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Hypersonic Impacts

Operational impacts of hypersonic weapons
and the change of America's strategic situation

By

Roman C. Lau

Colonel (GS), German Air Force

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Operational impacts of hypersonic weapons
and the change of America's strategic situation

by Roman C Lau

Colonel (GS), German Air Force

A paper submitted to the Faculty of the Joint Advanced Warfighting School in partial satisfaction of the requirements of a Master of Science Degree in Joint Campaign Planning Strategy. The contents of this paper reflect my own personal views and are not necessarily endorsed by the Joint Forces Staff College or the Department of Defense.

This paper is entirely my own work except as documented in footnotes (or appropriate statement per the Academic Integrity Policy).

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21 May 2021

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Abstract

The advent of hypersonic weapons defines new relationships and boundaries between space and airspace. Traveling at more than five times the speed of sound (Mach 5) on complex trajectories, they bring significant operational and strategic impacts, conquer the middle and upper atmosphere, leverage two main speed and altitude envelopes, and offer the possibility of a pre-stationing of hypersonic re-entry vehicles in space.

In the upper envelope, with speeds up to Mach 33 and altitudes up to several hundred kilometers, Hypersonic Glide Vehicles (HGVs) empower existing ballistic missile technology and will play a decisive role in rethinking intercontinental strategic missile threat and deterrence. In the lower envelope, with speeds presently up to Mach 6, Hypersonic Cruise Missiles (HCMs) will accompany the existing subsonic fleet of theater cruise missiles and will play their decisive role mainly in operational theaters.

The flight characteristics of HGVs and HCMs leverage the higher air layers of the atmosphere as *hypersonic airspace*, bridge the air and space domain, and call for an Integrated Air and Space Defense doctrine. S*pace-based* HGVs, could become a new and late observable threat, challenging the existing design of space-based IR-sensors.

Hypersonics have the potential to change the conduct of war at the operational level and influence the understanding of strategic deterrence. The Department of Defense (DoD) must consider the ramifications on the existing *space* and *airspace* doctrine and operational and strategic decision-making. For the combination of operational advantage and assured strategic deterrence, the dual-use of hypersonic weapons needs political discussion and military advice and elevates the importance of international arms control negotiations.

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Technical Disclaimer

The purpose of this thesis is not to explain hypersonic flight's scientific and technical details but to analyze their operational and strategic implications. Therefore, it applies a reasonable minimum of technical information in the main body.

Information about flight **altitudes** does not refer to one standard geodetic reference system. Instead, they refer to different barometric scales, GPS data, or other references. This limitation is sufficient for this thesis. For clarity and the most straightforward understanding, altitudes are given in kilometers and ft and rounded to useful measures.

Speeds are displayed with Mach numbers, in mph and km/s, for easy comparison. The speed of sound in the standard atmosphere depends on the air temperature and thus on the flight altitude. This thesis uses a constant speed of 0.3333 km/s for all altitudes, which is fair enough to calculate and explain the ramifications of hypersonic flight. Information from official datasheets has not been modified. Given the absence of sound transmission in space, there is no speed of sound and technically no Mach numbers. However, for comparability, it is fair enough to use matching Mach numbers for near-space objects.

A fundamental principle of this work is the exclusive use of publicly available information, which expressly has not been compared with classified data. This separation eliminates any possibility of compromising confidential information. Thus, the plausibility of the data in this study results from the physical background, the mutual comparison, and the overall context; the degree of accuracy is sufficient for the purpose of this work.

Most of the publications quoted are from recognized authors and organizations. In individual cases, after checking the plausibility, additional material from authors without a corresponding reputation is used for a supportive illustrational purpose.

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This thesis would not have been possible without the gracious invitation from the Chairman of the Joint Chief of Staff to the Inspector General of the German Armed Forces to send a representative to the Joint Advanced Warfighting School at National Defense University. I am grateful for this invitation and the opportunity to participate in U.S. Professional Military Education. My sincerest appreciation goes to the director and faculty of the Joint Advanced Warfighting School for investing their time and effort into my professional development as a senior military officer, a strategic thinker, and a writer. Finally, I could not have pursued my writing without the support of my thesis advisor, Dr. Bryon Greenwald. I would like to thank him, in particular, for helping me craft my arguments into appropriately academic English.

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Chapter 1: Introduction

The advent of hypersonic weapons will change how we fight and think of deterrence because these weapons define new relationships and boundaries within space and airspace. With speeds more than five times the speed of sound (Mach 5; 1.7 km/s; 3,700 mph), they bring significant impacts within two main speed and altitude envelopes.[1]

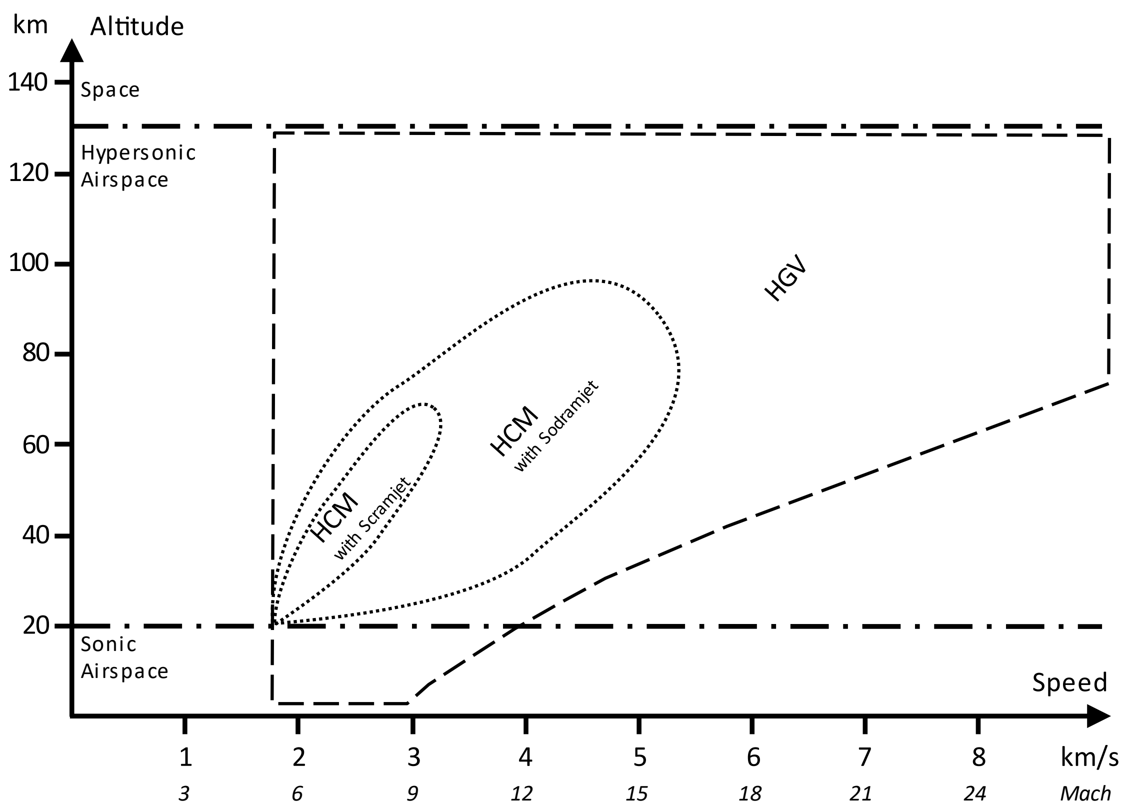

Figure 1: Hypersonic altitude and speed envelopes.

In the upper envelope, with speeds well up to Mach 33 (11km/s; 24,600mph) and skipping between 20 and 130 kilometers, Hypersonic Glide Vehicles (HGVs) enhance existing ballistic missile technology with maneuverable warheads, complex trajectories, and decisive agility in the terminal phase. Furthermore, launched by Intercontinental

[1] Appendix A offers a detailed background of hypersonic speed and altitude envelopes.

Ballistic Missiles (ICBM) as a carrier platform, HGVs can climb several hundred kilometers, re-enter the atmosphere several times, and constantly change directions. These maneuverable and agile HGVs will cause a rethinking of the intercontinental strategic missile threat and deterrence. HGVs may also play a role in operational theaters, deployed by short- and medium-range Tactical Boost Glide (TBG) systems.

In the lower hypersonic envelope, the Hypersonic Cruise Missile (HCM) attains speeds up to Mach 6 (2 km/s; 4,500 mph) and cruising altitudes between 20 and 40 kilometers. Powered by supersonic combustion ramjets (Scramjets), HCMs enhance the stand-off capability of today’s subsonic cruise missiles with significantly more speed and altitude. Therefore, HCMs will change operational fighting and deterrence thinking.

Both HGVs and HCMs use the atmosphere between 20 and 130 kilometers and exclusively leverage it as *hypersonic airspace*. Therefore, hypersonic weapons bridge the air and space domain to play out as a new threat and call for a revision of the existing Air and Missile Defense doctrine to a broader Integrated Air and Space Defense doctrine.

In recent years, there have been regular reports of new successes in developing and introducing these weapons. In a stunning 2018 national presentation, President Vladimir Putin announced spectacular Russian hypersonic capabilities.[2] China publicly paraded such weapons as operational.[3] While the careful analyst always needs to question the reliability of such reports, there is no substantial doubt in the relevant literature that the age of hypersonic weapons has come. More importantly, like the emergence of the airplane, jet

[2] “Putin Unveils New Nuclear Missile, Says ‘Listen to Us Now,’” NBC News, accessed February 17, 2021, https://www.nbcnews.com/news/world/vladimir-putin-set-state-union-speech-election-looms-n852211.

[3] “China Uses Communist Party’s 70th Anniversary to Show off New High-Tech Missiles,” accessed January 30, 2021, https://www.cbsnews.com/news/china-parade-70th-anniversary-communist-party-new-high-tech-missiles-hypersonic-df-17-today-2019-10-01/.

bomber, ICBM, submarine, and nuclear weapon, hypersonic missiles have the potential to revolutionize the conduct of war.

Therefore, any nation that wants credible armed forces must consider the capabilities and implications of hypersonic weapons. In the U.S., this discussion is already well underway. The Joint Chiefs and Congress have "shown a growing interest in pursuing the development and near-term deployment of hypersonic systems" in recent years.[4] The advent of hypersonic weapons has spurred a wide variety of study and commentary.

A 2017 *RAND* analysis on hypersonic weapons points to the dangers of worldwide diffusion of hypersonic technology and the potential for hair-trigger tactics.[5] An *Atlantic Council* primer discusses the Indo-Pacific theater and assesses how Russia and China view hypersonic weapons as an increased strategic deterrent.[6] Geist and Massicot assess Russia's claim of novel superweapons as an intended signal of competition readiness to prevent the U.S. from further investing in a decisive American strategic advantage.[7] Conversely, the American Foreign Policy Council (AFPC) suggests that Moscow and Beijing already possess powerful nuclear capability, and nuclear hypersonic weapons will not necessarily altering the strategic balance.[8] Terry and Cone generally conclude hypersonic nuclear delivery systems to have few advantages relative

[4] Kelley M. Sayler, "Hypersonic Weapons: Background and Issues for Congress, Version 9," August 27, 2020, 1, https://www.everycrsreport.com/reports/R45811.html#_Toc35330659.

[5] Richard H. Speier et al., *Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons* (Santa Monica, CA: RAND Corporation, 2017), 1, https://www.rand.org/pubs/research_reports/RR2137.html.

[6] John T. Watts, Christian Trotti, Mark J. Massa, "Hypersonic Weapons in the Indo-Pacific Region."

[7] Edward Geist and Dara Massicot, "Understanding Putin's Nuclear 'Superweapons,'" *SAIS Review of International Affairs* 39, no. Number 2, Summer-Fall 2019 (n.d.): 111.

[8] Margot van Loon, Dr Larry Wortzel, and Dr Mark B Schneider, "Hypersonic Weapons," *Defense Technology Program Brief*, no. 18 (May 2019): 22.

to existing systems.[9] The Congressional Research Service analyzes that today's U.S. multiple capabilities offer sufficient strike options and considers the advent of hypersonics less as a revolutionary new arms race between the three major nuclear powers and more as an evolutionary "competition in the development of new technologies."[10] The Stockholm International Peace Research Institute (SIPRI) gives a more detailed view on China's advancing hypersonic technology and arsenal.[11]

The literature discusses the technical fundamentals, various nations' progress, military value, possible scenarios, and international ramifications. However, it does not deliver a more tangible discussion about how hypersonic weapons might affect the planning and conduct of military operations—how they fit into the campaign. Military doctrine for integrating and using these weapons is still missing. As later analysis highlights, there has been no doctrinal publication about the role of hypersonic weapons in the air and space domains' warfare. Given the pace of hypersonic development, U.S. doctrine is falling further behind. Moreover, there is not much substantially written on how a nation, particularly a nuclear nation, might integrate these weapons into its arsenals in a way that is not destabilizing.

Furthermore, the examined literature does not discuss the potential of HGVs to weaponize space. The technical re-entry design offers the possibility of a *space-based HGV* lurking in a Low Earth Orbit (LEO).[12] Without a typical booster's infrared (IR) signature,

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[9] Nathan B. Terry and Paige Price Cone, "Hypersonic Technology: An Evolution in Nuclear Weapons?," *Strategic Studies Quarterly* 14, no. 2, Summer 2020 (May 27, 2020): 74.

[10] Amy F Woolf, "Conventional Prompt Global Strike and Long Range Ballistic Missiles: Background and Issues," no. V49 (February 14, 2020).

[11] Lora Saalmann, "China's Calculus on Hypersonic Glide," SIPRI Commentary/Backgrounder, Stockholm International Peace Research Institute, August 15, 2017, https://sipri.org/commentary/topical-backgrounder/2017/chinas-calculus-hypersonic-glide.

[12] Appendix B offers background for the space-based potential of HGVs.

such a weapon would be a significantly less observable threat. Therefore, the potential of pre-stationed space-based HGVs would challenge the existing layer of space-based IR-sensors and question the current integrated missile defense architecture.

This thesis examines how the combination of the significant characteristics of hypersonic weapons—speed, range, cruising maneuverability, and end-game agility—creates a series of challenges that will significantly influence how military organizations operate in the air and space domains. For the interested reader with less technical background, Appendix A and B examine the essential technical aspects of hypersonic weapons and their revolutionary potential.

Chapter Two assesses strategic risk, examines the effects of hypersonics on the principle of credible deterrence and alliance defense, and provides a foundation for strategic communication and a negotiation strategy with hypersonic competitors. Despite their characteristics and their potential to carry nuclear warheads, hypersonic weapons do not rewrite the rules of classic deterrence but challenge them. Indeed, at the strategic level, the U.S. and the other major powers should treat them as they do nuclear weapons today—ensure a second-strike capability, use arms control agreements, and reduce ambiguities.

Chapter Three discusses operational impacts. Hypersonic weapons are still under development—indeed, there are some questions as to their operational readiness. However, since the age of hypersonic weapons has undoubtfully arrived, conceptual, doctrinal, and technical gaps exist that exacerbate concern over these weapons.

Chapter Four concludes the main ideas, forms them into a perspective, and recommends further analysis to comprehend the actual risk and potential value of hypersonic weapons to U.S. and allied operations and to existing concepts of deterrence.

Chapter 2: Change in America's Strategic Situation

This chapter describes how the advent of hypersonic weapons changes America's strategic situation. With their speed, complex cruising trajectories, and decisive agility, these weapons force a rethinking about strategic risks and their mitigation. Hypersonic capabilities force competing nations to recognize conflicts of interest, prevent escalation, and leverage opportunities for arms reduction talks. Therefore, this chapter recommends clarifying strategic assumptions, rethinking strategic balance, seeking new negotiation frameworks, and closely coordinating with America's allies.

Hypersonic weapons bring a combination of uncertainties about direction, target, warhead, purpose, and probably their origin. Thus, they will have a lasting impact on the strategic security architecture. The 2018 National Defense Strategy connects these weapons to a "changing character of war."[1] Therefore, hypersonic weapons impact regional and global strategic balances, affect international relations, demand the deconfliction of capabilities and arsenals, and suggest the consolidation of treaties.

This is not the first time that a new threat complicated the architecture of international relations and security. In the mid-1970s, Soviet SS-20 missiles with nuclear warheads posed a new threat to NATO, causing severe concerns, specifically in European NATO countries, and led to the 1987 Intermediate-Range Nuclear Forces (INF) treaty.[2] Calmer heads prevailed, and the U.S.-U.S.S.R. entered a series of nuclear weapons treaties that reduced not only the size of their arsenals, but established protocols for keeping each

[1] Jim Mattis, "Summary of the 2018 United States National Defense Strategy of the United States of America" (Department of Defense, n.d.), 3.

[2] "The Intermediate-Range Nuclear Forces (INF) Treaty at a Glance | Arms Control Association," accessed February 12, 2021, https://www.armscontrol.org/factsheets/INFtreaty.

other informed in order to avoid tragic misinterpretation. Today's potential of hypersonic weapons to destabilize great power relationships reminds us of these solutions and gives hope for the hypersonic challenge.[3] First, however, several underlying strategic assumptions need clarifying. Additionally, the advent of hypersonics mandate a reevaluation of strategic risks and their mitigation, the functionality of international relations and deterrence, appropriate arms control, and the value of alliances.

Strategic Assumptions

Each viable deterrent strategy and each strategic negotiation builds upon assumptions about an adversary's motives, intent, capabilities, and behavior. Assuming a near equal capability, hypersonic competitors must share these assumptions to avoid a destabilizing arms race out of misinterpretation. Specifically, competitors must share and explain their rational and values as most driving factors of competition. For brevity, this section highlights three crucial assumptions indispensable for the hypersonic strategic framework. These assumptions appeared as an accompanying and useful outcome during the development of the operational and strategic impacts of hypersonic weapons for this thesis.[4] They focus on rationale, escalation control, and avoiding misunderstandings:

In principle, any adversary intends to survive and acts according to this rationale. This assumption is the intellectual last line of defense in any strategic competition. Without a distinct intention to survive, any negotiation loses its link to credible mutual deterrence and becomes incalculable. So far, America's strategic competitors seek survival.

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[3] The International Institute for Strategic Studies, "Hypersonic Weapons and Strategic Stability," *Strategic Comments* 26, no. 4 (March 6, 2020): x–xii, https://doi.org/10.1080/13567888.2020.1739872.

[4] Appendix C offers further examples of probable assumptions in the hypersonic context without reference or claim of completeness.

Every competitor wants to have escalation control. This assumption links the strategic to the operational level. The speed, range, and maneuverability of hypersonic weapons challenge concepts of escalation control. To maintain or regain escalation dominance or at least participate in escalation control, competitors depend on new instruments for de-escalation, such as a more robust defense, stronger deterrence, or adapted treaties. This pressure might increase mutual willingness to negotiate.

Nobody wants mutual misunderstandings or accidents. Nobody wants to appear as an attacker when not attacking. Nobody wants friendly fire. Furthermore, no one wants to kinetically engage a target, which afterward turns out to be a non-target, in the worst case causing civilian casualties or counterproductive effects. This assumption reflects the new ambiguities that come with the advent of hypersonic weapons. As operational decision pressure increases because of the higher speed and agility of hypersonic threats, the possibility of a fatal mistake rises. Therefore, a mutual interest in the mitigation of harm could open the field of negotiations between competitors.

Ambiguities

Assuming that the USA, China, and Russia share a rationale of survival, a striving for escalation control, and an intent to avoid misunderstandings, the emergence of hypersonic weapons entails new operational ambiguities that challenge these assumptions. Therefore, hypersonics bring strategic security risks for the United States. This section analyzes how these weapons bear a combination of *warhead ambiguity*, *destination ambiguity*, *target ambiguity*, *purpose ambiguity*, and *originator ambiguity* that challenges escalation-control, complicates the strategic risk calculus, and could question national survival.

Any approaching hypersonic weapon could bring a *warhead ambiguity* because it combines the uncertainty of whether it is *nuclear* or *conventional*.[5] An expert on hypersonic conventional weapons, James M. Acton has testified on this subject to the U.S. House of Representatives Armed Services Committee and the congressionally chartered U.S.-China Economic and Security Review Commission. His publications span the field of nuclear policy, and his current research focuses on the escalation risks of advanced conventional weapons and the future of arms control. He concludes in his 2020 analysis that the USA, China, and Russia should not acquire any warhead ambiguous intercontinental ballistic, cruise, or hypersonic boost-glide missiles because they could cause unintended escalation by assessing a conventional missile as a nuclear threat.[6] According to this argument, America would have to make every effort to clearly separate nuclear and conventional assets. In contrast, Michael T. Klare argues that a defender could never be certain that an enemy's assault would be entirely conventional and, therefore, the *warhead ambiguity* of hypersonic weapons would be inevitable.[7]

The hypersonic *destination ambiguity* connects to possible ramifications of conventional prompt global strike capabilities. In 2011, Bunn and Manzo introduced this ambiguity as a possible misperception of a state that observes a U.S. CPGS strike against a third party, but incorrectly concludes that it is under nuclear or conventional attack.[8] Furthermore, if a state correctly or incorrectly concluded that the United States is attacking

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[5] This thesis uses the phrase *conventional* only in the sense of *non-nuclear*. (see Appendix G)

[6] James M. Acton, "Is It a Nuke?" (Carnegie, April 9, 2020), 50, https://carnegieendowment.org/files/Acton_NukeorNot_final.pdf.

[7] Michael T. Klare, "An 'Arms Race in Speed': Hypersonic Weapons and the Changing Calculus of Battle | Arms Control Association," An 'Arms Race in Speed': Hypersonic Weapons and the Changing Calculus of Battle, June 2019, https://www.armscontrol.org/act/2019-06/features/arms-race-speed-hypersonic-weapons-changing-calculus-battle.

[8] M. Elaine Bunn and Vincent A. Manzo, "Conventional Prompt Global Strike," *Strategic Forum*, no. No.263 (February 2011): 16.

it with a CPGS weapon but does not know whether the strike is directed against its nuclear forces, conventional forces, or command and control centers, Bunn and Manzo would call this a variant of destination ambiguity. However, Acton terms this variant different.

In his 2013 work about the ramifications of Conventional Prompt Global Strike, Acton introduces *target ambiguity*. He argues that even a purely conventional attack could endanger the defender's strategic early-warning and command-and-control systems that defend their nuclear arsenal. Therefore, even a conventional attack would trigger the nuclear defense logic.[9] This ambiguity enfolds new potential with hypersonic agility. The combination of hypersonic speed and maneuverability leaves the defender with little time to respond. Hypersonics challenge the assessment of an opponent's intention and the choice of possible counteractions.

A conceivable conflict scenario illustrates the previous three ambiguities. It refers to Acton's 2015 comprehensive boost-glide analysis based on DoD Hypersonic Technology Vehicle-2 (HTV-2), with parameters for speed, range, and maneuverability of an HGV.[10] Classification concerns prevent further discussion in this thesis about deployment methods to achieve release-speeds of approximately Mach 18 (6 km/s; 13,400 mph) for intercontinental HGV ranges. However, these parameters are fair enough to support the following conflict scenario:

During a Middle-East crisis, a missile launches at a regional Space Center and accelerates westwards to Iraq. With its direction and ballistic launch from the surface, it initially imposes a regional ballistic threat in Central Command's (USCENTCOM) Area

[9] James M. Acton, "Silver Bullet? Asking the Right Questions About Conventional Prompt Global Strike" (Carnegy, September 3, 2013), 127, https://carnegieendowment.org/files/cpgs.pdf.

[10] James M Acton, "Hypersonic Boost-Glide Weapons," *Science & Global Security*, no. 23 (2015): 206, https://doi.org/10.1080/08929882.2015.1087242.

of Responsibility (AOR), maybe to Iraq, Saudi-Arabia, or Israel. However, passing Iraq after 2-3 minutes and accelerating to Mach 18 (6 km/s; 13,400mph), the missile turns out to be a Tactical Boost Glide (TBG) system that releases an HGV at an altitude around 100 kilometers after the boost phase. The HGV turns into a glide, changes direction slightly north-west, and enters European Command's (USEUCOM) AOR in Turkey. Therefore, it becomes a threat to Europe. It starts a skipping and turning trajectory, outmaneuvering U.S. Aegis Ashore missile defense capability in Romania.[11] Moreover, with a range of more than 6000 kilometers, this HGV might need less than another 20 minutes to reach Greenland, still traveling with Mach 6 (2 km/s; 4,500 mph) and becoming an imminent threat to the Continental United States (CONUS).[12]

This scenario illustrates the strategic impact of the first three combined hypersonic ambiguities. What started as a regional threat turned into a strategic weapon against America's homeland. Previously, an assumed theater ballistic missile might carry the potential for an intercontinental strategic threat but be restricted by direction and range. Now, any launch of a capable ballistic missile booster in a regional theater might bear an intercontinental TBG system, probably with a nuclear warhead. An assumed regional operational purpose could turn into a strategic purpose. Therefore, the advent of hypersonic glide weapons in operational warfare contributes to the blurring of operational and strategic levels and leaves a defender with a *purpose ambiguity*.

Beyond previous ambiguities, the pre-stationing of HGVs in space would bear the fifth ambiguity.[13] A re-entering space-based HGV without a detectable boost phase would

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[11] "Aegis Ashore," Missile Threat, accessed February 15, 2021, https://missilethreat.csis.org/defsys/aegis-ashore/.

[12] All parameters and locations are freely chosen and serve only to illustrate hypersonic potential.

[13] Appendix B offers background information about space-based HGV potential.

leave the defender uncertain about the weapons' origin. If the American space situational awareness is only periodically monitored via isolated ground stations and one Low Earth Orbit Satellite, the position of space objects cannot be wholly and permanently traced.[14] In the event of an HGV attack from space, it could be unclear whom to retaliate. The hypersonic weapon would bear an *originator ambiguity*.

warhead ambiguity	Any approaching hypersonic weapon combines the uncertainty of whether it is nuclear or conventional.
destination ambiguity	The possible misperception of a state that observes an opponent's strike against a third party, but incorrectly concludes that it is the actual target of this attack.
target ambiguity	A purely conventional attack could endanger the defender's strategic early-warning and command-and-control systems that defend their nuclear arsenal. This conventional hypersonic attack could trigger the defender's nuclear defense logic.
purpose ambiguity	The launch of a capable ballistic missile booster in a regional theater might bear an intercontinental TBG system bearing an HGV. An assumed regional operational purpose could turn into a strategic purpose.
originator ambiguity	A re-entering space-based HGV without a detectable boost phase would not only surprise the defender but leave them uncertain about the weapons' origin. In the event of an HGV attack from space, it could be unclear whom to retaliate.

Figure 2: Hypersonic weapon's ambiguities.

This hypersonic combination of warhead ambiguity, destination ambiguity, target ambiguity, purpose ambiguity, and originator ambiguity challenges escalation-control, complicates the strategic risk calculus, and could question national survival. Thus, the advent of hypersonic weapons brings forth three categories of strategic risks.

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[14] Roger Mola, "How Things Work: Space Fence," Air & Space Magazine, February 2016, https://www.airspacemag.com/space/how-things-work-space-fence-180957776/.

Strategic Risks

The first risk category rests on the idea that **U.S. national existence depends on a credible deterrence**. America's nuclear triad assures this credible deterrence with an assured second-strike capability.[15] Now it is time to consider what role hypersonics will play in this context. On the one hand, the Atlantic Council assesses that Russia and China view hypersonic weapons as an increased strategic deterrent that enhances their nuclear second-strike capability.[16] This argument would mean that Russia and China presently perceive their second-strike capability as too weak, making them vulnerable in the strategic deterrence balance. Therefore, with hypersonic weapons enhancing their second-strike capability, Russia and China could bring their threat perception into balance by changing the deterrence situation.

On the other hand, an American Foreign Policy Council (AFPC) paper refers to the assessment that today's nuclear ballistic missile arsenal already gives Moscow and Beijing an unstoppable nuclear capability, and strategic nuclear hypersonic weapons would not necessarily alter the strategic balance among the three powers.[17] This position would mean that hypersonics would not change the deterrence situation.

Completing this discussion, the AFPC concludes that Russia has linked its hypersonic capabilities to a nuclear decapitation attack on the U.S., which would seem to argue against its earlier position of an unaltered strategic balance.[18] Regarding China, the Director of National Intelligence (DNI) assesses that it continues to modernize its nuclear

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[15] "Nuclear Triad Important to America," U.S. Department of Defense, accessed February 12, 2021, https://www.defense.gov/Explore/News/Article/Article/1823014/nuclear-triad-important-to-americas-national-security/.

[16] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 2.

[17] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 2.

[18] van Loon, Wortzel, and Schneider, 15.

missile forces, forming a nuclear triad, providing a second-strike capability and a way to overcome missile defenses.[19] Hypersonics, overcoming these missile defenses, fit perfectly into this assessment, impact the strategic balance, and call for mitigation.

One may or may not like the consequences of such conclusions; given the enormous resources that Russia and China invest in hypersonic development and procurement, it is reasonable to assume that both countries expect a broad strategic return on investment, not only at the operational, but also at the strategic level. Russian and Chinese strategic intentions leverage the hypersonic speed and maneuverability for surprise, superiority, and strategic assertiveness. Both for China and Russia, hypersonics seem to add strategic value for two purposes. First, a scalable nuclear first-strike capability with a high probability to overcome America's homeland defenses. Second, an improved second-strike capability to assure responsiveness after being hit by U.S. strategic strikes against Russian or Chinese nuclear forces. For these purposes, a replacement of ballistic nuclear warheads with hypersonics would make sense.

Moreover, it is even more likely that both mature space nations would not miss the advantages of deploying hypersonics into space and leverage the strategic momentum gained from an orbital pre-stationing. In Chinese considerations about stationing anti-satellite (ASAT) weapons in space around twenty years ago, they proved an early awareness about orbital advantage.[20] China may develop covert hypersonic activities in space, as well as it has started other covert military activities, e.g. in Antarctica.[21]

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[19] Daniel R. Coats, "Director of National Intelligence, Worldwide Threat Assessment 2019" (Senate Select Committee on Intelligence, January 29, 2019), 9, https://www.dni.gov/files/ODNI/documents/2019-ATA-SFR---SSCI.pdf.

[20] Forrest E. Morgan et al., "Dangerous Thresholds: Managing Escalation in the 21st Century," July 7, 2008, 74, https://www.rand.org/pubs/monographs/MG614.html.

[21] Anne-Marie Brady, "Chinas Expanding Antarctic Interests: Implications for Australia," 2017, 13.

However, whether an opponent would only use nuclear HGVs as a replacement for existing ICBM warheads or even pre-station nuclear HGVs in a space orbit could question the existing U.S. first- and second-strike-logic. Any increased probability of a nuclear breach through U.S. missile defenses would require mitigation. Even if the hypersonic weaponization of space might emerge more in the long term, it could overstretch the framework of existing equilibria and be considerably more complicated to master within the existing security architecture. Today, nine countries can independently launch spacecraft: China, India, Iran, Israel, Japan, Russia, North Korea, South Korea, and the United States.[22] If any of the smaller space nations feel oppressed or ostracized, they might reach out for hypersonic technology, question existing space treaties, openly consider the pre-stationing of a nuclear warhead in space, and cause international turmoil.[23]

Furthermore, a nuclear hypersonic power play could serve smaller powers. Based on their rhetoric, Iran and North Korea are interested in capabilities to impose a significant strategic threat on the U.S. homeland. The agility of a nuclear HGV could give them the capability to breach U.S. missile defenses and strike America’s homeland. With a few nuclear hypersonics, these countries could create severe damage. The mere existence of a corresponding threat would create significant additional risk, lay a heavy burden on the U.S. polity, and underline the requirement for graduated U.S. escalation capabilities.

Therefore, hypersonic nuclear warheads enable an aggressor to overcome America’s homeland defenses on some scale as long as the U.S. cannot intercept these weapons. Only deterrence by massive retaliation keeps this risk in the strategic balance.

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[22] National Air and Space Intelligence Center (NASIC), “Competing in Space,” December 2018, 8, https://media.defense.gov/2019/Jan/16/2002080386/-1/-1/1/190115-F-NV711-0002.PDF.

[23] United Nations Office for Outer Space Affairs, *International Space Law: United Nations Instruments* (UN, 2018), https://doi.org/10.18356/014c0e55-en.

The second strategic risk category involves direct risks for America's global **freedom of movement and escalation dominance**. Escalation dominance brings the conventional use of hypersonic weapons and the warhead ambiguity into the calculus. As the Atlantic Council primer concludes:

> The speed and maneuverability of hypersonic weapons may increase the Chinese and Russian ability to strike in non-nuclear form, wherein the escalation and consequences would be comparatively lower, thereby changing their political calculations and increasing the likelihood that countries would employ that capability. This could shape the outset or early stages of great-power conflict. Even without an increased employment or use of the system, hypersonic weapons compound the existing ambiguity inherent in current deterrence calculations. Since their inherent advantage of surprise at the outset of a conflict incentivizes rapid escalation, they increase the risks of strategic miscalculation and preemptive action….[24]

A conventional hypersonic strike in any operational theater could be misinterpreted as a strategic nuclear attack. Moreover, under the umbrella of a paramount nuclear deterrence posture, an operational conventional hypersonic attack might evolve as a new central risk of the hypersonic age. Such a risk of strategic miscalculation is neither militarily nor politically acceptable, especially in nuclear superpowers relations.

Furthermore, China and Russia might easily leverage the operational characteristics of hypersonics as a supplement to anti-access/area denial (A2/AD)[25] postures; other nuclear powers might follow soon.[26] The use of Hypersonic Cruise Missiles (HCM) would surpass the existing fleet of subsonic cruise missiles and enlarge A2/AD areas. This denial of regional access would impact America's strategic range and question its credibility and reliability as an ally for regional partners.

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[24] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 9.
[25] Definition see Appendix G
[26] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 2.

Moreover, it is also about those competing powers' pursuit to use the hypersonic combination of maneuverability, range, and surprise to complicate American operational calculus. Russian Chief of the General Staff of the Armed Forces of Russia, General Valery Gerasimov, argued: "Frontal engagements of large formations of forces at the strategic and operational level are gradually becoming a thing of the past. Long-distance, contactless actions against the enemy are becoming the main means of achieving combat and operational goals."[27] And Russian Defense Minister Army General Sergei Shoigu confirmed hypersonic precision systems to comprise the backbone of Russia's non-nuclear deterrence forces.[28] Hypersonic pin-point strikes would exactly fit long-distance means without large formations' frontal engagements and would challenge America's strategic conventional superiority. If an adversary could use hypersonics to cause more uncertainties and convert U.S. wargaming into war gambling, the adversary would increase strategic deterrence against U.S. regional intervention.

Summarizing this category, the inherent escalation potential of the warhead ambiguity, the enhancement of an opponent's A2/AD posture, and the risk of an adversary's unstoppable hypersonic operational conventional attacks could question America's freedom of movement and escalation dominance. As the National Academies of Sciences, Engineering, and Medicine assessed in 2016, it could challenge the fundamental U.S. strategic construct of global reach and presence.[29]

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[27] Valery Gerasimov, "The Value of Science Is in the Foresight," *Military Review* 96, no. 1 (February 2016): 24.

[28] "Hypersonic Weapons to Comprise Backbone of Russia's Conventional Deterrence Forces," TASS, February 9, 2021, https://tass.com/defense/1254191.

[29] Engineering National Academies of Sciences, *A Threat to America's Global Vigilance, Reach, and Power–High-Speed, Maneuvering Weapons: Unclassified Summary* (Washington, DC: The National Academies Press, 2016), 5, https://doi.org/10.17226/23667.

The third strategic risk category incorporates regional escalation inflicting **international destabilization** with unavoidable impacts on U.S. national interests. A 2017 RAND report on hypersonic nonproliferation argues that the hypersonic threat might lead nations with limited strategic forces to set them up for "launch on warning."[30] These nations might take an incoming hypersonic conventional attack for a nuclear strike and launch a retaliatory attack before incoming missiles have reached their targets. They might launch even if they thought it was a non-nuclear attack. Such hair-trigger tactics would increase regional crisis instability. The authors conclude that such hair-trigger use of hypersonics could potentially draw the U.S. or its allies into unwanted regional conflicts because of treaty obligations or security concerns. It is difficult to predict the likelihood of such a hair-trigger escalation and to imagine how the speed of hypersonic weapons could leave the targeted nation even the time to retaliate before impact. However, hypersonic weapons in regional conflicts could lead to regional or international destabilization.

Therefore, the severity of the effects of such a development alone requires an appropriate risk calculation and calls for mitigation in this third risk category, international destabilization; so did the first two categories, U.S. national existence and credible deterrence, and freedom of movement and escalation dominance.

Mitigation

Mitigation necessities in the outlined three risk categories do not newly arise from the appearance of hypersonic weapons. Previous military capabilities did define these risks too. Therefore, strategic mitigations do not have to be reinvented, but already exist in the previous risk context and only must adapt to the hypersonic threat.

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[30] Speier et al., *Hypersonic Missile Nonproliferation*, 1.

The necessity of better **integrating existing Air and Missile Defense (AMD) architecture** is the overarching mitigation to the advent of hypersonics. The existing AMD architecture was already complex 20 years ago when space defense became more urgent. In May 2000, the Department of the Air Force (DAF) concluded that "air and space form a single seamless operational medium for the exercise of military power."[31]

However, this medium does not appear seamless. Today, two different services are responsible for the separate domains of *space* and *airspace*. General John E. Hyten (USAF), the former Commander of U.S. Strategic Command (USSTRATCOM), which in 2019 was responsible for America's nuclear arsenal as well as its space assets, emphasized the urgency of a ready space defense to the Senate Armed Services Committee. He summarized that "the best way to deter a war that starts in, or extends into space, is to be ready to fight and win."[32] Based on the space domain's complexity, expectations for this readiness in space were extraordinarily challenging and required focus. Therefore, the concentration of space efforts is reasonable, and the new U.S. Space Force (USSF) can be better positioned to address space defense issues. U.S. Space Command (USSPACECOM), responsible as the new Geographic Combatant Command for the *space* AOR, bundles the capabilities, skills, and readiness for the associated physical environment of *space*. A new National Defense Space Architecture (NDSA) will accompany former existing framework concepts of Integrated Air Defense System (IADS), Ballistic Missile Defense (BMD), and Integrated Air Missile Defense (IAMD).

[31] Michael E. Ryan and F. Whitten Peters, "The Aerospace Force" (Department of the Air Force, May 9, 2000), https://apps.dtic.mil/dtic/tr/fulltext/u2/a381077.pdf.

[32] Senate Committee on Armed Services, "Statement before Senate 2019, John E. Hyten, Commander U.S. STRATCOM" (Senate Committee on Armed Services, February 26, 2019), 18, https://www.armed-services.senate.gov/imo/media/doc/Hyten_02-26-19.pdf.

However, the advent of hypersonic weapons with their combination of speed and maneuverability, and the accompanying blurring of aerospatial boundaries, requires a holistic response, incorporating the full spectrum of defense layers from the Earth's orbits down to the point defense of high-value assets. This blending of defenses is an overarching change to America's strategic situation. As the DAF argued in 2000, "Support in the integration of air and space systems will lead to advances in our warfighting capabilities, new concepts of operations, and new technologies throughout the aerospace continuum."[33] Therefore, the advent of hypersonic weapons and the dissolution of the boundary between space and airspace require the existing and developing concepts and language of IADS, BMD, IAMD, and NDSA to merge into the development of one Integrated Air and Space Defense (IASD).

A second mitigation option against the hypersonic strategic risk is the consistent **hardening, dispersal, and redundancy of crucial U.S. infrastructure**. These are classical passive air and missile defense measures.[34] Since the formidable characteristics of hypersonic threats will probably continuously challenge any defense architecture, there will remain a need to rethink passive defense measures and the protection of High-Value Assets (HVA). Such assets will include U.S. Government strategic infrastructure, military C4ISR[35] installations, aircraft carriers, and other strategic military assets, as well as energy, communication, logistics, and industrial facilities. Chapter Three will elaborate on further operational ramifications of this mitigation.

[33] Ryan and Peters, "The Aerospace Force."

[34] Chairman of the Joint Chiefs of Staff, "Joint Publication 3-01, Countering Air and Missile Threats" (Joint Chiefs of Staff, May 2, 2018), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_01_pa.pdf.

[35] C4ISR - Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance.

The third strategic mitigation is a credible deterrence posture with an **assured second-strike capability**. In any escalation scenario, the U.S. must assure a diversified escalation spectrum with sustained U.S. dominance. A 2020 Congressional Research Service report analyzes whether today's long-range strike capabilities might offer America a good range of options, even if some lacked the promptness offered by ballistic missiles and hypersonic glide vehicles.[36] This logic would not see added value in a hypersonic upgrade of America's second-strike capability. Conversely, the Atlantic Council primer considers that if Russia and China view hypersonic weapons as an increased strategic deterrent enhancing their nuclear second-strike capability, so the U.S. might too.[37]

There are more voices to call the broad set of U.S. military instruments to maintain a credible framework to control escalation. The AFPC refers to General Hyten's perspective of the nuclear triad's deterrence force as viable mitigation to the new hypersonic risk.[38] Even if America does not yet have a hypersonic answer, the nuclear triad is sufficient for now. Moreover, even with probable U.S. operational defeat against hypersonic weapons, the deterrence force assures escalation dominance for America. The advent of hypersonic weapons does not neutralize America's second-strike capability and does not bring an imminent uncontrollable risk for U.S. national existence. If America's adversaries view hypersonics as useful additional strategic capability, such capability would confirm the importance of America's nuclear triad for a credible deterrence. Therefore, it is of no surprise that nuclear modernization is the U.S. Air Force's priority.[39]

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[36] Woolf, "CRS: CPGS," 48.

[37] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 2.

[38] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 3.

[39] Valerie Insinna, "US Air Force Chief's Top Modernization Priorities Aren't What You Think They Are," Defense News, November 17, 2020, https://www.defensenews.com/air/2020/11/17/the-air-force-chiefs-top-modernization-priorities-arent-what-you-think-they-are/.

On the other hand, the U.S. could procure conventional hypersonic weapons as a conventional fire extinguisher against nuclear escalation. As part of America's credible deterrence posture, conventional hypersonics could disrupt the operational dynamics of theater conflicts and expand response options without crossing the nuclear threshold.[40] As long as conventional hypersonic attacks could also be answered and overcome with conventional hypersonic counterattacks, nuclear escalation could be avoided because it remains available. This logic is supplemented by accepting a conventional hypersonic exchange of blows with possibly an open operational end and the accompanying acceptable loss of some of America's nuclear assets. Regardless of whether an attacker destroys U.S. nuclear assets with conventional hypersonic weapons or whether they might use nuclear warheads themself, America's nuclear second-strike capability is still available and thus forms the pivot of its deterrence and ultimate retaliation option. However, this nuclear pivot needs a flanking conventional hypersonic option to fence the nuclear escalation calculus.

Therefore, the ramifications of a complicated future strategic deterrence posture incorporating hypersonics might challenge the existing calculus of mutual deterrence. The hypersonic scenarios require extensive wargaming from scratch, and call for an adapted calculus of deterrence logic. The three risk categories, linked to three mitigation directions, can only be an initial guide for responding to hypersonic threats and their impact on America's strategic situation (Figure 3). The framework for a more extensive risk assessment and the mitigation of these risks would be a comprehensive joint risk analysis.[41]

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[40] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 2.

[41] Chairman of the Joint Chiefs of Staff, "Joint Risk Analysis Manual CJCSM 3105.01" (CJCS, October 14, 2016), https://www.jcs.mil/Library/CJCS-Manuals/.

Strategic Risks
Credibility of deterrence questioned, and U.S. national existence threatened.
U.S. freedom of movement and escalation dominance challenged or limited.
International destabilization.

Mitigations
Integrating the existing air, missile, and space defense architectures into one Integrated Air and Space Defense (IASD).
Hardening, dispersal, and redundancy of crucial U.S. infrastructure.
Assured second-strike capability.

Figure 3: Strategic Risks and Mitigations related to Adversaries' Hypersonic Weapons.

International Relations, Arms Control, and Proliferation

The Congressional Research Service considers the advent of hypersonics more "as a competition in the development of new technologies" and less as a new arms race between the three major nuclear powers.[42] That might be valid for a closed community of peer competitors with mutual total retaliation capability. However, even a strategic nuclear balance between the USA, Russia, and China leaves open the role of other hypersonic and nuclear powers. Hypersonic capabilities, new threats, and extended power projection would come with the risk of regional power-play, hair-trigger tactics, intended or

[42] Woolf, "CRS: CPGS," 48.

unintended escalation, and an increased crisis instability. Hypersonic weapons, therefore, affect international relations and invite all participants to the negotiating table. Even if the associated factors are too complex for further discussion at this point, corresponding international negotiations about hypersonic risks will be more beneficial than harmful.

It is necessary and reasonable to start a **new strategic dialogue** to align mutual assumptions and expectations, rethink strategic balance, prevent misunderstandings, and reduce the risk of inappropriate reactions. Such dialogue should start building a mutual understanding of the ramifications of the advent of hypersonics and the disadvantages and dangers of a new arms race in space. These ramifications might attract hypersonic military powers to the negotiation table and open a new gate to improve international relations.

There is a second gate to enter in international negotiations; that is the **mutual utilization of space**. The 2017 U.S. *National Security Strategy (NSS)* claims the unfettered freedom to operate in space as a vital interest.[43] Nonetheless, the unique physical conditions of space connected with the mutual dependencies in its use leave not much leeway for competition and certainly not for bickering. In his 2019 report to Congress, General Hyten addressed the need "to preserve the safety of, and accessibility to space, so that our Nation, allies, and even the rest of the world, can continue to reap the benefits of space."[44] None of the parties involved could use space without a coordination process. Therefore, the 2021 *Interim National Security Strategic Guidance* does indeed emphasize to promote shared norms and forge new agreements on emerging technologies and space.[45] The national

[43] The President of the United States, National Security Strategy of the United States of America, 2017 (The White House, December 18, 2017), 31.

[44] Senate Committee on Armed Services, "Statement 2019 of John E. Hyten," 17–18.

[45] The White House, "Interim National Security Strategic Guidance," March 2021, 20, https://www.whitehouse.gov/wp-content/uploads/2021/03/NSC-1v2.pdf.

interest is at stake, as is the interest of the rest of the world. Utilization of the increasingly contested Earth Orbits can only succeed if space competition does not turn into a conflict.

Space negotiations should include today's accepted boundary between space and airspace.[46] The question is whether one can and will still afford to view hypersonic objects at altitudes just above 100 kilometers as being above national airspace, or whether it is of mutual interest to rethink the boundary between space and airspace. A better definition and establishment of a legal regime for these altitudes will create legal certainty.[47]

Space negotiations should also include the correlation between hypersonic weapons and the weaponization of space. This issue leads to whether the future of Low Earth Orbit can be shaped and controlled in a multi-polar environment with national competitive egoisms, or whether it needs to be on a multi-lateral agenda with more balance of interests and transparency. The Congressional Report Service's suggestion of an exchange of weapons data or the conduct of joint technical studies might be a start.[48] If nations pursue hypersonics to the same strategic level as the nuclear equilibrium and involve the space domain, consultations will need appropriate transparency and confidence-building measures. These consultations may support the mutual understanding of the assumptions of a survival rationale, escalation control, and avoidance of misunderstandings.

For America, Russia, and China, hypersonic weapons can be a blessing or a curse. On the one hand, an inadequate negotiation approach can promote misunderstandings, rivalry, dominance, and mistrust, resulting in a new arms race and a significant escalation

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[46] See Appendix A for background information.

[47] Andrea Harrington and Ram Jakhu, "Near Space" (International Association for the Advancement of Space Safety, February 16, 2016), 7, https://www.unoosa.org/documents/pdf/copuos/lsc/2016/tech-03.pdf.

[48] Sayler, "CRS Report Hypersonic Weapons," 18–19.

potential. On the other hand, a sensible negotiation approach and a common perception of hypersonic weapons' escalation potential could build on the great powers' established practices in dealing with their nuclear weapons and contribute to continuity and stability. With such a de-escalation approach, hypersonic weapons could refine the escalation ladder and insert intermediate stages. Therefore, a de-escalation approach could acknowledge competition, but contain conflict in the same way.

On the issue of **proliferation**, the 2017 *RAND* study pointed to the dangers of hypersonic proliferation by seeing "diffusion of hypersonic technology underway in Europe, Japan, Australia, and India—with other nations beginning to explore such technology."[49] It would be pointless to start an up-to-date list of all countries that have demonstrated hypersonic ambitions, as it would also not be fruitful to try to prevent any country from further developing hypersonics, because few nations would agree to dispense from developing such front edge technology. The prognosis of the 2017 *RAND* study is reasonable: "There is probably less than a decade available to substantially hinder the potential proliferation of hypersonic missiles and associated technologies." Therefore, it is high time to talk about establishing rules and regulations to hedge hypersonic technology, for the increased efforts to develop hypersonic weapons are occurring in the absence of sufficient discussion of arms control implications.[50]

Therefore, no reasonable opportunity to create new arms control frameworks should go unused. One appropriate frame for such efforts is the *New START* treaty. Initially,

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[49] Speier et al., *Hypersonic Missile Nonproliferation*, 47.
[50] Klare, "Arms Race in Speed."

U.S. interpretation of the treaty precluded any prohibition of hypersonic weapons.[51] However, article V states the right to raise any emerging strategic offensive arm for consideration in a commission.[52] Within the new five-year horizon until 2026, *New START* offers the chance for a multi-lateral starting point.[53] The bi-lateral treaty has worked as a framework for the past ten years; it might help with additional countries and incorporating hypersonic weapons. With the Air Force expecting its hypersonic initial operational capability in 2022, it is a valid recommendation to address these weapons under the *New START* framework with the United States and Russia willing to limit the deployment of hypersonics.[54] Moreover, a SIPRI analysis sees the argument for a more tri-lateral engagement growing as China's hypersonic technology advances and its arsenal size grows in response to missile defense expansion in the Asia-Pacific region.[55] Indeed, with China and other hypersonic nations not yet in the treaty, there is much work to do, and the Biden administration wants to "engage in a meaningful dialogue with Russia and China on a range of emerging military technological developments that implicate strategic stability."[56]

Another tri-lateral docking point for the U.S. could be to quote the Russian and Chinese 2008 attempt to draft the *PPWT*.[57] America had rejected this framework against the proliferation of space weapons, but both China and Russia continue to propose this

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[51] Tracy Cameron, "Fitting Hypersonic Weapons into the Nuclear Arms Control Regime," All Things Nuclear, April 1, 2020, https://allthingsnuclear.org/ctracy/fitting-hypersonic-weapons-into-the-nuclear-arms-control-regime.

[52] Sayler, "CRS Report Hypersonic Weapons," 18–19.

[53] David E. Sanger and Anton Troianovski, "Biden and Putin Agree to Extend Nuclear Treaty," *The New York Times*, January 26, 2021, sec. World, https://www.nytimes.com/2021/01/26/world/europe/biden-putin-nuclear-treaty.html.

[54] Cameron, "Fitting Hypersonic Weapons into the Nuclear Arms Control Regime"; John A. Tirpak, "Roper Sees High-Low Mix for Hypersonic Missiles," *Air Force Magazine* (blog), May 14, 2020, https://www.airforcemag.com/roper-sees-high-low-mix-for-hypersonic-missiles/.

[55] Saalmann, "China's Calculus on Hypersonic Glide."

[56] The White House, "Interim National Security Strategic Guidance," 13.

[57] PPWT - *Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force against Outer Space Objects*.

treaty.[58] President Putin had expressed some interest when he recently signaled that "the world would have no future without a system of arms control."[59] With hypersonic weapons closing the gap between space and airspace, the incorporation of space-weapons into arms control negotiations is inevitable.

Today, the *International Space Law* framework only prohibits orbital weapons of mass destruction and lunar weaponization.[60] Therefore, the United Nation's treaties and principles offer another starting point for arms control negotiations. With hypersonic weapons blending space and airspace and a lurking weaponization of space, the usefulness of existing international space law needs careful consideration.

Arms control has never been an easy path. Different worldviews and diverging or competing interests can cause misunderstanding, irritation, escalation, and conflict. It is even more critical for the U.S. to engage its competitors in negotiations to recognize and name conflicts of interest, agree on assumptions, prevent escalation, and link mutual deterrence from irresponsible or aggressive behavior to a stable and reasonable foundation of common risk perception and reasonable assumptions. In 2014, David C. DeFrieze pointed out the importance of "peaceful dispute methodologies to prevent escalation" in space issues.[61] The advent of hypersonic weapons and their potential contribution to weaponize space require developing such methods more than ever.

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[58] David C. DeFrieze, "Defining and Regulating the Weaponization of Space," *Joint Force Quarterly*, no. 74 (July 1, 2014): 111.

[59] Reuters, "Russia's Putin Says World Has No Future without Arms Control System," *Reuters*, October 22, 2020, https://www.reuters.com/article/us-russia-putin-nuclear-idUSKBN2772FU.

[60] United Nations Office for Outer Space Affairs, *International Space Law*.

[61] DeFrieze, "Defining and Regulating the Weaponization of Space," 114.

Alliances

Hypersonic weapons are an additional instrument of escalation and, therefore, also a highly effective means of exerting pressure. As Alan Cummings argues, Russia's immediate application for hypersonic weapons in Europe reinforces the most salient message to deter the alliance from confronting Russian aggression: NATO cannot protect you.[62] As America's most crucial alliance, NATO suffers from hypersonic pressure, and some at least identify the potential need to upgrade NATO's theater air and missile defenses.[63] This hypersonic pressure from the outside demands capability development, procurement, and national budgeting inside NATO countries. Therefore, NATO and other alliances should synchronize defense solutions against the hypersonic threat; the Alliance Future Surveillance and Control (AFSC) initiative could be a docking point.[64]

Conversely, arms control and proliferation prevention work more effectively out of an alliance since the states within such treaties need to agree about verification options. Inwards and outwards, America needs alliances to bolster agreements and frame verification options for both aspects. Besides, hypersonic capabilities are only one aspect of a bouquet of threats that do not appear in isolation. To address the hypersonic threat, America needs to address the whole context, and this is regularly done within the frameworks of alliances. Therefore, allied political pressure is a crucial way to mitigate hypersonic threats.

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[62] Alan Cummings, "Hypersonic Weapons: Tactical Uses and Strategic Goals," War on the Rocks, November 12, 2019, https://warontherocks.com/2019/11/hypersonic-weapons-tactical-uses-and-strategic-goals/.

[63] Paul Bernstein and Harrison Menke, "Russia's Hypersonic Weapons," *Georgetown Journal of International Affairs* (blog), December 12, 2019, https://gjia.georgetown.edu/2019/12/12/russias-hypersonic-weapons/.

[64] NATO, "Alliance Future Surveillance and Control (AFSC) Initiative," July 1, 2020, https://www.nato.int/nato_static_fl2014/assets/pdf/2020/7/pdf/200701-Factsheet_Alliance_Future_Surveil-1.pdf.

Furthermore, the approach to international relations and international law cannot be unilateral. International law becomes more powerful by including as many nations as possible and, for sure, all political allies. Preceding allied agreements and a consolidated approach will consider U.S. interests more reliably and quickly than an isolated approach in which the allies may become competitors.

Deterrence is an allied effort, too. Even if the U.S. needs a significant national response to hypersonic threats, a North Atlantic response can flank and reinforce. With its global presence, the U.S. needs regional partners and allies to deter opponents from threatening America's overseas forces. Moreover, America needs to find regional Integrated Air and Space Defense (IASD) modules in cooperation with the regional allies. Over Europe, only cooperating NATO countries can build an overarching missile defense shield that would protect against hypersonic weapons.

Chapter 3: Operational Impacts of Hypersonic Weapons

Building on the last chapter's analysis on how the advent of hypersonic weapons changes America's strategic situation, this chapter takes a closer look at the operational impacts. Russian General Gerasimov concluded that in the development of modern warfare, "the differences between strategic, operational, and tactical levels, as well as between offensive and defensive operations, are being erased."[1] The previous chapter's Middle-East scenario illustrated how the advent of hypersonic weapons supports this conclusion. This chapter will link strategic risks to operational threats and strategic mitigations to operational capabilities and examines how hypersonic weapons will affect military operations in the future. It outlines the potential ramifications of an adversary keeping American power projection at a distance and considers a more decisive role for aerial and naval subsurface warfare.

Hypersonic Threats

Hypersonic Glide Vehicles (HGVs) leverage their agility and intercontinental range in the strategic context of the previous chapter.[2] At the operational level and in theater-related scenarios, the character of a Hypersonic Cruise Missile (HCM), with its air-breathing supersonic combustion ramjet (Scramjet), comes more into play as an enhanced cruise missile. It might cover speeds presently up to Mach 6 (2 km/s; 4,500 mph), in the future probably up to Mach 16 (5.3 km/s; 11,900 mph), and cruising altitudes between 20 kilometers (66,000 ft) and 40 kilometers (131,000 ft). HCMs will enlarge the stand-off

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[1] Gerasimov, "The Value of Science Is in the Foresight," 24.

[2] HGV may also play a role in operational theaters if they are not deployed by ICBM but by short- and medium-range Tactical Boost Glide systems (TBG). For more background information about differences between the HCM and the TBG HGV see Appendix A.

capabilities of today's existing subsonic cruise missiles fleets. Therefore, this chapter analyzes how HCMs will play a decisive role mainly in operational theaters and how they will enlarge A2/AD areas. This denial of regional access would impact America's strategic range and question its credibility and reliability as an ally for regional partners. The overall hypersonic threat in operational theaters will enfold in three ways against the U.S. Joint Forces: Enhancing an adversary's operational momentum, breaching existing U.S. theater defenses, and providing advanced freedom of movement for regional hegemons.

First, the **adversary's enhanced operational momentum** and overwhelming penetrating power suggest a probable U.S. operational inferiority and paralysis. This suggestion connects to the strategic risk of a U.S. limited freedom of movement, questioned escalation dominance, and threatened national integrity. Speed, maneuverability, and surprise are the core operational threats of the adversaries' hypersonics that blend into a leap in operational warfare. Moreover, in combination with a probable warhead ambiguity, the operational challenge for U.S. forces is even more significant. Such warhead ambiguity itself is not new and might also come with approaching aircraft or ground-launched missiles.[3] But this familiar class of weapons operated within a known framework and left the defender with operational decision space and a timeframe to follow adapted procedures and provide for decisions and combat. Hypersonic weapons might overwhelm and leave this familiar operational framework. In this context, advanced speed and maneuverability is the gamechanger. Given the additional ambiguities of trajectories and potential targets, they constitute a new threat to America and its allies and question decision-making in an already complex operational environment. Therefore, it is imperative to begin developing

[3] Acton, "Is It a Nuke?," 19.

operational concepts and warfighting doctrine to cope with this new adversaries' operational momentum. U.S. doctrine must address this new threat spectrum and offer guidance for operational response to the hypersonic threat.

Second, hypersonic weapons have the potential to **breach existing U.S. theater defenses** and reach the most sensitive forward assets of the U.S. and its allies. With selective shots, adversaries could disrupt critical defense, government, and economic infrastructure or decapitate an allied nation's leadership. The National Defense Strategy (NDS) addresses this rapid technological advancement expanding to more actors with lower barriers of entry and the resulting vulnerability to America.[4]

Russia's move to put the decapitation option on the table does not only illustrate how this new vulnerability also affects the U.S. homeland, but might encourage regional actors to leverage the hypersonic threat in their theaters.[5] Selective hypersonic attacks might become an adversary's conventional option between ICBMs and subsonic cruise missiles as a deterrent against U.S. overseas engagement. For regional powers, the credible threat of a hypersonic attack on the U.S. homeland in return for U.S. regional conflict engagement would influence U.S. operational decision making. The hypersonic capability to strike both the U.S. forward forces and the homeland would offer an opponent a powerful option at less cost and international concern than a ballistic nuclear strike. This breach requires not only a complete reconsideration of America's defense architecture but also, as Acton concludes, its traditional second-strike calculations and procedures.[6]

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[4] Mattis, "Summary of 2018 NDS," 3.

[5] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 15.

[6] Richard H. Speier, "Hypersonic Missiles: A New Proliferation Challenge," *Hypersonic Missiles: A New Proliferation Challenge* (blog), March 29, 2018, https://www.rand.org/blog/2018/03/hypersonic-missiles-a-new-proliferation-challenge.html.

The third hypersonic threat in operational theaters is enhanced **freedom of maneuver for regional hegemons.** With their capability of enhanced long-distance precision strikes, hypersonics would threaten U.S. aircraft carriers or forward infrastructure, leaving little warning time and limited defense options. Once widely fielded, hypersonics may empower some states enhancing their political power, gaining regional hegemony, or thwarting U.S. influence. As long as U.S. operational high-value assets do not have mature defenses against attacking hypersonic weapons, these weapons will affect the American calculus and challenge the willingness to take risks. For example, for years, and still today, deploying a Patriot battery to protect against an Iraqi or Iranian ballistic missile attack was the cost required to base out of Saudi Arabia, Kuwait, Bahrain, or Qatar.[7] Adequate protection is a prerequisite for stationing in the region. Moving forward, the American political leadership might be reluctant to move a warship near a crisis hotspot as long as there is a regional hypersonic threat. This reluctance could put the benefits of traditional naval power projection into perspective, take operational freedom of maneuver from the U.S., and hand it over to the regional hegemon. To ensure U.S. access might require shifting from larger and less agile naval assets to smaller and more agile aerial assets with long-distance weapons. Another option for this operational shift of assets might be the increased use of less visible submarines or uncrewed surface vessels with conventional HCM as weapons. However, these options sacrifice permanence, sustainability, and human interaction. Nevertheless, to defend against the effect of hypersonic weapons on U.S. operational freedom of maneuver, U.S. forward forces need either mature defenses against hypersonic attacks or alternative access concepts into regional theaters, preferably both.

[7] Bryon Greenwald, Advisor for this thesis, March 19, 2021

Summarizing, the operational threats of an adversary's enhanced operational momentum, the potential breach of existing defense layers, and enhanced freedom of maneuver for regional hegemons are the most significant operational impacts of the advent of hypersonic weapons. They significantly challenge America's power projection.

Hypersonic Values

Fortunately, all is not gloom and doom. The same unique characteristics that make hypersonic weapons a threat against the U.S. can become an added value whenever exploited by them. U.S. forces can leverage enhanced long-distance precision strikes for their advantage. Instead of deploying their high-value assets close to opposing coasts or airspaces and within range of hostile weapon systems, U.S. precision strikes could launch from a distance and hit targets within 6 inches.[8] While the mature military posture of a present and visible carrier strike group will probably prove its fundamental value for some time to come, it should possibly, in some cases, be replaced by hypersonic stand-off weapons. As a Center for Strategic and International Studies (CSIS) analysis considered, without effective defenses against adversaries' hypersonic threats, the U.S. may need to rebalance from forward-based forces towards more out-of-region standoff capabilities.[9]

However, hypersonic weapons offer an operational added value that is difficult to refuse. HGVs offer long-range strikes mainly with unpredictable trajectories and high agility in the terminal phase; HCMs mainly enhance the speed and altitude of existing cruise missile capabilities. For this reason, the NDS includes hypersonics as one of the new

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[8] Jen Judson, "US Army Begins Equipping First Unit with Hypersonic Capability," Defense News, February 10, 2021, https://www.defensenews.com/land/2021/02/09/us-army-begins-equipping-first-unit-with-hypersonic-capability/.

[9] Ian Williams, "Adapting to the Hypersonic Era" (Center for Strategic and International Studies, November 2, 2020), 13, https://defense360.csis.org/adapting-to-the-hypersonic-era/.

technologies "that ensure we will be able to fight and win the wars of the future."[10] Moreover, this is why the recent announcement of a planned refit of all U.S. Navy destroyers with hypersonic missiles should not be a surprise.[11] Furthermore, hypersonic flight principles support the concept of a worldwide delivery of kinetic force within a short time—the U.S. Conventional Prompt Global Strike (CPGS) program.[12] For the global offensive role of hypersonics, DoD recognizes their value in power projection, deterrence, and reassurance, particularly in the face of the advanced Russian and Chinese A2/AD strategies. Interestingly, a Congress report argues that such global strike weapons "might provide the United States with more capability than it needs under most circumstances."[13] Moreover, the report questions whether the U.S. would acquire useful targeting data on short notice to leverage the hypersonic advantage.

Importantly, with a hypersonic upgrade to CPGS, the question of warhead ambiguity occurs because the CPGS program uses ICBMs as carriers, and ICBMs so far come with nuclear warheads. Therefore, procurement of hypersonics for CPGS would always include the perception of a hypersonic warhead possibility for nuclear ICBMs, and this circumstance should be part of a public Congressional discussion. Conversely, the DoD seems to hide, and the context of an unwanted release of its intentions in 2020, first illuminated by Aviation Week, remains unclear.[14] The Air Force Nuclear Weapons Center

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[10] Mattis, "Summary of 2018 NDS," 3.

[11] Paul McLeary, "Signaling China, White House Floats Putting Hypersonic Missiles On Destroyers," *Breaking Defense* (blog), accessed November 17, 2020, https://breakingdefense.com/2020/10/signaling-china-white-house-floats-putting-hypersonic-missiles-on-destroyers/.

[12] Woolf, "CRS: CPGS."

[13] Woolf, 48.

[14] Steve Trimble, "USAF Errantly Reveals Research On ICBM-Range Hypersonic Glide Vehicle," Aviation Week Network, August 18, 2020, https://aviationweek.com/defense-space/missile-defense-weapons/usaf-errantly-reveals-research-icbm-range-hypersonic-glide.

had published a request for information (RFI) to companies on its webpage on August 12, showing the agency's interest in enabling technology for an intercontinental range HGV. The Air Force later removed the request from the website. The incident suggests that the Air Force considers the potential use of hypersonics as part of the "modular systems architecture" of its future Ground-Based Strategic Deterrent (GBSD) ICBM or does not exclude it. This consideration could lead to hypersonic technology for the modular system of a nuclear carrier system. Simultaneously, the Pentagon insists that its "entire hypersonic portfolio relies on delivering conventional warheads."[15] Therefore, contradicting signals are coming from Washington. So far, the Pentagon officially maintains its "strictly conventional" policy for hypersonic weapons, as confirmed in the August 2020 article. Congress is reluctant, too. Maybe concerns over the risks of warhead ambiguity have led them to bar funding to develop ICBM-launched HGV.[16] It remains unclear why the DoD itself has difficulty publicly discussing the ramifications of a dual-use of hypersonics. The challenges are apparent and must be put on the table. Neither politics nor the military need to shy away from public discussion.

Given the aforementioned debate, the following section takes a closer look at the value of hypersonics for nuclear deployment and CPGS and the relationship to nuclear deterrence. It elaborates on the operational perspectives, the strategic link, and the value of dual-use hypersonic weapons in the three deployment categories of strategic nuclear deployment, low-yield operational nuclear deployment, and selective or extensive operational conventional deployment.

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[15] Trimble.

[16] Klare, "Arms Race in Speed."

Nuclear Deployment and Conventional Prompt Global Strike (CPGS)

The first category of dual-use hypersonic weapons is the capability of an assured U.S. **strategic nuclear deployment** against a highly capable opponent's missile defense to significantly degrade or entirely incapacitate the enemy with a defined number of blows. The strategic decision for such a decisive strike could result as an operational escalation step, as a last line of defense, or as a responsive strike following an adversary nuclear strike against the United States. Today's capabilities for such a strike lean on the nuclear triad.[17] The triad logic is that a significant number of American nuclear assets will survive an adversary's first strike and successfully reach their targets. In 2013 Russian General Gerasimov pointed to the formation of a Russian aerospace defense force, and Russia is already working to arm its air and missile defense with new systems like the A-135[18] Moscow ABM System against the next generation threats.[19] These enhanced defense systems will likely be able to defeat, at least question, today's U.S. triad capabilities. Therefore, the U.S. cannot afford to limit the nuclear triad to purely ballistic and cruise missiles. From a purely operational point of view, a future credible nuclear triad will require incorporating the speed and the agility of hypersonic weapons to enhance all the triad's elements or as a fourth element in a then nuclear quartet. Fortunately, the DoD is following Russia's development of its layered missile defense that preserves its full range nuclear deterrent and a "range of missile defense systems that it claims will have the capability to intercept cruise missiles and hypersonic vehicles."[20]

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[17] "Nuclear Triad Important to America."

[18] Department of Defense, "Chinese And Russian Missile Defense - Fact Sheet" (Department of Defense, July 28, 2020), https://media.defense.gov/2020/Jul/28/2002466237/-1/-1/1/CHINESE_RUSSIAN_MISSILE_DEFENSE_FACT_SHEET.PDF.

[19] Gerasimov, "The Value of Science Is in the Foresight," 26.

[20] Department of Defense, "Department of Defense."

The hypersonic technological and operational leap has the potential to start a new arms race. Regardless of whether the advent of hypersonic weapons is evolutionary or revolutionary, they bring mutual pressure to innovate, and force the development of ever-faster and more agile delivery systems for nuclear warheads. Therefore, for operational reasons, the development and employment of strategic hypersonic weapons with nuclear warheads will become a substantial part of future mutual credible deterrence.

The second category of hypersonic weapons' dual-use is a **low-yield operational nuclear deployment** to surprise and overstrain the enemy and hinder or deter him from further countermeasures. Alan Cummings discusses how today America's theater capabilities "depend too much on aircraft and low-observable technology…being eroded by advancements in adversary air defenses."[21] Those advanced defenses could neutralize America's current low-yield nuclear capabilities in contested operational theaters. Therefore, he identifies the faster and more agile hypersonic weapon as "a prime candidate for becoming a dual-use weapon with conventional <u>and</u> low-yield nuclear variants."[22] Hypersonics could assure, that U.S. low-yield nuclear warheads would still overcome adversary air defenses, even the advanced ones.

However, the hypersonic added value for low-yield strikes depends on the adversary. Russian doctrine outlines the first use of a nuclear weapon as a legitimate response to "an opponent's conventional strikes on critical Russian targets" or critical loss

[21] Alan Cummings, "High Speed, Low-Yield: A U.S. Dual-Use Hypersonic Weapon," War on the Rocks, September 17, 2020, https://warontherocks.com/2020/09/high-speed-low-yield-a-u-s-dual-use-hypersonic-weapon/.

[22] Cummings.

levels in theater.[23] At least 11 different Russian delivery platforms underline this intent.[24] For Russia, nuclear weapons are an operational tool to prevent conventional defeat and link this operational purpose to the strategic objective of deterrence through rapid escalation. With a hypersonic low-yield nuclear strike or threat thereof, a peer competitor like Russia could prevent the U.S. from playing to their conventional strength or superiority. This strike would represent a peer competitor's desire for escalation dominance and would likely come with a warning. With the intention as a stop sign, not as a surprise, there would be little need for hypersonic employment. Conversely, Russia or China might even give the U.S. a warning shot to deescalate and withdraw. Thus, for America's peer competitors China and Russia, a hypersonic weapon does not add much value for a selective operational nuclear deployment. Similarly, it would not add much for America.

On the other hand, for minor opponents, the choice of a nuclear strike can emerge from their limited or exhausted conventional capabilities. Their decision for a selective nuclear strike would occur to gain escalation dominance out of weakness. For example, this could be an Iranian or North Korean attempt to stop a move against its national sovereignty. If a ballistic missile with a nuclear warhead would not get through U.S. theater ballistic missile defenses, hypersonic missiles could. Moreover, with the enormous power of a nuclear warhead, a hypersonic missile would not need to hit the target directly. Thus, the aggressor would need less technical effort to develop the hypersonic weapon's accuracy and have them ready to use sooner.

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[23] Michael Kofman, Anya Fink, and Jeffrey Edmonds, "Russian Strategy for Escalation Management: Evolution of Key Concepts" (Center for Naval Analyses, April 13, 2020), 51, https://www.cna.org/CNA_files/PDF/DRM-2019-U-022455-1Rev.pdf.

[24] Senate Committee on Armed Services, "Statement before Senate 2018, John E. Hyten, Commander U.S. STRATCOM," March 20, 2018, 16, https://www.armed-services.senate.gov/imo/media/doc/18-28_03-20-18.pdf.

Therefore, an inferior opponent could achieve an operational and strategic advantage by employing a nuclear warhead with a hypersonic weapon and would challenge the U.S. to counter that threat appropriately. Such a hypersonic threat would come less from Russia or China and more from weaker opponents. The U.S. should have an adequate response available. However, possible scenarios are highly complex and would need specific wargames with thoroughly defined parameters.

The third dual-use category is the selective or extensive **conventional deployment** to surprise, delay, or paralyze the opposing forces, gain operational advantage, and deter the opponent's further military actions. This conventional deployment could have operational or even strategic impact without the implications of a nuclear blast and fallout; thus, it links back to the idea of CPGS weapons that shall deter and defeat adversaries by threatening to hit their high-value targets worldwide with a conventional warhead in under an hour.[25] In 2019 General Hyten clearly highlighted the potential of hypersonic weapons in this role, and at the same time, placed it within the strategic context of deterrence:

> To maintain peace, the United States must continue to invest in technological innovation and development of survivable, long-range strike systems able to hold time-sensitive and high-value targets at risk. Today, the only prompt long-range strike capabilities are ballistic missile systems armed with nuclear warheads. We need a conventional prompt global strike capability. This is the USSTRATCOM requirement. Conventional hypersonic strike weapons could meet this requirement and provide responsive long-range strike options against distant, defended, and/or time-critical threats when other forces are unavailable, denied access, or not preferred. While conventional hypersonic weapons are not a replacement for nuclear weapons, their unique attributes will increase traditional warfighting advantages and bolster conventional and strategic deterrence.[26]

[25] Woolf, "CRS: CPGS."
[26] Senate Committee on Armed Services, "Statement 2019 of John E. Hyten," 16.

In Russia, there is consensus that hypersonic weapons will form a "system of non-nuclear deterrence" and that nuclear weapons will move further into the background in terms of relevance.[27] The Russian experts share the American view on the link between the operational and strategic value of conventional hypersonics. Hypersonic deterrence could replace nuclear deterrence, at least partially, and could contribute to strategic de-escalation.

On the other hand, there are two major escalation concerns about the conventional hypersonic calculus in a dual-use context. The first one is about the *warhead ambiguity* and the *target ambiguity* (see the previous chapter). These worries consider that it is less important what kind of warhead the missile carries than what kind the defender expects. The 2020 Congressional report argues that the launch of hypersonic equipped CPGS systems might not only be misinterpreted as the launch of nuclear weapons but alternatively as conventional weapons against nuclear targets.[28] Therefore, opponents might develop doctrines to instantly respond nuclear to any hypersonic attack.

The second concern is about the perceived easy-to-use characteristics of conventional hypersonics. Such weapons would allow opponents to threaten American and allied/partner targets with non-nuclear warheads.[29] Previously, these targets could only have been destroyed with nuclear weapons. In the future, with conventional hypersonics, the consequences of a conventional strike would be lower than a nuclear strike. Conversely, because of the lower consequences, the likelihood of a conventional use would rise, and because risk is a product of likelihood and consequence, the reduced consequences of a

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[27] Kofman, Fink, and Edmonds, "Russian Strategy for Escalation Management: Evolution of Key Concepts," 58.

[28] Woolf, "CRS: CPGS," 48.

[29] James M. Acton, "Hypersonic Weapons Explainer," Carnegie Endowment for International Peace, April 2, 2018, https://carnegieendowment.org/2018/04/02/hypersonic-weapons-explainer-pub-75957.

conventional hypersonic strike could be more than balanced by its higher likelihood. This *reverse dilemma* implies the idea of an increased temptation to use a weapon because it seems to be more scalable and controllable. The Atlantic Council concludes that a non-nuclear hypersonic strike capability could sufficiently increase the likelihood of extended military action and unintended escalation.[30] Therefore, all things considered, conventional hypersonics lead to the reverse dilemma of increased escalation potential instead of deterrence and may increase the overall strategic escalation risk.

Both escalation concerns about the *warhead and target ambiguity* and the *reverse dilemma* are reasonable and need further operational analysis and specific war-gaming scenarios. A political discussion is required to assure an equilibrium of deterrence. However, one cannot dismiss the potential added value of selective or extensive operational use of conventional hypersonic weapons for CPGS that offers scalable conventional effects, escalation dominance, and global power projection advantages.

In summary, the operational use of hypersonic weapons is more likely to develop its added value with conventional warheads, as long as their accuracy is sufficient. However, as part of an established strategic balance of a mutually assured credible nuclear deterrence, the U.S. can hardly avoid the strategic nuclear use of hypersonics. Thus, for America, the **dual-use of hypersonic weapons** is becoming imperative for the combination of operational advantage and assured strategic deterrence; the potential use as part of the future Ground-Based Strategic Deterrent (GBSD) ICBM needs caution, but it makes sense for operational reasons.

[30] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 9.

Operational Doctrine

Hypersonic objects neither fit fully into airspace nor into space; they come with contradictions. On the one hand, with their speeds, altitudes, and sub-orbital trajectories, they affect today's utilized airspace, but do not fit into the international *Rules of the Air*.[31] On the other hand, they affect the space domain, but are not orbital objects. Because hypersonic objects appear as foreign bodies for the air and space domain, but affect both of them, they must be taken into account in both doctrines.

Therefore, it is essential to analyze existing air and missile defense principles in U.S. doctrine. Moreover, deductions apply not only to the U.S. but also to all other nations, especially those with hypersonic ambitions. The HGV soaring over Iraq is a potential threat to all nations within a radius of several thousand kilometers. Therefore, it is not only in the American interest to regulate the dealing of hypersonic objects. This issue is also relevant for China and Russia; it could start a joint settlement.

DoD should start defining roles and doctrinal responsibilities between USAF and USSF, adapting air, space, and joint doctrine for hypersonic objects, and communicating ramifications with Moscow and Beijing to use common interests as a platform for improving cooperation. A detailed analysis of the current U.S. doctrine for this thesis resulted in a set of starting points to introduce hypersonic weapons' operational implications into doctrine.[32] U.S. doctrine should consider the following elements:

- Address the gradual transition area between 20 and 130 kilometers altitude between today's utilized *space* and *airspace* and define responsibilities and management for this *hypersonic airspace*.
- Define basics for hypersonic special procedures in the airspace.

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[31] International Civil Aviation Organization (ICAO), "ICAO - Rules of the Air" (ICAO, July 1, 2005), https://www.icao.int/Meetings/anconf12/Document%20Archive/an02_cons%5B1%5D.pdf.

[32] For details see Appendix E

- Discuss the new challenge of hypersonic trajectories for both space and airspace and conclude ramifications for U.S. air and space defense architecture.
- Define basics for a U.S. hypersonic Air Defense Identification Zone (ADIZ) with an appropriate horizontal and vertical buffer zone to ensure sufficient decision space.
- Synchronize future air warfare with space warfare and integrate the surface-based air and missile defenses with space defense architecture into an Integrated Air and Space Defense (IASD).
- Discuss the added value of the range, speed, and agility of hypersonic weapons for USAF counterair operations to reduce own forces' vulnerability.
- Discuss the added value of a long-range stand-off hypersonic precision attack for USAF counterair operation and Strategic Attack.
- Define roles and responsibilities of USSTRATCOM, USSPACECOM, and the other geographic combatant commands with respect to hypersonics.
- Discuss ramifications of further weaponization of space, including space-to-space, space-to-air, and space-to-surface weapons and how to counter them.

Summarizing Chapter Three, for the operational level, the advent of hypersonic weapons bears an enhanced adversary's operational momentum with overwhelming penetrating power, the potential breach of existing U.S. theater defenses, an enhanced freedom of maneuver for regional hegemons, and a significant challenge for America's power projection.

For America, the operational use of U.S. hypersonic weapons for global military theaters is more likely to develop its added value with conventional warheads, as long as their accuracy is sufficient. However, as part of an established strategic balance of an assured credible nuclear deterrence, the U.S. can hardly avoid the strategic nuclear use of hypersonics. Thus, for America, the **dual-use of hypersonic weapons** is becoming imperative as the combination of operational advantage and assured strategic deterrence is of severe concern and needs political discussion and military advice.

Chapter 4: Conclusion

Hypersonic weapons merge the characteristics of aerial and space vehicles and contribute to the dissolution of boundaries between nuclear and conventional munitions, long-range and short-range weapons, and space and airspace environments. They blend today's staggering threat spectrum into an amalgam and exploit it for operational uncertainty.

Hypersonic Glide Vehicles (HGVs) empower existing ballistic missile technology with maneuverable warheads, complex trajectories, and decisive terminal agility. HGVs might play a decisive role in rethinking intercontinental strategic deterrence. Hypersonic Cruise Missiles (HCMs) amplify the existing subsonic and supersonic cruise missile fleet with higher speeds, altitudes, and probably range. They will play their decisive role mainly in operational theaters.

Both HGVs and HCMs fill the previous operational gap between the speed and altitude envelopes of today’s utilized airspace and the space domain. Hypersonics conquer the higher atmosphere layers between 20 and 130 kilometers and leverage it as *hypersonic airspace*. Hypersonic weapons bridge the air and space domain and call for a revision of the existing Air and Missile Defense (AMD) doctrine to a broader Integrated Air and Space Defense (IASD) doctrine.

Hypersonic threats challenge the existing AMD architecture. Because hypersonic weapons might overcome contemporary defense and decision spaces, they also dissolve regional borders of responsibilities. Hypersonics transit across geographical commands within a few minutes, skipping between space and airspace, and challenging USSPACECOM and USSTRATCOM at the same time. This disregard for boundaries will affect the responsibilities, interoperability, and coordination between geographic and functional Combatant Commands to observe and defend against space and airspace threats. The U.S. military and its allies should build upon their existing knowledge of air and space operations to reduce anxiety over the inevitable emergence of hypersonic weapons and bolster air and space defense. DoD should start defining roles and doctrinal responsibilities between USAF and USSF and adapt its doctrine for hypersonic objects. Washington must communicate ramifications with Moscow and Beijing and use shared interests as a platform for improving cooperation. Specifically, the Department of Defense should:

1. Revise the Unified Command Plan and associated space and airspace responsibilities to account for the rapid cross-combatant command capability presented by hypersonic weapons.
2. Revise several of its joint and service manuals to provide concepts, doctrine, and procedures for all aspects of defense (active, passive, attack operations, and C2) against hypersonic attack. These revisions should begin with reimagining existing concepts of air and space. Given the lengthy time it usually takes to write and approve warfighting concepts, adjustments in doctrine need to begin now to ensure adequate employment and utilization of hypersonic weapons in the future.
3. Revise the Defense Space Strategy as a central reference for re-thinking the U.S. strategic air and space defense architecture. The current strategy does not yet elaborate on the ramifications of hypersonic threats that use and merge space and airspace.
4. Analyze the existing air and missile defense architecture and explore potential technical solutions to reduce the likelihood of a successful hypersonic attack

against high-value assets (HVA) in the homeland and forward.[1] These solutions should consider:

a. Enhancing the sensor-net capable of detecting/tracking hypersonic weapons from launch through terminal guidance. The sensor net should include U.S. and allied partner systems ranging from subsurface tracking of launch capable submarines to surface, air, and space-based active and passive radar.
b. Improving mid-course intercept options.
c. Creating terminal phase intercept options that include improved counter rocket, artillery, and mortar (C-RAM) capability and the potential for Unmanned Aerial System (UAS) swarms as part of an aerial "final protective fire."

Further investigation is required for possible misinterpretation or misidentification of a launching conventional hypersonic weapon as a nuclear weapon or as a conventional weapon against nuclear targets. A political process of open discussion about dual-use is required to provide an equilibrium of deterrence on the operational and strategic level.

On the strategic level, hypersonics challenge the principle of credible deterrence and alliance defense. The time is right to adapt existing defense strategy, integrate air and space defenses, prepare arms negotiations, and start strategic communication with hypersonic competitors.

To prepare for the advent of hypersonics, military leaders must comprehend the hypersonics' game-changing characteristics and implications. Moreover, senior leaders need to assess and alter how strategic and operational decision-making becomes more challenging due to the speed, range, agility, and effects of hypersonic weapons.

[1] See Appendix D.

Appendix A – Hypersonic Context

Appendix A-1 Characteristics and Utilization of Subsonic Flight

Subsonic vehicles					
	max. altitude		max. speed		
small private airplanes, helicopters, climbing and descending commercial planes	<6 km	<20,000 ft	<Mach 1	<0.33 km/s	<746 mph
cruising commercial airplanes	6-11.5 km	20,000 – 38,000 ft	<Mach 1	<0.33 km/s	<746 mph
executive business jets	14 km	46,000 ft	<Mach 1	<0.33 km/s	<746 mph
Bombardier Global 7500[1]	15.5 km	51,000 ft	<Mach 1	<0.33 km/s	<746 mph
RQ-4 Global Hawk[2]	18km	60,000ft	<Mach 1	<0.33 km/s	<746 mph
U-2 Dragon Lady[3]	21 km 27.5 km	70,000 ft 90,000 ft[4]	<Mach 1	<0.33 km/s	<746 mph
experimental glider airplane[5]	23 km 27.5 km	76,124 ft 90,000 ft	<Mach 1	<0.33 km/s	<746 mph
non-aerodynamic balloon flights[6]	41,5km	135,890 ft	<Mach 1	<0.33 km/s	<746 mph
			<Mach 1	<0.33 km/s	<746 mph

Figure 4: Maximum flight altitudes of subsonic vehicles.

The numbers in Figure 4 illustrate the practical physical altitude limits for routine aerodynamic subsonic flight, the practical boundaries of subsonic aerodynamic lift, and the upper edge of the routine subsonic use of airspace at an altitude of 20 kilometers (66,000

[1] Bombardier, "Bombardier Factsheet Global 7500," May 1, 2020, https://businessaircraft.bombardier.com/en/aircraft/global-7500.

[2] US Air Force, "USAF Factsheet RQ-4 Global Hawk," U.S. Air Force RQ-4 Global Hawk, October 27, 2014, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104516/rq-4-global-hawk/.

[3] US Air Force, "USAF Factsheet U-2S/TU-2S Dragon Lady," U.S. Air Force U-2S/TU-2S, September 23, 2015, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104560/u-2stu-2s/.

[4] John Pike, "FAS Datasheet U-2," Senior Year/ Aquatone / U-2 / TR-1, March 5, 2000, https://fas.org/irp/program/collect/u-2.htm.

[5] Perlan Project Inc., "2018 - So Many Perlan 'Firsts', Perlan Project Altitude Record," 2018 - So many Perlan "Firsts," December 29, 2018, https://perlanproject.org/blog/2018-so-many-perlan-firsts.

[6] John Markoff, "Parachutist's Record Fall: Over 25 Miles in 15 Minutes (Published 2014)," *The New York Times*, October 24, 2014, sec. Science, https://www.nytimes.com/2014/10/25/science/alan-eustace-jumps-from-stratosphere-breaking-felix-baumgartners-world-record.html.

ft). Even under exceptional conditions in singular aerodynamic record flights, altitudes remain below 30 kilometers (100,000 ft).

This subsonic speed and altitude envelope enable effective and efficient flight-conditions with distances up to 18,000 kilometers and flight times of 20 hours without refueling.[7] High Altitude Long Endurance (HALE) remotely piloted military aircraft go even further, ranging up to 23,000 kilometers and more than 34 hours of endurance.[8] Conversely, low-level cruise missiles can reach distances of 1500 kilometers with speeds around 880 km/h.[9] Subsonic flight offers global reach; it just takes cruising time.

Therefore, subsonic flight offers attractive commercial conditions and global reach of a broad spectrum military capabilities. U.S. Air Force doctrine links the merits of airpower to the combination of "speed, range, and three-dimensional perspective...in ways that are fundamentally different from other forms of military power."[10] However, fundamental physical conditions limit possible flying altitudes for routine aerodynamic subsonic airplanes to an altitude of 20 kilometers (66,000 ft).

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[7] "Airbus A350-900ULR Data," Airbus, October 31, 2020, https://www.airbus.com/aircraft/passenger-aircraft/a350xwb-family/a350-900.html.

[8] US Air Force, "Factsheet RQ-4 Global Hawk."

[9] David Larter, "The US Navy Has an Upgraded Tomahawk: Here's 5 Things You Should Know," Defense News, December 15, 2020, https://www.defensenews.com/naval/2020/12/14/the-us-navy-has-an-upgraded-tomahawk-heres-5-things-you-should-know/; "Tomahawk Long-Range Cruise Missile - Naval Technology," accessed December 30, 2020, https://www.naval-technology.com/projects/tomahawk-long-range-cruise-missile/.

[10] Chief of Staff USAF, "Air Force Doctrine Volume 1, Basic Doctrine" (United States Air Force, February 27, 2015), 28, https://www.doctrine.af.mil/Portals/61/documents/Volume_1/Volume-1-Basic-Doctrine.pdf.

Appendix A-2 Characteristics and Utilization of Supersonic Flight

Supersonic vehicles					
	max. altitude		max. speed		
F-35[1]	15 km	50,000 ft	Mach 1.6	0.5 km/s	1,200 mph
F-18[2]	15 km	50,000 ft	Mach 1.8	0.6 km/s	1,350 mph
F-16[3]	15 km	50,000 ft	Mach 2	0.7 km/s	1,500 mph
F-22[4]	15 km	50,000 ft	Mach 2	0.7 km/s	1,500 mph
F-15[5]	20 km	66,000 ft	Mach 2+	0.8 km/s	1,875 mph
A-12/SR-71[6]	27.5 km	90,000 ft	Mach 3.2	1 km/s	2,200 mph
MiG-25	37.6 km[7]	123,000 ft	Mach 2.8[8]	0.9 km/s	2,088 mph
AIM 120, air-to-air missile[9]	24 km	79,000 ft	Mach 5.5	1.8 km/s	4,100 mph
Meteor, air-to-air missile (Ramjet)[10]	18.5 km	61,000 ft	Mach 3	1 km/s	2,200 mph
Kh-32[11]	40 km	130,000 ft	Mach 4	1.3 km/s	3,000 mph

Figure 5: Maximum speeds and flight altitudes of supersonic vehicles.

[1] "F-35A Lightning II," U.S. Air Force, accessed March 9, 2021, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/478441/f-35a-lightning-ii/.

[2] "F/A-18A-D Hornet and F/A-18E/F Super Hornet Strike Fighter," accessed March 9, 2021, https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2383479/fa-18a-d-hornet-and-fa-18ef-super-hornet-strike-fighter/.

[3] "F-16 Fighting Falcon," U.S. Air Force, accessed March 9, 2021, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104505/f-16-fighting-falcon/.

[4] "F-22 Raptor," U.S. Air Force, accessed March 9, 2021, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104506/f-22-raptor/.

[5] "F-15 Eagle," U.S. Air Force, accessed March 9, 2021, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104501/f-15-eagle/.

[6] Central Intelligence Agency, "CIA Information A-12/SR-71," OXCART vs Blackbird: Do You Know the Difference? — Central Intelligence Agency, November 18, 2015, https://www.cia.gov/news-information/featured-story-archive/2015-featured-story-archive/oxcart-vs-blackbird.html.

[7] Dario Leone, "World Record: How One Russian MiG-25 Fighter Reached 123,523 Feet," Text, The National Interest (The Center for the National Interest, August 17, 2019), https://nationalinterest.org/blog/buzz/world-record-how-one-russian-mig-25-fighter-reached-123523-feet-74286.

[8] "MiG-25P Foxbat Interceptor - Airforce Technology," accessed March 9, 2021, https://www.airforce-technology.com/projects/mig25/.

[9] "METEOR Flight Profile," June 12, 2020, https://www.quora.com/How-does-the-Meteor-missile-compare-to-other-currently-fielded-missiles.

[10] "METEOR - Saab," accessed December 8, 2020, https://www.saab.com/products/meteor; "METEOR Flight Profile."

[11] Mark B. Schneider, "The Renewed Backfire Bomber Threat to the U.S. Navy," U.S. Naval Institute, January 1, 2019, https://www.usni.org/magazines/proceedings/2019/january/renewed-backfire-bomber-threat-us-navy.

Supersonic flight is famous for the sonic boom. However, in civil aviation, it plays a minor role. The supersonic altitude envelope ends at 20 kilometers (66,000 ft), the same as the subsonic envelope. In exceptional cases, stable cruising altitudes came close to 30 kilometers (100,000 ft), and only ballistic flight profiles achieved higher altitudes (e.g., MiG-25; Kh-32). Thus, subsonic and supersonic aircraft share the same airspace with an upper edge at 20 kilometers (66,000 ft). The airspace above is used only for particular purposes, e.g., space vehicles on their way into space or back to earth.

Supersonic flight empowers subsonic capabilities with a higher speed and shorter flight times, but with a price tag. A supersonic air transport flight could use 5 to 7 times more fuel per passenger and is not cost-effective.[12] Today, the only supersonic objects are military aircraft and missiles, and even the technophilic military cannot justify the technical and economic efforts required to provide supersonic transport, rescue, or evacuation aircraft. Even the usefulness of the SR-71 supersonic reconnaissance missions has faded and fighter aircraft go supersonic only for selective reasons. They regularly cruise at subsonic speeds to save fuel and enhance endurance.

Additionally, there are a variety of supersonic missiles and rockets for different mission purposes. Given the cost and associated scarcity of supersonic aircraft, it seems appropriate that the International Rules of the Air only reference supersonic flight four times.[13] Despite its ability to fly supersonic, Air Force doctrine does not reference it.[14]

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[12] Anastasia Kharina, Tim MacDonald, and Dan Rutherford, "Environmental Performance of Emerging Supersonic Transport Aircraft" (The International Council on Clean Transportation, July 17, 2018), https://theicct.org/sites/default/files/publications/Environmental_Supersonic_Aircraft_20180717.pdf.

[13] International Civil Aviation Organization (ICAO), "Rules of the Air."

[14] USAF, "AF Doctrine Vol 1, Basic Doctrine"; Chief of Staff USAF, "Air Force Doctrine ANNEX 3-01, Counterair Operations" (United States Air Force, September 6, 2019), https://www.doctrine.af.mil/Portals/61/documents/Annex_3-01/3-01-ANNEX-COUNTERAIR.pdf.

Supersonic speeds are not of natural origin, and acoustically, the observer perceives the aircraft only after the fly-by; any approach is silent. Without prior notice, the observer will visually identify a passing airplane only shortly before or after the fly-by. When the sound cone reaches the observer after the passing, the sonic boom strikes instantly and surprisingly. Furthermore, the human eye is generally unfamiliar with such movement. The processing of an appropriate reaction is difficult for the human brain. Therefore, supersonic flight is associated with surprise, uncertainty, insecurity, and paralysis for the observer.

Moreover, supersonic cruise conflicts with international air traffic's regular flow, and the generated supersonic boom is disturbing to the population. Thus, supersonic flights require coordination in space and time through distance from populated areas, separate flight routes, restricted areas, or other air traffic control measures.

Since today's supersonic objects are exclusively military objects, an Integrated Air Defense System (IADS) needs to identify them immediately as friend or foe. In the latter case, engagement must take place immediately. At the upper edge of supersonic threats, the Russian Kh-32 air-launched anti-ship missile challenges existing U.S. air defenses with a probable range of 1,000 kilometers and a speed of Mach 4 (1.3 km/s; 3,000 mph) out of an altitude of 40 kilometers (130,000 ft).[15] These numbers represent the edge between today's supersonic and hypersonic threats.

[15] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 11.

Appendix A-3 Characteristics and Utilization of Space Flight

Space and *airspace* are regularly perceived as two separated domains. Hypersonic Glide Vehicles alter between and blend these two domains. On the one side, there is *space* with the orbital physics of gravity, and on the other side, there is *airspace* with aerodynamic flight. The gradual transition area is often not further differentiated and certainly not further included from an operational perspective. Specifically, this dichotomy does not consider the transitional impacts of hypersonic trajectories and the resulting new challenges for managing space and airspace. One of the main characteristics of hypersonic weapons is that they use both the higher altitudes of airspace and, in certain circumstances, space.

Since *space* is the region under the command of USSPACECOM and, therefore, a military AOR, it is essential to know its boundaries. It should be clear where *airspace* ends and where *space* begins. Conversely, neither the 1944 Chicago Aeronautical Convention, as the first international agreement about the international use of airspace, nor various later space treaties cover an internationally recognized legal upper boundary of airspace and the beginning of space.[1] Despite this, the *Kármán Line* defines an often agreed-upon boundary between space and airspace at an altitude of 100 kilometers (330,000 ft), where aerodynamic steering becomes ineffective.[2] In 2016, the International Association for the Advancement of Space Safety (IAASS) argued in a dedicated operational analysis for an 18-160 kilometers *near space*, referring to specific physical conditions.

[1] Chicago Convention, "Convention on International Civil Aviation," December 7, 1944, https://www.icao.int/publications/documents/7300_orig.pdf; United Nations Office for Outer Space Affairs, *International Space Law*.

[2] Tommaso Sgobba, "International Space Governance" (COPUOS Scientific and Technical Subcommittee, 53rd session, Vienna, 2016), 3, https://www.unoosa.org/documents/pdf/copuos/stsc/2016/tech-06E.pdf.

Nonetheless, the recent Space Capstone Publication defines the space domain more vaguely as "the area above the altitude where atmospheric effects on airborne objects become negligible."[3] This less than precise demarcation occurs because the physical boundary between space and airspace, in practice, is not exactly sharp. Moreover, it is not so much the present altitude that defines an object as a space object; it is more the purpose and the character. A space object's purpose is to stay in space, usually as long as possible, and take advantage of weightlessness, lack of aerodynamic drag, and height about the Earth's surface.

The nature of space-based objects is entirely different from aerial objects. The laws and forces of aerodynamics cannot be used in the nearly-vacuum of space, neither for aerodynamic steering nor to produce aerodynamic lift to maintain altitude. Only gravitation and the thrust of rocket motors or control nozzles can influence speeds and directions. Without any air resistance, space objects could theoretically circle in orbits infinitely. However, air resistance goes well beyond the *Kármán Line*, slows down orbital objects, and draws them back towards the surface of the Earth. Any object built to remain in space needs re-boost maneuvers from time to time to climb back to the intended orbit. For example, at 400 kilometers (1,300,000 ft), the International Space Station loses approximately 200 m (650 ft) of its altitude every day due to drag.[4] It performs one orbit in 90 minutes at Mach 21 (7 km/s; 15,500 mph).[5] At a lower orbital altitude of only 200 kilometers (660,000 ft), the higher drag pulls an unpowered satellite so significantly further

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[3] United States Space Force, "Space Capstone Publication," vi.

[4] "ISS Environment," February 13, 2008, https://web.archive.org/web/20080213164432/http://pdlprod3.hosc.msfc.nasa.gov/D-aboutiss/D6.html.

[5] "Satellite Orbital Decay Calculations" (Australian Government, Bureau of Meteorology, January 1, 1999), http://www.sws.bom.gov.au/Category/Educational/Space%20Weather/Space%20Weather%20Effects/SatelliteOrbitalDecayCalculations.pdf.

down that it takes less than a day until it takes a significant plunge towards the Earth's surface.[6] At an altitude of 130 kilometers (430,000 ft), the drag becomes so significant that a satellite with a remaining speed close to 7.8 km/s cannot even finish another full 90-minute orbit before its remains hit the surface of the Earth.[7] Only at altitudes above 130 kilometers can one speak of the beginning of the orbital flight and space conditions. Thus, it is reasonable to refer to the boundary between space and the Earth's atmosphere at 130 kilometers.

Therefore, while the aerial use of subsonic and supersonic *airspace* practically ceases above an altitude of 20 kilometers, the orbital use of *space* only begins at an altitude above 130 kilometers. As the IAASS argues for 18-160 kilometers *near space* in general, hypersonic objects make perfect use of the characteristics of this world.[8]

Space offers significant advantages for **military applications**. Space-based devices enable and enhance communication, navigation, and observation—all crucial for military operations. Even if the costs are high, it is worthwhile to take advantage of the capabilities of space-based objects. Today, one-thousand to two-thousand satellites are likely to be operated by the U.S. government and U.S. companies.[9] That will increase quickly in the next few years into the tens of thousands as Elon Musk's SpaceX *Starlink* project will impact significantly.[10] Of the fleet of U.S. satellites today, it is likely that several hundred

[6] "Satellites and Probes - Reentry IRIDIUM 90," January 23, 2019, http://cristianopi.altervista.org/as/pred_iridium90.html.

[7] "Satellites and Probes - Reentry IRIDIUM 90."

[8] Harrington and Jakhu, "IAASS, Near Space."

[9] "Satellite Database | Union of Concerned Scientists," accessed January 3, 2021, https://www.ucsusa.org/resources/satellite-database.

[10] Mike Wall, "Satellite Megaconstellations Could Have 'extreme' Impact on Astronomy, Report Finds," Space.com, August 26, 2020, https://www.space.com/satellite-megaconstellation-impact-astronomy-report.html.

contribute to military operations.[11] Civil and military users often access the same capacities for communication, navigation, and optical imaging, thus, complicating this accounting further.

The military advantage of space assets challenges any adversary. Satellites and even spaceships are a worthwhile target in every conflict scenario. To cut off crucial U.S. communication, navigation, and ISR assets would be a central part of any adversary's action in an offensive or defensive military campaign; the same applies in reverse. Consequently, there are significant efforts to develop ground-launched and air-launched ASAT weapons, specifically in Russia and China.[12] U.S. Space Command (USSPACECOM) assessed Russia's direct-assent ASAT missile test from the Earth's surface into space in April 2020 as further proof of Russia "clearly having no intention of halting their counter space weapons programs."[13] Another step would be the pre-stationing of ASAT weapons in space.[14] The U.S. assesses that "China and Russia have weaponized space as a way to deter and counter a possible U.S. intervention during a regional military conflict."[15] Thus, the U.S. is "rapidly moving to meet and overcome challenges impeding [its] ability to access and freely operate in space."[16] As part of this movement, the U.S. established USSPACECOM to reflect "the importance of warfighting in space to the Joint Force, the value of space-focused deterrence elements, and the critical need for space-

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[11] "Satellite Database | Union of Concerned Scientists."

[12] Coats, "Director of National Intelligence, Worldwide Threat Assessment 2019," 17.

[13] "Russia Tests Direct-Ascent Anti-Satellite Missile," United States Space Command, April 15, 2020, https://www.spacecom.mil/News/Article-Display/Article/2151611/russia-tests-direct-ascent-anti-satellite-missile/.

[14] "Russia Tests Direct-Ascent Anti-Satellite Missile."

[15] "2020 Defense Space Strategy - Summary" (Department of Defense, June 17, 2020), 2, https://media.defense.gov/2020/Jun/17/2002317391/-1/-1/1/2020_DEFENSE_SPACE_STRATEGY_SUMMARY.PDF.

[16] Senate Committee on Armed Services, "Statement 2019 of John E. Hyten," 18.

related response options for the Nation."[17] U.S. military space capabilities have their own Joint Space Operations Doctrine and Space Capstone Publication for Spacepower.[18] However, these documents do not yet appreciate the use of space by hypersonic weapons.

The 2020 U.S. Space Force's Space Capstone Publication articulates specific orbital flight attributes and sets a distinction between *space* and *airspace*: "The boundaries of sovereign airspace do not extend into space…"[19] This quote reflects the common idea of space and airspace as two separated domains. On the one side, there is *space* somewhere above 100 kilometers with the orbital physics of gravity, and on the other side, there is *airspace* with the aerodynamic flight up to 20 km. The gradual transition area is not further differentiated and certainly not further included from an operational perspective.

Furthermore, this dichotomy does not consider the transitional impacts of hypersonic trajectories, skipping capabilities, and the resulting new challenges for managing space and airspace. One of the main characteristics of hypersonic weapons is that they use both the higher altitudes of airspace and, in certain circumstances, space.

[17] Senate Committee on Armed Services, 18.

[18] Chairman of the Joint Chiefs of Staff, "Joint Publication 3-14, Space Operations" (Joint Chiefs of Staff, April 10, 2018), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_14.pdf; United States Space Force, "Space Capstone Publication."

[19] United States Space Force, "Space Capstone Publication," 4.

Appendix A-4 Characteristics and Utilization of Hypersonic Flight

Hypersonic speed begins at Mach 5 (1.7 km/s; 3,700 mph)—five times the speed of sound.[1] The exploited hypersonic limit, so far, is approximately Mach 33 (11 km/s; 24,600 mph), experienced by the *Apollo* command module during re-entry into the Earth's atmosphere.[2] Higher speeds would only be reasonable for inter-planetary sample return vehicles (SRV).[3] However, physics might allow re-entry speeds in the upper atmosphere of almost Mach 45 (15 km/s; 33,500 mph) down to 70 kilometers (230,000 ft) altitude and Mach 25 (8.3 km/s; 18,600 mph) down to 30 kilometers (98,000 ft).[4]

Four types of weapons use hypersonic speeds:

- Rocket-propelled hypersonic missile
- Hypersonic Glide Vehicle (HGV)
- Hypersonic Cruise Missile (HCM)
- Hypervelocity Projectile (HVP)/Gun-Launched Guided Projectile (GLGP)

1. A **rocket-propelled hypersonic missile** is a surface-to-surface missile (SSM), surface-to-air missile (SAM), or air-launched ballistic missile (ALBM) with hypersonic velocity. The German *V2* reached nearly Mach 5 in World War II. However, SSM arsenals were limited for many years by the INF Treaty.[5] In recent years, Russia has claimed its *Kinzhal* as a fully operational hypersonic cruise missile.[6] Still, it is just a rocket-propelled

[1] Sayler, "CRS Report Hypersonic Weapons."
[2] "Apollo 11 Flight Journal - Day 9: Re-Entry and Splashdown," accessed December 5, 2020, https://history.nasa.gov/afj/ap11fj/26day9-reentry.html.
[3] Thomas Rivell, "Notes on Earth Atmospheric Entry for Mars Sample Return Missions," *NASA/TP–2006-213486*, September 30, 2006, 1.
[4] Rivell, 88.
[5] "The Intermediate-Range Nuclear Forces (INF) Treaty at a Glance | Arms Control Association."
[6] Amanda Macias, "Russia Claims Its New Hypersonic Weapon Is Ready for War," CNBC, December 27, 2019, https://www.cnbc.com/2019/12/27/russia-claims-its-new-hypersonic-weapon-is-ready-for-war.html.

air-launched ballistic missile with some maneuverability, developed from the SSM *Iskander-M* (9K720, SS-26 Stone).[7] However, it is a credible and cost-effective threat.

Rocket-propelled Hypersonic Missiles					
	max. altitude		max. speed		
V2[8]/Aggregat 4, surface-to-surface	84.5 km	280,000ft	Mach 4.7	1.6 km/s	3,480 mph
Iskander-M,[9] SS-26 Stone, surface-to-surface	50 km	164,000 ft	Mach 6	2 km/s	4,500 mph
Kinzhal,[10] air-to-ground			Mach 10	3.3 km/s	7,500 mph
Pershing II, MGM-31B[11]	240 km	788,000 ft	Mach 8	2.7 km/s	6000 mph
Minuteman I LGM-30B,[12] ICBM	1640 km	5,400.000 ft	Mach 23	7.7 km/s	17,200 mph
PAC-3,[13] anti-ballistic	45 km	148,000 ft	Mach 5	1.7 km/s	3,700 mph
Terminal High Altitude Area Defense (THAAD),[14] anti-ballistic	150 km	490,000 ft	Mach 7,5	2.5 km/s	6,700 mph
Ground-Based Interceptor (GBI)[15]	1800 km	5,900.000 ft	Mach 22.5	7.5 km/s	16,800 mph
SM-3 IIA (upper range),[16] anti-ballistic	2350 km	7,700.000 ft	Mach 16,5	5.5 km/s	12,300 mph

Figure 6: Maximum speeds and altitudes of Rocket-propelled Hypersonic Missiles.

[7] Williams, "Adapting to the Hypersonic Era," 5.

[8] Steffen Kahl, "V2 - Aggregat 4," accessed December 30, 2020, https://www.steffenkahl.de/luftfahrt/aggregat-4/.

[9] "Iskander-M 9K720 9P78E 9T250E SS-26 Stone Tactical Ballistic Missile Data | Russia Russian Missile System Vehicle UK | Russia Russian Army Military Equipment Vehicles UK," March 20, 2021, https://www.armyrecognition.com/russia_russian_missile_system_vehicle_uk/iskander_iskander-m_missile_9k720_9p78e_9t250e_ss-26_stone_tactical_ballistic_missile_russian_army.html.

[10] "Hypersonic Weapon Basics – Missile Defense Advocacy Alliance," accessed February 24, 2021, https://missiledefenseadvocacy.org/missile-threat-and-proliferation/missile-basics/hypersonic-missiles/.

[11] "Pershing 2 - United States Nuclear Forces," accessed March 12, 2021, https://www.globalsecurity.org/wmd/systems/pershing-specs.htm.

[12] Keith Baylor, "A Simulation of Minuteman Trajectories," 9, accessed December 8, 2020, https://cpb-us-e1.wpmucdn.com/wordpressua.uark.edu/dist/3/246/files/2016/05/Minuteman-Trajectory-Simulation.pdf.

[13] Shaoxin Feng and Yasheng Zhang, "Analysis of Near Space Hypersonic Glide Vehicle Trajectory Characteristics and Defense Difficulties" (2016 5th International Conference on Advanced Materials and Computer Science (ICAMCS 2016), Atlantis Press, 2016), 683, https://doi.org/10.2991/icamcs-16.2016.138.

[14] Feng and Zhang, 683.

[15] Feng and Zhang, 683.

[16] Laura Grego, "The Anti-Satellite Capability of the Phased Adaptive Approach Missile Defense System," Public Interest Report (Federation of American Scientists, 2011), 3, https://fas.org/pubs/pir/2011winter/2011Winter-Anti-Satellite.pdf.

2. **Hypersonic Glide Vehicles (HGVs)** launch with an Intercontinental Ballistic Missile (ICBM), Tactical Boost Glide (TBG) system, air-launched missile booster, or alternative carrier platforms to reach a sufficient release altitude and speed.

a. ICBM-launched HGVs launch on top of an ICBM to leave the atmosphere on a ballistic trajectory up to several hundred kilometers into space, re-enter the atmosphere, and start maneuvering aerodynamically towards the target. With its agility after re-entering the atmosphere, the HGV upgrades the ICBM compared to a merely ballistic warhead. Such HGVs are currently being deployed on existing means of intercontinental delivery (e.g., Avangard on SS-19). Figure 7 shows some examples of HGVs and re-entry vehicles. A launch with a Minuteman I could accelerate an American HGV to speeds above Mach 20. This speed envelope would also apply to the Russian Avangard on an SS-19. In both cases, the released HGV will have a ballistic trajectory through space and re-enter the atmosphere to start an agile and complex flight-profile towards its target, that would be very difficult to counteract. Further development of the carrier means might enable a flatter trajectory of the ICBM and make the midcourse intercept harder due to the missing exo-atmospheric ballistic part of the trajectory. Therefore, research and development for missile defense architectures should consider all trajectory phases: launch phase, mid-course/cruise, and terminal/end-game.

b. Tactical Boost Glide (TBG) systems are a subcategory of HGVs. A Tactical Ballistic Missile (TBM), smaller than an ICBM, brings the HGV to a lower release altitude and speed. An example would be a missile class like the former Pershing II, which could reach altitudes of 240 kilometers and release an HGV with a speed of Mach 8 into the atmosphere for a diverse aerodynamic flight profile. Such profiles could trade speed for maintaining altitude, e.g., maintaining 60 kilometers altitude and reducing speed from Mach 8 until reaching Mach 5 to start the dive for the end-game. Conversely, the HGV could start a continuous descent while keeping Mach 8 until impact. Skipping trajectory with various altitudes (40-100 km) and altering speeds are possible. Multiple changes of direction are feasible, and TBG HGVs would enable medium ranges with relatively low altitudes. Due to the Earth's curvature, ground-based air defense systems could detect TBG HGVs relatively late in their flight compared to ICBM that approach from much higher ballistic trajectories.

c. Air-launched HGV – The Air-Launched Rapid Response Weapon (ARRW) is an example of an air-launched HGV. This type of HGV does not start from the Earth's surface, but from a flying airplane. With the airplane's initial altitude and speed, the HGV needs less energy to reach its final cruising altitude and speed. Therefore, air-launched HGVs use a relatively small rocket booster to launch from a subsonic or supersonic aircraft. After their release from the aircraft, air-launched HGVs have similar flight profiles to TBG with lower costs. Their disadvantage is the dependence on an airplane.

Hypersonic Glide Vehicle (HGV) and Re-entry Vehicle					
	max. altitude		max. speed		
Avangard[17] (SS-19 launched)			Mach 27	9 km/s	20,100 mph
Hypersonic Technology Vehicle 2 (HTV-2)[18]	100 km	330,000 ft	Mach 18	6 km/s	13,400 mph
Air-Launched Rapid Response Weapon (ARRW), AGM-183[19]			Mach 20	6.7 km/s	15,000 mph
Common Hypersonic Glide Body (C-HGB),[20] surface-to-surface			Mach 17		
Space Shuttle re-entry[21]	120 km	394,000 ft	Mach 23	7.5 km/s	17,000 mph
Apollo command module, re-entry[22]			Mach 33	11 km/s	24,600 mph

Figure 7: Maximum speeds and altitudes of Hypersonic Glide Vehicles (HGV) and re-entry vehicles.

3. The **Hypersonic Cruise Missile (HCM)** has an air-breathing supersonic combustion ramjet (Scramjet) engine that supports hypersonic speed for a longer time and range than a rocket motor does (e.g., X-51A *Waverider,*[23] *Zircon*). HCMs need a release altitude and speed to start their Scramjet. Therefore, they use a rocket booster to launch from the surface or an aircraft and gain and maintain hypersonic speeds up to Mach 6. In

[17] Виктор БАРАНЕЦ, "'Komsomolskaya Pravda' Learned the Main Secrets of the Avangard Missile System," kp.ru, December 28, 2018, https://www.kp.ru/daily/26926.2/3974284/.

[18] Acton, "Hypersonic Boost-Glide Weapons," 205.

[19] Kyle Mizokami, "The B-1 Bomber Might Start Slinging Hypersonic Missiles," Popular Mechanics, April 9, 2020, https://www.popularmechanics.com/military/aviation/a32096936/the-b-1-bomber-hypersonic-missiles/.

[20] Joseph Trevithick, "Army Shows First-Ever Footage Of New Hypersonic Missile In Flight And Impacting," The Drive, accessed February 21, 2021, https://www.thedrive.com/the-war-zone/35369/army-shows-first-ever-footage-of-new-hypersonic-missile-in-flight-and-impacting.

[21] William L. Ko, Robert D. Quinn, and Leslie Gong, "NASA Technical Paper 2657, Reentry Analysis Space Shuttle" (NASA, December 1, 1986), 17, NASA Technical Reports Server (NTRS), https://ntrs.nasa.gov/citations/19870020362.

[22] "Apollo 11 Flight Journal - Day 9: Re-Entry and Splashdown."

[23] Contrary to the name's suggestion, the *Waverider* is not a gliding HGV.

the future, the Oblique Detonation Wave Ramjet[24] or Standing Oblique Detonation Ramjet (Sodramjet)[25] might reach Mach 16.

Hypersonic Cruise Missile (HCM)					
	max. altitude		max. speed		
NASA X-43[26] (2004)			Mach 9.6	3.2 km/s	7,200 mph
Boeing X-51A *Waverider*[27]			Mach 5	1.7 km/s	3,700 mph
SS-N-33 - T3K22 *Zircon*,[28] 3M22 rocket			Mach 6	2.0 km/s	2,500 mph
Expendable Hypersonic Air-Breathing Multi-Mission Demonstrator Program, *"Mayhem"*	*Mayhem* is built on efforts in HAWC, as well as the High-Speed Strike Weapon (HSSW).[29]				
Hypersonic Air-breathing Weapon Concept (HAWC)[30]			Mach 6	2.0 km/s	2,500 mph

Figure 8: Maximum speeds and altitudes of Hypersonic Cruise Missiles (HCM).

[24] Richard B. Morrison, "Evaluation of the Oblique Detonation Wave Ramjet," NASA Contract (Arlington, VA 22202: NASA; Universial Systems, Inc., January 1, 1978), https://ntrs.nasa.gov/api/citations/19780017411/downloads/19780017411.pdf; Richard B. Morrison, "Oblique Detonation Wave Ramjet," NASA Contract (Arlington, VA 22202: NASA; UNIVERSAL SYSTEMS, INC., January 1, 1980), https://ntrs.nasa.gov/api/citations/19800005874/downloads/19800005874.pdf.

[25] Zonglin Jiang et al., "The Criteria for Hypersonic Airbreathing Propulsion and Its Experimental Verification | Elsevier Enhanced Reader," *Chin J Aeronaut(2020)*, no. CJA 1841 (November 30, 2020): 11, https://doi.org/10.1016/j.cja.2020.11.001.

[26] "Boeing Wins Chance To Reenter Hypersonic Weapons Race | Aviation Week Network," accessed February 13, 2021, https://aviationweek.com/special-topics/air-dominance/boeing-wins-chance-reenter-hypersonic-weapons-race.

[27] "Wayback Machine," September 6, 2012, https://web.archive.org/web/20120906233323/http://www.boeing.com/defense-space/military/waverider/docs/X-51A_overview.pdf.

[28] "SS-N-33 - T3K22 Zircon / Tsirkon / 3M22 Rocket," 33, accessed March 12, 2021, https://www.globalsecurity.org/military/world/russia/zircon.htm.

[29] "'Mayhem' Will Be Larger, Multi-Role Air-Breathing Hypersonic System for USAF," *Air Force Magazine* (blog), August 19, 2020, https://www.airforcemag.com/mayhem-will-be-larger-multi-role-air-breathing-hypersonic-system-for-usaf/.

[30] "Boeing Wins Chance To Reenter Hypersonic Weapons Race | Aviation Week Network."

Compared to classical cruise missiles, HCMs show combinations of higher speeds and ranges. With typical altitudes of 20-60 km, HCMs fly below long-range radar coverage. Hypersonic cruise missiles will probably not be operational soon due to the complex Scramjet technology. Within Figure 8, the Russian *Zircon* and the American *Mayhem* represent ambitious projects. Reliable and comparable public data on the development status of these projects are scarce. HCMs have some way to go until becoming fully operationally available.

4. The **hypervelocity projectile (HVP)/Gun-Launched Guided Projectile (GLGP)** is any high-energy ammunition departing from guns or electromagnetic railguns with hypersonic speed.

Hypervelocity Projectile (HVP), Gun-Launched Guided Projectile (GLGP)[31]					
	max. altitude		max. speed		
105 mm Round M735[32]			Mach 4.5	1.5 km/s	3,400 mph
120 mm Round M829A2, anti-tank[33]			Mach 5	1.7 km/s	3,700 mph
Electromagnetic Railgun (EMRG)[34]			Mach 7.4	2.5 km/s	5,600 mph

Figure 9: Maximum speeds of Hypervelocity Projectile (HVP), Gun-Launched Guided Projectile (GLGP).

[31] Ronald O'Rourke, "Navy Lasers, Railgun, and Gun-Launched Guided Projectile: Background and Issues for Congress," *Congressional Research Service*, January 12, 2021, 49.

[32] Bernard J. Guidos and Paul Weinacht, "Parabolized Navier-Stokes Computation of Hypersonic KE Projectiles" (Army Research Laboratory, August 31, 1993), 11, https://apps.dtic.mil/dtic/tr/fulltext/u2/a268858.pdf.

[33] "120 Mm Round M829A2 with Armor Piercing, Fin Stabilized, Discarding Sabot – Tracer (APFSDS-T) For 120 Mm M256 Smoothbore Gun," *Arcon Partners Ltd* (blog), accessed February 20, 2021, https://arconpartners.net/products/ammunition/large-caliber/120-mm-round-m829a2-with-armor-piercing-fin-stabilized-discarding-sabot-tracer-apfsds-t-for-120-mm-m256-smoothbore-gun/.

[34] O'Rourke, "Navy Lasers, Railgun, and Gun-Launched Guided Projectile: Background and Issues for Congress," 21.

Hypersonic Airspace

In the past, hypersonic engineering focused on two efforts. First, the effective, safe, and smooth as possible atmospheric re-entry of crewed space vehicles. Second, the successful and fast re-entry of the intercontinental nuclear warheads.[35] Today, the development aims to enable hypersonic weapons to survive the physical effects of the hypersonic speed envelope as long as possible and take advantage of the vehicle's speed and agility. HGV skipping trajectories, starting at 120 kilometers with alternating altitudes and speeds, allow ranges of 7000 kilometers and probably more; maneuvers with accelerations of up to 5g are possible.[36] This new hypersonic footprint comes with blended characteristics between orbital behavior in space and aerial behavior in the airspace environment. Additionally, hypersonics appear different from aircraft and missiles in the electromagnetic spectrum (EMS).[37] Therefore, hypersonic objects are aliens in the airspace.

The hypersonic **altitude** envelope reaches from the surface of the Earth up into space. Hypersonic vehicles use the airspace up to 20km for launch and end-game and altitudes between 20 kilometers and 130 kilometers for the cruise. Furthermore, using an ICBM for launch, an HGV could reach hundreds of kilometers into *space* before reentering the atmosphere. Therefore, hypersonic vehicles blur the lines and fill the seam between *space and airspace*, highlight a new envelope for hypersonic flight between *space and airspace*, and demand a new set of rules, regulations, and doctrine. Introducing the altitudes

[35] National Academies of Sciences, *A Threat to America's Global Vigilance, Reach, and Power–High-Speed, Maneuvering Weapons, vii*.

[36] Feng and Zhang, "Analysis of Near Space Hypersonic Glide Vehicle Trajectory Characteristics and Defense Difficulties," 681.

[37] Y. Sha et al., "Analyses of Electromagnetic Properties of a Hypersonic Object With Plasma Sheath," *IEEE Transactions on Antennas and Propagation* 67, no. 4 (April 2019): 2470–81, https://doi.org/10.1109/TAP.2019.2891462.

between 20 kilometers and 130 kilometers as *hypersonic airspace* might help frame the operational envelope for hypersonic vehicles and assist with the development of air, space, and joint doctrine. Figure 1 illustrates the idea of *hypersonic airspace*. None of the sources used for this thesis show any indication for such a concept.

Time, Space, Forces

The *hypersonic airspace* concept offers an operational framework for the impact of hypersonics on time, space, and forces, in military operations in the air and space domain. The current upper edge of *Class A airspace* at an altitude of 60,000 ft (18km) could extend to 66,000 ft (20 km), where *hypersonic airspace* could start as a newly inaugurated *Class H airspace* to synchronize with the international airspace structure.[38]

Hypersonic Cruise Missiles shorten the operational **time** between America's near-peer competitors and U.S. forward targets. They also shorten the descent time from a cruising altitude to a potential impact on the Earth's surface. Therefore, they contribute to an "ever more lethal and disruptive battlefield, combined across domains, and conducted at increasing speed and reach—from close combat, throughout overseas theaters, and reaching to our homeland."[39]

Hypersonic Weapons dissolve operational **space**. Regional borders are becoming irrelevant; continental distances are shrinking. Crossing the Atlantic, the Pacific, or the Arctic at subsonic speed takes many hours, and a fundamental change of direction shortly before the destination is unlikely because of consumed endurance. With hypersonic speeds, such distances pass in minutes, and the target is only evident when the weapon closes in.

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[38] Federal Aviation Administration, "FAA Pilot's Handbook of Aeronautical Knowledge, Chapter 15 Airspace," August 24, 2016, https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/17_phak_ch15.pdf.

[39] Mattis, "Summary of 2018 NDS," 3.

Vertically, hypersonic weapons bridge between space and the surface of the Earth. With maneuvering speeds of Mach 25 (8,3 km/s; 18,500 mph), a hypersonic weapon would need less than 30 seconds to descend from an altitude of 130 kilometers to any target on the ground.

Hypersonic weapons revolutionize the **forces** by combining the speed of an ICBM with the maneuverability of a cruise missile and making them a qualitatively new capability.[40] Even a thousand miles away, any hypersonic object is alarming and becomes a potential threat. Any unidentified hypersonic vehicle passing above at an altitude of 130 kilometers is most likely not civilian and probably not friendly or neutral; it might demand engagement within seconds. These characteristics challenge existing detection systems, enable the attacker to gain surprising effects, and hinder the defender from preparing for active combat. Whether an adversary intends to use hypersonic weapons strategically or operationally, the defender must detect and identify them as soon and as precisely as possible. However, there is yet no such architecture for high-speed maneuvering weapon (HSMW) defense.[41] Therefore, the U.S. and its allies need to improve their defenses against this hypersonic threat.

Conversely, they need to incorporate these weapons' characteristics into their own arsenals and leverage them for an operational and strategic purpose. This question calls for further operational and strategical analysis of the advantages and disadvantages of integrating these weapons into arsenals. Because doctrine articulates how a military organization fights, it has to address how to use hypersonics and how to defeat them.

[40] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 2.

[41] National Academies of Sciences, *A Threat to America's Global Vigilance, Reach, and Power–High-Speed, Maneuvering Weapons*, 2.

Appendix B – Space-based Hypersonic Glide Vehicle

The speed envelope of a Hypersonic Glide Vehicle is very similar to the U.S. *Space Shuttle.* For the re-entry from space into airspace, engineers designed the *Space Shuttle* as a hypersonic vehicle. Its typical re-entry profile shows a smooth trajectory to bring the shuttle from a space speed of Mach 23 (7.5 km/s; 17,000 mph) and altitude of 120 kilometers (394,000 ft) back to a halt on the runway as gently as possible for the vehicle, crew, and payload.[42]

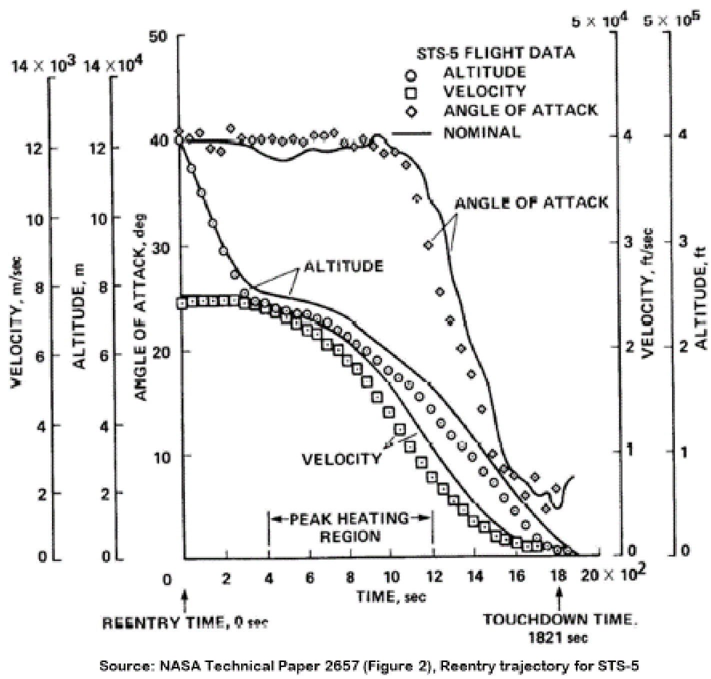

Figure 10: Hypersonic re-entry profile of the U.S. Space Shuttle.

For the first 300 seconds, the shuttle uses its high angle of attack ("nose up" maneuver) to reduce the altitude from 120 kilometers to 75 kilometers in a severe dive with continuous high speed. For the next 900 seconds, it keeps the nose up, reduces the altitude

[42] Ko, Quinn, and Gong, "NASA Technical Paper 2657," 17.

to 40 km, and reduces the speed to Mach 6 (2 km/s; 4,500 mph). The last 700 seconds transition the Space Shuttle back into the subsonic speed and altitude envelope and finally touch down. These three phases bring the shuttle down from orbit to the surface in 32 minutes in a smooth ride to provide the crew with a safe return to the Earth.

However, such a profile offers the potential of a modified trajectory for a weaponized vehicle. Instead of a gentle ride and a soft landing for a transport vehicle, such a trajectory could aim for a hard impact as fast as possible. It might be technically conceivable to engineer a vehicle for a decent phase of 800-1,200 seconds out of an altitude of 130 kilometers and an end-game speed of Mach 6-12 (2-4 km/s; 4,500-9,000 mph) until the impact. The HGV technology could link space, airspace, and the Earth's surface seamlessly as a new capability—the *space-based HGV*.

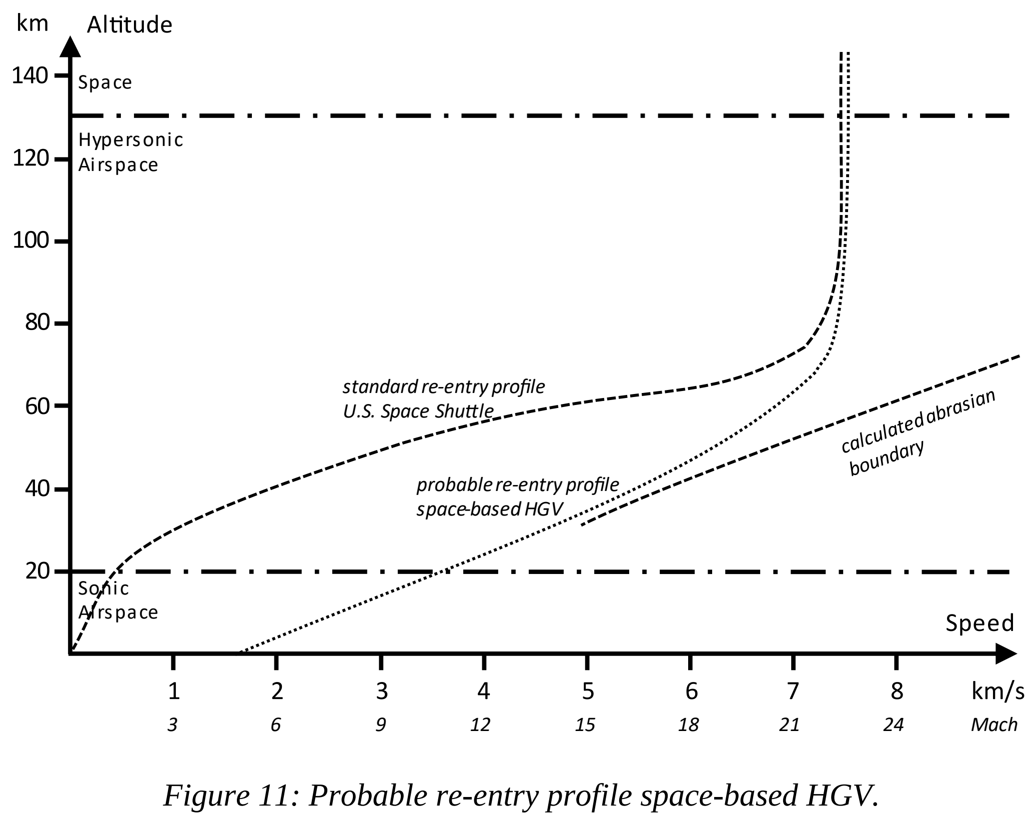

Figure 11: Probable re-entry profile space-based HGV.

Therefore, pre-stationing in space is conceivable and can be seductive for any competitor. With the help of a support module or even small control nozzles, an HGV, pre-stationed in space, could maneuver from a long-term stable orbit above 400 kilometers altitude down to 130 kilometers altitude. From there, it could turn into a steeper dive and reach objects on the Earth's surface with pinpoint accuracy within 15 minutes—without an observable classic booster phase. However, despite its feasibility, the existing literature does not consider the possibility of the deployment of HGVs in space:

- A 2017 article about the North Korean space program analyzes that North Korea might be or become able to use a satellite carrying a small nuclear warhead into orbit and then detonate it over the United States for an EMP strike. There is no discussion of potential use for HGV delivery.[43]
- A 2018 JAWS Masterthesis gives a comprehensive analysis of the weaponization of space but does not draw any conclusion to hypersonic weapons.[44]
- A 2019 DIA Report on Chinese military power discusses China's space efforts broadly and lists ground-launched hypersonic glide vehicles as technology to counter ballistic missile defense systems.[45] Furthermore, the report points out China's on-orbit assets, the strengthening of its military space capabilities, and the countering of "third-party intervention during military conflicts."[46] It does not discuss space-to-surface hypersonic weapons.
- The American Foreign Policy Council (AFPC) primer discusses China's significant R&D resources for space defense. These resources fund the deployment and "hardening" of multipurpose satellites and even targeting hypersonic weapons.[47] But not the pre-stationing of HGVs in space.
- Even an article from 2020 on Russian considerations about the possible use of the U.S. Space Shuttle as a space bomber in former years does not draw any

[43] Jim Oberg, "The Space Review: It's Vital to Verify the Harmlessness of North Korea's next Satellite," February 6, 2017, https://www.thespacereview.com/article/3164/1in.

[44] Mark A. Hauser, "The Modern Space Domain: On the Eve of Weaponization? - Master's Thesis," September 4, 2018, https://apps.dtic.mil/sti/pdfs/AD1051092.pdf.

[45] Defense Intelligence Agency, "China - Military Power, DIA Report," January 3, 2019, 37, https://www.dia.mil/Portals/27/Documents/News/Military%20Power%20Publications/China_Military_Power_FINAL_5MB_20190103.pdf.

[46] Defense Intelligence Agency, 40.

[47] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 9.

> link to the recent development of hypersonic weapons and the possibility of leveraging HGVs for space-based kill-vehicles.[48]

However, should America's competitors or adversaries start such a race, an imminent response could be possible. The U.S. would have a ready supply of launch vehicles to preposition space-based HGVs. The Air Force has begun to modify some of their 450 Minuteman II and 50 Peacekeeper (MX) missiles into Minotaur IV space-launch missiles and plans to use some of them to launch satellites.[49] Northrop Grumman even offers an improved Minotaur VI "capable of boosting payloads up to 3,100 kg (6,900 lb.) to low Earth orbit."[50] These missiles could also serve a low cost and low technical risk to pre-station HGVs in space. Nevertheless, before any nation takes that step, it should understand the effect of hypersonic weapons on strategic deterrence and consider a careful political and geo-strategic cost-benefit-analysis of a lurking arms race in space.

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[48] Bart Hendrickx and Dwayne A. Day, "Target Moscow: Soviet Suspicions about the Military Uses of the American Space Shuttle (Part 1)," The Space Review, January 27, 2020, https://www.thespacereview.com/article/3873/1.

[49] Woolf, "CRS: CPGS," 13.

[50] "Minotaur Rocket," *Northrop Grumman* (blog), accessed November 10, 2020, https://www.northropgrumman.com/space/minotaur-rocket.

Appendix C – Strategic Assumption Framework

Each viable strategy and each strategic negotiation refer to assumptions. Deterrence relies on specific assumptions concerning competitors and potential adversaries. When analyzing strategic challenges and developing suitable answers, such assumptions always exist and significantly influence the strategic dialogue.

The following assumptions might help to frame the strategic approach to counter hypersonic threats. This collection comes without referencing and without claim to completeness. There might be more, and the grades of relevance are only a visualization of a first guess and do not claim maturity. Chapter Two discusses only the first three assumptions briefly as most relevant and fundamental to strategic negotiations.

Assumption	relevance
In principle, any adversary intends to survive and acts according to this rationale.	+++
Every competitor wants to have control upon escalation.	+++
Nobody wants mutual misunderstandings or accidents. Nobody wants to appear as an attacker when not attacking. Nobody wants friendly fire. Furthermore, no one wants to kinetically engage a target, which afterward turns out to be a non-target, in the worst case causing civilian casualties.	+++
Any rational strategic actor will identify and avoid their own emotional, cultural, or traditional biases and prefer rational best strategic choices.	+
Competitors comply with standing agreements and treaties as long as monitored.	++
Adversaries and competitors use deception and propaganda.	+
Anyone interested in a balanced and stable mutual deterrence values a clear distinction between nuclear and conventional warheads.	?
However ambitious any competitor is, finally, they are more interested in their security and stability than in gaining competitive advantage.	+
Any strategic competitor puts more effort into concealing their confidential information than obtaining the competitors'.	+

Figure 12: Assumptions for strategic negotiations.

Appendix D – Defense and Counter Measures

Impact on Air and Missile Defense

Hypersonic weapons present a challenge to today's Air and Missile Defense (AMD). On the one hand, AMD can defend against classical highly maneuverable air-breathing fighter jets with capabilities such as the PATRIOT PAC-2 GEM.[1] On the other hand, AMD can counter high-speed, high-altitude ballistic missiles with limited maneuverability with multiple systems like PATRIOT PAC-3,[2] Ground-Based Interceptor (GBI),[3] or Terminal High Altitude Area Defense (THAAD).[4] The philosophy of air and missile defense is about not letting the enemy come close by engaging through appropriate air defense levels multiple times and as early and far away as is tactically feasible and algorithmically preferable.

However, an incoming hypersonic weapon's trajectory combines high speed with high vertical and horizontal maneuverability. In the endgame, these weapons fly close to the speed and diving-angle of a ballistic missile and the maneuverability of a high-performance aircraft. By overwhelming sensors, weapon computers, shooters, C2, and procedures, they challenge all current missile defense systems to find, target, and intercept.[5] They are too fast and high for the air defender and too agile for the missile defender. These factors along with their unique electromagnetic spectrum profile lead some

[1] "Patriot Missile Long-Range Air-Defence System, US Army," accessed January 3, 2021, https://www.army-technology.com/projects/patriot/.

[2] "Patriot PAC-3 | Military.Com," accessed January 3, 2021, https://www.military.com/equipment/patriot-pac-3.

[3] "Ground-Based Interceptor," Missile Threat, accessed January 3, 2021, https://missilethreat.csis.org/defsys/gbi/.

[4] "THAAD Theatre High Altitude Area Defense - Missile System - Army Technology," accessed January 3, 2021, https://www.army-technology.com/projects/thaad/.

[5] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 2.

analysts to recommend designating hypersonics as an "exotic new class of weapons."[6] On the strategic level, Tactical Boost Glide hypersonics with nuclear warheads could leverage atmospheric trajectories and avoid mid-course interception.

In regional theaters, Hypersonic Cruise Missiles and medium range HGVs leverage shorter response times and increased uncertainty, and shift the pressure for decision-making to lower hierarchical C2 levels. System operators routinely but decisively work through a chain of procedures. Fast approaching objects, like commercial airliners or fighter jets, require a timely and decisive response. The high speed results in little time before the aircraft reaches the line or point of defense. A short time creates decision pressure, and in combat situations, air defense personnel may engage such intruding objects. Therefore, the Identification Friend or Foe (IFF)[7] is one of the core challenges for integrated air defense systems (IADS) in dealing with subsonic and supersonic air traffic and is taken very seriously by all nations. However, in some cases, approaching objects engaged under increased operational pressure have turned out to be harmless civilian airliners or friendly military jets.[8]

The speed and agility of regional attacking hypersonic weapons will reduce decision space and outpace human-in-the-loop tactical defense performance. Fast approaching weapons urge instant decisions and do not allow for time-consuming long chains of command. Therefore, command authorities need to anticipate ramifications. They need to prepare and make certain decisions in advance, develop doctrine, and effect

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[6] van Loon, Wortzel, and Schneider, 1.

[7] See Annex G

[8] "Iran Air Flight 655," in *Wikipedia*, December 30, 2020, https://en.wikipedia.org/w/index.php?title=Iran_Air_Flight_655&oldid=997159195; "Patriot in New 'friendly Fire' Incident," the Guardian, April 4, 2003, http://www.theguardian.com/world/2003/apr/04/iraq.rorymccarthy4.

Standard Operating Procedures (SOP) that fit hypersonic circumstances. Leaders also need to urge the development of *Artificial Intelligence (A.I.)*-based decision support systems that identify hypersonic objects early, calculate interception options, and assist and accelerate human decision making in theater operations.[9]

Beyond regional scenarios, hypersonic weapons leverage their speed, altitude, and ability to overcome existing defense and decision spaces, showing little regard for the established borders between *Combatant Commands'* airspaces. They can transit across Geographical Commands within a few minutes, change to Space Command and back, and at the same time, they are of severe concern for Strategic Command. This challenge will affect the responsibilities, interoperability, and required coordination between geographic and functional combatant commands to observe and defend against space and airspace threats. Watts et al. conclude the obvious: "The compression of decision-making processes created by the limited time between launch and strike of the target (*flash to bang*), combined with its survivability against modern and near-term air-defense systems, makes this weapon a game-changer."[10]

The advent of hypersonic weapons into regional theaters contains a revolutionary and potentially destabilizing element that rips holes in the existing defense architectures. Similar to the exploitation of the mechanized land battle in the German *Blitzkrieg*, the exploitation of hypersonic weapons is likely to become a disruptive innovation—the *Hypersonic Blitz*. However, there are four potential ways for today's AMD to counter the evolving hypersonic technology.

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[9] Sydney J. Jr. Freedberg, "Army Tests New All Domain Kill Chain: From Space To AI," *Breaking Defense* (blog), August 5, 2020, https://breakingdefense.com/2020/08/army-tests-new-all-domain-kill-chain-from-space-to-ai/.

[10] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 1–2.

Countering the Operational Hypersonic Threat

First, modern AMD relies on **sensor** data; many of these sensors use radar technology. However, due to hypersonics' significantly lower flight trajectories compared to ICBMs, "terrestrial-based radar cannot detect hypersonic weapons until late in the weapon's flight."[11] Therefore, a robust defensive posture against hypersonic weapons requires a whole network of sensors, on the surface, in the air, and space. An Integrated Air and Space Defense needs a broad range of ISR capabilities, including multi-spectrum passive and active sensors. To start with, upgrading current surface missile-detection capabilities and creating a space sensor layer is reasonable.[12] As General Hyten told the Senate Committee on Armed Services: "In order to see those threats, I believe we need a new space sensor architecture."[13] The Space Development Agency (SDA) introduced the National Defense Space Architecture (NDSA) as a single, coherent, proliferated space architecture, and plans full global coverage with 550 satellites by 2025.[14]

However, if hypersonic glide vehicles were stationed in space in the future and launched from a Low Earth Orbit without a common booster's infra-red signature, the sensors of the NDSA would need to provide matching detection capability. If the Wide Field of View (WFOV) Overhead Persistent Infrared (OPIR) sensors only look downwards and only passively detect IR signatures, they will be insufficient for the detection of space-launched HGV.[15] In this context, it does become crucial to incorporate allies and partners.

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[11] Sayler, "CRS Report Hypersonic Weapons," 2.

[12] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 11.

[13] Senate Committee on Armed Services, "Statement 2018 of John E. Hyten," 28.

[14] Kelley M Sayler, Stephen M McCall, and Quintin A Reed, "Hypersonic Missile Defense: Issues for Congress" (Congressional Research Service, August 17, 2020), 1, https://fas.org/sgp/crs/weapons/IF11623.pdf.

[15] Nathan Strout, "SpaceX, L3 to Provide Hypersonic Tracking Satellites for Space Development Agency," C4ISRNET, October 6, 2020, https://www.c4isrnet.com/battlefield-tech/space/2020/10/05/space-development-agency-orders-8-hypersonic-weapon-tracking-satellites/.

Allied integration and data sharing, at least for ISR and eventually for C2, will be crucial and imperative to effectively counter regional and global hypersonic threats.[16]

Second, **computing capacity** needs to become both faster and more assistive. The Missile Defense Review's demand to "take advantage of the large area viewable from space" is valid.[17] However, monitoring a large area also takes a large computing capacity. The use of quantum computing and AI could empower fast and sufficient analysis of massive sensor data and contribute to reliable decision support. These technologies could identify and analyze deviating movement patterns early and suggest suitable and optimized countermeasures.

Third, **shooters** or intercept capabilities must improve in quality, quantity, and variety. Equipped with counter-hypersonic midcourse interceptor missiles, a future IASD would form the first line of defense against hypersonic weapons. Modern ICBMs with independently targetable and maneuverable reentry vehicles (MIRV/MaRV), along with decoys and jamming devices, already challenge the existing midcourse interceptors.[18] The even more agile HGVs would currently be overwhelming. If HGVs were pre-stationed in space, the sea-launched SM-3 missile could intercept an orbital object up to an altitude of 240 kilometers.[19] However, the missiles' effectiveness would fade if a space-based HGV reaches altitudes below 130 kilometers, where the HGV would gain aerodynamic agility and outmaneuver the SM-3. Therefore, a space-based HGV threat would suggest a space-based interceptor to enable early interception in space. The 2019 Missile Defense Review

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[16] Watts, Trotti, and Massa, "Hypersonic Weapons in the Indo-Pacific Region," 11.

[17] "2019 Missile Defense Review" (Department of Defense, January 17, 2019), 59, https://www.mda.mil/news/downloadable_resources.html.

[18] "2019 Missile Defense Review."

[19] Grego, "The Anti-Satellite Capability of the Phased Adaptive Approach Missile Defense System," 1.

is already dealing with the evaluation of "the possible effectiveness of space-based interceptor technologies and their cost-effectiveness when compared to other systems based on the land, sea, and in the air."[20] Therefore, the interplay between new threats and new countermeasures becomes part of an arms race.

Fourth, the **doctrine** needs to address and describe the new air and missile defense scenarios and the ramifications for **C2**. It has to blend existing and developing concepts and language of IADS, BMD, AMD, IAMD, and NDSA. As introduced earlier, the complex ramifications of hypersonic weapons and the dissolution of the boundary between space and airspace requires the development of an Integrated Air and Space Defense (IASD) doctrine to mitigate the emerging strategic risks. An example for a critical scenario would be if an unidentified missile launches spacewards and one U.S. defense system assesses it as an intercontinental threat and engages, while another U.S. defense system assesses it as an anti-satellite threat and engages at the same time with a second shooter. Unintentional redundant or even competing engagement with two shooters against the same target is neither effective nor efficient. It can even become dangerous and must be avoided. Therefore, all sensors, shooters, and decision support technology need to blend in with aerospace defense architecture.

However, given the defense industry's history of taking decades to produce new weapons, it is all the more important to adapt the operational and strategic framework immediately.[21] Success requires promptly conceptualizing, financing, and implementing the necessary development and procurement.

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[20] "2019 Missile Defense Review," 37.

[21] Michael E. O'Hanlon, "Forecasting Change in Military Technology, 2020-2040," *Brookings* (blog), September 11, 2018, https://www.brookings.edu/research/forecasting-change-in-military-technology-2020-2040/.

Impact on Terminal Defense and Point Defense

National High-Value Assets (HVAs) are a worthwhile target for hypersonic weapons. Because their safety is of strategic and political interest, a polity will want to have a clear assurance of protection. The Missile Defense Review claims "a limited capability to defend against HGVs in the terminal phase, and [the pursuit of] new capabilities for early warning and tracking of HGVs."[22] Instead of a clear assurance of protection, this is careful language to indicate the investment demand. Whoever assesses the existing defense architecture of HVAs too optimistically might not get the budget for better systems development and procurement. Conversely, whoever reveals a security gap calls Washington "undefended against hypersonic missiles," and claims a "lack of deep underground bunkers in Washington to protect the national command authority", revealing an exploitable weakness.[23] Therefore, public statements about the security of national HVAs can be ambiguous and not a measure of capabilities. The only place to discuss existing capabilities and future requirements is in a classified environment.

Even with a more capable Integrated Air and Space Defense there is always the probability that individual hypersonic threats will overcome the global defense umbrella and penetrate to close vicinity of HVA. Since the target remains unclear until the final approach and successful missile defense might not be entirely reliable, the importance of point-defense increases with the hypersonic threat. This recognition brings three consequences for terminal and point defense:

First, any HVA should have a **point defense** as the last line of defense. Some **close-in weapon systems (CIWS)** are available to serve as "final protection fire," to use an infantry

[22] "2019 Missile Defense Review," 58.
[23] van Loon, Wortzel, and Schneider, "Hypersonic Weapons," 11.

term. Raytheon's Phalanx serves "to defeat anti-ship missiles and close-in threats that have pierced other lines of defense."[24] Since the specific capabilities of such CIWS are classified, at this point, only the statements of General Hyten can be referred to as an assessment of the existing CIWS' limitations. Because hypersonic weapons might reach more high-value targets both forward and deep in the homeland and challenge terminal defense systems with higher speeds and agility, the demand for better CIWS arises. Therefore, point defense needs to improve in quality and concept.

Second, if the Integrated Air and Space Defense midcourse interception is the first line of defense against fast and agile hypersonics, and point defense is the very last line, the U.S. may need another defense line in between. This additional defense line could be an **air-based terminal protection-shield** against hypersonic threats, using different kinds and combinations of projectiles, shells, or barrage. This shield could function similar to the concept of ICBM Airborne Patrols, where HALE[25] UAVs serve as central platforms to build such shields.[26] These airborne platforms could span a flexible umbrella above the protected asset and engage in closing-in hypersonic threats. Additionally, concepts for swarms of smaller UAVs are conceivable.

Finally, if a hypersonic weapon with a conventional warhead gets through, resilience is needed to bolster against the hit. Classical passive air defense measures for headquarters and operation centers take on a new meaning. A new assessment of hardening, dispersal, and redundancy needs to calculate effectiveness and efficiency. For aircraft

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[24] "Phalanx Weapon System | Raytheon Missiles & Defense," accessed December 28, 2020, https://www.raytheonmissilesanddefense.com/capabilities/products/phalanx-close-in-weapon-system.

[25] High Altitude Long Endurance (HALE)

[26] Richard L Garwin and Theodore A Postol, "Technical Refinements in Design Features of the Airborne Patrol Against North Korean ICBMs," May 10, 2018.

carriers and other mobile assets, these new vulnerabilities also call for new calculations. The relocation of such forces in front of the enemy's territory is currently still an effective deterrent. However, under hypersonic threat, these forces might become too difficult or too expensive to defend, and the risk/benefit ratio can come into question. The new hypersonic threat makes strategic targets more vulnerable and does not allow weakness or negligence. In the age of social media, search engines, and tracking apps, HVAs quickly get unhealthy visibility and vulnerability. Therefore, within the force, a new sense and a new strategy of responsibility and confidentiality are necessary. Like in the cold war or even today, when service members were reminded that "if they see something, say something," personal security awareness and vigilance is critical in aiding the passive defense element of Integrated Air and Space Defense against hypersonic threats.

Appendix E – Analysis of U.S. Military Doctrine

An analysis of the current U.S. Joint, Air, and Space doctrine results in a set of starting points to introduce the operational implications of hypersonic weapons into doctrine.

Joint Publication 1 Doctrine for the Armed Forces[1]

The capstone publication for all joint doctrine presents fundamental principles and overarching guidance for the employment of the Armed Forces. It relates to space and airspace as aerospace and leaves the boundary between the two open. Thus, on the abstract level, it serves the characteristics of hypersonics well. Further amendments will soon incorporate the roles and responsibilities of the new USSPACECOM and offer an opportunity to coordinate aerospace responsibilities between the Combatant Commands.

Joint Publication 3-01 Countering Air and Missile Threats[2]

The joint publication to counter air and missile threats provides military guidance for the exercise of authority by combatant commanders and other joint force commanders.

The integrated consideration of space and airspace as *aerospace* is covered. However, it is noticeable that the organization of aerospace defense focuses on NORAD's role in North America. A global operational threat from hypersonics against forward-deployed forces or naval assets still leaves room for broader consideration.

The publication mentions the advent of hypersonic as a trend (2.e.(1)).[3] "The development of hypersonic weapons, combining the speed and range of

[1] Chairman of the Joint Chiefs of Staff, "Joint Publication 1, Doctrine for the Armed Forces of the United States" (Joint Chiefs of Staff, July 12, 2017), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp1_ch1.pdf.

[2] Chairman of the Joint Chiefs of Staff, "JP 3-01 Countering Air and Missile Threats."

[3] Chairman of the Joint Chiefs of Staff, 24.

BMs/IRBMs/ICBMs with the maneuverability of aerodynamic missiles, further stresses the capabilities of defensive systems." The same sentence occurs under air and missile threats (5.b.), only connected to ballistic missile threats, not air threats.[4] There is no more detailed description of the properties and no further conclusion for the defense architecture's ramifications.

JP 3-01 should describe and incorporate the operational impact of hypersonic weapons on joint warfare and introduce *hypersonic airspace* between 20km and 130km as a concept for organizing joint warfare. It should emphasize the restriction of hypersonic movements in this airspace over U.S. territory and an appropriate buffer zone.

Joint Publication 3-14 SPACE OPERATIONS[5]

The doctrine does not mention hypersonic weapons, their space-related characteristics, or their dissolving effect on the boundary between space and airspace. JP 3-14 defines the space domain as "the area above the altitude where atmospheric effects on airborne objects become negligible"[6] and avoids a fixed definition with altitude information. The doctrine notes that "the air and space domains also have a transitional region as the Earth's atmosphere and effects of gravity taper at increasing altitudes." This thesis recommends this transitional region as *hypersonic airspace* and explains why a specification could be helpful.

The doctrine also notes "that missile defense operations transiting through the [space domain] are not pre-coordinated due to the short-/no-notice self-defense actions required to defeat enemy ballistic missile attacks."[7] This approach isolates the surface-

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[4] Chairman of the Joint Chiefs of Staff, 113.
[5] Chairman of the Joint Chiefs of Staff, "JP 3-14 Space Operations."
[6] Chairman of the Joint Chiefs of Staff, 9.
[7] Chairman of the Joint Chiefs of Staff, 17.

based missile defense from the overall space architecture and does not consider space weaponization. If, in the future, space-based shooters come into play, this should change. Therefore, JP 3-14 should elaborate on the operational impact of hypersonic weapons on joint warfare in both *space* and *hypersonic airspace*.

Air Force Doctrine Volume 1, Basic Doctrine[8]

The Air Forces Basic Doctrine does not mention hypersonic weapons.

Volume 1 defines: "The air domain can be described as that region above the earth's surface in which aerodynamics generally govern the planning and conduct of military operations, while the space domain can be described as that region above the earth's surface in which astrodynamics generally govern the planning and conduct of military operations."[9] It further refers to Joint Publication 3-30, Command and Control for Joint Air Operations, for its definition of the air domain as "the atmosphere, beginning at the Earth's surface, extending to the altitude where its effects upon operations become negligible."

These definitions do not serve the advent of hypersonics. The Air Force Basic doctrine should incorporate and describe the operational impact of hypersonic weapons on air warfare and refer to hypersonic airspace, between 20 and 130 kilometers to organize air warfare. It should emphasize the restriction of hypersonic movements in this airspace over U.S. territory and an appropriate buffer zone.

Air Force Doctrine ANNEX 3-01 Counterair Operations[10]

The Annex for Counterair Operations identifies the development by peer and near-peer competitors of advanced aircraft, cruise and ballistic missiles, hypersonic glide

[8] USAF, "AF Doctrine Vol 1, Basic Doctrine."
[9] USAF, 26.
[10] USAF, "AF Doctrine 3-01 Counterair Operations."

vehicles, and sophisticated air and missile defenses, supported by peer and near-peer cyberspace and space advancements, as growing challenges to the joint force's ability to achieve control of the air.[11] However, it does not mention hypersonic cruise missiles, nor does it identify the obvious added value of a long-range stand-off hypersonic precision attack as a classic counterair operation.[12] It does not even list hypersonics as one of the resources and capabilities used to conduct Offensive Counter Air (OCA).[13] The Annex should discuss the added value of the range, speed, and agility of hypersonic weapons for counterair operations to reduce friendly forces vulnerability.

Air Force Doctrine ANNEX 3-14 Counterspace Operations[14]

With the Space Force established, the Air Force may not have its own doctrine on Counterspace Operations in the future. Nevertheless, the analysis of Annex 3-14 gives some suggestions to better frame such operations. There is little mention of a possible stationing of kinetic weapons in space, how to deal with them, and how to use them. Despite the possibility of on-orbit Anti-Satellite (ASAT) weapons that "may cause structural damage by impacting the target,"[15] there is no further reference to kinetic weapons in space, especially not as space-to-surface weapons. Since the boundaries between the space and airspace domains dissolve, and the operational merge has already begun, any new counter space doctrine should elaborate on the impacts of probable space-to-space, space-to-air, and space-to-surface weapons and how to counter them.

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[11] USAF, 2.

[12] USAF, 2.

[13] USAF, 34.

[14] Chief of Staff USAF, "Air Force Doctrine ANNEX 3-14, Counterspace Operations" (United States Air Force, August 27, 2018), https://www.doctrine.af.mil/Portals/61/documents/Annex_3-14/Annex-3-14-Counterspace-Ops.pdf.

[15] USAF, 4.

Air Force Doctrine ANNEX 3-52 Airspace Control[16]

The Annex *Airspace Control* would be the appropriate document to guide the ramifications of hypersonic flight on the coordination and control of the airspace. It should incorporate and describe the operational impact of hypersonic weapons on military airspace and refer to *hypersonic airspace* between 20 and 130 kilometers to organize future air warfare and synchronize with space warfare. It should emphasize the impact of hypersonic movements in the airspace above the homeland and abroad. The sample Airspace Control Plan (ACP) should incorporate a paragraph for hypersonics in SECTION BRAVO: SPECIAL PROCEDURES.[17]

Air Force Doctrine ANNEX 3-70 Strategic Attack[18]

The characteristics of hypersonic weapons perfectly fit the description of Strategic Attacks (SA) and the associated capabilities of this annex:

> Strategic attack involves the systematic application of force against enemy systems and centers of gravity, thereby producing the greatest effect for the least cost in lives, resources, and time. Vital systems affected may include leadership, critical processes, popular will and perception, and fielded forces. Strategic attack provides an effective capability that may drive an early end to conflict or achieve objectives more directly or efficiently than other applications of military power.[19]
> Strategic attack may be carried out with nuclear and conventional global strike capabilities from all the components: bombers, attack aircraft, special operation forces, ballistic and cruise missiles, information operations, space capabilities, cyberspace capabilities, electromagnetic spectrum operations, and surface forces. Each system or weapon has unique capabilities that should be exploited based on the nature of the desired effects. Often, Air

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16 Chief of Staff USAF, “Air Force Doctrine ANNEX 3-52, Airspace Control” (United States Air Force, July 12, 2019), https://www.doctrine.af.mil/Portals/61/documents/Annex_3-52/3-52-Annex-AIRSPACE-CONTROL.pdf.

17 USAF, 68.

18 Chief of Staff USAF, “Air Force Doctrine ANNEX 3-70, Strategic Attack” (United States Air Force, July 12, 2019), https://www.doctrine.af.mil/Portals/61/documents/Annex_3-70/3-70-Annex-STRATEGIC-ATTACK.pdf.

19 USAF, 2.

> Force forces will have the preponderance of capability to conduct and support SA air operations.[20]

However, the annex places Strategic Attack less as a singular effective operation to fight from a distance, and more in the context of an operational theater. It embeds Strategic Attack in a traditional and proven conduct of war that does not specifically emphasize the added value of fast and agile stand-off weapons.

> One of the highest-priority enabling objectives for air commanders will always be to gain the degree of control of the air needed to make other operations possible. Advances in air defense technology may necessitate devoting a substantial weight of effort to obtaining air superiority. This should be done in concert with (and sometimes before) SA operations are commenced if there is a significant risk of losing the assets employed.[21]

This passage reflects the doctrinal role of the Air Force to initially achieve the necessary air superiority with offensive counter air operations to be then able to operate freely with a lesser risk of losing the assets employed. There is no reference to the added value of stand-off weapons for SA throughout the whole annex and no elaboration on a possible change of the character of air war. If SA is about creating effects "without first having to fight the enemy's fielded forces,"[22] the selective use of hypersonic capabilities would be the perfect fit.

Space Capstone Publication SPACEPOWER[23]

With the Space Capstone Publication, the U.S. Space Force sets a clear demarcation from *space* versus *airspace* and elaborates the specific orbital flight attributes.[24] The only

[20] USAF, 39.
[21] USAF, 44.
[22] USAF, 8.
[23] United States Space Force, "Space Capstone Publication."
[24] United States Space Force, 3.

reference in the text of this doctrine to the *airspace* also shows a separation: “The boundaries of sovereign *airspace* do not extend into space.….“[25] This quote reflects the common idea of space and airspace as two different domains. On the one side, space with the orbital physics of gravity, and on the other side, the air space with aerodynamic flight. The gradual transition area is not further differentiated and certainly not further included from an operational perspective. This effort can be seen as a sign of a new service's independence, but it does not consider the new challenges of hypersonic trajectories for both space and airspace.

The doctrine defines the space domain as “the area above the altitude where atmospheric effects on airborne objects become negligible.”[26] Since atmospheric effects allow a complete orbital earth orbit at an altitude of 130 kilometers at the earliest, this definition would suggest a start of the space domain at 130 kilometers. With this doctrinal definition, the Space Force is pulling its area of responsibility upwards.

However, the capstone publication delivers a significant step forward in identifying space warfare impacts.

> Space was once a sanctuary from attack, but the emergence, advanced development, and proliferation of a wide range of demonstrated counter space weapons by potential adversaries has reversed this paradigm. Today, space, like all other domains, is realized to be contested due to the increasing threat to orbiting assets by adversary weapons systems. There is no forward edge of the battle area behind which military spacecraft can reconstitute and recover.[27]

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[25] United States Space Force, 4.
[26] United States Space Force, “Space Capstone Publication,” vi.
[27] United States Space Force, 7.

Appropriately, the doctrine incorporates *orbital warfare* and *space battle management* as two of seven space power disciplines.[28] These disciplines are a suitable approach to deal with a further weaponization of space, as well as against HGV. However, there is no approach to the transfer or coordination for objects that switch between the air and space domains, and the doctrinal idea for coordination of C2 between the air and space domain remains unclear.

[28] United States Space Force, 50.

Appendix F – Abbreviations

A2/AD	Anti-Access/Area Denial
ACP	Airspace Control Plan
ADIZ	Air Defense Identification Zone
AGM	Air-to-ground Missile
AI	Artificial Intelligence
ALBM	Air-launched Ballistic Missile
AMD	Air Missile Defense
AOR	Area of Responsibility
ARRW	Air-Launched Rapid Response Weapon
ASAT	Anti-satellite
BMD	Ballistic Missile Defense
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance
CIWS	Close-in Weapon System
C-HGB	Common Hypersonic Glide Body
CPGS	Conventional Prompt Global Strike
C-RAM	Counter Rocket, Artillery, and Mortar
EMRG	Electromagnetic Railgun
EMS	Electromagnetic Spectrum
GBI	Ground-Based Interceptor
GBSD	Ground-Based Strategic Deterrent
GLGP	Gun-Launched Guided Projectile
GPS	Global Positioning System
HALE	High Altitude Long Endurance
HAWC	Hypersonic Air-breathing Weapon Concept
HCM	Hypersonic Cruise Missile
HGV	Hypersonic Glide Vehicle
HOT	Hypersonic Operational Threat
HSMW	High-speed Maneuvering Weapon
HSSW	High-Speed Strike Weapon

HTV	Hypersonic Technology Vehicle
HVA	High-Value Asset
HVP	Hypervelocity Projectile
IAMD	Integrated Air and Missile Defense
IADS	Integrated Air Defense System
IASD	Integrated Air and Space Defense
ICBM	Intercontinental Ballistic Missile
IFF	Identification Friend or Foe
INF	Intermediate-Range Nuclear Forces treaty
IR	Infra-Red
IRBM	Intermediate-Range Ballistic Missile
ISR	Intelligence, Surveillance, and Reconnaissance
LEO	Low Earth Orbit
MaRV	Maneuvering Reentry Vehicle
MIRV	Multiple Independently targetable Re-entry Vehicle
NDSA	National Defense Space Architecture
OCA	Offensive Counter Air
OPIR WFOV	Overhead Persistent Infrared Wide Field of View
PPWT	Treaty on Prevention of the Placement of Weapons in Outer Space and of the Threat or Use of Force against Outer Space Objects
SA	Strategic Attacks
SAM	surface-to-air missile
Scramjet	Supersonic Combustion Ramjet
Sodramjet	Standing Oblique Detonation Ramjet
SOP	Standard Operating Procedures
SRV	Sample Return Vehicles
SSM	Surface-to-surface Missile
TBG	Tactical Boost Glide
TBM	Tactical Ballistic Missile
THAAD	Terminal High Altitude Area Defense
UAS/UAV	Unmanned Aerial System/ Vehicle

Appendix G – Terms and Definitions

Identification Friend or Foe (IFF) - is an identification system designed for command and control. It enables military and civilian air traffic control interrogation systems to identify aircraft, vehicles, or forces as friendly and determine their bearing and range from the interrogator.[1]

Conventional - For clear language, this thesis uses the phrase *conventional* only in the sense of *non-nuclear*. For example, a conventional warhead is meant to be a non-nuclear warhead but can be hypersonic. A non-nuclear cruise missile would be referred to as a conventional cruise missile but could be hypersonic. Depending on each specific context, this thesis distinguishes *non-hypersonic* technology or capability instead as *classical* or *contemporary* technology.

Anti-Access/Area Denial (A2/AD) - The objective of an anti-access or area-denial strategy is to prevent the attacker from bringing its forces into the contested region (anti-access) or preventing the attacker from freely operating within the region and maximizing its combat power (area-denial).[2]

Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) - The "nervous system" of the military, the collection of subsystems used to maximize situational awareness, is referred to as C4ISR—command, control, communications, computers, intelligence, surveillance, and reconnaissance.[3]

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[1] "Identification Friend or Foe | Raytheon," accessed February 25, 2021, https://www.raytheon.com/uk/capabilities/products/identification-friend-or-foe.

[2] Andreas Schmidt, "Countering A2/AD - Future Capability Requirements in NATO," *Joint Air Power Competence Centre* (blog), January 27, 2017, https://www.japcc.org/countering-anti-access-area-denial-future-capability-requirements-nato/.

[3] "C4ISR: The Military's Nervous System," Defense One, accessed February 25, 2021, https://www.defenseone.com/insights/cards/c4isr-military-nervous-system/.

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Vita

Colonel Roman Lau is a German General Staff Officer and Engineer with an aviation background and experience in Command & Leadership, Professional Military Education, and Complex Environment Evaluation. Prior to attending the Joint Advanced Warfighting School, Colonel Lau was the Air Force Faculty Chair and Course Director of the Bundeswehr Command and Staff College in Hamburg, Germany. Colonel Lau entered the Bundeswehr in July 1988. He graduated from the Offizierschule der Luftwaffe; Universität der Bundeswehr (Diplom-Ingenieur Electrical Engineering); Lufthansa Flight Training School (Certified Pilot); and Bundeswehr Command and Staff College (General Staff Officer). Colonel Lau collected more than 2000 flying hours, mainly with the Transall C-160. He served as squadron leader and group commander at Hohn airbase, Germany. His missions abroad led him to the Balkans, Mozambique, Libya, and other places. In his 2007 ISAF tour, he was squadron leader of the German C-160/CH-53 Air Medevac squadron Northern Afghanistan.

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[1] Science & Technology Organisation (STO)