THE HYPERSONIC MISSILE CONUNDRUM

RAJARAM NAGAPPA

The use of the Kinzhal hypersonic missile by Russia in the ongoing war in Ukraine to destroy an underground arms depot has reignited the discussion on the possible game-changing capabilities of hypersonic weapon systems. Much has been written about the dangers posed by hypersonic weapons in terms of their operating altitudes, Mach 5+ (M5+) operating speeds, manoeuvrability and their near invulnerability to current missile defence systems.

Hypersonic weapon systems operate in the challenging aero-thermodynamic environment, and their development is technology intensive. Additionally, one must cater for specialty materials, advanced fabrication techniques, development and testing infrastructure, simulation studies and investment in time and money. A few countries like the United States, Russia and China have made major headway in the development of hypersonic weapon systems. North Korea has also claimed to have carried out a flight test of a hypersonic glide vehicle. Some other countries like India, France, Japan and Australia have initiated development of hypersonic weapons stemming from their own research interests and security concerns. Some other countries may take advantage of technology proliferation avenues to acquire hypersonic weapons. Export control regulations may not be adequate to stem technology proliferation in view of existing ambiguities in the export control regimes and the dual use nature of hypersonic systems.

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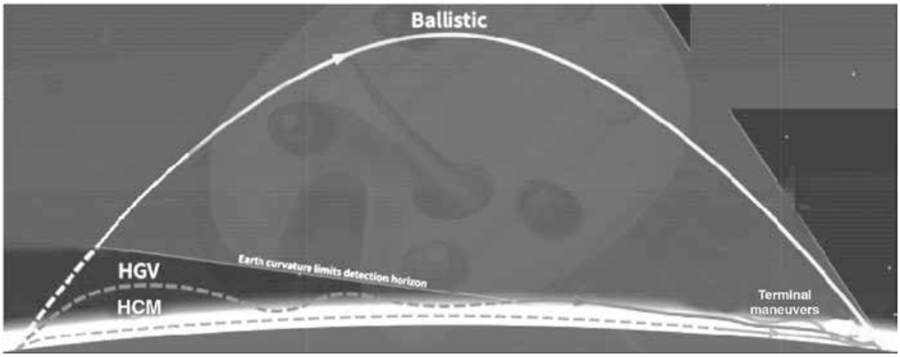
HYPERSONIC WEAPON SYSTEMS

Ballistic missiles of medium and intercontinental range which routinely travel at hypersonic speeds are excluded in this write-up, except where necessary, for the sake of comparison. Two types of Hypersonic Weapon Systems (HWS) are being pursued by some of the leading countries. These are the Hypersonic Glide Vehicle (HGV) and Hypersonic Cruise Missile (HCM). The HGV, also called the Boost-Glide Vehicle (BGV) is boosted by a rocket, either on a minimum energy trajectory or a depressed trajectory, followed by an unpowered glide to the target. The HGV operating regime could vary from M20+ to M5, depending upon the boost vehicle employed. At the start of the glide, a pull-up manoeuvre may be initiated, after which the missile enters the equilibrium glide phase. During this phase, the weapon can exercise further down-range as well as cross-range manoeuvres. The other system is the HCM, which is powered by either a supersonic combustion ramjet (scramjet) or by a dual mode ramjet. Both these power plants can operate at supersonic speeds and, hence, the missile has to be boosted by other means to hypersonic speeds. Normally, the missile is boosted by a missile stage or by air launch followed by rocket boost to initial starting conditions—typically around 30 km altitude and hypersonic velocity—and further cruise is then sustained by a scramjet engine. The HCM operating regime could be in the M number range of 4 to 8 while employing hydrocarbon fuel and at altitudes in the vicinity of 30-35 km.

The trajectory of ballistic missiles is mostly above the atmosphere and their trajectory is predictable and is not amenable to manoeuvring. However, a ballistic missile equipped with a Manoeuvring Reentry Vehicle (MaRV) is an exception as it can carry out manoeuvres in the terminal stage. The missile operating regime of hypersonic missiles is shown in Fig 1.

The air density at 100 km, though small ($5.08 \times 10^{-7} kg/m^3$) is reasonable enough for aerodynamic surfaces to be effective and, therefore, the glide phase of the HGV could typically commence from 100 km or lower. During the glide phase, the altitude of the HGV is managed for continuously

Fig 1: Typical Trajectories of Ballistic Missile, HGV and HCM (not to scale)

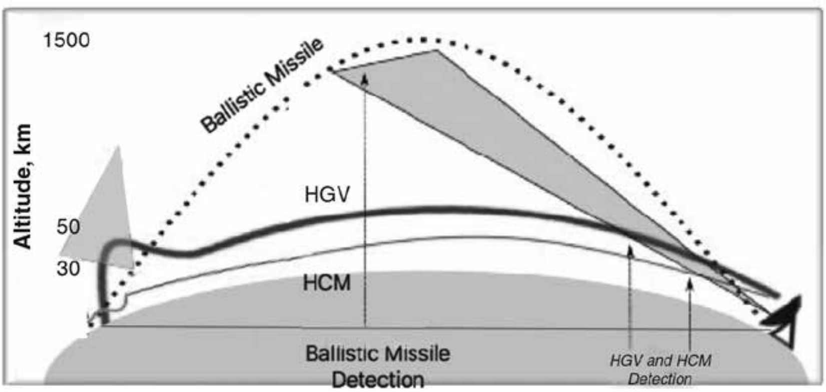


Source: Author's creation.

obtaining maximum lift to drag ratio. Manoeuvres are possible during this phase of flight but each manoeuvre will result in loss of velocity. The cruise missile, on the other hand, does a powered flight at an altitude of approximately 30 km at M 6-8.

The low altitude operating regime of hypersonic missiles delays their acquisition by terrestrial radars and severely compresses the reaction time for the adversary. This is shown in Fig 2.

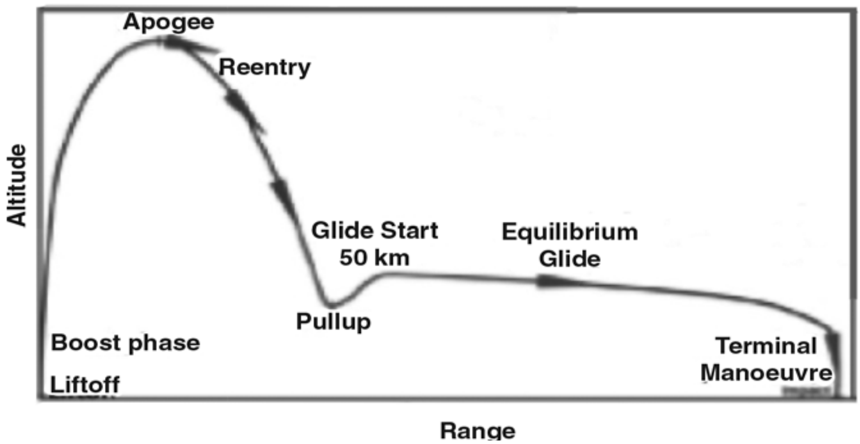
Fig 2: Compressed Detection/Reaction Time (not to scale)



Source: Author's creation.

The range and speed of the HGV is basically governed by the boost system employed. The different phases of an HGV flight are shown in Fig 3. A depressed trajectory can also be employed to boost the glide vehicle to an apogee near to 50-100 km followed by the pull-up and glide.

Fig 3: Typical HGV Trajectory



Source: Author's creation.

As opposed to the unpowered HGV, the HCM is powered throughout its flight. The Supersonic Combustion Ramjet (SCRAMJET) powered HCMs using hydrocarbon fuel can operate between M 4-8. The operating altitudes lie between 15 and 40 km—at low altitudes, the dynamic pressure and structural loads tend to be high, while at higher altitudes, lower air density affects the engine performance. An altitude of 30 km for M 6 operation appears to be a good compromise.

THE INTERNATIONAL SCENE

The US, Russia and China are at the forefront in the development of hypersonic weapon systems; North Korea pulled a surprise by claiming the successful flight test of an HGV in September 2021; countries including France, India, Japan, Australia are furthering research related to hypersonic missile systems.

China publicly displayed the DF-17/ DF-ZF HGV in the National Military Parade of October 1, 2019. US reports suggest the system may have been under development since 2014.

The US has been a pioneer in hypersonic research which resulted in the flight tests of the North American X-15 rocket powered research aircraft in the late 1950s. Hypersonic concepts, research, as well as ground and limited duration flight tests have been going on in the US, Russia and Europe since the 1990s, but the efforts did not fructify into an operational system. In recent times, the US flight tested the X-43A, a liquid hydrogen fuelled scramjet powered hypersonic vehicle up to M 8, and the X-51, a hydrocarbon fuelled hypersonic scramjet up to M 5. These formed the backdrop research for the US HCM effort.

Russian pursuit of hypersonic weapon systems was made public in President Putin's March 2018 State-of-the-Nation address. Both hypersonic glide vehicles and cruise missiles were part of the weapon systems disclosed in this address.

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France and Japan have a history of hypersonic research and both countries were experimenting with combined cycle propulsion and reusability for affordable access to space in the 1990s. They have now renewed their interest and are researching hypersonic weapon systems. The international hypersonic weapon status is captured in Table 1.

Table 1: International Hypersonic Weapon Systems

Missile	**Country**	**M No./ Range**	**Status**	**Remarks**
Hypersonic Glide Vehicles				
Avangard	Russia	20/6000+	Op	Boosted by SS-19 Stilleto. Planned to be boosted later by new ICBM Sarmat. The Sarmat launch is expected to enhance range and carry more than one glide vehicle.
Kinzhal	Russia	6-10/2000	Op	The missile is air launched (MiG 31K) and then powered by a solid propellant (dual thrust) motor. Range gain is using aero-ballistic trajectory
DF-ZF	China	10/2000-2500	Op	Boosted by the DF-17. Likely to be boosted later by the DF-26
ARRW	USA	6-8/1600	Dev	Air launch followed by rocket boost. First successful test in May 2022.
C-HGB	USA	6/	Dev	Development of common hypersonic glide body (led by the US Navy).
TBG	USA	7+/--	Dev	DARPA initiative to develop tactical boost-glide technologies
Hypersonic Missile	North Korea	--/700-1000	Dev	The Hwasong 8 may have been used to boost the missile
V-Max	France	M5/--	Prop-osed	
Hypersonic Cruise Missiles				
Tsirkon	Russia	6-8/500-1000	Op	Launched from ship/ submarine against naval targets

Starry Sky-2 (XingKong2)	China	6.5/--	Dev	Flight tested in August 2018 for a duration of 400 seconds
Lingyun 1	China	6/2000	Dev	Flying testbed for proving hypersonic technologies.
HAWC	USA		Dev	Combined programme of DARPA and US Navy with the aim of developing critical hypersonic cruise missile technologies
HIFIRE	Australia	8/--	Dev	Combined Australia-US technology development programme
ATLA	Japan	5-8/--	Dev	Dual mode scramjet to be developed
Perseus (CVS 401)	France	5/300	Dev	Joint Anglo-French project for the multi-platform/multi-role weapon system

INDIAN SCENARIO

As compared to the progress achieved in China, Russia and the US, the Indian achievement to date is modest. At the same time, technology development capability, basic and advanced test infrastructure as well as trained human resources are available and certain milestones including flight tests of technology demonstrators have been achieved. It is believed that hypersonic missile development activity is being pursued as the defence minister himself has urged the defence scientists to work on this (hypersonic) technology.[1]

Hypersonic Glide Vehicle (HGV)

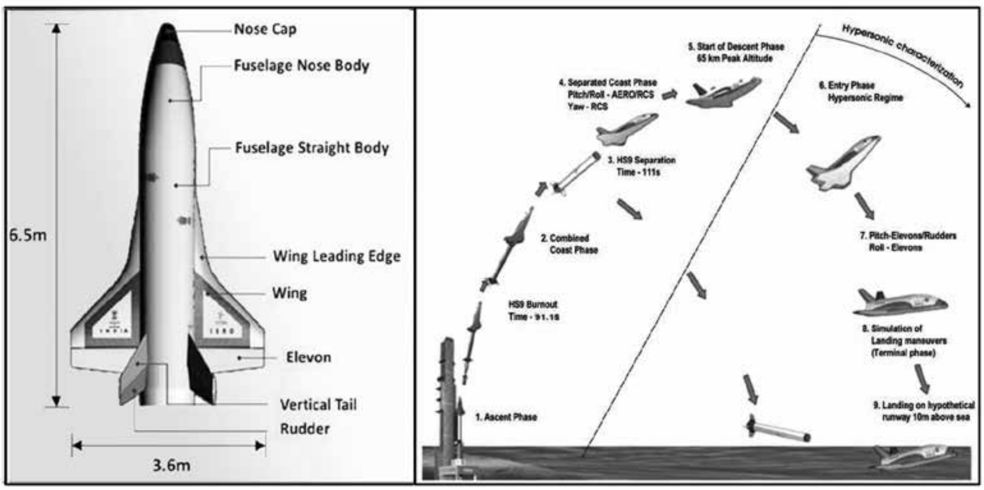
Information regarding the HGV development being undertaken in the Defence Research and Development Organisation (DRDO) is not available

1. "Does India Have Hypersonic Missile Technology? The Country gets to Strengthen its Capabilities", *Financial Express Online*, December 20, 2021, at https://www.financialexpress.com/defence/does-india-have-hypersonic-missile-technology-the-country-gets-ready-to-strengthen-its-capabilities-know-more/2384494/. Accessed on January 22, 2022.

in the public domain. However, given the government's backing, it can be surmised that the development of a hypersonic glide vehicle is an ongoing priority in DRDO. DRDO has a number of operational missile stages from which it can select and fashion the boost vehicle for the hypersonic glider.

Some useful design and performance inputs can be derived from the demonstration flight test of the Indian Space Research Organisation's (ISRO's) Reusable Launch Vehicle Technology Demonstrator (RLV-TD) in May 2016. This vehicle operated close to the hypersonic regime starting at M 4.78 while gliding from an altitude of 64.8 km to 45 km. The RLV-TD vehicle and its flight profile are reproduced in Fig 4.[2]

Fig 4: RLV-TD and Flight Profile



Source: ISRO.

The hypersonic flight regime was encountered in this flight between events 5-7 marked in the figure. The vehicle touched a peak Mach no of 4.78 at an altitude of 64.8 km and carried out hypersonic glide till it reached an altitude of 45 km approximately and M no 3.9. During the hypersonic

2. "RLV-TD", ISRO, May 23, 2016, at https://www.isro.gov.in/launcher/rlv-td. Accessed on January 22, 2022.

phase of the flight, the aerothermodynamic performance, autonomous navigation, guidance and control and performance of the thermal protection system could be demonstrated. These parameters are of relevance and can be used as stepping stones for HGV design and development. Detailed design and performance details of the RLV-TD are provided in a series of articles in *Current Science.*[3]

India has the basic wherewithal for undertaking full scale hypersonic system development. However, there will be need to consolidate the design information and database, carry out characterisation tests, identify and take up necessary facility augmentation and identify industry to assist in fabrication, assembly and testing needs.

Hypersonic Cruise Missile (HCM)

Development activities relating to the hypersonic cruise missile saw an uptick with the successful flight test of DRDO's Hypersonic Technology Demonstrator Vehicle (HSTDV) in September 2020. The test demonstrated autonomous sustained flight of a scramjet engine powered hypersonic vehicle at M 6. According to the press release relating to the flight, "The hypersonic combustion sustained and the cruise vehicle continued on its desired flight path at a velocity of six times the speed of sound i.e. nearly 2 km/second for more than 20 seconds. Critical events like fuel injection and autoignition of scramjet demonstrated technological maturity. The scramjet engine performed in a text-book manner".[4] HSTDV was boosted to scramjet initiation conditions in the fairing of Agni-1 missile.

Hypersonic scramjet engine flight performance has also been demonstrated by ISRO in the flight test of its Advanced Technology Vehicle (ATV) in August 2016. In this test, two scramjet propulsion modules were integrated with the ATV and tested in a captive fashion at M 6 for a duration

3. BN Suresh, et al. (Guest eds), "Special Section: Reusable Technology-Demonstrator Vehicle", *Current Science*, vol. 120, no. 01, January 10, 2018, pp. 34-147.
4. Ministry of Defence, "DRDO Successfully Flight Tests Hypersonic Technology Demonstrator Vehicle", Press Information Bureau, 2020, at www.pub.gov.in/PressReleasePage.aspx?PRID=1651956. Accessed on January 20, 2022.

of five seconds. The flight test using hydrogen fuel demonstrated ignition, air intake performance, fuel injection and flame holding.[5]

Based on the progress in hypersonic systems described in the foregoing paragraphs, it can be surmised that India has the basic wherewithal for undertaking full scale hypersonic system development. However, there will be need to consolidate the design information and database, carry out characterisation tests, identify and take up necessary facility augmentation and identify industry to assist in fabrication, assembly and testing needs. Prior to examining this, it may be useful to examine the threat scenario India faces and derive the useful range for our hypersonic system from attack/ deterrence considerations.

Threat Considerations

It is useful to examine the threat scenario India faces in relation to HWS and shape our response to mitigate or neutralise the threat situation. China, India and Pakistan are nuclear weapon states in a geographically contiguous region with territorial disputes. China, which considers the US as its main adversary, is modernising and increasing its nuclear arsenal and continues with its aggressive behaviour against India across the Line of Actual Control (LAC). Pakistan's nuclear posture is India-centric and its full-spectrum deterrence strategy accounts for India's conventional as well as nuclear weapons. Pakistan further feels emboldened by the tacit support it receives from China in the UN and other international fora in addition to its nuclear and missile cooperation with China. With flashpoints ever present, nuclear deterrence among the three cannot be termed stable. Introduction of new weapon systems like HWS will further aggravate a bad situation. The speed and manoeuvrability of HWS will severely challenge the efficacy of existing missile defence systems. The threat scenario gets murkier if the HWS proliferation possibility is taken into account.

5. Rajaram Nagappa, *Hypersonic Cruise Missiles—An Overview* (Bengaluru: National Institute of Advanced Studies, 2020), p. 5, at http://isssp.in/wp-content/uploads/2020/11/Hypersonic-Report_Final-3.pdf. Accessed on January 20, 2022.

As it is, the ballistic missiles of both China and Pakistan have adequate range to target all or most parts of India. The Chinese DF-21A (nuclear), DF-21C (conventional) and DF-26 can cover all important strategic locations in India; similarly, Pakistan's Shaheen-2 and Shaheen-3 fall in this category. Also, the missile flight times being small, the reaction time available for activating missile defence is rather compressed. This consideration negates any priority for fielding hypersonic weapons against India. However, China may prefer to further complicate India's ballistic missile defence capability by displaying the HWS threat—especially taking advantage of the destination, weapon type and range ambiguities, besides the hypersonic velocity of the HGVs. As far as Pakistan is concerned, it could use the Shaheen-2/3 first stage as the boost system and will need to develop only the glide vehicle. Pakistan could benefit from the longstanding Sino-Pak nuclear/ missile cooperation to obtain the needed design, technology, materials, components/subsystems and testing elements from China. The Missile Technology Control Regime (MTCR) rules in respect of hypersonic glide vehicles are not clearly stated and are open to ambiguous interpretations.[6] This could facilitate HGV proliferation from China and enable Pakistan to acquire HGV capability. Collusion with North Korea for HGV technology acquisition by Pakistan is another possibility.

Options for India

Defence against HWS is rather challenging and any country at the receiving end of a hypersonic weapon strike will be at a disadvantage. Terrestrial sensors can detect an incoming missile at a 'close-to-strike' time; space-borne sensors are an alternative but a non-starter considering the time and cost of realising and orbiting such sensors. The HWS velocities in the terminal phase are of a similar order as ballistic missile reentry vehicles and it may be possible to counter them with available exo/endo ballistic missile defence

6. Kolja Brockmann and Dmitry Stefanovich, *Hypersonic Boost-Glide Systems and Hypersonic Cruise Missiles: Challenges for the Missile Technology Control Regime* (Stockholm: SIPRI, April 2022), at https://www.sipri.org/sites/default/files/2022-04/2204_hgvs_and_hcm_challenges_for_the_mtcr.pdf. Accessed on May 22, 2022.

All three systems have their technology challenges—chiefly, the severe thermal environment, material selection, thermal protection systems and coatings, flowfield simulation, control and guidance, flight path management and precision targeting.

systems. However, compressed decision-making time and, more importantly, the manoeuvrability of HWS could render this action infructuous.

The best deterrence under these circumstances is to have our own HWS capability. The question that follows is the choice of HWS and the preferred range for the missiles. For effective deterrence, the range of HWS should be tailored for counter-value targets in the 1,000-5,000 km range. Of course, significant survey, information and knowledge of sensors and defence systems and mission design is a necessary prequel for targeting. Another consideration would be the launch mode. Consideration of launch from land, air, ship or submarine will have a bearing on the missile engineering and achievable range. Depending upon the adversary's capability, detection of the missile in the boost phase, glide/cruise phase or during the terminal phase and, therefore, system vulnerability, mitigatory methods may have to be kept in mind. To achieve this type of range, India should consider developing HWS based on (a) Hypersonic Glide Vehicles (HGVs); (b) Hypersonic Cruise Missiles (HCMs); and (c) Air Launched Hypersonic Glide Missiles (AL-HGMs). An AL-HGM, after aircraft release, using a solid propellant rocket to power it to hypersonic speeds and following an aero-ballistic trajectory (similar to the Russian Kinzhal missile) may be faster to realise and should be evaluated for priority development.

All three systems have their technology challenges—chiefly, the severe thermal environment, material selection, thermal protection systems and coatings, flowfield simulation, control and guidance, flight path management and precision targeting. In addition, the HCM design calls for proper airframe and engine integration, and modelling of the fuel injection and combustion process to maintain positive thrust over drag. The Air Launched Hypersonic

Glide Missile (AL-HGM) is more simple as it uses a time-tested and qualified solid rocket for its propulsion. Carriage by aircraft and release at supersonic speeds may pose challenges, but there is adequate experience with air-launched ordnance, including the Brahmos missile.

Of the three hypersonic weapon systems, in terms of complexity and technical challenges, one could rank the AL-HGM, HGV and then HCM in terms of increasing complexity.

Of the three hypersonic weapon systems, in terms of complexity and technical challenges, one could rank the AL-HGM, HGV and then HCM in terms of increasing complexity. The preferred range for the AL-HGV will be of the order of 1,000 km, excluding the standoff range provided by the aircraft; HGV could be, to start with, fashioned for a range of 2,000-2,500 km and subsequently, with a bigger booster for a range up to 5,000 km. A range of 1,000-2,000 km can be the aim for the HCM.

All the three weapon systems need a rocket boost and an appropriate missile stage could be picked from the available DRDO missile boosters; if necessary, some of these could be modified to meet a specific requirement or a new system developed. For both HGV and HCM, the primary choice is ground launch. In the subsequent phase of development, air launch, followed by rocket boost, could be adopted for the HCM which should be capable of operating up to M 8. Submarine launch reduces the vulnerability of the missile system and is a desirable option to pursue. For example, HGV with range of 4,000 km could cover strategic areas of our interest when launched from a submarine in the South Andaman Sea.

As the AL-HGM is ranked as easy to accomplish, some details of the same are provided below.

The **Russian Kinzhal** missile is of this category and is belly mounted on MiG-31K aircraft as shown in Fig 5. Some features of the Kinzhal are presented in Table 2.[7]

7. Missile Defense Project, "Kinzhal," Missile Threat, Centre for Strategic and International Studies, March 27, 2018, last updated March 19, 2022, at https://missilethreat.csis.org/missile/kinzhal/. Accessed on June 22, 2022.

Fig 5: Air Carriage of Kinzhal Missile

Source: Wikipedia.

Table 2: Kinzhal Missile Details

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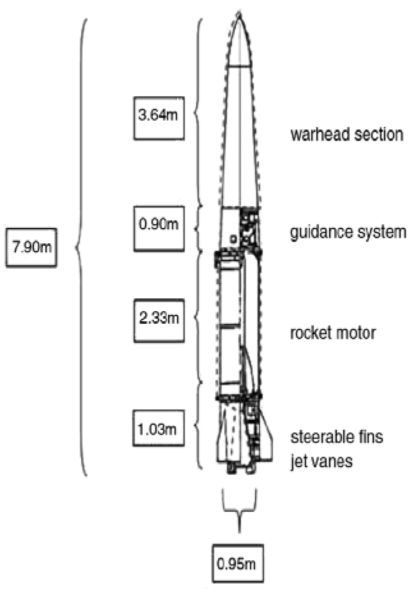
<tr><td rowspan="8">
</td><td>Length</td><td>8 m</td></tr>
<tr><td>Diameter</td><td>1 m</td></tr>
<tr><td>Propulsion</td><td>Single-stage solid propellant rocket</td></tr>
<tr><td>Speed</td><td>6-10 M</td></tr>
<tr><td>Launch weight</td><td>4,300 kg (payload: 430 kg)</td></tr>
<tr><td>Range</td><td>1,500-2,000 km, including standoff distance provided by aircraft carriage</td></tr>
<tr><td>Cruise altitude</td><td>20 km</td></tr>
<tr><td>Aircraft launch</td><td>Aircraft release at 18 km; the missile drops by 100′ before its solid rocket is ignited.</td></tr>
</table>

For an Air Launched Hypersonic Glide Missile (AL-HGM), the mother aircraft is equivalent to the missile's first stage. After release, the solid rocket motor accelerates the glide body to hypersonic speeds. Further range gain happens during the aeroballistic flight of the missile.

The Su-30MKI aircraft of the Indian Air Force (IAF) has been modified to mount the air launched version of the Brahmos supersonic cruise missile. The aircraft should be able to facilitate air launching of a solid propellant rocket powered glide missile if its dimensions, mass and other interfaces are similar to those of the Brahmos. The specifications of an air launched Brahmos are shown in Table 3.[8]

Table 3: Air Launched Brahmos Specifications

Brahmos Length	8.55 m
Brahmos Diameter	648 mm
Brahmos Weight	2,550 kg
Ground Clearance	1 m
Release Height	Up to 9 km
Release Speed	0.55-0.8 M
Free Fall	100-150 m

The Brahmos' dimensions and mass, therefore, set the limits for the AL-HGM for carriage by the Su-30MKI. It would be preferable to make the AL-HGM lighter and see the possible gains in release altitude and release speed.

The design of the missile attachment to the aircraft, related interfaces as well as the release system can be borrowed from the air launched Brahmos. Some design changes/adaptations will be required to account for differences

8. "Work to Integrate Brahmos on 40 Sukhoi Aircraft Begins", *The Economic Times*, July 14, 2018, at https://economictimes.indiatimes.com/news/defence/work-to-integrate-brahmos-on-40-sukhoi-aircraft-begins/articleshow/62104177.cms. Accessed on October 12, 2022.

The thermal environment in a hypersonic flight can be quite hostile. The nose tip and the leading edges could experience temperatures of the order of 1,200-1,600 K (degree Kelvin). Materials, thermal protection systems and coatings are available for thermal management.

in the dimensions and mass of a fully evolved AL-HGM.

The requirement of separating the nose cover equipped with divert thrusters used in the Brahmos is not needed for the AL-HGM and, to that extent, some weight reduction is evident but one needs to take a view after the detailed design is completed.

Solid Rocket Boost: This is provided by a dual thrust solid propellant motor. The dual thrust design involves larger propellant burning surface area exposure in the boost phase, followed by a lower surface area exposure during the sustain phase. Alternately, or in addition, a higher burn rate propellant in the boost phase followed by a lower burn rate propellant in the sustain phase can be employed. Designing with controlled burn surface exposure is a better alternative. DRDO has experience in design and realisation of dual-thrust motors of smaller calibre which can pave the way for realisation of larger systems.

Aero-ballistic Flight Trajectory: The AL-HGM will cruise between 20 and 30 km altitude, gaining range through pull-up manoeuvres. During this phase, cross-range manoeuvres can also be carried out. The aerodynamic surfaces have to be properly designed to achieve good Lift to Drag (L/D) ratio and also enable control of the vehicle. With each manoeuvre, there will be drop in velocity and the mission has to be designed keeping the trade-off between range and manoeuvres in mind. DRDO has experience in aero-ballistic trajectory planning and implementation and will have to supplement the same with data generated through hypersonic wind tunnel tests.

Thermal Management: The thermal environment in a hypersonic flight can be quite hostile. The nose tip and the leading edges could experience temperatures of the order of 1,200-1,600° K (degree Kelvin). Materials, thermal protection systems and coatings are available for thermal management. Materials and coatings technology to withstand such temperatures are available in the country. Scaling up and industry involvement will be needed.

While design details need to be worked out, it is felt that a range of 1,000 km (excluding standoff contribution of the mother aircraft) can be targeted for indigenous development.

The low flight altitudes of hypersonic missiles and the Earth's curvature severely impair the detection ranges of conventional air defence radars.

Defence Against Incoming Missiles[9]

In the terminal phase of flight of hypersonic missiles, the velocities are comparable or marginally higher than those of the ballistic missile reentry vehicles. While this factor may allow them to be engaged by ballistic missile defence systems, factors like compressed timelines for tracking/identifying/decision-making, their manoeuvrability as well as destination uncertainty present a complex situation.

The low flight altitudes of hypersonic missiles and the Earth's curvature severely impair the detection ranges of conventional air defence radars. For example, with a 700 km range radar, early warning time would be about 410 seconds for a hypersonic missile travelling at M 5; the time reduces correspondingly if the missile velocity is greater than M 5. Longer range radars add marginally to the warning times, e.g. for a M 5 missile with a 1,000 km range radar, the warning time would be of the order of 590 seconds and with a 1,500 km range radar, the warning time is better at 880 seconds. These times are tight and it makes sense to augment the capability of line of sight radars with over the horizon and airborne early warning radars. Space based Infra-Red (IR) sensors, while a good option, demand additional resources

9. PM Soundar Rajan, "System Requirements for Hypersonic Missile Defence", Internal Report, 2021.

in the space and ground segments, and are expensive. Keeping the current threat scenario in mind, the space option can be considered for a future date.

Electronic warfare options hold better promise. Cyber intrusion attacks could be used to disrupt the weapon's command and control networks before launch; activating the self-destruction mechanism of an airborne missile is another option. Spoofing, intrusion, jamming or interference could be exercised to disrupt the weapon's guidance and control functions or steer the missile off-course.

Directed Energy Weapons (DEWs), still under development, could be promising defence systems against hypersonic missiles. High energy lasers, to be effective against hypersonic missiles, need to be satellite mounted to illuminate and damage the missile's guidance system or warhead. A high power microwave device could be employed to scramble the adversary missile electronics on the launch pad or even during the cruise phase.

It is desirable to augment the capability derived from the development of endo and exo atmospheric missile interceptors to the hypersonic domain. Internationally, two hypersonic missile interceptor systems' development is underway. The Defence Advanced Research Projects Agency (DARPA) is progressing the glide breaker hypersonic missile and the European Union has initiated work on the Timely Warning and Interception with Space-based Theatre (TWISTER) system. Both systems are in the conceptual stage and will include an agile missile with ground and space based sensor inputs. It may be desirable to initiate a conceptual study for an Indian system.

Technology Spinoffs

India has missed opportunities in the development of civil transportation systems in the past and, at this stage, it will be difficult for late entrants to penetrate the field using contemporary technologies. It is, therefore, worthwhile to seriously examine how India could play a major role in the development of a scramjet powered hypersonic airliner. Drastic reduction in travel time—two hours for a trans-Atlantic flight—will be a winning

Fig 6: Boeing Hypersonic Airliner Concept

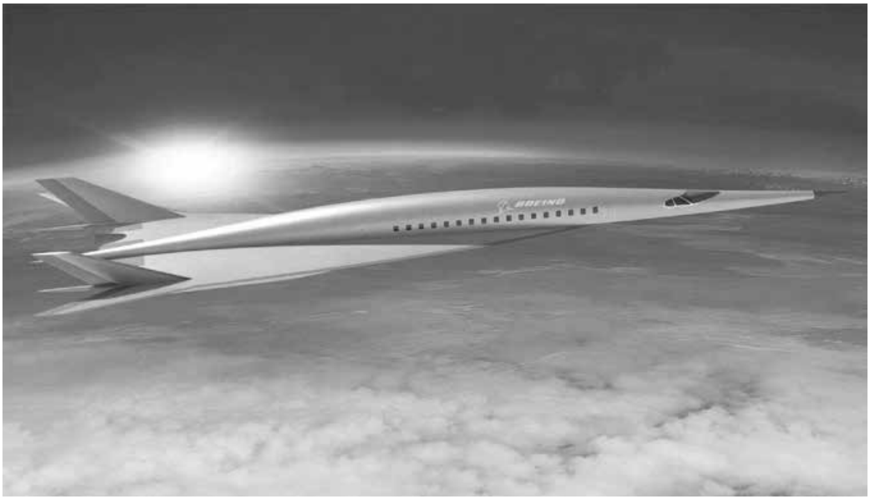


Fig 7: JAXA Hypersonic Airplane Concept

feature and there is certainly a future in pushing this technology. The idea is not new. Lockheed Martin has planned the SR-72 (also known as the Son of SR-71)—an M 5 hypersonic reconnaissance aircraft. In 1980, Boeing had unveiled its hypersonic airliner development. An artist's concept

Scaling up and capacity build-up in materials and process technology, testing infrastructure, avionics, high level of systems engineering, safety, quality control and inspection standards all have to be built in for progressing to airline development. As international initiatives are still in the conceptual stage, it will be opportune for India to step in at this stage.

of the aircraft is shown in Fig 6.[10] Boeing recently announced an M 5 aircraft—the Valkyrie II—for high speed reconnaissance. Japan also has plans to develop hypersonic airliner and its concept is shown in Fig 7.[11] Such a development in India also could serve a double advantage of a civil airliner as well as an aircraft for high speed reconnaissance.

Scaling up and capacity build-up in materials and process technology, testing infrastructure, avionics, high level of systems engineering, safety, quality control and inspection standards all have to be built in for progressing to airline development. As international initiatives are still in the conceptual stage, it will be opportune for India to step in at this stage. With some lead in technology development, India can play several roles ranging from consultancy, component/ subsystem development production and supply, standards generation as well as integrated aircraft manufacture and downstream supply and support system.

Major organisational change has to be ushered in as there is no agency tasked with the development of civil airliner aircraft in the country. In such a situation, the organisational initiative has to be taken by the private sector. Firms like Tata Aviation and Defence, Mahindra Aviation, Reliance Aviation, Hindustan Aeronautics Limited (HAL) or a consortium

10. Chris Young, "Boeing's New Hypersonic Aircraft Concept Reaches Speeds of Mach 5", *Interesting Engineering*, January 2022, at https://interestingengineering.com/innovation/boeings-new-hypersonic-aircraft-concept-reaches-speeds-of-mach-5. Accessed on January 22, 2022.
11. "The Future of Environmentally Friendly Aviation Technology: Clean Engines and Supersonic Transport", JAXA: n.d., at https://global.jaxa.jp/article/special/aviation/ishikawa02_e.html. Accessed on October 26, 2022.

of industries need to lead the way, using focussed Research and Development (R&D) catalysed by DRDO and ISRO in association with the Council of Scientific and Industrial Research/National Aerospace Laboratories (CSIR-NAL) and academia. This will be a major challenge, but India has the technological and managerial capability to undertake such major development. To start with, a high power committee, led by private industry, could make an assessment of the international status, the market, financial outlays, industrial and manufacturing infrastructure. The crucial question will be the synergy required among different domains—technology, policy, finance, management and international cooperation—for a favourable pointer for the go-ahead.

India has carried out a demonstration flight test of a hypersonic scramjet powered test vehicle and has most likely initiated work on the development of both types of missile systems.

CONCLUSION

Hypersonic glide missiles are operational with Russia and China. The US is close to completing the development of its own glide missiles. Russia has used the Kinzhal air launched hypersonic glide missile in the ongoing Ukraine conflict. In respect of hypersonic cruise missiles, Russia has carried out an adequate number of tests of its Tsirkon missile for anti-ship operations. China and the USA are continuing development of hypersonic cruise missiles.

India has carried out a demonstration flight test of a hypersonic scramjet powered test vehicle and has most likely initiated work on the development of both types of missile systems.

This paper advocates development of both categories of missiles with range of the order of 5,000 km for the HGV and 1,000+ km for the HCM. In addition, it is suggested that the development of an air launched solid propellant powered HGV should be prioritised. The paper also suggests serious consideration of hypersonic civil airliner development.

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