Hypersonic Technology and Weapons: A New Arms Race

Puneet Bhalla

> *Hypersonic aircraft, coupled with hypersonic missiles, could penetrate denied airspace and strike at nearly any location across a continent in less than an hour... Speed is the next aviation advancement to counter emerging threats in the next several decades. The technology would be a game-changer in the theatre, similar to how stealth is changing the battle space today.*
>
> Brad Leland, Lockheed's programme manager for hypersonics [1]

Since the dawn of flight, engineers and scientists have endeavoured to enhance the speed and reach of platforms that use the medium of air. Crossing the sound barrier was difficult owing to the distinct change in airflow patterns that occurred around the machine while transiting to, and within, this regime. Having first surmounted the challenge of supersonic flight in the Bell X-1 on October 14, 1947, many military, and a few civilian, platforms have consistently flown beyond the speed of sound.[2]

Hypersonic flight is defined as flight at five times the speed of sound (Mach 5) and beyond. Most exo-atmospheric ballistic missiles already operate in hypersonic regimes. The Space Shuttle and other

Group Captain **Puneet Bhalla** is former Senior Fellow, Centre for Land Warfare Studies, New Delhi.

N.B. The views expressed in this article are those of the author in his personal capacity and do not carry any official endorsement.

reentry vehicles pass through this regime (at Mach 20+) when entering the atmosphere, before decelerating during the descent for recovery. The endeavour to achieve hypersonic flight within the atmosphere was pursued at the same time as supersonic flight, but subsequent success has been elusive.[3] There were few strategic or commercial imperatives to make huge investments in such ventures. Progress was also marred by complex technological challenges and setbacks which resulted in inconsistent efforts by only a few advanced nations. Consequently, even decades after the breaking of the sound barrier, the next level of having operational hypersonic platforms transiting the atmosphere regularly has not been breached.

The past few years have seen more persistent pursuance of hypersonic flight, focussed at reducing flying times between places on Earth, for both civilian and military applications. As the number of nations pursuing hypersonic flight and its applications continue to increase, experts are warning of a new strategic arms race, with the associated risks and geopolitical pressures. This article would seek to cover the progress in the development of hypersonic non-ballistic missile technology that could provide advanced military capabilities or novel military applications and their influence on the global strategic equations.

Hypersonic Non-Ballistic Missiles

Presently, two types of hypersonic non-ballistic missiles are being developed: the unpowered gliders and those with internal propulsion.

- **Hypersonic Glide Vehicles (HGVs):** These are referred to as the boost-glide type, lacking propulsion. They are carried to around 100 km altitude while attached to a booster rocket. At this altitude, the vehicle detaches and glides down to Earth in a relatively flat trajectory, using the height to accelerate to hypersonic speeds between Mach 8–10. Ranges are dependent on the aerodynamic design and the resultant glide ratios. Provided with adequate control surfaces, the glide phase could also be used for manoeuvring the vehicle, enabling greater weapon accuracy and deception, as also evasive actions against enemy missile and air defence systems.

- **Hypersonic Cruise Vehicles (HCVs):** Hypersonic cruise missiles also need to be launched, either by booster rockets or a mother aircraft. The cruise phase would be supplemented with a propulsion system that would ignite after separation, furnishing additional speed and enabling greater manoeuvrability to the descending projectile. It would also extend the operational range considerably with potential to provide global strike capabilities.

Propulsion for Hypersonic Flight

Aerodynamic considerations limit the use of conventional turbojets, with their moving parts, to close to speeds of sound. Supersonic flight is best served by ramjets, which depend on the high air speed to pressurise the air-to-fuel mixture, achieving more efficient combustion and greater speeds. The propulsion system for sustained hypersonic flight would be the Supersonic Combustion Ramjet (SCRJ) (referred to as scramjets hereon).[4] Scramjets are variants of a Ramjet (RJ) air-breathing jet engine in which combustion takes place in supersonic airflow throughout the entire engine. They are air breathing engines, taking oxygen from the atmosphere and obviating the need to carry it as is done in rockets. They also have simpler designs as they do not have any rotating parts. This makes them smaller and lighter than conventional engines. However, they are effective only at very high velocities and, thus, require acceleration to these velocities by alternate means – mainly rocket power – before ignition. The first ever experiment to demonstrate scramjet technology outside a wind tunnel was the Australian HyShot II that in 2002 attained a speed of Mach 7.6 for six seconds. Since then, there have been a few successful tests of air breathing scramjets, but the technology is still some time away from achieving operational status.

With appropriate design and propulsion, strategically placed missiles could potentially achieve regional and global ranges, thus, providing more responsive options against time-sensitive targets.

Military Utility

Hypersonic flight with the advantages of speed and range and complemented by manoeuvrability has the potential to provide a decisive military edge over existing systems.

- Hypersonic missiles would enable delivery of weapon payloads across medium or long distances with unprecedented speed, significantly compressing the time lines when compared to existing subsonic and supersonic options.[5] Depending on the guidance system and payload, they could be employed against diverse static or slow moving targets.
- With appropriate design and propulsion, strategically placed missiles could potentially achieve regional and global ranges, thus, providing more responsive options against time-sensitive targets. Extended ranges would allow seizing of the initiative by preemptive targeting of the enemy's critical points of vulnerability, without having to resort to forward deployment of forces.
- Provision of adequate manoeuvrability would increase their accuracy and lethality and the flexibility to strike targets over wider areas.
- They enable greater survivability against existing defence systems by allowing strikes from greater standoff distances. This would be particularly effective in contested areas that use advanced Integrated Air Defence Systems (IADS) for Anti-Access/Area-Denial (A2/AD)[6] capabilities.[7]
- When employed in a defensive role, they would threaten the offensive forces at greater distances, forcing them further away from contested regions and inhibiting their effectiveness.
- Extreme speeds would significantly reduce the time available to detect, track, process and engage the incoming threat, greatly reducing their

vulnerability to existing air and missile defence systems that have become highly capable and lethal.

- Current missile defence systems have been developed to intercept and engage ballistic missiles, with their predictable trajectories, during the mid-course and terminal phases of their flight. Whole new missile defence structures with integrated sensors, faster processing speeds and communications as well as operational doctrine and organisational structures would have to be developed and made operational to sense, and respond to, these novel High Speed Manoeuvrable Weapons (HSMWs) and their varied, unpredictable and much flatter endo-atmospheric paths.[8]

Hypersonic research for civilian and military applications is currently conducted mainly by the United States (US), Russia and China. Other nations that also have programmes of more modest scales are Australia, Japan, France, Germany, South Korea and India. Each of the three prominent players has differing strategic motives for investing in hypersonic missile technology and all have attained varied levels of technological maturity.

United States

Conventional Prompt Global Strike (CPGS) Programme: The US has been the trendsetter and at the forefront of research into hypersonic technology, with research starting as early as the 1950s. In more recent years, the US' pursuance of hypersonic technologies has been in the context of its Prompt Global Strike (PGS) programme that seeks to develop "high-precision conventional weapons capable of striking a target anywhere in the world within one hour's time."[9] The objective is to be able to respond far more swiftly to rapidly emerging threats than is possible with conventional forces, complement the existing US rapid-response forces and decrease reliance on forward-based forces. At its inception in 2003, the programme was focussed on counter-terrorism efforts and the ability to strike critical

Pursuance of hypersonic options was also bolstered by Chinese and Russian concerns over ambiguities created by ballistic options (nuclear or conventional).

targets in 'rogue' states, but over the years, with a shift of its focus to the Asia-Pacific, the operational objectives have evolved to a greater emphasis on ability to project power across the globe in the new environment of improved enemy A2/AD capabilities by employing vastly enhanced long-range strike capabilities.[10]

Pursuance of hypersonic options was also bolstered by Chinese and Russian concerns over ambiguities created by ballistic options (nuclear or conventional) as well as restrictions imposed by the provisions of the Intermediate-Range Nuclear Forces (INF) Treaty and Strategic Arms Reduction Treaty (START). Hypersonic vehicles also did not count against the limitations laid down by the New START disarmament treaty's[11] limits on ballistic missiles.

Development of hypersonic payload vehicles to achieve the PGS mission began in 2003 through the combined Air Force and Defence Advanced Research Projects Agency (DARPA) Force Application and Launch from Continental United States (FALCON) programme. The major HGV projects being developed under this include:

- **Hypersonic Technology Vehicle 2 (HTV-2):** Development of the HTV-2 was initiated in 2003 and two full-scale intercontinental hypersonic aircraft flight tests were conducted in 2010. Launched by a Minotaur rocket as the boost vehicle from Vandenberg Air Force Base in California, the HTV-2 was planned to fly a distance of around 7,700 km, across the Pacific Ocean to Kwajalein Islands, in around 30 minutes. In both instances, following successful separation, the vehicles achieved speeds of around Mach 20 before disintegrating around 9 minutes into the glide flight.[12] The tests, however, were considered partially successful as they attained hypersonic speeds and were also able to validate two-way communication and navigation at those speeds.

- **Advanced Hypersonic Weapon (AHW):** The AHW was a competing boosted glide vehicle, which, after a few failures, reportedly achieved success in November 2011. Launched from its Pacific Test Range at Hawaii, it was able to strike a target on Marshall Islands, 3,700 km away, covering the distance in 30 minutes at an average speed of Mach 6. A follow-on test flight in August 2014, however, was a failure.[13] The AHW, with its relatively lesser range, is now being pursued as a more feasible option.

Experimental Powered Vehicles

Development of scramjet powered vehicles is also being pursued with an objective of having an operational Hypersonic Cruise Vehicle (HCV). Some of the more notable recent experimental vehicles include:

- **X-43:** The X-43 was an experimental single-use unmanned scramjet-powered aircraft for testing air-breathing engine powered hypersonic flight. Integrated with a winged booster rocket called Pegasus, it was to be air launched from a B-52 bomber. Pegasus would accelerate the X-43 to scramjet ignition speed (Mach 4–5), after which it would fly independently under its internal propulsion. After an initial failure in June 2001, in a test conducted in March 2004, it set a record speed of Mach 6.83. During the third and final test in November 2004, the scramjet engine operated for 12 seconds, accelerating the vehicle to Mach 9.8 (current record for fastest speed recorded by an air breathing vehicle) at up to 34 km altitude, before making a planned plunge into the Pacific Ocean.
- **X-51 Waverider:** The X-51 was a follow-on experimental DARPA programme, incorporating technological advancements of the X-43 programme, including the air launch from a B-52 bomber. The maiden test flight on May 26, 2010, used an Army Tactical Missile System (ATACMS) rocket booster in place of Pegasus. The test was partially successful and the scramjet propulsion maintained the top

speed of Mach 5 for 143 seconds, before the vehicle self-destructed due to instability and communication problems. The next two tests the 2011 and 2012 ended in failure. On its final test in May 2013, the vehicle set a record with a 200-second burn (planned 300 seconds) of its scramjet engine. The total flight lasted about six minutes and covered a distance of 426 km, setting a record for the longest duration hypersonic flight.[14]

- **HIFiRE (Hypersonic International Flight Research Experimentation Programme)** is a collaborative research project between the US and Australia. Between 2009 and 2017 (last on July 12, 2017)[15] eight ground-based launches were carried out on an Orion sounding rocket, to examine different aspects of hypersonic flight. Reports indicate that these tests involved both glide and scramjet-powered phases and although details of the test conducted in July 2017 have not been made public, the vehicle reportedly attained Mach 7.5 earlier, in 2016.
- Technologies and lessons learnt from these experiments are now contributing to the US Air Force's (USAF's) High Speed Hypersonic Strike Weapon (HSSW) mission, launched in 2014. The HGV is being pursued as Tactical Boost Glide (TBG) programme, limited to attaining only tactical ranges. The Hypersonic Air-breathing Weapon Concept (HAWC) is the HCV project.[16] The plan is to have an air launched, Mach 5-6 capable weapon by the early 2020s with a range of 500-600 miles.

The ultimate aim is to have long range strike weapons. Besides the specific programmes, these efforts would surely benefit from other US programmes, both government supported and those with commercial interests. These include the X-37B spacecraft[17] and the XS-1 programme that intends to accelerate vehicles to hypersonic speeds for launching small satellites into space. These would be supplemented by developments in programmes like Lockheed Martin's recently announced SR-72 hypersonic unmanned global reconnaissance and strike aircraft that is planned to be able to take-off and recover like a normal aircraft.

The accomplishments notwithstanding, the US progress in the realm has remained inconsistent and with recent Chinese and Russian successes, some analysts have cautioned against losing the technological and strategic advantage it has had over these adversaries. A 2016 National Academies of Sciences, Engineering, and Medicine study report commissioned by the USAF has denounced the "relatively leisurely pace of disjointed hypersonics technology development, the lack of diversity in concepts, and the absence of a clear acquisition pathway appear to stand in stark contrast to potential adversaries' feverish pace of research and development and test and evaluation, as well as their broadly cast net of technology options."[18] Consequently, there does seem to be a shift to a more determined and committed effort at developing both hypersonic missiles and counter-measures against high-speed manoeuvring weapons. The Pentagon has been authorised the setting up of a dedicated office for emerging hypersonic missile threats, and its Missile Defence Agency (MDA) has started studying the use of existing infrastructure, along with innovative counter-measures against these weapons.[19] Increasing government interest has also resulted in more private investment in Research and Development (R&D) in related technologies.

Russian and Chinese Considerations

Both Russia and China have considered the US withdrawal in 2003 from the Anti-Ballistic Missile (ABM) Treaty of 1972, as a destabilising move and have since stepped up their own efforts at weaponisation. Capabilities developed as part of the PGS programme, including hypersonic ones, are viewed for their ability to strike strategic targets, including nuclear capabilities, with a potential to disrupt the strategic balance of power. Both countries have denounced the increasing US deployment of its anti-missile defence systems[20] in nations close to their borders, with the potential of adversely impacting their regional dominance. Both nations see hypersonic weapons as critical elements for the negation of US technological and military advantage across the spectrum of conflict and as a counter capability that would act as a deterrent against American coercion.[21] With shared interests and concerns, they might influence each other's technological developments and benefit from progress made in individual programmes. The Chinese designs have imbibed a lot from Russia's hypersonic glide vehicle programme, and the closely conducted Russian and Chinese tests in April 2016 were no coincidence.[22] Both nations have ventured little information on their tests, leading to speculation on their outcomes and capabilities.

Russian Hypersonic Weapons' Evolution

Russia is known to have pursued its hypersonic aircraft projects in the late 1970s and early 1980s. Its Space Shuttle, the Buran, which flew only once, attained hypersonic velocities during reentry and recovery. Responding to the Strategic Defence Initiative (SDI)[23] announced by the US in 1983, it pursued development of a manoeuvrable HGV named Albatross (codenamed 'Project 4202') that would be boosted by its UR-100N (SS-19) Intercontinental Ballistic Missile (ICBM). Flight tests were reportedly conducted in 1991-92, and additional tests took place in 2001 and 2004.[24] As was with US efforts, technical and financial challenges resulted in slow progress.

Russia has now stepped up efforts towards acquiring hypersonic capabilities. Between 2011 and 2015, it is known to have carried out four tests of its YU-71 HGV, using the SS-19 missile as the booster.[25] In 2016, it announced a successful flight test of a new experimental hypersonic glider, the YU-74, carried by the RS-18A ICBM.[26] The YU-74 system specifications and the parameters achieved remain classified. Analysts have construed that the gliders would be compatible with the prospective heavy liquid-fuelled RS-28 Sarmat ICBM, enabling ranges of up to 10,000 km and would primarily be aimed at penetrating US missile defence with both conventional and nuclear options. The same was also voiced by Russian officials in August 2016.[27] *Jane's Intelligence Review* has put the operational deployment of such systems by Russia in the 2020-25 timeframe.[28]

In the case of China, hypersonic weapons are also intended to overcome the relatively smaller size of its nuclear arsenal.

These efforts would be complemented by other Russian developments. These include the Zircon ship-based, scramjet powered hypersonic manoeuvrable anti-ship missiles (expected range of around 400 km). The last successful launch was on June 03, 2017, in which the missile reportedly achieved Mach 8 speed. Additionally, Russia is developing an air-launched HCV, the X-32, being designed for the modernised long-range Tu-22M3M bomber[29], and is collaborating with India on the BrahMos II scramjet-powered HCV that would be able to cover tactical ranges at Mach 7.

Chinese Developments

The Chinese military has been pursuing the development of its rocket-boosted HGV, the DF-ZF (initially designated WU-14 by the US) since 2010. It reportedly conducted seven tests between 2014 and April 2016, of which all but one were considered successful. While the Chinese have not officially confirmed the conduct of any of these tests, evidently the US has been tracking them and discussed them in briefings, reports and other writings. All the test launches were performed at the Taiyuan Satellite Launch Centre, the Chinese military's main long-range missile testing centre, using a Medium-Range Ballistic Missile (MRBM) launcher and are believed to have achieved speeds between Mach 5 and Mach 10. All followed a linear flight path except the fifth one in August 2015, which included a manoeuvre that has been projected as either extreme or gentle by different analysts. [30] Very little information is available on the Chinese efforts at developing HCVs.

The DF-21 medium range missile would provide theatre level capability, when launched by the under development DF-41-based launcher.

In the case of China, hypersonic weapons are also intended to overcome the relatively smaller size of its nuclear arsenal even as the US' non-declaration of a no first use nuclear policy continues to be a point of concern. Moreover, Chinese strategic thought emphasises on developing asymmetric capabilities to target superior enemies. Its Anti-Satellite (ASAT) test was seen in this context – threatening the US space segment that is the keystone of its global operations.[31] The US views Chinese developments in the context of the A2/AD strategies – the ability of hypersonic anti-ship missiles to penetrate the layered defences of its Carrier Battle Groups (CBGs) – inhibiting its global power projection capability.[32] Such a capability to penetrate all kinds of air and missile defence systems would also enhance China's regional power projection capability, enabling greater freedom of manoeuvre and action to support its regional aspirations; a fact not lost on its neighbours.

There have been speculations in the Chinese media and similar interpretations have been put forth in reports prepared in the West on the mating of the HGV, in the future, with design modifications, with a variety of intercontinental and theatre ballistic missiles, thereby allowing expansion of its power projection capability beyond its immediate periphery and also for providing mobile options. The DF-21 medium range missile would provide theatre level capability, when launched by the under development DF-41 based launcher. And, it would potentially be able to reach the continental United States within 30 minutes.[33] Lora Saalman, an American expert, corroborates this through her analysis of Chinese studies on hypersonic vehicles, roughly a quarter of which, she says, remain focussed on US missile defences, rather than any A2/AD agenda.[34] However, this has been contested by another analyst, James Acton, who, in his testimony before the US-

China Economic and Security Review Commission, had highlighted the limited test ranges of between 1,250 km to 2,100 km in these tests as being indicative of less advanced technologies and regional aspirations than global ones.[35] He goes on to emphasise that placing a glider onboard any ICBM would not be a simple addition but would require complex integration and also need to cater to the fact that both vehicles are designed for operations at different speed characteristics.[36] He has also challenged most claims about the technological prowess of the Chinese tests, attributing hyped up claims in the media to lack of domain knowledge and diverse interests on both sides.[37] Others have supported Chinese claims that these developments in military technology are for scientific purposes and aimed at defending China's own interests and are not targeted at any country and specific goals.[38]

China's 2015 Military White Paper has emphasised on development of long range, precise and smart weapons. The reorganisation of its forces that amalgamated diverse elements into the People's Liberation Army Rocket Force (PLARF) and its elevated status, on par with the land, sea and air forces, as also the stress on leaner force levels based on technological innovation, all highlight the greater importance of medium and long range precision strike capability and the strategic importance of its missile forces.[39] The shift in emphasis from regional aspirations to rapid power projection capability in China's new guidance policy of 2016 have been construed by some Western analysts as referring to PGS capabilities.[40] HGVs are expected to be important components of these efforts.

Technical Challenges and Limitations

The successes have come after several failures and disasters and enough challenges remain in mastering the complexities unique to this speed regime. These include:

- Aerodynamic forces acting on the structure at these speeds cause extreme and highly dynamic pressures, posing major challenges for the structural integrity of such vehicles. This also makes it difficult to provide surfaces that could effectively provide adequate stability, manoeuvrability and controllability at these extreme speeds.

- The vehicle surface heats up with increasing velocities due to kinetic heating and the effect is compounded at lower altitudes with greater atmospheric density. Temperatures of up to 3,000 degrees centigrade have been recorded and some major disasters and failures, including the Space Shuttle Columbia accident in 2003, have been attributed to material failure due to extreme heating.
- Any composite hypersonic vehicle would have to be provided internal components for control, navigation, guidance, communication, and so on. Extreme skin temperatures would adversely affect the working of these components, placed close to the surface. The failures of the HTV-2 and AHW tests was attributed to the failure of the onboard electronics, leading to loss of communication.
- With increasing velocities, the boundary layer, the sheet of air adjacent to the vehicle's skin, becomes highly turbulent and complex. This also significantly contributes to increasing the air resistance and temperatures. The complexity of the boundary layer at these velocities is not yet totally understood due to the limitations of existing wind tunnels and computer generated simulation models.
- The highly turbulent layer at high temperatures causes plasma to form around the vehicle that hinders communications with the vehicle and operation of sensors and other components that depend on signal interactions.
- The mass and size of the vehicle would be defined by the design considerations and the compatibility with existing launch equipment. This would influence the aerodynamics and fuel capacity with a resultant impact on the range and endurance, and the weapon payload that could be carried.

Addressing these issues would require intricate aerodynamic designs and development of special materials that would provide adequate structural integrity at extreme stress and temperatures and shield internal components. The components themselves would have to be more robust, and appropriate software would be required for guidance and control at all stages of flight while ensuring consistent navigation inputs. Increasing automation would help to overcome some of these limitations. Much investment would be required in scramjet propulsion technology, currently in its nascent stages, to develop HCVs.

Countries involved in hypersonic research and developing scramjet technologies are investing in upgrading or constructing new wind tunnels and other infrastructure to enable testing at higher velocities.

Hypersonic research experiments and test flights conducted over the years have given valuable insights into this extreme flight environment and provided vital scientific data. This, coupled with technological advances and the advent of revolutionary enabling technologies, has brought hopes of major breakthroughs in engineering a more comprehensive hypersonic weapon as well as an appropriate launch system in the foreseeable future. Most countries involved in hypersonic research and developing scramjet technologies are investing in upgrading or constructing new wind tunnels and other infrastructure to enable testing at higher velocities of at least Mach 15. Academia is being involved extensively in research. With greater applicability to civil air transportation and in the launch of small satellites into outer space, interest and investments in related technologies are expected to see more focussed commitment in the future.

Developments would mostly be incremental in terms of range and speed, and boost glide HGVs are expected to be operational much before air breathing HCVs owing to the greater complexities involved with the latter. In April 2016, then USAF Deputy Assistant Secretary

Geostrategic interests, national pride, military advantages and technological advancements would spur advanced nations to pursue medium- to long-range hypersonic weapons with greater ranges, precision and capabilities as well as seeking counter-measures, with a consequent impact on strategic stability.

for Science, Technology and Engineering, David Walker laid out a roadmap for the US hypersonic programme that sees tactical boost glide missiles operational by 2020, unmanned offensive hypersonic surveillance platform by 2030s and a reusable Intelligence, Surveillance, Reconnaissance (ISR)/strike hypersonic aircraft by 2040.[41] For Russia and China, based on inputs available on their recent tests, predictions have put the availability of operational HGV systems in the next ten to fifteen years. However, such weapon units would be very expensive to produce and deploy, limiting their numbers initially.

Impending Arms Race

The US has repeatedly emphasised that its PGS programme is for conventional strikes only. Its pursuance of HGVs was based on the premise that their differing trajectories would clearly separate them from ballistic missiles, thereby conveying the use of conventional warheads.[42] At the same time, owing to the lack of transparency of Russian and Chinese developments, the US remains apprehensive of their use of hypersonic vehicles for carriage of both conventional and nuclear payloads,[43] emphasising in various discussions that weapons aimed at defeating US missile defences would mainly be nuclear armed.[44] Practically, it is virtually impossible for any early warning system to discern between conventional or nuclear warheads and any long range missile trajectory would be treated as potentially nuclear by an adversary. These, when coupled with compressed HGV timelines, could lower the threshold for

India needs to build its own versions of medium-range hypersonic weapons to maintain its balance of power.

hostile response actions and have the potential to escalate any conflict, if falsely interpreted.[45]

The USAF report highlights the potential for an arms race when it states that the "only reliable deterrent to the use of a hypersonic weapon may, in fact, be the threat of a corresponding hypersonic countermeasure that might hold at risk the very sites from which the adversaries' hypersonic strike would originate."[46] Geostrategic interests, national pride, military advantages and technological advancements would spur the advanced nations to pursue medium to long range hypersonic weapons with greater ranges, precision and capabilities as well as seeking counter-measures, with a consequent impact on strategic stability. For any nation possessing these weapons, they would form critical components of its deterrence strategies. There would also be a race to improve upon the capabilities – enhanced ranges, enhanced manoeuvrability and greater lethality. While the US, Russia and China would remain at the forefront, other nations would also strive to catch up, benefiting from growing technological sophistication and proliferation of technology that could be a result of commercial aspirations or as a means of forging or maintaining strategic alliances.

No current international treaty covers the HGVs and their use of nuclear warheads would be free of arms control restraints, making them lucrative options to be developed and fielded. It would be prudent to identify the escalatory potential of these weapons and proliferation concerns and utilise the time available till their operational deployment to put in place appropriate international norms and conventions, with special emphasis on nuclear payloads. It would be important to define limits to ensure balance of forces among nations for geostrategic stability and to give an impetus to suitable arms control mechanisms and non-proliferation efforts.[47] A ban on testing, although desirable, is highly improbable and would be

The advent of operational hypersonic weapons would revolutionise the strategic military space, thereby influencing national security strategies and military doctrines and possibly, the organisations and force structures.

difficult to enforce. Excluding new states from this novel technology would be seen as discriminatory and unwelcome. Trust and confidence building measures and transparency in testing, along with continuous dialogue, would be more desirable.[48]

India

In view of the Chinese developments, India needs to build its own versions of medium range hypersonic weapons to maintain its balance of power. Besides the collaborative BrahMos II project, the Defence Research and Development Organisation (DRDO) in India has also been pursuing an indigenous Hypersonic Technology Demonstrator Vehicle (HSTDV), an unmanned scramjet demonstration aircraft for hypersonic speed flight. The initial aim for the test vehicle is to attain autonomous scramjet flight for 20 seconds, using a solid rocket launch booster. The ultimate goal is to develop an unmanned HCV capable of speeds of up to Mach 7 at an altitude of 32.5 km. Both Israel and Russia have provided assistance to the programme, including wind tunnel testing in 2007 and 2009 respectively. A RAND report has also brought out the presence of 12 hypersonic wind tunnels in India, the newest being that at the Indian Institute of Science, inaugurated in April, 2014.[49] Though the scramjet engine has reportedly been ground-tested successfully for 20 seconds and scientists have claimed validation of some technologies, the programme has failed to meet other scheduled goals.

Conclusion

HGVs and HCVs, with their attributes of high speeds, compressed timelines, longer ranges and manoeuvrability could provide numerous strategic and military advantages when used for medium and long range precision strikes. They could complement the ballistic options but it would be their ability to penetrate conventional missile defences, influencing both A2/AD and counter A2/AD strategies, which would drive interest and investments in the future. There are still many hurdles to be overcome before hypersonic air vehicles and weapons are ready for operational deployment. However, the sector would surely see more vibrant participation not only to build capability but also towards the bringing down of overall costs to make fielding of such systems economically tenable. These efforts would also benefit from dual-use technologies. Although, initial success would be seen in the short and medium ranges, the ultimate goal would be the development of long range, even global, precision weapons.

India should strive to have operational hypersonic vehicles at the earliest to deter its adversaries and also ensure that it has greater influence in global negotiations.

The advent of operational hypersonic weapons would revolutionise the strategic military space, thereby influencing national security strategies and military doctrines and, possibly, organisations and force structures. Acquistion of medium to long range hypersonic weapon capability by more nations would have an impact on global power equations and strategic stability. Most destabilising would be the exercising of the nuclear option. To prevent an unbridled race to build or procure these new forms of weapons, global efforts at regulating them should commence at the earliest and progress in parallel with the technological advancements. India should strive to have operational hypersonic vehicles at the earliest to deter its adversaries and also to ensure that it has greater influence in global negotiations.

Notes

1. "Meet the SR-72", Official Website, Lockheed Martin, November 01, 2013, accessed at http://www.lockheedmartin.com/us/news/features/2015/sr-72.html
2. The speed of sound is not constant and is dependent on a number of environmental factors. Mach 1 denotes the speed of sound at prevalent conditions.
3. In the 1950s-60s, the United States tested an experimental boost-glide manned vehicle called the X-15. The aircraft still holds the official world record of the highest speed ever recorded by a manned, powered aircraft, of Mach 6.72 (4,520 miles per hour or 7,274 km per hour), set in October 1967.
4. Ramjet engines have a minimum operating speed of Mach 1, do not become efficient until Mach 2.5 and have a maximum speed of around Mach 6. Scramjets need to have a speed of around Mach 4.5 for ignition and can theoretically achieve a maximum speed of Mach 15 to Mach 20.
5. The time to target, over a distance of 1,000 km, at subsonic speeds of around at 800 km/h would be around 75 minutes. For a high supersonic system (Mach 2.8), the same would reduce to less than 18 minutes. At hypersonic speeds (at Mach 6), this would further reduce to around 9 and half minutes. The time advantage would increase proportionally over longer ranges.
6. A2/AD involves using long-range sensors and precision weaponry to deny the adversary the ability to operate in the vicinity of some strategically significant areas.
7. Hans-Ludwig Besser et. al., "Hypersonic Vehicles: Game Changers for Future Warfare? Joint Air Power Competence Centre, *JAPCC Journal*, No 24, July 2017, accessed at https://www.japcc.org/hypersonic-vehicles/
8. "A Threat to America's Global Vigilance, Reach, and Power: High-Speed Maneuvering Weapons", Committee on Future Air Force Needs for Defense Against High-Speed Weapon Systems, Air Force Studies Board, 2016 (Washington, DC: National Academies Press), accessed at https://www.nap.edu/read/23667/
9. Eleni Ekmektsioglou, Abstract of "Hypersonic Weapons and Escalation Control in East Asia", *Strategic Studies Quarterly*, Summer 2015, accessed at http://www.airuniversity.af.mil/Portals/10/SSQ/documents/Volume-09_Issue-2/ekmektsioglou.pdf
10. Amy F Woolf, "Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues", Congressional Research Service Report, February 03, 2017, accessed at https://news.usni.org/wp-content/uploads/2017/02/R41464-1.pdf#viewer.action=download
11. The New START Treaty, which entered into force on February 05, 2011, between the US and Russia, limits each country's number of nuclear warheads to 1,550. The number of deployed Intercontinental Ballistic Missiles (ICBMs), Submarine-Launched Ballistic Missiles (SLBMs) and heavy strategic bombers is limited to 700. These numbers are to be achieved by February 05, 2018.
12. "Superfast Military Aircraft Hit Mach 20 Before Ocean Crash, DARPA Says", SPACE.com August 18, 2011, accessed at https://www.space.com/12670-superfast-hypersonic-

military-aircraft-darpa-htv2.html
13. "Advanced Hypersonic Weapon (AHW)", Global Security.org, accessed at https://www.globalsecurity.org/military/systems/munitions/ahw.htm
14. "The X-51A Soars to New Heights", Official Website Boeing, May 03, 2013, accessed at http://www.boeing.com/features/2013/05/bds-x51-05-03-13.page
15. 1 Kyle Mizokami, "The U.S. and Australia Conducted a Secretive Hypersonic Missile Test", Popular Mechanics, July 18, 2017, available at http://www.popularmechanics.com/military/research/a27384/us-australia-hypersonic-missile-test/
16. Leonid Nersisyan, "America vs. Russia: When Will Hypersonic Weapons Change the Way We Wage War?", *The National Interest*, September 01, 2017, accessed at http://nationalinterest.org/blog/the-buzz/america-vs-russia-when-will-hypersonic-weapons-change-the-22151?page=2
17. Currently on its fifth mission into space, the X-37 is the only operational hypersonic glide vehicle in the world.
18. n.3
19. Bill Gertz, "Pentagon Studies Ways to Counter Hypersonic Missile Threat from China, Russia", *Washington Times*, February 22, 2017, accessed at http://m.washingtontimes.com/news/2017/feb/22/china-russia-hypersonic-missile-threat-under-revie/
20. China is concerned about US supplied air and missile defence systems in South Korea, Japan and Taiwan. Russia has mentioned PGS among a number of the new threats it faces, along with the US ground-based mid-course defence system in Alaska, the Aegis ballistic missile defence system in Europe, and increased NATO activity in Eastern Europe.
21. Prashanth Parameswaran, "China Challenging All Foundations of US Military Power: Ex-US Official", *The Diplomat*, August 20, 2015, accessed at https://thediplomat.com/2015/08/china-challenging-all-foundations-of-us-military-power-former-us-official/
22. Lora Saalman, "China's Calculus on Hypersonic Glide", Stockholm International Peace Research Institute, August 15, 2017, accessed at https://www.sipri.org/commentary/topical-backgrounder/2017/chinas-calculus-hypersonic-glide
23. SDI called for the development and deployment of strategic missile defence of space-, air-, sea-, and ground-based targets from a mass-scale Soviet ballistic missile attack.
24. Vladimir Dvorkin, "Hypersonic Threats: The Need for a Realistic Assessment", Carnegie Moscow Centre, August 09, 2016, accessed at http://carnegie.ru/2016/08/09/hypersonic-threats-need-for-realistic-assessment-pub-64281
25. Woolf, n.10.
26. Ibid.
27. Bill Gertz, "Russia to Field Hypersonic Missiles by 2020", *Free Beacon*, August 25, 2016, accessed at http://freebeacon.com/national-security/russia-field-hypersonic-missiles-2020/
28. "Hypersonics Disrupt Global Strategic Stability", *IHS Jane's Intelligence Review,* 2017, accessed at http://www.janes360.com/images/assets/515/67515/Hypersonics_disrupt_global_strategic_stability.pdf

29. Woolf, n.10.
30. "China's Advanced Weapons", Testimony by James M. Acton to US-China Economic and Security Review Commission on February 23, 2017, accessed at http://carnegieendowment.org/2017/02/23/china-s-advanced-weapons-pub-68095
31. Nayef Al-Rodhan, "Hypersonic Missiles and Global Security", *The Diplomat*, November 13, 2015, accessed at https://thediplomat.com/2015/11/hypersonic-missiles-and-global-security/
32. n.3.
33. Erika Solem and Karen Montague, "Updated – Chinese Hypersonic Weapons Development", *China Brief,* Vol 16, Issue 7, The Jamestown Foundation, April 21, 2016, accessed at https://jamestown.org/program/updated-chinese-hypersonic-weapons-development/
34. n.14.
35. Dvorkin, n.24.
36. Parameswaran, n.21.
37. Ibid.
38. Dvorkin, n.24.
39. n.14.
40. Lora Saalman ed., "China-Russia Relations and Regional Dynamics from Pivots to Peripheral Diplomacy", Stockholm International Peace Research Institute, March 2017, accessed at https://www.sipri.org/sites/default/files/China-Russia-relations-regional-dynamics.pdf
41. Benjamin Knudsen, "An Examination of US Hypersonic Weapon Systems", Technical Report, June 2017, accessed at https://www.researchgate.net/publication/317388988_An_Examination_of_US_Hypersonic_Weapon_Systems
42. Alexei Arbatov and Vladimir Dvorkin, "The Great Strategic Triangle", Carnegie Moscow Centre, April 01, 2013, accessed at http://carnegie.ru/2013/04/01/great-strategic-triangle-pub-51362
43. James M. Acton, "A New High-Speed Arms Race", Carnegie Endowment for International Peace, November 21, 2014, accessed at http://carnegieendowment.org/2014/11/21/new-high-speed-arms-race
44. n.14.
45. Dvorkin, n.24.
46. n.3.
47. Woolf, n.10.
48. Salmaan, n.22.
49. Richard H. Speier et al, "Hypersonic Missile Nonproliferation: Hindering the Spread of a New Class of Weapons", RAND Corporation, September 2017, accessed at https://www.rand.org/content/dam/rand/pubs/research_reports/RR2100/RR2137/RAND_RR2137.pdf