Hypersonic Weapons Summit

THE ROAD TO HYPERSONIC WEAPONS

Technical Challenges & Emerging Opportunities

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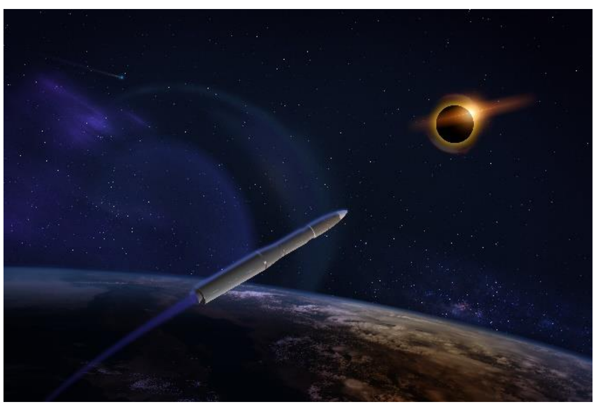
The Road to Hypersonic Weapons: Technical Challenges & Emerging Opportunities

Introduction

In the eternal arms race to maintain or regain a strategic advantage over its adversaries, the United States is turning its attention to the development of hypersonic weapons. The concept of a hypersonic weapon is not new – indeed the U.S. has developed them in some form or another for over 30 years. Yet as its adversaries – Russia and China most notably – push the development of hypersonic weapons and near the ability to field them, the U.S. has begun to increase its focus and funding on catching up. This article will discuss the current status of the Department of Defense's development efforts, it's challenges, and opportunities for the defense industry to contribute!

Overview of Hypersonic Weapons



Simply put, a hypersonic weapon is a missile capable of traveling at Mach 5 or greater – more than five times the speed of sound. More specifically, hypersonic weapons are intended to be maneuverable and able to carry a variety of payloads – some will rely on the speed of impact to create its blast effect, while others will carry a conventional payload. Russian and China claim they intend to equip hypersonic weapons with nuclear payloads.

There are two primary types of hypersonic weapons currently being developed across the board. Hypersonic Glide Vehicles (sometimes referred to as Hypersonic Boost-Glide Vehicles) are effectively advanced versions of ballistic missiles – launched using high-velocity boosters, separate, then use momentum and various control surfaces to glide and steer through the upper atmosphere towards their target. The other type – Hypersonic Cruise Missiles – use advanced Scram-Jet technology for powered flight.

That sounds quite impressive of course, but how much of a difference does that speed really make? Quite a bit, actually. To put that sort of speed into perspective, let's do some comparisons. In October and November 2015, Russia launched a salvo of 3M-14T Kalibr-NK cruise missiles from the Caspian Sea at ISIS targets in Syria. These missiles traveled approximately 1500 km (930 mi) to the target, and they are believed to have a max speed of 965 km/h (599.623 mph). Doing some rough calculations, that means that in ideal circumstances the Kalibr could have hit those targets in an hour and thirty-three minutes.

A hypersonic missile traveling at Mach 5 could reach that same target in about fourteen and a half minutes. The KH-47M2 Kinzhal – a Russian experimental air-launched Hypersonic Glide Vehicle (HGV) allegedly capable of traveling at Mach 10 – could strike those same targets in about seven minutes and fifteen seconds. For a little further perspective, it is a similar distance (approximately 960 miles as the missile flies) from New Orleans to Washington D.C., which means that same Kinzhal missile could make the trip in about seven and a half minutes. Russia is also developing the Avangard – a nuclear-capable HGV intended to be capable of Mach 20 with a range of over 6,000 km that they are attempting to field before the end of 2019. If we assume "over 6,000 km" means that it is capable of traveling at least, say 7,816 km (the distance from Moscow to Washington D.C.), an Avangard launched from Moscow would hit Washington in just under nineteen minutes.

This speed presents an obvious advantage. With speed like that, even assuming the missile is detected immediately, the timeline for decision-makers to be informed and make an effective decision is drastically reduced, which in turn reduces the window in which defensive systems can be employed. Additionally, hypersonic weapons are meant to be maneuverable, which can both add uncertainty for decision makers uncertain of the intended target as well as minimize the impact of most unguided defensive measures built for a ballistic missile following a predictable path. Finally, some hypersonic weapons are designed to fly lower and be less detectable than traditional ballistic missiles, which makes most current ground and space-based detection systems ineffective.

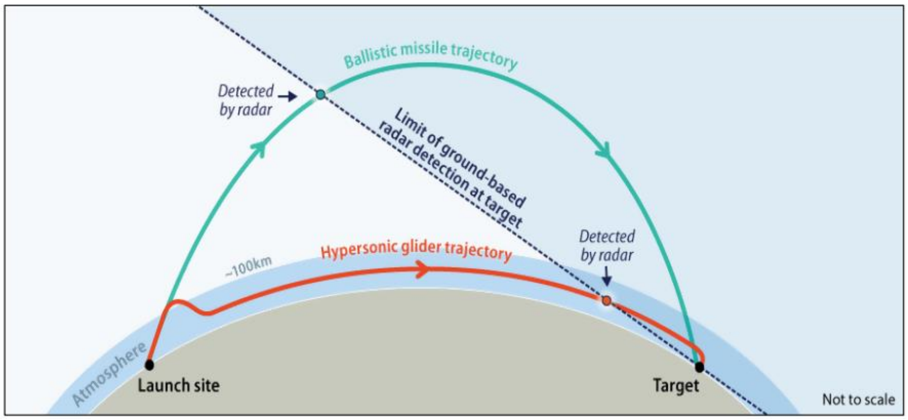


Figure 1: CRS image based on an image in "Gliding missiles that fly faster than Mach 5 are coming," The Economist, April 6, 2019, https://www.economist.com/science-and-technology/2019/04/06/gliding-missiles-that-flyfaster-than-mach-5-are-coming

Now that we have an understanding of hypersonic weapons and the potential impact they will have on the future of warfare, the rest of this paper will focus on hypersonic weapon development efforts by the Department of Defense, and specifically on the engineering challenges facing development efforts.

U.S. Hypersonic Weapon Development Overview

According to a 2019 report to Congress, the DoD is primarily developing hypersonic weapons under the U.S. Navy's Conventional Prompt Strike program, with supplemental programs being developed through the U.S. Air Force, Army, and Defense Advanced Research Projects Agency (DARPA). The Navy's program is responsible first for the development of a Common Glide Vehicle (CGV) that all services will use as the baseline for their hypersonic weapon development. Each service is responsible for designing their own booster system for the CGV, while various DARPA projects seek to improve on various hypersonic weapon concepts.

Table 1: Current DoD Hypersonic Weapon Programs

Program Title	Developer	Description	FY2019 ($ in millions)	PB2020 ($ in millions)	Schedule
Intermediated Range Conventional Prompt Strike Weapon (IR CPS)	U.S. Navy	Pairs the CGV with a submarine-launched booster system	11.25	593.12	Underwater launch tests planned in 2020 and 2022, continued prototyping through 2024
Land-Based Hypersonic Missile	U.S. Army	Pairs CGV with two-stage ground-launched booster system, 1,400-mile range, intended for use against "A2/AD capabilities, suppression of adversary Long Range Fires, and engage other high payoff/time-sensitive targets"	0	228	Flight tests through 2023
Hypersonic Conventional Strike Weapon (HCSW)	U.S. Air Force	Pairs CGV with solid-rocket-powered GPS-guided system launched from B-52	289.628	290	Critical design review through 2020
AGM-183A Air-launched Rapid Response Weapon (ARRW)	U.S. Air Force	Developing an air-launched HGV prototype capable of traveling at speeds up to Mach 20 at a range of approximately 575 miles	219.23	286	Flight tests through 2022
Tactical Boost Glide (TBG)	DARPA	Wedge-shaped HGV capable of Mach 7+ as a proof-of-concept for air-launched, tactical range hypersonic boost glide systems; also considering integration with Navy Vertical Launch System; will transition to both Air Force and Navy	147	162	Flight tests through 2020; additional testing and flight test planning through 2020
Advanced Full-Range Engine (AFRE)	DARPA	Prototype engine capable of enabling Mach 5+ flight for reusable aircraft	51.288	40.741	Testing through 2020
Operational Fires (OpFires)	DARPA	Leverage TBG technology to develop ground-launched system enabling tactical weapons to penetrate modern air defense systems	40	50	Complete integrated system trade studies and propulsion system critical design review in 2020; develop initial flight test plan in 2020

Hypersonic Air-Breathing Weapon Concept (HAWC)	DARPA/U.S. Air Force	Long-term program to develop air-launched Hypersonic Cruise Missiles	14.3	10	Complete flight tests and final program reviews in 2020

***Source**: Program information taken from U.S. Navy, Army, Air Force, and DARPA FY2020 Justification Books, available at https://comptroller.defense.gov/Budget-Materials/*

Let's take a more in-depth look at the DoD's efforts on the whole, focusing on the five key challenges the DoD is facing: Engineering, Testing, Materials Development, Propulsion Systems Development, and Sensors/Communications. We'll take a look at the goals, benefits, current inhibitors, and strategies and solutions the defense industry can use to help.

Engineering Challenges

The objectives and benefits of hypersonic weapon development are quite clear – developing and fielding hypersonic weapons would be a significant enhancement of our current capabilities, and could impact all levels and domains of warfare. A missile traveling at Mach 5 could travel from New York to Los Angeles in about 39 minutes. Hypersonic weapons give the U.S. a spectacular stand-off and support capability at the tactical level – they would be able to get strike support to the warfighter significantly faster than through conventional airpower. The ability to strike adversaries rapidly also provides a crucial deterrent at the strategic level; this is Mutually Assured Destruction doctrine at it's finest. Not only would strategic hypersonic weapons allow the U.S. to strike at great range like ballistic missiles, but their speed and maneuverability means they are all but guaranteed to strike their target – likely before the target has a chance to redeploy. That is a critical capability that U.S. needs to remain a strategic powerhouse. The 2018 National Defense Strategy identified hypersonic weapons as a key technology to "[ensuring the United States] will be able to fight and win the wars of tomorrow."

With that said, even at the highest levels, the U.S. development program is in its infancy at best. As of September 2019, the DoD had no programs of record for hypersonic weapons. Though multiple programs exist across the DoD, all of these efforts are aimed at creating operational prototypes. All current efforts are currently Research and Development; in point of fact, current funding for all DoD programs currently falls under Research, Development, Test, and Evaluation – not procurement.

The DoD is most likely several years away from seeing procurement contracts, which means the defense industry is still several years from being able to experiment and find cost-effective ways to mass-produce hypersonic weapons. Those engineering issues will require the defense industry to "relearn how to effectively, efficiently and economically produce them (hypersonic missiles)," according to Pentagon Undersecretary of Defense for Research and Engineering Michael Griffin.

We will discuss some of the engineering difficulties in greater detail later; the important thing to remember for now is that until these engineering challenges can be resolved in a workable prototype the industry can't move forward. At least, not completely. There are things the defense industry can do to prepare now for when a procurement budget is approved, though.

First, DoD and defense industry need to put a focus on informed acquisition and procurement. Hypersonic weapons will require a wealth of materials and equipment that have never been worked with on this scale. Quite simply, the faster quality materials can be acquired, and the engineering processes can be streamlined, the sooner the industry will be ready to work out the challenges of large-scale production of hypersonic weapons. That means truly searching for the best quotes and materials, knowing where your materials are coming from, and ensuring your provider is reputable and able to get you the materials you need quickly.

Similarly, both the DoD and defense industry need to revise our engineering methods to work through these issues quickly. Russia plans to begin fielding some of their hypersonic weapons by the end of the year, and while China is vague as always about their development timeline, they are almost certainly farther along than the U.S. is. The U.S. is losing its strategic edge, and time is of the essence to regain it. If we can improve our engineering abilities now to allow us to work through the issues quicker, we will be able to field hypersonic weapons quicker and minimize that advantage.

For now, a lot of the onus falls on the Primes and integrators developing these prototypes for the DoD, as does the responsibility to lead the way in process improvement. The quicker they can develop workable prototypes that will be approved for procurement, the sooner the rest of the defense industry can leverage it and help work through these issues!

Testing Challenges

Of course, whether we are talking about R&D or procurement, the ability to test our solutions is absolutely essential – and it's an area the U.S. is severely lacking in at this point. According to the most recent study on the topic (conducted by the Institute for Defense Analyses (IDA) in 2014), the U.S. has 48 critical hypersonic test facilities and mobile assets that were necessary at that point for the maturation of hypersonic technology through 2030. These facilities are intended to simulate the unique conditions experienced by a missile in hypersonic flight including the speed, pressure, and atmospheric heating effects unique to travel at hypersonic velocities.

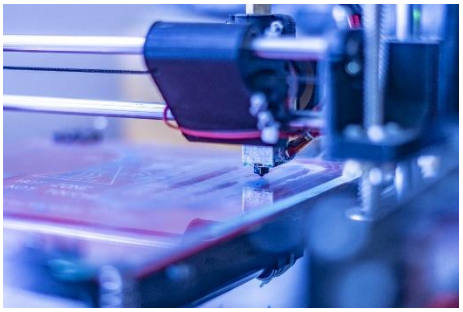
According to that report, these resources were comprised of 10 DoD hypersonic ground test facilities, 11 DoD open-air ranges, 11 DoD mobile assets, 9 NASA facilities, 2 Department of Energy facilities, and 5 assorted industry/academic facilities. Unfortunately, the report also noted that "no current U.S. facility can provide full-scale, time-dependent, coupled aerodynamic and thermal-loading environments for flight durations necessary to evaluate these characteristics above Mach 8."

This presents an obvious opportunity for the defense industry – proper engineering solutions require extensive testing, and the U.S. can't reasonably expect to field hypersonic weapons until it has an adequate ability to test them. That means we need more Federally Funded Research and Development Centers (FFRDCs), more testing facilities, more research and development laboratories; the list goes on. The U.S. will need facilities capable of testing navigation guidance and control systems, thermal propulsion systems, heat resistant materials and shielding.

The inhibitors here, of course, come down to money. The DoD hypersonic weapons program is so infantile at this point that rapid development is a major challenge. These weapons have to go through numerous levels of testing before they can even leave the prototyping stage, much less before they become fieldable. At this point, it is unclear if a large-scale procurement effort on hypersonic weapons will even be approved by the Pentagon, much less by Congress. Still, preparation and planning for future hypersonic testing will definitely benefit the development efforts. It will also put the defense industry as far ahead of the curve as possible when the time comes to begin developing these weapons in earnest.

Now we get into the meat and potatoes of the development challenges – the technical difficulties facing hypersonic weapons.

Materials Development Challenges



By far the single biggest technical challenge facing any hypersonic weapon is the material it's made of. The defense industry is no stranger to the challenge of creating advanced materials, but hypersonic weapons take it to a whole new level. An object traveling at Mach 5 or higher builds up an intense amount of heat as it travels through the atmosphere from the myriad gases and particles it travels through. For a point of reference, the Lockheed SR-71 cruising at 85,000 feet at Mach 3 had to deal with temperatures of over 500°F across most of the surface area of the aircraft. Similarly, the X-15 routinely had to deal with temperatures of up to 1,200°F at Mach 6. We know that the X-15 worked, but let's remember that the hypersonic range goes from Mach 5 to Mach 25. We've barely even scratched the surface of the sort of heat a hypersonic weapon needs to be able to withstand.

For hypersonic weapons to be successful, their material must be rugged enough to withstand the rigors that the speed and heat of hypersonic travel while protecting the delicate instrumentation inside. Since range and speed are paramount for weapons like this, it also needs to be light enough to not add extra weight or hurt the missile's maneuverability. It needs to have an advanced thermal management system. Finally, it needs to be cheap enough to be easily mass-produced.

No such material exists at this point, and creating such material presents a host of both difficulties and opportunities for the defense industry. Material development of this caliber will require substantial research and funding. Given that most legacy systems are built around legacy materials, much of the technology that goes into hypersonic weapons will likely need to be rebuilt from the ground up to account for the new material. Where this new material will be found, how available it will be, the cost per material… all of these are challenges that will need to be overcome.

On the other hand, there is a wealth of opportunity in developing this material, outside of the national security benefits. Any material developed can meet all of the above criteria would be such a massive leap forward in technology that it would all but require an examination on if it should see more widespread adoption across the DoD, and even into the civilian community. Any thermal protection systems developed for hypersonic weapons would absolutely have a use in other situations. Developing material and systems for hypersonic weapons is an incredible challenge, but one with a strong possibility of long-term benefits.

The primary need at this point is to maximize the DoD and defense industry's ability to develop and test new material and to figure out a way to mass-produce it. As noted previously, test ranges capable of rigorously taxing any new material are absolutely essential. The defense industry will need to collaborate, both among themselves and with the scientific community, to quickly come up with the best possible material. Manufacturing processes need to be streamlined and optimized, and when delivering any new material considerations such as whether it is compatible with 3D printing techniques must be considered. This is an opportunity for the defense industry to make extensive use of DoD Research, Development, Testing, and Evaluation (RDT&E) funds.

Propulsion Systems Development Challenges

The second biggest engineering challenge is equally crucial to consider – how will these weapons be propelled to the hypersonic speeds required? Once again, the defense industry is no stranger to powerful engines, but hypersonic flight is a completely new level of engineering. Propulsion systems exist that can reach hypersonic or greater speeds, such as the sort of rockets that propel ballistic missiles. Such systems are enormous, however, and are incapable of sustained hypersonic speeds. Current hypersonic propulsion system development efforts are based primarily on theory, with little true development so far. In short, current technology is still nowhere near what the DoD needs to make hypersonic weapons work.

As with material development, propulsion systems for hypersonic weapons must be lightweight, rugged, cheap, and easy to mass-produce. The propulsion systems also need to be perfectly integrated with any navigation systems to allow these weapons to accurately strike their targets at the necessary speeds. That is a tall order, and that technology simply does not exist at this point.

Much of what is needed to make this happen is wrapped up in the previous efforts we have discussed as well. Testing ranges and laboratories for developing these propulsion systems and putting them (and the materials they are made from, of course) are crucial. This level of engineering will necessitate collaboration in the public and private sectors to minimize the timeline for developing the needed technology in minimal time. Informed acquisition will again aid this process by ensuring that the supply chain is robust enough to cut out unnecessary delays as the DoD and industry experiment and research. Finally, propulsion system development has to work in tandem with materials development. These systems will require the same material and thermal protection systems as the rest of the missile, yet they are perhaps even more crucial to protect given that the primary benefit of the weapon is derived from the propulsion system.

Sensors & Communication Challenges

The final major challenge at this point involves the infrastructure that will go with hypersonic weapons. Beyond sheer speed, a major benefit to hypersonic weapons is that they tend to fly significantly lower than ballistic missiles; in the upper atmosphere rather than a low earth orbit. The vast majority of ground-based radar stations - the core of most air defense networks - simply cannot see a hypersonic weapon at those altitudes until it is extremely close. This very same fact provides difficulties for the side launching hypersonic weapons as well. Incredibly basic operations such as communicating with the missile become a significant challenge.

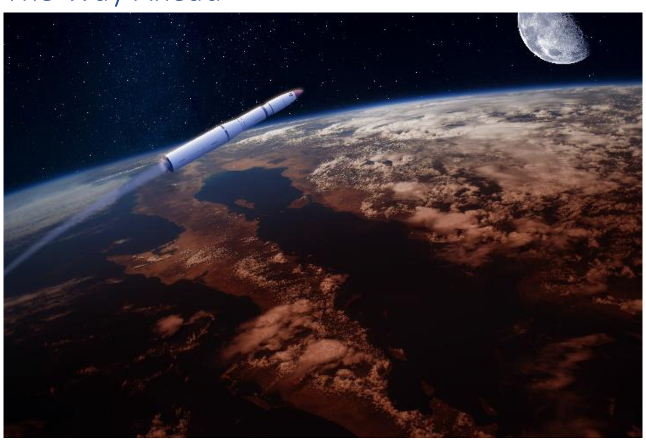
Hypersonic weapons are meant to be more than ballistic missiles, they should be able to change course in flight based on input from the operator, whether to confuse the enemy as to the intended target, adjust to hit a mobile target, or to update the aim. During hypersonic flight there is very little time to adjust like that, so even a momentary lapse in communication can be the difference between a successful strike or a catastrophe. Further, the DoD has not stated any intent to equip hypersonic weapons with nuclear warheads at this time, which means that any developed by the U.S. must be more accurate and reliable than any being developed by Russia or China.

Yet at this time, the U.S. lacks the infrastructure to guarantee complete control and constant communication with a hypersonic weapon throughout its entire flight. Ground-based stations are insufficient – true control over hypersonic weapons will require an advanced network of satellites and space-based sensors able to maintain communication, seamlessly handoff communications with a hypersonic weapon in flight to the next satellite, and able to transmit information to and from the missile in real-time. Though the U.S. certainly possesses an extensive satellite network, even this is insufficient for the needs of hypersonic weapons.

Of course, this solution presents many challenges of its own. Money naturally is the primary challenge – the defense industry is well aware that building a single satellite and putting it into space can be quite expensive, much less installing a network on the scale needed here. Political considerations come very much into play here as well. The most effective method for ensuring full sensor coverage is to put each satellite into a geosynchronous orbit. This means that a satellite capable of tracking and communicating with an object moving at speeds up to Mach 25 would be permanently parked over a particular area of the earth. Many nations will fear the possible intelligence collection value such a satellite would possess, and would likely refuse to allow us to place satellites over them – general protestations regarding the existence of such a satellite network aside. As a result, the DoD would have to calculate the best places to place these satellites to maximize their coverage and communication while respecting all territorial claims, which may, in turn, affect how these satellites are developed.

Extensive research is required into how to create an affordable, effective satellite network. Breakthroughs are being made in creating small, cheap satellites constantly, and the defense industry can set itself up to make breakthroughs in this technology. The situational awareness such a sensor network would provide the DoD alone makes it a worthwhile expenditure if the defense industry can find a way to quickly, cheaply, and reliably build and field such an extensive satellite network. For hypersonic weapons to be successful, it is a necessity.

The Way Ahead



There are major roadblocks that need to be overcome before the DoD is ready to procure and field hypersonic weapons. Whole new technologies and materials need to be created before such weapons can be fielded en masse, on top of the engineering challenges in producing a weapon capable of hypersonic flight to begin with. With its adversaries already developing these capabilities and potentially fielding them within the next year, however, these challenges must be identified and overcome swiftly. Though the DoD is not yet ready to begin the procurement phase of development, there are ample opportunities for the defense industr

y to aid in the research and development of hypersonic technology. Further opportunities are plentiful for the defense industry to position themselves for success if hypersonic weapon development is formally approved.