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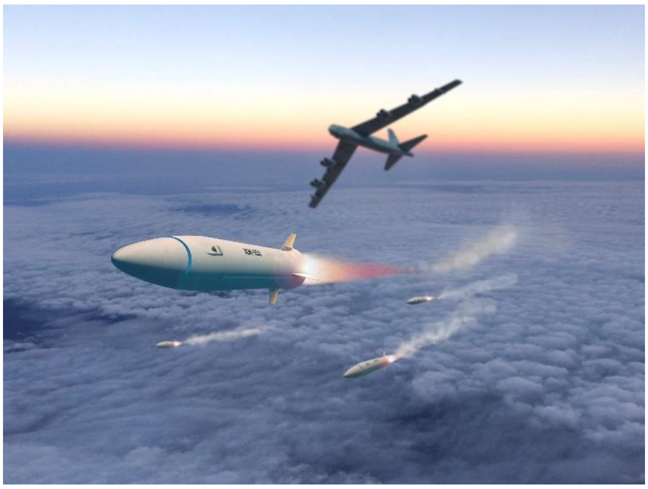
Hypersonic missiles



Hypersonic missiles are being developed and deployed by several countries, including China, Russia and the US. This POSTnote describes different hypersonic missile technologies, efforts to develop them, and the associated technical challenges. It also considers their use in military operations, the potential challenges they may present for missile defence, and possible implications for global stability.

Overview

- Hypersonic missiles combine speeds of over five times the speed of sound with significant manoeuvrability during flight.
- China and Russia have reportedly deployed hypersonic missiles that could deliver conventional or nuclear weapons. The US is testing multiple hypersonic technologies.
- The AUKUS agreement between the UK, US and Australia includes developing hypersonic and counter-hypersonic technologies.
- Hypersonic missiles are expensive and technically demanding to develop; their uses and effectiveness are still being assessed.
- Their speed, manoeuvrability and altitude may challenge existing missile defences.
- Some analysts say they could increase risk of conflict; others say they will not alter the strategic balance between nuclear powers.
- Arms control, export controls and other measures may help limit potential harm to peace and stability, but face challenges.

Background

'Hypersonic flight' refers to an object travelling within Earth's atmosphere at speeds greater than five times the speed of sound (Mach 5).[1] Sustained hypersonic flight is technically challenging; at these speeds the object experiences extreme conditions, such as significant air resistance (friction) that results in very high surface temperatures. 'Hypersonic missiles' are capable of flying and manoeuvring under these conditions for sustained periods.[2] Though many ballistic missiles exceed speeds of Mach 5, they are not usually classed as 'hypersonic'.[3] Intercontinental ballistic missiles (ICBMs), primarily designed to deliver nuclear weapons,[4] can exceed Mach 20, but most of their flight is outside the Earth's atmosphere and so they do not experience hypersonic flight conditions for a prolonged period.[5]

Though there is no universally accepted definition, 'hypersonic missiles' are typically defined as those that combine sustained hypersonic flight with significant manoeuvrability, while maintaining accurate targeting.[6,32] These characteristics could make them harder to detect and intercept than ballistic missiles, challenging existing missile defences.[2,3] Two main types of hypersonic missile are under development: hypersonic glide vehicles (HGVs, or 'boost-glide vehicles') and hypersonic cruise missiles (HCMs). Russia and China have announced advances in their hypersonic capabilities in the last few years and reportedly deployed HGV weapons.[4,7–10] The US is developing multiple hypersonic missile designs, and several other states are in the earlier stages of hypersonic weapon development.[11–14]

In the UK, hypersonics research in the last decade has largely focussed on civilian applications, such as aviation.[14–16] The UK Government has stated that the development of HGVs will pose significant challenges for missile defence systems.[17–19] In 2021, it committed £6.6 bn over four years to defence research and development, including advanced high-speed missiles.[18] The MOD's Science and Technology Portfolio includes a Hypersonics Programme to develop "future hypersonic concepts and technologies", and notes that the Missile Defence Science and Technology Programme will fund research to underpin the development of counter-hypersonic capabilities.[20] In April 2022, the UK, US and Australia announced they would cooperate on the development of hypersonic and counter-hypersonic capabilities via the AUKUS security partnership (see briefing CBP-9335).[21–25] The Commons Public Accounts Committee has questioned whether the MOD is developing new capabilities such as hypersonic weapons, with sufficient urgency.[26]

Hypersonic missile technologies

Ballistic missiles (e.g. ICBMs) are launched to high altitudes and fall to Earth under gravity, in an arc-shaped 'ballistic' trajectory. As a result, their flight-path and target can be predicted by missile defence systems, making it possible to target and destroy them with 'interceptor missiles'. The 'engagement' of ballistic missiles by interceptors is difficult, however.[27]

Hypersonic missiles are designed to evade existing ballistic missile defences.[28] They fly at lower altitudes than ballistic missiles and their significant manoeuvrability enables them to change trajectory during flight,[29] making their flight-path and target difficult to predict.[2,3] Flying at lower altitudes can make hypersonic missiles harder to track at long distances with some surface-based sensors, such as radar.[2] They fly closer to the Earth's surface and, because of the Earth's curvature, can stay hidden beyond the horizon and out of sight of certain radar for longer.[30] The combination of speed and reduced detectability may decrease the time available for engagement by interceptors.[2] Their ability to manoeuvre can also make interception difficult, and may require more agile interceptor missiles.[2]

The two main types of hypersonic missile, HGVs and HCMs,[11,31] could both deliver warheads containing either conventional explosives or nuclear weapons.[32] Some are designed so they are able to deliver either ('dual-capability'). Some ballistic missiles have some, but not all, of the characteristics of hypersonic missiles and are not widely considered to be "hypersonic" (Box 1).[2,29]

Hypersonic Glide Vehicles (HGVs)

HGVs are mounted onto rocket boosters (like ICBMs) for launch and may be accelerated to speeds of Mach 20 or more. The glider then separates from the booster and flies unpowered in the upper atmosphere at altitudes of 30-80 km, before diving towards the target.[29,33] The glider can manoeuvre to try to avoid missile defences and to make it harder to predict its target.[34] The speed and range of a HGV depends on the launching booster and the missile's design.[35] Many HGV designs use large launch rockets to boost them to the upper atmosphere, enabling longer ranges.[14]

Hypersonic Cruise Missiles (HCMs)

Regular cruise missiles fly on non-ballistic, flattened trajectories at low altitudes to avoid detection.[36] Most travel below the speed of sound and are propelled by a class of jet engine that uses rotating fans to suck air into the engine.[37] Fuel is mixed with oxygen in the air and ignited to create thrust.[38] HCMs are similar, but typically use either a ramjet or scramjet engine to reach hypersonic speeds at altitudes of 20-40 km.[29] Ramjets and scramjets have no moving parts and instead have a funnel-shaped opening into which air is forced as the HCM moves forward.[39] They need to travel at around Mach 3 or above to operate, and hence HCMs (unlike regular cruise missiles) must initially be accelerated by small rocket boosters or jet engines that can operate from stationary.[40,41] A ramjet HCM could reach around Mach 6, while scramjets would reach speeds over Mach 10.[41–43] Most HCM designs have ranges of below 2000 km.[14]

Box 1: Russia's aeroballistic 'Kinzhal' missile

Russia has used multiple 'Kinzhal' missiles against Ukraine.[44–47] Kinzhal has a reported range of up to 2000 km and a top speed of Mach 10.[11] It is believed to be a modified, aircraft-launched version of the ground-launched short-range Iskander-M missile.[48] Kinzhal is a 'aeroballistic' missile – it flies on a quasi-ballistic trajectory and is capable of limited manoeuvres.[2] Though aeroballistic missiles can reach hypersonic speeds (like many ballistic missiles), they are not widely considered to be 'hypersonic missiles'.[49]

Hypersonic missile capabilities worldwide

Developing hypersonic missiles requires significant research and development challenges to be overcome (Box 2),[12] contributing to high development and manufacturing costs.[50–52] Estimates suggest the US will spend almost $15 bn (£12 bn) between 2015-2024 on the development of hypersonic technologies.[53,54] Several countries have hypersonic missile programmes, but unclassified information about their capabilities is limited, making evaluation difficult. There may also be differences between reported capabilities and actual real-world effectiveness.[55–57] China, Russia, and the US are widely considered to have the most advanced hypersonic missile programmes, with missiles already deployed or likely to be deployed in the next few years (see below).[8–11,58] Multiple other countries, including France, India, Japan, North Korea and Iran, have programmes that are generally considered to be in the earlier stages of development.[11–14,59–63] Some countries have established collaborations with other nations to accelerate innovation and share knowledge and development costs.[12,24,64]

Box 2: Key research and development challenges

- **Heat-resistant materials** – the air resistance created at hypersonic speeds is huge, generating temperatures of several thousand degrees.[65] Advanced materials, such as ceramics, are needed to withstand this.[66] Thermal protection for the electronics, fuel and warhead is also critical.[67]
- **Aerodynamic design** – the missile's shape needs to minimise air resistance to enable hypersonic speeds without excessive heating.[34] For HGVs, it also needs to maximise lift to keep the glider in the air and enable it to turn while withstanding the high stresses experienced.[68,69]
- **Scramjet engines** – the production of a HCM scramjet system poses major difficulties.[70] It involves ensuring the mixing of air and fuel in a few milliseconds, which is challenging.[12,40] Sustaining scramjet combustion has been compared to "keeping a match lit in a hurricane".[71]
- **Plasma formation** – high temperatures experienced at hypersonic speeds can cause air around the missile to breakdown into plasma (a cloud of electrically charged particles),[72] which can interfere with signals sent to and from guidance and communication systems.[68,73]
- **Testing** – computer models can simulate hypersonic flight conditions[74] and wind tunnels can create hypersonic airflow for short periods.[75] However, real-world flight tests are crucial.[12] These are expensive and require launch capability, large open spaces and specialised equipment.[76,77]

China

In 2020, China reportedly deployed 'DF-17', a missile with a conventionally armed HGV (Box 3).[58,78] In 2021, there were reports that the Chinese military had conducted two tests of a 'fractional orbital bombardment system' that orbited Earth before releasing a nuclear-capable HGV that descended onto a target.[79–83] China's Foreign Ministry denied this, saying that it was testing a reusable space vehicle.[84] There have also been reports that China is researching and developing HCMs.[85,86]

Russia

Russia has deployed 'Avangard', a nuclear-capable HGV and is developing 'Tsirkon', among other programmes (Box 3).[87–90] It is also working jointly with India to develop 'BrahMos II', believed to be an adaptation of Tsirkon.[12,91] Some analysts have suggested that Russia's ability to manufacture large numbers of hypersonic missiles might be limited by current sanctions.[92–94]

The United States of America

The US has explored weaponized hypersonic technology as part of the Conventional Prompt Global Strike programme to enable a rapid precision strike capability.[95,96] Research and development has since expanded to include a wider range of hypersonic missiles, including HCMs (Box 3).[97,98,99] The US also participates in international collaborations, including on the 'SCIFiRE' HCM prototype with Australia,[100,101] and AUKUS.[24] The US Department of Defense stated in 2020 that nuclear-armed hypersonic weapons were not being considered.[77]

Potential uses in military operations

The type of missions a hypersonic missile could be used for will depend on the missile type (HGV or HCM), as well as its range, speed, type of warhead, and launch platform.[14] Selective use might be necessary, if the high cost of hypersonic missiles limits the number available.[50] Potential applications could include:

- **Rapidly striking mobile assets** – short-range hypersonic missiles have very short flight times, significantly reducing time-to-target and compressing an adversary's response window.[31,102] They could be used to target high-value, time-sensitive or mobile assets (such as aircraft carriers or transport vehicles)[103] with only limited time for defensive systems to react, or for the asset to move.[102]
- **Long-range precision strikes** – conventionally armed hypersonic missiles could be used to strike distant, well-defended targets such as military bases,[103,104] that were previously more difficult to access.[105,106] They might be used to disable part of an air and/or missile defence system, such as a radar station, hindering an adversary's ability to defend against more extensive attacks using other types of missiles.[92] The ability to strike from a distance may protect the launch platform from an adversary's defences.[107,108]
- **Enhancing nuclear deterrents** – owning nuclear-armed HGVs that can bypass an adversary's missile defences might strengthen deterrence against nuclear attacks.[33] However, the effectiveness of defensive systems and potential impact of nuclear-armed HGVs on global stability, is debated.[109,110]

Some academics suggest that physical limitations on hypersonic missiles' performance will curtail their advantages.[34] For example, HGVs will slow-down while gliding, due to air-resistance.[68,111] This could make long-range missiles more vulnerable to interception by missile defences as they approach their target. Manoeuvring will also slow HGVs significantly.[2]

Challenges for missile defence systems

The manoeuvrability, altitude and speed of hypersonic missiles may pose challenges for current missile defence systems designed to counter ballistic missiles.[32,141,103] These could include later detection and less time for decision-making and response.

Box 3: Select hypersonic missile programmes

Russia

- **Avangard** – a nuclear-armed HGV designed to overcome existing defence systems.[112,113] Reportedly, it is launched from an ICBM booster, can reach speeds of Mach 20 over intercontinental distances,[87,114] and is now deployed.[8,9]
- **Tsirkon (or 'Zircon')** – a missile that can be launched from naval vessels, which can reportedly reach speeds of Mach 9, fly over 1000 km, and strike both ground and naval targets.[115] It was reportedly deployed in 2023.[116–120] Tsirkon has been described as a HCM by Russian policy makers,[121] but some analysts have questioned this.[14,122,123]

China

- **DF-17** – a medium-range missile with a mounted dual-capable HGV (named DF-ZF). It has a reported top speed of Mach 10 and range of over 2000 km.[85,124,125] The DF-ZF HGV might be used on longer-range missiles in the future.[11,126]

United States of America

- **Common Hypersonic Glide Body** – a HGV that can be launched from either naval or ground-based systems as part of the 'Conventional Prompt Strike', or the 'Long-Range Hypersonic Weapon', programmes respectively. Further tests are planned for 2023.[105,127–130]
- **Air-Launched Rapid Response Weapon** – a medium range HGV, which is launched from B-52H aircraft.[131,132] This missile was flight-tested in 2022 and 2023.[133–137]
- **Hypersonic Attack Cruise Missile** – a HCM small enough to be launched from several aircraft.[138] This builds upon a prototype successfully tested in 2021.[139,140]

Existing missile defence systems

Missile defence systems, such as those in which the UK is involved (Box 4), are designed to deter attacks and, if missiles are launched, to protect critical assets and limit damage.[142,143] They have three main elements:

- **Detection** – a network of sensors identifies and tracks incoming missiles. This includes satellites that can detect the heat of a launch rocket's exhaust using infrared scanning and surface-based radars (on land or on naval vessels).[144]
- **Threat validation** – sensor data are transferred to a command and control centre, where potential threats are analysed and validated and a response is decided upon.[103] The collected sensor data are used to predict the missile's trajectory, which is relayed to a suitable interceptor.[145,146]
- **Interception** – interceptor missiles typically collide with the incoming missile to destroy it, though other 'engagement' mechanisms exist.[143] Different interceptors can target different points in the incoming missile's flight-path.[27,147]

Missile defence is complex, expensive and technically challenging, particularly for nationwide defence against long-range missiles like ICBMs.[146] For example, the US Ground-based Midcourse Defense system (designed to counter a limited ICBM attack on the US homeland) has cost approximately $53 bn (£42.5 bn) over 25 years, with plans to spend $10 bn (£8 bn) more from 2020-2025.[148] It has a test interception success rate of 55% (across multiple variants, 1999-2018).[149] Some analysts have suggested it would not be able to counter an extensive attack involving multiple missiles simulataneously.[150–152]

Box 4: UK missile defence
UK missile defence includes participation in the NATO Ballistic Missile Defence mission, which comprises a developing network of capabilities intended to protect European NATO territory against ballistic missile threats from outside the Euro-Atlantic area (excluding Russia).[145,153] The UK is investing in a ground-based ballistic missile defence radar to support national and NATO capabilities against threats that include hypersonics.[154–156] This is due to enter service in 2029.[157,158] In addition, RAF Fylingdales hosts one of five Upgraded Early Warning Radar stations that provide a continuous ballistic missile early warning service to the UK and US.[159,160] The UK also has limited missile defence capabilities on some ground and naval platforms to protect the area surrounding deployed assets.[161,162] Upgrades to ballistic missile defences aboard Royal Navy Type 45 destroyer warships were announced in 2022.[163–165]

Improving existing missile defences
Existing missile defence systems will need to be adapted to better counter hypersonic missiles. This could include measures to increase warning times for incoming hypersonic missiles and using different types of interceptors. Such improvements will likely require significant investment.[166] New ways to intercept hypersonic missiles could also be developed (Box 5).[2]

Increasing warning and response times
Missile defence systems that rely solely on surface-based radar for detection may detect hypersonic missiles late in their flight (see 'Hypersonic missile technologies', above).[30] Late interception can be problematic, as the missile may make last-minute evasive manoeuvres, leaving no time for further interception attempts.[142] If a missile is intercepted too close to the target, the debris produced can still cause damage.[2] The detection range of a missile defence system can be improved through the inclusion of complementary space-based sensors, such as infrared satellites, that can detect the surface heating of hypersonic missiles as they fly through the atmosphere.[167–170]

Maximising defensive coverage
Hypersonic missiles travel largely within the atmosphere, limiting the types of interceptors that can be used to those that engage within the atmosphere, rather than in space. Interceptors that engage with missiles in the atmosphere have shorter ranges than those that engage in space, so must be selectively located near potential targets.[171] Ensuring sufficient coverage could have significant cost implications. The performance of such interceptors against hypersonic missiles is not yet fully characterised.[2] However, defence contractors are currently working with the US and EU to upgrade certain systems,[172] and to develop novel interceptors that fly at hypersonic speeds and can engage both hypersonic and ballistic missiles.[173,174]

Implications for global peace and stability
Defence analysts disagree about the potential implications of hypersonic missiles for global stability.[11] Some suggest they could increase the risk of conflict escalation through:

- **Target ambiguity** – difficulty in predicting the target of an incoming hypersonic missile could further reduce the time available to states to assess threats and decide upon responses.[175] A 2017 analysis by the RAND Corporation suggested this could result in states being "trigger happy", potentially leading to unnecessary escalation during a crisis.[12]

Box 5: New approaches to hypersonic missile defence
Novel approaches to intercepting hypersonic missiles are being explored that seek to exploit vulnerabilities created by the demanding conditions of sustained hypersonic flight.[2] For example, discharging a cloud of particulates (such as dust or shrapnel) into the path of an incoming hypersonic missile could damage a missile's surface, destabilising it.[176,177] Alternatively, directed energy weapons (highly focused beams of energy, such as lasers or microwaves)[178] could be used to damage a missile's surface or electronics.[179–181]

- **Warhead ambiguity** – it may not be obvious if an incoming missile is conventional or nuclear-armed.[13] This might lead to a conventional missile being mistaken for a nuclear one, and another state launching its own nuclear weapon in response.[182] This is also a risk for other dual-capable missiles, not just hypersonic ones.[183–185]
- **Precision strike capability** – conventionally armed hypersonic missiles could be used in prompt global strike weapons systems,[96] which might enable states to pre-emptively disable an adversary's nuclear forces.[186] Concerns have been raised that this ability could undermine deterrents and might lead to the expansion of nuclear arsenals.[187–189] Hypersonic missiles are not the only class of weapon that might be used for precision global strikes.[187]

Other analysts say that the significance of hypersonic missiles has been exaggerated and that they will not alter the strategic balance between nuclear-armed states.[34,190,191] Missile defence systems designed to protect against existing nuclear-armed ballistic missiles may not always be effective,[192] and current systems may be unable to stop multiple ICBMs at the same time.[150–152] Nuclear-armed states without hypersonic missiles would therefore likely still be able to penetrate missile defences and thereby deter potential attacks.[191,193] Some analysts conclude that nuclear-armed hypersonic weapons offer few advantages compared to existing nuclear weapons delivery systems and that, for many states, they do not present a new threat beyond that of existing nuclear weapons.[194,171]

Arms control, export control and other measures
Some analysts have suggested amending existing arms control treaties,[195] or establishing new ones, to limit the deployment of hypersonic missiles.[14,33] A 2019 report by the UN Office for Disarmament Affairs noted several challenges for establishing new arms control agreements, including a prevailing climate of political mistrust and a diminished sense that arms control can be mutually beneficial.[13,196] In February 2023,[197,198] Russia said that it was suspending its participation in the New START nuclear arms control treaty between Russia and the US, which could cover some hypersonic missiles such as Avangard.[110,33]

International export controls may help to restrict the transfer of hypersonic missile technology to other states,[12,199] but are unlikely to inhibit states that already have hypersonic capabilities.[200] Other analysts have suggested using non-treaty mechanisms to try to minimise ambiguity and challenges to global stability.[6,201] These could include less formal arrangements between states, such as information exchanges, dialogues on doctrines and postures, and agreements to keep conventional and nuclear-armed missiles distinct.[33,110,202]

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