

# Hypersonic Weapons and Strategic Competition: From Science Project to Operational Reality

The United States stands at a critical inflection point in military technology and strategic competition. After decades of delays, shifting priorities, and bureaucratic obstacles, American hypersonic weapons programs are finally approaching operational deployment.

Yet the question remains whether the United States can transition these capabilities from laboratory curiosities to operational realities fast enough to maintain strategic deterrence in an increasingly contested world.

The journey of hypersonic weapons development in the United States has been neither swift nor straight. What began as a promising technological frontier during the Bush administration evolved into a critical national security imperative, shaped by shifting strategic priorities, bureaucratic challenges, and the relentless advance of peer competitors.

Today, as American hypersonic systems finally approach deployment, the fundamental question is no longer whether the United States can develop these game-changing weapons, but whether it can deploy them fast enough to maintain strategic deterrence in an increasingly contested Pacific theater.

This transformation represents more than technological advancement. It requires a fundamental evolution in how military forces are commanded, controlled, and employed in strategic competition. The compressed timelines that hypersonic weapons create force a reconsideration of traditional command relationships and decision-making processes. Military institutions must adapt to operating environments where critical decisions must be made at machine speed while maintaining strategic coherence and appropriate political oversight.

The strategic logic for hypersonic deployment has become increasingly clear, particularly in the Indo-Pacific region. China's primary military advantage lies in its ability to rapidly mass forces before the United States can effectively position its assets across vast Pacific distances. Hypersonic weapons deployed throughout the region would fundamentally complicate Chinese operational planning by threatening swift, precise strikes against advancing naval forces, providing crucial time for American and allied forces to achieve defensive positioning.

As Admiral Paparo, the current Indo-Pacific Command chief, has emphasized, "The coin of the realm in the 21st century is speed. Who does things faster wins." This insight captures the essence of why hypersonic weapons have evolved from interesting research topics to urgent operational requirements. The ability to strike targets thousands of miles away in minutes rather than hours fundamentally alters the strategic calculus of both deterrence and warfare.

## The Winding Road from Promise to Deployment

### **The Bush Era Vision and Its Derailment**

The story of American hypersonic weapons begins during a period of technological optimism and strategic foresight. Between 2004 and 2008, when Dr. Mark J. Lewis served as Chief Scientist of the U.S. Air Force alongside Secretary Michael Wynne and General "Buzz" Moseley, there was a comprehensive vision for transforming airpower. This vision extended far beyond conventional warfare, encompassing a revolution built around emerging platforms like the F-22 Raptor and the anticipated global F-35 enterprise.

Dr. Lewis, already recognized for his expertise in hypersonics, understood the transformative potential of weapons that could travel at speeds exceeding Mach 5 while maintaining unpredictable flight paths. The leadership team pushed aggressively for capabilities that would ensure American dominance in high-end warfare scenarios. Their approach was comprehensive, integrating advanced propulsion systems, long-range strike capabilities, and hypersonic vehicles into a coherent vision of future air and space power.

However, the decision to commit American forces to the wars in Iraq and Afghanistan fundamentally altered defense priorities. This strategic pivot had profound consequences for emerging technologies like hypersonics, which suddenly found themselves competing with urgent operational needs rather than receiving priority development funding. The watershed moment came in 2008 with the dismissal of Secretary Wynne and the broader reshuffling of Air Force leadership.

As the late Australian military strategist Jim Molan observed, "The U.S. is surfacing from decades of war in the Middle East with worn-out equipment, understandably having allocated a lot of its funding to 'today's wars' rather than investing in the future." The production of the F-22 Raptor was capped at just 187 aircraft, well below the numbers originally envisioned for maintaining air superiority against peer competitors. Most critically for hypersonic development, research programs that had been gaining momentum suddenly faced funding cuts and organizational disruption.

This period established a pattern that would persist for over a decade: American hypersonic development would consistently be subordinated to more immediate strategic priorities, allowing competitors to gain crucial advantages in both technology development and operational deployment.

### **The Obama Years: Strategic Pivot Meets Practical Constraints**

President Obama's election in 2008 brought renewed strategic thinking about America's global posture, culminating in the announced "Pivot to Asia" beginning in 2011. This strategic reorientation explicitly recognized China's rising power and the growing importance of East Asia to American interests. On paper, the pivot represented exactly the kind of strategic thinking that should have prioritized advanced weapons systems like hypersonics, which are particularly valuable in the vast distances and contested environments of the Pacific theater.

In practice, however, the Obama administration prioritized military commitments that consumed both attention and resources. Despite rhetorical emphasis on the Pacific rebalance, the main U.S. military effort remained focused on Afghanistan and the broader Middle East. This tension between stated priorities and operational realities had direct consequences for hypersonic development. While some research continued in national laboratories and defense contractors, there was neither significant funding increases nor urgent organizational pressure to accelerate development.

The administration's approach to advanced military systems reflected broader philosophical differences about the nature of future conflict. Obama and Defense Secretary Gates made the controversial decision to terminate F-22 production after 187 aircraft, arguing that the United States already possessed sufficient air-superiority fighters for existing and projected needs. Their logic emphasized platforms and capabilities needed for irregular warfare and counterinsurgency operations rather than what they characterized as "exquisite" systems designed for hypothetical peer conflicts.

The 2011 disbanding of the Navy's 2nd Fleet, responsible for North Atlantic operations during the Cold War, exemplified this perspective. The decision reflected post-Cold War assumptions about the likelihood of high-end naval conflict and prioritized budgetary efficiency over maintaining capability against potential threats.

These choices, viewed in retrospect, represented missed opportunities for hypersonic development. While China and Russia were beginning to invest seriously in hypersonic technologies during this period, the United States remained focused on perfecting counterinsurgency capabilities and managing fiscal constraints. The result was not merely

delayed development, but a fundamental loss of momentum that would take years to recover.

### **Trump I: Acceleration: Recognition and Response**

The 2016 election of Donald Trump marked a dramatic shift in American approach to hypersonic weapons development. The new administration's focus on great power competition and military modernization created an environment where hypersonic systems finally received the priority attention they had long deserved. This transformation was driven not by abstract strategic planning, but by the uncomfortable recognition that Russia and China had gained significant advantages in hypersonic development while the United States remained largely focused elsewhere.

Strategic competition became the organizing principle of Trump administration defense policy, with hypersonic weapons identified as a critical capability gap. Russian tests of systems like the Kinzhal and Avangard, combined with Chinese demonstrations of hypersonic glide vehicles, made clear that the United States faced a genuine technological challenge from peer competitors. Pentagon leadership, responding to this competitive pressure, designated hypersonics as one of the top modernization priorities, explicitly stating the goal to "dominate future battlefields."

The administration backed this strategic shift with substantial resources. The 2020 defense budget included a dramatic increase in hypersonic research and development funding, with Pentagon requests reaching \$2.6-\$3.2 billion which was a 23% increase over the previous year. This represented not merely incremental improvement, but a fundamental commitment to accelerating the transition from research to operational capability.

All service branches responded to this new priority by ramping up hypersonic efforts. The Army and Navy collaborated on developing a common hypersonic glide body, with the Army targeting its first Long-Range Hypersonic Weapon (LRHW) batteries for fielding by fiscal year 2023. The Air Force pursued the air-launched AGM-183A Air-Launched Rapid Response Weapon (ARRW), with initial flight tests scheduled for 2020. These programs represented concrete steps toward operational capability rather than indefinite research efforts.

President Trump personally championed hypersonic development, frequently referencing what he called a "super-duper missile" and tying American progress directly to national security and technological superiority. This high-level attention ensured that hypersonic programs received not only funding but also the organizational focus necessary to overcome bureaucratic obstacles and accelerate development timelines.

The administration also recognized the industrial base requirements for hypersonic production. Significant investments in test facilities and production infrastructure were designed to enable rapid fielding once development programs matured. This comprehensive approach addressed not only the technological challenges of hypersonic development but also the practical requirements for manufacturing and deploying these complex systems at scale.

By the end of Trump's first term, the trajectory toward operational hypersonic weapons appeared clear. Army officers confirmed plans to deploy the LRHW system by fiscal year 2023, with Navy submarine-launched variants following by 2025. While Air Force programs faced some delays, the overall expectation was that the United States would transition from testing and prototyping to fielding operational systems within the early 2020s.

### **Biden Administration: Funding Meets Bureaucratic Reality**

The Biden administration inherited hypersonic programs that were finally receiving appropriate attention and resources but struggled to translate increased funding into operational capability. Despite continued strong budgetary support for hypersonic development, the new administration encountered the full weight of institutional obstacles that had been building for decades.

Perhaps the most significant challenge was the fragmented nature of American hypersonic development. Unlike their Chinese and Russian counterparts, who could pursue more centralized approaches, U.S. programs remained divided among the Army, Navy, and Air Force, each with distinct technical standards, operational concepts, and procurement authorities. This fragmentation led to duplicative efforts, slower knowledge sharing between services, and competition for limited specialized resources.

The complexity extended beyond inter-service coordination to encompass the broader defense ecosystem. Successful hypersonic development requires seamless collaboration between the Department of Defense, national laboratories, intelligence agencies, and a vast defense industrial base. This coordination challenge is compounded by overlapping security protocols, bureaucratic mandates, and institutional inertia that had accumulated over decades of peacetime operations.

Testing infrastructure emerged as a particularly acute constraint. Hypersonic vehicles operate in extreme environments, requiring specialized wind tunnels and test ranges that simply did not exist in sufficient numbers to support accelerated development schedules. Much of the existing testing infrastructure dated to the Cold War and was inadequate for the sophisticated systems being developed in the 2020s. Even with increased investment

in testing capabilities, limited facility availability created bottlenecks and delays that forced programs to compete for access to critical validation trials.

Supply chain constraints further complicated development efforts. Only a handful of domestic suppliers possessed the capability to provide the advanced materials required for hypersonic vehicles, creating vulnerabilities and delays when demand exceeded capacity. Unlike conventional weapons systems, hypersonics require materials and components that operate reliably under extreme temperature and stress conditions, limiting the available supplier base. The pandemic was a major blow to any supply chain, let alone the sophisticated one required for hypersonic missile development.

The American defense acquisition culture also proved to be a significant obstacle. Where Chinese and Russian systems could potentially be fielded with less rigorous testing and validation, the U.S. system emphasized "getting it right" over "getting it first." This risk-averse approach, while ensuring high-quality systems, resulted in extensive review processes and re-baselining efforts whenever test programs encountered setbacks.

Congressional budget processes added another layer of complexity. While overall funding remained strong, appropriations were often tied to specific technical milestones. When programs experienced delays or test failures, as inevitably occurred in cutting-edge development efforts, funding could be delayed or redirected, interrupting program momentum and forcing schedule adjustments.

Despite these challenges, the Biden administration maintained commitment to hypersonic development and continued the high funding levels established during the Trump years. However, the gap between increased spending and operational deployment highlighted the depth of institutional obstacles that decades of neglect had created in American defense development processes.

## From Science Project to Operational Capability

As of 2025, American hypersonic development has reached a critical juncture. After years of bureaucratic delays and technical challenges, two Air Force hypersonic systems are approaching operational readiness, potentially transforming deterrence strategy in the Pacific theater where competition with China continues to intensify.

The strategic logic for hypersonic deployment has become increasingly clear. China's primary military advantage lies in its ability to rapidly mass forces before the United States can effectively position its assets across the vast Pacific distances. Hypersonic weapons deployed throughout the region would fundamentally complicate Chinese operational

planning by threatening rapid strikes against advancing naval forces, buying crucial time for American and allied forces to achieve optimal positioning.

As Dr. Mark Lewis explains, the fundamental appeal is straightforward: "If I can take a weapon that does everything that a Tomahawk does, same range, same package, but instead of flying at Mach 0.7 it flies at Mach 7, why wouldn't I want that?" This speed advantage translates directly into reduced warning time for adversaries and increased survivability against defensive systems.

The Air Force has developed two mature hypersonic weapons that are nearing deployment readiness. The Air-Launched Rapid Response Weapon (ARRW), developed by Lockheed Martin, represents a boost-glide system that has exceeded test expectations and can be mounted on B-52 bombers, with each aircraft capable of carrying four missiles. This system provides immediate capability for long-range precision strikes at hypersonic speeds.

The Hypersonic Attack Cruise Missile (HACM), developed through collaboration between Raytheon and Northrop Grumman, offers even greater versatility through its air-breathing scramjet engine. This system's design allows for exceptional platform integration, with a B-2 bomber potentially carrying 15 hypersonic cruise missiles and B-52 aircraft capable of carrying even more. The scramjet propulsion system provides sustained hypersonic flight rather than the ballistic trajectory of boost-glide systems.

Recent Air Force commitments to ARRW deployment signal recognition that hypersonic capabilities cannot remain perpetually in development while adversaries' field operational systems. The current Chinese advantage stems significantly from perception—their systems represent deployed threats that influence American operational planning, regardless of their actual effectiveness in combat scenarios.

## Moving Beyond the Science Project Mentality

The fundamental challenge hypersonic weapons pose to traditional military thinking lies in their compression of decision timelines. Where traditional cruise missiles might provide hours of warning and deliberation time, hypersonic weapons compress engagement windows to under a relatively few minutes from detection to impact. This temporal compression creates decision superiority requirements or the need to observe, orient, decide, and act faster than any adversary.

This acceleration fundamentally challenges traditional military command structures built around hierarchical decision-making and careful deliberation. The Pacific theater's vast distances, which already strain communication links and command relationships, become

even more problematic when commanders must make critical decisions in compressed timeframes while managing distributed forces across multiple time zones.

The solution lies in what might be called "parallel production" or simultaneously developing prototypes while manufacturing long-lead components for early operational deployment. This approach mirrors the successful 2001-2002 Ground-Based Midcourse Defense program, where the Bush administration prioritized getting five interceptors in silos by 2005 rather than waiting for the perfect system a decade later.

The methodology is straightforward: identify stable design elements, procure long-lead hardware, and complete integration as demonstration missions validate performance. This capabilities-based deployment approach recognizes that the best capability deployed by 2028 is infinitely more valuable than the perfect capability available in 2035, particularly when facing adversaries who don't wait for perfection.

Current funding profiles support steady development but not rapid deployment. The difference between a 2032 initial operating capability and a 2027 early operational prototype often comes down to resource allocation rather than technological barriers. This represents a strategic choice about whether America will field capabilities or continue studying them.

Hypersonic weapons aren't a monolithic capability but represent a mosaic of complementary systems, each with distinct operational advantages. Air-breathing systems operating at Mach 4-6 provide atmospheric flight profiles with unique targeting opportunities. Hypersonic glide bodies achieve Mach 10+ speeds while "skipping" along the atmosphere, creating complex defensive challenges. Maneuverable reentry vehicles combine ballistic efficiency with terminal maneuvering, offering rapid time-on-target effects.

This diversity isn't an acquisition burden. It's a strategic advantage. Different flight regimes provide warfighters with expanded decision space, allowing effects-based targeting that can overwhelm defensive systems through varied approach vectors and timing. The goal isn't to choose one system but to field a complementary suite that provides flexible response options across the spectrum of potential conflicts.

## The Targeting Enterprise: Ready Infrastructure

There tends to be a notion that a viable space network is necessary to use hypersonic missiles accurately and that this is in the process of development. What this overlooks is the extant targeting enterprise which already can guide the use of hypersonic missiles.

The MQ-4C Triton UAV and F-35 Lightning II aircraft present exceptional potential for integrated hypersonic missile defense and strike operations across the Indo-Pacific theater. Through persistent surveillance, advanced sensor fusion, and networked kill chains, these platforms can compress engagement timelines against hypersonic threats while enabling next-generation strike capabilities. This integration capability exists today and is being operationally validated, offering INDOPACOM forces a critical advantage in an increasingly contested hypersonic threat environment.

The MQ-4C Triton's AN/ZPY-3 Multi-Function Active Sensor radar provides 360-degree coverage while surveying 2.7 million square miles in 24 hours from altitudes exceeding 50,000 feet. This X-band AESA system offers critical advantages for hypersonic detection by operating above traditional radar horizon limitations that constrain ground-based sensors. The platform's 30+ hour endurance enables persistent monitoring of key launch corridors and approach routes across the Pacific.

Triton's multi-intelligence sensor suite extends beyond radar to include electro-optical/infrared systems, electronic support measures, and the new IFC-4 configuration adding enhanced SIGINT/ELINT capabilities. These sensors automatically correlate targets through onboard processing, providing both wide-area surveillance and precise target identification critical for hypersonic threat characterization.

The F-35's sensor fusion architecture complements Triton's persistent surveillance through its proven ballistic missile detection capability at ranges exceeding 800 miles. The Distributed Aperture System (DAS) provides 360-degree infrared coverage and has demonstrated missile launch detection and ground track extrapolation, capabilities directly applicable to hypersonic threats. When combined with the AN/APG-81 AESA radar's ultra-high-resolution modes, F-35s can provide engagement-quality tracking data for fast-moving, maneuvering targets.

Both platforms integrate seamlessly into JADC2 architecture through proven datalinks and demonstrated operational concepts. F-35s have successfully provided targeting data to Patriot batteries, Aegis systems, and other platforms during recent exercises, while Triton demonstrated persistent targeting capabilities during Northern Edge 2023. This sensor-to-shooter integration enables distributed engagements where Triton detects and F-35s engage, or vice versa.

## Command and Control Challenges

The command-and-control challenges posed by hypersonic weapons drive requirements for enhanced communication architectures capable of supporting distributed operations

under contested conditions. The integration of stealth platforms like the F-35 with persistent surveillance systems like Triton requires communication systems that can maintain connectivity while preserving operational security.

Machine-to-machine data transfer becomes essential because hypersonic engagement timelines leave little margin for communication latency or human decision delays. Automated sensor cueing where Triton's high-altitude surveillance extends detection ranges beyond traditional radar horizons while F-35's stealth enables closer engagement positioning represents a technical solution. But it also represents a fundamental shift toward pre-programmed responses rather than human-in-the-loop decision-making.

The speed requirements imposed by hypersonic weapons also accelerate the integration of artificial intelligence into command-and-control systems. Human decision-making speeds, even when enhanced by modern communication systems, may prove inadequate for the timelines that hypersonic engagement requires.

AI-enabled systems can process sensor data, identify threats, and coordinate responses at speeds that exceed human capability. But they also raise fundamental questions about human control over critical military decisions. How do military commanders maintain meaningful oversight over systems that must make targeting decisions at machine speed? How do democratic societies ensure appropriate political control over military systems that operate too quickly for traditional oversight mechanisms?

The integration of AI into hypersonic command and control systems represents both a technical necessity and a political challenge. While these systems may be essential for effective operations in compressed timelines, they also require new frameworks for ensuring appropriate human oversight and political control over potentially escalatory military actions.

## The Indo-Pacific Strategic Context

Ever since the Trump administration focused on what they termed the return of "Great Power" competition, the U.S. military has been working through ways to distribute forces in the Pacific, embedded with allies, but integratable to deliver the desired deterrent and combat effects. Under the current U.S. Indo-PACOM chief, Admiral Paparo, there has been accelerated focus on this approach.

The United States faces a tyranny of distance in dealing with the Pacific. As one Admiral put it: "In effect, the Indo-Pacific sea space is the equivalent of three Atlantic Oceans." Projecting from the United States, American forces need to generate force from the United States and then from a strategic triangle going from Hawaii to Guam and to Japan. From

there, forces must project into a strategic quadrangle which reaches from Japan to South Korea, to Singapore and to Australia.

Since 2013, the United States has worked to deepen relationships with the Philippines and Australia in terms of shaping additional paths from which to project force, and the Australian Defence Force is itself engaged in ways to extend its reach into the Pacific. The key necessity is to enhance the sensor and interactive reach of a distributed force, and over the past decade, the U.S. military has been engaged in a significant force distribution effort.

The U.S. Navy has pursued distributed maritime operations, the USAF has pursued agile combat employment, and the USMC is pursuing various force distribution efforts, notably Distributed Aviation Operations and Expeditionary Advanced Base Operations. By using aircraft, and air and maritime systems, American and allied forces will be able to distribute military power without needing traditional air basing or over-reliance on capital ships to affect the battlespace.

Such a distribution of military force packages or "combat clusters" has been done to enhance the survivability of forces against an adversary's forces, but such dispersion comes at a cost in terms of the investment that needs to be made in how to sustain and reinforce such a force with the weapons and fuel it needs to empower such a force.

A key advantage of such a force is that over the vast distances of the Pacific, by working more effective relationships with allies, a distributed American force can build a lego-block-like blanket force over the extended battlespace. It can allow a distributed force to have more effective presence and engagement with allies, which makes it much more difficult for the Chinese and the Russians to be certain of their ability to destroy enough American capability to ensure their own mission success.

### **Admiral Paparo's Strategic Vision**

Admiral Paparo clearly sees the network of allies and partners as enabling the distributed force posture necessary to deter China, while the visible presence of distributed U.S. forces reciprocally strengthens those alliances by demonstrating U.S. commitment to regional security. While force distributed interconnected with enhanced allied defense capabilities is foundational, such an approach only enhances the need for speed in terms of having longer range conventional capabilities that can reach out and touch the adversary's initial projection force and affect their decision cycle.

Admiral Paparo has emphasized the strategic importance of hypersonic weapons, stating he "favors speeding up the fielding of U.S. hypersonic missiles" for both the Army and Navy. He explained that these systems are needed to "close in time any actor's kill chain," warning that "If your adversary can strike you five times faster than you can strike your

enemy, it incentivizes first strikes." He emphasized that "The coin of the realm in the 21st century is speed. Who does things faster wins."

He specifically mentioned that "fielding U.S. hypersonic missiles is critical to countering the asymmetry of Chinese hypersonic missiles." Combining an ability to "fight at the speed of light" with a distributed force embedded in a grid of partner and allied defense efforts will significantly enhance the capabilities of the "fight tonight force" in the Indo-Pacific.

In his testimony, Admiral Paparo highlighted several ways by which the "fight tonight distributed force" can be realistically enhanced:

- **Enhanced C5ISR systems:** He emphasizes the need for superior information systems with AI and machine learning capabilities that can function in contested environments, reducing planning time from days to hours and providing comprehensive battlespace awareness.
- **Advanced autonomous systems:** The Admiral highlights AI-enabled autonomous systems (uncrewed surface vehicles, autonomous aerial systems, undersea vehicles) as providing "significant and affordable asymmetric advantage" against numerically superior opponents with legacy technology.
- **Distributed posture initiatives:** He advocates for expanding the number of operating locations across the region to complicate adversary planning, including using the Joint Posture Management Office to streamline construction projects in places like the Philippines, Papua New Guinea, Palau, and Micronesia.
- **Robust logistics networks:** The Admiral emphasizes developing Joint Theater Distribution Centers as critical logistics nodes, increasing assured fuel access points (18 added in the past year), and hardening existing facilities against missile and cyber attacks.
- **Strengthened alliances:** The Admiral repeatedly emphasizes that America's network of allies and partners is "a tremendous asymmetric advantage" that no competitor can match, focusing on multilateral activities like joint exercises (120 in total) to improve interoperability.

## Alliance Integration and Hypersonic Deployment

The hypersonic program's international dimension offers additional strategic advantages. Cooperation with Australia through the AUKUS and Strategic Capabilities International Framework (SCIF) programs has demonstrated allied interest in these capabilities. Australian F/A-18s could potentially carry hypersonic weapons, while future integration with F-35s would enable broader coalition participation.

In addition, Northrop Grumman is collaborating with the Japanese Ministry of Defense on the development and future deployment of advanced hypersonic defense technology. The cornerstone of this partnership is the co-development of the Glide Phase Interceptor (GPI), a missile defense system designed to detect, track, and intercept hypersonic missiles during the glide phase of their flight, before they reenter the atmosphere or strike targets.

This coalition approach serves multiple purposes. It provides additional deployment platforms and signals unified allied commitment to Pacific security. More importantly, it complicates Chinese planning by creating multiple launch points throughout the region. The window for effective deterrence may be narrowing. Chinese military modernization continues at pace, while American advantage in key technologies risks erosion through inaction. The tools for maintaining Pacific stability exist today, ready for deployment. The question is whether institutional momentum can overcome bureaucratic inertia to deliver these capabilities when they matter most.

Extended deterrence calculations become more complex when allies host weapons systems capable of rapidly striking adversary strategic assets. The traditional firebreaks between conventional and nuclear conflict may erode when conventional weapons achieve nuclear-like effects in terms of speed, precision, and strategic impact.

When Australian F/A-18s potentially carry hypersonic weapons, or when Japanese facilities support hypersonic operations, these allies become potential targets for nuclear retaliation in ways that conventional weapons might not trigger. The speed and strategic reach of hypersonic weapons mean that allied territories hosting these capabilities might face nuclear threats even in conflicts where they are not primary combatants.

## Technology and Operational Transformation

As hypersonic weapons rapidly transition from experimental concepts to operational reality, Command, Control, Communications, Computers, Cyber, Intelligence, Surveillance, and Reconnaissance (C5ISR) systems face unprecedented challenges that threaten to obsolete existing military architectures. The emergence of these capabilities by near-peer adversaries has fundamentally altered the strategic landscape, forcing defense planners to confront threats that can travel faster than a mile per second while maneuvering unpredictably through the atmosphere.

Modern C5ISR systems, originally designed for conventional ballistic missile threats that follow predictable parabolic trajectories, must evolve dramatically to address the unique characteristics of hypersonic weapons: extreme velocity exceeding Mach 5, unpredictable

maneuverability during flight, reduced radar cross-sections, and flight profiles that can evade traditional missile defense architectures.

Hypersonic weapons present operational challenges that extend far beyond mere speed considerations, stressing existing C5ISR architectures in ways that reveal fundamental limitations in current detection and tracking methodologies. Unlike ballistic missiles that follow predictable trajectories after their boost phase, hypersonic weapons maintain powered flight and can maneuver throughout their flight profile, making interception calculations exponentially more complex.

The physics of hypersonic flight compound detection challenges in counterintuitive ways. Hypersonic targets present thermal signatures that are significantly dimmer than traditional ballistic missiles, typically 10 to 20 times fainter than what current U.S. satellite systems normally track in geostationary orbit. This reduced thermal signature makes them extremely difficult to distinguish against the cluttered thermal background of Earth's surface, a challenge that has been likened to "tracking a slightly brighter candle in a sea of candles."

### **Advanced Sensor Architectures**

The inadequacy of current radar systems for hypersonic threat environments necessitates a complete paradigm shift from ground-based to air-enabled and integrated space-terrestrial detection networks. Traditional radar architectures, designed to see hundreds of kilometers, must be replaced by systems capable of detecting and tracking threats thousands of kilometers away to provide adequate warning time for defensive responses.

The cornerstone of future hypersonic detection lies in space-based sensor platforms, exemplified by the U.S. Department of Defense's Hypersonic and Ballistic Tracking Space Sensor (HBTSS) program. This initiative represents a critical technological leap forward in sensor capability. The current iteration focuses on developing an infrared sensor and algorithm system that, when mounted on satellites, can detect hypersonic weapons against the cluttered background of Earth's surface and provide intercept-quality data to defensive systems.

The HBTSS program has progressed significantly, with prototypes launched in February 2024 successfully tracking multiple hypersonic test events and collecting over 650,000 images of tailored test scenarios. The system's "birth-to-death" capability allows continuous tracking of potential threats from launch through potential interception, providing unprecedented situational awareness across the entire engagement timeline.

While space-based sensors provide the backbone of future detection capabilities, ground-based systems are evolving as well. Modern radar systems need to incorporate gallium

nitride (GaN) technology, which represents a revolutionary advancement in radar performance characteristics. GaN semiconductors enable twice the sensitivity and twice the range compared to previous gallium arsenide (GaAs) technologies, while providing superior power density and efficiency crucial for detecting low-observable hypersonic targets.

Beyond traditional radar and infrared detection methodologies, next-generation C5ISR systems need to incorporate novel detection approaches specifically tailored to hypersonic signatures. Hyperspectral sensors capable of detecting the unique electromagnetic emissions from plasma interactions, ultraviolet sensors optimized for detecting chemical byproducts of hypersonic flight, and radio frequency sensors designed to intercept data-linked missile communications all represent critical components of a comprehensive detection architecture.

### **Communication Networks and Kill Webs**

The compressed engagement timelines created by hypersonic weapons drive requirements for communication systems that operate at the theoretical limits of current technology while maintaining military standards for security, reliability, and resistance to electronic warfare attacks. When a hypersonic weapon is detected at maximum sensor range, the time available for detection, tracking, decision-making, and engagement may be measured in mere minutes, making every millisecond of communication delay a critical factor in mission success or failure.

Modern C5ISR architectures require advanced communication protocols such as 100G Ethernet and PAM-4 (Pulse Amplitude Modulation 4-level) signaling to enable high-speed data exchange at unprecedented rates. These protocols, originally developed for commercial high-speed computing applications, must be adapted and ruggedized for military environments while maintaining their performance characteristics under conditions of electronic warfare, physical damage, and environmental stress.

The network architecture supporting hypersonic operations must fundamentally differ from traditional military communications, embracing mesh networking principles that provide multiple redundant communication paths and automatic rerouting capabilities. The integration of various communication sources, radio systems, satellite links, terrestrial networks, and emerging communication technologies, into unified C5ISR architectures must be seamless to guarantee real-time information sharing and decision-making under contested conditions.

The concept of distributed mesh networks aligns directly with emerging kill web architectures that seek to connect every sensor to every shooter across the battlespace

dynamically and in real-time. Unlike traditional centralized command systems that create single points of failure, kill web architectures enable distributed units to access and share critical information, empowering rapid engagement of threats regardless of domain boundaries.

Modern mesh networks can be deployed across diverse platforms spanning the 360-degree combat space, from ground vehicles and aircraft to naval vessels and space-based assets. This diversity provides resilience through redundancy, ensuring that communications can be maintained even when individual network segments are compromised or destroyed.

### **Artificial Intelligence and Edge Computing**

The speed of hypersonic threats necessitates artificial intelligence and machine learning integration for real-time decision-making that far exceeds human cognitive capabilities. The human decision-making process, while sophisticated for complex strategic analysis, simply cannot operate at the millisecond response times required for hypersonic engagement scenarios.

Modern AI systems deployed in defense environments require immense computational power to process sensor data, detect patterns, and execute algorithms with minimal latency. These systems must handle terabytes of data per second while making life-or-death decisions in milliseconds, requirements that push the boundaries of current computing technology.

Traditional centralized computing architectures prove inadequate for hypersonic scenarios due to communication delays inherent in transmitting data to distant processing facilities. Edge computing architectures distribute processing capability throughout C5ISR networks, allowing critical decisions to be made at the point of data collection rather than requiring transmission to command centers. This distributed approach dramatically reduces decision-making timelines while increasing system resilience against network attacks or disruption.

Given the compressed timelines of hypersonic engagements, C5ISR systems must integrate sophisticated automated decision-making capabilities while maintaining appropriate human oversight for critical engagement decisions. This represents a fundamental shift in military command philosophy, moving from human-controlled to human-supervised operations for certain time-critical functions.

The challenge lies in developing AI systems that make autonomous decisions within clearly defined parameters while escalating ambiguous situations to human commanders when time permits. The integration of AI into hypersonic command and control systems represents both a technical necessity and a political challenge. While these systems may

be essential for effective operations in compressed timelines, they also require new frameworks for ensuring appropriate human oversight and political control over potentially escalatory military actions.

## Nuclear Threshold Implications and Crisis Management

Perhaps the most profound implications of hypersonic weapons deployment concern their effect on nuclear threshold calculations and crisis stability. These weapons create a paradox: while they provide conventional alternatives to nuclear escalation, their speed and penetration capabilities might paradoxically lower the nuclear threshold by creating credible first-strike scenarios that didn't previously exist.

The precision and conventional nature of hypersonic weapons theoretically offer graduated response options that can achieve strategic effects while maintaining escalation control. Political decision-makers gain military options that provide measured responses rather than binary choices between inaction and major escalation. A distributed force equipped with hypersonic capabilities can threaten time-sensitive targets without requiring the forward deployment of vulnerable assets or the escalation risks associated with nuclear employment.

However, this conventional precision creates its own escalation risks. The ability to rapidly target command and control nodes, nuclear forces, or critical infrastructure might incentivize preemption rather than deterrence. If adversaries believe their strategic assets are vulnerable to rapid conventional hypersonic strikes, they may feel compelled to "use or lose" their capabilities early in a conflict, potentially escalating to nuclear employment before their command structures can be degraded.

The speed differential that Admiral Paparo identified, "if your adversary can strike you five times faster than you can strike your enemy, it incentivizes first strikes", applies equally to nuclear decision-making. Nations facing hypersonic-armed adversaries may adopt more aggressive nuclear postures, including launch-on-warning doctrines or pre-delegation of nuclear authority, to avoid decapitation strikes.

Hypersonic weapons' speed and maneuverability create complex attribution challenges that could destabilize nuclear command and control. A hypersonic weapon approaching strategic targets might be indistinguishable from a nuclear-armed system until impact, potentially triggering nuclear responses based on mistaken threat assessment.

This ambiguity problem becomes particularly acute when considering the distributed nature of hypersonic deployment. Weapons launched from multiple platforms across different geographic locations create complex threat pictures that may be difficult to

assess accurately within the compressed timelines these systems create. The distinction between conventional and nuclear payloads may be impossible to determine until after impact, forcing nuclear-armed nations to make worst-case assumptions that bias toward escalation.

The plasma effects that hypersonic weapons create during flight can interfere with radar tracking and communication systems, further complicating attribution and command and control. These natural jamming effects, combined with the weapons' inherent speed and maneuverability, create what might be called "decision compression"—situations where critical choices must be made with incomplete information under extreme time pressure.

The integration of hypersonic weapons into alliance structures creates additional nuclear threshold complications. The deployment of these systems with allied forces throughout the Pacific creates shared nuclear risks that require careful management through command-and-control arrangements and strategic communication.

When Australian F/A-18s potentially carry hypersonic weapons, or when Japanese facilities support hypersonic operations, these allies become potential targets for nuclear retaliation in ways that conventional weapons might not trigger. The speed and strategic reach of hypersonic weapons mean that allied territories hosting these capabilities might face nuclear threats even in conflicts where they are not primary combatants.

Extended deterrence calculations become more complex when allies host weapons systems capable of rapidly striking adversary strategic assets. The traditional firebreaks between conventional and nuclear conflict may erode when conventional weapons achieve nuclear-like effects in terms of speed, precision, and strategic impact.

The deployment of hypersonic weapons requires enhanced crisis management protocols designed to prevent inadvertent escalation while maintaining deterrent effectiveness. These protocols must account for the compressed timelines that hypersonic weapons create while preserving the deliberate decision-making that effective crisis management requires.

Traditional crisis management assumes sufficient time for consultation, verification, and measured response. Hypersonic weapons eliminate this assumption, requiring pre-planned crisis response frameworks that can operate within compressed timelines while maintaining escalation control.

These frameworks likely require enhanced intelligence capabilities that can rapidly distinguish between different types of hypersonic threats, improved communication systems that can coordinate responses across distributed forces, and pre-planned response options that provide alternatives to immediate escalation.

The development of such protocols represents a critical requirement for managing the nuclear risks that hypersonic weapons create. Without effective crisis management frameworks, the speed and capability of these weapons might contribute to inadvertent escalation rather than enhanced deterrence.

The Pacific theater's geographic characteristics add additional complexity to crisis management protocols. The vast distances involved mean that crisis response decisions may need to be made by distributed commanders operating across multiple time zones with varying communication capabilities. How do crisis management protocols maintain coherence when distributed forces must respond to hypersonic threats within their individual operational areas? How do senior commanders maintain strategic oversight when tactical crisis response decisions must be made at machine speed?

These questions become particularly acute when considering scenarios involving multiple allied nations. Crisis management protocols must account for the possibility that hypersonic threats might target allied territory or forces, requiring coordinated responses that respect national sovereignty while maintaining alliance effectiveness. The speed of hypersonic weapons may not permit traditional consultation processes, requiring pre-negotiated response authorities and coordination mechanisms.

## The Path Forward - Integration Challenges and Solutions

The successful integration of hypersonic weapons requires institutional adaptations that extend beyond technical modifications to encompass fundamental changes in military culture and organizational processes. Traditional military institutions built around deliberate planning and hierarchical control must evolve to support operations that unfold at machine speed.

This adaptation challenge affects multiple levels of military organization. Senior leadership must develop comfort with pre-delegated authorities that allow subordinate commanders to make critical decisions without traditional consultation. Mid-level commanders must learn to operate with broader authorities while maintaining accountability for decisions made under extreme time pressure. Junior leaders must develop the judgment necessary to make tactical decisions with strategic implications.

The training and education implications of these changes are substantial. How do military educational institutions prepare officers for command responsibilities that may require split-second decisions with strategic consequences? How do they develop the judgment necessary for operating in environments where consultation time is measured in seconds

rather than hours? How do they maintain the analytical rigor that effective decision-making requires while operating under unprecedented time constraints?

These institutional challenges extend beyond individual preparation to encompass organizational culture and standard operating procedures. Military organizations traditionally emphasize careful planning, thorough coordination, and deliberate execution. Hypersonic operations may require more adaptive approaches that emphasize rapid response, distributed decision-making, and continuous adaptation based on real-time information.

The command-and-control challenges posed by hypersonic weapons also drive specific technology integration imperatives that traditional military systems were not designed to address. The integration of artificial intelligence, advanced sensors, and high-speed communication systems becomes essential for operations that exceed human decision-making speeds.

These technology requirements extend beyond individual platform capabilities to encompass the network architectures that enable distributed operations. How do communication systems maintain connectivity across vast Pacific distances while preserving the stealth characteristics that platform survival requires? How do they coordinate responses among platforms operating under different national authorities while maintaining operational security?

The challenge becomes particularly complex when considering the reliability requirements that hypersonic operations demand. Traditional military systems are designed with redundancy and fail-safe characteristics that may not be compatible with the speed requirements that hypersonic engagement imposes. How do system designers balance reliability against responsiveness when system failures might have strategic consequences?

One of the major implementation challenges involves deploying AI systems into small, lightweight embedded systems that meet stringent size, weight, and power (SWaP) constraints without sacrificing computational efficiency. Modern military platforms, particularly mobile ground systems and aircraft, have limited space and power budgets that cannot accommodate traditional data center-scale computing equipment.

This constraint drives innovation in specialized military computing hardware that maximizes processing capability while minimizing physical footprint and power consumption. Advanced semiconductor technologies, specialized AI processing chips, and innovative cooling systems all become essential components for meeting these

demanding specifications while maintaining the reliability standards essential for military operations.

The transition to hypersonic-capable C5ISR systems faces significant integration challenges stemming from decades of service-specific system development and procurement practices. Army systems historically could not communicate directly with Navy systems, and Navy systems lacked interoperability with Air Force systems, creating technological stovepipes that complicate unified response to hypersonic threats.

Breaking down these stovepipes requires extensive development of new communication systems, protocols, and interfaces that must be designed, tested, and installed across existing platforms throughout all military services. This represents not merely a technical challenge but also an organizational and procurement challenge.

However, the complexity of maintaining multi-domain networks in contested environments cannot be underestimated. Users must retain capabilities to operate in degraded or denied communication environments where portions of integrated networks are compromised or destroyed. This requirement drives development of systems that can gracefully degrade while maintaining essential functionality rather than failing catastrophically when individual components are lost.

Hardware architectures will need to adhere to open standards such as the Sensor Open Systems Architecture (SOSA) to enable interoperability and flexibility for future upgrades. The rapid pace of technological development in the hypersonic domain means that systems designed today must accommodate technologies that do not yet exist. SOSA compliance ensures that new capabilities can be integrated into existing systems without requiring complete replacement of expensive infrastructure.

The operational learning challenge becomes particularly complex when considering the alliance dimensions of hypersonic deployment. Australian, Japanese, and other allied forces operating hypersonic-capable platforms must develop interoperable command and control procedures while maintaining their sovereign decision-making authorities. This requires collaborative learning frameworks that enable shared tactical development while preserving national command prerogatives.

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## Conclusion: Strategic Choices and Future Implications

The integration of hypersonic weapons into modern warfare represents one of the most significant paradigm shifts facing military forces since the introduction of radar during World War II or the advent of satellite communications during the Cold War. Success in adapting to this new threat environment requires coordinated advances across sensor technology, communication systems, data processing, and integration architectures, all while maintaining the reliability and security standards essential for military operations.

The challenge extends beyond mere technological advancement to encompass organizational transformation, requiring new doctrine, training, and operational concepts that can fully exploit hypersonic defense capabilities while maintaining deterrence against hypersonic threats. Military personnel must be trained to operate systems that blend human decision-making with artificial intelligence in ways that have never been attempted at scale.

The United States now faces a fundamental choice about its hypersonic future. The technology has matured to the point where deployment is feasible, but continued delays risk allowing the competitive advantage to slip further toward peer competitors who have demonstrated greater willingness to field systems without perfect validation.

Deterrence in the modern strategic environment requires visible, credible capabilities. Weapons systems confined to test ranges and development programs do not influence adversary decision-making. Only deployed systems, operated by trained crews and integrated into operational planning, send unmistakable signals about American resolve and capability.

The immediate priority should be accelerating deployment of existing mature technologies rather than pursuing perfect solutions through extended development cycles. Both ARRW and HACM represent ready-for-deployment capabilities that would provide immediate operational value while generating the experience base necessary for future system improvements.

The path forward requires accepting that hypersonic weapons, like all military systems, will continue to evolve through operational use rather than laboratory perfection. Initial deployments will undoubtedly reveal areas for improvement, but the alternative—continued delay while competitors consolidate their advantages—poses far greater strategic risks.

Current Chinese advantages stem partly from the perception that their systems, regardless of actual effectiveness, represent deployed threats. American hypersonic weapons must transition from laboratory curiosities to operational realities to achieve similar psychological impact. From a deterrent point of view, if they're deployed with B-2s and other systems, the Chinese face a really difficult situation.

The weapons are ready. The strategy is clear. What remains is the institutional will to move decisively from development to deployment before the strategic window closes entirely. The ecosystem exists. The technology is ready. The strategic requirement is urgent. What remains is the decision to move beyond the science project mentality and start building the force that can win tonight's fight while deterring tomorrow's war.

The transformation demanded by hypersonic weapons represents more than technological adaptation. It requires a fundamental evolution in how military forces are commanded, controlled, and employed in strategic competition. The nations that successfully navigate this transformation while managing its associated risks will hold decisive advantages in the conflicts that may define the next generation of global security. Those that fail to adapt risk finding their most advanced weapons neutralized by their own institutional limitations.

The distributed force concept combined with hypersonic capabilities represents more than tactical flexibility; it's the foundation of credible deterrence in the Pacific. Traditional approaches that rely on a few heavily armed platforms create predictable targets and concentrated vulnerabilities. Distributed hypersonic capabilities embedded with allied forces create multiple dilemmas for potential adversaries while strengthening partnership relationships.

This coalition approach serves multiple purposes. It provides additional deployment platforms and signals unified allied commitment to Pacific security. More importantly, it complicates Chinese planning by creating multiple launch points throughout the region.

The window for effective deterrence may be narrowing. Chinese military modernization continues at pace, while American advantage in key technologies risks erosion through inaction.

America stands at a crossroads in hypersonic development. Two decades of interrupted progress, shifting priorities, and bureaucratic obstacles have finally led to mature, deployable systems. The question is no longer whether the United States can develop effective hypersonic weapons, but whether it possesses the institutional will to move decisively from development to deployment.

The choice facing military planners and policymakers is clear: adapt command and control structures to hypersonic realities or risk deploying weapons whose speed advantages are negated by institutional limitations and escalation risks. The future of strategic competition may well depend on how effectively military institutions can manage this transformation while maintaining the strategic stability that effective deterrence requires.

This integration cannot wait for perfect solutions or comprehensive studies. As the strategic competition intensifies and adversaries deploy their own hypersonic capabilities, the United States must move beyond treating these weapons as science projects and begin addressing the command-and-control challenges their deployment creates.

The tools for maintaining Pacific stability exist today, ready for deployment. The technological challenges have been largely solved. The strategic requirement is clear and urgent. What remains is the commitment to act on that readiness before the strategic window closes entirely. The ecosystem exists. The technology is ready. The strategic requirement is urgent. What remains is the decision to move beyond the science project mentality and start building the force that can win tonight's fight while deterring tomorrow's war.

Ultimately, the C5ISR systems that emerge from this transformation will not merely counter or enable hypersonic weapons but will enable military forces to operate with unprecedented speed, precision, and effectiveness across all domains of warfare. The hypersonic age demands nothing less than a complete reimagining of how military power is projected, sustained, and employed in an era of strategic competition. The nation that successfully makes this transition will possess decisive advantages in the contests that will define the twenty-first century security environment.