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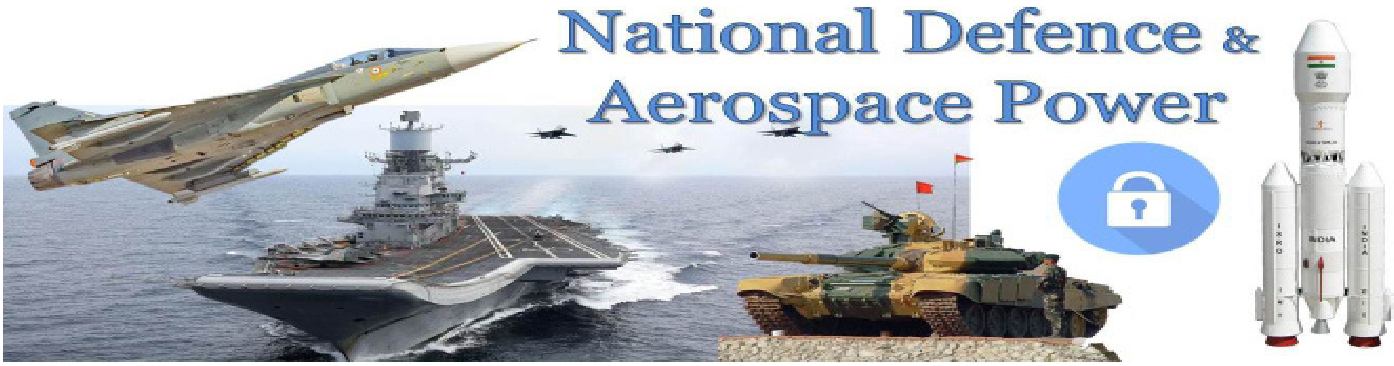

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HYPERSONIC MISSILE DEFENCE SYSTEM: A PERSPECTIVE

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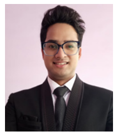


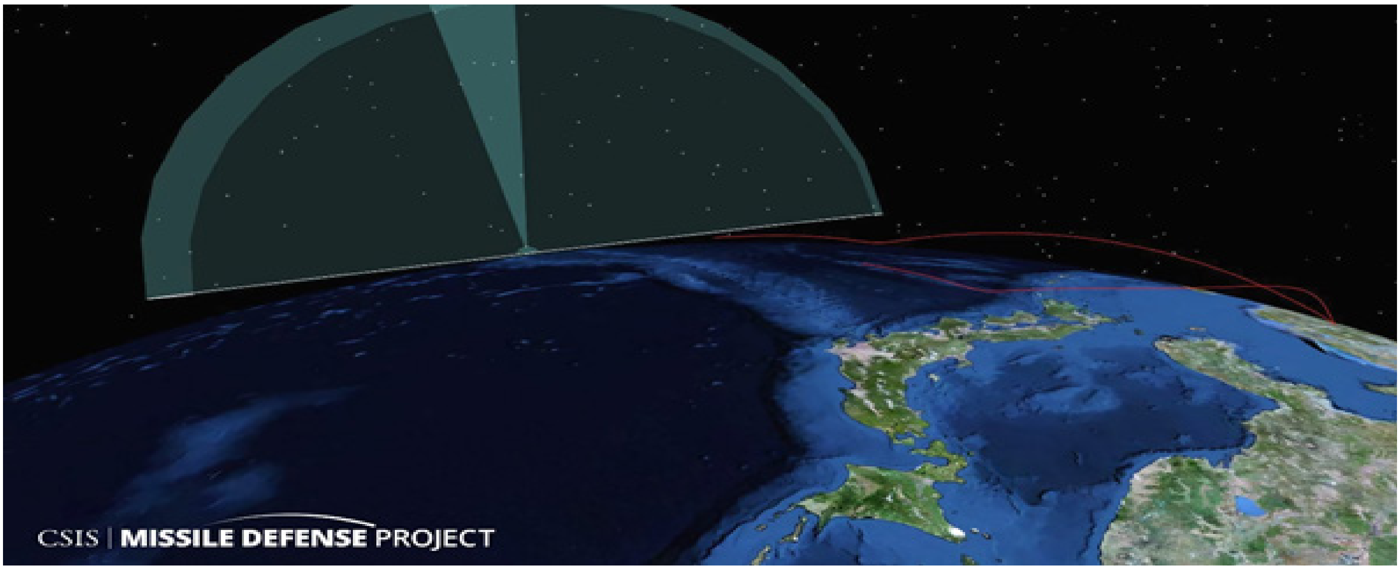
Not so Unstoppable: Defence is Possible

> **Hypersonic missiles exploit the limitations of conventional missile defences—the ability to detect, track, and intercept objects flying across a predictable parabolic trajectory—to gain an offensive advantage.**

Experts and scholars have dubbed hypersonic missiles invincible, unstoppable, and a missile defence panacea.[1] The underlying argument is that hypersonic missiles can carry out midcourse and terminal manoeuvres to evade missile defences, and thus it is impossible to develop protection against hypersonic threats. As illustrated through Figure 1, hypersonic missiles have an endoatmospheric flight, typically flying between 20 and 60 km, drastically reducing the surface radar detection range. Conceptually, hypersonic missiles exploit the limitations of conventional missile defences—the ability to detect, track, and intercept objects flying across a predictable parabolic trajectory— to gain an offensive advantage. The unpredictable flight trajectories of hypersonic missiles and their ability to execute extreme terminal manoeuvres render conventional missile defences obsolete.

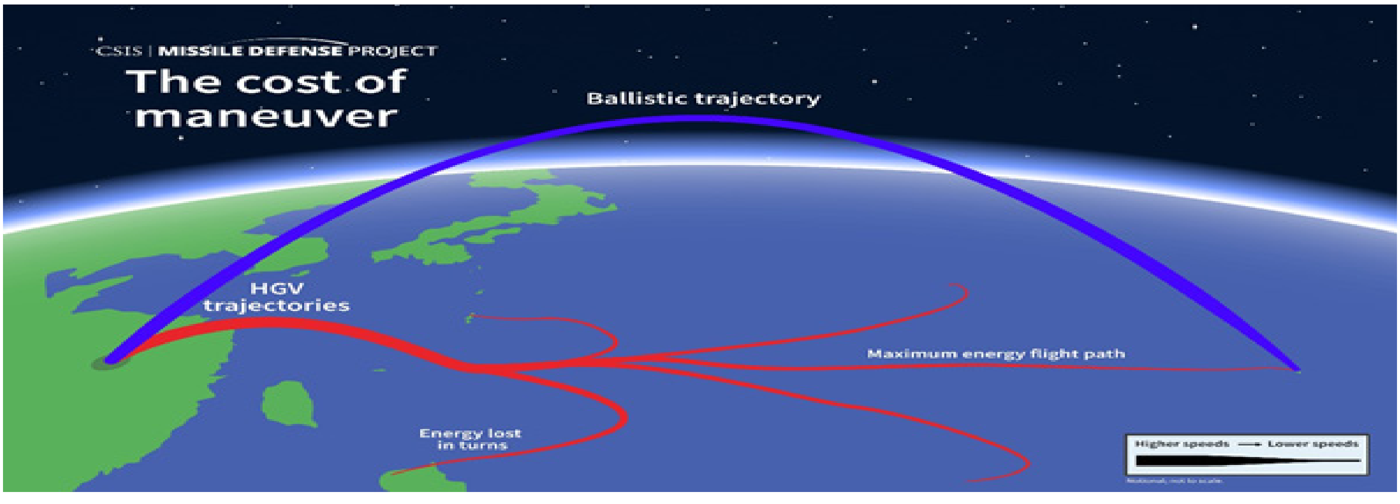
Undoubtedly, hypersonic missiles are better equipped to penetrate existing missile defences, but they are not unstoppable and not a missile defence panacea.[2] In a recent report published by the Center for Strategic and International Studies (CSIS), Tom Karako and Masao Dahlgren argue that "Hypersonic missile defence will not be easy, but neither is it impossible. Hypersonic missiles are not silver bullets, and they are not unstoppable."[3] Some of the attributes of hypersonic missiles that make them desirable weapons also present opportunities that the defender could seek to exploit. Although hypersonic missiles can manoeuvre, they have to spend considerable energy on them (refer Figure 2). In other words, manoeuvring comes at the cost of speed, range, and accuracy.[4] The costs impose constraints on the ability of hypersonic vehicles to manoeuvre in their gliding phase, which the potential defender could exploit to intercept them early in their flight when they are comparatively stable.[5]

Fig 1: Depiction of a Hypersonic Vehicle Underflying Surface Radar Sensors



Source: Tom Karako and Masao Dahlgren, *Complex Air Defense: Countering the Hypersonic Missile Threat*, CSIS Missile Defense Project (February 2022)

Fig 2: Costs of Maneuver



Source: Tom Karako and Masao Dahlgren, *Complex Air Defense: Countering the Hypersonic Missile Threat,* CSIS Missile Defense Project (February 2022)

Hypersonic missiles can fly at low altitudes, but they are not low enough to evade terrestrial radar systems when flying near the radar sensors. For "aerodynamic load and pressure limitations," hypersonic missiles cannot fly at lower altitudes where radar-evading cruise missiles fly.[6] Colonel Stephen Reny, US Air Force Academy, points out that, "lower altitudes are problematic for hypersonic flight because the lower altitudes overpressure hypersonic engines, and prolonged flight creates extreme thermal management issues."[7]

Moreover, because of challenging aerothermal conditions, hypersonic missiles generate an explicit infrared signature that infrared homing interceptor missiles can exploit.[8] Besides, it is challenging to deploy decoys and countermeasures on hypersonic missiles that fly in extremely harsh environments.[9] The absence of decoys and countermeasures simplifies the job of missile defence systems since they do not need to differentiate warheads from other objects.

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Conceptual And Technical Foundations of Hypersonic Missile Defense

The previous section has elaborated how defenders can exploit the potential weakness of hypersonic missiles to develop effective defences against hypersonic threats. However, is it practically possible to defend against hypersonic threats? In a recent CSIS report, Karako and Dahlgren argue that "Defending against hypersonic missiles is strategically necessary, technologically possible, and fiscally affordable, but it will not be easy."[10] In other words, defence against hypersonic missiles is tough but tractable.

Any missile defence system comprises three basic components: sensors and radars; interceptors; and command and control. Satellite sensors and ground/sea-based radars provide threat detection, discrimination (differentiating warheads from decoys and other countermeasures), and tracking capability; interceptors engage and destroy the missile threat with a kinetic or non-kinetic kill; and command and control centres coordinate the data processing and information sharing among radars, sensors, interceptors, and kill vehicle.[11]

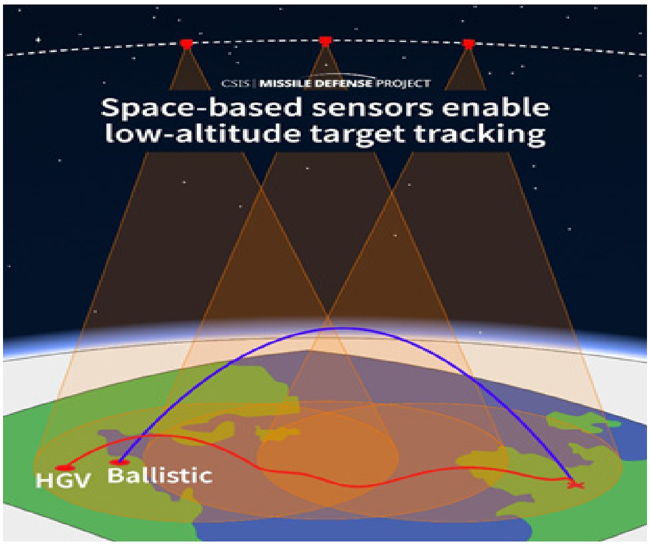
While the existing command and control infrastructure can be adapted for hypersonic defence, the current ground and space-based sensors and interceptor missiles face severe limitations in addressing hypersonic threats. Why are existing radar and space-based sensors incapable of detecting and tracking hypersonic missiles? First, a low-flying hypersonic glider might under fly the ground-based radar sensors whose range is limited by the earth's curvature and line-of-sight detection capabilities. Second, even if hypersonic missile launch can be detected from current space-based sensors in geostationary orbits, they lack the sensitivity to provide real-time tracking data for aerodynamic vehicles.[12] Also, hypersonic missiles have a low altitude of flight, which makes them faint and dimmer, as observed from space-based assets. As noted by former undersecretary of defence for research and engineering, Michael Griffin, "hypersonic missiles are 20 times dimmer, or more, than the targets we are able to track with the space-based infrared system."[13]

Hypersonic aerodynamic vehicles naturally, in their terminal phases, tend to come down and can be intercepted by normal terminal missile defences. However, it comes with two caveats. First, hypersonic missiles in their terminal phase carry out extreme manoeuvres to evade terminal defences and thus pose an intractable challenge to the interceptor missiles, designed to debilitate targets with predictable trajectories. Second, the current midcourse interceptors, such as Standard Missile-3 (SM-3), are designed to intercept ballistic missile threats in the exo-atmospheric environment.[14] They are incapable of operating in the harsher endo-atmospheric regime and would not address hypersonic threats.

Hypersonic missiles have unlocked an offence-defence spiral, risking hypersonic arms races and deterrence stability. Hypersonic missiles' accuracy, speed, and manoeuvrability make them an attractive counterforce weapon.

A recent CSIS report characterises the "resilient and persistent space sensor layer" and "glide-phase interceptor" as the single most important and second most important elements of hypersonic defence architecture, respectively.[15] The most crucial element of any form of missile defence is the ability to see and track the target, since one cannot hit what one cannot see. The solution to the challenges posed by low-flying hypersonic missiles lies in the proliferation of lower earth orbit (LEO) with infrared (IR) sensors (as illustrated in Figure 3). While the hypersonic missiles can hide from ground-based sensors, they cannot hide from the elevated sensors in LEO (subject to atmospheric disturbances and other limitations). Space-based sensors enable the tracking of hypersonic missiles through the entirety of their trajectory— "birth-to-death" tracking capability.[16]

Fig 3: Notional Depiction of Space-Based Sensors



Source: Tom Karako and Masao Dahlgren, *Complex Air Defense: Countering the Hypersonic Missile Threat*, CSIS Missile Defense Project (February 2022)

The challenge posed by extreme manoeuvres carried by hypersonic missiles in their terminal phase can be addressed by targeting it in the glide phase. Hypersonic missiles in their gliding phase encounter aerothermal challenges such as overheating, plasma formation, and aerodynamic constraints. Manoeuvring during the gliding phase comes at the cost of range, survivability, accuracy, and path differential. Glide vehicles in their glide phase are more stable and unwavering, and thus, are more vulnerable to be intercepted by missile defences.[17] Hypersonic missile interceptors need to be agile and manoeuvrable and target the hypersonic threat in its glide phase. The effector or interceptor could be a blast and fragmentation warhead or hit-to-kill vehicles. Also, area-wide effectors such as directed energy weapons (e.g., high-powered microwaves, electromagnetic disruptions, or powerful laser weapons) and particle-dispensing warheads can complement the kinetic kill interceptors.[18]

Unlike the sensor and intercept components of the hypersonic missile defence system, where novel methods such as IR sensors in LEO and glide-phase interceptors are needed, existing command and control systems can be upgraded for situational awareness, tracking capability, and data processing and adapted for addressing hypersonic threats.[19] For example, the US is pursuing adaptations to its existing Command, Control, Battle Management, and Communications (C2BMC) system for hypersonic defence.

Global Scan of Hypersonic Missile Defense Programmes

Hypersonic missile defence systems are not just theoretically and practically possible, but countries are already working intensively on them and they will be operationally deployed in a few years. While Russia and China are leading the race in hypersonic missile development, the United States is far ahead of both its adversaries in the pursuit of developing hypersonic missile defences. In the 2017 National Defense Authorization Act (NDAA), Congress designated the Missile Defense Agency (MDA) as the executive agent for missile defence. MDA is working closely with the Space Development Agency (SDA) to develop hypersonic defences.[20] The US hypersonic defence programme focuses on countering three types of hypersonic threats: hypersonic glide vehicle, hypersonic manoeuvring reentry vehicle, and hypersonic cruise missiles. It is part of the larger integrated air and missile defence architecture. Under the Hypersonic and Ballistic Tracking Space Sensor (HBTSS) initiative, MDA is developing satellites and sensor facilities in low-earth orbit to detect and track hypersonic missiles throughout their flight trajectory from launch to terminal phase.[21] The first eight HBTSS satellites are likely to be operationally deployed in 2022 and 2023 (Tranche 0), Tranche 1 would begin in 2024, and the follow-up Tranche 2 will begin in 2026.[22]

On the interceptor side, MDA is working on two interceptor programmes. First, under the Sea-Based Terminal (SBT) programme, MDA is developing defence systems to intercept high-speed manoeuvring reentry vehicles in the terminal phase.[23] SBT system consists of an Aegis Baseline 9 destroyer and the SM-6 interceptor. Second, under the Glide Phase Interceptor (GPI) initiative, MDA is working with the consortium of Raytheon, Northrup Grumman, and Lockheed Martin on an interceptor capable of targeting and destroying hypersonic missiles in its glide phase.[24] Also, the Defence Advanced Research Projects Agency (DARPA) of the US Department of Defense is developing a long-range intercept capability against hypersonic missiles under the Glide Breaker Program.[25]

In collaboration with the Israel Missile Defense Organization (IMDO), the US MDA is developing the next-generation Arrow 4 air-defence system.[26] The hypersonic speed of Arrow 4 interceptors and attached winglets for manoeuvrability would enable it to shoot down hypersonic missiles. Also, the US and Japan have agreed to conduct a joint analysis on counter-hypersonic technology.[27]

Russian President Vladimir Putin revealed in December 2020 that the Russian hypersonic missile defence programme is "working, among other things, on the 'antidote' against future hypersonic weapons in other countries."[28] Russia has claimed that its most advanced missile defence system, S-500, which has been recently deployed around Moscow, can defend against hypersonic threats.[29] Also, S-550, the lighter version of S-500, which is expected to enter service in 2025, would field a mobile launcher deployed with a hypersonic interceptor missile to defend against hypersonic threats.[30]

China has made remarkable progress in developing an infrared heat-seeking hypersonic missile that could target objects such as stealth aircraft, aircraft carriers, and hypersonic missiles.[31] Developing a hypersonic heat-seeking missile is a formidable challenge since the infrared sensor window needs to be protected from the overwhelming heat (background noise) released from the missile. However, Chinese scientists have made a series of breakthroughs by putting a lightweight air blowing device in front of the IR sensor, which generates extremely cold noble gases to avoid signal distortion.

The Japanese Defense Ministry is developing a new electromagnetic railgun that can fire magnetically powered projectiles to deter and intercept regional hypersonic threats.[32] The EM railgun can fire interceptors in rapid succession, which reaches speeds of up to 2300 m/s.

Offense-Defense Spiral

Cold War efforts to develop ballistic missile defences led to the development of MIRVed missiles deployed with multiple independently targetable warheads and countermeasures to confuse and overwhelm the missile defence systems. Improvements in radar and sensor technology, early warning systems, and interceptors have since led the United States to develop modern and advanced missile defence systems. Progress made by the United States in missile defence technology prompted Russia, China, and North Korea to develop offensive weapons such as manoeuvring reentry vehicles (MaRV) and hypersonic missiles capable of penetrating those defences. Advances made by Russia and China in hypersonic weapons technology have prompted the US to launch a comprehensive hypersonic missile defence programme.

Hypersonic missiles have unlocked an offence-defence spiral, risking hypersonic arms races and deterrence stability. Hypersonic missiles' accuracy, speed, and manoeuvrability make them an attractive counterforce weapon. Their ability to penetrate missile defences might incentivise an aggressor state to launch a pre-emptive first strike against its adversaries' nuclear forces, undermining its ability to retaliate. The evident offensive advantage of hypersonic missiles has forced the great powers to develop hypersonic missile defences to counter threats emerging from hypersonic missiles. It is expected that the development of hypersonic missile defences would further fuel the ongoing hypersonic race to develop more powerful, faster, and manoeuvrable hypersonic missiles. Indeed, Russia has already indicated that it would develop a superior hypersonic missile capable of penetrating even the hypersonic missile defences.[33] Great powers are caught up in an unending offence-defence spiral, seeking hypersonic superiority over their adversary.

While the quest for long-range hypersonic weapons has severe implications for strategic stability and arms control, they have received little attention in bilateral and multilateral strategic stability and disarmament discussions.[34] Unless great powers find ways and means to impose limits on the development and deployment of hypersonic missiles and missile defence systems, they will sink deeper into the quagmire of an unending, expensive, and dangerous offence-defence spiral. There is an urgent need for the United States and Russia to include hypersonic missiles in their ongoing strategic stability dialogue. Also, the hypersonic regime must be a part of any future arms control dialogue that China agrees to join.

Implications for India

Should India pursue hypersonic missile defence? Hypersonic missile defence is an expensive business. India need not dive into the expensive pursuit of developing a defence against hypersonic threats. It should focus on developing hypersonic missiles since offence is the best form of defence. India is reportedly working on two hypersonic delivery systems: indigenous Hypersonic Technology Demonstrator Vehicle (HSTDV)[35] and hypersonic anti-ship missile Brahmos II[36] with Russia. Cultivating and maintaining a talented workforce of hypersonic specialists and engineers, sizable and reusable wind tunnel and ground testing infrastructure, and sustained budget allocation remain key to the sustenance and success of India's hypersonic programme.

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