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Hypersonic Weapons and Strategic Stability

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Key Points

1. Aerial vehicles that can travel in excess of Mach-5 are labelled as hypersonic.
2. Three nations (Russia, China, USA) have been testing hypersonic glide vehicles (HGVs), although a number of other countries are also pursuing hypersonic programmes.
3. An HGV, armed with a nuclear or a conventional warhead, or merely relying on its kinetic energy, has the potential to allow a military to rapidly and pre-emptively strike distant targets anywhere on the globe within hours or less.
4. On account of their quick-launch capability, high speed, lower altitude and higher manoeuvrability vis-à-vis Intercontinental Ballistic Missiles , HGVs are difficult to detect and intercept with existing air and missile defence systems.
5. This capability could tempt a nation to consider using HGVs for a disarming and first-strike on an adversary's nuclear arsenal.
6. While numerous challenges remain, operational deployment of HGVs would thus compel target nations to set their nuclear forces on a hair-trigger readiness and "launch on warning" alerts, leading also to the devolution of command over nuclear weapons.
7. Overall, this would aggravate strategic instability, and also generate unacceptable levels of instability in crisis management at many levels.

On March 30, Russia stated that it had successfully carried out an ejection test of its most advanced, nuclear-capable intercontinental ballistic missile (ICBM), the RS-28 'Sarmat' (NATO designation: SS-X-30 Satan-2). Reportedly, the 'Sarmat' can carry around 10 heavy nuclear warheads, or more importantly, 3–5 warhead-equipped Yu-71 'Avangard' Hypersonic Glide Vehicles (HGV). On March 01, Russian President Vladimir Putin, in his State of the Union address, indicated that the underproduction Yu-71 HGV was developed in response to the United States' withdrawal in 2002 from the Anti-Ballistic Missile (ABM) treaty[1]. Earlier, in November 2017, China had carried out two tests of its HGV-mated Dongfeng (DF)-17 ballistic missile[2]. The HGV (called WU-14) for the DF-17 has undergone seven known tests and reportedly reached speeds between Mach-5 and Mach-10. The US intelligence community assessed that the Chinese DF-17, with a range of 1800–2500 km, could deliver both nuclear and conventional payloads, and is expected to reach the Initial Operating Capability (IOC) by around 2020. Separately, the US Air Force General John Hyten, Chief of the US Strategic Command, testified (March 20; to the Senate Armed Services Committee), that "we don't have any defence that could deny the employment of such a weapon against us." Recently (last week of April 2018), Secretary of Defense Jim Mattis told the Senate Armed Services Committee that "hypersonics, as also

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the defence against them, is the number one priority" for the US military's research and development.

Although the Pentagon is now warning about Russian and Chinese hypersonic weapons, the fact is that the United States has been developing this technology for years. According to James Acton of the Nuclear Policy Program at the Carnegie Endowment for International Peace, "evidence available in the open source suggests that the US is still the leader in these technologies." Thus, many consider the Chinese and Russian hypersonic programmes a consequence of the US initiatives. In the third week of April 2018, the US Air Force awarded M/s Lockheed Martin a contract to develop yet another hypersonic cruise missile, the hypersonic conventional strike weapon. However, it is not just the United States, Russia and China that are developing hypersonic vehicles—a number of other nations have hypersonic vehicle programmes. Similar to many other modern technologies, hypersonic vehicles also have a dual-use nature—they could be used for non-military purposes (including space launch, retrieval of satellites/spacecraft, transporting cargo to and from a space station, etc.)—and can be also turned into a weapon. Although formidable technical challenges in diverse fields, including in material sciences, need to be overcome for operational deployment of hypersonic weapons, the proliferation of hypersonic technology, and in turn, of hypersonic weapons, holds ominous portents—once operational, they would create new and substantial challenges to strategic stability and also encourage adventurism.

Hypersonic Vehicles

Aerial vehicles that can travel in excess of five times the speed of sound, or Mach-5, are labelled hypersonic. Hypersonic weapons can be broadly divided into two categories, that is, Hypersonic Glide Vehicles (HGV) and Hypersonic Cruise Missiles (HCM).

Hypersonic Glide Vehicles

The aerodynamic HGV is a boost-glide weapon—it is first 'boosted' up into near space atop a conventional rocket and then ejected at an appropriate altitude and speed. The height at which it is released depends on the intended

Impression showing a HGV atop a rocket just after the shroud / fairings have fallen off, exposing the HGV just prior to its release

trajectory to the target. Thereafter, the HGV starts to fall back to Earth, gaining more speed and gliding along the upper atmosphere, before diving on the target.

Hypersonic Cruise Missiles

An HCM on the other hand, is typically propelled to high speeds (around Mach 4 to 5) initially using a small rocket; thereafter, an air-breathing supersonic combustion ram jet or a 'scramjet' accelerates it further and maintains its hypersonic speed. HCMs are hypersonic versions of existing cruise missiles but would cruise at altitudes of 20–30 km in order to ensure adequate pressure for its scramjet. Standard cruise missiles are difficult to intercept—and the speed of the HCM and the altitude

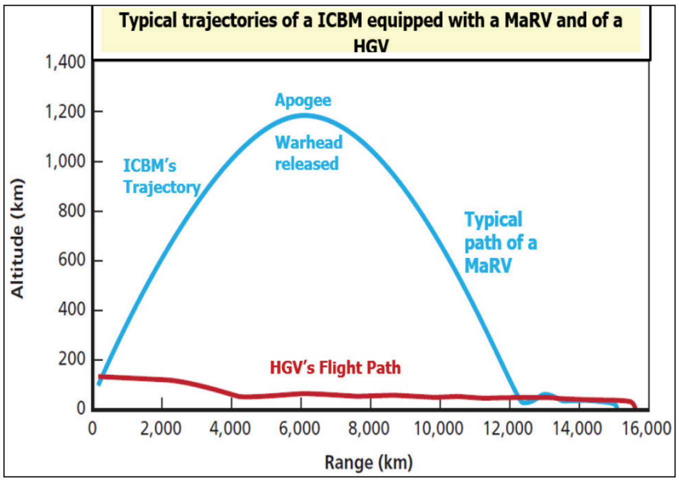
Boeing's X-51 "WaveRider" HCM (May 26, 2010; Edwards Air Force Base, USA)
Picture by USAF

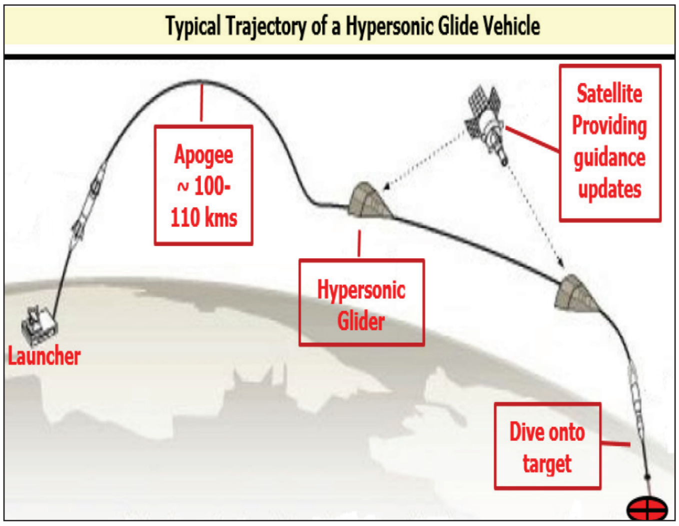
Russia's 'Kinzhal' HCM (reported range: 2000 kms). Its launch platform, the MiG-31BM, has a reported range of about 3000 kms un-refuelled. This implies that the 'Kinzhal' may have intercontinental strike

at which it travels complicates this task of interception manifold. The United States' underdevelopment 'WaveRider' is a typical HCM. Russia's HCM, the aircraft-launched Kh-47M2 'Kinzhal', (Dagger), has a reported top speed of Mach-10 and a range of about 2000 km. India's underdevelopment 'Hyper Sonic Technology Demonstrator Vehicle' (HSTDV) too, capable of speeds around Mach-7, falls in the category of an HCM[3].

Salient Differences Between an ICBM and an HGV

Altitude: The Intermediate Range Ballistic Missile (IRBM) and the Intercontinental Ballistic Missile (ICBM) rise to very high altitudes (~1000 km). After the various stages burn out, the flight, except in the case of Manoeuvrable Re-entry Vehicle (MaRV), is ballistic and dictated by gravity—the missile has a prescribed course that cannot be changed after the missile has burned its fuel, unless the warhead manoeuvres post-release from the missile body





or some form of terminal guidance is provided. HGVs, on the other hand, do not rise above 100–110 km altitude and spend over 80–100 percent of their flight time below 100 km altitude (i.e. within the atmosphere).

Heating: Another major difference between an ICBM's Re-entry Vehicle (RV) and an HGV is the heat that they are subjected to and have to handle. As stated above, an HGV spends 80–100 percent of its time within the atmosphere, whereas an ICBM and its RV spend most of its flight time (~80 percent) outside the atmosphere. HCMs conduct their entire flight within the atmosphere. In other words, the HGVs and HCMs require special materials and 'hardening' against the heat generated on account of the hypersonic flight through the atmosphere.

Manoeuvrability: The HGV would be far more manoeuvrable than the MaRVs of an ICBM. Apart from being able to evade air and missile defence systems, it can also keep its target a secret till the last few seconds.

Detection Time for Interception

Inter-continental Ballistic Missiles: Because ICBMs (launched from land or sea) tend to follow a predictable path and rise to an altitude of around 1000–1200 km, they can be detected and then intercepted by Anti-Ballistic Missile (ABM) systems, particularly in mid-course and terminal phases of their flight. Yet, in a 'launch on attack' scenario, as per an August 2017 assessment by the Nuclear Threat Initiative[4], the President of the United States would have just 2–3 min to make a decision to respond to an attack by Russia. The response timeline is indicated below[5]:

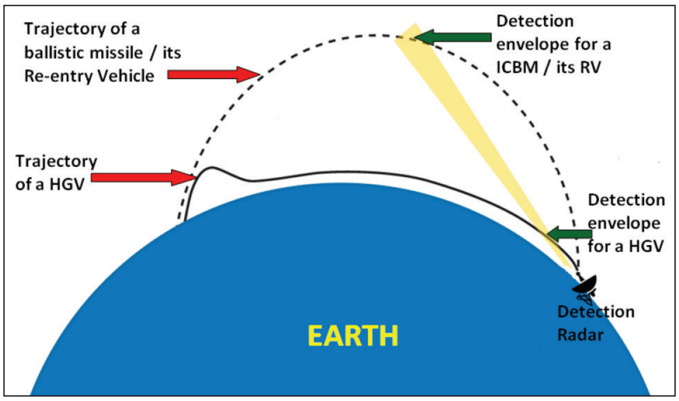
L (launch)	Russia launches ICBMs from its mainland and Submarine Launched Ballistic Missiles (SLBM) from its nuclear-powered ballistic missile equipped submarines (SSBNs) at sea
L + 1 min	US satellites detect Russian missiles as they break out of cloud cover, relay warning to a ground station in Germany
L + 2 min	US radars (e.g. in the United Kingdom) detect the missiles
L + 3 min	North American Aerospace Defence Command (NORAD) assesses this information (maximum 02 min permissible for decision)
L + 4/5 min	NORAD alerts the 'Crisis Coordinator' (usually the National Security Agency (NSA)) in the White House
L + 7 min	White House staffers locate President and advisers, assemble them, brief them, try and obtain a decision
L + 10 min	Russian SLBMs begin to land on targets in the United States
L + 13 min	Decision given by the President (provided the White House is not the target of a decapitation strike by Russian SLBMs)
L + 15 min	Decision transmitted to commence nuclear launch sequence
L + 18 min	Pre-formatted, encrypted 'Emergency Action Messages' (EAMs) sent from the US's National Military Command Centre, Pentagon, to nuclear forces to execute nuclear response attack
L + 20 min	Launch officers receive, decode and authenticate the orders
L + 23 min	Launch sequence completed (maximum 2 min available as Russian ICBMs would start to land on the US missile sites after that)
L + 25 min	Russian ICBMs hit targets in the United States. Remaining US's land-based ICBMs (that have not been launched till now) are likely destroyed

Detection-Interception Time: ICBMs

The above timeline also outlines the duration available for air defence, particularly ABM systems, to intercept the incoming ballistic missiles. It is important to note that in case of contiguous nations (e.g. India–Pakistan, India–China), the timelines would be far more compressed and any launch of a ballistic missile, even if tipped with a conventional warhead (e.g. India's 'Prithvi', China's massive arsenal of conventional warhead tipped SRBMs/ MRBMs intended for Anti-Access/Area Denial [A2/AD] tasks, etc.), could likely lead to a misunderstanding and inadvertent but swift escalation to nuclear levels.

Detection-Interception Time: HGVs

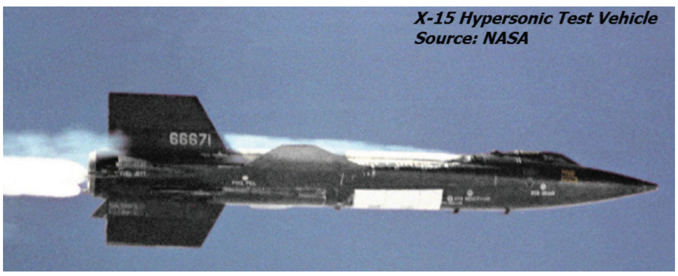
The detection-interception timeline in case of HGVs, travelling at speeds between Mach-5 and Mach-10, and with flatter trajectories vis-à-vis ICBMs, is far less. Given the Earth's curvature, this further complicates the task of detecting them. Together, these dynamics impinge on the ability to detect, decide and intercept HGVs. In other



words, the Observe, Orient, Decide and Act (OODA) cycle for HGVs is very tight and in case of contiguous nations, is almost non-existent.

Genesis of the HGV

Hypersonic vehicles are not a recent concept and the origins of the HGVs, or rather the 'boost-glide' system, can be traced back to the work done in Nazi Germany during World War-II—it had envisioned a rocket powered bomber attacking New York City from bases in Germany. It was, however, found that the heating load would be so high it would melt the spacecraft. Post-WW-II, research on this system continued in both the United States and Union of Soviet Socialist Republics (USSR)/Russia. The rocket-powered X-15 of the National Aeronautics and Space Administration (NASA), flown in 1959, was the first manned hypersonic air vehicle (average speed—about Mach-6.7). In addition are other aerial vehicles



X-15 Hypersonic Test Vehicle
Source: NASA

that have flown at hypersonic speeds, for example, the re-entry capsules of the Apollo and Soyuz spacecraft, the Space Shuttle, the RV of ICBMs, and so forth. Spacecrafts, however, are different from HGVs.

The genesis of the modern HGV and the HCM lies in the situation obtained after the '9/11' Attacks (September 11, 2001). Reflecting on the many missed opportunities to kill Osama bin Laden, US military experts had started to call for a system that could be launched from 'fortress America' and strike Al-Qaeda type of entities on the other side of the world in less than an hour. This concept got a boost from USA's post-Cold War basing construct. Throughout the Cold War, the United States had maintained a large number of military bases overseas so that it could deter conflict, and failing that, respond promptly to an attack. However, after the break-up of USSR, the United States restructured many of these forward bases and also closed some. This had impinged on the US military's capability to conduct precision strikes on emergent/fleeting targets.

The solution touted was a weapon that is based in, or near Continental United States [6] (CONUS) and could destroy a time-sensitive target around the globe within a matter of hours or less, either at the start of a conflict or during it, or before an adversary could camouflage/ conceal the target or flee[7]. With its Nuclear Posture Review (NPR) of 2001 and subsequent Quadrennial Defence Reviews emphasising the need for a prompt, long-range, global strike capability, the United States began work on a set of hypersonic 'Conventional Prompt Global Strike' (CPGS) weapons. It was felt that even if the CPGS was not equipped with either a nuclear or a conventional warhead, its massive kinetic energy (mass × hypersonic velocity) could unleash terminal effects that could be equal to a small-size nuclear strike but without the associated radiation and nuclear fallout, and importantly, without the danger of escalation to nuclear levels. It was left unstated whether hypersonic weapons could also be used for targeting military rockets/missiles about to be launched or for a 'disarming strike' against an adversary's nuclear assets.

Another factor was the increasing Chinese nuclear weapons delivery capabilities. Since 1972, the United States and Union of Soviet Socialist Republics (USSR)/ Russia had transacted a number of strategic arms limitations treaties[8]. Under these treaties[9], by 1991, the United States had eliminated all intermediate-range ground-launched ballistic missiles (range: 500–5500 km) under the 1987 Intermediate-range Nuclear Forces (INF) Treaty. In those days, China was not a military factor for the United States. Further, the United States had not developed road/rail mobile ICBMs—its 400 Minuteman-III ICBMs[10] (each with 1–3 warheads) are all ground-based in fixed silos and, hence, vulnerable to a 'first strike'. While the United States has a very substantial 'second-strike' capability, which is largely based around 12–14 Ohio-class SSBNs (each with 20 Trident-II/D-5 SLBMs[11]), the number of these submarines is expected to decline. Besides, under the New Strategic Arms Reduction Treaty (START), only 212 SLBMs are to be deployed (equivalent to 10 fully loaded SSBNs and two others in various stages of missile loading/offloading[12]). Further, the United States' fleet of heavy strategic bombers (20 × B-2 and 87 × B-52) are being converted to non-nuclear configuration or being retired gradually—by this year end, the number of deployed nuclear bombers is to be reduced to 60. Besides, nuclear weapons and their associated delivery systems are not only expensive to build but also involve huge recurring costs on their security and maintenance. With all three legs of the US strategic nuclear deterrent ageing, the Congressional Budget Office's October 2017 report assesses that USA's nuclear weapons spending plans are expected to cost about $1.2 trillion in inflation-adjusted dollars between fiscal year 2017 and 2046.

China, on the other hand, is not a signatory to any such treaty and has been modernising its nuclear forces. It now has road/rail-mobile IRBMs and ICBMs (e.g. the DF-5, DF-26, DF-31, DF-31A, DF-41). Such mobility bestows survivability and a 'second-strike' capability. In addition is the nascent capability of a few Type-094 Jin-class SSBNs equipped with the JL-2 SLBM. Thus, many US experts felt that their strategic concept, "the ICBM force provides responsiveness, the SLBM force provides survivability and bombers provide flexibility and recall capability,"[13] would get progressively imperiled as China built more survivable, agile and less-easily targetable IRBMs and ICBMs, and also progressed its substantial cruise missile programme. This gave an impetus to the HGV and HCM programmes in the United States.

China and Russia, however, perceive the United States' nuclear force modernisation as aggressive steps to enhance its military capabilities, and importantly, to build a capacity to fight and win a nuclear war by disarming enemies with a surprise 'first strike'. In this context they tend to cite, inter alia, four aspects, namely, (i) the United States' new 'super-fuze', (ii) the increased strike capability of the United States, (iii) the inadequate capacity of Russia and China to monitor US missile launches and (iv) their nascent ABM capabilities vis-à-vis the United States.

The New 'Super-Fuze'

From 2009 onwards, the US Navy's W76-1/Mk4A 100-kt nuclear warheads have been progressively fitted with the new 'super-fuze'. This "significantly increases the probability that a warhead will explode close enough to destroy the target even though the accuracy of the missile-warhead system has itself not improved"[14]. Consequently, as compared to about 20 percent about a decade ago, almost the entire US submarine force now has a 'hard-target kill capability'[15]. This significant increase in the USA's nuclear targeting capability has serious implications for strategic stability. Russian strategic experts, thus, tend to see the fuzing capability as empowering an increasingly feasible US pre-emptive nuclear strike capability[16] and consequently, a capability that would require Russia to place its nuclear forces at an even more dangerously high state of readiness. In turn, this increases the risk of inadvertent escalation.

Increased Second-Strike Capability of the United States

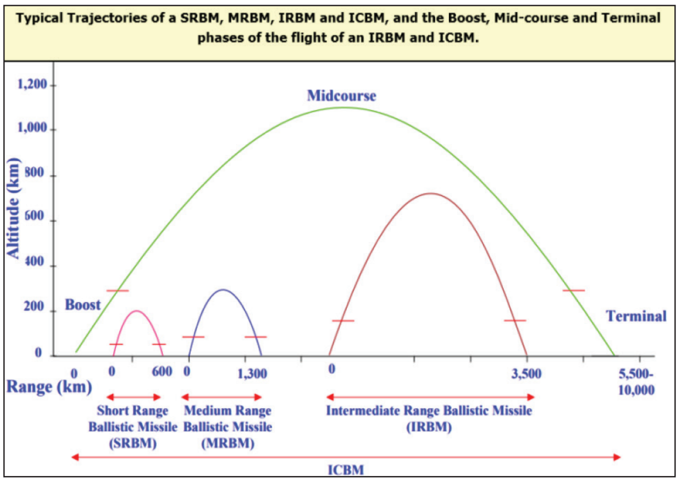
The newly created capability to destroy Russian silo-based nuclear forces with 100-kt W76-1/Mk4A warheads vastly expands the nuclear warfighting capabilities of US nuclear forces. The United States has approximately 890 warheads available for deployment on its SSBNs. Russia has about 136 silo-based ICBMs, which could be destroyed by targeting each silo with two super fuze-equipped warheads, that is, with a total of 272 warheads. In other words, only a part of the USA's sea-based nuclear force would be required to eliminate Russia's silo-based ICBMs, leaving the United States with a large number of other warheads of various yields (~79 percent of its missile force), including those on its 400 Minuteman-III missiles, available for 'other missions'[17].

Inadequate Capacity of Russia and China to Monitor US Missile Launches

Russia (and China) do not have a functioning Space-Based Infrared (SBIR) early warning system but relies primarily on ground-based early warning radars to detect a US missile attack. Since these radars cannot see over the horizon, Russia has less than half as much early-warning time (~15 min) vis-à-vis the United States (~30 min) [18]. The inability of Russia to globally monitor missile launches means that Russian military and political leaders would have no 'situational awareness' to help them assess whether an early-warning radar indication of a surprise attack is real or the result of a technical error or something else[19]. This combination of a lack of Russian 'situational awareness', short warning times, high-readiness alert postures, and the increasing US strike capacity creates a deeply destabilising and dangerous strategic nuclear situation.

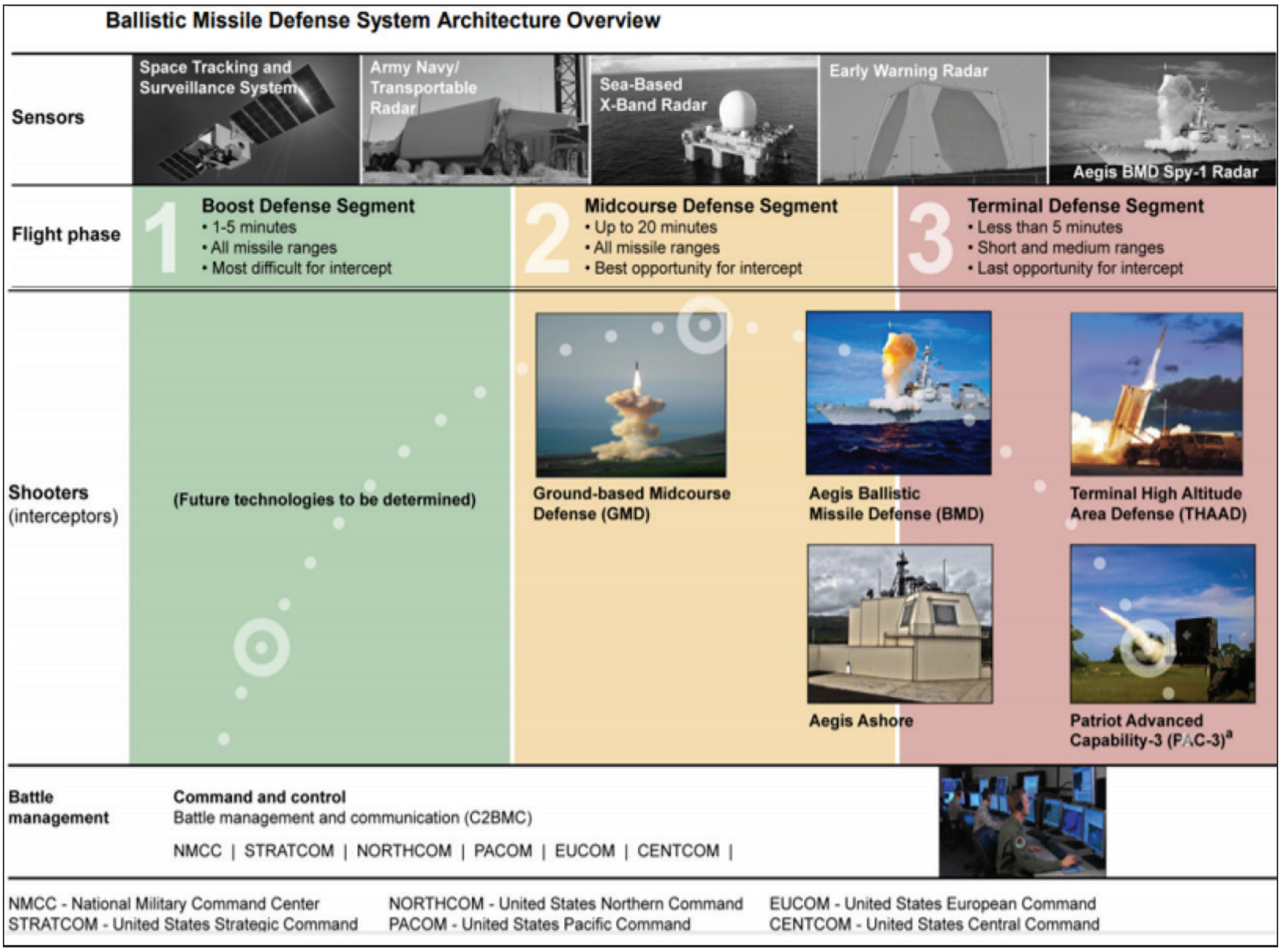
ABM Capability

ABM systems were the first to pose a challenge to strategic stability and consequently, the United States and former Union of Soviet Socialist Republics had transacted the



ABM treaty in May 1972 as part of the Strategic Arms Limitation Talks (SALT). The treaty originally permitted both countries to deploy two fixed, ground-based ABM sites of 100 missile interceptors each. One site could protect the national capital, while the second could be used to guard an ICBM silo field. In a protocol signed in July 1974, the two sides halved the number of permitted defences. Without an effective ABM system, each superpower remained vulnerable to the other's nuclear weapons, deterring either side from launching an attack first because it faced a potential retaliatory strike that would assure its own destruction[20]. In June 2002, the United States withdrew from this treaty, premising that the treaty thwarted its development of ABM defences against possible terrorist or 'rogue-state' ballistic missile attacks. Since then, the United States has built a wide array of ABM systems aimed at intercepting ballistic missiles in various phases of their flight. While it, yet, does not have the capability to intercept ballistic missiles in its boost phase, it has ground-based interceptors for interception in the mid-course phase, and the Aegis, Terminal High Altitude Area Defense (THAAD) as well as the Patriot Advanced Capability-1 (PAC-3) for terminal phase interception. While these systems are not 100 percent reliable and foolproof, these are far more advanced than any system that Russia or China have. Notably, the Chinese ambassador to the United Nations Conference on Disarmament had, in a June 2012 speech, stated that "China believes that the development of missile defence systems that disrupt global strategic balance and stability should be abandoned."

In addition to the above developments are the United States' HGV and HCM programmes. The Russians have, therefore, reacted to the above-mentioned developments by showcasing new nuclear weapons and delivery



platforms, and by developing HGVs. The Chinese too have responded with an HGV programme. According to George Nacouzi of RAND Corporation, "the US does not have any intention of putting nuclear warheads on its HGVs", but "China and Russia—especially Russia—have been pretty vocal about their worries about the US' missile defences. They worry that if the US can defeat their missiles, then their deterrence value goes away", and "it's apparent that Russia and China do plan on equipping hypersonic weapons with nuclear warheads" with "Russian and Chinese hypersonic development [also] likely focused on defeating US missile defence systems."

Implications for Strategic Stability

The launch-and-response timelines in the case of IRBMs and ICBMs, as also the submarine-based 'second-strike' capability of both nations, had given rise to the concept of Mutually Assured Destruction (MAD) during the Cold War. In turn, this had enforced strategic stability.

Both the HGV and HCM can carry nuclear or conventional warheads; the HGV however, need not carry any warhead but can rely on its kinetic energy to wreak damage. Unlike an IRBM or an ICBM, an HGV particularly, because of its flatter trajectory and high speed, will be far more difficult to detect, track and intercept with standard air and missile defence systems. Besides, on account of its quick launch capability, the HGV technology has the potential to allow a military to rapidly and pre-emptively strike distant targets anywhere on the globe and thereby 'defeat the tyranny of time and distance' (sensor-to-shooter lag, travel time to time-sensitive targets). This would sharply escalate the tempo of war. Such a situation would compel a target nation to set its nuclear forces on a hair-trigger readiness[21] and 'launch on warning' alerts. In turn, such readiness would logically lead to (i) devolution of command over nuclear weapons, thereby increasing the risk of accidental escalation and (ii) wider dispersal of nuclear weapons; a larger number of sites could result in weaker security. Thus, the deployment of HGVs would not only aggravate strategic instability but also generate unacceptable levels of instability in crisis management at many levels. Consequently, experts are warning that the operational deployment of HGVs by the United States, Russia and China will seriously imperil strategic nuclear stability. The development of HGVs by other nations pursuing such programmes (India, France, Australia, Japan and the European Union), particularly nations involved in conflicts, will severely undermine it further.

A few of the likely scenarios involving use of HGVs are outlined below:

- Lesser powers may consider using HGVs to reduce the force asymmetry vis-à-vis an adversary. 'Decapitation strikes' on leadership, attacks on a carrier battle group or major military bases, and so forth, are some of the plausible targets.
- Apprehending that its ABM systems would face challenges in intercepting a swarm of HGVs and HCMs, a major power may be tempted to consider a disarming, first-strike on an adversary's nuclear arsenal. In this case, it could even use HGVs equipped with conventional warheads (or a pure kinetic energy strike) while posturing its nuclear arsenal for a response. The response however, is unlikely to be with conventional weapons/warheads.
- Major powers, even those with advanced ABM systems, finding that the warning and reaction/response time against HGVs are vastly reduced, may place their nuclear weapons on a 'launch on warning' status, as also delegate control to the lower levels. Further, in absence of comprehensive CBMs between many nations, the apprehension is that nations with incomplete information or poor surveillance systems might presume a rocket launch as an HGV strike, and rather than waiting for more information, respond with nuclear weapons. This dynamic would be especially pronounced in case of contiguous nations like India and Pakistan as well as China and India.

Besides, HGVs and HCMs will likely lead to another debilitating arms race—advanced nations with adequate resources may be forced to invest heavily in strengthening their nuclear response systems against an HGV threat; others may be forced to rethink air and missile defence and evolve new systems at monumental costs. It is on account of all such apprehensions that strategic experts[22] opine that with a full-scale HGV arms race just around the corner, it is time to consider a ban on HGVs. The reality is that no one is listening.

Operational Deployment of HGVs

This year and the past ones have seen several tests of the HGV concept. However, involved nations have to refine two main challenges before HGVs can be deployed operationally and utilised, namely, (i) the heat shielding of the HGV and all its components and (ii) its guidance. Even when HGV weapon platforms are ready per se, the mission capability requirements for operational use of an HGV mission would require a series of networked sensors, feedback mechanisms and 'very definitive, real-time intelligence with progressive feedback'[23]. Most analysts agree that as of now, neither the United States, nor Russia nor China have the capabilities to fully support an HGV mission globally. Hence, there is, yet, time for the global community to rethink development of HGVs.

... Strategic Stability

Notes

1. The ABM treaty, signed between the United States and former Soviet Union in 1972, barred both countries from deploying defences against strategic ballistic missiles.
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4. http://www.nti.org/analysis/articles/launch-under-attack-feasible/
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7. U.S. Department of Defence, Office of the Under Secretary of Defence for Acquisition, Technology and Logistics, *Time Critical Conventional Strike from Strategic Standoff,* Report of the Defence Science Board Task Force, (Washington, D.C., 2009), p. 2, http://www.acq.osd.mil/dsb/reports/ADA498403.pdf.
8. SALT-I (1972); the Interim Agreement on Offensive Arms; SALT-II (1979); the 1972-1974 Anti-Ballistic Missile Treaty; the 1987 Treaty on the Elimination of Intermediate-Range and Shorter-Range Missiles / Intermediate-range Nuclear Forces (INF) Treaty; the July 1991 Strategic Arms Reduction Treaty (START-I)
9. Bulletin of the Atomic Scientists, "Nuclear notebook – US Nuclear Forces-2014".
10. Bulletin of the Atomic Scientists, "Nuclear notebook—US Nuclear Forces-2018": *"450 ICBM silos, in which 400 ICBMs and as many warheads are deployed. The 50 empty silos are "kept warm"* so missiles can be reloaded if necessary.
11. Bulletin of the Atomic Scientists, "Nuclear notebook—US Nuclear Forces-2018"; The US Navy has now reduced the number of missile tubes on each nuclear missile submarine to 20 from 24.
12. Bulletin of the Atomic Scientists, "Nuclear notebook—US Nuclear Forces-2018".
13. Admiral James Ellis, former Commander of US Strategic Command, in "The Future Missile Force", October 2005.
14. Bulletin of Atomic Scientists (January 25, 2017): "How US nuclear force modernization is undermining strategic stability."
15. Ibid.
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