ANALYSIS OF VIABILITY AND POTENTIAL APPLICATIONS FOR HYPERSONIC TECHNOLOGIES AS THEY PERTAIN TO MILITARY STRATEGY AND DIPLOMACY FOR THE UNITED STATES

STS Thesis

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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction:

Global conflict has always been an exceptionally effective catalyst for the progression of technological development. The Second World War produced several technologies with large roles in life today. The atomic bomb was the most impactful example and played a significant role in the onset of the Cold War and global tensions throughout the remainder of the 20th century. More recently, the Israeli-Palestinian conflict and the Russian-Ukrainian war have both played major roles in flaring up global tensions. These modern conflicts have demonstrated the modern capabilities of technology with the use of the Iron Dome anti-missile system in Israel and Russia's use of air-breathing, maneuverable, hypersonic missiles in Ukraine. The Iron Dome is primarily designed to counter the deployment of short-range ballistic missiles. However, anti-missile defense systems designed to counter long-range Intercontinental Ballistic Missiles have also seen use in these modern conflicts with the Israeli Arrow-3 seeing successful use[1] and the Russian development of the A-135 anti-ballistic missile (ABM) interceptor[2].

Historical Context:

Balance of power is an important theme in world history over the past 500 years. In the nuclear age, the concept of balance of power is represented by the term mutually assured destruction (MAD). Although the wording has changed, the general theme of balance has not. These recent global conflicts reiterate the importance of balance because once a global superpower believes they can attack and perpetrate the sovereignty of other countries without retaliation, the start of another world war and the end of modern civilization becomes increasingly possible.

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[1] Giveh, M. (2023, December). *Israeli Arrow System Downs First Missiles in Combat* | Arms Control Association. www.armscontrol.org.

[2] Shaikh, S. (2020, December 3). *Russian Tests Anti-Ballistic Missile Interceptor*. Missile Threat.

Balance of power is best described as a pendulum swinging back and forth as new technologies are developed to counter the previous new technology. Global power can be characterized by military strength and technological capabilities. This topic of hypersonic weapons plays a larger role in the technological capabilities' hemisphere of global power. The newest technology that has been utilized in real world applications is the anti-ballistic missile defense system. Although this technology serves a defensive purpose, it threatens to throw off the balance of global power because it undermines the concept of MAD in the theoretical onset of nuclear war. It does so because it allows for one country to have the ability to launch potentially nuclear strikes on another country while not being struck with nuclear strikes themselves since they have the ability to neutralize the ICBMs launched in response. The development of anti-missile technology is the motivation for the development of hypersonic weapons. Hypersonic weapons provide the potential capabilities necessary to invalidate anti-missile systems. These capabilities include a "combination of speed, accuracy, range, and survivability" that would be useful in military applications and not currently possessed by other forms of strike ordinances such as ICBMs or cruise missiles[3].

<u>Defining Hypersonics:</u>

The goal of this evaluation is to better understand the role hypersonics could fulfill for the US with respect to the purpose of national defense. To clarify, the usage of the term "hypersonic weapon" is strictly reserved for missiles that travel faster than five times the speed of sound, exist primarily within the Earth's atmosphere, and are equipped with aerodynamic control surfaces to allow for maneuverability. Is this new realm of weapons a purposeful and effective method of threat deterrence, or is it another example of impractical, cost inefficient

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[3] Kramer, C. (2023, January 31). *U.S. Hypersonic Weapons and Alternatives* | Congressional Budget Office. www.cbo.gov.

technology? The criteria for evaluating the level of competency of hypersonic weapons will include the intended uses in military strategy, the intended uses in threat deterrence, the potential challenges and roadblocks the technology and its development will have to compensate for and overcome, a comparison of the hypersonic weapon to pre existing technologies that share similar capabilities and intended uses, and an evaluation of the costs opposed to the expected benefits of the development of hypersonic weapons.

Intended Applications:

The first step to evaluate if the hypersonic weapon is worth the United States' investment of their resources is to explore the intended applications for the weapons in strategic military operations. The proposed usefulness of the hypersonic weapon falls into the particular niche of flying low to avoid enemy radar defense systems and having the fastest response time of any strike technology. John Hyten, former Vice Chairman of the Joint Chiefs of Staff and former Commander of U.S. Strategic Command General, stated, "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."[4]

Applications in Military Strategy

There are two categories of hypersonics that need to be considered when understanding the complete spectrum of capabilities and intended uses. The first category is the hypersonic boost-glide vehicle (BGV). The delivery of this weapon begins when the glider is boosted to a hypersonic speed at high altitude where it then glides through the atmosphere to the target. The

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[4] Hyten, J. (2019, February 26). *Testimony of John E. Hyten*. Hearing on United States Strategic Command and United States Northern Command.

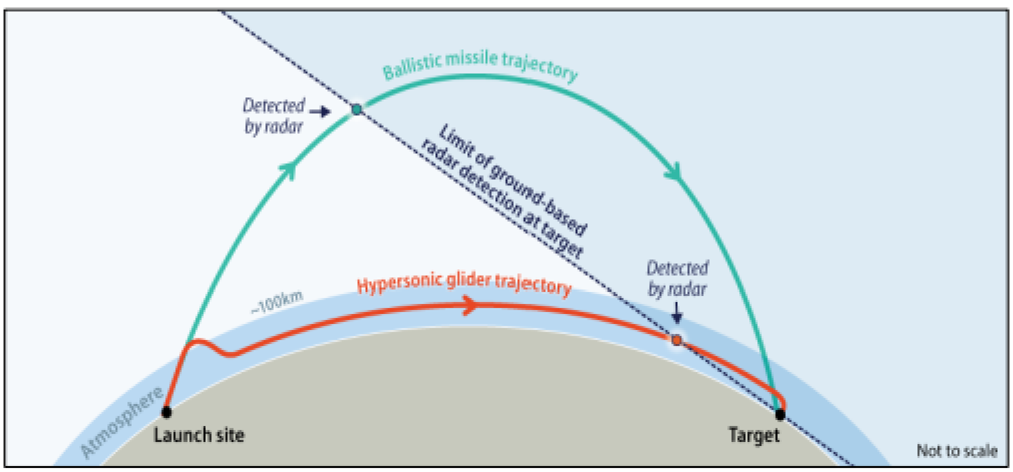
second category is the hypersonic cruise missile (HCM), which is reliant on the scramjet, or supersonic combustion ramjet, technology. The methods for delivery of these weapons are also categorized into two separate groups. The weapons can be delivered with a ballistic missile of varying range or out of another aircraft. The munitions deployed from a subsonic aircraft require a booster rocket to bring the weapon's speed to Mach 3 in the case of a ramjet or Mach 5 with a scramjet. However, the use of supersonic aircrafts allow the HCM to deploy without the assistance of a rocket booster. BGVs need a ballistic missile to boost them to hypersonic speeds before deployment, but HCMs can be delivered by a ballistic missile or aircraft. The preferred delivery system is primarily attributed to the range at which the target is located with the aircraft method used for shorter range targets and rocket-boosted method utilized primarily for intermediate to long range targets.

Figure 1. Source: Air Force Air-Launched Rapid Response Weapon program office (Lockheed Martin illustration).

The Tactical Boost Glide (TBG) vehicle developed by the Defense Advanced Research Projects Agency forms the basis for the hypersonic boost-glide missile that the Air Force is developing, the Air-Launched Rapid Response Weapon (ARRW). The TBG is shown here as a slender, pointed object on the front end of the missile. The cone in the upper left of the drawing is the protective shroud from the front of the missile, which has just been ejected in preparation for releasing the TBG.[5]

[5] Figure 1-3 from Kramer, C. (2023, January 31). *U.S. Hypersonic Weapons and Alternatives* | Congressional Budget Office. www.cbo.gov.

The intended application for the use of hypersonics in military strategy is to effectively strike a target within enemy territory with almost total certainty the strike will be successful. The culmination of several developmental technologies over the past century has produced an accurate, precise, and maneuverable technology. Materials that perform effectively in the harsh conditions of hypersonic, atmospheric flight underwent a lot of successful development, specifically during the development of the SR-71 Blackbird. Other examples include the ramjet and the scramjet, which are new technologies for air-breathing propulsion and necessary for HCMs, and significant improvement of precision-guided munitions. The combination of these technologies has produced a device capable of prolonging enemy radar detection, antiquating defensive measures, and almost guaranteeing successful contact with the target.



Source: CRS image based on an image in "Gliding missiles that fly faster than Mach 5 are coming," *The Economist*, April 6, 2019, https://www.economist.com/science-and-technology/2019/04/06/gliding-missiles-that-fly-faster-than-mach-5-are-coming.

Figure 2. Terrestrial-Based Detection of Ballistic Missiles vs.
Hypersonic Glide Vehicles[6]

The intended methodology for utilizing hypersonic weapons imposes a hefty challenge to modern radar detection and defense capabilities. Kelley Sayler, a Specialist in Advanced Technology and Global Security, stated "hypersonic weapons could challenge detection and

[6] Sayler, K. (2024). *Hypersonic Weapons: Background and Issues for Congress*. pg 3

defense due to their speed, maneuverability,and low altitude of flight. For example, terrestrial-based radar cannot detect hypersonic weapons until late in the weapon's flight." Modern radar, predominantly terrestrial radar systems, suffer tremendously trying to detect objects flying at low altitudes because the Earth is between the radar and object. Ballistic missiles are different from hypersonic weapons in the ways Sayler describes because ballistic missiles travel at high altitudes on a ballistic trajectory, which is highly predictable and much easier to defend against. Adversarial response times are heavily influenced by when the weapon is detected. There are theoretical solutions to a terrestrial radar's inability to detect hypersonic weapons as John Hyten states "a space tracking and discrimination constellation combined with next generation Overhead Persistent Infrared systems would provide significant improvements necessary to detect advanced threats."[7] However, these space-based radar constellations are not currently capable of serving as a viable detection and defense system against hypersonic weapons, "U.S. defense officials have stated both terrestrial- and current space-based sensor architectures are insufficient to detect and track hypersonic weapons, with former USD(R&E) Griffin noting 'hypersonic targets are 10 to 20 times dimmer than what the U.S. normally tracks by satellites in geostationary orbit.'"[8]

Applications in Diplomacy

These weapons also serve a purpose in politics and world diplomacy as an effective and justifiably usable alternative to nuclear strikes. In order to destroy a target, there are two methods. The first is a weapon with such a large release of energy that everything within miles is destroyed. This is the nuclear method. The second is to use a weapon capable of penetrating into

[7] Hyten, J. (2019, February 26). *Testimony of John E. Hyten*. Hearing on United States Strategic Command and United States Northern Command.

[8] Washington, H. (2018). Stenographic Transcript Before the Subcommittee on Committee on Armed Services United States Senate, "*Testimony of Michael Griffin,*" Hearing on New Technologies to Meet Emerging Threats.; and Hyten, J. (2019, February 26). *Testimony of John E. Hyten*. Hearing on United States Strategic Command and United States Northern Command.

adversarial territory and delivering an accurate strike with a smaller, conventional payload. Hypersonics have the potential to be so good at the second method they could prove to have the same effectiveness as nuclear weapons. John Hyten indirectly mentioned this possibility when he stated "their *unique attributes* will increase traditional warfighting advantages and *bolster conventional and strategic deterrence*." It is encouraging that influential entities have recognized the potential for conventional hypersonics as "the Air Force continues to explore both air-launched hypersonic boost-glide and cruise missile concepts for fielding on a variety of strike and bomber aircraft. The Army plans to incorporate hypersonic strike systems into their traditional long-range precision fires portfolio to expand the reach of surface-to-surface engagements. This flexible mix of capabilities will provide persistent, visible and credible strike options *without crossing the nuclear threshold*."[9] It is also encouraging to note the US does not intend to implement nuclear warheads onto their hypersonic weapons. The Chinese and Russians are integrating nuclear warheads into their hypersonic weapons systems, but that may be a strategic oversight on their parts.[10]

Comparison to Alternative Technologies:

The second step for evaluating hypersonic development programs is to compare the expected capabilities of the technology to the capabilities of technologies the US already possesses. Hypersonics can best be compared to nuclear ICBMs, maneuverable reentry vehicles (MaRVs), and subsonic cruise missiles for their technological capabilities and strike methodologies.

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[9] Hyten, J. (2019, February 26). *Testimony of John E. Hyten*. Hearing on United States Strategic Command and United States Northern Command.
[10] Sayler, K. (2024). *Hypersonic Weapons: Background and Issues for Congress*.

Technologies with Similar Methodologies

The range capability is very important. There needs to be a balance found with operational ranges less than 5500 km - the launch platform needs to be located close enough to strike the target, yet far enough to not be destroyed by an adversary. The longest proposed range for a BGV is 3000 km. At this range, a launch battery could be placed on Guam and have the ability "to reach China's militarily important coastal regions. But in doing so, it would be within range of China's medium-range bombers and ballistic missiles."[11] Current technologies with the desired long-range capabilities are either very vulnerable to current defense systems (ballistic missiles) or incredibly cost inefficient (stealth bombers). The range for the HCM is not released at this time, but once the scramjet is ready for field applications, it would provide better long-range capability than its boost-glide counterpart.[12]

Type of Weapon System	Example	Range (Kilometers)
Existing Weapons		
Ground-launched tactical ballistic missile	Army Tactical Missile System (ATACMS)	300
Subsonic cruise missile	Tomahawk	1,000 to 2,400[a]
Submarine-launched ballistic missile	Trident	7,400
Ground-launched ballistic missile	Minuteman III	13,000
Supersonic stealth fighter aircraft	F-22 Raptor	1,500[b]
Subsonic stealth bomber	B-2 Bomber	4,800[b]
Weapons Under Development		
Intermediate-range hypersonic boost-glide missile (Ground- or sea-launched)	Long-Range Hypersonic Weapon (LRHW)/ Intermediate-Range Conventional Prompt Strike (IR-CPS) prototype	3,000[c]
Medium-range hypersonic boost-glide missile (Air-launched)	Air-Launched Rapid Response Weapon (ARRW) prototype	1,000[d]

Figure 3. Ranges of Various U.S. Weapon Systems[13]

Another important capability is responsiveness. The current United States' arsenal of long-range conventional weapons do not possess quick response times. Lack of quick

[11] Kramer, C. (2023, January 31). *U.S. Hypersonic Weapons and Alternatives* | Congressional Budget Office. www.cbo.gov.
[12] ibid.
[13] Congressional Budget Office, using data from the Department of Defense. See www.cbo.gov/publication/58255#data.

responsiveness has been a persisting ailment for the Strategic Air Command (SAC) ever since its creation in 1946. BGVs are estimated to have longer flight times than ballistic missiles at all ranges. However, "because of their low, flat trajectory, *hypersonic cruise missiles would take less time to reach their targets than either boost-glide or ballistic missiles*." Subsonic cruise missiles have a vastly inferior flight time to BGVs. "CBO compared subsonic cruise missiles over the ranges available with existing weapons and found their flight times would be 9 to 11 times as long as those of hypersonic boost-glide missiles and ballistic missiles."[14]

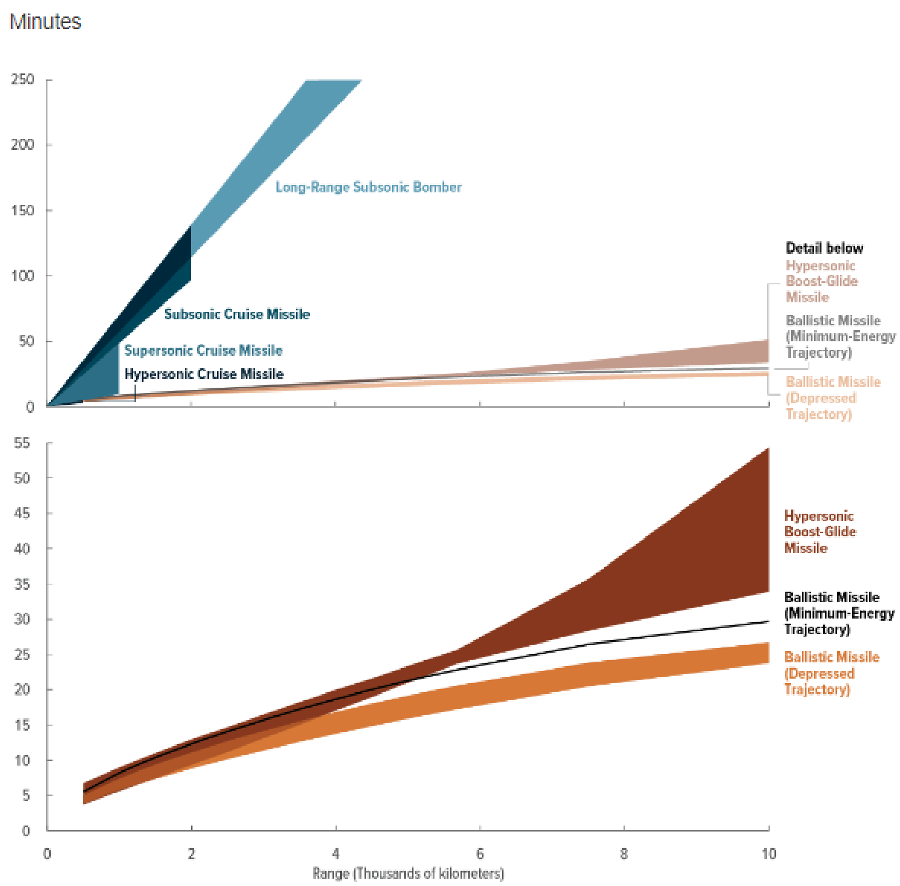

Figure 4. Spans of Flight Times for Hypersonic and Other Weapon Systems
For cruise missiles and subsonic bombers, the end of the colored band represents the estimated maximum range. CBO does not know the maximum range for hypersonic boost-glide missiles, but it extended the analysis to 10,000 kilometers to compare their potential flight times with those of ballistic missiles, which can currently achieve intercontinental ranges up to 12,000 kilometers.[15]

[14] Kramer, C. (2023, January 31). *U.S. Hypersonic Weapons and Alternatives* | Congressional Budget Office. www.cbo.gov.
[15] ibid.

The most important capability is survivability. Space-based infrared boost-phase detection systems can detect hypersonic launches similar to other launches. The predictable ballistic flight path is able to be tracked with the initial infrared detection and physics calculations even without continuous observation throughout the intermediate stages of flight. However, the maneuverability of hypersonics makes them harder to track and intercept following an initial infrared detection because the ability to change trajectories mid-flight makes the initial trajectory calculations worthless.[16]

Maneuverable reentry vehicles (MaRVs) are a type of ballistic warhead capable of maneuvering after deployment from a missile. They are similar to BGVs in this manner, but the BGVs are able to maneuver for a larger portion of their flight. In terms of speed, BGVs are "likely to be traveling more slowly than a MaRV as it gets close to its target because hypersonic missiles use up much of their energy while gliding toward their targets." This is because the gliders do not have propulsion systems themselves, so they lose kinetic energy throughout their flight especially when performing maneuvers "and therefore may not offer a particular advantage over MaRVs."[17] This is not a weakness of HCMs. Although MaRVs are not a part of the United States' arsenal currently, the technology for MaRVs is well-developed as MaRVs were integrated into the Pershing II IRBMs before the INF treaty required the destruction of "all nuclear and conventional ground-launched ballistic and cruise missiles with ranges of 500 to 5,500 kilometers" in 1987.[18] They can be pursued again since "the US withdrew from the treaty in 2019, citing Russian violations."[19]

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[16] Hyten, J. (2019, February 26). *Testimony of John E. Hyten*. Hearing on United States Strategic Command and United States Northern Command.
[17] Wright, D., & Tracy, C. L. (2023). *Hypersonic Weapons: Vulnerability to Missile Defenses and Comparison to MaRVs*. Science & Global Security, 31(3), 68–114.
[18] Kimball, D. (2019, August). *The Intermediate-Range Nuclear Forces (INF) Treaty at a Glance* | Arms Control Association. Armscontrol.org.
[19] Kramer, C. (2023, January 31). *U.S. Hypersonic Weapons and Alternatives* | Congressional Budget Office. www.cbo.gov.

Key:
■ = Mature Technology
☑ = In Development as Part of DoD's Current Budget Plan
□ = Would Require Investment Not in DoD's Current Budget Plan

					Able to Survive Defenses[a]		
Weapon Type	Exist Today in U.S. Inventory	Average Speed Greater Than Mach 5[b]	Range Greater Than 3,000 km[c]	Accurate Enough to Use a Conventional Warhead[d]	Air Defenses	Midcourse Ballistic Missile Defenses	Terminal Ballistic Missile Defenses
Intercontinental Ballistic Missiles	■	■	■	□	■	□	□
Medium- to Intermediate-Range Ballistic Missiles		□	□	□	□	□	□
Hypersonic Boost-Glide Missiles		☑	☑	☑	□	☑	☑
Subsonic Cruise Missiles	■			■	□	■	■
Supersonic Cruise Missiles				□	□	□	□
Hypersonic Cruise Missiles		☑	Unknown	☑	□	☑	☑

Figure 5. Characteristics of Different Missiles Included in This Analysis, by Development and Funding Status[20]

Each of these technologies could be chosen as the best for a specific situation, but the best alternative to hypersonics when considering all of the desired capabilities is the MaRV. MaRVs and BGVs are fairly balanced in terms of their capabilities and trade-offs. The fact that the MaRV technology is already developed and has been integrated into operational platforms before gives it the upper hand over the BGV. However, the superiority of the HCM in all considered capabilities suggests that it is the best overall option.

Low-Observable (Stealth) Technology

Stealth was another technology that showed promise in the intended applications for military strategy and political diplomacy of hypersonic weapons. During stealth's early development in the 1970s, Nikolai Ogarkov, chief of Soviet general staff in 1977, believed that "stealth technology would allow an adversary to identify and attack heavily defended targets far

[20] ibid.

behind the front lines."[21] In reference to deterrence, "stealth was like nuclear weapons, which served their purpose simply by existing."[22] Stealth's potential to replace nuclear weapons is reiterated as Ogarkov discussed in a 1984 interview that stealth "made it possible to sharply increase the destructive potential of conventional weapons, bringing them closer to weapons of mass destruction *in terms of effectiveness*."[23] This opinion was shared by DARPA and the Defense Nuclear Agency in the 1970s. They believed that the use of conventional weapons, integrated with stealth platforms and precision-guided munitions, "could blunt a Soviet attack in Western Europe *without nuclear weapons*."[24] This is precisely the same goal the US has for hypersonics. The stealth programs went on to successfully provide the US with effective products. However, the technology failed to be a diplomatic alternative to nuclear deterrence and proved impractical in application due to the immense costs of procurement and maintenance.[25]

Technological and Diplomatic Challenges:

The third step of the evaluation process for the hypersonic weapon is to identify the technological and diplomatic challenges that must be overcome during the development of this new technology. The technological challenges include heating and thermal shielding, stability and maneuvering, communications and targeting, and scramjet technology.

Technological Challenges

Heating and thermal shielding is a materials problem. The US has experience working with materials that can withstand the temperatures predicted to be present during hypersonic flight, which are between 1000 - 2000 K. These temperatures are below the temperatures where

[21] Westwick, P. J. (2020). *Stealth : The Secret Contest to Invent Invisible Aircraft*. Oxford University Press. pg 116-117
[22] ibid. pg 116
[23] Macgregor Knox, & Murray, W. (2001). *The Dynamics of Military Revolution*, 1300-2050 (p. 3). Cambridge University Press.
[24] Westwick, P. J. (2020). *Stealth : The Secret Contest to Invent Invisible Aircraft*. Oxford University Press. pg 118
[25] ibid. pg 183

air would turn into an ionized plasma, which is beneficial for communications because plasma absorbs electromagnetic signals. This experience was gained from the SR-71 Blackbird, Space Shuttle, and other reentry vehicles such as ballistic missiles. The list of materials that proved useful include titanium, superalloys, ceramic composites, carbon-fibers, and carbon-carbon composites. However, these materials are not currently sufficient for sustained hypersonic, atmospheric flight as they were meant to withstand these temperatures through a reentry process that only lasted a few minutes. Not to mention the manufacturing processes for these materials are incredibly difficult and expensive.

Stable flight is incredibly challenging at hypersonic speeds, and maneuvering only exacerbates the challenge. The issues fall into two categories: the behavior of the shock layer and the maintenance of the vehicle's energy. "One of the biggest challenges that designers of hypersonic missiles face is predicting the behavior of the shock layer. The transition from smooth to turbulent air flow around a moving body can disrupt its stability and cause sudden, localized increases in temperature."[26] These localized increases in temperature could be devastating to the integrity of the vehicle. When traveling at hypersonic speeds, the aerodynamic loads are immense, and when the vehicle is tasked with maneuvering it will experience an incredibly high amount of drag. This will decrease the vehicle's speed, range, and increase the temperature even more.

Communication with a vehicle traveling at hypersonic speed is also a uniquely difficult challenge. The ability to communicate becomes much more feasible when the temperatures are kept below the point of ionization. Still, the incredibly delicate electronic systems that enable communication need to be kept far below the vehicle's surface temperature. The CBO also

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[26] Kramer, C. (2023, January 31). *U.S. Hypersonic Weapons and Alternatives* | Congressional Budget Office. www.cbo.gov.

discusses that "the missile needs to have windows (called radomes) through which signals can be emitted or received. The materials for such radomes are inherently difficult to develop because they must allow radio frequency or infrared radiation to pass through them while also providing significant thermal shielding."

The final technological challenge facing hypersonic weapons is the development of the scramjet. The US has experience with ramjet engines (namely the P&W J58 engines on the SR-71), but the scramjet is much more challenging technology. Sustained flight with a scramjet engine requires "designing engine components that can maintain proper air–fuel mixing at the right temperature, air pressure, and density for a supersonic combustion ramjet to operate for the duration of a missile's flight."[27] The US had only achieved sustained flight with a scramjet for a few minutes prior to 2022, but there has been a recent test that demonstrated sustained burn of a scramjet for as long as 300 seconds.[28] BGVs can operate without the use of a scramjet engine, but they don't provide a sufficient upgrade over other methods already available to the US, so the development of the scramjet is vital so that the superior HCM can achieve its full potential.

Challenges in Diplomatic and Political Environment

Hypersonics have the potential to provide a diplomatic alternative to nuclear deterrence because of their ability to pierce adversarial defensive lines and deliver strikes with accuracy. However, there are challenges with the political environment that could prevent this from becoming a reality. The last technology that demonstrated potential to challenge the world's reliance on nuclear deterrence was stealth. Unfortunately, this did not happen as the B-2 became "a delivery vehicle for nuclear weapons," which "*demonstrates the sheer inertia–military, political, and intellectual–that nuclear strategy had acquired*. The concept of technological

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[27] ibid.
[28] Trimble, S. (2023, May 2). *U.S. Hypersonic Testing Shows Mixed Results In Pivotal Year* | Aviation Week Network. Aviationweek.com.

momentum is referenced here and is explained by Hughes as "the large mass of a technological system arises especially from the organizations and people committed by various interests to the system… politicians often have vested interests in the growth and durability of a system."[29] Stealth was unable to overcome the momentum of nuclear technology. The US "spent trillions of dollars," invested tons of resources, and necessary infrastructure for "its nuclear capability and would not abandon it easily."[30] The difference between stealth platforms and hypersonic weapons is that stealth served as an alternative infrastructure altogether, but hypersonic weapons are able to be integrated into the preexisting infrastructure that was developed for the delivery of nuclear weapons. This is true because the infrastructure for the delivery of nuclear weapons is also a method for delivering hypersonics. Hypersonics has the potential to shift the direction of the momentum, but stealth was forced to meet the momentum head on, which resulted in its assimilation into the nuclear mass. Stealth saw "*explicit resistance from the military services*, along with political opposition. Critics *saw little difference between the new conventional technologies and nuclear weapons and feared a new, nonnuclear arms race that would undermine deterrence* [and] make war more likely"[31] Nuclear deterrence has not proven to be truly effective at deterring conflict. Westwick details this when he says "neither side believed the other would commit civilizational suicide to defend a swath of territory. A case in point: nuclear weapons had evidently failed to deter the Soviets from invading Afghanistan. The US was relying on 'empty threats.' US and NATO's plan to rely on nuclear weapons to stop a Soviet invasion of Western Europe meant laying waste to NATO territory with its own nuclear weapons, not exactly an optimal strategy."[32] Russia's war with Ukraine is another example of nuclear

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[29] Thomas Parke Hughes. (1986). *The Evolution of Large Technological Systems* (pp. 76–77).
[30] Westwick, P. J. (2020). *Stealth : The Secret Contest to Invent Invisible Aircraft*. Oxford University Press. pg 122
[31] ibid. pg 121
[32] ibid. pg 119

weapons not deterring the United States' adversaries from waging war with other countries. The scale of a nuclear strike is simply too large to be effective in diplomatic affairs while hypersonic weapons could be utilized to destroy vital infrastructure to an adversary's war effort, which would not warrant a nuclear response, but would serve as substantial, legitimate deterrence against further encroachments on the interests of the United States and its allies.

Cost Analysis:

The final step to evaluate hypersonics is to explore a cost analysis of the technology and compare it with past technological ventures in the US. It is important to compare hypersonics to the nuclear arsenal and alternatives such as MaRVs. Stealth will also be further compared to hypersonic weapons.

Nuclear Weapons

The total cost of nuclear programs amounted to at least $5.5 trillion between 1940-1996. "The lack of data for some programs and the difficulty of segregating costs for programs that had both nuclear and conventional roles mean that the actual figure is higher. This figure does not include $320 billion in estimated future-year costs for" dealing with waste and dismantling systems. "When those amounts are factored in, the total incurred costs of the U.S. nuclear weapons program exceed $5.8 trillion."[33] The Congressional Budget Office also estimates a further $756 billion for further development and maintenance of the nuclear arsenal between 2023-2032.

[33] Schwartz, S. (2011). *Cost of U.S. Nuclear Weapons | How Much Does a Nuclear Bomb Cost?* | NTI. Nti.org.

Billions of Dollars

	2023			Total, 2023–2032		
	DoD	DOE	Total	DoD	DOE	Total
CBO's Projections of Budgeted Amounts for Nuclear Forces[a]						
Nuclear delivery systems and weapons						
Strategic nuclear delivery systems and weapons						
Ballistic missile submarines	11.4	1.2	12.7	172	16	188
Intercontinental ballistic missiles	6.4	0.9	7.3	103	16	118
Bombers	4.2	1.7	5.8	52	11	63
Other DoD nuclear activities[b]	1.6	n.a.	1.6	19	n.a.	19
Subtotal	23.6	3.8	27.5	346	43	389
Tactical nuclear delivery systems and weapons	0.6	0.4	1.0	5	2	6
Nuclear weapons laboratories and supporting activities						
Stockpile services	n.a.	1.1	1.1	n.a.	12	12
Facilities and infrastructure	n.a.	7.3	7.3	n.a.	79	79
Other stewardship and support activities[c]	n.a.	5.1	5.1	n.a.	57	57
Subtotal	n.a.	13.4	13.4	n.a.	148	148
Subtotal, Nuclear Delivery Systems and Weapons	24.2	17.7	41.9	351	192	543
Command, control, communications, and early-warning systems						
Command and control	1.5	n.a.	1.5	24	n.a.	24
Communications	2.7	n.a.	2.7	34	n.a.	34
Early-warning	6.3	n.a.	6.3	58	n.a.	58
Subtotal, Command, Control, Communications, and Early-Warning Systems	10.5	n.a.	10.5	117	n.a.	117
Total Budgeted Amounts for Nuclear Forces	**34.7**	**17.7**	**52.4**	**468**	**192**	**660**
CBO's Estimates of Additional Costs Based on Historical Cost Growth	n.a.	n.a.	n.a.	56	40	96
Total Estimated Cost of Nuclear Forces	**34.7**	**17.7**	**52.4**	**524**	**232**	**756**

Figure 6. Projected Costs of Nuclear Forces, by Department and Function, 2023 to 2032[34]

Maneuverable Reentry Vehicles (MaRVs)

MaRVs provide a cheaper alternative to BGVs with very comparable strike capabilities. "MaRVs have the significant advantage that they rely largely on existing technology, and therefore present fewer technical challenges and may therefore have higher reliability and lower cost than BGVs and HCMs."[35] Option 1 in Figure 7 is the hypersonic boost glide weapon and Option 2 is the MaRV weapon. The cost for one hypersonic boost-glide missile is $41 million and the cost for one MaRV missile is $26 million. As previously discussed, option 1 does offer a higher rate of survivability than option 2, so the costs of the ballistic missiles used to deliver

[34] Bennett, M. (2023, April 6). *Projected Costs of U.S. Nuclear Forces, 2023 to 2032* | Congressional Budget Office. www.cbo.gov.
[35] Wright, D., & Tracy, C. L. (2023). *Hypersonic Weapons: Vulnerability to Missile Defenses and Comparison to MaRVs*. Science & Global Security, 31(3), 68–114.

MaRVs would increase in order to implement additional counter measures should adversarial defenses prove to be effective at neutralizing the MaRVs during the intermediate stage of flight.

	Number of Missiles Purchased	Average Procurement Cost per Missile (Millions of 2023 dollars)[a]	Costs of Option (Billions of 2023 dollars)			
			Missile Procurement[a]	Platform Integration	20 Years of Sustainment	Total[b]
	Intermediate-Range Missiles (Range 3,000–5,500 km)					
Option 1: Ground- or Sea-Launched Hypersonic Boost-Glide Missiles (Similar to LRHW/IR-CPS)	300	41	12.2	2.7[c]	3.0	17.9
Option 2: Ground- or Sea-Launched Ballistic Missiles Equipped With MaRVs	300	26	7.7	2.7	3.0	13.4

Figure 7. Costs of the Missile Options That CBO Analyzed[36]

Stealth Technology

The biggest failure of stealth is the immense cost of the vehicles and their maintenance. The F-22 program amounted to a cost exceeding $67 billion, which would mean that each plane cost $350 million.[37] The F-35 program is estimated to amount to over $1.7 trillion.[38] The Defense Department had to scale the B-2 program back from 132 to 20 aircraft. This did not change the program cost of $45 billion. That's $2 billion per aircraft. This left people wondering "what targets are worth risking $2 billion to hit?" Stealth platforms are also an increasingly expensive challenge to maintain as it was found that flying the airplanes "damaged the radar-absorbing material and undermined the plane's stealthiness. That meant that B-2s in service needed climate-controlled aircraft shelters and long and costly maintenance after each flight. As a result, only one-fourth of the deployed B-2s were actually mission-capable on average."[39] The B-2 is

[36] Kramer, C. (2023, January 31). *U.S. Hypersonic Weapons and Alternatives* | Congressional Budget Office. www.cbo.gov.
[37] Suciu, P. (2023, December 22). *Why the F-22 Raptor Stealth Fighter Is So Expensive*. The National Interest.
[38] Office, U. S. G. A. (2023, December 12). *F-35 Joint Strike Fighter: More Actions Needed to Explain Cost Growth and Support Engine Modernization Decision* | U.S. GAO. www.gao.gov.
[39] Westwick, P. J. (2020). *Stealth : The Secret Contest to Invent Invisible Aircraft*. Oxford University Press. (pg 183)

the most relevant stealth aircraft for this discussion as it is intended for long-range strikes deep behind enemy lines.

Cost Analysis Conclusions

The estimated cost for hypersonic boost-glide weapons is $17.9 billion for 300 units, but the estimated cost for HCMs is not available. As of March 12, 2024, the US has invested around $10 billion on hypersonic research and weapons. Billions of dollars is an incredibly large sum of money, but when compared to the trillions that have been invested into nuclear weapons and the trillions that have been invested into cost-inefficient stealth platforms, hypersonic weapons are relatively cheap.[40]

Nuclear ICBMs are the cheapest per strike of the discussed options, but using them is not an option, so that's irrelevant. The development of stealth has provided technologies that are very effective at their intended applications, but the cost of stealth platforms and their maintenance is several worlds beyond the costs of alternatives such as BGVs and MaRVs. The costs of these alternatives are comparable when compared to stealth, but one MaRV costs $15 million less than one BGV.

Conclusion:

The entirety of the Cold War period saw an emphasis on deterrence between the two largest global powers following the end of World War II. This emphasis can be summarized as the balancing act of technological capabilities between the US and the Soviet Union. This balancing act is a recent example of the repeated historical theme of a balance of power. In this specific case, the balance played its part as a method of deterrence effectively as there were no direct conflicts between the US and the Soviet Union. Even at the most intense instances where

[40] Diaz-Maurin, F. (2024, March 12). *Hypersonic weapons are mediocre. It's time to stop wasting money on them*. Bulletin of the Atomic Scientists.

wars were waged in third-party theaters, neither the US nor the Soviet Union were able to completely commit themselves to the conflicts because the opposition shared their technological capabilities. However, nuclear deterrence failed with the Soviet invasion of Afghanistan and the Russian invasion of Ukraine, so total reliance on it as a diplomatic tool should be reconsidered. This historical timeline now leads us to the current technological competition–the development of hypersonic weapons. It can be concluded, following several steps of evaluation to determine the investment worthiness of hypersonics, that this technology provides unique enough capabilities both strategically and diplomatically to be worth it for the US to commit its resources to the development of hypersonic weapons. The MaRV is incredibly similar to the hypersonic boost-glide vehicle and should be considered a viable alternative, but since the MaRV arsenal was destroyed following the INF treaty, a commitment to the development of the hypersonic boost-glide vehicle should be made to take advantage of its increased survivability. The hypersonic cruise missile with the integration of scramjets is far superior to the hypersonic boost-glide vehicle and is the real game changer that should be pursued with conviction. The hypersonic cruise missile's abilities to achieve the highest speeds, maintain its energy during flight, and provide a long-range hypersonic option are difference makers for military strategy and diplomatic deterrence. For a technology to be a diplomatic alternative to nuclear weapons in the game of deterrence, the technology needs to be capable of accessing adversarial territory and deliver a precise and accurate strike. Both hypersonics and stealth are capable of precision and accuracy. Stealth platforms are able to access adversarial territory by avoiding detection by the adversary's defensive systems. Hypersonic weapons are able to access adversarial territory because they make current defensive systems obsolete since current defensive systems are incapable of reliably tracking and intercepting an object traveling at hypersonic speeds with an unpredictable trajectory, which allows the weapons to access targets deep behind the front lines. Both technologies have the required capabilities to be diplomatic alternatives, but hypersonic weapons are the far cheaper alternative, which could be the difference that allows hypersonics to achieve what stealth could not. An immediate diplomatic switch from nuclear weapons should not be expected, but a gradual conversion to a world where deterrence does not involve the apocalyptic end of society is a feasible possibility if the hypersonic cruise missile is provided the necessary resources and developed to its full potential.

Acronym Glossary

ABM - Anti-Ballistic Missile

ARRW - Air-Launched Rapid Response Weapon

BGV - Boost-Glide Vehicle

CBO - Congressional Budget Office

DARPA - Defense Advanced Research Projects Agency

HCM - Hypersonic Cruise Missile

ICBM - Intercontinental Ballistic Missile

INF - Intermediate-Range Nuclear Forces Treaty

IRBM - Intermediate Range Ballistic Missile

MAD - Mutually Assured Destruction

MaRV - Maneuverable Reentry Vehicles

NATO - North Atlantic Treaty Organization

P&W - Pratt and Whitney

TBG - Tactical Boost Glide

USD(R&E) - Under Secretary of Defense for Research and Engineering

USSTRATCOM - United States Strategic Command

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