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HYPERSONIC WEAPONS: WHAT ARE THE CHALLENGES FOR THE ARMED FORCES?

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Key takeaways

- In just a few years, hypersonic glide vehicles and cruise missiles have become new symbols of military power, signaling a return to strategic competition between States.

- Hypersonic weapons are an alternative to "conventional" ballistic or cruise missiles and combine the advantages of speed and maneuverability to overcome theatre and homeland anti-missile defense systems, thus being able to reach targets deep in enemy territory or at sea.

- Although uncertainties remain with regard to the budgetary sustainability of such weapons, the gradually increasing maturity of hypersonic technologies makes the adoption of such systems by the major powers inevitable. They will significantly modify the nature of future military operations, notably influencing the decision-making cycles and command architectures.

Introduction

Since the 2010s, hypersonic systems have cropped up with increasing frequency both in the general media and the specialized press. As they are capable of maneuvering at speeds higher than five times the speed of sound (Mach 5, or more than 6,000 km/h), they represent a variety of types and missions. They are above all becoming symbols of power for the States designing and implementing them, even though this leads to the risk of rekindling an arms race. The purpose of this document is to shed light on how they function, ongoing projects, but also their political uses and the strategic challenges that are involved.

Speed and Its Constraints

Since the appearance of missiles, which entered service for the first time during World War II – with the German V1 and V2 but also remote-controlled suicide aircraft – their speed and maneuverability have constantly evolved. The effect is an increased probability of penetrating enemy defenses. Historically, progress has focused on speed – hypersonic (beyond Mach 5) or the high supersonic (greater than Mach 3) – confronting the engineers with increasingly complex challenges (propulsion, materials, aerodynamics, etc.). During the cold war, two main families of missiles emerged.

- **Ballistic devices** are at present the only ones capable of "intercontinental" range (more than 5,500 km, as agreed in the treaties).[1] These carriers follow a parabolic trajectory and are only powered during their climb, or boost phase, enabling them typically to reach speeds of 7 km/s (or Mach 20) before a flight phase, following which the re-entry phase is even faster, generally close to 8 km/s (Mach 23[2]) for an intercontinental missile. Despite these high speeds, the ballistic trajectory is relatively predictable because it is bound by the laws of gravity, with the notable exception of the atmospheric re-entry phase, where particular constraints apply.
- **Cruise missiles** fly through the atmosphere with constant propulsion – similar to an aircraft – and follow trajectories that involve maneuvers and which are therefore less predictable – sometimes in "terrain following" mode – enabling them to penetrate enemy defenses during the final phase. Their range is also shorter (less than 2,000 km for the longest, although this is more usually a few hundred kilometers), and they operate at speeds that are on the whole subsonic, or barely supersonic – between Mach 0.7 (about 880 km/h)

1. The strategic range cruise missiles solution, with the American *Snark* and *Navaho*, was finally abandoned in favor of strategic ballistic missiles.
2. D. K. Strumpf, "Reentry Vehicle Development Leading to the Minuteman Avco Mark 5 and 11", *Airpower History*, Vol. 64, No. 3, 2017, pp. 13-36.

for a *Tomahawk* missile (United States) or *Kalibr* (Russia), and up to Mach 3 for a device such as the French improved medium-range air-to-ground nuclear missile (ASMP-A).

Although most supersonic systems (aircraft of cruise missiles) have a speed that is generally between Mach 1 and Mach 3, the literature generally considers a vehicle to be hypersonic when its speed exceeds Mach 5. As the speed of sound varies with air density – which is itself dependent on ambient temperature and altitude – Mach 5 represents more than 6,000 km/h at altitude.[3] Quite apart from the problems inherent in propulsion, speeds such as these entail numerous stresses, such as pressure and atmospheric friction, which generates extremely high temperatures – again dependent on air density, more than 1,800°C on the protruding parts[4] – severely stressing structures and materials, including inside the compartments of the aircraft or missile. Furthermore, any change in trajectory exerts aerodynamic stresses and acceleration forces on the system, but also on its components, which have to be able to continue to function. Two types of systems have so far been designed:

- **The Hypersonic Glide Vehicle** (HGV) is carried by a ballistic missile to speeds of up to Mach 20. During the climb phase, the HGV separates from its missile and is injected into the upper atmosphere (above 50 km). It then proceeds to its target following an unpredictable trajectory, alternating ballistic phases with skip or glide maneuvers. As it flies, the aim is to remain at altitudes higher than those that can be reached by the surface-to-air defense systems. It has no active propulsion and decelerates gradually, all the more so as it uses multiple skip phases. If it has sufficient energy reserves in the terminal phase, it can then carry out evasive maneuvers in order to reach its target by penetrating enemy intercept systems.
- **The Hypersonic Cruise Missile** (HCM) has its own propulsion system. This uses a ramjet or a scramjet. These are air-breathing types of jet engines suitable for very high speeds (high supersonic, even hypersonic for a ramjet and potentially beyond Mach 6 for a scramjet) and which have no moving parts.[5] The incoming air, compressed by the engine's own structure, enters the combustion chamber, where it is ignited to produce thrust.[6] In order to function, the ramjet must first reach a high speed, which is why it is combined with a booster, and must remain at altitudes ensuring a sufficient oxygen supply. Once in flight, the missile is capable of maneuvering at high speed, before diving onto its target.

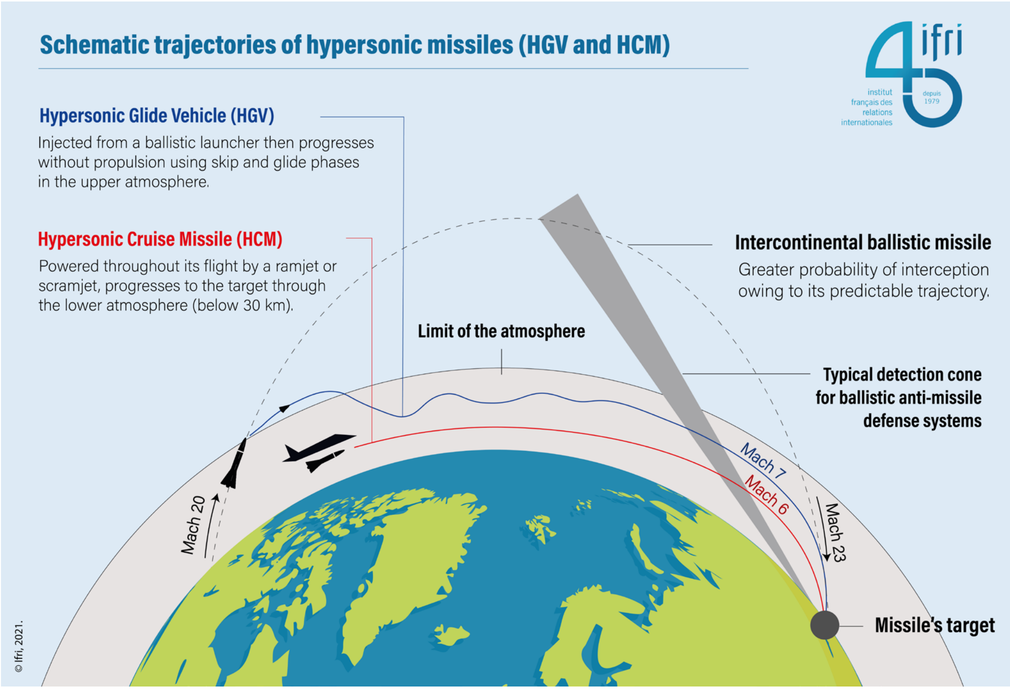
3. Mach 1 represents 1,000 km/h at sea level and at 0°C.

4. R. Trice, "Hot Stuff: Tackling Extreme Temperatures of Hypersonic Flight", *Medium*, 23 March 2020, available on: www.medium.com.

5. The ramjet functions in a similar manner, but the air is slowed by the structure of the combustion chamber and enters it at subsonic speed. The thermal and physical stresses on the system are thus lower.

6. On *scramjets*: C. Segal, *The Scramjet Engine. Processes and Characteristics*, Cambridge: Cambridge University Press, 2013.

Schematic trajectories of hypersonic missiles (HGV and HCM)



Why develop such systems? Generally speaking, maneuvering hypersonic systems have two advantages over ballistic or "conventional" cruise alternatives. On the one hand, both HCMs and medium-range HGVs have a shorter flight time than a "conventional" cruise missile (subsonic or low supersonic) with an equivalent range. A device flying at Mach 6 would thus take a little over four minutes to reach a target 500 km away, leaving little time for an appropriate reaction. In addition, the unpredictability of an HGV trajectory in the very high layers of the atmosphere, of that of an HCM in the lower layers, makes them less vulnerable to any interceptor systems, whether used for theatre or homeland defense systems.[7] While these systems could proliferate in the coming years and decades – at least the theatre systems – hypersonic technology is one of the solutions for maintaining the capability to penetrate enemy defenses. The trajectory of hypersonic weapons also make's the defender's task more difficult, because it maintains a degree of ambiguity as to the actual target, thus preventing advance determination of the point of impact and the corresponding initiation of any preventive or passive defense measures. From an operational viewpoint and depending on the payload carried, this type of weapon could be of use for rapidly taking out command posts and other enemy nerve centers, even mobile ones. The characteristics of these weapons mean that they have considerable potential against carrier vessel battle groups or command vessels.

7. While the first are optimized to intercept short and medium-range ballistic missiles, which is easier, the second have to intercept intercontinental missiles, which are faster and harder to intercept.

Progress and Capabilities

The first work was done on HCMs in the USSR in the 1970s, notably via the 3M25/Kh-80 *Meteorit* program. The missile had to be launchable from the ground, from bombers or submarines, for nuclear strike purposes. At the same time, the Soviet Union was exploring HGVs. Meanwhile, the United States was looking to develop MaRV (Maneuverable Reentry Vehicle) payloads, with the payloads being maneuvered at the end of atmospheric re-entry, following a ballistic flight phase. In both cases, the work was in part put on hold with the end of the cold war, because the penetration capability of ballistic systems was then felt to be sufficient, or because systems such as the Pershing 2 were in the process of being decommissioned. Interest was renewed in the early 2000s, especially in Russia, in order to counter the development of American exo-atmospheric defense systems. The renewed efforts on National Missile Defense, and the USA's withdrawal from the ABM (Anti-Ballistic Missile) Treaty in 2002, were perceived in Moscow as a threat to the credibility of Russia's deterrence. In order to restore a balance, various hypersonic system projects were revealed by Russia in order to demonstrate its ability to counter Washington's anti-missile defenses and its naval capacity.

The United States saw things differently: as of the first half of the 2000s, the question was one of being able to make a conventional strike anywhere in the world in less than an hour, as part of the Prompt Global Strike program, since then renamed Conventional Prompt Strike. China's ambitions focused more on attacking well-protected American and Japanese bases, but also on sea denial operations with Anti-Ship Ballistic Missiles (ASBM) equipped with maneuvering warheads (re-entry body with aerodynamic piloting system). The work being done on maneuvering hypersonic vehicles is thus evolving, with two key aspects being apparent:

- **A broader range of missions:** hypersonic speed is no longer envisaged solely for nuclear deterrence strategy, but also for ground and anti-ship strikes. The Russian *Zircon* missile, for example, is primarily designed as an anti-ship missile enabling the largest ships to be sunk from a safe distance, but also for striking land-based targets. It could also be equipped with a nuclear warhead or a conventional warhead, creating ambiguity with regard to its strategic utilization. If this threat were to become a reality, it would create a dilemma in terms of strategic stability.[8]
- **The beginning of proliferation among the major powers:** HGV technology, partly derived from intercontinental missiles, would today appear to be the most mature and promising of the projects liable to become operational. HCM projects, more particularly those based on

8. A. Samaran, "Hypersonic Weapons and Strategic Stability: How Grave is The Challenge?", *CISS Insight Journal*, Vol. 8, No. 1, 2020, pp. 28-47.

scramjets, for which the extremely complex technology would still appear to be problematical, would seem to be for a more distant future.

So, in addition to America and Russia, in 2010 India announced the development of an HCM demonstrator. China is also working on several systems, but based mainly on HGV technology. Japan and South Korea announced research into HGVs and HCMs in 2019 and 2020 respectively, but this has not gone beyond the initial development stages. For its part, the United Kingdom has an HGV program (*Thresher*), which is to run until 2023 in cooperation with the US Air Force (USAF), but for the time being no operational capability is being envisaged.

Finally, in France, the development of these technologies is primarily based on the ASN4G (4th generation nuclear air-to-ground), as part of the refurbishment of the airborne component of the nuclear deterrent. This HCM, designed by MBDA, is to succeed the renovated ASMP-A by 2035, and should be equipped with a scramjet, currently being studied by the French aerospace lab ONERA (Office Nationale d'Études et de Recherches Aérospatiales). An HGV demonstrator program, the V-MAX (for experimental maneuvering vehicle) has also been started. It is designed by ArianeGroup drawing on the expertise of ONERA, and should make its first flights as early as this year. In short, hypersonic systems are becoming a "strategic attractor": over and above their military uses, they are becoming emblems of a State's capability modernization and true symbols of power.

Hypersonic weapons programs officially under way

Type	Country	1st flight	Type/Function	Comments
DF-17	China	2014	HGV/Ground attack (or anti-ship)	Range greater than 1,500 km. Combines a DF-16 booster and the DF-ZF glide vehicle. This latter could carry intercontinental ballistic missiles for nuclear deterrence – Claimed to have been tested on the DF-5 missile. The DF-17 may have been operational since 2019.[9]
DF-100	China	2018 (?)	HCM ?/Ground attack, anti-ship strikes mentioned	Would appear to be operational since 2019. Hypervelocity weapon status to be confirmed.
***Long Range Hypersonic Weapon* (LRHW)**	United States	(2017*)	HGV fired from a TEL (*Transporter Erector Launcher*)/truck Ground attack	Uses the *Common-Hypersonic Glide Body* (C-HGB). In May 2021, range indicated as being greater than 2,775 km. A first battery should enter service with the US Army as of 2023.
***Intermediate Range Conventional Prompt Strike* (IRCPS)**	United States	(2017*)	HGV fired from a submarine or surface vessel/Ground attack	Uses the *Common-Hypersonic Glide Body* (C-HGB). Will be installed on the SSN Virginia and possibly first of all on the Zumwalt then Arleigh Burke class surface vessels. Announced as being operational as of 2025.
AGM-183 ARRW (*Air launched Rapid Response Weapon*)	United States	2021	Airborne HGV /Ground attack	The test of its booster in early 2021 was aborted and is still pending. The associated TBG (Tactical Boost Glide) vehicle is to be tested in 2021. It should be carried by a B-52, B-1B (up to 31 missiles), F-15EX and, according to certain information, the F-35. Could reach Mach 20[10]. Announced as being operational in 2023.
OpFires	United States	*ns*†	HGV/Demonstrator	Program conducted by the DARPA using the TBG. At one time intended for the US Army, but the latter prefers the LRHW. Uncertain future.

9. P. Langloit, "Armement hypersonique : des progrès notables", *Défense & Sécurité Internationale*, hors-série No. 75, December 2020 - January 2021, pp. 96-98.
10. K. Mizokami, "The B-1 Bomber Might Start Slinging Hypersonic Missiles", *Popular Mechanics*, April 9, 2020, available on: www.popularmechanics.com.

Hypersonic Attack Cruise Missile **(HACM)**	United States	2021 (?)	HCM/Demonstrator for ground attack	Has still not flown, despite a maiden flight announced in 2020. On 27 April 2020, the USAF announced its intention to launch an airborne hypersonic cruise missile weapons program for carriage by its bombers and the F-15EX. To do this, it aims to launch an HCM prototype in 2025.
ns[†]	United States /Australia	*ns*[†]	HCM/Demonstrator	Cooperative design, development and testing program under the *Southern Cross Integrated Flight Research Experiment* (SCIFRE) program announced in 2020. Scramjet propulsion for eventual development of an HCM fired from Australian F/A-18F, F-35, and EA-18G.
Avangard	Russia	2014	HGV/Nuclear deterrence	Maneuverability at Mach 20+ at 100 km altitude. Operational on the RS-18 and RS-24[11] intercontinental missiles, will be operational on the RS-28 *Sarmat*.
Kh47M2 *Kinzhal*	Russia	2018	Aeroballistic missile: ballistic missile carried under an aircraft. Ground attack, anti-ship strikes mentioned[12]	Mach 10 claimed in terminal phase. Launch from MiG-31K or Tu-22M3. Operational since 2018. A smaller scale version for carriage on the Su-57 fighter is apparently under development.
3M22 *Zircon/ Tsirkon*	Russia	2020	Probable HCM/Anti-ship strikes, ground attack mentioned[13]	Mach 8 claimed, range announced at 500 to 1,000 km. Launched from surface vessels and submarines[14]. Could enter service by 2023.
BrahMos 2	India/ Russia	*ns*[†]	HCM/Anti-ship strikes and ground attack	Development announced in 2010. No flight reported as yet. Range of 300 km and speed of Mach 7.
Hypersonic Technology Demonstrator Vehicle **(HSTDV)**	India	2020	HCM/Demonstrator	Equipped with a Scramjet ignited at 30 km altitude, flight of about twenty seconds. A first test in 2019 failed.

11. Tass, "First Regiment of Avangard Hypersonic Missile Systems Goes on Combat Duty in Russia", December 27, 2019.
12. A. Sheldon-Duplaix, "Zircon et Kinzhal : révolution navale et stratégique ?", *Défense & Sécurité Internationale*, hors-série No. 74, October-November 2020, pp. 52-57.
13. *Ibid*.
14. It would be launched from the 3S14 universal silo also capable of launching the *Yakhont* (SS-N-26 *Strobile*) and the *Kalibr* (SS-N-27 *Sizzler*).

ASN4G	France	*ns*†	HCM/Nuclear deterrence	Announced at the beginning of the 2010s. To replace the ASMP-A in the airborne component of the deterrent force by 2035-2040.
V-MAX (Véhicule Manœuvrant Expérimental)	France	2021 (?)	HGV/Demonstrator	Official launch in January 2019. Construction awarded to ArianeGroup.
Hypersonic cruise missile	Japan	*ns*†	HCM/Anti-ship strike	Development confirmed in May 2020 but probably started earlier. Entry into service announced as of 2024.
Hyper velocity gliding projectile	Japan	*ns*†	HGV/Ground attack	Development confirmed in May 2020 but probably started earlier. Entry into service announced for 2026 (first version) and then 2028 (higher-performance version).

* Test of the missile's HGV Common-Hypersonic Glide Body (C-HGB).
† Not specified.

The cost of access to hypersonic technologies is high, whether in terms of budget or with regard to human resources and know-how. Even if Governments are reluctant to release too many details about their efforts, the American case gives us an idea. Washington has thus initiated several test programs, including the HGV Advanced Hypersonic Weapon (AHW/C-HGB) tested in 2011, 2014 and 2020; the HGV Hypersonic Technology Vehicle 2 (HTV-2) tested in 2010 and 2011; and the HCM X-51 Waverider tested between 2010 and 2013. These tests led to programs that aim to be operational and require considerable investment. This rose from 340 million dollars in 2016 to 3.5 billion in 2021. At the same time, about fifty universities were also mobilized, coordinated by Texas A&M, under the supervision of the Joint Hypersonic Transition Office (JHTO), an *ad hoc* organization set up by the Pentagon in October 2020.[15] In addition to the programs officially under way, others could well be in progress either experimentally or in order to lead to a confirmed operational capability.

Despite the large number of publications about hypersonic weapons, relatively little information is actually available concerning the programs under way – probably not all of them are yet known[16] – and the progress actually made. Yet questions concerning guidance (in-flight updates, dynamic targeting on a moving target and terminal guidance) or flight envelopes – in other words the effective maneuverability and the range – are essential if one is to be able to judge whether strategic goals are achievable

15. J. A. Tirpak, "The US is Playing Catch-Up on Hypersonic. Here's How", *Air Force Magazine*, March 25, 2021, available on: www.airforcemag.com.
16. Simple example, in March 2020, it became apparent that a new version of the American SM-6 anti-air missile could be used as a hypersonic anti-ship missile. S. Trimble, "Document Likely Shows SM-6 Hypersonic Speed, Anti-Surface Role", *Aviationweek.com*, available on: www.aviationweek.com.

and the investments justified. The questions of terminal phase maneuverability, and above all targeting, are thus essential in determining which types of combat vessels are threatened by hypersonic systems, and to what extent. Similarly, even if HGVs and HCMs are unanimously recognized as being costly, they should be compared with other, equally expensive alternatives. For example, China announced that the DF-17 would cost less than a "conventional" cruise missile, for a comparable range. However, their budgetary parameters are unclear, both with regard to R&D and in terms of purchase and life cycle costs.

Guidance and Range

The guidance systems mentioned for hypersonic vehicles combine inertial navigation and satellite navigation, sometimes with remarkable results. The second test of the American C-HGB glide body, on 19 March 2020, is claimed to have struck 15 cm from the target point after a 4,000 km flight.[17] In Japan, one of the justifications given for the Government's *Quasi-Zenith* satellite navigation system is to offer centimeter precision, which will notably be of use for future hypersonic systems. From this point of view, hypersonic systems are creating leverage effects in the R&D ecosystems. They could also lead to the appearance of new targeting methods, involving HALE (High Altitude, Long Endurance) UAVs or even radar or optical reconnaissance satellites. There still remains the question of terminal guidance to a moving target, which would appear to be complicated owing to the thermal stresses and the dynamic pressure on the sensors on-board the HGV or the HCM.

Strategic Uses

With regard to the planning intentions of the various Governments, the strategic functions of hypersonic systems are numerous – nuclear and conventional ground or anti-ship attack – with ranges from several hundred up to ten thousand kilometers for certain HGVs. A range such as this would expand the geographical engagement space, while compressing the response times for the shorter range systems, but would also more generally offer a means of circumventing anti-missile systems. This combination partially changes the situation with regard to high-intensity engagements and contributes to the perception of a "return" of power politics. But these characteristics also generate a series of constraints and problems.

The questions relating to any long-range system and the problem of targeting are all the more acute when dealing with hypersonic vehicles. Although hypersonic missiles can be used for planned strikes, notably against protected targets, they however pose an interesting operational dilemma when having to deal with highly mobile targets (Time Sensitive Targets). This capability implies a kill-chain (detection, validation, targeting,

17. Which would only be half the envisaged operational range: C. Tracy, "The Latest US Test Flight of a Hypersonic Weapon: the Common Hypersonic Glide Body", available on: www.allthingsnuclear.org.

launch and actual strike) that is extremely fast, otherwise the advantage of the hypersonic missile would be neutralized. On the other hand, the desire to preserve this advantage, whatever the cost, could lead to more flexible rules of engagement, with the risk of errors or escalation. The technical obstacles are thus compounded by organizational and doctrine issues.

The field of naval operations would therefore appear to be the most promising in the immediate future for the use of hypersonic missiles – which would replace slower devices such as subsonic cruise missiles – provided, of course, that long-range illumination capabilities are actually available, with national capabilities in this respect not yet being officially known (see box). This does not mean that hypersonic vehicles are of no use in A2/AD (Anti-Access/Area Denial) scenarios – for example in order to neutralize complex anti-air or anti-missile systems, or strike targets themselves defended by anti-access and area denial capabilities. However, discipline in planning and targeting would be essential in such scenarios and ongoing debates around multi-field operations or even about Mosaic warfare could play a role in facilitating the adoption of hypersonic systems by the armed forces.[18] That covers the attack aspect of the question.

Naval and A2/AD operations would seem to be the most promising for the use of hypersonic missiles

Now, from the defensive viewpoint, the strategic relevance of hypersonic systems raises questions at several levels. On the one hand, these systems will be more maneuverable than conventional ballistic missiles, but they will be less stealthy owing to their greater thermal signature. Apart from the fact that, in the same way as any intercontinental missile, the launch would be detected by early warning satellites, the very high temperatures generated during the flight would be a very clear indication of any strike. On the other hand, however, hypersonic systems can fly at altitudes where early warning systems are less effective; it should also be recalled that the plasma generated by the high temperatures partly absorbs radar waves.

In addition, in a nuclear scenario, there is as yet little proliferation of homeland anti-missile defenses and they are in any case insufficient to protect against a ballistic salvo with intercontinental range, so the benefits of developing HGVs by comparison with existing ballistic missile systems could appear to be limited. The picture is however totally different for short or medium-range HCMs or HGVs which will operate at lower

18. In particular see D. A. Deptula, “Mosaic warfare : une philosophie d’exploitation des forces”, *Défense & Sécurité Internationale*, hors-série No. 70, February-March 2020, pp. 72-76 ; and D. Pappalardo, “Apporter de la tangibilité au concept du combat multi-domaine. To buzz or not to buzz ?”, *Défense & Sécurité Internationale*, April 2020, pp. 68-71.

altitudes, where theater anti-air and anti-missile capabilities are far denser. In this segment, their performance does give them a substantial edge over conventional cruise missiles.[19]

There is also the fact that the proliferation of short and medium-range hypersonic missiles raises serious questions regarding the protection of high value-added targets – command centers, logistics depots, airports and seaports for troop landings, air bases, etc. In this particular case, the thermal and radar signature of the hypersonic vehicles could be used by new defensive systems, as is planned for the space-based detection and surveillance component of the TWISTER (*Timely Warning and Interception with Space-based Theater surveillance*) program. This program (the intercept component of which is coordinated by France) was initiated under the European Permanent Structured Cooperation (PESCO) and aims to establish an early warning and command and control (C2) system associated with a range of interceptors to neutralize regional range ballistic and hypersonic threats, whether nuclear or conventional. The question of countermeasures is also one that cannot be avoided, including for the deployed devices or within the naval context, as this will be decisive for future air defense and the protection of the larger units, including aircraft carriers.

Protecting against hypersonic systems could also revive the debate surrounding pre-emptive strikes, which seek to eliminate the maximum number of enemy launchers before any inevitable outbreak of hostilities. In this respect, they participate in a problem of strategic stability. This is especially the case given that the combination of conventional and nuclear functions within the same arsenal could, were the situation to arise, revive the debate around discrimination between warheads, with doctrinal debates among most of the players regarding the question of the posture to be adopted – whether launch following an alert or other measures.

Conclusion

The qualitative and quantitative spread of hypersonic systems is becoming apparent, such that they are becoming a symbol of power for those who possess them, and perhaps an attractor for the others. In this respect, because hypersonic systems are historically associated with nuclear systems in France, French and, more broadly, European reticence could be interpreted as either prudence or a lack of foresight, with the real risk of lagging behind the progress made by rival powers. Furthermore, although hypersonic references are relatively rare in official communications, whether political or military, other than explanations about the programs launched, it is clear that Paris has embraced the subject. It is also clear that France has done so in a measured manner, without

19. In particular see: C. Brustlein, E. de Durand and E. Tenenbaum, *La suprématie aérienne en péril. Menaces et contre-stratégies à l'horizon 2030*, Paris: La Documentation Française, 2014.

unduly fueling proliferation or proving right those critics of a new "arms race". In any case, France does have a number of very real advantages. Whether the armed forces, ONERA, or MBDA for HCMs, or ArianeGroup for HGVs – which is for the first time investing in an entirely military field – there is considerable experience and know-how in computing, materials and, more particularly, propulsion. In its technological progression, France is thus a step ahead of a number of States.

However, from this point of view, the real issues go far beyond the technical questions, including the mobilization of civil research capacity. The strategic questions implied by the dissemination of hypersonic systems and their effects on high-intensity operations are far from having all been resolved and will certainly trigger debates, both among allies and on the international stage, which will have to be addressed other than through vain appeals to proliferation restraint. Although it would be wrong to see the dissemination of hypersonic systems as the first signs of "hyper-warfare" conducted entirely at high speed, the nature of future military operations will doubtless be affected by systems tipping the balance in favor of surprise, riding roughshod over decision-making cycles, distorting perceptions, and increasing the freedom of action of States in a series of scenarios. Once again, the words of Hervé Coutau-Bégarie are as relevant as ever: "The greater the material investment, the greater the intellectual investment that must follow."[20]

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20. H. Coutau-Bégarie, *Traité de stratégie*, Bibliothèque Stratégique, Paris: Economica/ISC, 1999, p. 249.

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