Hypersonic Weapons and Strategic Stability

Dean Wilkening

Hypersonic weapons – in particular, hypersonic boost-glide vehicles and hypersonic cruise missiles – are rapidly becoming a reality. China, Russia, the United States and several other countries are pursuing these weapons. Some may carry nuclear warheads. China, in particular, has sprinted ahead in the competition to exploit the near-space domain (20 to 60 kilometres in altitude) with a large number of recent flight tests and infrastructure improvements to become a world leader in some facets of hypersonic technology.[1] The principal rationale for developing similar weapons in the United States is to hold Russian and Chinese mobile targets at risk and to improve the ability to penetrate advanced integrated air-defence systems. These weapons, especially when conventionally armed, could have a profound effect on strategic stability. So far, suggested approaches to avoiding their destabilising effects do not appear promising.

Hypersonic weapons

Hypersonic weapons travel faster than Mach 5, at a speed of approximately one mile (1.6 km) per second. They come in three classes: ballistic missiles, boost-glide vehicles and cruise missiles. Hypersonic gun-launched weapons also are being developed, but they are less relevant to strategic stability due to their relatively short range. Ballistic missiles with ranges greater than approximately 300 km re-enter the atmosphere at speeds above

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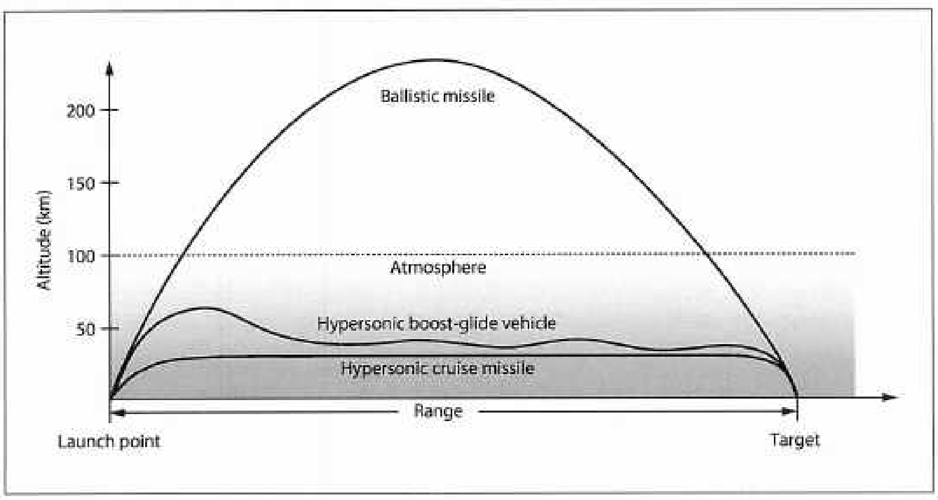
Mach 5. Ballistic missiles have been around for decades. The two new types of non-ballistic hypersonic weapons — hypersonic boost-glide vehicles and hypersonic cruise missiles — are on the threshold of becoming viable weapons systems because new technology is overcoming the challenges associated with surviving the intense aerothermal environment of extended high-speed flight in the upper atmosphere.[2]

Hypersonic boost-glide vehicles are launched by rockets in much the same way as ballistic missiles; however, instead of sending their payload into outer space on a ballistic trajectory, they boost the glide vehicle into a flatter trajectory that allows the vehicle to re-enter the upper atmosphere, whereupon it uses aerodynamic lift to glide as it slowly descends in altitude. To extend their range, boost-glide vehicles may adopt a porpoising motion in the upper atmosphere.

Hypersonic cruise missiles, on the other hand, are powered by supersonic combustion ramjet – scramjet – engines. Scramjets, as opposed to traditional ramjet engines, are required to achieve speeds above approximately Mach 5. A hypersonic cruise missile is boosted to high speeds by a rocket motor. Then the scramjet engine ignites, and the missile follows a high-altitude cruise trajectory at a more or less constant speed and altitude. While ballistic missiles spend a relatively short period inside the atmosphere – only during their boost and re-entry phases – hypersonic boost-glide vehicles and cruise

Figure 1: **Hypersonic ballistic, boost-glide and cruise-missile flight paths**



missiles spend the bulk of their flight paths within the upper atmosphere, typically at altitudes of between 20 and 60 km. Figure 1 illustrates notional flight paths for these different hypersonic vehicles.

The range of a hypersonic boost-glide vehicle depends on the speed with which it re-enters the atmosphere and the lift-to-drag ratio of the vehicle. The range of hypersonic cruise missiles depends on the ratio of the initial mass divided by the final mass after fuel exhaustion, scramjet fuel efficiency (that is, specific impulse) and the vehicle lift-to-drag ratio.[3]

Perhaps the most significant difference between hypersonic ballistic missiles and hypersonic boost-glide vehicles and cruise missiles is the latter's superior manoeuvrability. Ballistic missiles follow a relatively predictable flight path, which allows for accurate attack warning and attack assessment. Attack warning arises from detecting the large infrared signature from the rocket motors during lift-off. Attack assessment derives from tracking incoming ballistic missiles in mid-course with radar so as to predict, with reasonable accuracy, where the warheads will land and hence which targets are under attack. This information provides useful clues about the intent of the attack.

Attack warning for non-ballistic hypersonic weapons is possible because they too are launched with fairly large rocket motors. However, radar will detect these vehicles relatively late in their mid-course flight (that is, their glide phase) because they fly at low altitudes compared to ballistic missiles. Infrared sensors on satellites or high-altitude aircraft can, in principle, track non-ballistic hypersonic vehicles in mid-course from greater ranges due to their bright infrared signature (they become very hot as they fly through the upper atmosphere). Attack assessment, however, is more difficult because hypersonic boost-glide vehicles and cruise missiles can manoeuvre hundreds of kilometres in cross range during their glide phase. Therefore, even if these vehicles can be tracked, what targets are under attack will remain uncertain until late in the vehicles' trajectory. This inability to arrive at accurate attack assessments for non-ballistic hypersonic vehicles – a major difference between ballistic and non-ballistic hypersonic weapons – makes it much more difficult to determine the intent of an attack from hypersonic boost-glide vehicles and hypersonic cruise missiles.

Strategic stability

Strategic stability has been an organising concept in US nuclear-weapons policy for decades. It has been enshrined in nuclear-arms-control treaties, and Washington has used it to justify US nuclear-weapons programmes. Whether or not it should be an objective for US nuclear policy is not so much a strategic choice as an indelible feature of the nuclear balance between major nuclear powers. Much as one might desire nuclear superiority, major powers always have the option to deny it to their opponent. The term 'strategic instability' means different things to different audiences. Frequently, it refers to any action that increases the likelihood of war – an intuitively reasonable definition, but one that admits too many interpretations to be useful.[4] During the Cold War, the concept of strategic stability had two precise meanings: crisis stability and arms-race stability.[5]

Crisis stability refers to a situation between nuclear powers in which both sides believe their strategic nuclear forces are largely invulnerable, and that they can penetrate any defences the adversary might construct in sufficient numbers to deter attacks. In other words, both sides believe they can deter their opponent from attacking first in a crisis by assuring devastating retaliation.[6] The opposite, crisis instability, refers to what Thomas C. Schelling called the 'reciprocal fear of surprise attack'.[7] Two types of weapons systems were implicated in crisis instability during the Cold War: counterforce weapons that could destroy a large portion of an opponent's strategic nuclear forces or its strategic nuclear command, control and communication system in a surprise attack; and nationwide air and ballistic-missile defences (often called strategic defences or homeland defences, as opposed to theatre defences intended to protect military assets on the battlefield). Ballistic missiles with short flight times and accurate multiple independently targetable re-entry vehicles (MIRVs) are an example of the first kind of destabilising weapon. The second kind, nationwide defences, were thought to be destabilising if robust enough to intercept a large fraction of the opponent's retaliatory strikes after its retaliatory capability had been degraded by a pre-emptive counterforce attack. Thus, the Anti-Ballistic Missile Treaty did not ban nationwide ballistic-missile defences altogether but rather limited their size and technical characteristics so they could not effectively blunt a retaliatory strike.[8]

Pre-emptive counterforce options and strategic defences fall under the rubric of damage-limiting capabilities that allow a nuclear power to limit the damage an opponent's strategic nuclear forces can inflict in retaliation. Note that counterforce in this context contemplates pre-emptive attacks against an opponent's strategic (typically intercontinental-range), as opposed to non-strategic (typically theatre-range), nuclear forces because the former could strike the American and Russian homelands. Non-strategic nuclear weapons usually are associated with use on the battlefield or in a theatre campaign, and consequently are not tied directly to the survival of the homeland, although some US non-strategic nuclear weapons could reach Soviet territory during the Cold War – a point of considerable concern to Soviet leaders at the time.

If a state can limit damage through a combination of pre-emptive counterforce and defence to such a degree that striking first is no longer unthinkable, this would be destabilising. Thus, strategic instability involves a quantitative as well as a qualitative assessment. For example, if a state can reduce the damage from a retaliatory strike against its homeland by 30% through a combination of counterforce and defence, that state presumably would have little incentive to strike first in a crisis because the damage caused by the remaining 70% in a nuclear war would still be devastating. But a reduction in damage by 95% might provide such an incentive. During the Cold War, US and Russian planners worried about the vulnerability of their strategic nuclear forces under a range of different scenarios. 'Bolt out of the blue' attacks – a major US preoccupation – would occur with little strategic warning when nuclear forces were not on high alert and were relatively more vulnerable. At the other extreme, nuclear forces on high alert (for example, during a major conventional war) would be much less vulnerable. Accordingly, debates about crisis instability often turned on the credibility of different scenarios for nuclear war.

Most importantly, crisis instability depends on reciprocal fear. Only when both sides can significantly limit damage by striking first is there a strong incentive to pre-empt out of fear that, if one waits, the opponent may attack first and gain a tremendous advantage. One-sided damage-limiting options are not crisis destabilising to the same degree because there is no corresponding fear that the less capable side will attack first. It is sometimes argued that the vulnerable side might attack first because it faces a 'use them or lose them' situation; however, this would be suicidal because launching an attack under these circumstances would be met with the full force of the opponent's survivable nuclear force. Threatening to launch one's vulnerable forces on warning that a massive counterforce attack was under way might give the attacking country pause, thus contributing to deterrence, but if implemented it would lead to tragic nuclear escalation if the warning were in error. Accordingly, this tactic largely has been, and should be, avoided.

Actions that make nuclear escalation difficult to control constitute another central aspect of crisis instability. During the Cold War, the United States and the Soviet Union considered crossing the nuclear threshold first to deter various acts of aggression, especially in the context of losing a conventional battle. Strategists worried about how to control escalation once the nuclear threshold was crossed because in most scenarios the stakes involved were not commensurate with the destruction wreaked by an all-out nuclear war.[9] 'Off ramps' were sought for an escalating nuclear conflict, but few plausible ones that provided much comfort arose. By the end of the Cold War, few strategists were confident that escalation could be controlled in a rational manner, and threats to cross the nuclear threshold first were considered those that left something to chance. Controlling escalation clearly is more difficult than ensuring the survival of one's strategic nuclear forces because the former involves human behaviour *in extremis*, while the latter is more akin to a problem in engineering.

If the strategic nuclear forces of only one side are vulnerable, that side can be coerced at will by its opponent. Consequently, the vulnerable side has a strong incentive to modernise its strategic nuclear forces to reduce their vulnerability to pre-emptive attack and to improve their ability to penetrate strategic defences. This gives rise to the second common understanding of strategic instability, namely, arms-race instability. The more vulnerable side has a strong incentive to modernise its strategic nuclear forces, if not to increase their size, to re-establish the effectiveness of its strategic deterrent. Whether this leads to an action–reaction cycle depends on whether the dominant side continues to threaten the opponent's strategic nuclear forces. If so, the dominant side will invest in further damage-limiting capabilities, which then stimulate the opponent to neutralise them, and so on. However, if the threat to the opponent's strategic nuclear forces is unintentional (for example, if it results from a capability to hold at risk the opponent's conventional military forces), the action–reaction cycle might stop after one iteration.

Many examples of arms-race instability arose between the United States and the Soviet Union. Highly accurate MIRVed intercontinental ballistic missiles (ICBMs) threatened the survival of silo-based ICBMs, giving rise to programmes to harden missile silos and deploy mobile ICBMs. Submarine-launched ballistic missiles (SLBMs) and nuclear-armed cruise missiles had a theoretical capability to threaten bomber bases, submarine bases and nuclear command-and-control sites with short-warning surprise attacks, which prompted modernisation efforts. Anti-submarine warfare (ASW) against conventional submarines potentially threatened ballistic-missile submarines, stimulating the development of new generations of quieter ballistic-missile submarines that were harder to find.[10]

More recently, Russia has raised concerns about conventional counterforce capabilities – in particular, US long-range precision-guided conventional weapons. This concern is reflected in the preamble to the New Strategic Arms Reduction Treaty (New START), which states that both parties are 'mindful of the impact of conventionally armed ICBMs and SLBMs on strategic stability'. While most US analysts have cast Russian concerns as exaggerated, this may change with the advent of long-range conventionally armed hypersonic weapons.

Hypersonic weapons and crisis instability

Many countries, Russia and China in particular, ensure the survival of their military forces by making them mobile. China has amassed a large arsenal of conventionally armed short-, medium- and intermediate-range mobile land-based ballistic missiles, and many reportedly can attack targets on land as well as ships at sea.[11] The United States and Russia were banned from deploying such systems by the Intermediate-Range Nuclear Forces (INF) Treaty, which both parties have now repudiated. China is not a party to this treaty. In the future, China, which has an active hypersonic-weapons programme, will probably add mobile hypersonic boost-glide vehicles and hypersonic cruise missiles to its arsenal. Russia's conventionally armed mobile ballistic missiles, such as the *Iskander*-M, reportedly have ranges of less than 500 km in compliance with the INF Treaty, although Russia too is exploring other types of theatre-range hypersonic weapons.

Medium- and intermediate-range hypersonic weapons pose a serious threat to US forces deployed in Europe and the western Pacific, frequently called an anti-access/area-denial (A2/AD) threat. The US is seeking to neutralise this threat by developing the means to destroy these weapons before they can be used. Attacking mobile missile transporter-erector launchers (TELs) while they are moving is difficult. To launch its missile, however, the TEL must stop for a short period of time, during which it is vulnerable. Because this window of vulnerability can be short, attacking weapons either have to be very close to their target or travel at very high speeds. Destroying mobile targets while stationary, before they move, is one of the principal rationales for US hypersonic-weapons programmes.

Russia is exploring theatre-range hypersonic weapons

The question naturally arises whether US conventionally armed hypersonic weapons also can threaten the survival of Russian or Chinese mobile ICBMs, the backbone of their land-based strategic nuclear forces and their respective nuclear deterrents. Mobile ICBMs operate in much the same way as mobile theatre-range ballistic missiles (TBMs), remaining garrisoned or hidden until called upon to attack, whereupon they move to remote launch locations, stop to erect and launch their missiles, then move back to hide sites. Because mobile ICBM TELs are similar to TBM TELs, holding the latter at risk may give rise to a capability to threaten the former, depending on whether hypersonic weapons have sufficient range to reach mobile ICBM sites.

Threatening the survival of mobile ICBMs is crisis destabilising, although other elements of Russia's and China's strategic nuclear forces could remain intact. For Russia, these include SLBMs and long-range bombers. For China, they currently include only SLBMs, although it may add long-range bombers in the future. Thus, if the United States could not significantly limit damage through a combination of counterforce and strategic defence, there would be very little incentive to strike first in a crisis, and the strategic nuclear balance would remain quite stable even if mobile ICBMs became vulnerable.

Threats to a portion of an opponent's strategic nuclear force are not a new phenomenon. During the Cold War, accurate MIRVed ICBMs threatened silo-based ICBMs, and ASW capability against conventional submarines could threaten some ballistic-missile submarines. Yet at no time did the strategic nuclear balance between the United States and the former Soviet Union give rise to a serious incentive to strike first in a crisis. Such an incentive would have arisen only if other US attack options could have simultaneously destroyed most of the Soviet Union's strategic nuclear forces. This was never the case. Today, US ASW may appear more threatening to China – although accurate quantitative assessments are difficult to obtain because submarine operations and ASW capability are shrouded in secrecy – because China has yet to develop a long-range bomber force and relies solely on ballistic missiles for its strategic deterrent.

Finally, Russian and Chinese conventionally armed hypersonic weapons cannot threaten the US strategic nuclear arsenal to any significant degree, so a US capability to hold mobile ICBMs at risk would be a one-sided advantage. Consequently, it would not lead to a reciprocal fear of surprise attack. However, it almost certainly would induce Russia and China to modernise their ICBM forces, which could lead to arms-race instability. More problematically, Russia or China could adopt a launch-on-warning posture to mitigate the vulnerability of their mobile ICBMs. As noted, launching a nuclear retaliatory strike based only on tactical warning would be the height of folly. What makes launch-on-warning particularly troubling in the hypersonic age is that, whereas the impact area of a ballistic missile can be determined with reasonable accuracy within a few minutes after launch, hypersonic boost-glide vehicles' and cruise missiles' substantial manoeuvrability enables them to divert to targets hundreds of kilometres to either side of their initial trajectory. Therefore, Russia and China would not know the intended targets of a US hypersonic attack until the last few minutes before impact, potentially inducing fears that their strategic nuclear forces might be under attack when they were not.

The compressed timeline associated with hypersonic attacks – whether ballistic, boost-glide or cruise – also contributes to crisis instability because there will be precious little time for careful decision-making in the midst of an attack. Hypersonic weapons, however, are only one aspect of a trend towards increasing speed in modern conventional war brought about by technical advances in new anti-satellite weapons, cyber attacks and possibly artificial intelligence. This, combined with the lack of accurate attack assessment for non-ballistic hypersonic weapons, means that misperception, misunderstanding and miscommunication in the midst of war are more likely, contributing to inadvertent escalation.

There will be little time for careful decision-making

Ultimately, conventionally armed hypersonic weapons raise a fundamental tension between the goal in conventional war – to destroy the opponent's military forces as fast as possible – and the goal of maintaining a stable nuclear balance – avoiding threats to an opponent's strategic nuclear forces, not as a strategic preference but because no state with the wherewithal to prevent this from occurring will allow it to happen. It is not clear how to resolve this dilemma. Similar concerns were raised in the early days of the Cold War, when debates arose about how best to fight conventional wars beneath the nuclear threshold given the paramount goal of avoiding a major nuclear war.[12] These debates should be revisited in the hypersonic age for insight into how limited conventional wars can be managed without risking nuclear Armageddon.

Hypersonic weapons also may create problems of warhead ambiguity.[13] An adversary may not know whether an incoming hypersonic strike is nuclear or conventional if it is possible to arm hypersonic weapons with either warhead type. This issue became salient in the US debate over the Conventional Trident Modification programme, a plan to place conventional warheads on *Trident* SLBMs, customarily used only to deliver nuclear weapons, and was in part responsible for the cancellation of the programme. Analogous concerns came up during the Cold War when NATO deployed aircraft that could deliver both conventional and nuclear ordnance, but because dual-capable aircraft were essentially tactical, the intent behind the use of such weapons was assumed to be conventional until proven otherwise – a not unreasonable assumption, because assuming otherwise could trigger unnecessary nuclear escalation.

None of the hypersonic weapons the US is currently pursuing use delivery systems previously associated with nuclear weapons, so warhead ambiguity should be less of a problem. Nor are there any current plans to place nuclear payloads on US hypersonic weapons.[14] As of now, they will be conventionally armed tactical systems forward-deployed during a crisis and used in a conventional military conflict. In addition, the trajectory of non-ballistic hypersonic weapons is quite distinct from a ballistic trajectory (see Figure 1). Accordingly, although Russia and China may not believe US claims that its theatre-range hypersonic systems are entirely non-nuclear without some form of verification, mistaking a conventional attack for a nuclear one is considerably less likely than it would have been with, say, a conventionally armed *Trident* SLBM. It is less clear whether Russia and China will eschew hypersonic weapons with nuclear warheads. China reportedly has deployed some mobile TBM variants with nuclear warheads, and Russia may have done likewise.[15] If so, such systems would create warhead-ambiguity problems.

Ultimately, arms-control measures designed to verify the presence of nuclear warheads on different hypersonic weapons could be devised. Arms-control treaties have met the challenge of distinguishing nuclear from non-nuclear warheads in the past. For example, New START authorises technical means of verifying the actual number of nuclear warheads deployed on a given ballistic missile. These include radiation-monitoring techniques, requiring only limited physical access to the payload, to detect the presence of nuclear warheads without revealing sensitive nuclear-design information.[16] Thus, verifying that hypersonic weapons are not deployed with nuclear warheads is, in principle, possible with current techniques.

In addition, a problem with target ambiguity arises when conventional- and nuclear-delivery systems or command-and-control systems are commingled at the same site. Attacking such sites could blur the distinction between conventional and nuclear war. This increases the chance that the attack will be misperceived as an attempt to degrade a country's nuclear, as opposed to conventional, military forces. Commingling, however, typically occurs only with non-strategic nuclear forces. Threats to the survival of these forces are not as destabilising as threats to strategic nuclear forces. More importantly, it is the target side rather than the attacking side that would create this problem. If an adversary chooses to commingle conventional and non-strategic nuclear forces, it should understand that these assets likely will come under attack in the event of a conventional war because it may not be possible to distinguish between the two. Obviously, to minimise the chance that such attacks would be misinterpreted as a prelude to nuclear war, the United States should communicate clearly in advance that commingling nuclear and conventional weapons will not establish a sanctuary for conventional forces.

Unfortunately, avoiding commingling will not entirely solve this problem because the exceptional manoeuvrability of hypersonic boost-glide vehicles and hypersonic cruise missiles makes their targets difficult to discern until the last few minutes before impact. While timely warning of non-ballistic hypersonic attacks should be possible, timely attack assessment may not be. Hardened dual-purpose command-and-control sites are less vulnerable to attack by non-ballistic hypersonic weapons because these weapons have relatively small conventional warheads. But leaders may not know if ICBM silos, mobile ICBM garrisons, bomber bases or submarine bases are under attack until it is too late to guarantee their survival, even if they are not co-located with conventional systems.

Finally, concerns may arise about the signal sent when an intercontinental-range hypersonic weapon, as opposed to a tactical hypersonic weapon, is launched. Tactical or theatre hypersonic weapons will be deployed forward in a crisis in larger numbers, and their use authorised by theatre commanders as part of a conventional conflict that is likely to appear less escalatory. Intercontinental-range weapons will necessarily be fewer in number due to their high cost, and likely will require national command authorisation for release. Therefore, an adversary who detects the launch of such a weapon may infer that the attack is strategic in nature and, hence, escalatory.[17]

Hypersonic weapons and arms-race instability

Threatening Russian or Chinese mobile ICBMs with US conventionally armed hypersonic weapons will exacerbate arms-race instability because Russia and China will need to modernise their mobile ICBM forces to make them less vulnerable. This should not worry the United States if it is merely the collateral effect of holding mobile TBMs at risk, and the United States need not respond to Russian and Chinese modernisation efforts. Any action–reaction cycle would stop after the first step, and only a mild form of arms-race instability would result. However, if the same technique used to reduce the vulnerability of mobile ICBMs is employed to ensure the survival of mobile TBMs, this could stimulate an action–reaction cycle as the United States continues to pursue the capability to hold Russian and Chinese A2/AD capabilities at risk.

Penetrating advanced integrated air-defence systems is another key rationale for developing US hypersonic weapons. Currently, the United States relies on stealth, electronic attack, saturation and low-altitude penetration tactics to defeat such systems. While these means are effective, their utility may be eroding. Hypersonic weapons, by virtue of their high speed, high altitude and substantial manoeuvrability, stress air defences in fundamentally different ways and represent an attractive option for penetrating defences well into the future. High speeds compress the battlespace for defensive systems and challenge the performance of interceptors. Their high altitude keeps hypersonic weapons out of reach from most air-defence systems.

The manoeuvre capability of hypersonic weapons, however, differs by type. Ballistic missiles have virtually no manoeuvre capability in outer space, but have substantial manoeuvrability in the terminal phase if they possess manoeuvrable re-entry vehicles. Hence, ballistic missiles are a readily available means for defeating Russian and Chinese integrated air-defence systems, barring any constraints imposed by treaty on the kinds and numbers of allowed US ballistic missiles, which appear less salient given the Trump administration's withdrawal from the INF Treaty.[18] Russia and China are developing ballistic-missile defences to some extent, which implies that US ballistic missiles might become vulnerable to mid-course defences at some point in the future. Hypersonic boost-glide vehicles and cruise missiles, on the other hand, fly beneath mid-course ballistic-missile defences and can fly above or around most integrated air-defence systems. The manoeuvrability of non-ballistic hypersonic weapons makes it difficult to track them with sufficient precision to launch interceptors against them should they enter the envelope of advanced surface-to-air missile (SAM) systems. In addition, the acceleration overmatch required for successful intercepts against manoeuvring hypersonic vehicles stresses SAM agility. Consequently, hypersonic boost-glide vehicles and cruise missiles are a better long-term option for defeating Russian and Chinese air and ballistic-missile defence systems. Moreover, defences against hypersonic weapons of any type likely will be more expensive than offensive hypersonic weapons, implying that defences will not be cost-effective at the margin. In fact, hypersonic weapons, especially boost-glide and cruise missiles, may be so difficult to intercept that they may usher in an era of offence dominance in conventional-strike warfare.

The upshot is that hypersonic weapons of all types will stimulate an intense offence–defence competition – a classic form of arms-race instability. This is already occurring with US efforts to improve its ballistic-missile defences in response to Russian and Chinese hypersonic weapons. This response raises the important question of the extent to which the United States should engage in this competition given its cost, with the understanding that limited defences still have a legitimate role in blocking less sophisticated attacks, whether intentional or accidental. From another perspective, the United States could invite an offence–defence competition between US hypersonic weapons and Russian and Chinese advanced air-defence systems as a cost-imposing strategy that would force them to spend disproportionate sums to improve their air defences. To the extent hypersonic weapons – ballistic missiles, boost-glide vehicles and cruise missiles – introduce offence dominance in conventional-strike warfare, reliance on conventional deterrence will be the least unattractive strategy to adopt.

Avoiding strategic instability

The problems of crisis instability and arms-race instability that hypersonic weapons create do not imply that the United States should forgo developing these weapons. The US has sound strategic reasons – in particular, holding mobile targets at risk and penetrating advanced integrated air-defence systems – for pursuing them. The fact remains that large numbers of conventionally armed hypersonic weapons may create a less stable strategic environment. Consequently, it behoves the major nuclear powers to think carefully about how to mitigate potential instabilities before they become truly unmanageable.

There are no ready solutions. It is difficult to see how the United States can avoid increasing the threat to mobile ICBMs while holding at risk conventionally armed mobile TBMs. But Russian and Chinese efforts to modernise their mobile ICBMs need not lead to endless action–reaction cycles unless the same means of ensuring the survival of ICBMs is used to ensure the survival of TBMs. For example, one might deploy ICBMs deep underground so they survive attack while providing for their egress in the event of nuclear war, indicating to the adversary that retaliation is assured even if not immediate. Such a basing mode would not be appropriate for conventional TBMs due to the need to have hundreds of them at the ready to launch on short notice against forward-deployed US forces in a conventional war. Eventually, Russia and China will have to decide if land mobility remains a viable means of ensuring the survival of critical military assets. For the past several decades, it has worked. Although camouflage, concealment and deception techniques improve the survival of mobile systems, the advent of hypersonic weapons guided by off-board sensors or advanced seekers still may render mobile systems vulnerable.

The speed with which conventional hypersonic attacks may unfold is cause for concern. It is arguable that the United States should avoid developing offensive hypersonic weapons altogether and rely instead on defences. However, defences against hypersonic weapons will be difficult to develop, expensive to deploy and of uncertain effectiveness. Point defences might be an option for protecting some critical military assets. More importantly, the offence–defence competition stimulated by hypersonic weapons may provide the United States with attractive asymmetric leverage against any state with advanced integrated air-defence systems, especially China. If so, conventional arms competitions will be an enduring feature of the future, much as they have been in the past.

Arms control is the traditional approach to ameliorating the destabilising consequences of novel weapons. That was the motivation for banning MIRVed ICBMs by way of START II. Expanding the INF Treaty to include China probably has little appeal to Beijing and, in any case, would only ban ground-launched ballistic missiles and cruise missiles, not other types of hypersonic weapons. This approach appears moribund in any case with the imminent demise of the INF Treaty. Banning new classes of hypersonic weapons – hypersonic boost-glide vehicles and hypersonic cruise missiles – might appear attractive. But ballistic missiles also are hypersonic weapons. Although leaving ballistic missiles unconstrained would improve the ability to obtain accurate attack assessment, it would not remove the problems of conventional counterforce and the rapid speed of conventional warfare. Furthermore, banning non-ballistic hypersonic weapons would reduce the US opportunity to impose asymmetric costs on Russian and Chinese integrated air-defence systems, in the event they deploy effective mid-course ballistic-missile defences.

If strategic stability is the paramount goal, then banning all short-time-of-flight counterforce weapons, including ballistic missiles, would make sense. A world with only subsonic aircraft and cruise missiles is much more stable than one with hypersonic weapons because, owing to the former's long flight times, counterforce attacks are virtually impossible. Escalation also would be easier to control given the relatively slow pace at which conventional and nuclear attacks would unfold. The existence of stealth aircraft does not change this conclusion because they cannot hide from detection by some types of early-warning radar, thus allowing most strategic nuclear forces to survive through dispersal. In such a world, concerns about the effectiveness of strategic air defences in blunting retaliatory capability would still exist, so they too might have to be constrained. Nevertheless, banning 'fast flyers' is unlikely to gain much traction because Russia and China would have to abandon ICBMs, the backbone of their strategic nuclear forces, and the

United States would have to abandon SLBMs, the most survivable component of its strategic nuclear triad. Nor would France or Great Britain have much enthusiasm for this proposal, as their respective nuclear deterrents depend heavily on ballistic missiles.

Confidence-building measures – reciprocal actions taken to reduce the dangerous consequences of particular weapons systems without formal treaties – constitute another possible way to improve strategic stability. For example, keep-out zones for hypersonic weapons could increase their flight times. However, given the multiplicity of possible hypersonic launch platforms – land-based mobile missiles, aircraft, surface ships and submarines – it is difficult to imagine how keep-out zones could be enforced. The problem of warhead ambiguity would be reduced, but not eliminated entirely, if conventional hypersonic weapons were not launched by rockets previously associated with nuclear weapons, and if verification mechanisms could be employed to ensure that hypersonic weapons were not armed with nuclear warheads. This would require a level of trust and an acceptance of on-site inspections that do not exist in the current political environment. Target ambiguity can be avoided by not co-locating nuclear and conventional forces at the same site. Finally, 'hotlines' often are invoked as a way to avoid inadvertent escalation, the idea being that rapid communication between heads of state may avert misunderstandings. But they could also be used to convey disinformation, thereby obfuscating the intent of an attack.

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Near-space is becoming a critical new domain for military competition. Moreover, the speed and manoeuvrability of hypersonic weapons make defending against them difficult to accomplish at an affordable cost, potentially ushering in an era of offence dominance in conventional-strike warfare. If this materialises, these weapons may stimulate an intense offence–defence competition that favours the offence. From this perspective, US hypersonic weapons could be an effective asymmetric strategy for defeating Russian and Chinese integrated air-defence systems. Fundamental to the problem of maintaining strategic stability will be balancing the demands of conventional warfare with the need to maintain a stable strategic nuclear balance with Russia and China. This quandary will demand much more careful thought lest the major powers find themselves in a situation in which escalation, perhaps across the nuclear threshold, becomes difficult to control. Other destabilising considerations – in particular, warhead ambiguity and target ambiguity – are less relevant to US hypersonic-weapons programmes but should be considered carefully by Russia and China.

At this juncture, unilaterally curtailing US hypersonic-weapons programmes owing to concerns about strategic stability will not impede Russian and Chinese hypersonic-weapons programmes. In fact, deploying such weapons might be required for Russia and China to take seriously attempts to limit the weapons' destabilising effects, much as NATO's two-track decision to deploy ground-launched ballistic and cruise missiles in Europe in the 1980s led to efforts to eliminate these weapons by way of the INF Treaty. Accordingly, the time is right for the United States, Russia and China to begin discussing together the destabilising implications of hypersonic weapons in an effort to avoid potential misunderstandings, misperceptions and miscommunications in the event that they are ever used in war.

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Notes

1 See, for example, James Acton, *Silver Bullet: Asking the Right Questions About Conventional Prompt Global Strike* (Washington DC: Carnegie Endowment for International Peace, 2013); Guy Norris, 'Hyper Threat', *Aviation Week and Space Technology*, 20 February–5 March 2017; Mark Stokes, 'China's Evolving Conventional Strategic Strike Capability', Project 2019 Institute, 14 September 2009; and John Tirpak, 'The Great Hypersonic Race', *Air Force Magazine*, August 2018.

2 Ivett A. Leyva, 'The Relentless Pursuit of Hypersonic Flight', *Physics Today*,

vol. 70, no. 11, November 2017, pp. 30–6.

3 For a more detailed treatment of hypersonic-vehicle ranges, see James Acton, 'Hypersonic Boost-Glide Weapons', *Science & Global Security*, vol. 23, no. 5, October 2015, pp. 191–219; Preston H. Carter, II, Darryll J. Pinest and Lael von Eggers Rudd, 'Approximate Performance of Periodic Hypersonic Cruise Trajectories for Global Reach', *IBM Journal of Research and Development*, vol. 44, no. 5, September 2000, pp. 703–14; and Alfred J. Eggers, Jr, H. Julian Allen and Stanford E. Neice, 'A Comparative Analysis of the Performance of Long-Range Hypervelocity Vehicles', NACA Technical Report 1382, 1957.

4 Many actions arguably increase the likelihood of war and therefore could be destabilising under this definition. Such debates rapidly degenerate into criticisms of any undesirable action by one's opponent. Russia's annexation of Crimea and intervention in eastern Ukraine; Russian and Chinese cyber activities against the United States; and China's construction of human-made military outposts in the South China Sea in violation of the UN Convention on the Law of the Sea all arguably increase the likelihood of war and, therefore, according to this definition, could upset strategic stability. This is not the meaning given to this term in this article.

5 See Thomas C. Schelling, *Arms and Influence* (New Haven, CT: Yale University Press, 1966); and Thomas C. Schelling and Morton H. Halperin, *Strategy and Arms Control* (Washington DC: Pergamon-Brassey, 1975).

6 See, for instance, Bernard Brodie, 'The Development of Nuclear Strategy', *International Security*, vol. 2, no. 4, Spring 1978, pp. 65–83.

7 Thomas C. Schelling, *The Strategy of Conflict* (Cambridge, MA: Harvard University Press, 1960).

8 The Anti-Ballistic Missile Treaty specifically limited nationwide ballistic-missile defences to no more than 100 interceptors at a single launch site. This treaty no longer is in force because the United States withdrew in 2002. New START, signed in April 2010, also draws attention to the impact of strategic defences on strategic stability in its preamble, wherein it states that the United States and Russia recognise 'the existence of the interrelationship between strategic offensive arms and strategic defensive arms ... and that current strategic defensive arms do not undermine the viability and effectiveness of the strategic offensive arms of the Parties'.

9 See, for example, Desmond Ball, *Can Nuclear War Be Controlled?*, IISS *Adelphi Paper* 169 (London: International Institute for Strategic Studies, 1981); and Morton H. Halperin, *Limited War in the Nuclear Age* (Westport, CT: Greenwood Press, 1963).

10 The dynamics of arms-race instability during the Cold War were not confined to threats against the opponent's nuclear forces alone. For example, simply increasing the size of one's nuclear arsenal often made the other side feel disadvantaged, not because its deterrent was vulnerable but because parity was considered necessary to prevent intimidation in the midst of a crisis. The large Warsaw

Pact conventional armies facing NATO also gave rise to pressures to modernise US strategic and non-strategic nuclear forces to buttress extended deterrence, giving rise to nuclear arsenals with tens of thousands of nuclear weapons on both sides at considerable cost, and with questionable benefits for each side's security.

11 Office of the Secretary of Defense, 'Annual Report to Congress: Military and Security Developments Involving the People's Republic of China 2018', US Department of Defense, May 2018, pp. 36, 60, 71.

12 See Barry R. Posen, *Inadvertent Escalation: Conventional War and Nuclear Risks* (Ithaca, NY: Cornell University Press, 1992).

13 See Acton, *Silver Bullet*.

14 Amy F. Woolf, 'Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues', Congressional Research Service, 8 January 2019, https://fas.org/sgp/crs/nuke/R41464.pdf.

15 Office of the Secretary of Defense, 'Annual Report to Congress', p. 76.

16 Jonathan Medalia, 'Detection of Nuclear Weapons and Materials: Science, Technologies, Observations', Congressional Research Service, 4 June 2010, https://fas.org/sgp/crs/nuke/R40154.pdf; and Steve Fetter et al., 'Detecting Nuclear Warheads', *Science and Global Security*, vol. 1, nos 3–4, December 2007, pp. 225–302.

17 The preference for intercontinental-range weapons over theatre-range weapons arises, in part, from a debate about how much strategic warning is prudent to assume for conflicts with Russia and China. If the assumption is that less warning time will be available, systems based in the continental United States will be favoured because they can be available for use on a moment's notice. However, if the assumption is that strategic warning is available so that theatre systems can be forward-deployed in a crisis, the preference shifts to less expensive theatre-range hypersonic weapons that can be deployed in larger numbers.

18 For a discussion of arms-control constraints on hypersonic weapons, see Dean Wilkening, 'Hypersonic Arms Control: Treaty Constraints on Development and Deployment', Johns Hopkins University Applied Physics Laboratory, FPS-R-19-0216, April 2019.