Threat*, NASIC-1031-0985-13 (Wright-Patterson Air Force Base, OH: NASIC, 2013), 18, https://fas.org/. See also James M. Acton, "Prompt Global Strike: American and Foreign Developments," testimony before the House Armed Services Subcommittee on Strategic Forces, Washington, D.C., 8 December 2015, Carnegie Endowment for International Peace, https://carnegieendowment.org/; and Minnie Chan, "China's latest hypersonic vehicle test seen as 'nuclear deterrent' amid US interference," *South China Morning Post,* 13 June 2015, http://www.scmp.com/.

50. NASIC, *Ballistic & Cruise Missile Threat*, 18.

51. Kelsey Davenport, "India Tests Hypersonic Missile," Arms Control Association, October 2020, https://www.armscontrol.org/

52. Rahul Singh, "India's Tribute to Missile Man: New BrahMos Gets Kalam Name," *Hindustantimes*, 8 August 2015, http://www.hindustantimes.com/.

53. Quoted in Joseph Cirincione, "Brief History of Ballistic Missile Defense and Current Programs in the United States," testimony, 1 February 2000, Carnegie Endowment for International Peace, https://carnegieendowment.org/.

54. Department of Defense, *Quadrennial Defense Review 2014* (Washington, D.C.: Department of Defense, 2014), 14, https://archive.defense.gov/; and Department of Defense, *Missile Defense Review 2019* (Washington, D.C.: Department of Defense, 2019), ii, https://www.defense.gov/.

55. Herman Kahn, "Twelve Nonissues and Twelve Almost Nonissues," Hudson Institute, 1 January 1984, https://hudson.org/.

56. Herman Kahn, *On Thermonucler War* (New Brunswick: Transaction Publishers, 2007), 519.

57. Both Lt Gen Glenn Kent, USAF, an analyst and developer of American defense policy, and Schelling discuss "first-strike stability" where neither force has an advantage in striking first. Ballistic missile defenses put any advesary at a "first strike" disadvantage, sowing instability. Schelling states, "Thus ABM systems deployed in both countries would make preemptive war more likely and the arms race more expensive." See Glenn A. Kent et al., *Thinking About America's Defense: An Analytical Memoir* (Santa Monica, CA: RAND Corporation, 2008), 73–80, https://www.rand.org/; and Thomas C. Schelling, "What Went Wrong with Arms Control?," *Foreign Affairs* 64, no. 2 (Winter 1985–86): 219–33.

58. Schelling, 219–33.

59. For US speculation on Chinese development of a nuclear hypersonic glider, see United States-China Economic and Security Review Commission, "China's Offensive Missile Forces," Hearing before the US - China Economic and Security Review Commission, 114th Cong., 1st sess., Washington, D.C., 1 April 2015, transcript, https://www.uscc.gov/, 1. For further speculation on Russian and Chinese nuclear hypersonic gliders, see Bill Gertz, "Russia and China Are Building Hypersonic Missiles and It's 'Complicating' Things for the US," *Business Insider*, 30 July 2015, https://www.businessinsider.com/; Lora Saalman, *Factoring Russia into The US-Chinese Equation on Hypersonic Glide Vehicles* (Solna: Stockholm International Peace Research Institute, 2017), 6, https://www.sipri.org/; and Department of Defense, *Missile Defense Review 2019*, iii.

60. Wohlstetter, "Delicate Balance of Terror," 213.

61. For specifics on this point, see Missile Defense Agency, "The Ballistic Missile Defense System," fact sheet, January 2018, https://www.mda.mil/; Missile Defense Agency, "Elements: Terminal High Altitude Area Defense (THAAD), accessed 9 February 2017, https://www.mda.mil/; and

Congressional Research Service, *Navy Aegis Ballistic Missile Defense (BMD) Program: Background and Issues for Congress* (Washington, D.C.: Congressional Research Service, 13 October 2020), https://fas.org/.

62. Dean A. Wilkening, "Does Missile Defence in Europe Threaten Russia?," *Survival* 54, no. 1 (2012): 31–52, https://doi.org/10.1080/00396338.2012.657531. For analysis of Chinese rhetoric against THAAD deployment in South Korea, see Jaganath Sankaran and Bryan L. Fearey, "Missile Defense and Strategic Stability: Terminal High Altitude Area Defense (THAAD) in South Korea," *Contemporary Security Policy* 38 no. 3 (2017): 321–44, https://doi.org/10.1080/13523260.2017.1280744; and Eric Gomez, "Why Putin Is Obsessed with America's Missile Defense," CATO Institute, 3 March 2018, https://www.cato.org/.

63. Keir A. Lieber and Daryl G. Press, "The New Era of Counterforce: Technological Change and the Future of Nuclear Deterrence," *International Security* 41, no. 4 (Spring 2017): 9–49, https://www.belfercenter.org/. In this article, the authors scan sensing technologies that could compromise locations of submarines, possibly jeopardizing the one nuclear triad counterforce capability that is considered the most concealed and invulnerable of the nuclear triad.

64. Until recently, many speculated that Pakistan and India kept their warheads unmated or disassembled from their delivery systems. David J. Karl, "Pakistan's Evolving Nuclear Weapon Posture," *The Nonproliferation Review* 21, no. 3-4 (2014): 317–36, http://dx.doi.org/10.1080/10736700.2014.1072998. However, some literature speculates that some of India's ballistic systems are sealed with a mated warhead. With India's no-first-use policy, this posture change does not alter my conclusion of reliance on posture rather than true stability as outlined by Wohlstetter. Vipin Narang, "Five Myths about India's Nuclear Posture," *Washington Quarterly* 36, no. 3 (2014):143–57, https://doi.org/10.1080/0163660X.2013.825555.

65. Rajesh Rajagopalan, "India: The Logic of Assured Retaliation," in *The Long Shadow: Nuclear Weapons and Security in 21st Century Asia*, ed. Muthiah Alagappa (Stanford: Stanford University Press, 2008), 196.

66. "INS Arihant: Nuclear Submarine Not "Fully Ready" for Patrols Carrying Nukes," *India.com*, 18 October 2016, http://www.india.com/.

67. In April 2016, it was reported that India finalized a deal with Russia to purchase 12 battalions of S-400 integrated air defense systems, which have missile defense capabilities. See Naveed Ahmad, "Analysis: Will India's S-400 missiles checkmate Pakistan?," *Express Tribune,* 29 April 2016, https://tribune.com.pk/. Additionally, India's missiles are all solid-fueled rockets, allowing them to remain on alert indefinitely—a clear advantage over Pakistan's liquid-fueled rockets that can remain on alert for only a day or so once fueled.

68. In the book section of *The Long Shadow*, Kahn states that China is "the only major power that sees the utility of a nuclear Pakistan as a balancer against India." However, there is no indication at this time that China is providing, or plans to provide, hypersonic technology to Pakistan. Feroz Hassan Khan and Peter R. Lavoy, "Pakistan: The Dilemma of Nuclear Deterrence," in Alagappa, *The Long Shadow*, 233.

69. John Reed, "What Do North Korea's Air Defenses Look Like?," *Foreign Policy*, 1 April 2013, http://foreignpolicy.com/.

70. In an interview, an Air Force acquisition official for hypersonic programs stated, "Each [conventional] hypersonic weapon costs 10–15 times less than a surface-to-air missile system" it would destroy. The official noted this was based on a $130M estimate per SAM site and $10M per production copy of a hypersonic missile. Air Force acquisition official, interview.

71. Department of Defense, *Quadrennial Defense Review 2014*, 14–32.

72. For more information on Israeli missile defenses, see Ruth Eglash and William Booth, "Israel to Launch One of the Most Advanced Missile Defense Systems in the World, with US Help," *Washington Post*, 3 March 2016, https://www.washingtonpost.com/.

73. Schelling, *Arms and Influence*, 233.