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Article36

# Hypersonic Weapons

## Discussion paper for the Convention on Certain Conventional Weapons (CCW)

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Article 36 is a UK-based not-for-profit organisation working to promote public scrutiny over the development and use of weapons.*

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**Hypersonic weapons have in recent years attracted attention from militaries, governments and, increasingly, multilateral institutions following reports of successful prototype testing. In 2018, the UN Secretary-General highlighted hypersonic glide vehicles and cruise missiles in a report on the role of science and technology in the context of international security and disarmament, and called on the international community to 'remain vigilant in understanding new and emerging weapon technologies that could imperil the security of future generations'.[1] The development of hypersonic weapons is said to pose a challenge to strategic missile defences and raise wider international security concerns due to their 'considerable potential to further complicate strategic relations, encourage new arms competition and endanger stability'.[2]**

Several modern militaries are currently working to develop hypersonic weapons, which after decades of research could soon be fielded in significant numbers.[3] Predictions over how quickly this may occur, absent any multilateral efforts to curb or halt the weaponization of hypersonic technology, vary.[4] NATO has commented that 'the systems being developed and tested today are mature enough to lead us to believe they will be fielded in the foreseeable future'.[5] Hypersonic glide vehicles could be deployed within five years.[6]

'Hypersonic' is generally understood to refer to flight within the atmosphere at speeds above Mach 5 (five times the speed of sound), or above around 6,100 km per hour. One focus of military interest is hypersonic missiles that can travel at approximately 5,000 to 25,000 km per hour (or between 1.4 and 7 metres per second)[7] – up to 25 times faster than a standard airliner.

The development and potential future deployment of hypersonic weapons illuminates a number of broader themes and questions that deserve attention from the perspective of multilateral weapons control, including within the framework of the Convention on Certain Conventional Weapons (CCW), a 'hybrid treaty' that sits at the intersection of arms control, disarmament and humanitarian law:[8]

- The development of hypersonic weapons is driving research and development of technologies to defend against them, including kinetic interceptors, electromagnetic railguns and high-power lasers,[9] which may also have potential uses as offensive weapons,[10] in turn spurring further armament reaction cycles. Hypersonic weapons are also more expensive than existing alternatives. This has implications for international stability, security, peace and sustainable development.
- In certain scenarios, hypersonic weapons may provide less time to respond, compared to existing cruise and ballistic missiles. This can be expected to compress decision time, contributing to the trend towards increasing reliance on artificial intelligence, both to inform human decision makers and to automate certain processes,[11] raising concern about the risk inherent in decision-making under time pressure. Speed of action is a common thread in the hypersonic and autonomous weapons debates.
- Both nuclear and conventional hypersonic weapons affect nuclear stability and thereby international peace and security. This complicates efforts aimed at preventing or limiting these weapons, but also offers additional avenues and opportunities for multilateral control.
- Hypersonic weapons are likely to increase the risk of pre-emptive strikes, accidents, miscalculations, conflict instability and rapid

conflict escalation due to their potential to shorten decision times and the nuclear ambiguity surrounding them, among other reasons. The introduction of hypersonic weapons risks undermining long-standing arms control and disarmament efforts in various domains.

- These factors underscore the need to consider the wider arms control and disarmament implications of specific weapon developments, and to consider the intersections of categories used to delimit the scope of multilateral weapons control mechanisms. These tend to approach different weapons largely in isolation from each other, creating potential gaps or responses that inadequately account for cross-cutting issues.
- There is no shortage of suggestions for the control of hypersonic weapons. What has been missing thus far is the political will to take them forward. As with other (emerging) weapon technologies, progress in this regard does not only require agreeing on where to draw the line between the acceptable and the unacceptable on technical grounds.[12] It is also calls for efforts to conceptualize the issue and organize policy work in such a way that those who risk being affected by these weapons are empowered to take measures for their control.

## Current state of play

The development of hypersonic technologies for military use has been pursued by states since the 1940s, when attempts to establish space-ready vehicles produced the first piloted supersonic aircraft flight to break the sound barrier, with several decades of research programmes that at best produced mixed results.[13] Scientific and technological advances in recent years have, however, made practical hypersonic weapons appear to be within reach. Most prominently, China, Russia and the US have pursued, and claimed varying successes in the testing of, hypersonic missiles.[14]

There are currently two primary streams of development in hypersonic weapons:

- **Hypersonic glide vehicles** (HGVs)[15] are typically launched by rocket into the upper atmosphere and released at an altitude of between 40 and 100 km from where they glide to their target at hypersonic speed. HGVs have a reach comparable to ballistic missiles but they fly at a lower altitude, and a negligible portion of their flight path follows a ballistic trajectory.[16] This results in the time between detection by ground-based sensors and impact being shorter compared to a ballistic missile's re-entry vehicle.[17] HGVs are manoeuvrable during their glide phase and can be redirected in flight to a different target than initially planned.[18]
- **Hypersonic cruise missiles** (HCMs), sometimes referred to as 'air-breathing cruise missiles', are powered during their entire flight. They need to be accelerated to a speed of Mach 5 before an advanced jet (ramjet, scramjet) engine can take over to maintain speed.[19] HCMs could be ground-, air- or ship-launched and would likely fly at an altitude of 20 to 30 km,[20] beyond the reach of most current air-to-surface missile defence systems. They could reach targets that are 1000 km away within minutes.

In addition, missile systems, such as Russia's Iskander-M, that feature aerodynamic manoeuvring at high-supersonic speeds or manoeuvring ballistic missile warheads are sometimes described as hypersonic.[21] Projectiles fired from electromagnetic or powder guns may also reach low-hypersonic speeds. These applications may complicate the debate and potential regulatory efforts regarding hypersonic weapons but are beyond the scope of this paper.[22]

In the US, current attempts to develop hypersonic weapons began in 2003 under the Conventional Prompt Global Strike programme, which seeks to develop a system that can deliver a precision-guided airstrike anywhere in the world within one hour.[23] In 2018, the Pentagon indicated that the US Army, Navy and Air Force would work together to develop and deploy a common hypersonic glide vehicle by the early 2020s.[24]

Information on defence technology developments in states other than the US tends to be less available, with programmes shrouded in secrecy, but reports suggest that in November 2017, China flight-tested a hypersonic glide vehicle, the DF-17, which is predicted to reach operational capacity in 2020. Russia's version of a hypersonic cruise missile, the ship-based 3M22 Zircon/Tsirkon, is reported to be at a similarly advanced stage of development with successful tests in late 2018.[25] In December 2018, Russia also successfully tested its 'Avangard' system, which will reportedly be deployed in 2019[26] and has been described as a nuclear-capable long-range hypersonic glider.[27] Over 20 additional states, including France, India, Australia, Germany and Japan are now thought to be pursuing the technology for military purposes.[28]

Hypersonic weapons are expected to combine significantly higher speeds with enhanced manoeuvrability. They would enable offensive missile strikes to destroy targets at great distances. They are designed to operate at altitudes that make them particularly 'difficult to detect, either from the ground, because of the limited viewing angle, or from space because of background clutter',[29] and therefore offer a way of circumventing current advanced defence systems built to intercept ballistic missiles.[30] As one analyst has summarized, '[t]hey are able to evade and conceal their precise targets from defences until just seconds before impact. This leaves targets with almost no time to respond.'[31]

There is, however, considerable ambiguity regarding precise goals,[32] – in certain cases purposefully maintained by some and severely criticized by others – especially regarding their role in nuclear war and deterrence ('nuclear ambiguity').[33] This uncertainty adds to the difficulty of assessing from public information the targets and warhead types under development. HGMs and HCMs could be equipped with a nuclear or conventional (explosive) warhead and they could damage certain targets by way of their high kinetic energy alone.[34] Some commentators therefore describe hypersonic weapons as 'most appropriate for hard and deeply buried targets'.[35] Others deem hypersonic weapons most suited for use against 'fixed, soft targets'.[36] Among the diverse targets mentioned by commentators are command and control centres and bunkers, radar and surveillance systems, missile launch vehicles[37] and other 'strategic' assets,[38] as well as island bases, shore facilities and ships,[39] including ships in ports.[40]

Though the technology is being developed and refined, notable technical barriers remain to the operationalization and deployment of hypersonic weapons.[41] In addition to these technical challenges, questions remain about the economic viability of hypersonic weapons programmes, which thus far have proven hugely expensive to fund.[42] The altitude at which they are designed to fly makes in-atmosphere testing, modelling and simulation difficult and costly, not least because hypersonic wind tunnels need to be constructed and engineered to produce flight-representative conditions.

## Adverse effects and risks

Concerns about hypersonic weapons centre on their implications for international stability, security and peace. For states relying on advanced missile defence systems (and by extension, their allies), hypersonic missiles represent a circumvention of their systems. This is motivating an effort to extend capabilities to intercept hypersonic weapons, including the development of directed energy weapons and deployment of space-based sensors, with space weapons potentially to follow.[43]

Furthermore, the operationalization of hypersonic weapons could negatively affect the security of all states and populations. Key concerns include:

- The difficulty of predicting the trajectory and target of a hypersonic weapon and the possibility of fitting it with a nuclear or a conventional warhead could increase the risk of mistaking a conventionally-armed missile for a nuclear-armed one or associating it with a completely disarming attack. This could prompt states to put their militaries on a 'state of hair-trigger readiness'.[44] It could also lead to a greater tendency to use pre-emptive strikes against states that possess hypersonic technology or induce 'a reconsideration of traditional second-strike calculations'.[45] Attempts by states to develop effective defence systems against hypersonic weapons may increase the militarization of space.[46] Taken together, these dynamics would increase conflict instability and the risk of rapid conflict escalation, run counter to de-alerting efforts and undermine long-standing arms control and disarmament efforts.
- The compressed timeline for decision-making forced by hypersonic weapons could further reduce states' ability to exert a measure of control over the escalation of tensions and conflict and increase the risk of miscalculations and accidents. It could also erode democratic control and oversight of uses of force, as there is a risk that the need to react swiftly incites some states to move authorization to conduct military strikes down the chain of command.
- A costly hypersonic weapons-driven arms race could also undermine the achievement of the Sustainable Development Goals.

## Governance and regulation

No multilateral weapons control body has thus far given hypersonic weapons focused attention[47] despite the enthusiasm generated in certain quarters and widespread agreement among arms control experts that the developing arms race in hypersonic weapons is wasteful, destabilizing and dangerous.[48] Tackling hypersonic weapons is complicated by the dynamics of both nuclear and conventional arms control, and challenges facing multilateral missile control.[49]

There are, however, a number of existing regulatory frameworks that limit the use of, as well as other activities involving, hypersonic weapons:

- Although there is no universally accepted norm or instrument that governs missiles in all their aspects, multilateral regimes to control access to missile technologies with a view to maintaining international stability or security offer some controls on hypersonic weapons. An example is the Missile Technology Control Regime (MTCR), a politically binding agreement subscribed to by 35 states with the aim of limiting the spread of missiles and other unmanned air vehicles capable of delivering biological, chemical or nuclear payloads.[50] The MTCR Annex Handbook 2017 mentions 'hypersonic glide vehicles' as one potential type of Manoeuvring Re-entry Vehicle (MARV) controlled under Category I.[51] However, Category I only captures re-entry vehicles 'if they meet the criteria of a 500-kg payload and a greater than 300-km range and are not designed as a peaceful payload'.[52] As hypersonic weapons can inflict damage with a small conventional payload or their kinetic energy alone, many types may fall below this weight threshold.[53] In addition, certain countries developing hypersonic weapons, like China, do not participate in the regime.[54]
- The use of hypersonic missiles is, in any case, subject to international legal rules on the resort to force by states (jus ad bellum) and constrained by the rules of international humanitarian law governing the conduct of hostilities. Certain scenarios involving hypersonic weapons, such as their use 'to interdict illicit transfers of nuclear weapons, material, or technology among rogue states, terrorist groups, and criminal networks'[55] raise concerns regarding compliance with Article 2(4) of the UN Charter and peremptory norms of customary international law.[56] Consideration should also be given – including in the legal review of new hypersonic weapons –[57] to how the use of hypersonic weapons affects the protection of civilians against the effects of hostilities,[58] notably in light of concerns regarding their 'inadequate precision'.[59]
- The threat or use of hypersonic weapons with a nuclear warhead would 'generally be contrary to the rules of international law applicable in armed conflict, and in particular the principles and rules of humanitarian law'.[60] Like other nuclear weapons, they would be prohibited under the 2017 Treaty on the Prohibition of Nuclear Weapons (not yet in force) and limited by the Nuclear Non-Proliferation Treaty (NPT), nuclear weapons free zone treaties and other nuclear disarmament and arms control instruments.

Arms control experts from different schools of thought have voiced concern that hypersonic weapons might threaten international stability and/or security and have suggested avenues to either prevent their emergence or deployment or to control their possession or limit their use:

- Ghoshal considers that **a complete ban** on hypersonic weapons would be the 'ideal' and 'the only solution viable for preventing proliferation challenges in future', but acknowledges that such a ban may not be accepted by states who have invested heavily in these weapons already.[61]
- Based on the premise that states would not make substantial investments in or rely on untested hypersonic weapons, Gubrud has proposed an international hypersonic missile **test ban**,[62] starting with an informal **moratorium** among those countries currently pursuing this technology.[63] A similar proposal was subsequently advanced by a US Air Force officer.[64] Aune et al consider a test ban to be the 'best mechanism for control',[65] but questions have been raised about unequal access to the means of verification, possible impacts on civilian (peaceful) applications of hypersonic technologies,[66] the risk of replicating or further entrenching power imbalances between have and have-not states, and the

willingness of states that have dedicated large sums towards the development of hypersonic weapons to support a test ban.[67]

- A **targeting ban** has also been suggested, either as a unilateral risk reduction measure by which a state would refrain from developing strategies that involve using hypersonic missiles against nuclear targets and command, control and communications centres,[68] or as multilaterally agreed **limitations on targets or missions** assigned to hypersonic weapons.[69] Similarly, Podvig suggests banning nuclear launched cruise missiles or nuclear boost-glide systems to eliminate 'nuclear ambiguity'.[70] Whereas this may help to increase nuclear stability and reduce the risk of inadvertent escalation and miscalculation, it does not prevent the emergence, deployment and spread of hypersonic weapons. These measures may also be perceived as being directed only at those states that acknowledge a nuclear role for hypersonic weapons, letting others 'off the hook'.
- Various **non-proliferation measures** have also been proposed. Aune et al suggest an agreement modelled after the NPT, 'where non-hypersonic states agree to not pursue the technology, and existing hypersonic states agree to keep the hardware and expertise required for hypersonic technology to themselves'.[71] In a recent report for RAND Corporation, Speier et al propose an initial **tripartite agreement** between Russia, China and the US to limit the proliferation of certain hypersonic technologies, followed or paralleled by an agreement by a broader set of states on export controls, within or outside of the MTCR.[72] More or less far-reaching **amendments to the MTCR and similar instruments** have also been proposed.[73] Speier et al recommend a policy of export denial for complete hypersonic delivery vehicles and major subsystems coupled with a policy of case-by-case export reviews for scramjets and other hypersonic engines and components, fuels for hypersonic use and relevant sensors, navigation, communication, simulation and testing equipment.[74] Siddhartha suggests including 'Lifting Bodies' or 'Hypersonic Gliders' and certain of their components among the controlled items.[75] Van Ham proposes broadening the scope of the MTCR to control 'Weapons of Mass Effect' (rather than mass destruction) so as to cover 'hypersonic kinetic energy weapons'.[76] Whereas there is some optimism about the effectiveness and political feasibility of export controls on hypersonic missiles,[77] non-proliferation measures are always vulnerable to the criticism of replicating the oft-resented 'haves and have-nots' dynamics,[78] and only partially address the destabilizing potential of current hypersonic weapon developments. They do not prevent further development of hypersonic capabilities by states already engaged on this path and other states may therefore be unwilling to forego potential future acquisition.
- Zhao has suggested that hypersonic weapons should be 'accounted for' in **arrangements limiting or reducing strategic arms**,[79] for example, within the framework of the successor to the New Strategic Arms Reduction Treaty (New START) concluded between the US and Russia and expected to last into 2021.[80] This would go some way in addressing the risks of 'entanglement' of conventional and nuclear aspects, but bilateral agreements do not bind other relevant states, and there appears to be limited appetite for such cooperative measures between the US and Russia at present.[81]
- Others have emphasized the importance of **confidence-building measures** similar to those pursued with regard to ballistic missiles, such as giving advance notice of tests, placing restraints on the location of tests and specifying 'that hypersonic missiles will be used only with non-nuclear warheads',[82] and have identified **transparency measures** such as data exchanges and notifications as realistically achievable options.[83]
- The organization of an **international conference** to discuss the issue has also been proposed,[84] and the Secretary-General has tasked the UN Office for Disarmament Affairs and the UN Institute for Disarmament Research to **study** the peace and security implications of long-range conventional weapons, including those using hypersonic technologies, to enable his Advisory Board on Disarmament Matters to 'make practical recommendations for arms control measures'.[85]

Despite some shortcomings, these proposals point to valuable avenues to explore, in combination or individually. Inaction risks complicating other arms control endeavours, especially in relation to nuclear disarmament, missile control and efforts to restrain the weaponization of outer space.[86] Generating the political will to move forward is, thus, critical. At present, there is a tendency to expect that a small number of states – those who actively pursue the development of hypersonic weapons – champion control initiatives. This leaves the majority of states and other actors without a stake in the debate despite the fact that the effects of hypersonic weapons will be felt by states and communities worldwide. Recognizing how hypersonic weapons threaten our common security may help mobilize political will to move forward. As the UN Institute for Disarmament Research (UNIDIR) and the UN Office for Disarmament Affairs (UNODA) underline in a recent report: 'it is feasible and desirable for States to pursue a multilateral process that would address issues related to the development of hypersonic weapons'.[87]

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**END NOTES**

1 Report of the Secretary-General on current developments in science and technology and their potential impact on international security and disarmament efforts, UN doc A/73/177, 17 July 2018, §3.

2 UN Office for Disarmament Affairs (UNODA), *Securing Our Common Future: An Agenda for Disarmament*, 2018, p. 30, https://www.un.org/disarmament/publications/more/securing-our-common-future/.

3 J. M. Acton, 'Hypersonic Boost-Glide Weapons', 23(3) *Science & Global Security* (2015) 191–192; P. Podvig and A. Stukalin, 'Russia Tests Hypersonic Glide Vehicle', *Jane's Intelligence Review*, 4 June 2015; R. Kheel, 'Russia, China Eclipse US in Hypersonic Missiles, Prompting Fears', *The Hill*, 27 March 2017, http://thehill.com/policy/defense/380364-china-russia-eclipse-us-in-hypersonic-missiles-prompting-fears.

4 Besser et al suggest that 'the boost-glide vehicle is likely to be the first operational system, as the number of global successful tests of prototype systems outpaces any other hypersonic technology by far. An operational system is attainable by 2022–2025'. They also note that '[o]perational readiness of long-range, air-launched hypersonic cruise missiles is very unlikely within the next decade, because of the higher complexity of a powered vehicle in comparison to a glider, but should be attainable within 20 years' (H. Besser et al, 'Hypersonic Vehicles: Game Changers for Future Warfare?', 24 *Journal of the Joint Air Power Competence Centre (JAPCC)* (2017) 21–22, https://elib.dlr.de/113912/1/Hypersonic%20Vehicles%20-%20JAPCC%20Journal%20-%20Volume%2024_2017.pdf).

5 NATO Science and Technology Board, *STO Tech Trends Report 2017*, 8 August 2017, p. 20, https://www.nato.int/nato_static_fl2014/assets/pdf/pdf_topics/20180522_TTR_Public_release_final.pdf. Russia says it will deploy its Avangard system 'which includes a hypersonic glide vehicle carried on a UR-100NUTTH/SS-19 missile' in 2019 (P. Podvig, 'Avangard System Is Tested, Said to Be Fully Ready for Deployment', *Russian Strategic Nuclear Forces*, 26 December 2018, http://russianforces.org/blog/2018/12/avangard_system_is_tested_said.shtml).

6 Report of the Secretary-General on current developments in science and technology, §29.

7 'Missiles and other flying vehicles can travel in three speed ranges – subsonic, supersonic, and hypersonic. Subsonic missiles fly at less than the speed at which

sound travels (Mach 1), about 1,000 kilometers per hour (km/hr). Supersonic missiles fly above Mach 1. They are generally regarded as flying between Mach 1 and Mach 5, about 1,000 to 5,000 km/hr' (R. H. Speier et al, *Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons*, Rand Corporation, 2017, p. 2, https://www.rand.org/pubs/research_reports/RR2137.html).

8 The CCW's preamble, equally concerned with the prevention of unnecessary suffering, the protection of civilians, the ending of the arms race and disarmament, attests to this. See also, O. Bring, 'Regulating Conventional Weapons in the Future – Humanitarian Law or Arms Control?', 24(3) *Journal of Peace Research* (1987) 275–286; K. Carter, 'New Crimes Against Peace: The Application of International Humanitarian Law Compliance and Enforcement Mechanisms to Arms Control and Disarmament Treaties', The Markland Group and Canadian Council on International Relations (eds), *Treaty Compliance: Some Concerns and Remedies*, Brill/Nijhoff, 1998, pp. 1–21.

9 See, e.g., Article 36, *Directed Energy Weapons*, Discussion Paper, November 2017, http://www.article36.org/wp-content/uploads/2019/06/directed-energy-weapons.pdf

10 For example, the US Navy's SM-6 missiles can not only 'intercept ballistic missiles' but could also be used in an offensive capacity to target enemy ground forces, surface ships and even submarines. See, e.g., D. Axe, 'The SM-6 Is the U.S. Navy's Most Important Missile (It Can Kill Almost Anything)', *The National Interest*, 1 February 2019, https://nationalinterest.org/blog/buzz/sm-6-us-navys-most-important-missile-it-can-kill-almost-anything-42987.

11 'When combined with the benefits of faster C4ISR, enabled by improved processing capabilities and augmented by artificial intelligence, not only will weapons themselves be faster but so too will the capacity to find a target and process all the information necessary to decide whether or not to engage' (International Institute of Strategic Studies, 'The Speed of War: Faster Weapons; Faster Organisations', *Strategic Survey 2018: The Annual Assessment of Geopolitics*, November 2018, Chapter 3, Part IV, https://www.iiss.org/publications/strategic-survey/strategic-survey-2018-the-annual-assessment-of-geopolitics/ss18-04-strategic-policy-issues-4).

12 Zhao opines that '[n]o clear technical distinction can be made between hypersonic missiles and other conventional capabilities that are less prompt, have shorter ranges, and also have the potential to undermine nuclear deterrence' (T. Zhao, 'Going Too Fast: Time to Ban Hypersonic Missile Tests?: A Chinese Response', 71(5) *Bulletin of the Atomic Scientists* (2015) 6).

13 The US was at the forefront of these technology developments and published the results of several of its earlier test programmes including the DARPA Hypersonic Test Vehicle (HTV-2) boost glide, whose test flight ended after just a few seconds. The US Army Advanced Hypersonic Weapon (AHW) and supersonic combustion ramjet (scramjet) programmes also had mixed records of success with the X-51 missile reaching Mach 5 for 210 seconds but only one out of four tests being fully successful. The US Navy HyFly failed to reach hypersonic speed in all tests. Russia has also conducted successful tests of at least two types of hypersonic weapon, the Zircon/Tsirkon and the Avangard, which are reportedly expected to be ready for deployment within the next few years (M. J. Lewis, 'Global Strike Hypersonic Weapons', 1898(1) *AIP Conference Proceedings* (2017), https://doi.org/10.1063/1.5009210; J. M. Acton, 'The Arms Race Goes Hypersonic', *Foreign Policy*, 30 January 2014, https://foreignpolicy.com/2014/01/30/the-arms-race-goes-hypersonic/; Podvig and Stukalin, 'Russia Tests Hypersonic Glide Vehicle'; S. Taheran, 'Putin Sets Hypersonic Deployment Plan', *Arms Control Today*, 8 January 2019, https://www.armscontrol.org/act/2019-01/news-briefs/putin-sets-hypersonic-deployment-plan).

14 Acton, 'Hypersonic Boost-Glide Weapons'; Podvig and Stukalin, 'Russia Tests Hypersonic Glide Vehicle'; L. Saalman, 'China's Calculus on Hypersonic Glide', Commentary, SIPRI, 15 August 2017, https://www.sipri.org/commentary/topical-backgrounder/2017/chinas-calculus-hypersonic-glide. Japan is also reportedly seeking to develop hypersonic weapons, A. Ragge, 'Japan: Plans for Electronic-Warfare and Hypersonic Capabilities', *Military Balance*, 3 December 2018, https://www.iiss.org/blogs/military-balance/2018/12/japan-plans-hypersonic-capabilities.

15 Speier et al, *Hypersonic Missile Nonproliferation*, p. xi.

16 Ibid, pp. 2, 3, 8, 10.

17 Ibid, p. 11. The major part of the trajectory of existing manoeuvring re-entry vehicles (MARVs) is ballistic.

18 Ibid, p. 8.

19 Ibid, pp. xii, 103.

20 Ibid, p. 12.

21 See, e.g., D. Axe, 'Russia's Deadly Iskander-M Ballistic Missile Is Headed to Kaliningrad Exclave', *The National Interest*, 2 January 2019, https://nationalinterest.org/blog/buzz/russias-deadly-iskander-m-ballistic-missile-headed-kaliningrad-exclave-40397.

22 Hypersonic weapons potentially under development include hypersonic bullets (see, e.g., M. Episkopos, 'Russian Snipers Might Soon Have a New Weapon: Hypersonic Bullets', *The National Interest*, 22 November 2018, https://nationalinterest.org/blog/buzz/russian-snipers-might-soon-have-new-weapon-hypersonic-bullets-36807) and hypersonic projectiles for railguns (e.g. Department of the Navy, 'Special Program Announcement for 2012 Office of Naval Research Research Opportunity: "Hyper Velocity Projectile (HVP) Research"', Special Notice 12-SN-0017, 2012, https://www.fbo.gov/index?s=opportunity&mode=form&id=be58c376763c82be08f9dd44f58637ce&tab=core&_cview=0), as well as the use of hypersonic technologies in relation to 'manned and unmanned reusable air vehicles' (Speier et al, *Hypersonic Missile Nonproliferation*, p. 4), and 'fast penetrating intelligence, surveillance, and reconnaissance (ISR) platforms' that could supplement or replace space surveillance or operate as cueing systems for weapons (Lewis, 'Global Strike Hypersonic Weapons', 02005-3.

23 A. F. Woolf, 'Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues', CRS Report for Congress, R41464, April 2018 (updated 8 January 2019), p. 10, http://www.fas.org/sgp/crs/nuke/R41464.pdf.

24 Ibid, p. 17.

25 A. Macias, 'Russia Again Successfully Tests Ship-Based Hypersonic Missile Which Will Likely be Ready for Combat by 2022', CNBC, 20 December 2018, https://www.cnbc.com/2018/12/20/russia-tests-hypersonic-missile-that-could-be-ready-for-war-by-2022.html.

26 Taheran, 'Putin Sets Hypersonic Deployment Plan'.

27 M. Bodner, 'Russia to World: Our New Nukes Are "No Bluff"', Defense News, 12 March 2018, https://www.defensenews.com/industry/techwatch/2018/03/12/russia-to-world-our-new-nukes-are-no-bluff/.

28 Besser et al, 'Hypersonic Vehicles', p. 13.

29 Lewis, 'Global Strike Hypersonic Weapons', p. 020005-2.

30 Once in the atmosphere, hypersonic weapons could change trajectory, marking a significant departure from ballistic missiles, which follow a trajectory determined by physical forces such as gravity and air resistance and are therefore more predictable and interceptable. Together with their much greater speed compared to existing cruise missiles, this makes hypersonic weapons especially difficult to defend against (Speier et al, *Hypersonic Missile Nonproliferation*, p. xii).

31 R. H. Speier, 'Hypersonic Missiles: A New Proliferation Challenge', *The RAND Blog*, 29 March 2018, https://www.rand.org/blog/2018/03/hypersonic-missiles-a-new-proliferation-challenge.html.

32 In 1998, a committee charged with reviewing the US Air Force Hypersonic Technology Program concluded that, except for 'the need to strike time-critical and exceptionally hardened targets', the Air Force had not established operational requirements or assessed whether the hypersonic weapon under development would in fact be the best means to fulfil that need (Committee on Review and Evaluation of the Air Force Hypersonic Technology Program, *National Research Council, Review and Evaluation of the Air Force Hypersonic Technology Program*, The National Academies Press, 1998, p. 13).

33 P. Podvig, 'Blurring the Line Between Nuclear and Nonnuclear Weapons: Increasing the Risk of Accidental Nuclear War?', 72(3) *Bulletin of the Atomic Scientists* (2016) 146; J. M. Acton (ed.), *Entanglement: Chinese and Russian Perspectives on Non-Nuclear Weapons and Nuclear Risks*, Carnegie Endowment for International Peace, 2017.

34 Speier et al, *Hypersonic Missile Nonproliferation*, pp. 13, 18.

35 D. Ghoshal, *Hypersonic Weapons: The New Age Weapon System*, Opinion Document 98/2018, Spanish Institute for Strategic Studies, 27 September 2018, http://www.ieee.es/en/Galerias/fichero/docs_opinion/2018/DIEEEO98-2018_DEBGOS_Hypersonics_eng.pdf; S. Brimley et al, 'Building the Future Force: Guaranteeing American Leadership in a Contested Environment', Center for a New American Security (CNAS), 29 March 2018, https://www.cnas.org/publications/reports/building-the-future-force, p. 26.

36 R. Nagappa, 'Hypersonic Missiles: Where the Technology Leads', 29 July 2015, M. Gubrud, R. Nagappa, T. Zhao, 'Test Ban for Hypersonic Missiles', Roundtable, Round 3, *Bulletin of the Atomic Scientists*, 6 August 2015, https://thebulletin.org/roundtable/test-ban-for-hypersonic-missiles/.

37 Zhao, 'Going Too Fast', 6.

38 Ibid, 2.

39 M. Gubrud, 'The Argument for a Hypersonic Missile Testing Ban', 2 September 2014, *Bulletin of the Atomic Scientists*, https://thebulletin.org/2014/09/the-argument-for-a-hypersonic-missile-testing-ban/.

40 T. Walton, 'Why We Need the Advanced Hypersonic Weapon', *War on the Rocks*, 9 June 2014, https://warontherocks.com/2014/06/why-we-need-advanced-hypersonic-weapon/.

41 In tests, hypersonic cruise missiles have proven difficult to launch, with igniting their engine being compared to 'lighting a match in a 2,000-mile-per-hour wind'. Engineers working on HCMs – which rely on an air-breathing propulsion system – are also struggling to ensure that adequate thrust is provided by scramjet engines for the entire duration of the flight, from subsonic to hypersonic speeds (Speier et al, *Hypersonic Missile Nonproliferation*, pp. 104–105.) Once in flight, maintaining the structural integrity of a hypersonic missile at peak speeds as well as the ability to control and navigate is a challenge, particularly due to to significant kinetic heating, depending on the thermal conductivity of its materials (Besser et al, 'Hypersonic Vehicles', p. 16.)

42 Speier et al, *Hypersonic Missile Nonproliferation*, pp. 106–107.

43 Ibid, p. 14.
44 K. Reif, 'Hypersonic Advances Spark Concern', *Arms Control Today*, January/ February 2018, https://www.armscontrol.org/act/2018-01/news/hypersonic-advances-spark-concern. The policy of 'hair-trigger alert' evolved during the Cold War in relation to nuclear weapons, and the concern among US military strategists that a Soviet first strike could compromise the ability of the US to retaliate. Weapons or weapon launch systems on 'hair-trigger' or high alert are generally maintained in a ready-for-launch state.
45 Hypersonic weapons have the potential to 'decapitate a nation's leadership before it has the opportunity to launch a counter attack', R. Speier, 'Hypersonic Missiles'.
46 For example, on 9 August 2019 US Vice President Mike Pence outlined plans to create a Space Operations Force by 2020, citing the existence of Russian and Chinese military operations in space and the potential of 'highly threatening in-orbit activities and evasive hypersonic missiles' ('Pence Says U.S. Aims to Create New Space Force by 2020', Radio Free Europe/Radio Liberty, 24 October 2018, https://www.rferl.org/a/white-house-vice-president-pence-says-aim-create-new-space-force-in-steps-by-2020/29560686.html; E. Durkin, 'Space Force: All You Need to Know About Trump's Bold New Interstellar Plan', *The Guardian*, 10 August 2018, https://www.theguardian.com/us-news/2018/aug/10/space-force-everything-you-need-to-know).
47 Garcia sees the reason for this 'lack of normative alarm' in the attention having shifted 'from weapons systems of interstate strategic consequence to weapons systems of individual consequence,' i.e. from a Cold War arms control paradigm to a humanitarian arms control agenda (O. Garcia, 'No Alarm: Hypersonic Weapons Development and the Shifting Logics of Arms Control', MA Thesis, University of British Columbia, August 2016, 29–30).
48 Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles?'.
49 Egeli deplores that nuclear-armed states 'show little inclination to limit their "post- ballistic" capabilities in weapons of mass destruction (WMD) delivery', which, in turn, provides no incentive to other states to pursue missile control measures (S. Egeli, 'Seeking a Path Toward Missile Nonproliferation', 72(6) *Bulletin of the Atomic Scientists* (2016) 363).
50 For more information, see http://mtcr.info/. On other relevant regimes, see, See *Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control*, UNIDIR and UNODA, 2019, §§ 56-59.
51 Missile Technology Control Regime (MTCR), *Annex Handbook*, 2017, p. 24.
52 Speier et al, *Hypersonic Missile Nonproliferation*, p. 111, who note that 'rocket boosters for HGVs are generally controlled as Category I in the current MTCR Annex. (New to MTCR Annex item 2.A.1.b)'. For more detail, see ibid, pp. 42–45.
53 Speier, 'Hypersonic Missiles'.
54 Bilateral arms control instruments, such as the 1987 Intermediate-Range Nuclear Forces (INF) Treaty would also have the potential to constrain hypersonic weapons, but do not presently apply to them because their definitions do not take account of hypersonic technologies. See, e.g., S. J. Freedberg, 'Army Insists 1,000-Mile Missiles Won't Breach INF Treaty', *Breaking Defense*, 17 September 2018, https://breakingdefense.com/2018/09/army-insists-1000-mile-missiles-wont-breach-inf-treaty/. Similarly, the New Strategic Arms Reduction Treaty (New START) would not capture warheads deployed on hypersonic glide vehicles (A. F. Woolf, 'Conventional Prompt Global Strike and Long-Range Ballistic Missiles', p. 42).
55 T. Scheber and K. Guthe, 'Conventional Prompt Global Strike: A Fresh Perspective', 32(1) *Comparative Strategy* (2013) 19.
56 Art 2(4), 1945 United Nations Charter; UNGA Res 2625 (XXV), 24 October 1970; UNGA Res 3314 (XXIX), 14 December 1974.
57 Art 36, 1977 Additional Protocol I to the Geneva Conventions (AP I).
58 Arts 48, 51(2) and 52(2), AP I; ICRC Customary IHL Study, Rules 1, 11 and 71.
59 The UN Secretary-General expresses wariness about 'inadequate precision of current guidance systems' (Report of the Secretary-General on current developments in science and technology, §28). Besser et al consider that 'achieving a precise hit will remain very difficult' for HGVs (Besser et al, 'Hypersonic Vehicles', p. 20), and Gubrud warns that hypersonic missiles 'have difficulty using sensors for precise navigation – or to locate and home on mobile targets' (M. Gubrud, 'Hypersonic Missiles: Junk Nobody Needs', 24 July 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 3).
60 International Court of Justice, Legality of the Threat or Use of Nuclear Weapons, Advisory Opinion, 8 July 1996, § 105(2)(E).
61 Ghoshal, *Hypersonic Weapons*, p. 16.
62 Gubrud, 'The Argument for a Hypersonic Missile Testing Ban'.
63 M. Gubrud, 'Just Say No', 24 June 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 1.
64 J. Schreiner, 'Hypersonic Weapons Could Create New Arms Race', *Stars and Stripes*, 14 October 2014.
65 J. Aune et al, *Hypersonic Missiles and Arms Control*, Great Plains National Security Education Consortium, n.d., http://www.stratcom.mil/Portals/8/Documents/Hypersonic%20Missiles%20and%20Arms%20Control.pdf?ver=2017-03-31-134237-917.
66 R. Nagappa, 'New Technology, Familiar Risks', 25 June 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 1; T. Zhao, 'Political Obstacles, Technical Tangles', 16 July 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 2.
67 Nagappa believes their support is only likely after they have perfected their hypersonic weapons through testing (R. Nagappa, 'Hypersonics Are Here to Stay', 9 July 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles', Round 2).
68 T. Zhao, 'What's Possible: Hypersonic Harm Reduction', 6 August 2015, Gubrud, Nagappa and Zhao, 'Test Ban for Hypersonic Missiles'.
69 Aune et al, Hypersonic Missiles and Arms Control.
70 Podvig, 'Blurring the Line Between Nuclear and Nonnuclear Weapons, 148.
71 Aune et al, *Hypersonic Missiles and Arms Control*.
72 Speier et al, *Hypersonic Missile Nonproliferation*, p. 44.
73 Egeli suggests adding 'hypersonic vehicles' to the 2002 International Code of Conduct against Ballistic Missile Proliferation (Hague Code of Conduct, HCoC), and using it as a basis for a missile test ban (Egeli, 'Seeking a Path Toward Missile Nonproliferation', 363). The politically binding HCoC has 139 subscribing states and aims to prevent and curb the proliferation of ballistic missile systems capable of delivering weapons of mass destruction, and to promote transparency and build confidence. For more information, see https://www.hcoc.at/.
74 Speier et al, *Hypersonic Missile Nonproliferation*, pp. xiv, 45, 110–115.
75 V. Siddhartha, *Spaceplanes, Hypersonic Platforms and the Missile Technology Control Regime*, International Strategic and Security Studies Programme, National Institute of Advanced Studies, Bangalore, 2017, pp. 6–7. Siddharta defines 'Lifting Bodies' or 'Hypersonic Gliders' as 'vehicles capable of return to land or water after traversing the atmosphere from space at speeds of Mach 5 or more, and capable of refurbishment for reuse after such return' (ibid, p. 6).
76 P. van Ham, *The MTCR at 30: Ideas to Strengthen the Missile Technology Control Norm*, Policy Brief, Clindgendael Institute, November 2017, p. 11, https://www.clingendael.org/sites/default/files/2017-11/PB_The_MCTR_at_30.pdf.
77 Speier et al, *Hypersonic Missile Nonproliferation*, p. 48.
78 Siddhartha severely criticizes the report by Speier et al for adopting a 'disdainful, derisive and dismissive attitude to any Indian effort', whilst at the same time arguing that it is 'in India's interest to stymie the self-development by other countries of hypersonic platforms' (Siddhartha, *Spaceplanes*, pp. 2, 6).
79 Zhao, 'What's Possible'.
80 A. Arbatov et al, 'Entanglement as a New Security Threat: A Russian Perspective', Acton, *Entanglement*, p. 40; J. M. Acton, 'A U.S. Perspective on Policy Implications', ibid, p. 83.
81 Although hypersonic glide vehicles had reportedly been raised in bilateral arms reduction talks between the US and Russia, they were expressly omitted from the limits on missile holdings in the New START (Report of the Secretary-General on current developments in science and technology, §41). Hypersonic weapons do not fall within the scope of the INF Treaty because they do not fit its definitions of ballistic and cruise missiles. A hypersonic glide vehicle spends a negligible portion (and not most) of its trajectory in ballistic mode. In December 2018, the US Government announced its intention to suspend the INF Treaty, alleging a material breach by Russia. See *Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control*, §§ 44-45.
82 Nagappa, 'New Technology, Familiar Risks'.
83 Zhao, 'Going Too Fast', 7. See also J. H. Pollack, 'Boost-glide Weapons and US-China Strategic Stability', 22(2) *The Nonproliferation Review* (2015) 161.
84 Work of the Advisory Board on Disarmament Matters, Report of the Secretary-General, UN doc A/71/176, 21 July 2016, §14.
85 UNODA, Securing our Common Future; Work of the Advisory Board on Disarmament Matters, §14.
86 'Pence Says U.S. Aims To Create New Space Force By 2020': 'potential threats in space include ... "highly threatening in-orbit activities and evasive hypersonic missiles" ... "Space is a war-fighting domain".'
87 *Hypersonic Weapons: A Challenge and Opportunity for Strategic Arms Control*, §§ 74-75.

Article36

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