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BELIEVE THE HYPE: **HYPERSONIC WEAPONS AND RADAR-ELECTRONIC WARFARE CHALLENGES**

DR. THOMAS WITHINGTON – RUSI, UK

Hypersonic missiles, defined by speeds exceeding Mach 5, present unique challenges to modern air defence systems due to their velocity, trajectory, and the heat generated during flight. These characteristics affect the performance of radar and Electronic Warfare (EW) sensors, complicating the detection, identification, and tracking of such weapons. In addition, the plasma (super-heated, ionised gas) produced by hypersonic missiles may impact radar and Electronic Support Measure (ESM) detection. This article examines the technical challenges posed by hypersonic threats and explores how networked sensor systems, including radar, ESM, infrared, and acoustic detection, can be integrated to improve early warning and interception capabilities.

Keywords
Hypersonic Missiles, Electronic Warfare, Air Defence, Airpower, Stealth, Strategic Weapons.

Introduction

As their appellation suggests, hypersonic missiles move at exceptionally high speeds. Standard definitions say that such weapons travel over Mach 5, equating to 3,334 knots (6,174 kilometres per hour) (Hypersonic, 2022). Hypersonic speeds translate into short flight times. Russia's 3M22 Zircon (NATO reporting name SS-N-23), surface-to-surface hypersonic missile has a 540-nautical miles (1,000 kilometres) range ('3M22 Zircon', 8th August 2025). The missile may have reached speeds of circa 5,334 knots (9,878 kilometres per hour) during tests ('3M22 Zircon', 8th August 2025). Assuming this average speed is sustained during flight, it would take the missile six minutes and four seconds to cover this distance. Hypersonic velocities help reduce the warning time available to the defender and hence their ability to detect and intercept the missile before it hits its target. Furthermore, the long ranges of weapons like the 3M22 increase the stand-off distance such weapons can be deployed. This enhances the survivability of the launching platform, be that a land-based site, aircraft, warship or submarine.

This article examines the challenges of processing hypersonic missile threats using electromagnetic technologies such as radar and Electronic Support Measures (ESMs). It considers claims that hypersonic missiles may generate plasma to reduce radar detectability and explores how radar and ESMs can be integrated with other sensor systems to improve situational awareness and response times.

CONTACT: Dr. Thomas Withington ✉ rusi@rusi.org Rusi, UK

Flight characteristics and radar

The 3M22 may have a cruising altitude of around 65,617 feet (20,000 metres). Most ground-based air surveillance radars must have a line-of-sight range between the radar's antenna and the target. Most conventional radars cannot detect targets beyond the horizon. This is because the curvature of the Earth acts as an obstruction. High altitude airborne targets can appear above the horizon much earlier than those flying nap-of-Earth flight profiles. A 3M22 flying at 65,617 feet could appear within the field-of-view of a radar watching the skies at a range of 314 nautical miles (582 kilometres). Given the missile's speed, detecting the target at this range may only provide a window of three minutes and 32 seconds to process the threat. After that time, the missile will have overflown the radar and continued towards its target.

Hypersonic missiles are challenging to detect with radar as they are likely to employ low Radar Cross Section (RCS) airframe designs. Radars transmit Radio Frequency (RF) signals in the form of pulses or continuous waves. These signals move at the speed of light; 161,595 knots per second (299,274 kilometres per second). Signals collide with a target in the line-of-sight from the radar's antenna and are reflected to that antenna as echoes. Radars measure how long it takes the signal to leave the antenna, collide with a target and return as an echo. By dividing this distance in two, the radar ascertains the target's range.

Radars ascertain a target's speed by exploiting the Doppler effect. The Doppler effect is the phenomenon by which signal frequency appears to increase or decrease relative to the observer if the target is moving towards or away from them. Suppose a radar is transmitting a two gigahertz (GHz) signal which is equivalent to 2,000,000 hertz (Hz). Our target is a 3M22 missile flying at 5,334 knots. The echo returned to the radar will have a frequency of 2,000,018.31 Hz. This increase in frequency indicates that the missile is approaching.

A radar's ability to process a target is governed by how much RF energy returns to its antenna as an echo. The strength of the echo is measured in decibels (dB). RF signals are like long-distance runners; the further they go, the less strength they have when they reach their destination. The efficacy of a radar is measured not only in the strength of signal it transmits but also the extent to which it can focus the signal in a specific direction, which is referred to as the radar's gain.

Suppose a ground-based air surveillance radar generates a two-megahertz signal. That signal has 10,000 watts (70 dB) of power when it leaves the antenna. When taking the antenna's gain into account, the radar will transmit a signal with 72.85 dB (19,275 W) of power towards the target. For the purpose of this example, the target is a Boeing 747 airliner 35 nautical miles (65 kilometres) away with a 100 square metre RCS. The outgoing radar signal strength is 72.85 dB. As this signal moves through the atmosphere, it loses strength, hits the target, and loses more strength as the signal is reflected as an echo. This entire process causes a loss of 78.69 dB, resulting in an echo with a signal strength of -5.84 dB when it reaches the radar antenna.

The 3M22 missile may have a radar section of 0.05 square metres or less which helps to reduce the strength of the echo it reflects to a radar. It will be assumed that all the other radar parameters discussed above are the same, with the exception of the target. The two megahertz signal still has 72.85 dB of power when it leaves the antenna, and the target remains at 65 kilometres range. The signal loss for the echo on the return journey is now 111.70 dB, resulting in an echo with -38.85 dB signal when it reaches the radar.

Electronic Support Measure detection

Radar detection of a hypersonic missile, while difficult, could be supplemented by using ESMs capable of detecting signals from the missile's own Active Radar Homing (ARH) seeker. Missiles can use ARH seekers to detect and recognise their intended targets. Anti-ship missiles tend to use seekers transmitting in X-band (8.5 GHz to 10.68 GHz), Ku-band (13.4 GHz to 14 GHz/15.7 GHz to 17.7 GHz) and Ka-band (33.4 GHz to 36 GHz). These wavebands are useful for target detection as they can depict targets in detail making it easier for the missile to positively identify its target, compared to radars transmitting in lower frequencies.

An ESM within range of the missile can detect the radar signals from the former. The ESM could be mounted on an aircraft or warship, deployed on land or on a satellite in space. The electronic support measure will be tuned to detect certain frequencies, in this case, the X-band, Ku-band and/or Ka-band signals. A key attribute of an ESM is that it detects a radar in less time than it takes the latter to detect a target. Returning to the above example, the 3M22 missile has been detected by an S-band radar at a range of 65 kilometres. It takes the radar signal 0.000434385 seconds (0.434 milliseconds) to perform the round trip from the radar's antenna, to collide with the missile and to return as an echo. It will take an ESM within range half this time (0.000217193 seconds/0.217 ms) to detect the incoming radar signal from the 3M22's seeker.

While this time difference seems infinitesimally small it is important. Hypersonic velocities mean that any advantage in early warning time, however small, should be exploited. Nonetheless, radar signals in these wavebands can rapidly lose energy the further they travel, compared to lower frequencies. Physics dictates that higher RFs depict targets in sharp detail but at the expense of range. Conversely, lower frequency radars achieve impressive ranges, but do not depict targets in such rich detail. Any ESM designed to detect a hypersonic missile ARH seeker must be extremely sensitive to detect such weak radar signals.

Cloaking devices

Some claims have been made that weapons like the 3M22 use so-called 'plasma stealth' devices to mask their detection by radar. Plasma stealth works by exploiting a cloud of plasma. As plasma is an electrified gas it can have significant effects on incoming radar signals. Like radio signals, plasma will have a specific frequency when produced. The frequency is governed by the rate at which the electrons in the plasma oscillate and, like radio signals, this oscillation is measured in hertz. If the incoming radio signal from the radar, and the plasma frequency are the same, the latter absorbs the former. Theoretically, this means that no echo will return to the radar and thus no target will be detected (Trevithick, J, and Rogoway, T, 2019).

In practice, using plasma stealth may be extremely difficult. Objects like hypersonic missiles may automatically generate plasma by their flight characteristics. As the missile moves through the atmosphere it experiences friction with molecules in the air. This friction can generate extreme heat which in turn creates plasma. Firstly, the plasma frequency will need to match the frequency of the incoming radar signal; if not, this process may not be effective. An alternative is to have the missile actively generate plasma at the correct frequency to match the radar signal. This would require a plasma generation system to be housed on the missile, adding weight, complexity and cost to the design, potentially impinging on performance.

Secondly, the plasma generation device would need an ESM to identify the parameters of the incoming radar signal such as signal frequency and strength. Once the parameters are ascertained, suitable plasma would then be generated to surround the missile. Nonetheless, there would still be a short interval between the incoming radar signal hitting the missile and the echo returning to the radar. This interval could still enable the radar to process the missile threat. As noted above, having a low RCS design may deprive the radar of a workable echo to process, possibly causing it to be ignored. This may afford time for the missile's plasma generation device to do its work to pre-empt future, incoming signals.

An additional problem is that this process will be complicated by the fact that radar signals can change frequency thousands of times per second. Frequency hopping can make the signal difficult to detect, as it is always changing. A radar signal that is difficult to detect is hence difficult to jam. For a plasma stealth device to be effective, it would have to be able to predict the signal's pseudo-random frequency hopping pattern. Accurate prediction would be necessary to ensure the ESM was always correctly anticipating the characteristics of the next signal and adapting plasma production accordingly. The latter process is likely to be extremely difficult.

While plasma stealth may theoretically be capable of masking a hypersonic missile from radar detection, plasma produces intense heat. This heat could be visible to satellites equipped with Infra-Red (IR) optical trackers looking down towards Earth's atmosphere. These sensors may detect the heat plume generated by the missile, the plasma and its engine exhaust during its flight (Shepard, 2025). Nonetheless, a word of caution should be mentioned here. While hypersonic missiles generate heat via their engine and movement through the upper atmosphere, their heat signatures can be notably less than those generated by ballistic missile rocket engines (Richardson, 2024). Space-based IR sensors would thus need the appropriate sensitivity to detect hypersonic threats. Another shortcoming is that hypersonic missiles may also have their heat signature obscured to satellite IR sensors by clouds. It may thus be prudent to also locate sensitive IR seekers on land, aircraft or warships for additional threat detection (Microphones can spot radar-evading hypersonic missiles, 2025).

Processing hypersonic threats

It is unlikely that one single technology is capable of adequately detecting, identifying and tracking all hypersonic missile threats. Instead, several sensing capabilities are likely to be needed which can be networked to send their data to a central point for merging and processing to manage these threats. This approach is not altogether different from how air defenders currently address conventional air threats. Radars, optronics, infrared and ESM detection are all employed for detection, identification and tracking.

Early space-based detection of an incoming hypersonic threat may provide useful data which can then be shared with surface-based radars and ESMs. The missile's speed and trajectory can be derived using the space-based sensors. This information will help to cue Earth-bound sensors to ensure they are monitoring the correct section of the sky from where the threat is expected to arrive. Radars and ESMs will need the requisite sensitivities to detect the missiles' faint echoes and ARH seeker signals. Although plasma stealth has been highlighted as a potential impediment to radar detection, the efficacy of this technology is debatable.

All these sensors will need to be networked to ensure that threat data can flow between them, Command and Control (C2) systems and interceptors like surface-to-air missiles. The breakneck speeds of hypersonic threats make every millisecond count. Time gained in processing a hypersonic threat translates into time to intercept the threat before it hits the target. Low latency communications are vital in this respect. Fifth and sixth (5G/6G) generation cellular communications standards offer one potential means to network hypersonic missile sensors, C2 systems and interceptors. 5G provides very low latency rates of under ten milliseconds (What are 5G speeds?, 2025). 6G reduces latencies to below one millisecond (What are the latest developments on 6G?, 2025). Moreover, both 5G and 6G networks boast impressive data carriage, reaching rates of around 20 gigabits per second and one terabit per second respectively (Everything you need to know about 5G, 2025; What are the latest developments on 6G?, 2025). Data rates are important. They allow significant quantities of information concerning the incoming threat to be shared rapidly. The more information regarding the threat that can be shared, the better the chances of intercepting the missile successfully.

IR, radar and ESMs are not the only technologies relevant to processing hypersonic missile threats. Acoustic detection has a role to play. Given their speeds, hypersonic missiles generate a sonic boom which could be detected by networks of sensitive microphones. By using two or more microphones the source of the sound can be triangulated, and hence the location of the missile revealed (Microphones can spot radar-evading hypersonic missiles, 2025). Given the speed of the missile, it will have flown some distance by the time the source of the boom is pinpointed. Nonetheless, by matching the boom heard by multiple networks deployed in a large area, the missile's trajectory could be plotted. This would provide useful indication of the direction that other sensors, and interceptors, should be cued in preparation for the threat's arrival. Excessive background noise, which might mask the sonic boom from the microphones, could be avoided by deploying the microphones at sea. Regular maritime noise such as waves, marine life and weather could be filtered out using software. This filtering process would help improve the microphone's ability to detect the boom when it occurs.

As this article has illustrated radar, ESMs, IR and acoustic sensors have their strengths and weaknesses. As a result, wide area, networked, diverse sensors must be deployed to provide the timely processing of hypersonic missile threats. Networking these sensors with wideband, low latency communications will be vital, although 5G and 6G cellular protocols are two technologies that hold promise in this regard. Recent conflicts have shown that hypersonic threats are here to stay. Deploying capable and survivable networked sensors is as important as deploying the correct interceptors if these threats are to be effectively countered.

Hypersonic missile proliferation has clear implications for armed forces, defence planners and policy makers. The weapons cannot be neutralised by one kinetic or electronic means alone. As this article has illustrated, a holistic approach must be taken to counter hypersonic threats. What this means in principle is that air defence forces initially need to examine the suitability of their air defence systems to detect, process and engage hypersonic missiles. The acumen of these capabilities should not only be assessed to this end individually, but as one component of a networked 'system-of-systems' intended to engage these threats. Where capability gaps are identified, these must be addressed with the same mindset. The question must be asked regarding the extent to which new air defence capabilities can seamlessly 'plug into' existing air defence systems. Put bluntly, if new capabilities cannot easily integrate with legacy systems to engage hypersonic targets, they should not be procured. Likewise, legacy air defence systems that cannot be effectively networked should not be employed as part of the counter-hypersonic mission. Hypersonic threats are not 'ten feet tall'. With a combination of the correct sensors, and kinetic and electronic effectors, underpinned by a low-latency, wideband network they can be defeated. It is vital that nations and militaries perform this important work now to adequately prepare for these threats which are likely to become a standard feature of future warfare.

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