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Hypersonic Weapons

The proprieties of sound have fascinated humans for a long time. The first known theoretical treatise on sound was provided by Sir Isaac Newton in his *Principia* (1687). Since then, scientists have been researching on quantifying the speed of sound. The speed of sound estimated by Newton was around 15 per cent less than the actual (the standard value for speed of sound[1] has been decided based on the experimentation carried out during 1963). On 14 October 1947, the sound barrier was broken for the first time in a manned level flight in a Bell X-1, piloted by Chuck Yeager. With this began the age of the supersonic aircraft. Objects which move at supersonic speeds[2] actually travel faster than the speed of sound. Many modern day military aircraft fly at supersonic speeds; and so does a bullet fired from a gun. The space shuttle also flies at supersonic speeds during parts of its mission. Even the passenger aircraft Concorde (1976–2003) used to fly at supersonic speeds. The London to New York flight used to take around 3 hours against the routine flying time of 8 to 9 hours on a regular flight.

Essentially, since the invention of an aircraft, speed has been central to various developments for flying machines (space crafts, unmanned vehicles, missiles, etc). Over the years, significant progress has been made to ensure that the flying platforms (manned or otherwise) move with great speeds. Along with speed, manoeuvrability is also an important element in designing any flying machine. The process of evolution of flying machines witnessed a major breakthrough during the early years of the 21st century: on 16

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1 The speed of sound is the distance travelled per unit time by a sound wave while propagating via an elastic medium. This speed depends on the tempterature of the air, and at 15°C (at sea level), it is about 1,225 km/h, while in dry air— say at 20 °C— it is 1,236 km/h. Broadly, it could be said that a distance of one kilometre gets coverd in 3 seconds.

2 Supersonic speed is the rate of travel of an object that exceeds the speed of sound (Mach 1).

November 2004, the National Aeronautics and Space Administration (NASA), the famous US space agency, flew the X-43A aircraft nine times faster than the speed of sound (Mach 9.6).[3] When such high speeds are reached by any flying platform, they are termed hypersonic vehicles.

Theoretically, speeds that are five times higher than the speed of sound (Mach 5) belong to the category of hypersonic. The term hypersonic was coined by an aerodynamic engineer called Hsue-shen Tsien at the California Institute of Technology (Caltech) in 1946.[4] This paper discusses hypersonic platforms, mainly in the context of their military relevance.

About the Hypersonic

The 21st century is witnessing various asymmetric threats. There have been cases when even a truck has been converted as a weapon to kill—for example, in Nice, France (14 July 2016), a truck was deliberately driven in a crowed place, killing more than 80 people. Also, the world witnessed one of the most horrific terror attacks in history, on the World Trade Centre (9/11) in which the platform of a passenger aircraft was converted into a weapon. Even a satellite can be converted into a weapon platform if it is armed with weapons such as Tungsten rods for a kinetic bombardment or a kinetic orbital strike. Alternatively, a small satellite like a nano or micro satellite has the potential to also get used as a space mine to damage a target satellite. Apart from such weapon platforms, there are occasions where missiles do not carry any specific warheads but only metal pieces to hit targets, and may be described as kinetic energy weapons. Such weapons could be launched from a missile silo or from other platforms. Normally, a vehicle occupied by humans could also be considered as a platform. Even supersonic speed aircrafts are occupied by humans, though not always. Platforms which travel at hypersonic or super-hypersonic speeds (normally in space) are known as space-craft or space planes/shuttles. Sometimes they are occupied by humans.

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3 http://www.livescience.com/37022-speed-of-sound-mach-1.html#sthash.MBP21t9w.dpuf, accessed 2 Jun 2016.

4 T. A. Heppenheimer, *Facing the Heat Barrier: A History of Hypersonics*, NASA History Division, Washington, DC, September 2007, p. 9.

In any discussion about the hypersonic, the words platform/s and weapons are used interchangeably. There is a very thin line between hypersonic systems and hypersonic missiles. Presently, the strategic utility of hypersonic technology is mainly in the realm of missiles, and lesser attention is being given to developing hypersonic military platforms which would be occupied by humans. However, private industry is known to be developing space planes for human travel for the purposes of promoting space tourism.

To appreciate the conceptual design of a hypersonic platform, a detailed assessment of various geometrical configuration parameters affecting the aerodynamic performance of the vehicle is required to be carried out.[5] Some important details about the nature of hypersonic technology have been discussed in the following sections of this paper.

A Hypersonic Platform

Anything that moves through air reacts to aerodynamics; and the rules of aerodynamics explain how platforms in air are able to fly. The speed of sound varies in response to the temperature of the surrounding air. Sound waves are known to move faster through warmer air. The speed required to break the sound barrier decreases higher in the atmosphere, where temperatures are colder.

Hypersonic is the study of flight at speed where aerodynamics heating dominates the physics of the problem. Typically, this is Mach 5 (Mach 1 is equal to the speed of sound in air) or higher, and is closely linked with the engine design.[6] This speed regime can be further divided into two parts. The speeds in the range of Mach 5 and Mach 10 are simply referred as the 'hypersonic speeds', and the one in the range of Mach 10 to Mach 25 are

[5] A. K. Sreekanth, *Aerodynamic Predictive Methods and their Validation in Hypersonic Flows*, DRDO Monographs Series, DESIDOC: New Delhi, 2003, p. 2.

[6] Young, Donald F.; Bruce R. Munson; Theodore H. Okiishi; Wade W. Huebsch (eds.), *A Brief Introduction to Fluid Mechanics*, New Jersey: John Wiley & Sons, 2010, p. 95.

known as 'high-Hypersonic Speeds'. Table 1 below provides some useful details above various 'categories' of speed.

Table 1 Categories of Speed

Speed Regime	Mach	km/h	Application
Subsonic	<0.8	<980	Commercial aircraft, Turbofan, turbojet planes
Transonic	0.8-1.2	980-1,470	Jet Aircraft, cruise missiles
Supersonic	1.2-5.0	1,470-6,150	Aircraft, Cruise missiles, anti-missiles systems
Hypersonic	5.0-10.0	6,150-12,300	Re-entry vehicle, Short range Ballistic Missile, Hypersonic Cruise missiles, hypersonic aircraft, Inter-continental ballistic missile, boost-glide vehicles[7]
High-hypersonic	10.0-25.0	12,300-30,740	Re-entry vehicle, ICBM, Advance Hypersonic vehicles, Boost-glide vehicles
Ultrasonic	>25.0	>30,740	Re-entry vehicle

Source: Based on various web inputs

Hypersonic platforms have two main categories depending on the type of engine they use. Hence, both air-breathing and rocket-based systems

7 Boost-glide trajectories are a class of spacecraft guidance and re-entry trajectories that encompass the range of suborbital space planes and re-entry vehicles by employing aerodynamic lift in the high upper atmosphere. Boost-glide approximately doubles the range over the purely ballistic trajectory. Fundamental aerodynamic concepts have been used to produce manoeuvrable re-entry vehicles (MARV), to increase the accuracy of some missiles. Source: based on information available on internet.

are categorised as hypersonic systems if they move with a velocity at or above Mach 5. Non-rocket-based systems involve high-speed propulsion, and this has led to the development of the concept of scramjet as an advanced air breathing ramjet. For hypersonic platforms, heating is very intense at the altitude for atmospheric re-entry, and various platforms are required to have adequate thermal protection for this purpose.

Broadly speaking, vehicles with hypersonic air breathing propulsion systems offer various advantages—like rapid response at long range, increased manoeuvrability, better survivability, and assured access to space. Historically, rocket boosters have been used to propel hypersonic vehicles for applications such as space launch, long-range ballistic flight, and air-defence interceptor missiles. Air breathing propulsion systems are expected to provide a means for sustained and accelerating flight within the atmosphere at hypersonic speeds. Hypersonic propulsion systems can be categorized as liquid- and solid-fuelled rockets, turbojets, ramjets, ducted rockets,[8] scramjets, and the dual-combustion ramjets (DCR).

All existing hypersonic systems use either liquid or solid rockets as their propulsion system. As with liquid fuelled rockets, solid-fuelled rockets carry both fuel and oxidizer—either separately in liquid fuel tanks or combined within a solid propellant grain—which are burned within a high-pressure chamber to produce hot gaseous products that are expanded through an exhaust nozzle to produce thrust. Both types of rocket systems have drawbacks. Liquid engines typically operate with either cryogenic or toxic storable propellants, while solid propellant systems usually cannot be throttled or stopped and restarted. Some of the drawbacks of pure rocket motors—mainly the inefficiency of carrying all required oxidizers

8 A solid propellant Ducted Rocket is a hybrid type propulsion system, comprising of a solid propellant rocket motor with an inlet air duct. The rocket motor contains a solid propellant of low oxidizer content which, upon burning, releases a fuel-rich gas into an afterburner section. DUCTED rocket engine (DRE) is one of the promising ramjet propulsion systems for the next generation missiles since DRE enables supersonic flight with higher specific impulse than conventional solid rocket motors. Source: based on information available on internet.

on-board—can be addressed by using a ducted rocket. Further improvement in efficiency is achieved by using pure air breathing engines'.[9]

Mostly, various studies use the term hypersonic mainly to indicate the speed aspect. However, there are other aspects—like the properties of the medium of travel, ambient temperature, and altitude—which could better the performance of the platform. For many years, scientists are working towards using hypersonic technology in the arena of missile development—like cruise missiles, ballistic missiles, and boost-glide missiles. In this connection, a significant amount of work is happening in fields like ballistic nose cone designing and testing, improving the re-entry vehicle dynamics, identifying smart materials, and the development of specific software applications. Presently, militaries are looking at hypersonic technologies more from the point of view of boosting their weapons capabilities rather than having fast moving aircraft for the travel of troops or as hypersonic manned fighter planes.

Table 2[10] below offers a broad idea about hypersonic speeds in comparison with other existing vehicles.

Table 2 Hypersonic Speeds

Modern Passenger Airplanes	fly at 550 miles per hour (885km/h)	about 9 miles per minute
Fighter Jet (at Mach 2)	400 miles per hour (640km/h)	about 6.5 miles per minute
Hypersonic Vehicles to fly	scramjet powered missile	1 mile per second
	for example, the Hypersonic Technology Vehicle-2 (HTV-2)	4 miles per second

Source: Based on various web inputs

[9] David M. Van Wie, Stephen M. D'Alessio, and Michael E. White, "Hypersonic Airbreathing Propulsion", *Johns Hopkins APL Technical Digest*, Volume 26, Number 4 , 2005, pp 430–431.

[10] "What It Takes to Build a Hypersonic Vehicle", at http://www.sippican.com/us/news/features/2015/webt-hypersonic.html, accessed on 25 August 2016

Account of Advance

The hypersonic is normally considered as the technology for the 21st century. However, the development of this technology goes back much before the development of the modern airplane period—that is, the 1930s. Three persons are credited for the innovative ideas which indirectly sowed the seeds for the development of the hypersonic. The first person to establish many of the main ideas of modern rocketry was a Russian school teacher named Konstantin Tsiolkovsky (1857–1935). Most of his work was done before the first airplane flight which took place in 1903. The second person was an American named Robert Goddard (1882–1945). He told the world about the use of liquid fuel, and using multiple stages for rockets. Even today, some of his innovations get used in rocketry. The third person was the Romanian-born German scientist Hermann Oberth (1894–1989). His ideas were similar to those of the other two, and he built a liquid-fuelled rocket (1929). He was part of the German military team which developed various rocket systems, such as the V-2 missile which was used during the Second World War. In 1942, the V-2 was launched to an altitude of 176 km (109 miles), making it the first human-made object to travel into space (normally 'space' is considered to begin an altitude of 100 km).[11]

For the German government, rocket research was the key area of focus during the World War II period. The Germans have been supporting rocket research since 1932. By 1941, German scientists had developed the capability to test a missile called the Vergeltungswaffe 1 (Vengeance 1) or V-1. They did achieve success in engaging the target correctly after few initial launches. In fact, much earlier in December 1933, they demonstrated their capabilities with the first rocket A-1 of the Aggregate series.[12] The Aggregate programme was designed to develop long-range missiles. The

11 http://www.ck12.org/book/CK-12-Earth-Science-For-High-School/section/23.2/, accessed November 14, 2016

12 https://en.wikipedia.org/wiki/V-1_flying_bomb, accessed April12, 2016 and http://ethw.org/V1_and_V2_Rockets., accessed March 10, 2016

A-4 missile in this series was considered as a game changer during the Second Work War as there was no defence against it. The A-4, commonly known as V-2 (*Vergeltungswaffe* 2), is the world's first long-range guided ballistic missile. The missile was capable of delivering a one tonne payload to 332 km at an altitude of about 90 km.[23] The top speed of V-2 was around 1,600 to 1,700 meters per second. Normally, the speed of sound at these altitudes is expected to be around 295 meters per second.[13] Naturally, the missile was five times faster than the speed of sound. Hence, A-4 or V-2 could be considered as the first missile to fly at hypersonic speeds. However, no separate nomenclature was given for this achievement of a missile travelling much above the speed of sound. Hence, the word hypersonic, or any other suitable word, did not get coined then. The Germans used steel in its design, and aerodynamic heating played only a limited role in its overall design. It is probable that, at that time, not much thought was given to the need for developing technology for thermal protection.

The first conceptual hypersonic design was put forth during 1938 by the Austrian Eugen Sanger, and his mathematician wife Irene Bredt. Their extraordinarily influential design study of the vehicle called Silbewogel (Silver Bird) is known as the first detailed scrutiny of requirements for a hypersonic SSTO (single-stage-to-orbit) vehicle. Their design had the potential to develop a vehicle which could move at Mach 3.5. Subsequently, the Nazis defeat in World War II actually ended this development programme. However, the concept remained alive. After the Second World War ended, Sänger and Bredt worked for the French government. There was significant interest in their concept globally. Their design (actually their idea) remained at a design stage only, and it was much later that the scientific

13 The top speed of the V-2 is given as 1,600 meters per second (Dornberger, *V-2*, p. xix), and as 1,700 meters per second, Naval Research Laboratory, *Upper*, cited in Ley, *Rockets*, pp. 596-–597; the speed of sound at the pertinent altitudes is 295 meters per second, Kuethe and Chow, *Founda-tions*, p. 518, T. A. Heppenheimer, *Facing the Heat Barrier: A History of Hypersonics*, NASA History Division, Washington, DC September 2007, p xiii

community understood that this design may not have worked because it had not catered for heating at the stage of atmospheric re-entry. However, at that time, their work was so attractive that Joseph Stalin (dictator of the erstwhile USSR from 1929 to 1953) actually tried to kidnap / win them over, but failed to do so.[14]

The Development of Hypersonic Technology

A simple logical approach to understanding how, over the years, hypersonic technology has developed is by scanning earlier developments in various aircraft and missile technologies which led to the development of this technology. Since hypersonic technology is about reaching the five Mach speeds, it would be prudent to check when and how the sound barrier got broken and how further developments in this field took place.

There is no exact knowledge about when the sound barrier was first breached. After the discovery of the airplane, and during the process of further developments, it was realized that propeller aircrafts were able to reach the speed of sound in a dive. At Mach 2, the F-104 fighter and the Concorde transport aircraft are the best examples. The Lockheed F-104 Starfighter, a single-engine supersonic, took the first flight in 1956, and was in service from 1958 to 2004. The Concorde commercial airliner took first flight in 1969, and was in service from 1976 to 2003. The Lockheed SR-71 "Blackbird"—a long range strategic reconnaissance aircraft—crossed the Mach 3 barrier, and was in the service of the US Air Force during 1964–98. The SR-71 climbed till 85,000 feet (25km) height with Mach 3.2 speed. It is important to note that Mach 4 or Mach 4.5 onwards, the challenges of heating become very severe, and various problems arise owing to structural issues. Although the regime of hypersonic begins Mach 5 onwards, it needs to be appreciated that similar

14 Richard P. Hallion, "The History of Hypersonics: or, 'Back to the Future-Again and Again'", 43rd AIAA Aerospace Sciences Meeting and Exhibit, January 2005, the American Institute of Aeronautics and Astronautics, Inc.

technological challenges are also faced Mach 4 onwards. No version of the turbojet has served at such speeds, and that is why it becomes necessary to use a ramjet or rocket. At Mach 4, it becomes necessary to use a ramjet or rocket. The X-7, a ramjet testbed craft of the 1950s, had reached speeds to the tune of Mach 4.3 in 1958. Mach 5 speed is the lower boundary for the hypersonic regime. Speeds above Mach 20 to 25 include the velocities of long-range ballistic missiles of satellites re-entering from orbit.

Interestingly, the X-15 aircraft could achieve a speed of Mach 6.72. This aircraft was retired from service in 1970. Those who flew this aircraft flew at heights above 80km (263,000 feet) were awarded astronaut wings in 2005 (35 years after they took the flight). One such pilot was Neil Armstrong.[15] On 17 September 1959, the X-15 with the B-52 Stratofortress took off from Edwards Air Force Base in California, carrying under its wing a rocket-powered experimental aircraft, the X-15, to 45,000 feet (14km). This was the first flight of the X-15 which eventually attained velocities of Mach 4, 5 and 6, giving rise to the era of hypersonic flights.[16]

The military technologist realised the problem of re-entry during the mid-1950s when the US Air force was developing the Atlas ICBM, with the purpose of developing the capability of carrying a nuclear warhead to Moscow. It was realised that, without any protection, the warhead would heat up like a meteor when it fell back into the atmosphere. This led to the development of a heat shield to protect the missile against intense aerodynamic heating. The maturing of technology to address the problem

15 Theoretically, as per the international definition of a space flight, the flight has to exceed 100 km altitude to earn these wings; only two X-15 pilots have crossed these speeds.

16 See, http://www.criticalpast.com/video/65675021470_X-15_Edwards-Air-Force-Base_B-52-Stratofortress_in-flight; and also, “What It Takes to Build a Hypersonic Vehicle”, at http://www.sippican.com/us/news/features/2015/webt-hypersonic.html, accessed 25 August 2016.

of aerodynamic heating has opened the door to several other initiatives—like the development of strategic missiles, man-in-space programmes, etc.[17]

The hypersonic revolution, particularly after the end of the Second World War, took place in American laboratories. The traditional federal-industrial partnership assisted the development of this technology. The US Air Force, Navy, the National Advisory Committee for Aeronautics (NACA), and its successor the National Aeronautics and Space Administration (NASA) have been responsible for investing (financial), researching, innovating, testing, and developing diverse technologies leading to the development of hypersonic vehicles/weapons.[18] From 1930 onwards till today, various ideas and designs have been put forth in connection with the structures, materials, propulsion, aerodynamics, controls, and sensors. There are various layers in the development of this technology; the breakthroughs were achieved much earlier. In the space domain, scientists have succeeded sometime ago, with technologies and procedures allowing controlled atmospheric entry. Also, with the increase in range and re-entry velocity requirements for ballistic missiles, much of the investment took place towards the development of re-entry systems. Rocket development was a key focus in the post Second World War era. It was argued that only rocket engines could propel a vehicle moving at, say, speeds like four/five Mach. Also, since the problems related to aerodynamic heating had found solutions, much of the attention (read funding) was provided towards rocket development.

At the same time, innovative air-breathing engines—the scramjets—also demonstrated their competence to fly at hypersonic speeds. Scramjets or supersonic combustion ramjets are known to operate in the realm beyond

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17 See, http://www.livescience.com/39829-fastest-military-airplanes.html, accessed 12 November 2016; and also, T. A. Heppenheimer, *Facing the Heat Barrier: A History of Hypersonics*, NASA History Division, Washington, DC, September 2007, pp. 1–4

18 "From Max Valier to Project PRIME (1924–1967)", in *The Hypersonic Revolution: Case Studies in the History of Hypersonic Technology*, Vol. I., Air Force Historical Studies Office, Washington, DC, p. vi.

the reach of turbojet engines. In the case of scramjets, the initial attention in terms of military/political and financial support was less. For scramjets, the combustion takes place in supersonic airflow, and zero amount of oxidiser is required to be carried along with the fuel. This is because the oxygen from the atmosphere gets used as an oxidizer. Presently, four countries—the USA, Russia, China, and India—have succeeded in developing scramjet technologies. This technology has various advantages—like absence of rotating parts—which makes it easier to manufacture than a turbojet. Moreover, as compared to a rocket launch, the launch cost is less because the absence of the oxidizer directly amounts to weight saving. However, there are problems associated with this technology because of mediocre thrust-to-weight ratios. Also, at higher altitudes, engine performance gets compromised owing to the absence of oxygen. For the development of scramjet technology—and earlier, in respect of ramjet technology which is the basis for scramjet development—various projects were designed, some of which were executed successfully. It is not the purpose of this essay to identify and discuss all such projects, many details of which are available in literature.

The entire process of the development of hypersonic weapons and associated technologies indicates that it has been a complex and challenging process. The major investment was done by the USA, particularly from the beginning of the Cold War era. However, from the point of view of inducting such weapons in the armed forces, the process of development is far from complete even in 2017.

Launch Systems and Weapons

Since the field of hypersonic is still under the process of development, various launch platforms and weapon systems are at different levels of the developmental cycle; some are at the level of invention while others are at the drawing board designing stage.

When a weapon gets mounted on particular structures, then such structures are called weapon platforms (weapon delivery systems). Weapons come in various shapes and sizes—from a small bullet to explosive devices to bombs to missiles. A bullet could be fired from a pistol, gun, or cannon. Typically, any standard missile (or a bomb) may be of a conventional variety; could be fired from the platforms like a missile silo (underground/

ground based), specially made guns (or their variants), aircraft, ship, or submarine. Normally, a hypersonic weapon is expected to be of a missile variety, and can be fired from land, air, space, and water based platforms.

Typically, weapon delivery on the target involves three operative phases: (a) target acquisition; (b) manoeuvring to weapon release; and (c) post-release egress manoeuvre. The same could be true for hypersonic weapons too. In the case of hypersonic weapons, the extremely high speeds need to be catered for during the design stage of the delivery platforms along with other features like performance, delivery accuracy, and manoeuvring delivery profile.[19]

Particularly for long-range weapons like missiles, the most suitable launching option is a ground-based launch platform. Such platforms include underground missile silos, standard launch facilities (LF), and Mobile Launchers—like truck based or rail based launch platforms. In the case of underground missile silos, an underground vertical structure is made to house a missile and subsequent launching. Normally, such missiles are of intermediate range or intercontinental ballistic missiles. Mobile launch vehicles are used for firing ground to ground or ground to air missiles. Since hypersonic weapons are similar to ballistic missiles during the boost phase, the better option for launching is to use ground based launch platforms. Also, it is possible to use water based platforms—like the Vertical Launching System (VLS), normally used by the navies for missile firing (both surface ships and submarine based). However, it may be noted that the development of submarine based platforms (for hypersonic weapons) will take some more time. In the arena of aerial platforms also, more work is required. It is presently possible to deliver a hypersonic weapon on the target by using a bomber aircraft. However, in the case of using fighter aircraft as a platform, various challenges still need to be resolved, including the integration of warheads. Theoretical possibilities do exist

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19 At http://www.globalspec.com/reference/37701/203279/chapter-5-weapon-delivery-systems, accessed 22 December 2016.

with regard to using space based platforms for delivering a hypersonic weapon for a target on the ground. However, such proposals are not cost-effective, and this could be one of the reasons for less interest in developing such technologies. Broadly, a hypersonic weapon could be any weapon capable of striking a target with hypersonic speed. It is possible to achieve hypersonic speeds both in cruise and ballistic modes. Also, hypersonic weapons are being developed as boost-glide weapons and also as weapons in the realm of the anti-ballistic missile structures.

Missiles gets categorised based on their range, warhead carrying capability, speed, accuracy, and launch profile. A cruise[20] missile travels with constant velocity, and is used to strike terrestrial targets. Over a period of time, a significant number of technological developments have taken place in the field of cruise weapons. Modern cruise weapons can travel in subsonic, supersonic, and hypersonic zones. The US Agency, Defence Advanced Research Projects Agency (DARPA) is engaged in a work on Hypersonic Cruise Vehicle (HCV), possibly since 2000 onwards. Such a vehicle could carry a 12,000-pound payload consisting of Common Aero Vehicles (CAVs), cruise missiles, small diameter bombs or other munitions. DARPA attempted to fly the fastest aircraft ever built in 2011. The Agency's Falcon Hypersonic Technology Vehicle 2 (HTV-2) is designed to fly anywhere in the world in less than 60 minutes. This capability requires an aircraft that can fly at 13,000 mph and, probably, this test was partially successful. Not many details are available. Any success with such technology would allow the delivering of a military strike anywhere in the world in less than an hour.[21] Also, there were proposals to develop a third Hypersonic

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[20] The speed for a particular vehicle, ship, or aircraft, is usually somewhat below maximum; this is comfortable and economical. '[T]he boat is powered by a pair of 425-hp diesels that push it along at a cruising speed of 28 knots'. The aircraft has a cruising speed of up to 530 km/h, with a maximum speed of 560 km/h.

[21] At http://www.globalsecurity.org/space/systems/hcv.htm, http://www.sanluisobispo.com/news/local/article39160353.html#storylink=cpy and http://latimesblogs.latimes.com/technology/2011/08/vandenberg-launch-hypersonic-technology-vehicle-falcon.html, assessed 9 May 2017.

Technology Vehicle (HTV-3) focusing on reusable materials. Not much information is available on this subject.

Ballistic[22] missiles have a ballistic trajectory over most of their flight path, regardless of whether or not it is a weapon-delivery vehicle. Ballistic missiles are categorized mainly by their range—like Intermediate-Range Ballistic Missile (IRBM) which has a range of 3,000 to 5,500 km, and the Intercontinental Ballistic Missile (ICBM) has over 5,500 km range.[23] The missile travels through three phases—the boost, midcourse, and terminal phases.

The concept of Boost-glide has roots in the idea of increasing the range of ballistic missiles. However, over a period of time, Boost-glide is getting identified with the manoeuvring warhead concept. Such missiles can fly in much lower altitudes, thus avoiding radar detection for significant amounts of time. Also, this concept depends on the lift generated in the course of the hypersonic flight of re-entry into the earth's atmosphere. The relevance of hypersonic is also getting judged in the case of developing effective missile defence systems. For the purposes of interception missiles, the effectiveness of hypersonic is being experimented. At the same time, owing to the speed, hypersonic weapons could make the traditional Ballistic Missile Defence programmes (like ground based interception systems) inoperable. These weapons are also capable of evading early-warning radars.

Over a period of time, Boost-glide could emerge as a most effective weapon. However, very complex risks are associated with these weapons because there is no credible way of distinguishing between a boost glide weapon and a guided ballistic missile.

22 The ballistic trajectory of a projectile is the path that a thrown or launched projectile or missile without propulsion, takes under the action of gravity—neglecting all other forces such as friction from aerodynamic drag.

23 At https://fas.org/nuke/intro/missile/basics.htm, accessed 20 November 2016.

> For example, a ballistic missile is entirely predictable: when it is launched, its probable landing zone is known. But, a boost-glide weapon is not predictable because it can manoeuvre mid-course. That creates the possibility that a weapon fired at, say, North Korea, could be misinterpreted by China that it is heading towards China. Or a weapon fired at Iran could be interpreted as heading towards Russia. This is destination ambiguity.[24]

Many states, like the USA, Russia, China, and India, are making investments in developing hypersonic weapons. The nature of investment differs from country to country, depending on the individual country's technology proficiency, strategic need, and funding support.

Some available details of these states hypersonic programmes are discussed below. Appendix A provides a Birdseye view of these investments.

Hypersonic Weapons Programme of the USA

The Defence Advanced Research Projects Agency (DARPA) is an agency of the Department of Defence of the US government. This is responsible for the research and development of emerging technologies for the armed forces. Their Falcon Project (Force Application and Launch from Continental United States) is in collaboration with the United States Air Force (USAF), and is a part of their Prompt Global Strike[25] project. This project aims at creating a system to launch an airstrike to engage any target globally with precision by using conventional weaponry.

One part of this programme is to develop a reusable, rapid-strike Hypersonic Weapon System (HWS), now re-titled the Hypersonic Cruise Vehicle (HCV). The second part is for the development of a launch system capable of accelerating an HCV to cruise

24 "Hypersonic missile developments raise regulatory concerns", at https://www.flightglobal.com/news/articles/hypersonic-missile-developments-raise-regulatory-con-418984/, accessed 12 May 2017.

25 http://www.space-travel.com/reports/US_looks_for_answers_after_hypersonic_plane_fails_999.html

speeds, as well as launching small satellites into earth orbit.[26] The initial idea was formulated under project Blackswift (2007). Here the aim was to develop a fighter-sized unmanned reusable aircraft which could fly at the Mach 6 speeds. However, this project got shelved owing to funding problems around 2010.[27] The current research being undertaken in the FALCON programme centres on the development of the X-41 Common Aero Vehicle (CAV), a common aerial platform for hypersonic ICBMs and cruise missiles as well as for reusable and expendable (single use) launch systems.

The field of hypersonic has some overlap with various ideas and projects undertaken in the USA since 1950s onwards. However, the term 'hypersonic' came into general parlance only in the 1970s. Thus, it becomes difficult to clearly trace the history of various experiments associated with the platforms/weapons which could move with a speed of Mach 5 and above. It appears that, since the 1950s, the focus on technology research has been oscillating between the vertically launched rocket systems to space plane designs.

During the last half a decade, various projects have been undertaken in this regard. Some of these projects are discussed below.

HyperSoar

HyperSoar is an interesting next-generation hypersonic aircraft being developed by Lawrence Livermore National Laboratory (LLNL). This technology has both civilian and military utility, and the craft design is to transport people or cargo, and strike enemy targets. It is expected to be an economical concept. HyperSoar is to fly at Mach 10 (3 kilometres per second), and can carry approximately twice the payload of subsonic aircraft

26 http://www.theinfolist.com/php/SummaryGet.php?FindGo=Force%20Application%20and%20Launch%20from%20Continental%20United%20States

27 Ibid

of the same take-off weight. The bomber version of HyperSoar (size of an F-22 but would not require any mid-air refuelling to reach targets at a longer distance) could deliver its payload from an altitude, and at a speed that would defy all current defensive measures.

Additional potential applications for HyperSoar aircraft include:

- Space lift—as the first stage of a two-stage-to-orbit space launch system. Theoretically, such a launch could carry approximately twice the payload.

- Passenger aircraft—a commercial HyperSoar airliner or business jet could reach any destination on the planet in two/three hours or even less, depending on the location of take-off.

- Freighter—significant increase in cargo carrying capability, with multiple trips per day being a feasible feature.

Most hypersonic designs rely on rocket engines while HyperSoar has a major advantage in its use of air-breathing engines. Such engines are inherently more efficient than rocket engines. Also, the use of such engines greatly simplifies the design, reduces technical risks, and permits cost saving.

The Hypersoar concept was acquired from LLNL by DARPA and, in 2002, was combined with the USAF X-41 Common Aero Vehicle to form the Falcon programme. The Boeing X-51 (or X-51 WaveRider) is an unmanned research scramjet carried in a B-52H Launcher, and is designed to fly at Mach 5, at an altitude of 70,000 feet (21,000 m). This technology is likely to be used in the High Speed Strike Weapon (HSSW), a Mach 5+ missile planned to enter service in the mid-2020s.[28] During the 2013 test, the X-51 travelled at Mach 5 (X-51 Waverider hypersonic scramjet), and collected data on its flight. However, the idea is to develop

[28] All details of this programme are at https://str.llnl.gov/str/Carter.html, and at http://www.globalsecurity.org/military/systems/aircraft/hypersoar.htm, and at http://www.af.mil/AboutUs/FactSheets/Display/tabid/224/Article/104467/x-51a-waverider.aspx; accessed 10 January 2017

an aircraft that could actually transport equipment. Currently, the USAF and DARPA are working together and proposing to make such an aircraft by 2023.[29]

Advanced Hypersonic Weapon

As part of the development of the conventional prompt global strike (CPGS) capability for striking time-sensitive high-value targets, the US Department of Defence has conceptualised the Advanced Hypersonic Weapon (AHW) programme. This AHW technology demonstration programme is being managed by the US Army Space and Missile Defence Command (USASMDC)/Army Forces Strategic Command (ARSTRAT). The AHW is designed to provide a 6,000km range with a 35-minute time-of-flight and achieve less than ten-metre accuracy. The need for developing such a programme has its roots in the Department of Defence Quadrennial Defence Review Report of 2006. This report highlighted the need for "prompt and high-volume global strike'' capability to deter aggression, and provide a broader range of conventional options to the administration, if deterrence fails.

The concept of AHW evolves from the Boost glide vehicles. The Hypersonic Boost Glide Vehicle is used for extending the range of ballistic missiles. In fact, the concept of hypersonic boost-glide weapons is almost eight to nine decades old. The idea of using a rocket to launch a re-entry vehicle (RV) capable of gliding for long distances at hypersonic speeds dates to the 1930s. In recent times, after the George W. Bush (2003) Administration initiated the CPGS programme, efforts to develop the AHW began. Initially, there were two flights of the Hypersonic Technology Vehicle-2 (HTV-2). These efforts, during 2010–11, were not very successful, with both flights of the prototype HTV-2 ending prematurely. However, these tests were sufficient for providing data on flight aerodynamics and high-temperature effects on the aeroshell. Now this programme stands

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29 At http://www.washingtontimes.com/news/2015/jun/2/air-force-aims-new-hypersonic-aircraft-2023-scient/, accessed 6 December 2016.

cancelled, and efforts are focused on the AHW. The AHW was tested successfully in November 2011; but the second test (August 2014) has failed owing to the booster problem.[30] Boost-glide weapons have high manoeuvrability, and can avoid flight over third party nations when approaching the target. Thus, it could be argued that such weapons are not escalatory.

There is a DARPA-USAF Tactical Boost Glide (TBG) programme meant for developing and demonstrating technologies to enable future air-launched, tactical-range hypersonic boost glide systems. The TBG programme plans to focus on the following three primary objectives.[31]

- Vehicle Feasibility—Vehicle concepts possessing the required aerodynamic and aerothermal performance, controllability, and robustness for a wide operational envelope
- Effectiveness—System attributes and subsystems required to be effective in relevant operational environments
- Affordability—Approaches to reducing cost and increasing value for both the demonstration system and future operational systems

TBG is using the knowledge gained and information (data) collected during the HTV-2 programme, and involves developing ground and flight testing as well as various other critical technologies.

In September 2016, the US administration contracted Lockheed Martin (worth US$ 147 million) to build a vehicle capable of flying at speeds of Mach 20. This TBG will be an air-launched Boost glide weapon system. The idea is to develop a high-speed delivery system which can bomb targets thousands of km away within an hour, or even less. It is difficult to

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30 At http://www.army-technology.com/projects/advanced-hypersonic-weapon-ahw/, accessed 2 January 2017; see also, James M. Acton, "Hypersonic Boost-Glide Weapons", *Science & Global Security,* 2015, 23:3, pp. 191–219.

31 At http://www.darpa.mil/program/tactical-boost-glide, accessed 2 May 2017.

develop counter measures against Boost glide systems as they are difficult to shoot down. Their high speeds and different launch profile reduces reaction time, and makes them tricky targets for existing, slower-moving interceptor missiles.[32]

Hypersonic Air Breathing Weapons Concept (HAWC)

The Hypersonic Air-breathing Weapon Concept (HAWC) programme is another joint programme of DARPA and the USAF. This programme is focused on developing an air-launched hypersonic cruise missile system. The focus of the programme is to develop and demonstrate critical technologies required for this purpose. The programme aims to analyze, design, and develop following technologies.

- Advanced air vehicle configurations capable of efficient hypersonic flight
- Hydrocarbon scramjet-powered propulsion to enable sustained hypersonic cruise
- Approaches to managing the thermal stresses of high-temperature cruise
- Affordable system designs and manufacturing approaches

It is also expected that various technologies developed under this programme could also have relevance for future reusable hypersonic air platforms for uses such as intelligence, surveillance, reconnaissance (ISR), and space access.[33] To perform research work under the second phase of HAWC programme, the US administration is engaging one of their major

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32 Kyle Mizokami, "Lockheed to Build a Mach 20 Hypersonic Weapon System", 21 September 2016, at http://www.popularmechanics.com/military/research/a22970/lockheed-hypersonic-weapon/, accessed 27 September 2016.

33 Mark Gustafson, "Hypersonic Air-breathing Weapon Concept (HAWC)", at http://www.darpa.mil/program/hypersonic-air-breathing-weapon-concept, accessed 14 January 2017.

companies which is part of their defence industry. In November 2016, this contract—worth US$ 174.7—million was given to Raytheon, mainly to develop hypersonic cruise missile systems for use in future offensive strike missions.[34]

Russia and Hypersonic Weapons

Russia has been investing in the development of hypersonic technologies since the days of the Cold War. In the mid-1980s, the erstwhile USSR began researching hypersonic weapons under a project called "Albatross". It was a direct response to the USA' conceptualization of the Strategic Defence initiative (SDI)/Star Wars programme and the two tests they had conducted at about 70–80 km altitude. However, owing to some technical difficulties, the project was closed down. In the mid-1990s, the Scientific and Production Association (NPO) restarted development on the same project, and renamed it "4202".[35]

While there is not much open source clarity around the Russian Hypersonic programme, unofficial sources have confirmed that tests for the same were resumed in the 2000s, and a strategic exercise on 18 February 2004 included the testing of an UR-100NUTTH missile which was later identified as a new hypersonic vehicle. It might not have been the same Albatross that was flown in 1990; but nonetheless the two were definitely related. Based on some documents it can also be inferred that a test might have been conducted in June 2001, followed by another hypersonic missile test on 27 December 2011. Based on these experimental tests, and the unofficial documentation surrounding them, relations can be found between the Yu–71, Project 4202, and Object 370 (which is a large construction project). Furthermore, linkages can also be traced between Project 4202 and the

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34 At https://www.govconwire.com/2016/11/darpa-picks-raytheon-for-175m-hypersonic-air-breathing-weapon-phase-ii-research-contract/, accessed 4 December 2016.

35 At http://www.pravdareport.com/science/tech/28-10-2016/136013-hypersonic_weapon-0/#sthash.qpG5Idu1.dpuf

UR-100NUTTH missile (tested in 2004) based on the fact that in June 2014, the KBKhA Design Bureau had placed an order to explore the extension of the service life of rocket engines used in the UR-100NUTTH missile to 42 years.[36]

Presently, it can be speculated that Russia appears to be putting in place a major hypersonic programme. There are some media reports that a hypersonic cruise missile is being developed for Russian naval vessels, an example of which would be the 5th generation Husky missile submarine that is currently under development. As Russia's next-generation nuclear attack boat project, this is expected to be a successor to the Project 955A Borei-class ballistic missile submarine. This new project is expected to be a plan for the construction of a submarine combining key elements of strategic and multi-purpose submarines. Meanwhile, the ship is likely to be equipped with a new hypersonic cruise missile called the 3M22 Zircon.[37] The missile is expected to become operational by 2018. It is obvious that the entire project will take a few more years for maturation. The development of glide-strike vehicles and manoeuvring warheads are high-priority programmes.[38] A wide-scan of open source information indicates that Russia has few important projects in place with respect to the development of hypersonic platforms/weapons. Currently, they are at different phases of development. A brief summary of some of these projects is given below.

Zirkon

Russia's 3M22 Zircon hypersonic cruise missile is expected to enter production in 2018 if the tests in 2017 are successful. The hypersonic missile—which is a component of the 3K22 Zircon system—will be

36 At http://russianforces.org/blog/2014/08/russian_hypersonic_vehicle_-_m.shtml

37 Please see, http://www.nationalinterest.org/blog/the-buzz/breaking-russia-tests-new-hypersonic-cruise-missile-15527, accessed 5 February 2017.

38 At http://freebeacon.com/national-security/russia-tested-hypersonic-glide-vehicle-in-february/, accessed on 3 February 2017.

incorporated into the nuclear-powered Project 11442 Orlan-class battle cruiser (NATO: Kirov-class) *Pyotr Velikiy* when it is overhauled by late 2022. Its sister ship, *Admiral Nakhimov*, is also currently under modification, and is likely to be the first Russian warship equipped with the new missile when it returns to service in 2018. These missiles would replace the two battle cruisers' 390-mile range P-700 Granit supersonic anti-ship missile armament.

The range of Zircon is expected to be about 400km, and its high speed (more than 6 Mach) is expected to make any interception with available missile defence technology difficult.[39] It is expected that, along with Russia's next-generation Husky-class nuclear attack submarines, these weapons could also find a place on-board Russia's existing fleet of conventional and nuclear submarines (like the Project 855M Yasen-class), or on one of its older Projects (the 971 Shchuka-B-class submarine). Moreover, the Russians are expected to use hypersonic missiles on-board both the newly produced Tupolev Tu-160M2 Blackjack and the developmental Tupolev PAK-DA stealth bomber. The combination of a long-range bomber and hypersonic cruise missiles would be a dangerous threat to the USA and its allies. It is also possible that the two bombers could be equipped with a version of the Zircon, post testing.[40]

The Yu-71 or "Project 4202"

The Russians have been trying to develop the new Yu-71 vehicle; but there are several reports that indicate that success has eluded them in this field. The most recent test of the Yu-71 vehicle was reportedly conducted the on 19 April 2016. The Yu-71 is a secret missile programme (codenamed "Project 4202"), and is expected to have the speed of up to 11,200 kmh (7,000 mph). This weapon is expected to be extremely manoeuvrable and

39 At http://tass.ru/armiya-i-opk/3217394, accessed 10 May 2017.

40 At http://nationalinterest.org/blog/the-buzz/russias-lethal-hypersonic-zircon-cruise-missile-enter-15909 accessed 10 May 2017.

difficult to target. It can easily evade the enemy's missile defence systems.[41] This weapon could be mounted on Russia's new super-heavy thermonuclear-armed intercontinental ballistic missile, the RS-28 Sarmat. With its 10 heavy or 15 (or 16) lighter warheads, the silo-based ICBM, once operational, would have the potential to wipe-out an area of the size of Texas or France. Some experts estimate that the RS-28 will be able to carry up to three YU-71 HGVs.[42]

The Yu-74

This system's standard specifications as well as the other technical details of the testing are considered to be top secret. Reportedly, these gliders are developed to be loaded onto Russia's RS-28 Sarmat (SS-X-30 by NATO classification)—a state-of-the-art heavy liquid-propelled intercontinental ballistic missile which is presently being developed for use by the Russian army. Each Sarmat ballistic missile will be able to hit any target located within a 6.2 thousand mile radius in one hour. Each Yu-74 glider can be equipped with a nuclear warhead, electronic warfare (EW) applications or false target simulators.[43]

The 15Y71

Russia has tested a prototype of this radical new hypersonic nuclear warhead. The "product 4202" was tested on 25 October 2016 by the Russian military. This was a hypersonic weapon that can travel at a speed of Mach 15. This supersonic projectile is also known as 15Y71. This was the first fully successful test of this weapon. This 4202 hypersonic weapon is designed to be installed instead of traditional warheads on ICBMs. Before entering dense atmospheric layers, this projectile executes a complex

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41 At https://sputniknews.com/military/201506281023954331, accessed 11 May 2017.

42 At http://thediplomat.com/2016/10/russia-test-fires-nuclear-capable-hypersonic-glider-warhead/, accessed 10 May 2017.

43 At https://sputniknews.com/politics/201606111041185729-russia-hypersonic-glider/, accessed 11 May 2017

manoeuvre directly over the target. This makes it difficult for any anti-missile defence system to intercept it.[44]

China's Hypersonic Programme

China is known to be developing various advanced weapons for several years. Since 1985, Chinese missile forces have been under the command of the Second Artillery Force (SAF) or the Second Artillery Corps (SAC). Initially, China established its nuclear deterrent force primarily on intermediate and medium-range missiles. Subsequently, they expanded their capabilities by developing intercontinental missiles. Recently, on 31 December 2015, the Chinese authorities re-commissioned the SAF as the PLA Rocket Force (PLARF) Also, the PLARF was elevated from an independent branch to the fourth military service, alongside the PLA, PLAN, and PLAAF. This decision to reconstitute the PLARF as a military service indicates that China has a major interest in maintaining modern missile forces.[45]

Security analysts are of the opinion that China is developing various modern weapons as part of a long-term strategy which could be called Anti-Access Area-Denial, or A2-AD.[46] The implementation of such a strategy necessitates investment in a variety of missiles—both cruise and ballistic missiles. It is important to view China's interest in hypersonic weapons in the context of these realities. Also, since China is reaching close to full maturation and the possible induction of hypersonic missiles, it is but obvious that they could establish an independent branch of the military dealing specifically with various missiles (formerly the Second Artillery Corps is now known as PLA Rocket Force from 1 January 2016).

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44 At http://rbth.com/defence/2016/10/31/russia-successfully-tests-new-hypersonic-warhead_643865, accessed on 10 May 2017.

45 Anthony H. Cordesman, "The PLA Rocket Force: Evolving beyond the Second Artillery Corps (SAC) and Nuclear Dimension", 13 October 2016, at https://www.csis.org/analysis/pla-rocket-force-evolving-beyond-second-artillery-corps-sac-and-nuclear-dimension, accessed 25 January 2017.

46 Harry J. Kazianis, "China's carrier-killer missile", 31 October 2013, at http://www.washingtontimes.com/news/2013/oct/31/kazianis-chinas-carrier-killer-missile/, accessed 14 January 2017.

Globally, it has been observed that many Chinese professors and scientists (both Chinese nationals as well as non-resident Chinese) have been working on the issues of hypersonic for many years. Various technical publications, with many Chinese scientists as lead authors on this subject, are available, indicating broad progress in their developing this technology and its applications. Such publications by Chinese scientists indicate that they are working on issues like “trajectory optimization”, “guidance systems”, “control design”, and “optimal glide conditions”. It has been found that this research was mainly undertaken during 2000–2010. It is probable that actual experimentation started subsequently.[47]

China has made major investments in hypersonic gliders. These are known as Hypersonic Glide Vehicles (HGVs), and are capable of reaching speeds to the level of Mach 10. These are ideal attack munitions which could be used against a variety of hard targets—like warships, command and control facilities, communications links, hangars, and intelligence facilities. The Chinese vehicle is known as the WU-14 glider or DF-ZF. So far, China has conducted seven hypersonic tests, of which six have been successful. These tests have been conducted between January 2014 and April 2016. The conduction of seven tests within a span of less than two years indicates China’s commitment to the development of this technology. China’s 10th Research Institute (also known as the “Near Space Flight Vehicle Research Institute”) is a part of the China Aerospace Science Industry Corporation (CASIC) 1st Academy, which is the only body responsible for the development of HGVs. China is presumed to be using a medium-range ballistic missile (MRBM) transporter erector launcher (TEL) as the delivery method.[48] The DF-ZF is not known to be using a scramjet technology; however, the PRC has announced that it is now the second country to possess this technology. These tests have not exactly been made official;

47 Jeffrey Lin and P.W. Singer, “Hypersonic Gliders, Scramjets, and Even Faster Things Coming To China’s Military”, 25 August 2014, at http://www.popsci.com/blog-network/eastern-arsenal/hypersonic-gliders-scramjets-and-even-faster-things-coming-chinas, accessed 25 January 2017.

48 At http://www.nextbigfuture.com/2016/05/chinese-hypersonic-weapons-development.html, accessed 24 January 2017.

but there are some indications that probably the project started around 2011, and the tests were completed by 2014.[49]

The DF-ZF HGV could also have the capability of being launched atop an anti-ship ballistic missile to target naval assets. For example, a DF-21 armed with a DF-ZF HGV may extend the missile's range from 2,000 to over 3,000 km. The DF-21 is expected to be a solid fuelled rocket launch platform. However, the assessment of the failed HGV test indicates the possibility of the use of a liquid fuelled launch platform. It may be noted that the DF-31 is known to be a liquid-fuelled intercontinental ballistic missile. The use of liquid fuel is expected to compensate for the weight of the glider during acceleration to hypersonic speed. Alternately, there is also the possibility that the liquid fuelled launch platform could assist the use of both the nuclear and conventional missile payloads. The DF-ZF system is expected to be capable of hitting targets all across the world within an hour's time. It is also capable of evading various modern ballistic missile defence systems. It is expected that the DF-26— which is the next version of DF-2—could emerge as a platform for the DF-ZF in the future.[50]

India's Hypersonic Programme[51]

India is a relatively new entrant in the field of hypersonic, and its programme appears to be on a much smaller scale as compared to those of the countries

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49 At http://www.popsci.com/chinese-hypersonic-engine-wins-award-reshapes-speed-race, accessed 23 January 2017.

50 At http://carnegieendowment.org/2014/11/21/new-high-speed-arms-race and http://freebeacon.com/national-security/russia-tests-hypersonic-glide-vehicle/ ; see also, https://jamestown.org/program/updated-chinese-hypersonic-weapons-development/, accessed 24 January 2017.

51 *The Hindu*, Chennai, 24 September 2011. Also see, http://www.indiandefencereview.com/spotlights/indias-multifunction-missile-for-credible-deterrent/; and https://www.quora.com/Military-Technology-Which-countries-have-developed-fully-functioning-Hypersonic-Missiles-What-is-the-ongoing-development-How-do-other-Hypersonic-missiles-fare-compared-to-Shaurya, accessed 12 January 2017. See also, Riordan Roett and Guadalupe Paz Westchester, *Latin America and the Asian Giants*, The Brookings Institution, Westchester Publishing Services, Washington DC, 2016.

discussed above. Like the other countries, India's programme also remains classified, and only some limited information is available. In India, hypersonic research is being pursued by the Defence Ministries, the Defence Research and Development Organisation (DRDO), and another private sector agency called BrahMos Aerospace (a joint venture with Moscow). The DRDO's prototype is known as the HSTDV (Hyper-Sonic Technology Demonstrator Vehicle), and BrahMos Aerospace is known to be developing the BrahMos-II.

The DRDO's is developing a missile called Shourya, a surface to surface ballistic missile while BrahMos is a cruise missile. Shourya is a compact, slender, two-stage, solid fuel, surface-to-surface missile. This missile development was initiated as project K15, and was first flight tested on 27 October 2004. This missile is known to support a range of unitary warhead configurations; it weighs 180 to 1,000 kg, and can carry both nuclear and conventional warheads. One of the test flights of this missile on November 12, 2008 was a depressed trajectory flight (at Mach 6 and 50 km altitude). The missile is known to have attended the speeds of Mach 7.5 during the third test (September 2011), and was subsequently inducted into the armed forces. This missile can be launched from silos and canisters mounted on a truck and fixed on the ground. It has been reported that Shourya's maritime version is the K-15 missile which is launched under water, and is being fitted into the Navy's nuclear-powered submarine *Arihant*. However, there is no clarity on this issue.

BrahMos II, a hypersonic cruise missile, is currently under development. Initially, this missile was expected to have a range of less than 300km (speed of Mach 7). However now, ever since India has become a member of the Missile Technology Control Regime (MTCR),[52] this range could be increased. The BrahMos-II could be a variant of one of the hypersonic anti-ship missile developed by Russia. In February 2014, India's Ministry

52 MTCR restricts the proliferation of missiles and related technologies for those systems capable of carrying a 500 kilograms payload for at least 300 kilometers.

of Defence is known to be have authored the sale of the hypersonic missile BrahMos to other countries; and Brazil, China, and Venezuela are known to have shown interest.

The Deterrence Dilemma

The Cold War nuclear legacy is increasingly under acute scrutiny. During the Cold War confrontation, nuclear deterrence was the central over-riding strategic concept that ruled the political and military relationship between Washington and Moscow.[53] Deterrence is used in academic and policy-making circles to refer to a process and to a condition or situation. Deterrence is a psychological route by which an actor influences one or more actors to act in accord with the wishes of the first actor. In literature, there is a significant amount of focus on the theoretical conceptualisations of deterrence. Various logical arguments are presented to describe and analyse the notion of deterrence. However, Alexander L. George, Professor of Political Science at Stanford from 1968 to 1990 and one of the most respected scholars of International Relations, emphasizes that the successful practice of deterrence is not necessarily guaranteed by a careful study of the theory.[54] How can one calculate what it takes to deter? First of all, deterrence is in the eyes of beholders—what they think is going to happen. If they are dealing with the very survival of their societies, they have to assume the worst.[55]

It could be argued that, post the Second World War, the concept of nuclear deterrence started building up during the 1950s when, probably, the erstwhile USSR was not able to occupy Western Europe owing to the

53 Dr. Lewis A. Dunn, "Beyond the Cold War Nuclear Legacy: Offense-Defence and the Role of Nuclear Deterrence?", *IFRI Security Studies* Winter 2001, at https://www.ifri.org/sites/default/files/atoms/files/Prolif_Paper_Dunn.pdf

54 Stephen Cimbala, "Deterrence and friction: implications for missile defence", *Defence & Security Analysis*, 2002, 18: 3, p. 202.

55 Admiral Stansfield Turner, "The Dilemma of Nuclear Weapons In The Twenty-First Century", *Naval War College Review*, Spring 2001, Vol. LIV, No. 2, p. 16

fearful possibility of them receiving unacceptable punishment in the form of a nuclear attack. Since then, the credibility of nuclear deterrence has grown by leaps and bounds. There has been much debate about the significance of deterrence, and how the deterrence mechanism should be developed. It is also important to appreciate how the deterrence mechanism works in reality. The notion of deterrence is being given a chance in the post-Cold War era. Today, amongst the major powers such as the USA and Russia, there is acceptability about the need to reduce—at least in principal—the number of nuclear weapons. However, a few smaller powers are finding that the nuclear weapons are actually tools for survival.

In the 21st century, while the scenario of a global nuclear war is less probable, regional challenges are found to be increasing manifold. Post the 1991 Gulf War, mainly smaller countries have realised that they are vulnerable because they do not have missile and NBC capabilities, capable of attacking targets that are located at longer distances. Leaders like Saddam Hussein and Mu'ammar Gaddafi told their followers that only the capability of threatening the USA and its allies could insulate a third party from the prospect of a strong US and allies response to regional aggression. Also, the academic community and military commentators from the Third World have noted the prospective deterrent value of ballistic missiles and NBC weapons.[56] It is but obvious that Syria gets pounced onby the USA—and even by Russia—only because they do not have nuclear weapons and missile capabilities. It is probable that the lack of this capability has made them actually use chemical weapons locally instead of using them as a weapon of deterrence against the USA. In contrast, North Korea is able to deter the global power owing to their missile and nuclear capability.

The capability of deterrence is not static; it is ever evolving, depending mainly on the growth of technology. There is a broad acceptance of the view that nuclear deterrence has helped to keep the peace. There are only

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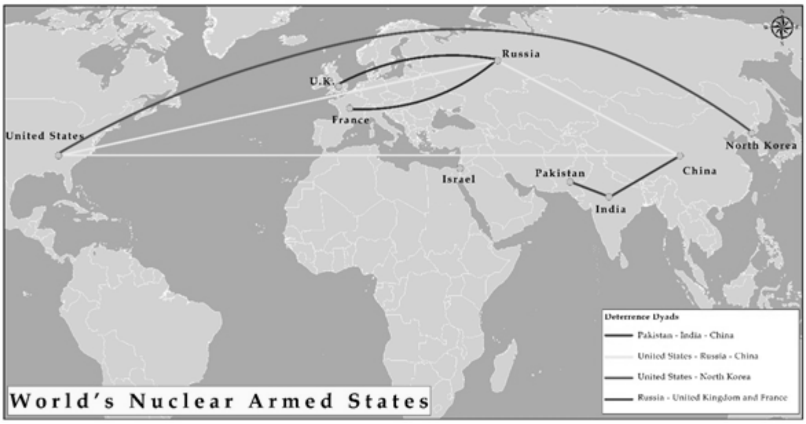
56 Keith B. Payne, "Deterrence and US strategic force requirements after the Cold War", *Comparative Strategy*, 1992, 11:3, pp. 269–282.

a limited number of countries with nuclear weapon capabilities, and it is expected that there will be no growth in the number of nuclear weapon states at least in the immediate future. Every nuclear weapon state is involved in developing their own deterrence mechanisms which are based on the nature of their threat perceptions. Figure 1[57] depicts the nuclear deterrence dyads among the world's nuclear armed states.

Figure 1 Nuclear Armed Countries



Presently, there are only five countries which are permitted to possess nuclear weapons under the Non-proliferation Treaty (NPT) mechanism. Incidentally, these countries are also permanent members of the United Nations Security Council (UNSC) too. For many years, efforts are been made (nuclear arms reduction mechanisms) to reduce the size of the nuclear weapons arsenal globally; however, it has met with little success.

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57 Based on James M. Acton, "Technology, Doctrine and the Risk of Nuclear War", Carnegie Endowment for International Pace, at https://www.amacad.org/pdfs/James-Acton-Technology-Doctrine-and-the-Risk-of-Nuclear-War.pdf, accessed 2 January 2017.

Nuclear Rivalries

There are major disparities in the size of nuclear weapons possessed by different countries (see Table 3).

Broadly, the following could be combinations for nuclear rivalries amongst nuclear weapons states. In may be noted that, for the sake of simplicity, France and the UK are considered as the Western Block (same as the USA) but are passive players, and hence are not mentioned separately.

Table 3 Nuclear Rivalries

Name of NWS	Nuclear Rivalry	Status of Nuclear Tried	Hypersonic interests / investments
Russia	USA	In place	Yes
USA	Russia, China, North Korea (?)	In place	Yes
China	USA, India	In place	Yes
India	Pakistan, China	In progress	Yes
Pakistan	India		
North Korea	USA		

This table is based on available information in the literature

All nuclear weapon states are making efforts to develop (some have already established) nuclear triads to add teeth to their deterrence mechanisms; some have also made investments in developing Ballistic Missile Defence Programmes (BMD). Thus, overall, various developments are taking place in the area of developing Intercontinental Ballistic Missiles (ICBMs), Submarine Launched Ballistic Missiles (SLBMs), and interceptor missiles.

The weaponisation of hypersonic technology is normally expected to take place, or is taking place, in the conventional weapons arena. However, these weapons are expected to reduce the relevance of the BMD programme because of difficulties in intercepting such missiles. Thus, the maturing of this technology could challenge the present notion of nuclear deterrence. Will this technology emerge as a disruptive technology? Actually, it does have all the elements to do so; however, only time will tell about such a possibility.

Hypersonic technology has capabilities of making existing counter-missile technologies redundant. However, if effectively developed, and if a specific context gets developed by a strategic community, then this technology could challenge the notion of nuclear deterrence itself. Conducting nuclear tests to learn more about designing modern generation nuclear weapons—at least by established/responsible nuclear weapon states—appears unlikely. In this context, it could be argued that the present generation nuclear weapons are relics of the past, and present generation nuclear weapons are somewhat similar to the Second World War era nuclear weapons. An exaggerated view of this even mentions bows, arrows, and nuclear weapons in same breath!

In the post-Second World War period, the theory of deterrence—particularly in strategic spheres—was debated in the context of nuclear weapons. Nuclear deterrence is perceived to have remained beneficial for maintaining peace during the Cold War era period, and continues to retain currency even in the post-Cold War era. But, nuclear weapons also have a shelf-life with regard to their deterrence potential, and cannot be viewed as weapons having deterrence potential in perpetuity! Presently, there could be a view that there are no serious mission requirements for hypersonic weapons. However, space weapons (for targets in space), space-based weapons (for targets on earth), and hypersonic weapons (launched from the earth/air) have the potential of causing major destruction to both humans and critical infrastructure. What remains important for the possessor states is to articulate the deterrence potential of such weapons in the present context. Currently, all nuclear weapon states are not making investments in hypersonic technology; and also, such states do not have the technology capability to develop space weapons or hypersonic weapons. Hence, the possession of hypersonic weapons could add more teeth to the existing nuclear deterrence potential of states developing such technology.

Broadly, the operational dilemmas presented by nuclear weapons and the deterrence doctrine have been with us now for a few decades. So has the ethical dilemma of trusting nuclear weapons to threaten a greater evil—

nuclear devastation. Understanding the heinous nature of this threat, many with a military background in the past, political leadership, members of the strategic studies community, intellectuals, and anti-nuclear activists are all voicing their concerns regarding the presence of nuclear weapons today.[58] However, nuclear weapon countries are not likely renounce them because, for most of them, the threats (read nuclear) are real, and they have no option but to hold on to their nuclear arsenals. Maybe in the present, the concept of overwhelming strategic superiority may not be as real as in the Cold War era. However, no doubt countries will look for better options to enhance the lethality of their nuclear weapons. Maybe the 21st century dilemma could force countries with hypersonic weapons capability to identify a deterrence mechanism with the inclusion of hypersonic weapons. However, it is too early to identify exactly the nature of such a mechanism. It is probable that only when such weapons are available along with their operational status, will the nuclear doctrines be re-written.

The Arms Race

The Offense-defence theory (or security dilemma theory) argues that when defence has advantage over offense, major war can be avoided. In addition, the likelihood of arms races and war can sometimes be further reduced by carefully designed arms control. The simple expectations concerning the offense-defence balance are that as the value of offense increases, the security dilemma becomes more severe, the arms races become more intense, and war becomes more likely.[59]

Presently, the various aspects of the relevance and future of hypersonic weapons are being debated. The views are varied amongst the experts. One opinion is that since this technology is still under the development

58 Michael McGwire, "Dilemmas and Delusions of Deterrence", *World Policy Journal*, Vol. 1, No. 4, Summer, 1984, pp. 745–767.

59 Charles L. Glaser and Chaim Kaufman, "What is the offense-defense balance and can we measure it?" *International Security*, Spring, 1998, Vol. 22, no. 4, pp. 39–44.

mode, it is the correct time to ask for banning such weapons. These weapons could be viewed as an alternative to nuclear weapons and, as discussed, could change the notion of deterrence. On the other hand, at this stage since such weapons do not suffer from the burden of being categorised as so called "useable or un-useable weapons", the military doctrines of different countries could identify specific tasks and targets for such weapons—like attacking critical infrastructure. Also, there is a possibility that any use of, or threat to us such weapons could increase the chances of a nuclear war. At times, the opponent could even be forced to take irrational decisions. With this technology maturing, there exists a further possibility that such weapons could even become capable carrying nuclear warheads. All this essentially indicates that these weapons could be destabilising in nature. This may lead to a hypersonic arms race.

With the USA, Russia, and China perusing their hypersonic programme with great vigour, it is but obvious that the major European and Asian states would also start making efforts to develop such technology. A typical arms control argument could be developed with regards to the banning of hypersonic weapons. It could be argued that all testing in regard to the of hypersonic weapons be stopped, and the major powers involved in the development of this technology could agree for an informal moratorium. Eventually, a process could be established leading to a verifiable mechanism. However, past experience in attempting to establish any such mechanism has demonstrated the difficulties involved in any such proposal. Thus, it is unlikely that this technology will be stifled before becoming fully operational in its weapons avatar.

It is possible that the major powers in the world (obviously they are nuclear powers too) would majorly increase their investment in this technology in the near future. It is said that this technology promises to revolutionize military affairs in a significant way, and comparisons have been drawn with the stealth technology revolution of a generation ago, and the turbojet engine in an even earlier generation. Today, various categories of hypersonic weapons are being researched. Boost-glide hypersonic weapons are expected to be much in demand owing to features like long ranges and high survivable factor. Concepts of a reusable hypersonic missile are also being studied. Also, compatibility with launching platforms like aircraft, ground based launchers, ships, and submarines are also being worked out. Apart from technological challenges, cost is another factor which countries will have to cater for while investing in such technologies. Based on present trends, it appears that major states are keen to weaponize this technology, and are investing to that effect.

Reports[60]suggest that hypersonic weapons have some specific advantages for the USA.

- They can project striking power at range without falling victim to increasingly sophisticated defences. They can hit targets which are difficult to hit by subsonic weapons.
- They compress the shooter-to-target window, and open new engagement opportunities.
- They rise to the challenge of addressing numerous types of strikes.
- They enhance future joint and combined operations. Also, they force potential adversaries to develop new air defence systems—or re-programme existing ones—to address this new threat.

The investments made by China and Russia in hypersonic are bound to make the USA concerned. All these three countries are likely to develop these weapons for their own requirements—and also because the others are developing them. No doubt, over a period of time, they would identify the targets for such weapons, and the present notion that such weapons have no utility to may subside. In this context, it is expected that such a situation could lead to an arms race. At this point in time, it is difficult to judge the exact nature of such a race (in the future); however, some symptoms of the possibility of this coming true are visible.

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60 At https://www.rand.org/blog/2016/10/the-future-of-hypersonic-weapons.html, accessed 11 May 2017.

Assessment

Human ambition has always desired the ability to travel at incredibly high speeds. On 2 March 1969, the Concorde supersonic passenger aircraft (flying at the speed of around Mach 2) undertook its first flight. Today, the possible successor to the Concorde is expected to take around one hour (as against the earlier three hours) from London to New York. However, at present, much of the global focus is on increasing the speed capabilities of the weapons/weapon platforms than any human transportation system. For more than five decades, humans have been aware about the science behind the development of hypersonic, and have also successfully developed a few machines which can travel with a speed of more than Mach 5. With today's extremely focused research and development, and proper investments, a few countries have made significant progress and are currently in a position to induct hypersonic weapons in their military arsenal in the near future. With this, the era of hypersonic weapons could be said to have actually arrived.

The design of hypersonic machines is an intricate multidisciplinary challenge. Hence, presently only few countries are making investments in developing such platforms. These states have already established superiority in the field of missiles, including ballistic missiles; they are also space-faring states with proven nuclear weapons capabilities too. Also, it is but obvious that such weapons are being developed by countries that are facing major security challenges.

Military technology is one area wherein for every strategic success there is always an attempt to develop a counter measure. For example, in order to eliminate the effect of electronic counter measures (ECM) on electronic sensors, various practices have been designed which are Electronic counter-countermeasures (ECCM). Another interesting case could be that of stealth technology. Particularly in the Cold War period, countries with modern stealth warplanes (read USA) were known to have strategic advantage. However, subsequently, more improvements in this technology took place to overcome various deficiencies. Moreover, counter-stealth capabilities were developed by few other countries also. There could be many such examples. Essentially, the field military technology will always remain a dynamic one. In this context, the hypersonic is getting viewed as the 'new stealth' (in this case speed being understood as the new stealth.)[61] Hypersonic weapons are also getting described as 'game-changing weapons'. Once these weapons become fully operational, they could challenge (or expand) the existing philosophy behind nuclear deterrence. The existing missile defence architecture would not be able to neutralise any incoming hypersonic missile threat simply because of the speeds of these missiles.

Countries which are not in a position to develop this technology could look for other soft and hard options as defensive mechanisms. Efforts are underway to develop a defence system to defeat hypersonic boost-glide and manoeuvring ballistic missiles. Sponsored research by the US Air Force has found that hypersonic weapons (say with a speed of approximately 8 Mach) are within the design envelopes of several modern air-defence systems. These are specifically designed to defend against tactical ballistic missiles with hypersonic terminal velocities.[62] Also, there could be multilateral and/or United Nations supported attempts to halt/control the progress of this technology. Again, innovation efforts could begin in the realm of BMD to discover a counter to this technology. Also, various asymmetric approaches could be thought off to neutralize their impact.

At present, there are more questions than answers with regard to how effectively this technology could be put to use. Could states use them for denying possible new proliferators the ability to use WMDs? What could be the nature of the spinoff benefits offered—or have already been offered—by the entire process of the development of these weapons? Since, all the countries which are developing this technology are nuclear weapon states, would they restrict themselves to using these missiles in conventional modes? Would these missiles have anti-satellite capabilities? What nature of doctrinal change could be brought in by these missiles?

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61 At http://www.economist.com/news/technology-quarterly/21578522-hypersonic-weapons-building-vehicles-fly-five-times-speed-sound, accessed 9 February 2017.

62 *Review and Evaluation of Air Force Hypersonic Technology Program*, National Academics Press, 1998 p. 58, www.nap.edu/catalog/6195.htm, accessed 12 February, 2015.

Russia, China and the USA are the three dominating powers in the world. Amongst these powers there would always be over or covert rivalry for strategic, technological, and economic superiority. There is a possibility that, in the future, Russia and China could merge together as the world's new superpower-axis. It is expected that the 'politics' of hypersonic weapons would be dominated mainly by these powers.

Hypersonic weapons are considered destabilizing weapons. No country has yet fully operationalised this technology for military purposes. However, their emergence is a foregone conclusion. Presently, even though the technology is at the development level, there appears to be some kind of race on amongst between the USA, China, and Russia to operationalise and induct these weapons in their military arsenal at the earliest. The chances of the proliferation (overt or covert) of this technology look remote because these countries would not like to surrender their technological superiority. Technology development in the hypersonic realm is very challenging, time-consuming, and expensive. Also, the induction of hypersonic missiles with nuclear warheads would require new designs as well as the production of suitable nuclear warheads. At the same time, these countries are keen to develop counter-hypersonic technologies also.

On the whole, it is expected that the presence of hypersonic weapon systems could lead to changes in the rules of engagement (ROE). The presence of hypersonic missiles in the nuclear triad architectures of countries would change the face of existing nuclear deterrence mechanisms. In the near future, these weapons are likely to emerge as instruments for decisive power projection.

Appendix A

Hypersonic Weapons

The following tables provides information about various programmes by the three major states making investments towards the development of hypersonic weapons. This information has been gathered based on various inputs available on the internet and some of the main sources have been quoted at places.

Table 1

Project / Missile	Type	Country	Manufacturer	Speed	Test Date	Result
DF-4	ICBM	China	Factory 211 (Capital Astronautics Co.)	Replaced by DF - 31		
DF-31	ICBM	China	Academy of Rocket Motors Technology (ARMT)		2nd August 1999	Success
DF-31[1]	ICBM	China	Academy of Rocket Motors Technology (ARMT)		Early 2000	
DF-31[2]	ICBM	China	Academy of Rocket Motors Technology (ARMT)		4th November 2000	
DF-5[3]	ICBM	China	Factory 211 (Capital Astronautics Co.)		1971-1980	

1 Operational deployment began in 2006

2 DF 31-A and B have also been developed and improved upon

3 It is speculated that this was to be replaced by DF-41 which was to be replaced by DF-31A but there have been tests in 2015 with MIRV versions of DF-5A

Project/ Missile	Type	Country	Manufacturer	Speed	Test Date	Result
DF-41	ICBM	China	China Academy of Launch Vehicle Technology (CALT)		21st July 2012	
Wu-14/ DF-ZF	Boost-glide	China		10 Mach	9th January 2014	Successful
Wu-14/ DF-ZF	Boost-glide	China		10 Mach	7th August 2014	Successful
Wu-14/ DF-ZF	Boost-glide	China		10 Mach	2nd December 2014	Successful
Wu-14/ DF-ZF	Boost-glide	China		10 Mach	7th June 2015	Successful
Wu-14/ DF-ZF	Boost-glide	China		10 Mach	27th November 2015	Successful
Wu-14/ DF-ZF	Boost-glide	China		10 Mach	April 2016	Successful

Table A (2)

Project/ Missile	Type	Country	Manu-facturer	Speed	Test Date	Result
BrahMos -II	Cruise	Russia	Yuzhny Machine Building Plant		Expected: 2020	
R-36 M[4]	ICBM	Russia	Votkinsk Machine Building Plant		September 26th 1963	Failed
R-36 M	ICBM	Russia	Votkinsk Machine Building Plant		1963	Success

4 R-36 Tests were conducted on two surface pads: LC – 67 1 and LC – 67 2 and six silos: two at LC – 80, LC - 140, LC – 141, LC - 142

Project/ Missile	Type	Country	Manu-facturer	Speed	Test Date	Result
R-36M (SS-18)	ICBM	Russia	Votkinsk Machine Building Plant		Cold Launch Tests: 1971	
R-36M (SS-18)	ICBM	Russia	Votkinsk Machine Building Plant		Actual Flight Tests: February 1973 – October 1975	56 Deployed in 1977 but replaced by Mod 3&4 in 1984
R-36M (SS-18)	ICBM	Russia	Votkinsk Machine Building Plant		1973-1975	Replaced by Mod 4 due to serious Design Flaws
RS – 28 (Sarmat)	ICBM	Russia	Makeyev Rocket Design Bureau		10th August 2016	Successful
Yu – 71	Boost-Glide	Russia		Mach 5	27th December 2011	
Yu – 71	Boost-Glide	Russia		Mach 5	26th September 2013	Reportedly unsuccessful
Yu – 71	Boost-Glide	Russia		Mach 5	September 2014 (Not Confirmed)	Reportedly Unsuccessful
Yu – 71	Boost-Glide	Russia		Mach 5	26th Feb 2015	Reportedly Unsuccessful
Yu - 74	Boost Glide	Russia			2016	Reportedly Successful[5]

Note

Russian case is bit peculiar and lacks specificity in regards to the available information. Hence, some additional inputs are provided here for better clarity.

[5] http://www.globalsecurity.org/wmd/world/russia/objekt-4202.htm and http://www.military-today.com/missiles/ss18_satan.htm

R-36s are the ICMBs and Space Launch Vehicles designed by the Soviet Union during the Cold War. Since all the R-36s were designed in Ukraine Russia is planning to replace them with RS Sarmat which will be capable of holding 24 hypersonic vehicles like Yu – 71 / Yu - 74

The progression of the RS 36 missiles has been:

- "R-36M (SS-18 Mod 1). This missile had a single 18 MT warhead or warhead with 8 MIRVs (4 x 0.4 MT and 4 x 1 MT). It had a range of 11 200 km and a CEP of 700 m. A total of 148 missiles were deployed between 1974 and 1983;
- R-36M (SS-18 Mod 2). This missile had a warhead with 10 MIRVs with a blast yield of 0.4 MT. It had a range of 10 200 km with a CEP of 700 m. Only 10 of these missiles were deployed between 1976 and 1980;
- R-36M (SS-18 Mod 3) was an upgrade of the Mod 1, carrying a single reentry vehicle with blast yield of 25 MT. This missile had a range of 16 000 km and a CEP of 700 m. It was deployed between 1976 and 1986;
- R-36MUTTKh (SS-18 Mod 4). The "UTTKh" designation stands for "improved tactical and technical characteristics". This missile introduced lighter weight MIRV warheads. Western intelligence suggests that it could carry as much as 14 MIRVs, but Russians denied that, saying that Mod 4 is capable of carrying 10 independent warheads with a blast yield of 0.5 MT. This missile has a range of 11 000 km and a CEP of 370 m. It was deployed in large numbers. A total of 278 missiles were deployed between 1979 and 2005;
- R-36MUTTKh (SS-18 Mod 5). This missile had a single 20 MT warhead. It had a range of 16 000 km and a CEP of 200 m. It was deployed since 1986. A total of 30 missiles were deployed. All of them were retired by 2009;
- R-36M2 Voevoda (SS-18 Mod 6). It was first deployed in 1988. It was deployed in both single warhead and with 10 MIRVs with a blast yield of 0.75-1 MT. This missile has a range of 11 000 km with

a CEP of 220 m. A total of 58 missile were deployed. This missile is still in service with the Russian Strategic Missile Forces.

Table A (3)

Project/ Missile	Type	Country	Manufacture r	Speed	Test Date	Result
High Speed Strike Weapon (X-51)	Cruise	USA	Boeing	5 Mach	26th May 2010	Successful
High Speed Strike Weapon (X-51)	Cruise	USA	Boeing	5 Mach	13th June 2011	Partial Success
High Speed Strike Weapon (X-51)	Cruise	USA	Boeing	5 Mach	14th August 2012	Failure
Advanced Hypersonic Weapon	Boost Glide	USA	Sandia National Laboratories		18th November 2011	Success
Advanced Hypersonic Weapon	Boost Glide	USA	Sandia National Laboratories		25th August 2015	Failure
Minuteman III	ICBM	USA	Boeing	23+ Mach	26th April 2017	
Falcon HTV-1	Boost Glide	USA	DARPA	Cancelled	Cancelled	Cancelled
Falcon HTV-2	Boost Glide	USA	Raytheon/ DARPA		22nd April 2010	7,600 km Partial
Falcon HTV-2	Boost Glide	USA	Raytheon/ DARPA		11th August 2011	7,600 km Partial

Hypersonic weapons are weapons that move at speeds of Mach 5 or more. Presently, hypersonic weapon technology is a work in progress and these weapons are yet to become fully operational for military deployment. However, a few states have already conducted multiple tests of these weapons and the results are encouraging. They are being regarded as "game-changing" weapons, and successful hypersonic defence is considered to be difficult to achieve. At the same time, hypersonic weapons are also seen as destabilising weapons and there is a view that such weapons could fuel an arms race. This paper debates various aspects of hypersonic weapons.

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