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An Integrated Air and Missile Defence Architecture for the UK

Options to Defend the UK from the Russian Missile Threat

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Acronyms and Abbreviations

AIM: air-intercept missile

AMRAAM: Advanced Medium-Range Air-to-Air Missile

AN/TPY-2: Army/Navy Transportable Radar Surveillance

ASRAAM: Advanced Short Range Air-to-Air Missile

ATACMS: MGM-140 Army Tactical Missile System

AUKUS: trilateral security partnership between Australia, the UK and the US

AWACS: Airborne Warning and Control System

BMD: ballistic missile defence

C2: command and control

CAMM: Common Anti-Air Modular Missile

CEC: cooperative engagement capability

CEP: circular error probable

CNI: critical national infrastructure

DCA: defensive counterair

DF-26: Dong Feng-26

E2-D: Grumman E-2 Advanced Hawkeye

ECRS: European Common Radar System

E-7: Boeing E-7 Wedgetail

F-35: Lockheed Martin F-35 Lightning II

F/A-18: McDonnell Douglas F/A-18 Hornet

FADS: Future Air Dominance System

GAMB: Giraffe Agile Multibeam

G/ATOR: Ground/Air Task Oriented Radar

HGV: hypersonic glide vehicle

HYDIS: Hypersonic Defence Interceptor Programme

IAMD: integrated air and missile defence

ICBM: intercontinental ballistic missile

IRBM: intermediate-range ballistic missile

IRIS-T: Infrared Imaging System Tail/Thrust Vector-Controlled

ISO: International Organization for Standardization

JLENS: Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System

JWP: Joint Warfare Publication

MADL: Multifunction Advanced Data Link

MIC4AD: Modular, Integrated C4I Air & Missile Defense System

MIRV: multiple independently targetable re-entry vehicle

MK 41 VLS: Mark 41 Vertical Launching System

MRAD: medium-range air defence

NASAMS: National Advanced Surface-to-Air Missile System

NATINADS: NATO Integrated Air Defense System

NIFC-CA: Navy Integrated Fire Control – Counter Air

OPIR: Overhead Persistent Infrared

OSK Sever: Russian Northern Fleet Joint Strategic Command

OTH: over the horizon

PAC-2 GEM-T: Patriot Advanced Capability-2 Guidance Enhanced Missile – Tactical

PAC-3: Patriot Advanced Capability-3

P-8: Boeing P-8 Poseidon

RCS: radar cross-section

SAM: surface-to-air missile

SAMP/T: surface-to-air missile platform/terrain

SBIRS: Space-Based Infrared System

SDI: Strategic Defense Initiative

SHORAD: short-range air defence

SLCM: submarine-launched cruise missile

SM-3IIA: Standard Missile-3 Block IIA

SM-6: Standard Missile-6

SODCIT: Strategic Operation for the Destruction of Critically Important Targets

SSGN: nuclear-powered guided-missile submarine

SSN: nuclear-powered attack submarine

THAAD: Terminal High Altitude Area Defense

Tu-22M3: Tupolev Tu-22M3

Tu-95: Tupolev Tu-95

Tu-160: Tupolev Tu-160

TWISTER: Timely Warning and Interception with Space-Based TheatER Surveillance

UCAV: uncrewed combat aerial vehicle

VKS: Russian Aerospace Forces

VMF: Russian navy

VLS: vertical launch system

VSHORAD: very short-range air defence

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Executive Summary

The prominence of long-range strike capabilities in recent conflicts, most notably in Ukraine, has driven a newfound interest in integrated air and missile defence (IAMD) for the UK. Until recently, this was an area that had received limited interest, given that much British military planning had an expeditionary focus and there were limited threats to the homeland. The size of Russia's arsenal of long-range strike capabilities – and the demonstrated Russian ability to employ conventional precision strike in both a counterforce and a countervalue role – makes discussions on the risk to the UK germane. The threat spectrum will evolve to become multi-vector, encompassing a combination of air-breathing, ballistic and hypersonic threats. However, any effort to buttress the air and missile defence system protecting the UK homeland will take place at a time when multiple parts of the Joint Force will require recapitalisation of both platforms and stockpiles, after decades of downsizing. It is therefore vital that an IAMD system be developed in a way that does not render it an opportunity cost to the UK's ability to project power. Instead, it must add to the UK's credibility. The paper seeks to describe how an IAMD capability to achieve this might be developed in the coming decades.

Key Findings

- Different components of the Russian threat are likely to become acute at different periods during the next two decades. This allows the UK to sequence its commitments.
- In the next five years, cruise missiles will probably be the primary Russian threat at depth. This is due to the limited production rates for systems such as the Oreshnik intermediate-range ballistic missile and the allocation of produced hypersonic glide vehicles to the Russian Strategic Missile Forces for deterrence against the US. Beyond the mid-2030s, however, it is likely that the threat spectrum will broaden.
- The employment of missiles against the UK would currently involve risks to scarce and expensive Russian launch platforms, such as bombers and guided-missile submarines. Russia has not generally faced such risks in the war in Ukraine. Moscow will thus need to be more judicious in target selection to maximise impact in order to justify this risk.
- Of the Russian concepts for the employment of long-range strike capabilities – the strategic operation for repelling an aerospace attack (offensive counterair against submarine bases, airbases and cruise-missile-carrying platforms)

and SODCIT (the destruction of critical infrastructure) – Moscow is likely to give precedence to repelling aerospace attacks from the UK. Military targets will probably be priorities early in a conflict, when the UK's vulnerabilities are likely to be most acute.

- Until 2030, improving UK national defences against subsonic cruise missiles should take precedence. The availability of elevated L-band sensors and longer-ranged surface-to-air missile systems will be particularly important.
- Additionally, there is room to build on capabilities such as Guardian and Nexus to leverage currently unused, but IAMD-relevant, data from across the Joint Force.
- In the mid-2030s to the early 2040s, a degree of homeland ballistic missile defence will probably be important. Fielding a number of the Royal Navy's MK 41 vertical launch system-equipped platforms during this period can provide some opportunities in this regard as the MK 41 is compatible with several BMD-capable exo-atmospheric interceptors. Opportunities to iterate on work being conducted for programmes such as the Royal Navy's Future Air Dominance System can be exploited.
- Beyond 2040, defences against targets such as hypersonic glide vehicles will also become a higher priority.
- A carefully sequenced approach to generating a national IAMD capability – that matches investments to the evolution of the threat and leverages existing multipurpose systems as well as more bespoke capabilities – can mitigate risks to the homeland in a way in a way that supports other joint force priorities.

Introduction

The experience of recent conflict has driven a renaissance of interest in integrated air and missile defence (IAMD) within the UK. Russia's large-scale use of cruise and ballistic missiles against both military and civilian targets in Ukraine, and Iranian attacks on Israel in April and October 2024, have produced calls in some quarters for the creation of a 'British Iron Dome', and led to legislators publicly scrutinising a perceived gap in the UK's defences.[1]

On the one hand, given the centrality of long-range conventional precision strike to Russia's concepts of operations and the country's considerable capacity in this area, this concern is warranted.[2] On the other hand, there are important differences between the UK's circumstances and those of a state such as Israel or Ukraine, including geographical depth and NATO membership. Moreover, missile defence for the homeland will compete with other pressing defence priorities for resources. Therefore, policymakers must be able to bind the threat in both temporal and geographical terms, identify gaps in British and Allied defences where targeted investments are needed, and be able to weigh the costs and trade-offs that different IAMD architectures will entail.

This paper discusses the factors that should be taken into consideration as the UK weighs its options for an IAMD architecture for the homeland, and the capabilities which might underpin different viable architectures. It is informed by desk research and basic operational analysis. Chapter I examines the Russian threat as it pertains to the UK homeland and discusses both the areas where this threat is acute and somewhat more marginal. Chapter II examines the gaps in the UK's defensive architecture and the extent to which they represent a cause for concern. Chapter III discusses a proposed phased approach whereby the UK can iteratively improve its air defence capabilities as the threat evolves.

The paper focuses on a specific part of IAMD: active defence against missiles. This is a conceptual narrowing of IAMD, as the concept can encompass a range of activities, including left-of-launch attack and passive defence, and air threats can encompass more than missiles, but is doctrinally consistent with NATO's understanding of the concept. More practically, this paper deems Russian missiles to be the most important component of the air threat to the homeland. The reasons for this are discussed fully.

1. George Allison, 'MPs Warn of Urgent Gaps in Britain's Air and Missile Defence', *UK Defence Journal*, 27 November 2024, <https://ukdefencejournal.org.uk/mps-warn-of-urgent-gaps-in-british-air-and-missile-defence/>, accessed 7 July 2025.
2. On Russian concepts for long-range strike, see Michael Kofman, Anya Fink and Jeffrey Edmonds, 'Russian Strategy for Escalation Management: Evolution and Key Concepts', CNA, April 2020.

The paper articulates the timelines within which different threats will mature and a sequenced approach to fielding defensive capabilities that can counter them. While the paper does not propose specific technological solutions, it does discuss the strengths and weaknesses of different viable options. Its purpose is to allow policymakers to weigh their choices as they consider the UK's options for air and missile defence for the homeland.

I. The Russian Threat to the UK

Russian Concepts for Missile Employment

In Russian military literature, long-range precision strike is seen as an integral part of modern warfare. Its employment can be grouped within two functions. The first is a combined effort to repel a strategic aerospace attack.[3] Russian planners recognise their inferiority in the air domain and have made considerable efforts in developing concepts to mitigate this inferiority.[4] While integrated air defences and electronic warfare are an important part of the Russian answer to Allied airpower, there is a broad agreement among Russian military analysts that a purely passive approach is not sustainable. Instead, the air threat (which includes cruise missiles launched from platforms such as submarines) must, as far as possible, be pre-emptively destroyed.[5] Long-range precision strikes against threats at their source are an important component of Russia's concept of how it must offset Allied airpower. Within this, the destruction of aircraft on the ground is particularly salient.[6] However, the destruction of nuclear attack submarines (SSNs) that carry submarine-launched cruise missiles (SLCMs) is also described as a priority. This is most easily achieved when SSNs are in port or in maintenance at sites such as HMNB Clyde and Devonport.[7]

The second concept for the employment of long-range precision strike – viewed as a means of war termination – is SODCIT (Strategic Operation for the Destruction of Critically Important Enemy Targets).[8] This concept describes the systematic

3. Dmitry (Dima) Adamsky, 'Moscow's Aerospace Theory of Victory: Western Assumptions and Russian Reality', CNA, February 2021, p. 5, <https://www.cna.org/analyses/2021/03/moscows-aerospace-theory-of-victory>, accessed 7 July 2025.
4. *Ibid*.
5. Clint Reach et al., *Russia's Evolution Towards a Unified Strategic Operation: The Influence of Geography and Conventional Capacity* (Santa Monica, CA: RAND, 2023), p. 7.
6. *Ibid*.
7. *Ibid*.
8. Michael Kofman et al., 'Russian Military Strategy: Core Tenets and Operational Concepts', CNA, August 2021, pp. 44–46, <https://www.cna.org/analyses/2021/10/russian-military-strategy-core-tenets-and-concepts>, accessed 7 July 2025; A V Skripnik, « Методический аппарат ранжирования критически важных объектов противника в целях решения задачи силового стратегического сдерживания »

targeting of critical national infrastructure (CNI) including (but not limited to) a state's energy grid and encompassing – according to one Russian author – all of the non-nuclear means of supporting modern cities (that is, any supporting infrastructure excluding nuclear power plants).[9] Generally speaking, SODCIT intensifies during the mid- to late stages of a war and is meant to combine with cumulative losses at the front and threats of further escalation. Together, these are designed to compel an opposing alliance or state to sue for peace on terms favourable to Russia.[10] Third, Russia has never forgone the employment of substrategic nuclear weapons if conventional operations fail at tasks such as suppressing aerospace threats. Figures such as A E Sterlin, head of the Main Operations Directorate of the Russian General Staff, have written that, in the final instance, the efficiency of nuclear weapons at the theatre level cannot be completely replicated by conventional capabilities. If conventional suppression of capabilities proves unviable and operations against CNI do not force war termination on favourable terms, many Russian theatre-range missiles might be employed with low-yield nuclear payloads against military targets.[11] As Sterlin describes it, a SODCIT operation is a stepping stone towards nuclear use, intended to reduce the shock of the transition from conventional warfare.

On balance, the pre-emptive targeting of military sites – particularly those associated with airpower – in the opening days of a conflict is the most immediate conventional threat for the UK. This is the case for several reasons, two of which bear special consideration.

First, countervalue targeting has a limited record of producing strategic results. In contrast, the pre-emptive destruction of critical elements of the UK Joint Force, including SSNs and fifth-generation aircraft, could decisively impact the UK's ability to contribute to a NATO effort to confront Russia.[12] These assets will be distributed in a conflict, but might be vulnerable in the first days of a conflict when Russia will have the initiator's advantages.

Second, the UK enjoys a comparatively comfortable geographic position. As a conflict unfolds and Allied air and maritime component commands are stood up, many of the Russian launch platforms, such as bombers and submarines

['Methodological Apparatus for Ranking Critical Enemy Targets in Order to Solve the Problem of Strategic Deterrence'], *Вооружение и экономика* (No. 15, 2011).

9. A A Kokoshin, « Стратегическое Ядерное И Неядерное Сдерживание: Приоритеты Современной Эпохи » ['Strategic Nuclear and Non-Nuclear Containment: Priorities of the Modern Era'], *Известия Российской академии наук* (Vol. 84, No. 3, 2014), p. 202.
10. Kofman et al., 'Russian Military Strategy', pp. 44–46.
11. A E Sterlin, A A Protasov and S V Kriedin, « Современные трансформации концепций и силовых инструментов стратегического сдерживания » ['Modern Transformations and Concepts and Power Instruments of Strategic Deterrence'], *Военная мысль* (Vol. 8, 2019).
12. See Robert A Pape, *Bombing to Win: Strategic Airpower and Coercion in War* (Ithaca, NY: Cornell University Press, 1994).

that might be employed to strike the UK, would have to operate at considerable risk. In the mid- and later stages of a conflict – during which Russia would more likely turn to heavily targeting CNI – striking targets in the UK would involve risking the loss of scarce and strategically valuable launch platforms, including bombers which are part of Russia's nuclear triad. Against targets which need to be struck repeatedly to ensure their destruction (for example, power stations), these costs would rise even further. This is unlike, for example, the situation in Ukraine where Russia can strike targets from the relative safety of its own airspace, with little to no risk to launch platforms. Certainly, Russia does not lose its ability to strike the UK, including CNI, in the mid-stages of a conflict. However, the costs of doing so increase considerably relative to the reward. While Russian attacks on CNI cannot be categorically ruled out, attacks against military sites in the early stages of a conflict appear the more likely and more consequential outcome against which limited resources should be initially focused.

These two reasons are explored in greater depth later in the paper.

Of course, the threat to CNI is not unimportant, particularly when this infrastructure relies on a small set of nodes (as with the UK's capacity to import liquefied natural gas, which depends on just three terminals).[13] Even if it is unlikely to be strategically decisive, Russian countervalue targeting could impose both human and economic costs. Moreover, Russian planners view the ability to destroy CNI as a key component of the military balance, and their assessments of whether this can be done easily will have ramifications for deterrence.[14] It is worth noting that public and political concerns over the risk to civilian life posed by adversary airpower have undermined deterrence in the past. They partly contributed, for example, to the decision to opt for appeasement at Munich in 1938.[15] A degree of protection for critical civilian infrastructure is thus likely to be necessary.

On balance, Russia would more likely be able to strike the UK with conventional capabilities in the opening hours of a conflict – particularly if an Allied air component command has not been stood up. Military targets would probably take precedence at this stage of a conflict.

13. Izzy Andrewes and Addy Mettrick, 'Supply of Liquified Natural Gas in the UK, 2022', Energy Trends Collection, Department for Energy Security and Net Zero, 30 March 2023, <https://assets.publishing.service.gov.uk/media/642434bd3d885d000cdade0f/Supply_of_Liquefied_Natural_Gas_in_the_UK__2022.pdf>, accessed 22 November 2024.
14. For example, see Kokoshin, « Стратегическое Ядерное И Неядерное Сдерживание: Приоритеты Современной Эпохи » ['Strategic Nuclear and Non-Nuclear Containment: Priorities of the Modern Era'], p. 202.
15. Jeffrey Record, *Appeasement Reconsidered: Investigating the Mythology of the 1930s* (Carlisle, PA: Strategic Studies Institute, 2005), pp. 30–31.

Russian Capabilities and the Geography of the Defended Area

The Spectrum of Russian Capabilities

The spectrum of Russian threats to the UK is evolving from a single-vector cruise missile threat into one that involves a broader spectrum of capabilities with different altitudes and speed regimes. This complexity creates conflicting requirements for both sensor and effector types. As an illustrative example, the detection and targeting of high-flying fast targets, such as ballistic missiles, tend to require high resolution at long ranges, even if this is power consuming and thus results in the employment of surface-based S- and X-band radar for high-resolution tracking.[16] Ballistic missile detection can also depend on infrared satellites to detect the initial heat plume during its boost phase, and hence the initial detection of the threat. The potential target is then handed over to radar for tracking as it appears above the radar horizon. By contrast, against low-flying targets – such as cruise missiles – it is, in general, useful to employ elevated sensors. These achieve better range-to-power ratios on a size-limited platform by using somewhat lower-frequency L-band radar (although range also depends on several other factors, such as radar gain, output power, antenna size and target). As another example, blast-fragmentation effectors tend to work well against cruise missiles; against complex ballistic targets, hit-to-kill interceptors with very high-frequency Ka band seekers are optimal (particularly against smaller targets, such as warheads).

The challenge for the UK will be to both decide which target types to optimise against (while noting that no single threat can be entirely ignored) and generate a mix of sensors and effectors across the whole force, since no single service can afford or operate the full spectrum of capabilities that are needed. Equally, it should be recognised that the attacker faces trade-offs when developing strike packages; missile types vary in range, accuracy and the level of risk that their employment creates for the launch platform.

This section outlines the technical characteristics of the different parts of the Russian missile arsenal that are relevant to the UK, the trade-offs which different missile types impose on both the attacker, and the defences and timelines within which different parts of the threat will mature.

16. On the broad trade-offs among different sensor types, see Warren J Boord and John B Hoffman, *Air and Missile Defence Systems Engineering* (New York, NY: CRC Press, 2016), pp. 81–82.

Cruise Missiles

Currently, at what the Russians define as operational-strategic depths (ranges beyond 500 km), the primary strike capability of the Russian military is cruise missiles held by the VKS (Russian air force) and the VMF (Russian navy). Over the past decade, the ability to launch the 3M-14 Kalibr cruise missile (which has a maximum range of 2,500 km) has become a near-ubiquitous feature of both Russian surface vessels and submarines; older nuclear attack submarines of the Russian Northern Fleet have been refitted to launch Kalibr missiles.[17] In addition, the VKS maintains 66 strategic bombers of the Tu-95 and Tu-160 classes. These are capable of carrying air-launched cruise missiles, such as the KH-101 and the KH-55/555 (although this does not account for the impact of Operation *Spiders Web*, which is still to be determined with certainty).[18] The Tu-160 will also carry Russia's new KH-BD cruise missile, which has a range of 6,500 km.[19] Russia's other bomber class, the Tu-22M3 (of which the VKS expects to maintain up to 30 modernised Tu-22M3M airframes) primarily carry long-range anti-ship missiles, such as the KH-22, which can be employed against either maritime targets in port or air defences.[20] Russia has also demonstrated the capacity to deploy containerised versions of the Klub-K (an export variant of the Kalibr) on commercial vessels. These can be used as auxiliary launch platforms.[21]

Cruise missiles pose two challenges. First, they spend part of their trajectories at low altitudes. This limits the detection ranges of surface-based radar (because radar horizons are limited by the Earth's curvature). Second, low-flying objects are relatively difficult for airborne radar to distinguish from ground and maritime clutter (returns from terrain features and waves can mask an object of interest and generate false positives).[22] Over the next five years, as the KH-BD is fielded, the air-launched cruise missile threat will have a new dimension. At the moment, for an attack against the UK, launching aircraft for missiles such as the KH-101 – to retain enough range to be used as a manoeuvring missile rather than a

17. Joshua Menks and Michael B Petersen, 'The "Kalibrization" of the Russian Fleet', *USNI Proceedings* (Vol. 148/5/1,431, May 2022).
18. Xiaodon Liang, 'Russian Strategic Nuclear Forces Under START', Arms Control Association, last updated January 2025, <https://www.armscontrol.org/factsheets/russian-strategic-nuclear-forces-under-new-start>, accessed 7 July 2025.
19. Thomas Newdick, 'Let's Talk About Russia's New Long-Range KH-BD Cruise Missiles', *War Zone*, 19 September 2023, <https://www.twz.com/lets-talk-about-russias-new-long-range-kh-bd-cruise-missile>, accessed 4 December 2024.
20. National Interest, 'Russia's TU-22M3 Backfire Bomber Has a New Supersonic Missile (and the Navy is Worried)', 19 November 2019, <https://nationalinterest.org/blog/buzz/russias-tu-22m3-backfire-bomber-has-new-supersonic-missile-and-navy-worried-97722>, accessed 8 July 2025.
21. *GlobalSecurity*, 'Klub-K Container Launched 3M-54 Klub / Caliber – SS-N-27 Sizzler', <https://www.globalsecurity.org/military/world/russia/club.htm>, accessed 7 July 2025.
22. See Ann Marie Raynal and Armin Walter Doerry, 'Doppler Characteristics of Sea Clutter', Sandia National Laboratories, June 2010, <https://www.osti.gov/servlets/purl/992329/>, accessed 8 July 2025.

straight-line weapon – must be placed within reach of some, particularly Norwegian, air patrols. In fact, these patrols do not currently provide absolute security, given the ranges involved in operating against bombers in the north. The addition of the KH-BD cruise missile (which has a 5,950-km range) will create new challenges. It will enable Russian bombers to launch missiles from locations such as north of Svalbard, where the Russian Northern Fleet Joint Strategic Command has conducted exercises.[23] Intercepting bombers in this context entails a much greater reliance on tankers, as well as operating in contested airspace.

A subset of the Russian cruise missile threat is the hypersonic Zircon cruise missile. This is deployed on the *Yasen*-class guided-missile submarine (SSGN), as well as the *Gorshkov*- and *Grigorovich*-class frigates.[24] Hypersonic cruise missiles – powered by scramjet engines – travel at speeds of over Mach 5, which can make intercepting them considerably more difficult. However, the attacker must also consider certain trade-offs. Given the inverse relationship between speed and range, hypersonic cruise missiles will, all else being equal, be considerably shorter-ranged than slower missiles of a similar size (although this depends on factors such as the missile's altitude, as higher-altitude trajectories may provide additional range). Hypersonic cruise missiles must also fly at relatively high altitudes of 20 km for scramjet engines to be effective, and in their terminal phase, these missiles may have to slow down to prevent plasma layers from interfering with their seekers.[25] In effect, a hypersonic cruise missile may be detected earlier but poses a more aerodynamically challenging target for air defence interceptors. The attacker, however, faces the costs of both system complexity and range limitations, which require some acceptance of risk to the launch platform. As an illustration, a Yasen-class SSGN targeting RAF Coningsby with an (approximately) 700-km range Zircon from suitably deep waters in the Atlantic (the North Sea is too shallow for SSNs) would have to be relatively close to the UK's western coastline when it launched its missiles.

Ballistic Missiles

Ballistic missiles can be detected more easily than cruise missiles as they fly at higher altitudes and their trajectories are often (although not always) comparatively predictable. However, tracking and engaging them is made

23. Kristian Åtland, Thomas Nilsen and Torbjørn Pedersen, 'Bolstering the Bastion: The Changing Pattern of Russia's Military Exercises in the High North', *Scandinavian Journal of Military Studies* (Vol. 7, No. 4, 2024), pp. 145–60.
24. Sidharth Kaushal, 'The Zircon: How Much of a Threat Does Russia's Hypersonic Missile Pose?', *RUSI Commentary*, 24 January 2023, <https://www.rusi.org/explore-our-research/publications/commentary/zircon-how-much-threat-does-russias-hypersonic-missile-pose>, accessed 5 December 2024.
25. *Ibid*.

considerably more difficult because of their speed. Ballistic missiles leave defenders with very little warning time, which makes them an attractive tool for employment against time-sensitive targets. Engaging ballistic missiles can be further complicated by an attacker's employment of countermeasures which mimic the missile's warhead (the Russian short-ranged 9M723 deploys six) and by manoeuvring re-entry vehicles (six are seemingly carried on the newly fielded RS-26/Oreshnik).[26] The procedures for preparing a ballistic missile for launch are also less time consuming than for weapons such as air-launched cruise missiles, which must be loaded and flown to their launch points. A modern solid-fuelled ballistic missile can be launched within minutes of receipt of an order to do so.

The restraints of the now-defunct Intermediate-Range Nuclear Forces Treaty somewhat bounded the Russian ballistic missile threat. This is now changing. Until now, the primary Russian ballistic missile threat at operational depth was the KH-47M2 Kinzhal, an aero-ballistic missile launched from both the Tu-22 and the MiG-31K.[27] Despite an advertised range of 2,000 km (a figure which Russian sources probably arrived at by including the combat radius of the MiG-31), the Kinzhal is structurally similar (although not identical) to the 9M723 Iskander short-range ballistic missile. While it has greater range than the Iskander (given that it is air-launched), it probably has a real range of 400–700 km, depending on the energy efficiency of its trajectory.[28] This would mean that against targets in the UK, the Kinzhal could only be employed at considerable risk to the launch platform. That said, the combat radius of a bomber such as the Tu-22 would still compel the commitment of multiple assets to cover likely launch vectors.

The Oreshnik – which Russia describes as a 'medium-range ballistic missile' – has demonstrated Russia's theatre-range ballistic missile capability. The missile appears to be a variant of the RS-26, which has a maximum range of 5,500 km and might more accurately be described as an intermediate-range ballistic missile (IRBM).[29] Russia also appears to be in the process of developing an intermediate-range anti-ship ballistic missile, the Zmeevik, although at the moment this seems to have been put on hold. Even if this capability proves difficult for Russia to cue against dynamic maritime targets without a substantial

26. Gerry Doyle, Tom Balmforth and Mariano Zafra, 'Enter "Oreshnik"', *Reuters*, 28 November 2024; Thomas Newdick, 'The Story of Russia's Secretive RS-26 Intermediate Range Ballistic Missile', *War Zone*, 21 November 2024, <https://www.twz.com/land/the-story-of-russias-secretive-rs-26-intermediate-range-ballistic-missile>, accessed 5 December 2024.
27. *Airforce Technology*, 'Kinzhal Hypersonic Missile, Russia', 23 February 2024, <https://www.airforce-technology.com/projects/kinzhal-hypersonic-missile-russia/>, accessed 7 July 2025.
28. The 700-km range can be derived from strikes in Ukraine launched from Tambov. See Kateryna Tyshchenko, 'Russians Launched Kinzhal Missiles at Ukraine', *Ukrainska Pravda*, 5 August 2023, <https://www.pravda.com.ua/eng/news/2023/08/5/7414363/>, accessed 5 December 2024.
29. Newdick, 'The Story of Russia's Secretive RS-26 Intermediate Range Ballistic Missile'.

improvement in Russia's space-based ISR capabilities, it could pose a risk to vessels in port.

An IRBM typically has a maximum speed of about Mach 10. At this speed, it would reach the UK within 10 minutes if launched from western Russia. Their longer trajectories (which result in accumulating errors) and high speed on re-entry (which limits options for error correction and manoeuvre) mean that, unlike short- and medium-range variants, IRBMs often lack the accuracy to strike many targets with conventional warheads. For example, the Chinese DF-26 (a relatively modern IRBM) is estimated to have a circular error probable (CEP) of 150 m.[30] With a CEP of 150 m – or even 90 m (comparable to the Trident submarine-launched ballistic missile fired on an intermediate-range depressed trajectory) – a missile such as the RS-26 would have bounded utility as a conventional strike capability. A ballistic missile with a CEP of 90 m and a 1,200-pound unitary warhead (of the kind a missile such as the Oreshnik could theoretically carry) has a roughly 10% chance of inflicting irreversible damage on an unhardened structure, implying a requirement for 20 warheads.[31] Assuming that Russia eventually produces the RS-26 at roughly the rate that the Soviet Union was able to produce comparable missiles, such as the SS-20 (a generous estimate given the Soviet Union's greater capacity), Russia should be able to produce around 200 medium-range ballistic missiles or IRBMs by the end of this decade.[32]

President Vladimir Putin has suggested an aspiration to employ the missile with conventional payloads that are claimed to approximate the destructiveness of nuclear weapons (a likely allusion to tungsten rods like those used in the attack on Dnipro).[33] This would imply a concept of operations focused on conventionally destroying hardened targets, such as command nodes. In theory, such attacks could have a disproportionate impact. However, the utility of warheads equipped with tungsten rods against hardened targets is somewhat unproven since kinetic energy can dissipate rapidly (notably, the Russian attack on Yuzmash seems to have caused superficial damage[34]) and their employment would still require considerable accuracy.

30. CSIS Missile Threat, 'DF-26', last updated 23 April 2024, <https://missilethreat.csis.org/missile/dong-feng-26-df-26/>, accessed 5 December 2024.
31. The likelihood of damage is derived from the equation where RL is the lethal radius. Assumptions about lethal radiuses are derived from UN Saf*er*Guard, 'Blast Damage Estimation', <https://unsaferguard.org/un-saferguard/blast-damage-estimation>, accessed 4 December 2024.
32. Federation of American Scientists, 'Soviet Military Power, 1985', Chapter 2, <https://irp.fas.org/dia/product/smp_85_ch2.htm>, accessed 5 January 2025.
33. Euractiv, 'Russia Could Launch Another Hypersonic Missile at Ukraine Soon, US Official Says', 12 December 2024, <https://www.euractiv.com/section/politics/news/russia-could-launch-another-hypersonic-missile-at-ukraine-soon-us-official-says/>, accessed 12 March 2025.
34. David Hambling, 'Oreshnik Threat: "Rods from God" are not as Dangerous as Putin Thinks', *Forbes*, 2 December 2024, <https://www.forbes.com/sites/davidhambling/2024/12/02/oreshnik-threat-rods-from-

Russia's limited number of IRBMs will probably function as a theatre-level nuclear capability that is more reliable than cruise missiles (given their high rates of interception) in the near- to medium term. This is due to the number of missiles needed to cripple a military target – assuming a CEP of about 100 m – and the fact that Russia would need to strike targets across Europe to achieve decisive military effect in a conflict with NATO. Figures such as Sterlin have indicated that the efficiency per warhead of nuclear weapons is still something Russian planners consider important when available numbers of a given missile are low.[35]

That said, Russia is expanding its capacity to produce inputs, such as solid fuel. As a result, missile production should increase within the next decade.[36] By the late 2030s, if Russia does achieve production rates comparable to the Soviet Union's, Moscow might have a sufficient number of IRBMs to enable conventional targeting, at scale, within Europe. A significant increase in the accuracy of Russian IRBMs is also possible. This could make them a credible conventional threat to a range of targets, and a far smaller number of missiles would be needed. It is, in theory, possible to achieve considerably higher levels of accuracy with an IRBM. For example, as part of the Conventional Prompt Strike programme in the early 2000s, the US experimented with accurate conventionally armed submarine-launched ballistic missiles that were meant to strike within 5 m of their target.[37] The programme was shelved due to a lack of Congressional funding and the assumption that the Defense Advanced Research Projects Agency's hypersonic test vehicle was a more future-oriented solution. However, the project was never regarded to be technically infeasible. Although Russia has not demonstrated that it can achieve this level of accuracy, it is plausible that Moscow could do so within the next decade.

Even in the short term, a limited number of IRBMs can fulfil useful conventional roles: for example, trapping aircraft (especially larger aircraft, such as AWACS and maritime patrol aircraft) on runways or targeting them in stand areas. As ballistic missiles are considerably faster than cruise missiles, in a counterairbase role they leave dynamic targets – such as aircraft – with less warning time to scramble to escape from being hit. By cratering runways (and therefore preventing aircraft from departing), ballistic missiles equipped with submunitions might be used to trap aircraft on airbases before the arrival of a slower moving wave

god-are-not-as-dangerous-as-putin-thinks/>, accessed 18 July 2025.

35. Sterlin, Protasov and Kriedin, « Современные трансформации концепций и силовых инструментов стратегического сдерживания » ['Modern Transformations and Concepts and Power Instruments of Strategic Deterrence'], *Военная мысль* (Vol. 8, 2019).

36. Jonathan Landay, 'Satellite Photos Show Russia Plans to Expand Missile Production, Researcher Says', *Reuters*, 18 November 2024.

37. Amy F Woolf, 'Conventional Prompt Global Strike and Long-Range Ballistic Missiles: Background and Issues', Congressional Research Service Report, updated 16 July 2021, pp. 21–24, <https://www.congress.gov/crs-product/R41464>, accessed 8 July 2025.

of cruise missiles. In this capacity, the accuracy limitations of an IRBM matter somewhat less. For example, a 750-kg warhead could, in theory, dispense 825 bomblets over a radius of 150 m.[38] For a missile with a CEP of between 100 m and 150 m, this would still not guarantee the destruction of aircraft on the ground (unless the aircraft were packed together), but it could allow for the cratering of runways.[39] However, in this role, the IRBM threat is a function of the cruise missile threat – if a follow-on salvo of cruise missiles can be intercepted, the consequences of runway damage are not entirely significant. Actors such as Taiwan can repair runways in as little as 2.5 hours.

Even so, active ballistic missile defence (BMD) for key airbases would still add a margin of safety. It is also conceivable that Russia deems specific fixed targets in the UK, such as C2 nodes or defence industrial capabilities, to be worth the expenditure of a large proportion of its IRBM capability. As such, the employment of conventionally armed IRBMs in this capacity cannot be ruled out, notwithstanding the arguments made above. And even if the UK decides to temporarily accept risk in the area of BMD (given the more sizeable cruise missile threat), Russia's increasing production rates will mean that this challenge materialises in the medium term.

Hypersonic Glide Vehicles

Russia has invested considerable effort into the development of the Avangard HGV. The Avangard is a boost glide vehicle. It relies on the initial impulse provided by a ballistic missile booster to fly unpowered within the Earth's atmosphere at speeds of over Mach 20.[40] Boost glide vehicles pose a particular problem for missile defence systems because they fly at speeds comparable to ballistic missiles but on more unpredictable trajectories, and their lower altitudes mean that they are detected later in their journey to a target than a comparable ballistic target.

Russia could deploy HGVs on the RS-26, which would make the missile a much more accurate and challenging target at the theatre level. Currently, it appears that the Avangard is intended to be carried on silo-based ICBMs, such as the RS-28. However, in theory, either it or another HGV could be mounted on a shorter-range system, similar to the Chinese DF-17.[41] However, HGVs are costly and difficult to produce in large numbers; just 12 Avangard launchers across

38. John Stillion and David T Orletsky, *Airbase Vulnerability to Conventional Cruise-Missile and Ballistic-Missile Attacks: Technology, Scenarios, and U.S. Air Force Responses* (Santa Monica, CA: RAND, 1999), p. 12.
39. *Ibid*.
40. Spenser A Warren, 'Avangard and Transatlantic Security', CSIS, 23 September 2020, <https://www.csis.org/blogs/post-soviet-post/avangard-and-transatlantic-security>, accessed 20 March 2025.
41. CSIS Missile Threat, 'DF-17'.

two regiments are planned by Russia for deployment between 2020 and 2027.[42] Russian leaders view HGVs as a means of hedging against potential future improvements in US ballistic missile defences. As such, HGVs are being prioritised for deployment on silo-based intercontinental capabilities, such as the R-36 and RS-28.[43] However, from the late 2030s this may change if Russia has fielded enough hypersonics on intercontinental systems to be confident of its second-strike capability against the US and shifts its focus to the theatre level.

One-Way Attack UAVs

One-way attack UAVs, such as the Iranian-made Shahed-136, are worth mentioning briefly. The limitations of these systems with respect to speed make them a very poor tool for striking targets in the UK. This was illustrated in Iran's April 2024 attack against Israel. The launch of Shahed-136s provided the defending force with 6–7 hours of warning. In many ways, they undercut the employment of cruise and ballistic missiles and led Iran to opt for the exclusive employment of ballistic missiles during its second attack. Limited payloads and stability in wind conditions along the northern vector of attack are further limiting factors. If approaching the UK from the east, UAVs would have to cross a considerable amount of Allied airspace and would probably suffer attrition rates comparable to those that Iran endured in its April 2024 attack – no Shahed-136 reached Israeli airspace due to air-to-air intercepts over Iraq and Jordan.[44]

UAVs still pose a threat. Russia would probably find one-way attack UAVs useful as pathfinders to map Allied radar and to compel the expenditure of more expensive interceptors. However, their employment against targets in the UK is likely to be inefficient and thus relatively unlikely. Some consideration will have to be paid, however, to cost-effective means of interception if these UAVs are used for functions such as terror bombing (the strategic bombing of civilian targets without military value, in the hope of damaging an enemy's morale). Even with a low level of efficiency, they can compel the allocation of disproportionate resources to defensive counterair (DCA) missions.

A final risk worth considering is the use of shorter-ranged one-way attack UAVs launched from ISO containers in a manner comparable to Klub-K – arguably more viable than the use of cruise missiles in containers, given that many UAVs can be packed in a single container in a more nondescript manner. The use of

42. *ТАСС*, « Источник: первые комплексы «Авангард» встанут на боевое дежурство в 2019 году » ['First "Avangard" Missiles to Go Online by 2019'], 28 October 2018, <https://tass.ru/armiya-i-opk/5731436>, accessed 8 July 2025.
43. Amy F Woolf, 'Defence Primer: Hypersonic Glide Vehicles', In Focus, Congressional Research Service, updated 1 November 2024, p. 1, <https://apps.dtic.mil/sti/citations/AD1170009>, accessed 8 July 2025.
44. Uzi Rubin, Speech at RUSI Integrated Air and Missile Defence Conference, London, 18 April 2024.

short-range UAVs by adversary special forces also represents a risk. Since the planning accompanying this kind of use case is likely to be considerable and the options for repeated attempts limited, likely targets will be high-value military assets, implying a requirement for very short-range air defence (VSHORAD) at military facilities to defend against large numbers of lower-cost assets.

The Geography of the Defended Area

Missiles would be launched at the UK from the north, east and/or west of the country. There are different threat vectors for each point. Recognising such differences is important in understanding the differences in the missile types and launch platforms that would probably be faced on each vector. Of course, Russian capabilities would not be isolated to a single vector or be used separately. Indeed, it is likely that they would be coordinated to overwhelm air defences. However, separating a problem into its constituent parts is a necessary pre-condition for analysis.

Threats from the North

In the north, the primary threats posed by the assets held by OSK Sever (the Russian Northern Fleet Joint Strategic Command) are bombers such as the Tu-22M3 and SSNs equipped with cruise missiles. Russia's other strategic bombers, such as the Tu-95 and Tu-160, are not held under OSK Sever. However, they would also probably use the northern route to attack the UK given the amount of defended Allied airspace that would have to be traversed by any missile launched from the east.

Of the threats posed from the northern vector, the SLCM threat is the most dangerous with respect to the challenge that it poses to targets, such as airbases or C2 nodes. Bombers typically undergo a visible process of being loaded and flown to their launch points. For many years, the Alliance has maintained a quick response alert posture in the north. The US's current assumption is that national early-warning systems combining signals intelligence, electronic intelligence and satellite imagery should provide warning of a missile launch several days in advance; the margin of warning time for the employment of strategic bombers is similar.[45] This implies a high degree of Alliance-wide alertness against bombers flying over northern routes and the risk (to Russia) of high attrition rates against both UK and Scandinavian fixed-wing aircraft. The bomber threat is still relevant. However, unless US ISR assets are tasked to

45. Tom Karako and Masao Dahlgren, 'Complex Air Defense: Countering the Hypersonic Missile Threat', CSIS, February 2022, p. 51, <https://www.csis.org/analysis/complex-air-defense-countering-hypersonic-missile-threat>, accessed 8 July 2025.

the Pacific – in a way that implies a complete deprioritisation of NATO – a bomber attack is unlikely to be a complete surprise.[46]

By contrast, an SSGN at sea does not require visible preparations for launch, once underway. Assuming a launch rate comparable to the US's *Ohio*-class, a *Yasen*-class submarine should be able to empty its vertical launch system (VLS) tubes within a minute of receiving an order. From positions in the Norwegian Sea or Atlantic Ocean, a *Yasen*-class SSGN could deliver 40 cruise missiles against a fixed target with relatively low warning (for reference, the Russians appear to have calculated that 60 cruise missiles should be more than sufficient to cripple an airbase).[47] While the presence of multiple SSNs at sea might be a warning indicator, this would be more ambiguous if the tempo of steady-state Russian submarine activity rises over the years and if SSGNs routinely patrol with cruise missile loadouts.

As noted, the bomber threat also poses risks, despite the availability of better early warning. The collective throw-weight of Russia's bombers is estimated to be about 350 cruise missiles in a single salvo (assuming adequate coordination), and air-launched cruise missiles would pose a considerable threat, even assuming the interception of some launch platforms.[48] The distances from which Russian bombers flying over the northern route can launch missiles would stress the sortie generation of intercepting aircraft, such as the Typhoon, even if they were forward-based in Allied territory. This challenge could be mitigated through the forward deployment of aircraft carriers and destroyers. However, this risks imposing conflicting demands on the UK's fifth-generation fighter fleet and carrier strike capability, which might be earmarked for offensive functions in the context of the Deterrence and Defence of the Euro-Atlantic Area family of plans. While the time to target for air-launched cruise missiles would pose challenges for Russia if they were employed against some dynamic targets, such as aircraft, this problem could be offset if the aircraft were trapped on the ground for several hours by a prompt-strike capability, such as an IRBM salvo. Such an

46. Even in this eventuality, systems such as Norway's Globus radar should provide a degree of early warning.
47. William P Houley, 'Making the Case for SSGNs', *USNI Proceedings* (Vol. 125/7/1,157, July 1999); on Russian calculations, see Pavel Ivanov, 'Bearded Tomahawks', *ВПК* (No. 14 (678), April 2017), <https://vpk.name/news/179082_borodatye_tomagavki.html>, accessed 7 July 2025. Ivanov describes the surprise of Russian observers that 60 missiles had not destroyed Shayrat Airbase, an outcome ascribed to the lower payload of the tactical Tomahawk. It should be noted that this assessment may have evolved based on the experience of Ukraine.
48. See Tomas Malmlöf and Johan Engvall, 'Russian Armament Deliveries', in Fredrik Westerlund and Susanne Oxenstierna (eds), *Russian Military Capability in a Ten-year Perspective – 2019* (Stockholm: FOI, 2019), p. 135. Of course, it is unlikely that all bombers would be coordinated against the UK; the figure is meant to illustrate the fact that interceptions of bombers do not eliminate the cruise missile threat.

approach would roughly correspond to how China's People's Liberation Army plans to combine cruise and ballistic missiles in airbase attacks in the Pacific.[49]

Moreover, in the initial period of a conflict, Russia's strategic bombers might operate at somewhat lower risk before an Allied air component was stood up and might achieve surprise, despite the availability of early warning. This would be especially true if the conflict began under the aegis of a large-scale exercise (a notion that Russian planners have entertained since the Soviet era, albeit typically ascribing this intent to opponents), which would make the arming of bombers less of an unambiguous early-warning indicator.[50]

The tail end risk of catastrophic surprise missile attacks on airbases such as Evenes in Norway (which would have shorter warning times and are within range of missiles such as the Kinzhal fired from Russian airspace) would open a significant hole in NATO's northern posture, given the importance of Scandinavian air forces to the northern flank. Given NATO's depth of ground based radar coverage, this is a relatively low probability scenario but historical instances of tactical surprise, despite the availability of sufficient early warning – for example, because information was open to multiple interpretations or was not tactically specific – illustrate that this risk should not be categorically ruled out.[51]

Threats from the West

The threat from the west is closely related to the northern threat. It would be likely to emerge if one or more Russian SSNs/SSGNs slipped through the Greenland–Iceland–UK Gap and launched missiles from unexpected vectors in the Atlantic. When operating, Russian submarines are increasingly quiet, and critical aspects of the Allied approach to anti-submarine warfare may well prove difficult to scale against multiple contacts. As such, this threat is a real possibility.

Additionally, Russian bombers flying over the northern route could launch their cruise missiles from launch points over the Atlantic. This would involve more risks to the launch platform than attacks from the north, since a submarine would have to run the gauntlet of two chokepoints rather than one. However, it cannot be excluded entirely.

49. Thomas Shugart and Javier Gonzalez, 'First Strike: China's Missile Threat to U.S. Bases in Asia', Center for a New American Security, 28 June 2017, p. 15, <https://www.cnas.org/publications/reports/first-strike-chinas-missile-threat-to-u-s-bases-to-asia>, accessed 8 July 2025.
50. On the idea of transition from exercises to operations, see Nate Jones (ed.), *Able Archer 83: The Secret History of a NATO Exercise that Almost Triggered a War* (New York, NY: New Press, 2016).
51. Erik J Dahl, *Intelligence and Surprise Attack: Failure and Success from Pearl Harbour to 9/11* (Washington, DC: Georgetown University Press, 2013).

Threats from the East

The threat from the east is more bounded in the short term; any Russian missile launched from the Baltic Sea or Kaliningrad would have to traverse a considerable amount of defended Allied airspace to reach the UK. There are, however, two possibilities that cannot be ruled out.

The first is that the Russian Baltic Fleet positions some of its vessels (for example, missile-equipped corvettes) forward in the North Sea during an escalating crisis, with orders to launch cruise missiles if a crisis led to conflict. These vessels would be marked and probably quickly sunk, but not necessarily before they launched some of their missiles. The Soviet navy similarly positioned its vessels near US carrier strike groups cheek by jowl in several crises during the Cold War, on the assumption that the ships would be lost if shooting started, but might well be able to fire their anti-ship cruise missiles and remove a target more valuable than themselves.[52] The Russian Baltic Fleet is overmatched by Allied assets and its survivability would probably be limited in a conflict. Consequently, sacrificing some of its vessels to improve Russia's chances of striking a more valuable target might, similarly, be deemed acceptable.

A second threat which might emerge from the east (and perhaps even from shipping lanes to the south) is containerised missiles such as the Klub-K. These are designed to be fired from launchers that are indistinguishable from ISO containers aboard what are ostensibly commercial vessels.[53] Since cruise missiles have to be stored and maintained in temperature-controlled military facilities, the loading of containerised missiles would leave telltale signs, as would any communications with a vessel at sea required to coordinate missile launches. As such, an auxiliary vessel being used in this way would not automatically be indistinguishable from commercial traffic.[54] In a conflict, moreover, any vessel leaving a Russian port would be suspicious. However, in the buildup to a conflict, the possibility of a vessel loaded with containerised cruise missiles escaping identification cannot be excluded and the consequences of even one such vessel launching missiles from an unexpected vector would be considerable given the significant number of missiles that can be loaded on a standard container vessel.[55]

52. Lyle J Goldstein and Yuri M Zhukov, 'A Tale of Two Fleets—A Russian Perspective on the 1973 Naval Standoff in the Mediterranean', *Naval War College Review* (Vol. 57, No. 2, 2004), pp. 22–25.
53. Globalsecurity.com, 'Klub-K Container Launched 3M-54 Klub/Caliber – SS-N-27 Sizzler', <https://www.globalsecurity.org/military/world/russia/club-k.htm#google_vignette>, accessed 18 July 2024.
54. Sidharth Kaushal, 'Optimising the Royal Netherlands Navy for its Role within NATO', *RUSI Whitehall Reports*, 3-24 (December 2024), p. 14, <https://www.rusi.org/explore-our-research/publications/whitehall-reports/optimising-royal-netherlands-navy-its-role-within-nato>, accessed 8 July 2025.
55. T X Hammes and R Robinson Harris, 'Warship Weapons for Merchant Ship Platforms', *USNI Proceedings* (Vol. 151/2/1,464, February 2025).

The Russian IRBM arsenal, which is likely to grow over the next decade and beyond, will pose a risk primarily from the east and northeast, given that most plausible ballistic trajectories fly over this area. As the Russian IRBM arsenal matures in the longer term, the importance of the eastern vector is likely to grow considerably, given that relatively few allies in this direction are likely (based on current European defence plans) to have the capacity to intercept an IRBM en route to the UK.[56] While BMD is a subject of growing interest in much of Europe, most solutions that are being explored are terminal-phase solutions that can protect critical targets on a state's own territory, but not provide coverage against a ballistic missile overflying a country's territory en route to another target.

Fixed-Wing Threats

Given the limitations of the VKS, the air and missile threats have been treated in this paper as effectively synonymous. However, the emergence of very-low observable uncrewed combat aerial vehicles (UCAVs), such as the Su-70 Okhotnik, could upend this dynamic. With no pilot, UCAVs can be built in shapes that are relatively stealthy. These would not be viable for a crewed system and would allow them to be used over longer distances.

The UCAV threat is not fundamentally different from the threat posed by other air assets against which DCA occurs. However, the risk that it poses to both tankers and fixed radar will further complicate the task of DCA, particularly at reach, given the long unrefuelled ranges of these aircraft. Elements of the VKS air threat, such as the Su-70 and Su-57, will probably take time to field at scale but will complicate the task of intercepting bombers by presenting a credible 4.5-generation threat to aircraft involved in DCA. The addition of low RCS (radar cross-section) aircraft – that may be optimised for different bands of the radar spectrum – will reinforce the requirement for multiple sensors to be integrated into the IAMD network.

56. Germany is an exception. It could, in principle, have this capability in the form of the Arrow-3 missile, which it is procuring from Israel.

II. The UK's IAMD Capabilities and Gaps in its Defensive Architecture

Existing IAMD Capabilities

The UK currently fields several capabilities across its frontline commands that are relevant to defence against different missile types. The RAF (which would have primary responsibility for coordinating IAMD under both UK and NATO doctrine) directly controls fixed-wing aircraft, such as the Typhoon and the F-35. These can employ air-to-air interceptors against cruise missiles. It also controls platforms such as the E-7 Wedgetail early-warning aircraft, which would be important for tracking them. The Wedgetail would be particularly important for tracking low-observable targets over the seas surrounding the UK. This is because the early detection, at long ranges, of low-flying low-observable objects over the Norwegian Sea or the Atlantic Ocean would, to a substantial degree, depend on the L-band radar on the E-7. The RAF also operates the UK's remote radar heads – surface-based S-band and L-band radar deployed on the UK's coastlines. These feed into the Guardian C2 system and provide a recognised air picture over the UK. These radars will be important to the detection of cruise missiles and other air-breathing threats, although the horizon limits their capability – and surface-based radar in general – against low-flying objects. As an ageing capability, they will also probably need to be replaced relatively soon. Long-range early warning systems, such as the UHF radar at RAF Fylingdales, are also RAF assets.

The Royal Navy also has medium- and long-range air defence capabilities. These are held on the Type 45 destroyers that employ both L- and S-band radars (the S180M and Sampson), and are capable of engaging both cruise missiles and ballistic targets.[57] The Type 45 destroyer is currently equipped with the Aster

57. Medium-range air defence capabilities have ranges of 18–90 km (10–50 nautical miles), while long-range air defence systems have ranges above 90 km (50 nautical miles). See Chiefs of Staff, 'Joint Air Defence', Joint Warfare Publication 3-63, Joint Doctrine and Concepts Centre, 2003, <https://assets.publishing.service.gov.uk/media/5c814432e5274a2a5d70cd2c/archive_doctrine_uk_joint_air_defence_jwp_3_63.pdf>, accessed 7 July 2025. Although this publication has been withdrawn, it has not been superseded and therefore its definitions are the most current ones available. They remain consistent with Allied

15 and Aster 30 missiles and can engage air-breathing targets at maximum ranges of 30 km and 120 km, respectively (although real effective ranges are significantly lower than the kinematic qualities of a missile suggest, given the challenges of target tracking). They will be equipped with the Aster 301NT, which can intercept medium-range ballistic missiles in their terminal phase. At the time of writing, the Royal Navy is also the only part of the Joint Force that is scheduled to employ a BMD-capable interceptor as part of the Sea Viper Evolution Programme, albeit one which is optimised against short- and medium-range threats. This would be relevant against a threat such as the Kinzhal, although future variants of the Aster series would need to be deployed if the Type 45 and Type 83 are to be employable against the Oreshnik.

The British Army's Sky Sabre ground-based air defence system can provide point defence out to 25 km against air-breathing threats using the common anti-air modular missile (CAMM). The CAMM is also being introduced on the Type 45 as a replacement for Aster 15.[58] The system's GAMB (Giraffe Agile Multibeam) radar can, under certain circumstances, generate tracks against cruise missiles beyond the ranges at which it can currently intercept them (although this depends on factors such as target altitude).

Gaps in the UK's IAMD Architecture

The UK's most pressing challenge is capacity in key areas. Capacity constraints would force trade-offs between deploying capabilities in alignment with the NATO force model and national defence. For example, the RAF's currently planned procurement of three E-7 Wedgetails (down from a planned five) is insufficient to guarantee a round-the-clock orbit on station.[59] Without an E-7 on station, early warning against cruise missiles and their discrimination from maritime clutter becomes considerably more difficult. In turn, this limits the effectiveness of a Typhoon combat air patrol, although this is partly mitigated by the ability to rely on Allied capability. The longer ranges at which Russian bombers would launch cruise missiles would impact the operational tempo of the defending force. This limits the extent to which engaging launch platforms, rather than missiles, could be relied on as the preferred mode of defence. In the future, it must be assumed that intercepting missiles over water will become a

definitions. See *Navy Lookout*, 'Upgrading the Royal Navy's Type 45 Destroyers', 4 April 2022, <https://www.navylookout.com/upgrading-the-royal-navys-type-45-destroyers/>, accessed 6 December 2024.

58. Tom Dunlop, 'UK Signs for Aster Block 1 Anti-Ballistic Missile Weapons', *UK Defence Journal*, 13 December 2022, <https://ukdefencejournal.org.uk/uk-signs-for-aster-30-block-1-anti-ballistic-missile-weapons/>, accessed 1 December 2024.

59. Justin Bronk, 'US Air Force Request for Funds to Buy E-7 Should Prompt a Rethink on RAF Fleet Size', *RUSI Commentary*, 4 May 2022, <https://rusi.org/explore-our-research/publications/commentary/us-air-force-request-funds-buy-e-7-should-prompt-rethink-raf-fleet-size>, accessed 7 July 2025.

more prominent feature of defensive counterair missions protecting the UK. In this context, managing the consequences of the limited availability of platforms such as the E-7 will become even more challenging.

In a similar vein, the Royal Navy can force-generate two to three Type 45 destroyers. During a crisis where the Alliance wished to deploy a carrier strike group for deterrence (much as it did during the early stages of the war in Ukraine), the UK would face a choice between stripping the homeland of some of its air and missile defence capability and being unable to deploy a carrier strike group on a sovereign basis. This trade-off would not be unmanageable. For example, if Allied capacity is available, protection of the aircraft carrier might be provided by non-UK assets. However, given that relatively few navies in NATO deploy medium-range BMD interceptors (and the likely existence of an anti-ship ballistic missile threat to the carrier), planning will be challenging.[60] Additional capacity from the Type 45 fleet might also be generated on an accelerated basis by accepting shorter workup periods for vessels tasked with homeland defence and crewing them on a leaner basis than those tasked with expeditionary activity, given that most crewing requirements are baselined against this latter task and vessels being used for homeland defence could be crewed on a leaner basis.[61] Even if these arrangements ensure that one or two additional Type 45 destroyers can be made available for homeland defence in a crisis (assuming that at least two will always be in maintenance and deep refit), this is still a limited number of vessels.

The British Army, with its five–six Sky Sabre systems, would face similarly conflicting demands (at the time of writing) between the defence of the Allied Rapid Reaction Corps (to which 7 Air Defence Group is currently subordinated) and the provision of ground-based air defences to critical military infrastructure in the UK.[62]

There is also a question of what the UK owes the Alliance under the NATO Defence Planning Process. While not publicly available, this might involve trade-offs with homeland defence if the Alliance requires key maritime and air platforms to be placed under Supreme Allied Commander Europe early in a crisis. It is also conceivable that a crisis in Europe might be preceded by one elsewhere (perhaps exacerbated by Russia). This would require the deployment

60. Currently, of European navies, only the Royal Navy employs a BMD-capable interceptor. See *Navy Lookout*, 'What is the State of Royal Navy Anti-Ballistic Missile Capability?', 7 October 2024, <https://www.navylookout.com/what-is-the-state-of-royal-navy-anti-ballistic-missile-capability/>, accessed 6 December 2024.
61. Kaushal, 'Optimising the Royal Netherlands Navy for its Role within NATO'.
62. John Hill, 'Analysis: Why Must the UK Repurpose Its Ground-Based Air Defences?', *Army Technology*, 29 April 2024, <https://www.army-technology.com/news/analysis-why-must-the-uk-reprioritise-its-ground-based-air-defence/>, accessed 7 July 2025; L Paul James, 'Rethink Navy Ballistic Missile Defense', *USNI Proceedings* (Vol. 145/10/1,400, October 2019).

of maritime and air platforms that would be out of position at the onset of a European conflict. An illustrative example might be the crisis in the Red Sea and the allegations that Russia has considered transferring anti-ship cruise missiles to Yemen's Houthis (Ansarallah).[63]

The final consideration is that as the threat evolves in the medium term from one centred on cruise missiles to one encompassing both cruise and ballistic missiles, and eventually HGVs, the UK will require an answer to a potentially much more complex threat. It currently lacks both the number of sensors and necessary effectors to address these challenges.

63. Andrew McGregor, 'Russia Considers Supplying Anti-Ship Missiles to Ansarallah', *Eurasia Daily Monitor* (Vol. 21, No. 121, 6 August 2024).

III. The Way Forward: A Sequenced Approach

The full spectrum of capabilities needed to meet the challenges outlined is unlikely to emerge quickly given both budget considerations and the time taken to field any system. However, since different parts of the air and missile threat spectrum will become acute threats at different times, the Ministry of Defence can sequence its efforts to enhance the defence of the homeland out to 2040 in ways that allocate resources adroitly. Broadly speaking, a sequenced model to enhance the UK's capacity for homeland IAMD might proceed in three phases:

1. Enhancing national air defence against cruise missiles – including hypersonic cruise missiles – by 2030 and ensuring that Guardian can incorporate new capabilities that may not become available until later.
2. Providing limited coverage against medium- and intermediate-range ballistic targets by the late 2030s.
3. Providing wider national coverage against ballistic targets and the capacity to intercept HGVs in the 2040s.

Given the need to prioritise, this paper outlines a sequenced approach that emphasises incremental improvements to national defences against air-breathing targets out to 2035, followed by a pivot to defences against ballistic targets by the end of the 2030s, and HGVs beyond the 2030s. Optimising the approach in this way involves incurring risk at different periods. For example, deciding to focus primarily on cruise missiles in the short term carries risks if the Russian ballistic threat develops much faster than described earlier. However, since the development of an IAMD capability is a time-consuming process – occurring in the context of potential resource constraints – sequencing commitments is an important means of mitigating other programmatic risks, such as the possibility that an overambitious approach is either underfunded or results in several individually poorly funded lines of effort.

Phase 1: Enhancing National Cruise Missile Defence and Using the UK's C2 Architecture to Include Future Capabilities

The primary threat that can be launched against the UK at comparatively safe distances is subsonic submarine- and air-launched cruise missiles. Therefore, the most immediate challenge for homeland IAMD is, as mentioned, the paucity of elevated L-band sensors that can detect cruise missiles skimming over the sea at greater distances than can be provided by the UK's remote radar heads, which are constrained by the Earth's curvature against lower flying targets.

In principle, the UK's Typhoon fleet can conduct air-to-air intercepts against cruise missiles using AIM-132 ASRAAM and potentially AIM-120 AMRAAM interceptors, much as it did during the April 2024 attack on Israel. However, the tracking of cruise missiles in dynamic maritime clutter – particularly in high sea conditions – will pose a considerable challenge. This is particularly the case for the Captor-M and future ECRS MK II radar. They are not publicly known to have been optimised for maritime clutter rejection, unlike the AN/APG-65 radar on dedicated naval aircraft, such as the F/A-18.[64]

Even if publicly available information does not reflect the capabilities of Captor-M and ECRS MK II (clutter rejection for a final engagement is a feature of most modern radar), it remains the case that long-range detection provided by a lower-frequency L-band radar is critical to early detection and thus the timely vectoring of fighter aircraft to a range from which they can launch effectors. In this context, the relatively low number of E-7 Wedgetails is a considerable challenge, given the multiple vectors from which Russian submarines and bombers might fire cruise missiles at the UK.

Options for Enhancing Early Detection and Tracking of Low-Flying Threats

Option 1: Additional AWACS

One solution might be to revert to the UK government's original decision to procure five AWACS. This would be reasonable. However, the ability to maintain a single aircraft on round-the-clock patrol would not necessarily be sufficient

64. On the F/A-18, see Forecast International, 'AN-APG/65', October 2004, <https://www.forecastinternational.com/archive/disp_pdf.cfm?DACH_RECNO=726>, accessed 4 December 2024.

to both patrol the multiple vectors (particularly the north and west) from which missiles might strike the UK homeland, and contribute to other air force missions in the context of an escalating crisis, such as one leading to Article 4 being invoked (which might require the UK to support a greater tempo of activity in the north, for example). One answer might be the procurement of additional AWACS (over the five needed to maintain a single round-the-clock orbit). However, this would both involve significant costs (at £630 million per aircraft), as well as impose burdens for operations and maintenance.[65] That said, the E-7 is a proven capability that the RAF is preparing to operate in any case; additional AWACS would also be useful to NATO as a whole, even once the air and missile threat to the UK in the initial period of war has been mitigated. As a capability, it thus has a value that extends beyond homeland IAMD. It should be noted that Allied AWACs will also be available in most contingencies.

Option 2: Over-The-Horizon Backscatter Early-Warning Radar

An alternative means of ensuring the better employment of the E-7 would be to rely on longer-range early warning. This would rationalise the employment of the E-7 fleet. Persistent early warning at sufficiently long ranges can allow an aircraft such as the E-7 to be flown when a threat is identified, mitigating the impact of a lack of round-the-clock orbit. If the problem of false positives could be resolved, long-range early-warning capabilities could also be used as a means of tracking targets that can be launched with very little prior warning (such as submarine-launched cruise missiles launched from the Atlantic Ocean).

An early-warning system could comprise over-the-horizon backscatter (OTH-B) radar, such as those used as part of the Australian Jindalee network (which can monitor air and sea movements across 37,000 sq km). OTH radar typically works by bouncing ultra-high frequency waves off the Earth's ionosphere. This allows such radars to detect targets at ranges of over 3,000 km. These radars do not generate particularly granular returns, and so cannot be employed for track and engagement. However, they can allow for targets of interest to be identified based on factors such as their Doppler radar returns. While maritime clutter and the false positives that it generates have typically posed a problem for OTH-B radar, software advances are making it increasingly viable to sift false positives from returns. Several states, including the US, envision employing OTH-B radar for cruise missile defence over maritime approaches.[66] If software-defined solutions allow OTH radar to be used for track, rather than just early warning,

65. Richard Thomas, 'Latest Figures Show UK E-7 Wedgetails Will Cost £630m Apiece', *Airforce Technology*, 14 December 2022, <https://www.airforce-technology.com/features/latest-figures-show-uk-e7-wedgetails-will-cost-630m-apiece/>, accessed 7 July 2025.
66. David Roza, 'How the Ionosphere Can Help NORAD Detect Cruise Missiles Faster', *Air and Space Forces*, 5 September 2023, <https://www.airandspaceforces.com/norad-over-the-horizon-radar/>, accessed 7 July 2025.

these radars can perform some of the vectoring functions that an AWACS currently plays. Even if this proves more distant, the long-range detection that OTH-B radar provides allows for the rational use of a limited E-7 fleet. By providing sufficient warning time and early tracking, AWACS can be sortied and vectored towards approaches as needed rather than maintaining round-the-clock sorties.

In addition, OTH-B provides a sensing layer that complements the assets of countries such as Norway. By virtue of backscatter dynamics, radars can deliver a top-down and bottom-up look at low-RCS targets and would therefore be of use against future air-breathing threats, such as the stealth uncrewed combat aerial vehicle, Okhotnik.

OTH radar would complement Allied capabilities. OTH-B radar is operated by NATO members, such as France, which operates the Nostradamus radar to track low-observable targets. OTH-B radar works by focusing beams sequentially over individual parts of an area. This means that their scan rates are relatively slow.[67] The addition of a second OTH-B radar to the Alliance would improve the rates at which the recognised air picture of both the UK and France are refreshed in areas such as the Atlantic. It could also create a degree of resilience in the face of possible attack or disruption in any one country by, for example, Russian special operations forces (which may have recently demonstrated capacity to operate as saboteurs in Europe).[68] Similarly, it is worth noting that Russian bombers have practised early attacks for the suppression of radar systems, such as against the Globus II radar in Norway.[69] As such, OTH-B radar could provide a degree of redundancy for the early-warning systems of Scandinavian countries.

It might be assumed that fixed radar is an appealing target for other modes of attack, such as ballistic missiles or drones. However, UAV and missile attacks would need to damage a relatively large number of spatially separated transmitter or receiver arrays – which are often buried, as in the case of the French Nostradamus – to cripple an OTH radar system. In any event, generators and control centres can be hardened.

The OTH-B system's minimum range of roughly 1,000 km (given the incident angles of waves with the ionosphere) is a major limitation. This excludes coverage of some positions from which SLCMs could be launched against the UK, such

67. Tom Karako et al., 'North America is a Region, Too: An Integrated, Phased, and Affordable Approach to Air Defence for the Homeland', CSIS Missile Threat, 14 July 2022, <https://missilethreat.csis.org/north-america-is-a-region-too-an-integrated-phased-and-affordable-approach-to-air-and-missile-defense-for-the-homeland/>, accessed 8 July 2025.
68. *The Economist*, 'Russia is Ramping up Sabotage Across Europe', 18 May 2024.
69. Joseph Trevithick, 'Norway Says Russian Aircraft Ran Mock Attacks on a Secretive Radar Base', *War Zone*, updated 30 June 2019, <https://www.twz.com/19047/norway-says-russian-aircraft-ran-mock-attacks-on-a-secretive-radar-base>, accessed 7 July 2025.

as the deeper waters north of Ireland.[70] That said, a UK OTH radar could complement the French Nostradamus since, depending on its location, each radar could cover the blind spots created by the other's minimum range and their different arcs of coverage.

Option 3: Alternative Elevated Sensors

An alternative solution for both early warning and engagement might use elevated sensors. This would emulate the US's JLENS (Joint Land Attack Cruise Missile Defense Elevated Netted Sensor System) programme, which envisioned the employment of radar on tethered aerostats. This would itself be linked to other IAMD assets via the cooperative engagement capability, developed as part of the Navy Integrated Fire Control – Counter Air (NIFC-CA) programme.[71] Given the radius of detection of an aerostat-mounted radar against low-flying targets is about 500 km, a network of four aerostats could provide medium-range coverage of incoming threats from the northern, eastern and western sectors. The unit costs of tethered aerostat-based radar are not much lower than an E-7 (an estimated $500 million per aerostat). However, their operations and maintenance costs are a tenth of those of an AWACS.[72] A system comparable to JLENS with an L-band radar could provide situational awareness out to 500 km to enable intercepts by Typhoon patrols against cruise missiles as they approached the UK.

A cooperative engagement capability (CEC) would be required. Moreover, high speed datalinks are often short range. Such a constraint might pose a challenge for networking a coastal aerostat and a Typhoon over 100 km away. However, a Link 16 data link network could also be used in this role; it has been used for NATO BMD and to link the E2-D and F/A-18 for NIFC-CA.[73]

A CEC similar to NIFC-CA – linking an aerostat-based solution to platforms carrying effectors, such as ground-based surface-to-air missile (SAM) systems or nearby destroyers – would come at an additional cost. Yet, CEC is a capability that is, in any case, required across the Joint Force. Its absence from the UK's carrier strike group, for example, significantly increases the number of aircraft that must be committed to combat air patrols.[74] As such, the additional cost of

70. Thayananthan Thayaparan et al., 'Extracting the Parameters for Sky Wave Over the Horizon Radar Using Ray Tracing from a Model of the Atmosphere', Defence Research and Development Canada, 2019, p. 7, <https://cradpdf.drdc-rddc.gc.ca/PDFS/unc342/p811300_A1b.pdf>, accessed 7 July 2025.
71. Forecast International, 'JLENS', November 2018, <https://www.forecastinternational.com/archive/disp_pdf.cfm?DACH_RECNO=1347>, accessed 28 November 2024.
72. See Congressional Budget Office, 'National Cruise Missile Defence: Issues and Alternatives', February 2021, <https://www.cbo.gov/publication/56950>, accessed 8 July 2025.
73. Nicholas A O'Donoughue, Samantha McBirney and Brian Persons, *Distributed Kill Chains: Drawing Insights for Mosaic Warfare from the Immune System and from the Navy* (Santa Monica, CA: RAND, 2021), p. 48.
74. Justin Bronk, 'Maximum Value from the F-35: Harnessing Transformational Fifth-Generation Capabilities for the UK Military', *RUSI Whitehall Reports*, 1-16 (February 2016), <https://www.rusi.org/explore-our-

a cooperative engagement capability might be seen less as a cost imposed on the Joint Force by the requirements of IAMD, and more as a Joint Force enabler that is relevant to IAMD.

Option 4: Space-Based Sensors

Space-based sensors have limited immediate use against subsonic cruise missiles, although work in this area may provide longer-term advantages. If radar-based solutions were used, propagation losses over long distances would impose considerable power, and thus weight, requirements on satellites in the lower Earth orbit. Moreover, a considerable number of satellites are needed to ensure persistent coverage over even a small area – 24 satellites, for example, would provide only intermittent coverage over an area the size of North Korea.[75]

Infrared sensors can be employed on geostationary satellites, such as the US Space-based Infrared System (SBIRS). These cover much larger areas and detect the launches of ballistic missiles and HGVs. However, currently, such systems are of limited utility against cruise missiles, given the dim infrared signatures of their boosters. However, it is worth noting that the US is currently exploring updating the software on its Overhead Persistent Infrared (OPIR) satellites (the successor to SBIRS) to enable the early detection of faster supersonic and hypersonic cruise missiles that have larger infrared signatures than subsonic ones. If the US allows a willing UK to participate in collaborative research in this area – much as it did with several Strategic Defense Initiative (SDI) programmes in the 1980s – there may be opportunities for the UK to buy in to the short-term and medium-to long-term programme should the technology mature.[76] Collaboration with the US and Australia in the area of counter-hypersonics is already intended to be a part of AUKUS Pillar 2. So, the possibility of trilateral participation in OPIR might be explored as neither the UK nor Australia can necessarily afford to launch enough satellites to maintain persistent surveillance. However, they could conceivably participate in OPIR and potentially contribute to its planned successor which will focus on systems in the medium and lower Earth orbit with greater redundancy.[77]

research/publications/whitehall-reports/maximum-value-f-35-harnessing-transformational-fifth-generation-capabilities-uk-military>, accessed 7 July 2025.

75. Thomas G Roberts, 'What Can 24 Satellites do for U.S. Missile Defence?', CSIS, October 2018, <https://www.csis.org/analysis/what-can-24-satellites-do-us-missile-defense>, accessed 8 July 2025.

76. Courtney Albon, 'SDA Seeking New Algorithms to Boost OPIR Target Recognition, Acquisition', *Inside Defence*, 11 March 2021, <https://insidedefense.com/insider/sda-seeking-new-algorithms-boost-opir-target-recognition-acquisition>, accessed 7 July 2025; Jeremy Stocker, *Britain and Ballistic Missile Defence: 1942-2002* (London: Frank Cass, 2005), pp. 153–60.

77. Theresa Hitchens, 'Space Force Phasing out Missile Warning from GEO, Will Focus on Lower Orbits', *Breaking Defense*, 21 September 2022, <https://breakingdefense.com/2022/09/space-force-phasing-out-missile-warning-from-geo-will-focus-on-lower-orbits/>, accessed 8 July 2025.

Infrared sensors may be especially well suited to provide early detection of hypersonic cruise missiles. Such missiles must be accelerated to supersonic speeds at which a scramjet engine operates by a booster that is typically similar to that on a ballistic missile (for example, the X-51A Waverider used the booster from an ATACMS for this purpose).[78]

Participation in the research that supports programmes such as OPIR – either through AUKUS or bespoke memorandums of understanding with the US, such as those used for SDI research during the 1980s – may serve as both a basis for validating technology and as a foundation for future programme buy in.

The Requirement for Additional Surface-Based Air and Missile Defences

The second consideration is surface-based effectors. An outer screen of aircraft can be expected to attrit a cruise missile salvo. However, a single-layer air defence system lacks redundancy.

Missiles such as the AIM-120 and the ASRAAM have performed well against cruise missiles in both the war in Ukraine (when fired from NASAMS batteries) and the Iranian attack on Israel in April 2024, notwithstanding noteworthy contextual differences.[79] In Ukraine, interceptors have generally been fired from ground-based batteries with their seekers tracking missiles against the sky from below the missile. This removes the problem of clutter. The defence against the Iranian attack of April 2024 involved interceptors fired from aircraft that were tracking missiles against ground clutter, but not dynamic maritime clutter. In the Red Sea, F/A-18s equipped with AIM-9X and AIM-120 have performed well against maritime clutter. However, these were part of a layered system where many intercepts were conducted by Aegis destroyers and in more modest sea conditions than those of the Norwegian Sea and Atlantic Ocean.[80] The experience of combating Western SAM systems, such as IRIS-T, in Ukraine has led Russia to incorporate countermeasures including infrared decoys on missiles such as the KH-101. It is therefore likely that the relative effectiveness of Russian missiles in evading air defence interceptors will increase. It is also likely that in higher sea states – which create more dynamic maritime clutter – the effectiveness of missile seekers against complex low-flying targets may be reduced, and at least

78. Jeffrey Lane, 'Design Processes and Criteria for the X-51A Vehicle Airframe', NATO, pp. 1.7-1–14, <https://apps.dtic.mil/sti/citations/ADA478731>, accessed 8 July 2025.
79. See *Reuters*, 'NASAMS Air Defense System Have 100% Success Rate in Ukraine- Pentagon Chief', 16 November 2022.
80. See *Global Defense News*, 'F/A-18 in Red Sea Anticipates Houthis Confrontation Take Off Full Air-to Air Configuration', 14 May 2024, <https://armyrecognition.com/news/aerospace-news/2024/f-a-18-in-red-sea-anticipate-houthis-confrontation-take-off-full-air-to-air-configuration>, accessed 7 July 2025.

some missiles would leak through the first defensive layers comprising aircraft, particularly if initial salvo sizes were large.

As such, there will probably be a requirement for some form of surface-based inner layer of defence. There are several options available. These can broadly be subdivided into options for point defence (involving the protection of a specific site, such as an airbase) and area defence (involving using either medium- or long-range air defence to provide coverage over a wider area). Medium-range SAMs have a range of between 18 and 90 km, while long-range SAMs have a range greater than 90 km.[81]

Area defence has the advantage of providing coverage to a wider range of targets as well as enabling a 'shoot, look, shoot' approach. This involves a second interceptor being fired after observing the impact of an initial intercept attempt. This is unlike point defence, when interceptors often must be ripple-fired. Despite the higher cost of longer-range air defence interceptors, most operational analysis suggests that – as interceptors are not conserved – point defence is the more resource-intensive.[82] Several European Allied countries either possess or are procuring long-range SAM systems. For example, Finland has concluded the purchase of the Israeli David's Sling system, which has a maximum range of 300 km against air-breathing targets.[83] Similarly, Germany has commenced the licensed production of PAC 2 GEM-T missiles, which have a range greater than 120 km.[84] The Aster 30, currently employed on the Royal Navy's Type 45 destroyers, has a maximum range of 120 km and is employed by allies such as France on the ground-based SAMP/T SAM system. Although the maximum ranges of missiles are rarely achieved in real world conditions, given the limitations of the radar horizon, networking surface-based SAMs with air- or aerostat-based radar could enable longer-range interceptions.

While it is unlikely that the entirety of the UK can be covered using long-range SAM systems, the function of area air defences is often to canalise a threat and provide more time for other response mechanisms. As an example, consider the hypothetical case of a SAM system with a 120-km range deployed in Cornwall defending against a submarine-launched Kalibr launched from the southwest and aimed at RAF Marham. A cruise missile could manoeuvre around the SAM

81. Chiefs of Staff, 'Joint Air Defence'.
82. Eric V Larson and Glenn A Kent, *A New Methodology for Assessing Multilayer Missile Defence Options* (Santa Monica, CA: RAND, 1994).
83. Emanuel Fabian, 'Israel Signs Landmark Deal to Sell David's Sling Air Defense System to Finland', *Times of Israel*, 12 November 2023, <https://www.timesofisrael.com/israel-signs-landmark-deal-to-sell-davids-sling-air-defense-system-to-finland/>, accessed 7 July 2025.
84. *Global Defense News*, 'Germany Enhances Patriot Missile Production Capacity with New MBDA Facility in Europe', 19 November 2024, <https://armyrecognition.com/news/army-news/army-news-2024/germany-enhances-patriot-missile-production-capacity-with-new-mbda-facility-in-europe>, accessed 7 July 2025.

envelope but at a cost in terms of time to target. This could allow additional fighter aircraft to be sortied to intercept it.

The procurement of longer-range SAM systems is also potentially valuable for delivering the British Army's requirement to provide a reserve corps to NATO. Under the emerging NATO force model, the army, in a reserve corps role, will be required to provide all the enablers involved in the defence of the Allied Rapid Reaction Corps. This includes defence against tactical ballistic missiles, such as the 9M723 Iskander. Many long-range interceptors – such as Aster 30 1NT, PAC-3 and (to a lesser degree) PAC-2 GEM-T – provide some coverage against tactical ballistic missiles. The same capabilities that can enhance the defence of the homeland in the initial period of a conflict can be employed to defend fielded forces as a conflict develops.

There are two avenues through which longer-range air defences can be generated. The first entails the procurement of available off-the-shelf systems, potentially through a framework such as the German-led European Sky Shield Initiative. The UK intends to participate in this initiative, although the extent remains to be clarified.[85] The advantage of this approach is the speed at which off-the-shelf systems can be procured. There is a further medium-term opportunity to participate in the licensed production of systems such as PAC-2 in Europe, or, at a minimum, to benefit from the capacity being developed to field the system at scale. Other off-the-shelf options include systems developed by other states – such as Israel's David's Sling system described above. However, the integration of non-NATO systems into the NATO air defence architecture may raise security considerations. France has noted these concerns, although it is not universally accepted given the procurements that other allies have made.[86]

Alternatively, the UK could seek to field a domestic ground-based system such as the French SAMP/T. A domestic air defence system could, for example, employ the 100-km extended-range version of the Common Anti-Air Modular Missile (CAMM) which is currently being co-developed with Poland (called CAMM-MR).[87] Adopting an extended-range variant of CAMM as part of an incremental increase in the capability of the Sky Sabre system would afford advantages: both for operators who gain system familiarity, and for cross-service component commonality. Operator familiarity represents a particular advantage, since training on new systems can impose burdens across the force. Training to

85. Claire Mills and Nigel Walker, 'European Sky Shield Initiative', House of Commons Library Debate Pack, CDP-0154, 22 November 2024, p. 5.
86. Jean Auran, 'European Ground-Based Air Defence Programmes', European Security and Defence, 28 July 2023, <https://euro-sd.com/2023/07/articles/32874/european-ground-based-air-defence-programmes/>, accessed 7 July 2025.
87. Tom Dunlop, 'MBDA and PGZ Collaborate on CAMM-MR Missile Development', *UK Defence Journal*, 28 September 2023, <https://ukdefencejournal.org.uk/mbda-and-pgz-collaborate-on-new-camm-mr-missile-development/>, accessed 7 July 2025.

operate the fire control system on a Patriot battery, for example, is a 20-week process. Its deployment would both increase the time allocated to training for a limited pool of operators and increase demands in other areas, such as maintenance (where 50 weeks are needed to certify an individual).[88] This would be true of any other system discussed in this area. By contrast, a variant of a missile that is compatible with Sky Sabre and thus its MIC4AD battle management system could be more rapidly integrated into 16th Regiment.

The disadvantage of CAMM-MR is that, as currently designed, it offers no protection against tactical ballistic missiles. If, as a conflict developed, its role is repurposed from homeland defence to defending the fielded force, the missile would not provide the Allied Rapid Reaction Corps with defences against tactical ballistic missiles. This does not mean the missile lacks utility as a solution (especially as the UK fields no tactical ground-based BMD), but it would mean that if a UK BMD solution for ARRC were needed, an alternative would have to be found. A requirement for a version of CAMM with a hit-to-kill warhead could be introduced into the programme. However, this would exceed the requirements of partners such as Poland, which will operate PAC-3 in a BMD role. As such, the UK would either insert a separate requirement into the CAMM programme or accept that it would rely on allies for tactical BMD. Additionally, existing facilities in the UK service multiple complex weapons pipelines. This creates capacity limitations that would need to be overcome. This would probably be achieved by expanding facilities – to some extent this is occurring.[89]

In addition to longer-range systems, a point defence system – such as the Phalanx or the DragonFire directed energy weapon – could provide a low cost-per-shot last line of defence at ranges of a few kilometres from critical facilities.[90] The DragonFire is currently being integrated on Royal Navy vessels. To destroy targets such as cruise missiles at longer ranges, directed energy weapons would need a power output greater than 50 kw (that is, greater than the output of the DragonFire). This is arguably most easily achievable around fixed sites, where access to power is not a consideration. Fixed SHORAD and VSHORAD solutions would also mitigate the threat posed by UAVs employed from near critical sites.

In addition to capability choices, the UK will need to grapple with (irrespective of which option it opts for) the question of how new capabilities are integrated into 7 Air Defence Group, which is currently a limited force of two regiments

88. Andrew Feickert, 'PATRIOT Air and Missile Defense System for Ukraine', Congressional Research Service, updated 18 January 2023, p. 2, <https://sgp.fas.org/crs/row/IF12297.pdf>, accessed 8 July 2025.
89. Joe Harrigan, 'Bolton Based MBDA "To Increase Workforce Threefold"', *Bolton News*, 7 January 2024, <https://www.theboltonnews.co.uk/news/24831362.bolton-based-mbda-to-increase-workforce-threefold/>, accessed 7 July 2025.
90. See Kristin Houser, 'The UK Test-Fires its First High-Energy Laser Weapon', *Freethink*, 17 November 2022, <https://www.freethink.com/futurology/laser-weapon>, accessed 6 December 2024.

(12th and 16th), with a third regiment of reservists. It is tasked with the full spectrum of air defence from VSHORAD to medium-range air defence (MRAD). There are two models that might be adopted.

The first might emulate the French air force's four escadrons de défense sol-air (EDSA; ground-to-air defence squadrons), which are numerically comparable to 7 Air Defence Group. However, they operate both SHORAD systems (Crotale) and MRAD/BMD systems (Aster 30). To achieve this, the air force (which operates the squadrons) divested itself of VSHORAD: Mistral VSHORAD systems were distributed among artillery regiments.[91] 7 Air Defence group's two regiments could be reallocated to MRAD (using Sky Sabre), long-range air defence and tactical BMD (using a new system). Distributing the VSHORAD solution that replaces the Stormer military armoured vehicle – either to other parts of the Royal Artillery or the manoeuvre units that will primarily rely on VSHORAD – is, in principle, possible, particularly so since the British Army's future VSHORAD solution is meant to be based on a variant of the future medium-protected vehicle family, implying a degree of component commonality for, for example, field maintenance.[92] This would impose a requirement for more personnel across the force to be certified in VSHORAD systems. The training burden involving, among other things, 1,000 successful defensive attempts on a simulator, is time consuming. That said, this is already true of the man-portable variants of systems such as the High Velocity Missile – mounted on Stormer – for which certified personnel exist across the force.

Alternatively, a structure comparable to the Netherlands' Defence Ground-Based Air Defence Command – an amalgamation of elements of the Netherlands army and air force – might be considered. The command operates capabilities along the spectrum of air defence, from longer-range systems such as Patriot to shorter-range Stinger missiles.[93] Force protection-oriented units such as the RAF regiment (which operated Rapier squadrons until 2008) could contribute to a joint capability. This would involve units, such as the RAF regiment, reducing their emphasis on other roles relevant to the defence of air bases – at least to an extent. This should be done carefully given the plausible close-range threat from the Russian special services. However, the threat to rear areas from missiles is less well-resourced than defence against adversary special operations forces to which multiple units and agencies contribute; certifying part of the force for the

91. Jean Pierre Petit, *Un siècle de défense sol-air française* [*A Century of France's Ground-Based Air Defence*] (Paris: CICDE, 2013), pp. 70–77.
92. Sonny Butterworth and Christopher Petrov, 'IAV 2024: British Army Mulls Procurement of Interim SHORAD System', *Janes*, 31 January 2024, <https://www.janes.com/osint-insights/defence-news/land/iav-2024-british-army-mulls-procurement-of-interim-shorad-system>, accessed 7 July 2025.
93. Royal Netherlands Army, 'Defence Ground-Based Air Defence Command', <https://english.defensie.nl/organisation/army/units/defence-ground-based-air-defence-command>, accessed 7 July 2025.

operation of air defence systems could allow for capacity to be expanded, as in the Netherlands' model.

C2: Building the Flexibility to Enable Longer-Term Capability Growth

The UK has recently rolled out its Guardian C2 system, which provides a recognised air picture over the UK and is intended to be linked to NATO's IAMD C2. The RAF is increasingly focusing on the ability to ingest and route data from across the assets under its disposal to non-traditional users. For example, much of the data gathered from an F-35 may be of importance to users other than the four-ship formation (including air and missile defence assets on the surface).[94]

Many platforms used across the services carry IAMD-relevant data. It will be important to progressively expand the ability to draw this from those platforms and route it to users. Currently, a large amount of data in the system – that which is not necessarily relevant to the task for which the platform generating it is optimised – is unused and wasted. Yet, many relevant capabilities are not dedicated IAMD systems. For example, consider the fact that the X-band AN/APG-81 radar on the F-35 has been tested alongside the Patriot in a counter-cruise missile role and the F-35 is theoretically capable of contributing to BMD with both its X-band radar and AN/AAQ-87 electro-optical system.[95] Similarly, the P-8 Poseidon carries an infrared sensor. This may be of some use in providing data on the location of a hypersonic cruise missile, such as the Zircon, with its large infrared signature, if a P-8 is operating near the missile's pathway. It will be important to draw on the ability of systems to rely on both organic sensors and sensors from systems that may incidentally inhabit the same battlespace for periods of time: a large amount of IAMD-relevant data is held across the force.

Recent tests demonstrated that the RAF was able to move data off an F-35 using commercial networks. Private sector networks can also receive data mediated by gateways, but the ability of the F-35 to do this is a function of the very high

94. For a discussion of some of this work, see Lockheed Martin, 'UK Royal Air Force and Lockheed Martin Skunk Works® Demonstrate Advanced Interoperability with Project DEIMOS', 4 April 2024, <https://news.lockheedmartin.com/2024-12-04-UK-Royal-Air-Force-and-Lockheed-Martin-Skunk-Works-R-Demonstrate-Advanced-Interoperability-with-Project-DEIMOS>, accessed 07/07/2025.
95. Kris Osborn, 'Army Patriot Connects with Air Force F-35 to Destroy Cruise Missile', *National Interest*, 7 June 2020, <https://nationalinterest.org/blog/reboot/army-patriot-missile-connects-air-force-f-35-destroy-cruise-missile-161241>, accessed 8 July 2025; *Airforce Technology*, 'Northrop F-35 DAS System Completes BMD Test', 12 September 2010, <https://www.airforce-technology.com/news/news95659-html/>, accessed 7 July 2025.

standards of data encryption.[96] As such, the wider the bearer network needed, the more stringent data standards across the force will need to be.

To do this effectively at scale will, however, require a system of bearers and, crucially, message brokers that can translate data across formats, as well as procedures for identifying and routing relevant data if systems are not to be overwhelmed.

One challenge is that many systems within each domain currently have separate software architectures. In addition, the ability to move data across platforms depends on two elements. First, the availability of bearers capable of moving data at requisite speeds. Second, gateways that can receive and retransmit data from sensitive networks such as MADL (Multifunction Advanced Data Link) since receiving terminals are unlikely to be distributed across the force. The ability to build a system with an open architecture that can integrate capabilities held across the Joint Force will serve two aims: better employing available data; and creating an architecture that is capable of absorbing new systems, such as BMD capabilities, in the medium term.

There are two viable avenues to achieve this. The first is to leverage publish–subscribe models in which subscriber systems share data with a central message broker that relies on translation layers to move data across software formats. To achieve this, the structure and formatting of the data used by a system is required rather than its underlying source code.[97] This has been demonstrated in tests where US Marine Corps G/ATOR Radar, the F-35 and the Patriot have contributed to the same recognised air picture using a publish–subscribe model.[98] There are considerable advantages to publish–subscribe models, but they involve the movement of large volumes of data on a persistent basis (with ramifications for latency) and require considerable processing power.

Another type of software solution is a service-oriented architecture that involves tighter coupling between client interfaces. Examples include the BMD-Flex software that has been fielded to enable non-Aegis users, such as Denmark, to share data with Aegis systems.[99] This option requires less consistent transfer of data than publish–subscribe models and involves a comparatively simple approach to backwards integration: application programming interfaces can transfer

96. Lockheed Martin, 'UK Royal Air Force and Lockheed Martin Skunk Works® Demonstrate Advanced Interoperability with Project DEIMOS'.
97. James Dimarogonas et al., *Universal Command and Control Language Early System Engineering Study* (Santa Monica, CA: RAND, 2023), pp. 20–40.
98. Jack Watling and Sidharth Kaushal, 'Requirements for the Command and Control of the UK's Ground-Based Air Defence', *RUSI Occasional Papers* (April 2024), <https://www.rusi.org/explore-our-research/publications/occasional-papers/requirements-command-and-control-uks-ground-based-air-defence>, accessed 7 July 2025.
99. *Defense Daily*, 'Lockheed Martin, Terma AS's OA Effort Bringing BMD Capability to European Frigates', 14 January 2010, <https://www.defensedaily.com/lockheed-martin-terma-ass-oa-effort-bringing-bmd-capability-to-european-frigates-2/international/>, accessed 7 July 2025.

relevant data across systems without the requirement for a message broker moving data across multiple formats on a persistent basis.[100] Service-oriented architectures tend to suit systems with tight coupling of specific types of sensors and effectors. While this approach introduces a certain rigidity into data flows across the system – which can, in the long run, limit the ability of all nodes in the system to form links on an agile basis – it is arguably less of a challenge for homeland defence where persistent electronic warfare disruption is less likely than on the frontline. This limits the requirement to rapidly reconstitute kill chains. This approach would mean, however, that while non-traditional sensors could be incorporated into the IAMD network, a clear set of sensor–effector relationships would need to be specified in advance, given that the approach depends on interfaces that underpin well-specified relationships. A service-oriented architecture approach, while not without its limitations, would be consistent with both the homeland defence function and the approach inherent to the RAF's Nexus, as currently constituted.

Network bearers and gateways will be a second concern, particularly when data needs to be transferred between two networks at different levels of sensitivity. Work conducted by the RAF as part of the Nexus programme saw the use of tanker aircraft as gateways and relay nodes. Such an approach could be usefully expanded to encompass IAMD missions for the homeland.[101] Adapting the model that has already been demonstrated with tankers (and could readily be applied to other platforms) is a simpler issue than the need to select platforms that will act as gateways and bearers (since many of these systems will be dual-hatted).

The requirement for backwards integration could also be limited – to an extent. The Rapid Capabilities Office that oversees the Nexus programme could be empowered to act as an effective functional owner. It could be capable of inserting requirements into future air defence capabilities that are procured across the services as well as software updates for existing services. This would mirror the approach of the programme office for the US Navy's NIFC-CA, which was used to integrate platforms such as the F/A-18, Aegis and JLENS.[102]

An additional concern will be coordination across NATO. The Alliance has a C2 architecture for IAMD (the NATO Integrated Air Defense System), and Allies can create regional recognised air pictures. Deeper integration across the Alliance, for example to share tracks in peacetime, might initially be best achieved on a minilateral basis consistent with the structure of NATO's regional plans. The UK

100. Akshay Kumar, 'What is Service-Oriented Architecture (SOA)?', *Builtin*, 20 August 2024, <https://builtin.com/software-engineering-perspectives/service-oriented-architecture>, accessed 7 July 2025.
101. RAF, 'RAF Rapid Capabilities Office Demonstrates New Technologies Developed with Industry Partners', 12 March 2021, <https://www.raf.mod.uk/news/articles/raf-rapid-capabilities-office-demonstrates-new-technologies-developed-with-industry-partners/>, accessed 7 July 2025.
102. O'Donoughue, McBirney and Persons, *Distributed Kill Chains*, p. 49.

has links to the Alliance's northern members and existing interoperability with them, and might seek to expand on this foundation. For example, mechanisms to align – or perhaps even integrate – the UK's air defences with the Joint Nordic Air Command (for example by sharing missile tracks) might be a first step.

Phase 2: Ballistic Missile Defence

As noted, IRBMs pose a mostly medium-term threat to the homeland. However, the UK might need to grapple with this challenge beyond the mid-2030s if there is either an increase in Russian magazine depth or a step change in missile accuracy. It will therefore need to consider solutions now.

Broadly, there are two types of defensive options: terminal-phase defence, and mid-course defence. The former entails the interception of a ballistic target either just before it re-enters the Earth's atmosphere (at altitudes of about 100 km) or shortly after re-entry (at altitudes of 50 km). Mid-course defence involves engaging a ballistic target in the longest period of its trajectory, during which it is outside the Earth's atmosphere. Both modes of interception depend on hit-to-kill interceptors which destroy a target through kinetic impact, as opposed to blast-fragmentation warheads, which use an explosive charge to scatter pellets (usually made of tungsten) over a wide area. Blast-fragmentation interceptors are useful against softer-skinned targets, such as cruise missiles, but are suboptimal against ballistic targets which combine mass, hardening and high kinetic energy.[103]

Given the distances over which a target must be tracked, mid-course interception typically involves a cooperative effort by multiple sensors. For example, NATO's BMD capability against Iranian IRBMs – rolled out as part of the European Phased Adaptive Approach – relies on forward-positioned AN/TPY-2 radar in Kürecik, Turkey to pass on data to Arleigh Burke destroyers in the Eastern Mediterranean. These, in turn, hand data off to the Alliance's two Aegis ashore sites in Deveselu and Redzikowo.[104]

Intercepting a missile in its terminal phase imposes less stringent requirements for the rapid transfer of data between geographically distributed systems. For example, a terminal-phase defensive system such as the THAAD (Terminal High Altitude Area Defence) can rely largely on its organic AN-TPY/2 radar to conduct engagements.

103. Boord and Hoffman, *Air and Missile Defence Systems Engineering*, p. 139; Watling and Kaushal, 'Requirements for the Command and Control of the UK's Ground-Based Air Defence'.
104. Jaganath Sankaran, 'The United States' European Phased Adaptive Approach Missile Defense System: Defending Against Iranian Missile Threats Without Diluting the Russian Deterrent', RAND Research Report, 2015, <https://www.rand.org/pubs/research_reports/RR957.html>, accessed 8 July 2025.

In the medium term, there are several advantages of a focus on terminal-phase BMD. Kill chains for terminal-phase defence are simpler. Additionally, the ongoing development of the Aster 30 Block II – which has an endo-atmospheric intercept capability – means that a terminal-phase BMD capability against IRBMs may be integrated relatively quickly on the Type 45 (which will soon be equipped with the Aster 30 Block1NT). Unlike mid-course systems, some terminal-phase systems can be iterated against hypersonic targets – the SM-6 is equipped with active radar seekers and can be employed against hypersonics. Mid-course interceptors cannot be adapted in this way as they are designed to find a hot target against a cold background (outer space) and are therefore equipped with infrared seekers. These cannot operate effectively at lower altitudes within the Earth's environment where the interceptor is subject to levels of aerodynamic friction that generate large amounts of heat.

There are, however, offsetting costs to terminal-phase defence, which will become apparent in the long term. Given their intercept ranges of 150–200 km, the defended area of a terminal-phase system is considerably smaller than that of a mid-course equivalent. As such, a terminal-phase system cannot cover the entirety of the UK.[105] Terminal-phase interception also involves other complications. Given the speed of an IRBM in its terminal phase, there would be limited time for interception, precluding a 'shoot, look, shoot' approach in favour of ripple-firing interceptors. Thus, single-layer BMD systems often expend several times the number of interceptors than that fired by a system with multiple layers.[106] Moreover, missiles such as the Oreshnik release their MIRVs (multiple independently targetable re-entry vehicles) during the terminal phase. This presents the defence with several targets rather than one. In the mid-2030s, a terminal-phase intercept capability on maritime platforms may be both more immediately achievable and sufficient to counter the presumed IRBM threat (involving small salvos). However, as the scale of the threat grows – and its accuracy increases – a single-layer system will become uneconomical. A two-layer system is preferable in the long term.

Given the associated costs of developing exo-atmospheric interceptors, there is a strong incentive to secure access to off-the-shelf systems. US capabilities (such as SM-3IIA) and Israeli systems (such as Arrow-3) are the currently viable mid-course solutions. The integration of an existing mid-course defensive system such as SM-3IIA on platforms such as the Type 45 would impose a requirement to incorporate an MK 41 VLS on the vessel. This has implications for both cost and vessel readiness. However, if the ballistic missile threat matures towards the latter half of the next decade, this will coincide with the time when the

105. Andrew Feickert, 'The Terminal High Altitude Area Defence System (THAAD)', Congressional Research Service, 17 October 2024, p. 1, <https://www.congress.gov/crs-product/IF12645>, accessed 8 July 2025.
106. Eric and Kent, *A New Methodology for Assessing Multilayer Missile Defence Options*.

Type 83 destroyer will have entered service as part of the Royal Navy's wider Future Air Dominance System (FADS), along with the uncrewed Type 91, which is meant to act as a missile-carrying arsenal ship. During this period, vessels such as the Type 26 and multirole support ship – both of which will be equipped with the MK 41 VLS – will also enter service (although this is still not confirmed for the MRSS). While these are not dedicated BMD systems, they could be cued against ballistic targets by destroyers such as the Type 83. Since the concept of operations for FADS centres on systems, rather than platforms, pairing as many sensors and effectors as possible would be consistent with its approach. Within this rubric, the capacity to field BMD-capable interceptors on as many vessels as possible could allow the UK to manage the trade-offs between homeland defence and other activity based on vessel availability. This approach would leverage whichever vessels are available on a contingent basis for BMD roles. However, if balancing competing requirements in this way, available sensors to cue vessels will be needed. These may carry effectors, but not BMD-capable sensors. In turn, if a Type 45 or Type 83 is not to be always tasked for homeland defence, there would be strong incentives for the development of a ground-based radar capable of tracking ballistic targets. This would be similar to the system proposed in the 2015 Strategic Defence and Security Review[107] and could be networked with available vessels. Such a radar could represent the first incremental step to an exo-atmospheric intercept capability.

An alternative approach would rely entirely on a ground-based system comparable to the US's Aegis Ashore capability, which use both the sensors and effectors that are employed on an Arleigh Burke destroyer, albeit at fixed sites. Such a system involves additional capital costs (Aegis Ashore costs $750 million) but would free up assets for other missions. One component of FADS, for example, might be a Type 83 Ashore.

There is time to develop BMD solutions for the homeland. So, an initially limited terminal-phase intercept capability – deployed on vessels such as the Type 45 – along with a ground-based BMD radar would be a logical first step. This could occur while an exo-atmospheric intercept capability – either through the mission profile for FADS or the development of bespoke ground-based systems – is being developed as a basis for the evolution of the capability by the end of the next decade.

Should the UK opt for an exo-atmospheric intercept capability, it would probably benefit from being able to leverage data from Allied sources, such as NATO's Aegis Ashore sites and Norway's X-band Globus radar. Such data would add to

107. Ministry of Defence, 'SDSR 2015 Defence Fact Sheets', p. 4, <https://www.gov.uk/government/publications/sdsr-2015-factsheets>, accessed 29 July 2025.

the UK's own BMD early warning radar at RAF Fylingdales.[108] Given the requirement for very low latency data transfer in BMD and the national sensitivities surrounding many of the systems involved, preliminary agreements and work on the integration of capabilities would need to begin in this decade, even if physical capabilities were delivered late in the 2030s.

Alternatively, it may be possible to adopt a simpler approach and conduct mid-course tracking and intercept based on information from lower-frequency L-band radar, much as Israel's Arrow-3 system does. This provides considerable advantages in range.[109] Compensation must be made for the lower granularity of L-band radar – this may be achieved through the characteristics of the seeker. It must be able to survey a wider area and manoeuvre to compensate for differences between the presumed and real position of a missile. This may explain the inclusion of a gimballed seeker with hemispheric coverage as well as the very high terminal-phase manoeuvrability requirements that are built into the design requirements of Arrow-3 (which was deemed ambitious, even by the US Missile Defence Agency).[110] The Israelis have demonstrated that this is feasible, but it nonetheless underscores the fact that simplicity in one area imposes complexity elsewhere. Such an option would probably compel the UK to incur the programme costs associated with a more complex interceptor. Of course, an off-the-shelf solution such as Arrow-3 might be preferred, especially if a ground-based system is employed to free vessels for other roles. However, such a system would not be easily integrated with maritime platforms. This would be most viable if the UK opts for a single-purpose ground-based homeland defence capability.

As discussed, as the UK approaches the midpoint of the next decade, a limited endo-atmospheric capability would be a reasonable evolution of capabilities that the UK is already fielding. It would provide a means of defending critical parts of the homeland against small IRBM salvos while providing BMD coverage for fielded forces (if launchers can also carry shorter-range systems). Potentially, it would also hedge against future developments in areas such as hypersonics.

Towards the end of the next decade, an exo-atmospheric option might be necessary because of its potential to conserve magazine depth in the face of a growing IRBM threat. Accordingly, the UK might opt either to build this capability into existing programmes, such as FADS, or develop a more bespoke homeland

108. Globalsecurity.org, 'AN/FPS-129 Have Stare X-Band Dish Radar', <https://www.globalsecurity.org/space/systems/havestare.htm>, accessed 7 July 2025.
109. *Airforce Technology*, 'Arrow 3 Air Defence Missile System, Israel', 16 September 2022, <https://www.airforce-technology.com/projects/arrow-3-air-defence-missile-system-israel/>, accessed 7 July 2025.
110. *Defense Update*, 'Israel, U.S. to Embark on Collaborative "Upper-Tier" Missile Intercept Program to Include Arrow 3 and Land-Based SM-3 Missiles', 24 May 2009, <https://defense-update.com/20090524_arrow-3_0609.html>, accessed 7 July 2025.

defensive system. Each option has strengths and drawbacks, as discussed above, and the function of this section has been to articulate these trade-offs.

Phase 3: Countering Hypersonic Glide Vehicles

There is also the question of intercepting HGVs should Russia deploy a version of the Avangard on the RS-26. This is a much longer-term consideration given Russia's limitations and priorities, as discussed earlier in this paper. However, given the lifecycle of defence programmes, the options available (and principles for selecting between them) should be considered now.

The US has emphasised the interception of HGVs in their glide phase. This entails considerable challenges, given the requirement to track a target that is moving at speeds far above Mach 5 and which, unlike a ballistic target, is manoeuvring. HGVs fly under a radar's field of view for part of their trajectory, have plasma layers that partially absorb radar and manoeuvre in ways that make tracking with surface-based radar difficult. As a result, their engagement in glide phase depends on space-based sensors, and in particular infrared-equipped satellites.[111] However, the issue of plasma and radar detection is complicated. Plasma is thought to absorb radar signals at some frequencies, but not all, meaning the missiles may be detectable in specific radar wavebands. A focus on glide phase intercept may underpin EU projects such as HYDIS (Hypersonic Defence Interceptor System) which aims to deliver an endo-atmospheric interceptor in support of the TWISTER (Timely Warning and Interception with Space-Based Theater Surveillance) programme.[112]

It has been argued, however, that late glide phase and terminal phase intercept against hypersonics is more feasible than is often considered. HGVs travel through the Earth's atmosphere and are generally slower than comparably ranged ballistic targets in their terminal phase.[113]

It is worth noting that some systems that can engage ballistic targets within the atmosphere – such as SM-6 – can be equipped with dual-mode Ka-band seekers (which offer high resolutions despite an HGV's plasma shielding) and infrared

111. Karako and Dahlgren, 'Complex Air Defense'.
112. Andrew Salerno-Garthwaite, 'Hypersonic Interceptor HYDIS Backed by European Commission', *Airforce Technology*, 3 August 2023, <https://www.airforce-technology.com/news/hypersonic-interceptor-hydis-backed-by-european-commission/>, accessed 7 July 2025.
113. Ivan Oelrich, 'Cool Your Jets: Some Perspective on the Hyping of Hypersonic Weapons', *Bulletin of the Atomic Scientists*, 1 January 2020, <https://thebulletin.org/premium/2020-01/cool-your-jets-some-perspective-on-the-hyping-of-hypersonic-weapons/>, accessed 07/07/2025.

seekers, as payload requirements of a dual-seeker system are more easily managed over shorter ranges and higher-frequency seekers can be employed more readily when there is less uncertainty over the difference between a radar track and target location (a problem more acute in mid-course).[114] The ability to employ larger, more complex sensor payloads means that they can also be used for counter-hypersonic roles. As such, variants of endo-atmospheric BMD interceptors may be an early (if limited) means of engaging intermediate-range ballistic targets and can provide some future proofing against HGVs if the need for this capability growth is built into design requirements.

Since the future hypersonic threat will probably mature over the longer term, the UK can approach the question on a more iterative basis. In the medium term, an incremental improvement to maritime endo-atmospheric BMD, through Aster 30 Block II, would be an optimal choice for an eventual counter-hypersonic capability. This capability could be iterated to have a counter-hypersonic role, much as the US has with SM-6 Block IB. This would provide some protection for high-value platforms, such as aircraft carriers, against HGVs. If necessary, a ground-based version of this interceptor, if linked to both surface-based radar and sensors from across the joint force, could be fielded for the terminal-phase defence of key sites in the UK. This would be comparatively simple if an interceptor were already operational (as seen with systems such as Aster 30, which France employs on ground-based systems).

Simultaneously, exploratory work on the UK's participation in OPIR through AUKUS might be conducted. As the threat matures, the UK could, if viable, channel greater investments into OPIR and contribute with its own sensors. This would also enable the future fielding of a glide phase interceptor. Many of the medium-term steps which may enable BMD (such as the development of endo-atmospheric interceptors for BMD and building partnerships in space-based sensing) could serve as foundations for an eventual counter-hypersonic capability.

114. Brian Everstine, 'MDA Plans to Field SM-6 Counter-Hypersonic Update in '25', *Aviation Week*, 8 August 2024, <https://aviationweek.com/shows-events/smd-symposium/mda-plans-field-sm-6-counter-hypersonic-update-25>, accessed 7 July 2025.

Conclusion

The UK must avoid both fear-driven overinvestment in national IAMD and the risk of complacency. In a long war, the country enjoys several advantages. These include geographical depth and its status as a nuclear power. However, this should not be conflated with absolute security. During the Cold War, despite all its advantages, planners recognised that the UK could still find itself the target of pre-emptive attacks. For much of the Cold War, these could have crippled the country's nuclear deterrent. Today, this risk also applies to the UK's conventional deterrent capabilities, many of which are concentrated on just a few sites. Against an opponent that has placed pre-emption and deep strikes at the centre of its military thinking, such capabilities would be highly vulnerable at the outset of a conflict.

The UK must therefore be able to incrementally increase its capacity for homeland air and missile defence over the next two decades. The initial priority is the expansion of its capacity for the defence of critical military installations against what is primarily a cruise missile threat. However, as the threat becomes a more full-spectrum challenge over the next two decades, the UK's IAMD capabilities will need to keep pace. A phased approach which initially optimises against cruise missiles and then develops solutions against ballistic – and eventually hypersonic – threats can allow the UK's air defences to evolve in tandem with the threat.

This paper has outlined multiple options for the sensor architectures, effectors and associated platforms that might underpin a national IAMD architecture. While the paper seeks to articulate the strengths of different options, rather than advocate a specific solution, its key suggestion is that the UK can adopt an iterative approach to developing IAMD. Such an approach involves early optimisation against the cruise missile threat followed by an effort to gradually roll out capabilities that can secure the homeland against evolving adversary capabilities.

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