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Hypersonic Weapons Technology for the Time Critical Ground Mobile Threat

A State-of-the-Art Review

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13. ABSTRACT (<i>Maximum 200 words</i>) As a result of growing concern about threat time critical or mobile targets (TCMT), the Department of Defense (DoD) has recognized the need for ability to place TCMT, with 1 to 15 minute (or less) dwell times, at risk from surface, subsurface, subsurface and/or airborne platforms. This requires the need for a hypersonic weapons capability to deliver lethal payloads at standoff ranges. This document is intended to address the state-of-the-art in the development of hypersonic system development as well as provide some level of operational effectiveness in order to illustrate the advantages of hypersonic velocities.					
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1.0 Introduction

It is predicted that the US will have at least three objectives in any conflict in 2025. These objectives include: (1) delivering decisive blows at the outset of hostilities, reducing the chances of fighting a protracted war, (2) deliver cost-effective weapons to defeat time-critical targets and to establish in-theater dominance, if a protracted war cannot be avoided, and (3) maintain flexible, readily accomplished access to space.

As a result of growing concern about threat time critical or mobile targets (TCMT), the Department of Defense (DoD) has recognized the need for ability to place TCMT, with 1 to 15 minute (or less) dwell times, at risk from surface, subsurface, subsurface and/or airborne platforms. For the most part, DoD has the capability to satisfy such a requirement in situations such as Standing Outside an Enemies Point Defense (SOPD) where shooters stand off about 10 to 15 nautical miles and Standing Outside Area Defense (SOAD) where the shooters launch weapons from about 35 to 150 nautical miles. However, in many cases DoD forces may be restricted to Standing Outside Theater Defenses (SOTD) at ranges of 150 to 600 nautical miles such as in the Gulf war, 1998 weapons inspection crises in IRAQ, or in retaliation against the terrorist bombings outside the U.S. embassies in Kenya and Tanzania in August of 1998. In addition, DoD urgently needs the capability to defeat TCMTs that carry Weapons of Mass Destruction (WMD) while restricted to these operations.

In early 1998, the Navy started a Hypersonic Weapons Technology (HWT) program, which is coordinated with hypersonic programs in the Air Force and Defense Advance Research Projects Agency (DARPA). The HWT program is sponsored by the Office of Naval Research and is aimed at maturing technologies, not in procuring a weapon. The HWT technology development program is based on a Mission Needs Statement (MNS) for A Joint Tactical Strike Capability Against Time Critical or Mobile Targets (TCMT)¹ produced by the Navy.

Today's military technology to deliver ordnance quickly enough to take advantage of the increasing capability in Command, Control, Communication, Computers, and Intelligence (C4I) has not followed suit. Our present force structure lacks the capability to attack the detected targets of opportunity considered time critical. These time critical targets include mobile ballistic missile launchers or military commanders whose whereabouts is considered time critical. This is the advantage of increased speed and range a hypersonic missile will provide.

Basically, the MNS outlines the need for a hypersonic weapons capability to engage time critical targets as well as the high value hard target assets such as, command bunkers buried underground and reinforced by concrete. Not only does hypersonic capability provide the speed and range to engage the time critical assets, but also provides the kinetic energy to penetrate the buried assets as well. Hypersonic weapons are difficult to detect and even more difficult to kill.

The purpose of this document is to review state-of-the-art in hypersonic technology as well as provide some level of many-on-many effectiveness in order to illustrate the advantages of hypersonic speed.

2.0 Hypersonic Technology Programs

There are several Navy, Air Force, DARPA, and NASA programs studying technologies, designs and concepts of operation for hypersonic systems. In addition, several other countries, including France, Russia, Germany, and Japan have all initiated development of Mach 4+ systems for a variety of roles. However, as far as we know no other country, including the U.S., currently fields a hypersonic Mach 4+ system. Hypersonic refers to Mach 3.5 to Mach 8, which is 2700 to 6100 miles per hour.

2.1 Navy

The Navy is currently studying a hypersonic replacement, called Fasthawk, for its Tomahawk cruise missile. The Low-Cost Missile (LCM) program called Fasthawk is expected to cruise at Mach 4 and be capable of striking concrete reinforced targets as deep as 100 feet underground. The Office of Naval Research (ONR) sponsors the Fasthawk program as well as the more recent HWT program. Both ONR programs will feed into the Hypersonic Strike (HyStrike) Program sponsored by chief of naval operations.

2.2 Air Force

The Air Force initiated a Hypersonic Technology (HyTech) program in 1995, to provide a research program on hypersonic technologies. Initially, the program focused on propulsion and airframe systems, but was restructured in 1996 to concentrate solely on engine development. The goal of the program is to ground test a hypersonic scramjet propulsion system by 2003. However, it is reported in an August 13, 1998 issue of Defense Daily, that the Air Force will not be able to produce a hypersonic weapon system before 2015 at the current rate of development. The Air Force Science and Technology Board of the National Research Council's study of the problems of producing and fielding a hypersonic missile found the Air Force lacks both the infrastructure to support such a development and the defined operational requirements that would allow research to go forward².

2.3 DARPA

DARPA is participating in hypersonic weapon development through a program called the Affordable Rapid Response Missile Development (ARRMD) which is envisioned as a multiservice weapon system. In FY 1998, the program plan was to conduct missile concept developments to include manufacturing process definition, propulsion integrated flowpath and manufacturability demonstration. Also under the FY 1998 program, plans included defining flight test plans, affordability assessment, and mission assessments. In FY 1999, the program plans are to complete propulsion

integrated flowpath and manufacturability demonstrations, perform unit cost analysis, and conduct warfighting analysis lab exercises.

2.4 NASA

Hypersonic aircraft is certainly nothing new to the National Aeronautic Space Administration (NASA) with the development of the X-15 back in 1967. The X-15 was rocket-powered and attained a high speed of Mach 6.7. In addition, NASA has acquired some of the retired SR-71 aircraft for study and testing. The SR-71 is the world's fastest air-breathing aircraft, which cruises at speeds slightly above Mach 3. The SR-71 technology was developed in the late 50's, for the Air Force and the aircraft was put into service in 1964 and retired in 1990.

The X-30 National Aerospace Plane (NASP) program has been considered a follow on program to the SR-71. The program initially began as a highly classified, Special Access Required, DARPA project called Copper Canyon, which ran from 1982 to 1985. Copper Canyon originally started out as a feasibility study for a single-stage-to-orbit (SSTO) airplane which could take off and land horizontally³. NASA and the Air Force got involved in phase 2 of the program which is known as NASP. The objectives of phase 2 were intended to develop technologies for a vehicle that could go into orbit as well as travel intercontinental ranges at hypersonic speeds⁴. The actual design, construction and flight test of the aircraft was intended to be phase 3 and originally planned for 1990. However, the program never reached phase 3 and was cancelled in November 1994.

After cancellation of the NASP program, NASA started the Hypersonic Experimental Research Vehicle (Hyper-X) program. The Hyper-X Phase I program goal is to develop and demonstrate technologies for air-breathing hypersonic flight. Hyper-X will leverage off NASP technology, and move toward the next step, which is a demonstration of hypersonic airbreathing propulsion in flight. The first flight is scheduled to fly at Mach 7 in the year 2000⁵. One major difference between the Hyper-X program and the NASP program is the technical approach taken. The NASP program sought to integrate many new, unproven technologies into a full-scale test vehicle. The Hyper-X program approach is incremental starts with propulsion technology⁶.

2.5 Foreign Programs

France is a world leader in ramjet propulsion technology and has developed a ramjet-powered, air-launched, nuclear-armed cruise missile capable of speeds of Mach 3.5 and a range of 186 miles. France is currently investigating a scramjet missile design for a Mach 5+ air-launched strategic missile. In 1995, it was reported that France and Russia started a program to build an experimental variable-thrust scramjet engine capable of speeds between Mach 2 and 12. It was further reported in 1996, that Germany was participating with the French and Russians with the development of scramjet technology⁷.

In Germany, development of a Mach 2.5-4 air-launched weapon called ASS 500 will be delivered in 2015. This weapon is designed as a hard target penetrator and is delivered by an air platform. In addition, the Germans are studying a hypersonic surface-to-air missile for application in a short-range air defense system. This missile will be designed to reach speeds of Mach 5.5 and could be available by 2001⁸.

The Russians, like the U.S., have experimented with Mach 3+ aircraft and cruise missile designs dating back to the early 1950s. They began work on a ramjet-powered delta-wing configuration and conducted a flight test in 1957. In the early 1990s, the Russians began conducting tests of hydrogen-fueled ramjet/scramjet engines as part of a high-speed flight program designed to investigate Mach 5-7 systems for commercial transports, a single-stage-to-orbit spaceplane, and more probable, hypersonic cruise missiles. It has been reported, in November 1991 a test was conducted at a military installation near the Baikonur Cosmodrome in Kazakhstan where a scramjet/ramjet vehicle was launched from atop an obsolete ground-to-air missile. The mission was believed to have lasted about 130 seconds and may have achieved a speed of Mach 8. In 1995, a high-Mach ramjet program called GELA (the Hypersonic Experimental Flying Testbed), an air-launched strategic cruise missile, was unveiled at a Moscow Air Show⁹.

In Japan the National Aerospace Laboratory, the Science and Technology Agency, and Mitsubishi Heavy Industries are undertaking a Space Plane program employing a scramjet engine to achieve hypersonic speeds. The design is planned to be manned capable of taking off as a conventional aircraft, fly into space (low altitude geocentric orbit), perform missions, and return to earth with a conventional landing. The projects' development timeframe is 2005. The Japanese Space Plane is a civilian-oriented program and there is no intention to pursue military weapons based on hypersonic technology¹⁰.

3.0 Development of Enabling Technologies

The U.S. is rapidly advancing in hypersonic technology. The Deputy Administrator, NASA, testified before a joint hearing on the NASP Program in March 1991, that the U.S. is "quite a bit ahead" of Europe and Japan in the development of hypersonic technologies due to U.S. levels of investment. The Director of Defense Research and Engineering, DoD, testified at the same hearing that the U.S. is the "pacesetter" in all hypersonic technologies and is clearly ahead of its competition¹¹.

The U.S. has gained strength in the development of two enabling technologies considered critical in the development of hypersonic flight. These two technologies are air breathing propulsion and advanced materials.

3.1 Hypersonic Air Breathing Propulsion Systems

Hypersonic air breathing propulsion technology is a DoD priority. Air breathing propulsion has the potential, through existing technology programs, to extend military missions to new flight regimes and to provide more cost-effective and on-demand assured access to space. Efforts to enhance propulsion capabilities by establishing programs and research centers will result in major advances in the field of hypersonic air breathing propulsion.

An operational ramjet/scramjet propulsion system is key to designing a hypersonic aircraft/missile. Ramjets operate by subsonic combustion of fuel in a stream of air compressed by the forward speed of the aircraft itself, as opposed to conventional turbojet engines, in which the compressor section (fan blades) compresses the air. However, the scramjet engine is the key enabling technology for sustained hypersonic flight. Scramjets (supersonic-combustion ramjets) are ramjet engines in which the airflow through the whole engine remains supersonic.

An air breathing scramjet engine burns oxygen scooped from the atmosphere. Scramjets, therefore, get their oxygen in the same manner as normal jet engines do. However, there is a limit in altitude because of depleted oxygen by which a scramjet will operate. The altitude limit for scramjets is a function of flight velocity but the useful limit peaks out around 150,000 feet. After this point if the flight is required to go higher in altitude, the engines transition to rocket power. Some vehicle concepts save some of the air during ascent by liquefying and separating out the oxygen for rocket use later in the ascent. An air breathing hypersonic vehicle should be able to carry more cargo/payload than equivalent rocket-powered systems, due simply to having more weight and payload space available because of not having to carry oxidizer on-board.

The scramjet engine has no moving parts; therefore the overall cost of manufacturing it should be fairly low. This is an important consideration in a single-use weapon system. The materials contained in the scramjet/rocket engine mostly drive the

cost of the scramjet. Further reductions in cost are subject to a one-design point of Mach speed. For example, Mach 8 is a desired cruising speed and the inlet to the scramjet will be a fixed geometry designed for Mach 8-freestream velocity.

The ideal design of a hypersonic vehicle might incorporate one propulsion system which would be an air breathing scramjet. However, the drawback of a scramjet is its inability to function at low speeds¹¹. Scramjets need the supersonic airflow before they can sustain hypersonic cruising speeds. Currently, the only way to achieve this would be to incorporate a booster motor such as a rocket or turbojet. Rockets have excellent acceleration characteristics but poor cruising characteristics. The rocket system, with high initial acceleration, will be used to boost the platform up to a speed and altitude where the scramjet becomes efficient. Limited trade studies have shown optimum altitude of 100,000 feet and mach 6 for the transition from rocket propulsion to scramjet power¹². The scramjet will keep the platform at its altitude and speed until reaching descent point for the target. Unlike the air breathing propulsion systems, rockets require their own oxidizer fuel supply. The air breathing systems only need the supply of hydrogen, and the oxygen comes from the atmosphere.

A low-speed air-breathing concept without rocket acceleration would probably include a turbopropulsion system. However, a turbojet cannot provide the quick boost of acceleration to scramjet operating speed and altitude that a rocket can. The high acceleration is desirable to reduce mission time and increase survivability. If there is a requirement for quick response time and a long range, a combined propulsion system like the rocket and scramjet combination is a must.

The Japanese are conducting several analytical investigations and experimental programs involving component testing and demonstration engines on several aerospace plane advanced propulsion systems, including a turbojet, ramjet, turboramjet, air-turboramjet, liquid air cycle engine, and scramjet. The propulsion systems of primary interest to the Japanese are (1) those in the mach 3 to 6 range for hypersonic cruise airplanes and single-stage-to-orbit space launch vehicles, (2) strap-on booster augmentation engines for vertical launch systems, and (3) air breathing engines for a high-speed commercial transport aircraft.

3.1.1 Fuels

The fuels used to power a hypersonic platform depend on the motor design. Endothermic hydrocarbons such as the kerosene rich JP-8 or Jet A fuels used in turbojet propulsion systems may support a design which limits the vehicle to a maximum mach number of 8¹³. The first stage of the Saturn V rocket was fueled by kerosene and LOX (liquid oxygen) and managed to propel the massive vehicle to a speed just above mach 8 before first stage burnout¹⁴. However, rocket engines require a supply of LOX on board the platform and are limited in range. Liquid hydrogen and LOX are also used to fuel other rocket engine designs as well.

The ramjet/scramjet engines use hydrogen and oxygen. As previously mentioned, these engines get the oxidizer from the oxygen scooped up from the atmosphere. One report discussed the flameholder and fuel injector design of the scramjet must be highly advanced in design to successfully mix the fuel and airflow and fully combust it in the chamber for the most efficient burn. This is critical at high mach numbers. One solution to this is to use highly reactive fuels (such as hydrocarbons with 20 percent ethyl decaborane). Reactive fuels spontaneously combust when mixed with the airflow, thus eliminating the need for flameholders. This would enhance the performance of the engine by reducing the drag and flow problems caused by the flameholders. However, one problem with reactive fuels is safety of storage and maintaining them as well as their high cost when compared to conventional fuels.

3.1.2 Testing

Scramjet technology is challenging because only limited testing can be performed in ground facilities. As of 1992, it was reported that ground test facilities cannot simulate flow conditions above mach 8, especially for testing the propulsion system¹⁵. Scramjets are expected to achieve speeds of mach 25 and sustained cruise in the atmosphere in the mach 5 to 14 range and at altitudes of up to 150,000 feet.

By 1992, the U.S. was the only country that has gone beyond the initial design phases and tested major subscale air-breathing aerospace plane components¹⁶. For example, during the NASP program major components of subscale scramjet were tested up to speeds of mach 17 and simulated the airflow within a scramjet up to speeds of mach 24. Also at that time, large-scale ramjet and scramjet models had been tested up to mach 5 and plans were to go up to mach 8¹⁷.

Because today's requirements are demanding more realistic testing of integrated propulsion/airframe aerodynamics and extreme hypersonic environments, significant improvements are being made to existing wind tunnel facilities. NASA's Langley Research Center in Hampton, Virginia is undergoing renovations and upgrades to eight facilities used for aerodynamic and aerothermodynamic research on advanced aerospace vehicle configurations¹⁸. Performance capabilities will include:

- temperatures up to 1,050°F
- mach numbers from 6 to 22
- Reynolds numbers from 0.1 to 15 million/ft
- normal shock density ratios from 4 to 12

Key features will include:

- multiple model support and injection/retraction systems
- air supply system heater bundles for temperatures to 1,050°F
- flowfield survey and pitot probe systems
- installation of mach 8 and mach 12 nozzles and mach 10 nozzle throat

- high capacity helium heater for temperatures to 600°F
- model cooling system
- test section evacuation line
- vacuum pumping system

The U.S. Air Force Arnold Engineering Development Center in Tullahoma, Tennessee has a large scale, world-class, supersonic/hypersonic aerodynamic and aerothermal test complex, which delivers high productivity and excellent flow qualities. The facility is comprised of one supersonic and two hypersonic wind tunnels featuring continuous flow, closed circuit, and variable density¹⁹. Performance capabilities are listed below:

- Tunnel A, supersonic, aerodynamic
 - mach numbers from 1.5 to 5.5
 - temperatures from 90° to 260°F
 - Reynolds numbers from 0.41 to 8.50 million/ft
 - dynamic pressure (lb/ft²) from 50 to 1800
 - stagnation pressure (psia) from 6 to 148
- Tunnel B, hypersonic, aerodynamic
 - mach 6 or 8
 - temperatures up to 890°F
 - Reynolds numbers from 0.4 to 4.7 million/ft
 - dynamic pressure (lb/ft²) from 72 to 634
 - stagnation pressure (psia) from 40 to 850
- Tunnel C, hypersonic, aerodynamic/aerothermal
 - mach 4, 8, or 10
 - temperatures up to 1,4440°F
 - Reynolds numbers from 0.3 to 7.8 million/ft at mach 4, from 0.5 to 7.2 million/ft at mach 8, and from 0.3 to 2.3 million/ft at mach 10
 - dynamic pressure (lb/ft²) from 72 to 1,944 at mach 4, from 144 to 1,224 at mach 8, and from 43 to 432 at mach 10
 - stagnation pressure (psia) from 20 to 180 at mach 4, and from 200 to 1,900 at mach 8 and 10

Key Features include:

- 40 in. x 40 in. test section with computer-controlled flexible nozzle in Tunnel A
- 50 in. diameter test section in Tunnel B
- 25 in. diameter test section with mach 4 and mach 8 nozzles and 50 in. diameter test section with mach 10 nozzle in Tunnel C
- open circuit mode for tests requiring injection of foreign gases into airstream
- model injection systems with pitch and roll mechanisms, allowing model access with tunnel in operation
- captive trajectory store separation systems

- natural-gas-fired combustion heaters and electrical resistance heaters
- integral, external water jacket coolers
- support systems
 - 1,500 lb. vertical load in Tunnels B and C; 3,500 lb. in Tunnel A
 - 1,000 lb. horizontal load in Tunnels B and C; 1,500 lb. in Tunnel A
- 92,500 hp air compressor plant

A Science Daily News release²⁰ posted September 4, 1998 announced the first hypersonic propulsion hardware for NASA's Hyper-X program had been delivered for testing. It is a 30 inch long scramjet engine and is the first program hardware to be completed and will be used in high-speed ground tests at Langley Research Center in Hampton, VA. An identical scramjet engine will be integrated with the X-43 flight vehicle in February 1999 and the first flight test of the program is scheduled in early 2000.

Under the Hyper-X program, three flight tests are planned -- two at mach 7 and one at mach 10. Depending on the mission, the vehicles will be launched from a B-52 at an altitude of 19,000 to 43,000 feet and boosted by the first stage of a modified Pegasus booster rocket to a speed of mach 7 or 10 and at an altitude up to 100,000 feet. Once achieving the altitude and speed, the booster will separate and the vehicle is expected to fly a sustained cruise velocity under scramjet power. The X-43 will be the first free-flying demonstration of an airframe-integrated, air-breathing engine and will extend the flight range to mach 10²¹.

3.2 Advanced Materials

The second most enabling technologies considered critical in the development of hypersonic flight is advanced materials. Materials must be high-strength, lightweight, reusable, and more importantly can withstand extremely high temperatures. These advanced materials include carbon-carbon composites, carbon-fiber, ceramics, titanium-based alloys, beryllium-based alloys, fiber composites, and titanium aluminide produced either conventionally or by rapid solidification technology²².

The Japanese are one of the world's leaders in advanced material technology. According to DoD, ongoing R&D in Japan in the following areas indicate technical capability with leadership in some areas of advanced materials technology. This makes for important contributions to meeting U.S. challenges and goals in advanced development of composite materials capable of retaining structural properties at high temperatures; development of improved nondestructive evaluation techniques for advanced composites; and improvements in modeling and life prediction²³.

According to DoD, the U.S. is judged to be the world's leader in composite materials, but trend indicators show that Japan's capability to develop composite materials is increasing at a rate faster than that of the U.S. Also, trend indicator show that Japan's capability to develop improved nondestructive evaluation techniques for

advanced composites and improve modeling and prediction of life-cycle failure is increasing at a rate similar to the U.S. However, according to DoD the U.S. has the overall lead in the design and effective use of advanced composite materials in specific military applications²⁴.

3.2.1 Structures

The development of high-strength, lightweight materials for the structural development of airframes and propulsion systems is high priority. These airframes are required to bear load-carrying properties as well as the extreme thermal protection from the pressures and heat generated from hypersonic velocities.

NASA, under the NASP program was developing advanced Diboride Ceramic Matrix Composites (CMC), including Zirconium Diboride and Hafnium Diboride materials which are reportedly able to withstand repeated exposure to temperatures of 3,660 °F and 4,130 °F, respectively²⁵. Titanium and nickel based super alloy materials possess good properties at high temperatures, but not to the extreme as 3000 °F. These material technologies certainly lend themselves in the development of proposed hypersonic weapon systems.

Aerothermal heating which is caused by friction of air passing the weapon body, is one area of intensive research. For a hypersonic vehicle, at mach 4 as it passes through the lower atmosphere in the terminal phase of its flight, its surface reaches about 1200 °F. At mach 6 the temperature can exceed 2800 °F and at mach 8 over 5600 °F. Structural materials, as well as internal temperature control will be the challenges in the development of these systems. These advanced materials must have advanced heat dissipation properties. In addition to the extreme temperatures, mechanical loading due to aeroacoustics on the structure will also present technical challenges.

3.2.2 Technology issues

According to NASA, temperatures for any vehicle will peak at speeds of about mach 15. Officials say 5,000 degrees F corresponds to the maximum heating of an uncooled vehicle and 4,000 degrees would still be too high a temperature for the same vehicle even with active structural cooling. According to some U.S. experts in hypersonics, 5,000 degrees F is too high a temperature for most airframe or engine materials to withstand without active cooling. Even with the advanced heat-resistant materials, the areas of a platform (nose cone, wing, tail, engine cowl leading edges, and the inside walls of the engine combustion chamber) would be actively cooled.

Structural and material technology has been advanced through the fabrication and testing of small and large-scale components. For example, McDonnell Douglas Corporation has built a full-size (8 x 8 x 4 feet) X-30 (NASP) fuselage section from silicon carbide-reinforced titanium and manufactured a 900-gallon cryogenic hydrogen

fuel tank from a graphite-epoxy composite and installed it in a titanium aluminide composite structure representative of a segment of the X-30's fuselage. The tank-fuselage assembly was instrumented and tested. Other structures being tested include wing sections, fuselage panels, elevons, and actively cooled panels.

General Dynamics Corporation has fabricated and tested large, oxidation resistant coated carbon-carbon composite structures, but according to U.S. aerospace industry representatives, carbon-carbon composites still lack the strength to be used as structural materials. Nonetheless, manufacturing and coating techniques for advanced (very high-temperature) carbon-carbon composites are progressing well. The carbon-carbon materials are strong, lightweight, and heat resistant. Under the NASP program, other technology developments and testing included vehicle flight controls; the production, handling, and storage of slush hydrogen; and special high temperature instrumentation.

Back in 1990 the NASP National Program Office selected a single composite design configuration for the X-30 from multiple concepts: a lifting body incorporating short wings, twin vertical stabilizers, a two-person dorsal crew compartment, and three to five scramjet engine modules incorporating a small rocket.

4.0 Hypersonic Weapon System Effectiveness

In this section, we will present the results of a limited set of parametric simulation runs in order to illustrate the advantages in operational effectiveness of a hypersonic weapon system against the time critical target scenario. The GENERIC Smart Indirect fire Simulation (GENESIS) was used to simulate the various scenarios.

GENESIS is a generic many-on-many (M-on-N), indirect fire submunition (IFSM) weapon system endgame effectiveness simulation. It is a Monte Carlo simulation and allows evaluation of multiple systems, concepts, and technologies in the context of a single, generic simulation. Effectiveness simulations are used in many studies and analyses throughout DoD.

GENESIS provides system effectiveness results. Here, System effectiveness describes (1) the ability of the IFSM weapon system to perform its mission in terms of the number of kills achieved by a given volley and (2) measures such as number of encounters, detections, engagements, and hits as well as kills. The determination of system effectiveness is based on the performance of all elements making up the weapon system, including C³I/RSTA, launchers, carriers, and smart munition, and their interaction with the targets and battlefield.

4.1 Time Critical Target Scenario

The time critical scenarios consist of a transporter erector launcher (TEL) single target, which has the capability to shoot and move in less than 10 minutes. Upon firing a theater ballistic missile (TBM), detection occurs and the fire mission (C3) is sent to the hypersonic launching platform and fired toward the targeting position. As the hypersonic missile will egress, the TEL executes march orders and moves out. Therefore as a function of time, the distance traveled from the original aimpoint is defined as the moving target uncertainty (MTU) radius. The figure below illustrates the scenario.

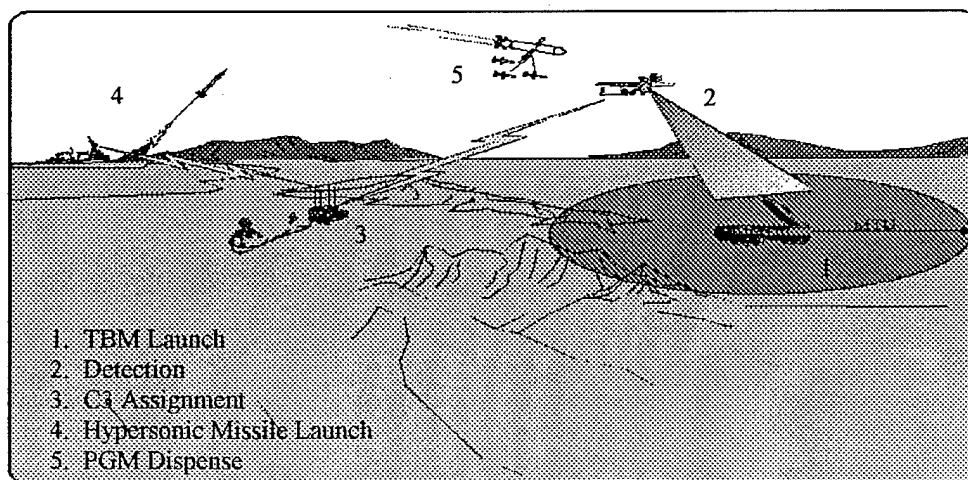


Figure 1 Shoot and Scoot Scenario

The equation representing the MTU is presented below:

$$MTU = v_{TEL} \cdot (t_f + t_{c3} - t_{TEL})$$

Time of missile flight = t_f

Time for targeting (C3) = t_{c3}

Time for TEL to start travel (dwell time) = t_{TEL}

Velocity of TEL = v_{TEL}

Below are subsequent tables listing the results of MTU calculations based on various timelines. The time data, t_{TEL} and t_{c3} , was based on results from Time Critical Target Technology Study²² presented in May 1998. The velocity of the scud launcher used in this scenario is 30 miles per hour (48 km per hour).

Table 1 MTU in meters for $t_{TEL}=2$ minutes, $t_{c3}=3$ minutes

Flight Distance (miles)	Missile Speed (mach)		
	4	5	6
400	7080	5950	4990
500	8690	7080	6115
600	10330	8400	7155
700	11920	9700	8215

Table 2 MTU in meters for $t_{TEL}=5$ minutes, $t_{c3}=3$ minutes

Flight Distance (miles)	Missile Speed (mach)		
	4	5	6
400	4740	3472	2625
500	6330	4740	3680
600	7920	6010	4740
700	9505	7280	5800

Table 3 MTU in meters for $t_{TEL}=7$ minutes, $t_{c3}=3$ minutes

Flight Distance (miles)	Missile Speed (mach)		
	4	5	6
400	3130	1860	1020
500	4720	3130	2075
600	6310	4400	3130
700	7900	5670	4200

Table 4 MTU in meters for $t_{TEL}=2$ minutes, $t_{c3}=2$ minutes

Flight Distance (miles)	Missile Speed (mach)		
	4	5	6
400	6350	5080	4234
500	7940	6350	5290
600	9530	7620	6350
700	11100	8890	7410

Table 5 MTU in meters for $t_{TEL}=5$ minutes, $t_{c3}=2$ minutes

Flight Distance (miles)	Missile Speed (mach)		
	4	5	6
400	3940	2670	1820
500	5530	3940	2880
600	7110	5210	3940
700	8700	6480	5000

Table 6 MTU in meters for $t_{TEL}=7$ minutes, $t_{c3}=2$ minutes

Flight Distance (miles)	Missile Speed (mach)		
	4	5	6
400	2330	1060	210
500	3920	2330	1270
600	5504	3600	2340
700	7100	4870	3390

The data in the tables show the trend in a reduction of the MTU with an increase in mach speed of the missile. Furthermore, even further reduction in MTU as the target dwell time (t_{TEL}) increases. This should be no surprise since the longer the target dwell time the less time the target spends on the move, therefore reducing the overall distance traveled.

The hypersonic weapon system is modeled as a delivery of smart munitions payload. Three generic smart munition concepts (figures 2a, 2b, and 2c) were modeled against the above target scenario: (1) Sensor Fuzed Munition (SFM) concept 1 (2) Sensor Fuzed Munition (SFM) concept 2 and (3) Terminally Guided Munition (TGM).

Concept 1 is a generic representation of the Army's Sense And Destroy ARMor (SADARM) munition with a 130 meter radius footprint. The hypersonic carrier for this concept contains 48 submunitions. The dispense pattern is a 1500 meter x 1500 meter circular area.

Concept 2 is similar to the Navy/Air Force Joint Stand-Off Weapon (JSOW). For this analysis, the hypersonic carrier contained 12 canisters each containing 4 projectiles for a total of 48 projectiles. The dispense pattern is a 1500 meter x 1500 meter circular area.

Concept 3 is a hit-to-kill terminally guided munition similar to the Army's millimeter wave Terminally Guided Weapon (TGW) or the Brilliant Anti-armor Submunition (BAT) Preplanned Product Improvement (P3I). The dispense pattern is called a spoke or rose pedal pattern, with 13 subs distributed on a 2400 meter radius and 13 subs distributed on a 4800 meter radius, flying toward the center.

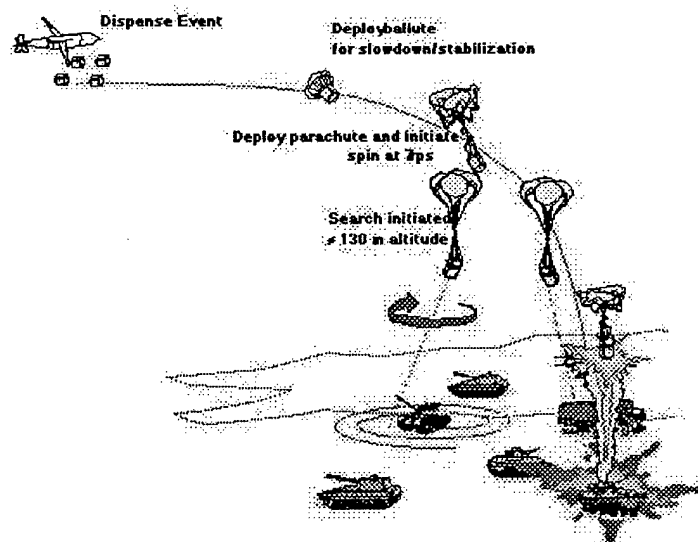


Figure 2a Sensor Fuzed Munition - Concept 1

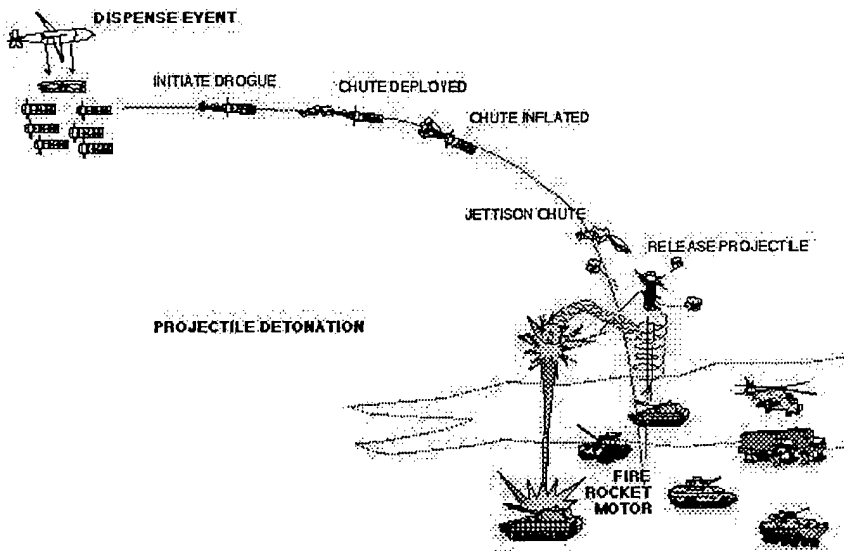


Figure 2b Sensor Fuzed Munition - Concept 2

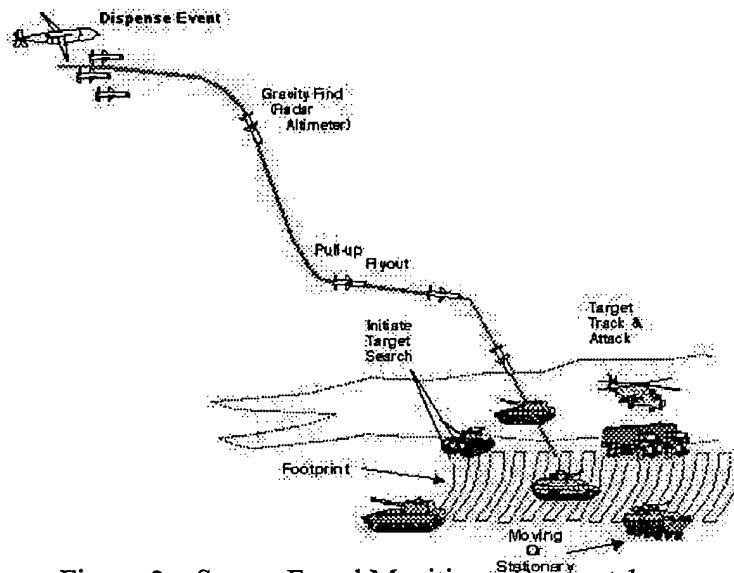


Figure 2a Sensor Fuzed Munition - Concept 1

Figure 2c Terminally Guided Munition - Concept 3

The following figures 3a - 3c illustrate the dispense pattern and coverage used for each concept. It becomes apparent from these figures as to why the effectiveness trends tend to improve from concept 1 to concept 3 because of the amount of area coverage.

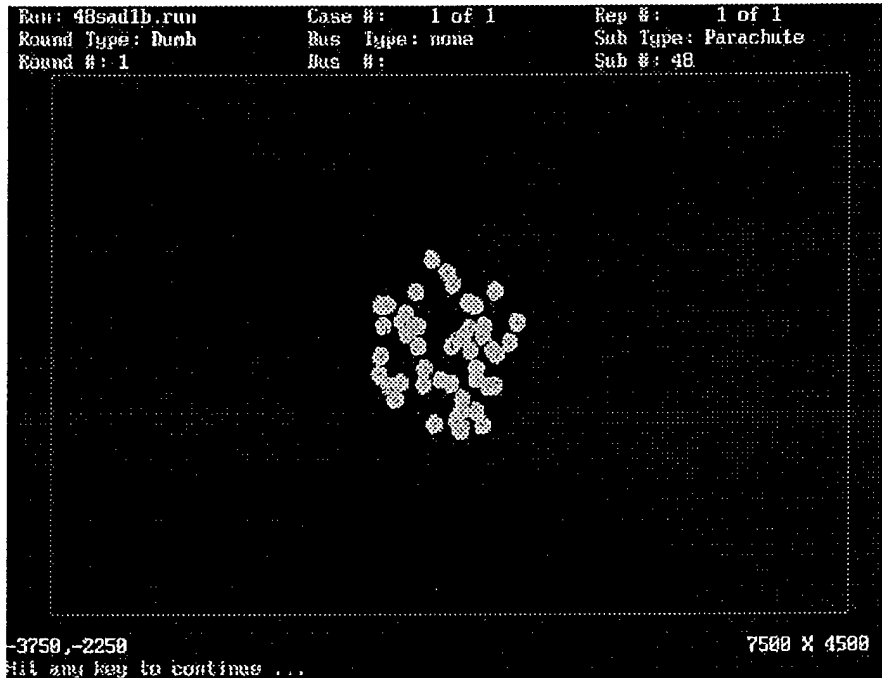


Figure 3a Concept 1 Dispense and Area Coverage - 7500 x 4500 meter battlefield

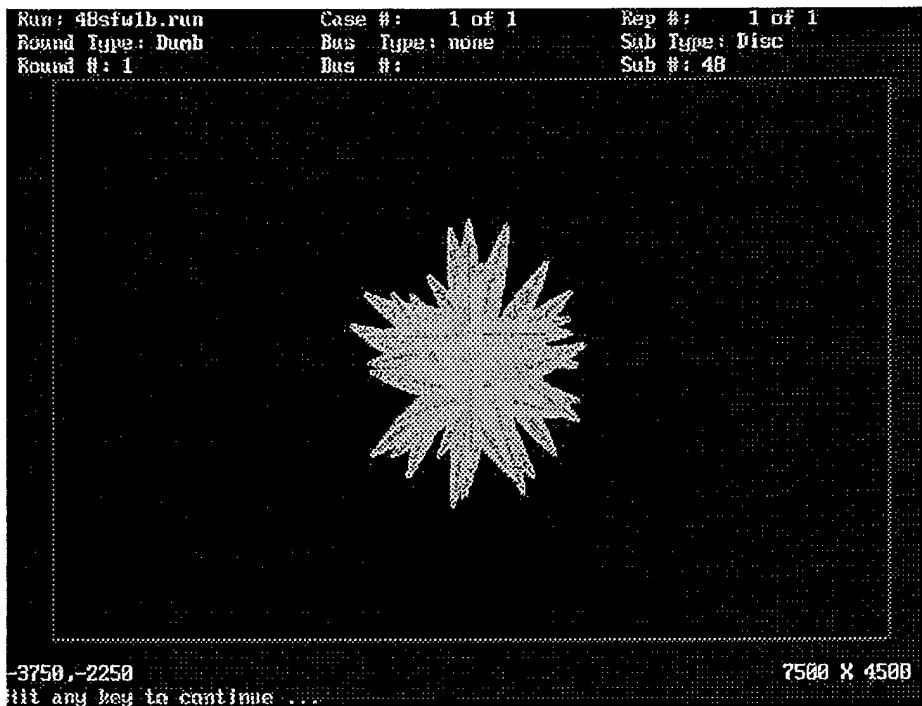


Figure 3b Concept 2 Dispense and Area Coverage - 7500 x 4500 meter battlefield

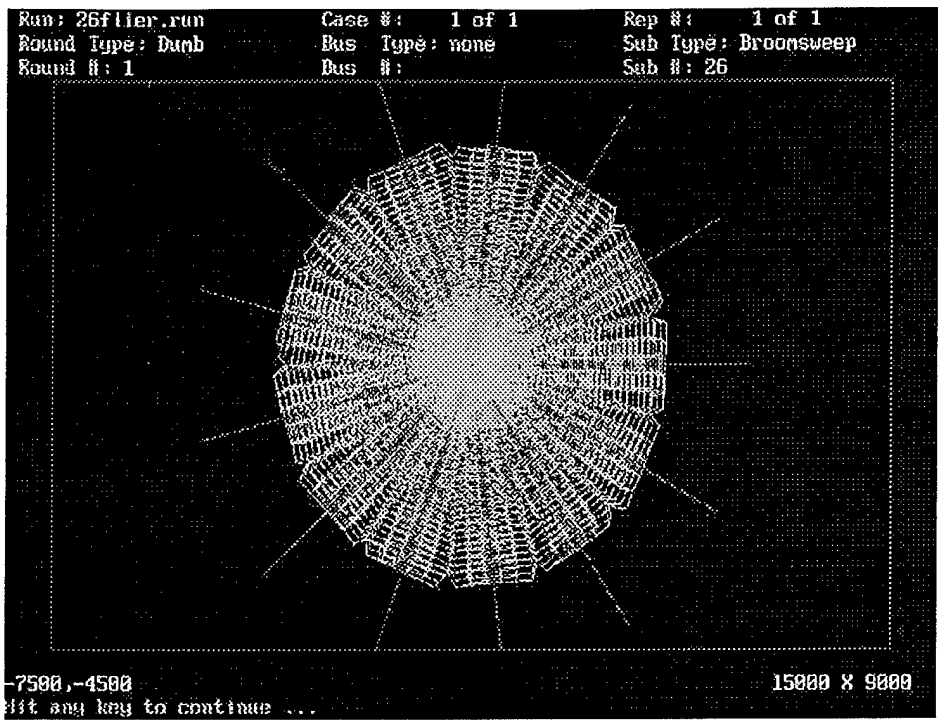


Figure 3c Concept 3 Dispense and Area Coverage - 15000 x 9000 meter battlefield

4.2 Results

Below (figure 4) are the results of operational effectiveness as a function of MTU against the single time critical target scenario. The base line case represents perfect reliability and performance numbers, whereas the actual case represents some degradation in reliability and performance. Please note these are generic representations of the submunition concepts. Also, note the value of MTU is defined here as the range of uncertainty by which the target can move. For example, an MTU value of 1000 meters means the target can be randomly located per replication at some point between 0 and 1000 meters. These results are based on 500 monte-carlo replications.

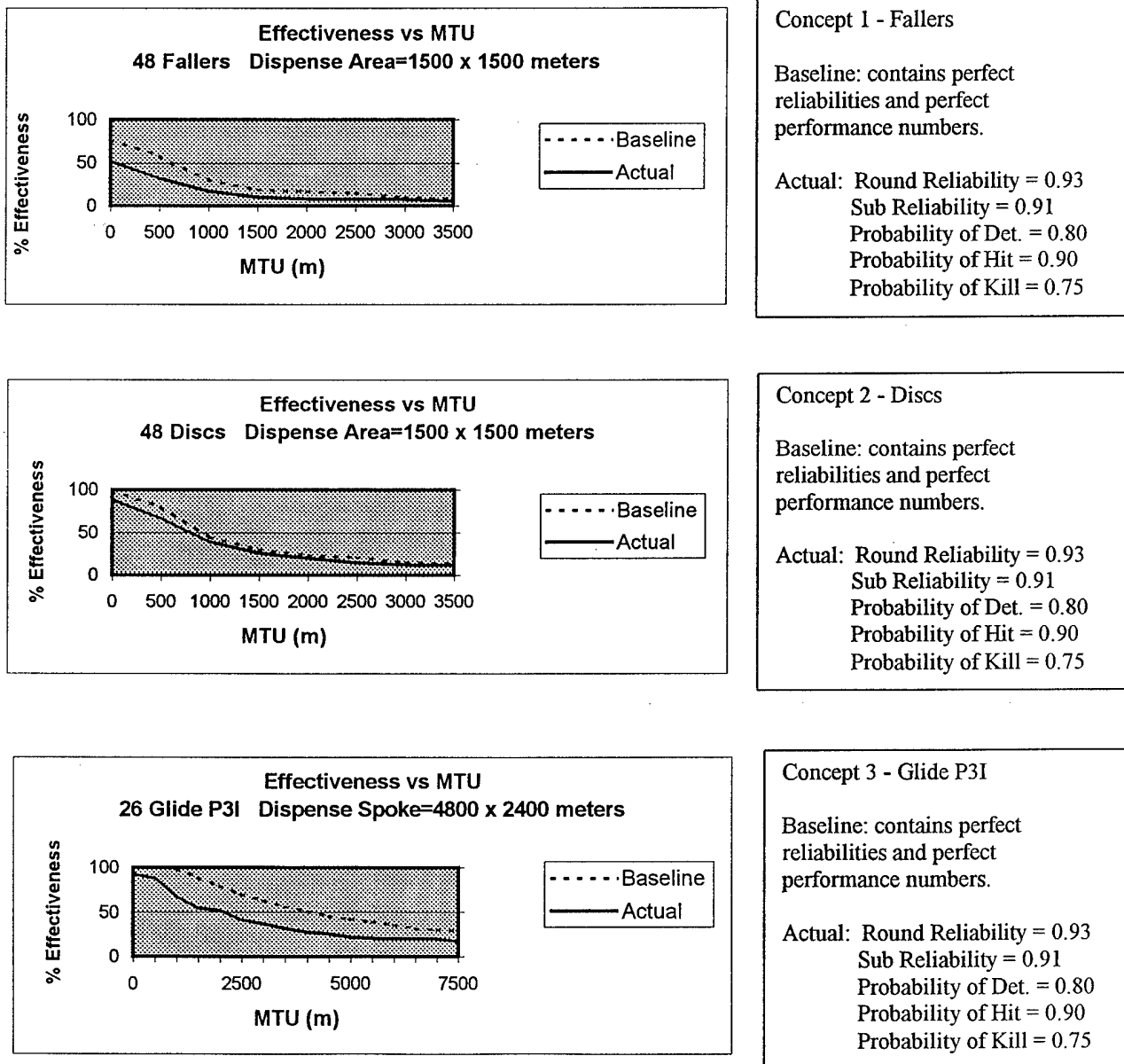


Figure 4 Operational Effectiveness Results

The results show that concept 3 provides the best operational effectiveness against this target array over an MTU domain twice that of the other 2 concepts. These results clearly illustrate that the amount of area coverage by the volley of submunitions produces the best performance.

We can conclude that given a dwell time of 2 minutes and a C3 time of 3 minutes (see table 1), a hypersonic carrier traveling mach 6 over a distance of 400 miles can achieve a 20% effectiveness if dispensing 26 glide P3I submunitions. As the target dwell time increases, then MTU values decrease thus improving effectiveness over a broader range of flight distance for a mach 4 to mach 6 system.

4.3 Payload Dispense

In the world of hypersonic weapons technology, consideration is that these systems be developed with varied capabilities to be able to attack multiple types of target arrays. These target arrays will include the single time critical arrays, assembly areas, aircraft hangers, etc. Therefore, there will exist a variety of different payloads and ordinance based on the target type, required effectiveness, and cost. Possible payloads include penetrating rods, flechettes, conventional bombs, self-guided (smart) antiarmor munitions, subnuclear munitions, and whatever is developed in future years.

The standard payload area of the hypersonic carrier should be able to accept a variety of different weapons and clusters or weapons. It should be capable of striking not only multiple targets in one sortie, but striking different target types with the various types of munitions it can carry.

There are issues associated with dispensing a payload of submunitions while traveling at hypersonic velocities. It may be required the hypersonic carrier slow down before dispense or dispense canisters, which will slow down and dispense the submunitions. Efforts are ongoing to address and solve the problem of shock/shock interactions associated with two objects flying in close proximity at hypersonic velocities²³.

5.0 Summary

According to U.S. experts in hypersonic propulsion, propulsion technology is the best indicator of where a country intends to go in future hypersonic vehicle applications. Unlike materials technology, for example, hypersonic propulsion has virtually no spinoff to other applications. Thus, hypersonic propulsion is a clear indicator of the future markets a country intends to capture. Hypersonic air-breathing (primarily scramjet) propulsion technology is a DoD high priority effort. According to DoD, foreign activity in the development of hydrogen-fueled scramjets is not comparable to the U.S. level of activity starting during the NASP Program.

It is clear that operational effectiveness is significantly improved, given a hypersonic capability, against the time critical target. Hard target effectiveness, such as reinforced command bunkers buried beneath the ground, is also improved with the hypersonic weapon due to the fact that energy is proportional to the velocity squared. However, in addition to the propulsion and materials technology other issues associated with flow dynamics, guidance and control, and survivability will present challenges in the development of hypersonic systems.

A hypersonic cruise missile/delivery system with sustained cruise capability between speeds of mach 4 and 15 can enhance military capability by carrying out potential missions, such as interdiction, continuous operations (CONOPS), reconnaissance, surveillance, precision targeting and weapons guidance, strategic bombing, and strategic airlift.

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