Hypersonic Weapons Come of Age

By Mark J. Lewis

Will the US—or some other nation—be first to field these game-changing weapons?

“17 September 2035 ... The enemy did not detect the approaching hypersonic missiles until it was too late. ... The enemy [integrated air defense system], saturated by the formation of decoy-jammers, had missed the one fleeting opportunity to target the high-speed munitions. Now in the terminal phase, the hypersonic missiles streaked into their targets.”

The vignette above was taken from “Air Force Future Operating Concept: A View of the Air Force in 2035,” a paper released by USAF at AFA’s 2015 Air & Space Conference. Endorsed by both the Secretary of the Air Force and the Chief of Staff, the document presents a view of the service two decades hence. Though fictional for now, the vignette captures the great promise of nearly unstoppable high-speed weapons that could strike quickly at targets deep within an enemy’s territory—weapons that today are rapidly accelerating toward reality.

This most recent document is just one in a series of USAF publications that have highlighted the utility of such high-speed weapons. A year earlier, USAF released “America’s Air Force: A Call to the Future.” In it, Chief of Staff Gen. Mark A. Welsh III urged the service to “continue to adapt and respond faster than our potential adversaries.” Hypersonics was one of five key game-changing technologies the report identified, the others being nanotechnology, unmanned systems, autonomy, and directed energy.

Hypersonics generally refers to flight in excess of about five times the speed of sound, or above Mach 5. “A Call to the Future” noted that the “leap” to hypersonics will have a revolutionary effect on how USAF approaches its core missions, “from investments, to force posture, to tactics, techniques, and procedures.” The paper said that the catchphrase “speed is life” is often true, and while “we may not always desire to operate at the fastest possible speed, the ability to do so creates a significant advantage.”

Coincident with the release of “A Call to the Future,” the Air Force Scientific Advisory Board completed a classified technology readiness study.

Former Air Force Historian Richard P. Hallion and retired Maj. Gen. Curtis M.
Bedke have also recently written about the utility of hypersonic weapons for AFA’s Mitchell Institute for Aerospace Studies, in “Hypersonic Weapons and US National Security: A 21st Century Breakthrough.” Hallion and Bedke highlighted the main advantage of this technology: that it can counter the so-called “tyranny of distance” associated with global reach. Such weapons would compress the shooter-to-target timeline, allowing for the prosecution of fleeting targets or providing more decision time before engagement. Hypersonic weapons, they wrote, would enhance joint operations, would be able to address a variety of targets, and would be deployable from a variety of platforms.

To accomplish this, Hallion and Bedke call for a national strategy that includes continued research and development, maintenance, and support for testing infrastructure. They also call for new investments in a future workforce.

The credibility of these various reports has been enhanced by recent successful flight efforts, especially the Air Force’s X-51 program and the series of Hypersonic International Flight Research Experimentation (HIFiRE) trials conducted jointly with Australia. Taken with other well-publicized activities around the world, there is a renewed sense that hypersonic weapons are not only plausible but seemingly inevitable.

In the early 1960s, USAF began a project to build a hypersonic vehicle called the Aerospace Plane, canceled after the Air Force Scientific Advisory Board identified “many clearly infeasible factors” in the program.

The roster of abandoned hypersonic programs has grown since, including the 1980s X-30 National Aerospace Plane (NASP), the Navy’s HyFly test program (discontinued after three failed tests), and the Defense Advanced Research Project Agency’s HTV-2 hypersonic glider (canceled after two flights).

Even ongoing hypersonic efforts have had setbacks. The August 2015 HIFiRE flight test of a new hypersonic engine design suffered a frustrating loss of flight telemetry. Similarly, the US Army’s Advanced Hypersonic Weapon, an unpiloted hypersonic glide vehicle, had a successful flight in the Pacific Missile Range Facility in 2011, followed by a launch failure three years later.

Some of these setbacks, such as HyFly and the AHV, had nothing to do with the soundness of the hypersonic technologies being studied. Other failures, such as the DARPA flights, yielded increased understanding of aerodynamics and materials. Despite this, even some enthusiastic supporters of high-speed technology have quipped, “Hypersonics is the future—and always will be.”

That view is now changing, due not only to tangible flight successes and
initially powered by a solid rocket motor derived from an Army Tactical Missile System (ATACMS) booster, intended to carry the test vehicle to 4.8 times the speed of sound, then separate and allow the X-51’s main engine to take over. On its last flight, the X-51’s hypersonic “scramjet” engine, built by Rocketdyne, accelerated the craft for 210 seconds, to a final speed of Mach 5.1 before its fuel was exhausted and the vehicle coasted to a planned crash into the Pacific.

In addition to proving the propulsion technology, the X-51 flights represented a triumph of Air Force-led research and design where numerical simulation, using the latest in computational codes for design and analysis, was combined with state-of-the-art ground test and real-world flight experience.

**RAMJETS TO SCRAMJETS**

Hypersonic scramjets were almost six decades in the making. In the late 1950s, Richard J. Weber and John S. MacKay wrote their landmark National Advisory Committee for Aeronautics (NACA) Technical Note 4386 exploring a concept for a new type of aircraft engine—one that could burn fuel in air moving at high Mach numbers. Working at the Lewis Flight Propulsion Laboratory (the precursor to today’s NASA John H. Glenn Research Center at Lewis Field in Cleveland) Weber and MacKay looked at ways to increase the flight speed of a conventional ramjet engine. Though the NACA researchers didn’t know it at the time, engineers in the Soviet Union were working on the same problems.

A ramjet is the mechanically simplest type of jet engine. The development of the modern ramjet dates from the 1920s, though the basic concept was proposed over 100 years ago by the Frenchman René Lorin. By the late 1940s prototype ramjet engines were being tested and flown in Europe and the United States and were later used to power the Soviet Union’s Burya cruise missile, the US Navy’s Gorgon IV missile, and USAF’s Bomarc interceptor.

The ramjet derives its name from the basic operating principle where air is forced into an inlet by the engine’s own motion through the air. On entering the engine, the air decelerates to low relative velocity, resulting in a corresponding rise in pressure and temperature. That hot compressed air moves into a combustor where fuel is injected and mixed. The combination ignites and adds heat energy, resulting in hot gas accelerating through a nozzle to create net thrust. Because the air is compressed by the ramming effect of the engine’s motion, a ramjet doesn’t require a mechanical compressor ahead of the combustor. Without a compressor, there’s no need for turbines, so a ramjet has no primary moving parts.

Because of their dependence on their own motion through the air, ramjets work poorly at low speeds and can’t produce any thrust at all when standing still. As a result, ramjets are generally reserved for supersonic flight, beyond Mach 1, the speed of sound. That means they must be accelerated to operational speed by another kind of engine, such as a rocket motor (in the case of the Bomarc missile) or a gas turbine engine.

Ramjets also perform poorly at very high speeds, above about Mach 4, although the exact limits depend on a number of factors. There are two primary reasons for this performance loss. First, any craft flying faster than the speed of sound generates shock waves—sudden increases in local temperature.
and pressure that create the well-known sonic boom. Shock waves waste energy, adding drag on an airplane but also causing a loss of energy in the ramjet inlet that ultimately reduces thrust. This energy loss becomes increasingly severe at higher speeds.

Another problem has to do with the temperatures associated with the ram compression effect. At extremely high speeds the temperature of the air as it slows down in the inlet can be so high that it’s above the temperature at which fuel burns. When that happens, combustion stops and there can be no energy addition inside the engine—hence, no thrust.

Weber and MacKay asked a simple question: What would happen if the air that enters a ramjet at high Mach number doesn’t slow down much but instead continues to move at high speeds through the entire engine flow path? By keeping the air moving at supersonic speeds, inside the engine, thrust could be produced all the way up the Mach scale. The resulting engine type has the appropriate name of supersonic combustion ramjet, or “scramjet.”

Such an engine makes a whole new realm of atmospheric flight possible, with a corresponding list of possible missions and vehicle applications. However, actually building a practical scramjet proved quite difficult. For example, trying to burn fuel in a supersonic stream has been likened to lighting a match in a hurricane. There is precious little time to inject the fuel, mix it with the air, and burn it to completion.

In a reasonably sized scramjet, the air entering the front of the engine would spend only one or two thousandths of a second in the combustor before exiting through the nozzle. Even if combustion were possible, the very process of adding heat to fast-moving air results in significant energy losses as compared to ramjets.

Despite efforts beginning in the 1960s, including the construction of various scramjet test articles (notably, the pioneering work of Antonio Ferri), these challenges and others delayed the practical development of a scramjet-powered vehicle for more than 45 years. The HyShot research team at Australia’s University of Queensland flew what is generally credited as the first scramjet in July 2002 on the nose of a sounding rocket, though its thrust was less than the overall drag. HyShot was soon followed by two successful flights of NASA’s highly sophisticated X-43 vehicle, proving once and for all that scramjet thrust could be greater than vehicle drag.

Though impressive accomplishments and important steps along the way, both the Queensland work and NASA’s X-43 were powered by scramjets that burned hydrogen and could only operate for a few seconds.

The Air Force’s X-51 took scramjets further by burning a more easily handled jet fuel for almost 3.5 minutes in flight, albeit at a more moderate flight speed. It was the defining breakthrough that may lead the way to practical hypersonic missiles.

USAF continues to invest in hypersonics, including activities at the Air
lead in X-43 and the HyBoLt—Hypersonic Boundary Layer Transition—
aerodynamics experiment. Although hypersonics funding at NASA has been
decreasing in the last few years, the agency recently committed to expand-
ing its research efforts for fundamental science and to providing ongoing test
and modeling support.

Despite these successes, there’s a long way to go to achieving fully operational
weapons systems. Advanced guidance systems, sensors, and warheads will be
required to make practical weapons. Figuring out how to integrate these weapons
with existing or future platforms will be a challenge.

Two DARPA programs, funded in part with USAF dollars, are attempt-

China’s People’s Liberation Army has
boasted of a rocket-powered hypersonic
missile apparently designed to attack
aircraft carriers. Russian leaders, in-
cluding Deputy Prime Minister Dmitry
Rogozin, have voiced strong support for
continued hypersonics development, and
Russia has announced a joint program
with India to develop a hypersonic
successor to the BrahMos supersonic
cruise missile.

The push for practical hypersonic
weapons has been construed by some
as a new arms race, focused on speed.
As Hallion and Bedke have warned,
hypersonic weapon technology is “ripe
for exploitation as a theater and global
strike game changer” but it’s not yet clear
“whether America will own that advan-
tage first.” Though the US is investing
in hypersonics and their maturation, “it
is not on a guaranteed path to near-term
success.” As the authors noted, there’s
still no firm national commitment to a
disciplined plan tackling the remain-
ing hypersonic challenges, let alone a
plan to develop and acquire high-speed
weapons even if planned demonstrations
are successful.

The US has clearly established itself
as the early leader in the hypersonics
field, but it remains to be seen whether
the first practical hypersonic weapons
will bear the markings of the US or the
insignia of some other nation.

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