



Royal United Services Institute
for Defence and Security Studies

Occasional Paper

Modern Russian and Chinese Integrated Air Defence Systems

The Nature of the Threat, Growth Trajectory
and Western Options

Justin Bronk



Modern Russian and Chinese Integrated Air Defence Systems

The Nature of the Threat, Growth Trajectory
and Western Options

Justin Bronk

RUSI Occasional Paper, January 2020



Royal United Services Institute
for Defence and Security Studies

189 years of independent thinking on defence and security

The Royal United Services Institute (RUSI) is the world's oldest and the UK's leading defence and security think tank. Its mission is to inform, influence and enhance public debate on a safer and more stable world. RUSI is a research-led institute, producing independent, practical and innovative analysis to address today's complex challenges.

Since its foundation in 1831, RUSI has relied on its members to support its activities. Together with revenue from research, publications and conferences, RUSI has sustained its political independence for 189 years.

The views expressed in this publication are those of the author, and do not reflect the views of RUSI or any other institution.

Published in 2020 by the Royal United Services Institute for Defence and Security Studies.



This work is licensed under a Creative Commons Attribution – Non-Commercial – No-Derivatives 4.0 International Licence. For more information, see <<http://creativecommons.org/licenses/by-nc-nd/4.0/>>.

RUSI Occasional Paper, January 2020. ISSN 2397-0286 (Online); ISSN 2397-0278 (Print).

Printed in the UK by Stephen Austin and Sons, Ltd.

Royal United Services Institute
for Defence and Security Studies
Whitehall
London SW1A 2ET
United Kingdom
+44 (0)20 7747 2600
www.rusi.org

RUSI is a registered charity (No. 210639)

Contents

- Executive Summary v

- Introduction 1**

- I. Surface-to-Air Missile Systems and Integrated Air Defence Systems 3**
 - The Basics of Surface-to-Air Missile Systems Operations 3
 - The Integrated Air Defence System 9
 - Traditional vs Asymmetric Surface-to-Air Missile System Tactics 12

- II. How Russia and China Use Integrated Air Defence Systems 15**
 - Russia’s Integrated Air Defence System as a Tool of National Power 15
 - China’s Evolving Integrated Air Defence System Strategy 20

- III. Suppression and Destruction of Enemy Air Defences in the Modern World 25**

- Conclusions 31**

- About the Author 33

Executive Summary

INTEGRATED AIR DEFENCE systems (IADS) are a key feature of modern warfare. IADS – like the one Russia has deployed on NATO’s Eastern Flank and which China is creating within the First Island Chain – are complex, multilayered defence systems incorporating a range of ground-based and aerial sensors, as well as surface-to-air missile (SAM) systems.

Modern SAM systems are highly mobile, able to set up and pack away in minutes prior to and after firing. They are also supported by point-defence systems, electronic warfare assets and deception measures such as decoys. This makes them very difficult to reliably track, target and destroy from long ranges. They are also increasingly equipped with digital radars capable of frequency-hopping, offering much better resistance to jamming interference and also making them harder to detect when in operation.

IADS are not in themselves a new phenomenon. However, the SAM systems and radars which make up modern IADS are much more capable than previous generations. The territory which they can cover is also much larger than in previous generations due to several very long-range SAM systems such as the Russian S-400 (SA-21 in NATO terminology), S-300V4 (SA-23) and Chinese HQ-9. These systems mean that Russia and China, as well as other overseas users of such systems, can threaten to restrict freedom of manoeuvre well outside their own land borders.

Advertised maximum range for SAM systems is usually for large, non-agile targets like tankers flying at medium-high altitudes. Against agile, lower flying targets practical ranges are significantly shorter. However, the long-range SAM systems are connected to a larger number of medium- and short-range SAM systems, as well as other sensors such as those carried by AWACS aircraft. Drawing on these external sources of target data allows systems like the SA-21 to fire their own long-range active seeker missiles against targets far beyond their own radar-horizon. Therefore, for Western air forces, planning operations against modern IADS is more complex and challenging than against a standalone system – even a very modern one like the SA-21.

The key conclusions are:

- Russia’s IADS threatens to keep NATO airpower at arm’s length and predominately occupied with the task of suppression of enemy air defences (SEAD) during the initial critical phases of any armed clash. The strategic SA-21 and SA-23 long-range SAM elements coordinate and are supported by a range of medium-range systems including the SA-17, and shorter-range and point-defence systems like the SA-15 and SA-22. The medium- and shorter-range systems would doctrinally tend to be attached to ground force units closer to the frontlines, whilst the strategic SAMs are used to protect key facilities. However, they operate functionally as part of the same IADS and present a challenging opponent for NATO air forces. The question is not whether the Russian IADS

could eventually be degraded and rolled back, but whether NATO forces could do so quickly enough to avoid defeat on the ground while deprived of regular close air support in the meantime.

- China's IADS is less well integrated than Russia's but is more heavily distributed and mobile. It is comprised of land-based HQ-9 and SA-21 long-range and multiple medium-range SAM systems on the mainland as well as on artificial reefs, and an increasingly potent naval component in the shape of People's Liberation Army Navy major surface combatants with the navalised HHQ-9 series. China is also pursuing multiple aerial and ground-based exotic radar and multi-spectral sensor technologies to support both its IADS and the People's Liberation Army Air Force. In conjunction with increasing aerial capabilities, the Chinese IADS presents a dynamic and growing challenge to the freedom of action of the US and its allies near the Chinese mainland.
- Chinese and Russian air defence systems continue to proliferate globally, along with the electronic warfare assets and integration assistance required to turn SAM systems into a capable IADS. This means that a modern SEAD capability will soon be required in far more military situations than the peer-clash scenario of a conflict with Russia or China.
- There are multiple potential ways to approach the problem of tackling hostile SAM systems, including stand-off attacks with cruise missiles, stand-off or stand-in jamming, or being able to get close enough without being detected to directly attack or bypass threat systems through stealth capabilities. However, against a modern IADS, a combination of these techniques, along with the ability to detect, classify, track and pass target data to other coalition assets without being shot down in the process, will be required. These capabilities are too expensive for any one country aside from the US to operate alone. If the Alliance wants to improve its ability to conduct effective SEAD operations and reduce the threat from modern IADS, it will need to cooperate and exercise collectively, as well as purchase new equipment.

Introduction

SINCE THE RETURN of open great-power competition from 2014, and with it a potential challenge to the military supremacy of the US and NATO in both Europe and the Asia-Pacific, anti-access area denial (A2/AD) has become a central buzzword in policy debates around defence planning and deterrence.¹ Whilst there are other elements of A2/AD networks – such as anti-ship missiles and long-range ballistic missiles – the most threatening elements of this perceived challenge to the Western way of war are ground-based air defences, since they threaten to deny NATO’s greatest advantage: airpower. Specifically, the greatest threat comes from integrated air defence systems (IADS) which are generally made up of surface-to-air missile (SAM) systems, radars and other sensors to provide early warning and target tracking of any incoming threats. Both Russia and China rely heavily on their respective IADS to provide the core of their A2/AD challenge to Western military freedom of action, by contesting the latter’s ability to gain and maintain air superiority near their borders.

Despite having seemingly woken up to the threat posed by IADS to traditional military capabilities, the level of debate and understanding in most policy circles remains poor. Individual systems, especially the Russian SA-21 (Russian designation S-400) SAM, are also often discussed in lieu of the larger IADS within which they operate.² Too often, IADS are discussed as either an inconvenience to be neutralised by stealth fighters if required, or as red-coloured no-fly bubbles acting as strategic game changers on large maps of Eastern Europe and the Asia-Pacific. The truth lies between these two extremes, and the true nature of the challenge posed is highly context dependent. What is true is that IADS incorporating the latest air defence systems are a significant challenge to legacy platforms and concepts of operations which still underpin NATO’s airpower. However, if properly understood, even the most modern Russian and Chinese air defence systems can be countered to a degree with the requisite equipment and tactics. These need not involve a complete overhaul of existing air force inventories but would require significant investment in key enablers such as electronic warfare and penetrating strike fighters and intelligence, surveillance, target acquisition and reconnaissance (ISTAR) aircraft.

-
1. For example, see Luis Simon, ‘Demystifying the A2/AD Buzz’, *War on the Rocks*, 4 January 2017; Sebastien Roblin, ‘A2/AD: The Phrase That Terrifies the U.S. Military (And China and Russia Love It)’, *National Interest*, 9 April 2019. On the return to great-power competition, see Congressional Research Service, ‘Renewed Great Power Competition: Implications for Defense—Issues for Congress’, 7 November 2019, <<https://fas.org/sgp/crs/natsec/R43838.pdf>>, accessed 9 December 2019. See also Uri Freedman, ‘The New Concept Everyone in Washington is Talking About’, *The Atlantic*, 6 August 2019.
 2. For example, see Stephen Bryen, ‘Why Russia’s S-400 Anti-Air System Is Deadlier Than You Think’, *National Interest*, 9 November 2019; Christopher Woody, ‘Russia is Reportedly Shipping its Advanced S-400 Anti-Aircraft Missile System to China’, *Reuters*, 19 January 2018.

This paper first seeks to explain the essential components of an IADS, including how the various types of SAM systems within them work. The subsequent chapter examines how Russia and China employ these systems as instruments of national power.³ The third chapter outlines potential suppression of enemy air defences (SEAD) and destruction of enemy air defences (DEAD) approaches which can be taken by militaries seeking to counter such A2/AD networks. The aim is to provide a baseline reference guide for policymakers seeking to understand the new requirements placed on Western air forces and NATO countries and partners more broadly by the threat of modern air defences.

3. Instruments of national power include a range of diplomatic, information, military and economic levers.

I. Surface-to-Air Missile Systems and Integrated Air Defence Systems

The Basics of Surface-to-Air Missile Systems Operations

THE CORE LETHAL component of any IADS is the SAM system. Understanding the basics of how SAMs work is important to understand why the perceived A2/AD threat from the latest systems – like the Russian SA-21 (S-400 in Russian terminology) – is so much greater than in previous generations, and to understand what IADS are and why the distinction matters.

SAM technology has evolved significantly since they first became a major component of aerial warfare in the 1960s. However, the core mechanics behind how a SAM system works continue to follow broadly the same principles. Most SAM systems are radar-guided, meaning that they detect airborne targets and guide missiles to intercept them by emitting radar energy and analysing the reflections which come back when this energy hits an aircraft or missile. All types of radar-guided SAM systems utilise early-warning and target-detection radars to provide wide-area scanning, detection, classification and tracking of targets in a given area. They then use a higher-resolution fire control radar to guide and control actual missile engagements. Most SAM systems also include some sort of command post or command vehicle which coordinates the activities and engagement sequences of the various radars and missile launchers in each battery. SAM systems are generally classified according to range, with short-range systems designed to engage targets up to around 15 km, medium-range systems up to around 75 km, and long-range systems up to 400 km against certain medium- and high-altitude targets.

In terms of functionality, there are several types of radar-guided SAM systems, the most important of which are command guidance systems, semi-active radar homing and active radar homing. There are also passive coherent location (PCL) radars which rely on detecting and analysing signals from third-party emissions like mobile phone and wifi networks which are reflected off targets.¹

Command guidance systems use a fire control radar in each battery to track a target and produce updates on its movements, which are then transmitted to the missile in flight either by a trailing

1. It is unclear from publicly available sources at the time of writing how capable these systems are and whether they could be used to guide a SAM to a target. For a detailed open-source assessment of current passive radar technology, see Hugh Griffiths and Christopher Baker, *An Introduction to Passive Radar* (London: Artech House, 2017).

wire or radio links. This means that the missiles themselves do not need to carry complex seeker heads, as they merely fly to where the fire control radars tell them. However, this can leave the system vulnerable to enemy jamming: if either the fire control radar itself or the datalink between the radar and the missile in flight is disrupted, then the missile will lose tracking and likely miss the target. Where a trailing wire is used, the signals between the radar and missile cannot be jammed, although the fire control radar remains vulnerable. Command guidance also requires the SAM battery's radar to be continuously emitting throughout the launch sequence to generate target track updates which can then be transmitted to the missile. This exposes the radar's location to enemy forces and gives them more time to jam the signal or take evasive action. The SA-2 Guideline (S-75) is an example of a command guidance SAM system.²

Semi-active radar homing systems also use the battery's fire control radar to illuminate the target using radar energy, but instead of relying on the fire control radar to receive, interpret and then transmit target position updates to the missile in flight, the missile itself carries a seeker head which homes in on the reflected energy. Whilst the requirement to carry a passive radar seeker head makes these SAMs more expensive and complex than command guidance missiles, the system provides significantly better probability of kill (Pk) against manoeuvring targets and is harder to jam. This is because the system does not have to rely on signals being clearly reflected all the way to the ground-based fire control radar throughout the whole launch sequence, or on a radio or wire link to the missile to provide course corrections during flight. Furthermore, the closer that the missile gets to an illuminated target, the stronger the radar reflections become and the harder it gets to jam. Semi-active missiles can also be launched on a rough bearing provided by the early warning and detection radar or third-party radars, with an expected target position sufficient to get the missile near its target without mid-course updates. Then, once the missile is nearing the intercept point, the fire control radar illuminates the target to provide the passive seeker with reflected energy for terminal homing.

Despite these advantages, a semi-active radar homing SAM still requires the battery fire control radar to be illuminating the target during the terminal phase of flight. This makes the system potentially vulnerable to detection and limits the practical engagement range to within the radar horizon. The SA-5 Gammon (S-200) long-range SAM is an example of a semi-active radar homing system.³

Active radar homing systems are the most modern, capable and flexible type of SAM. These SAMs incorporate an active radar seeker head on the missiles, allowing them to search for

-
2. For detailed technical information on SA-2 (S-75), see Carlo Kopp, 'Air Defence System/HQ-2A/B/CSA-1/SA-2 Guideline', Air Power Australia, April 2012, <<https://www.ousairpower.net/APA-S-75-Volkhov.html>>, accessed 23 September 2019. Whilst last updated in 2014, the Air Power Australia's technical reports series by Kopp still represents the most detailed open-source technical collection on Russian SAM system component parts and broad functionality.
 3. For detailed technical information on SA-5 (S-200), see Carlo Kopp, 'Long Range Air Defence System/SA-5 Gammon', Air Power Australia, April 2012, <<https://www.ousairpower.net/APA-S-200VE-Vega.html>>, accessed 23 September 2019.

and home in on targets independently during the cruise and terminal stages of flight without needing it to be illuminated by a ground-based fire control radar. When operating as a single battery or battalion, an active radar homing missile-equipped SAM system will use one or more early-warning and wide-area search and track radars to provide initial target detection, and can still use a fire control radar to provide semi-active homing for missiles. However, once the missile seeker heads go active and acquire the target themselves, no further ground-based guidance or illumination is required. This brings several advantages for modern SAM systems over semi-active or command guidance types. First, they can fire more SAMs at more targets in a given period since they only need to provide an initial target track and projected intercept point for each missile to enable a launch rather than having to guide each one throughout the whole engagement. Providing semi-active guidance mid-flight will increase the Pk by providing mid-course target updates to the missile in flight before the latter has got close enough to acquire it with its own seeker, but is not necessarily required. It also means that a SAM can be launched against targets which cannot be detected and tracked directly by the battery's own radars. This is particularly useful for active radar homing SAM systems operating within IADS rather than as standalone units.

If integrated within a broader air defence system, radar information from over-the-horizon early-warning radars, SAM sites further forward than the launching system or aerial assets can be fed to an active radar homing SAM system. This enables missiles to be launched on a projected intercept trajectory, relying on their own seeker heads to acquire and home in on each target. Such an approach has a lower Pk than a conventional semi-active or command-guided launch profile, especially against manoeuvring targets since their position might be significantly different from that projected at launch when the active SAM reaches the intercept point, causing it to miss. However, active SAMs can be significantly harder to jam and potentially offer very little warning of the incoming threat to the targeted aircraft. Like most SAM types, active radar-guided SAMs are also typically launched in pairs at each target to increase the overall engagement Pk. They are much more useful than semi- or command-guided SAMs against very low-flying targets due to the inherent radar horizon and terrain-masking effects of the Earth's surface at longer ranges on ground-based fire control radars. Modern SAM systems like the Russian SA-23 (S-300V4) and SA-21 (S-400) and the Chinese HQ-9 can all launch active radar seeker head and semi-active radar seeker head type missiles, typically reserving the former for long-range or low-altitude engagements where their advantages are greatest.⁴

Modern SAM systems have two additional features which make them hard to counter and allow for advanced tactics to be employed by units operating these systems. The first

4. For detailed technical information on S-300V4, see Carlo Kopp, 'Self Propelled Air Defence System/SA-12/SA-23 Giant/Gladiator', Air Power Australia, April 2012, <<https://www.ausairpower.net/APA-Giant-Gladiator.html>>, accessed 23 September 2019; on S-400, see Carlo Kopp, 'Self Propelled Air Defence System/SA-21', Air Power Australia, April 2012, <<https://www.ausairpower.net/APA-S-400-Triumf.html>>, accessed 23 September 2019; on HQ-9, see Carlo Kopp, 'CPMIEC HQ-9/HHQ-9/FD-2000/FT-2000', Air Power Australia, April 2012, <<https://www.ausairpower.net/APA-HQ-9-FD-FT-2000.html>>, accessed 23 September 2019.

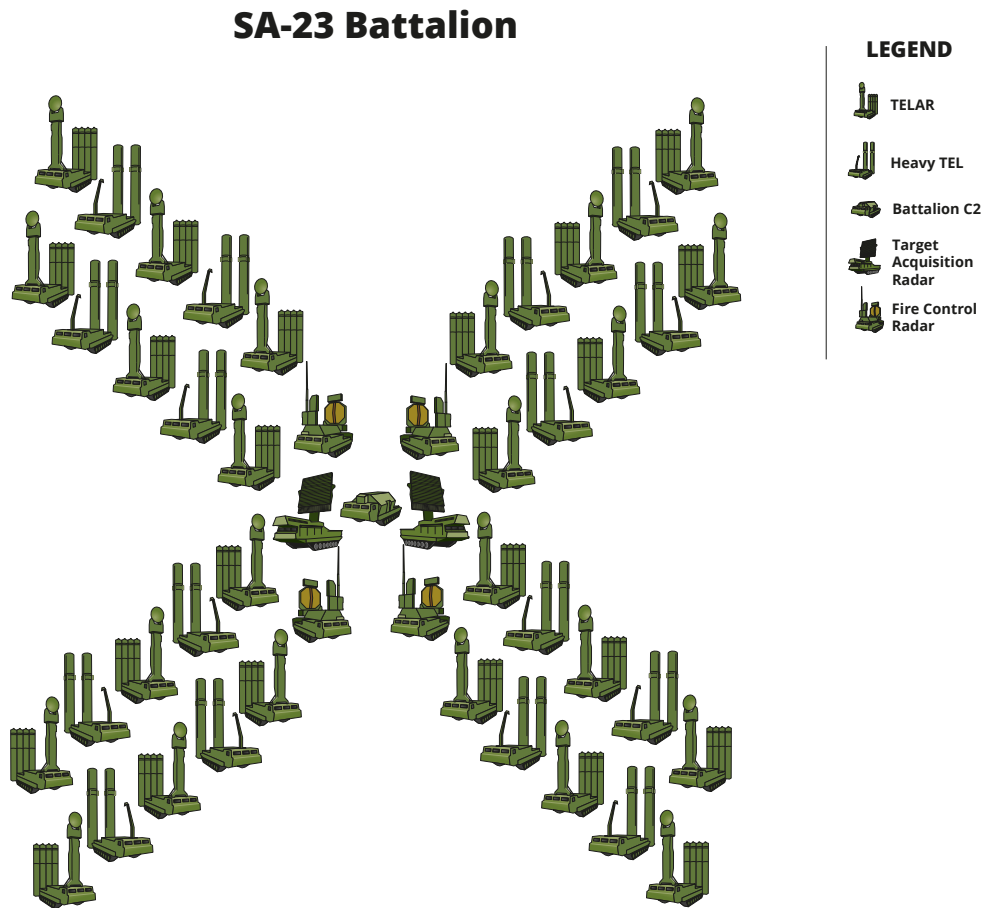
is that they are all highly mobile, with radars, missile launchers, reloading cranes and command-and-control (C2) posts mounted on tracked or wheeled all-terrain vehicle chassis. They can generally stop, set up and be ready to fire in a matter of minutes, and be ready to move again within five minutes of conducting an engagement. The different vehicles making up each battery or battalion are connected by various radio and datalink systems, allowing them to adopt dispersal tactics in combat to avoid being targeted all at once, and still function effectively unless heavily jammed.⁵ This makes it much harder to find, fix and attack modern SAM systems since they can rapidly and repeatedly change position while continuing to pose a threat to incoming missiles and aircraft. They also do not have to adopt easily identifiable deployment formations in single locations to function as a unit, as previous generations of SAMs did.

The second major feature of modern SAM systems is that they are increasingly equipped with digital rather than analogue radars, control systems and radio datalinks. Aside from faster signal processing, greater signal analysis power and more accurate tracking and guidance solutions especially against very fast, small or low-radar cross-section (stealth) targets, digital radars make SAMs significantly harder to counter with traditional electronic warfare techniques. Traditional SAM detection and defence by aircraft involves detecting and correctly identifying the waveforms emitted by the search and track and/or fire control radars.⁶ Once correctly identified and located, a hostile SAM site could then be jammed using a tailored jamming signal to interfere with the radar waveforms or attacked with anti-radiation or cruise missiles.⁷ Digital radars of the type increasingly used by modern SAM systems are frequency-agile, meaning that they can rapidly adapt to being jammed by changing their frequencies. They are also more difficult to positively pick out and identify in the busy electromagnetic background noise of a modern battlespace, and are inherently more resistant to brute-force jamming than analogue radars of a similar power level.⁸

The various radar and launcher units which make up a typical Russian long-range SAM unit are illustrated with an SA-23 battalion in Figure 1 and an SA-23 brigade in Figure 2.

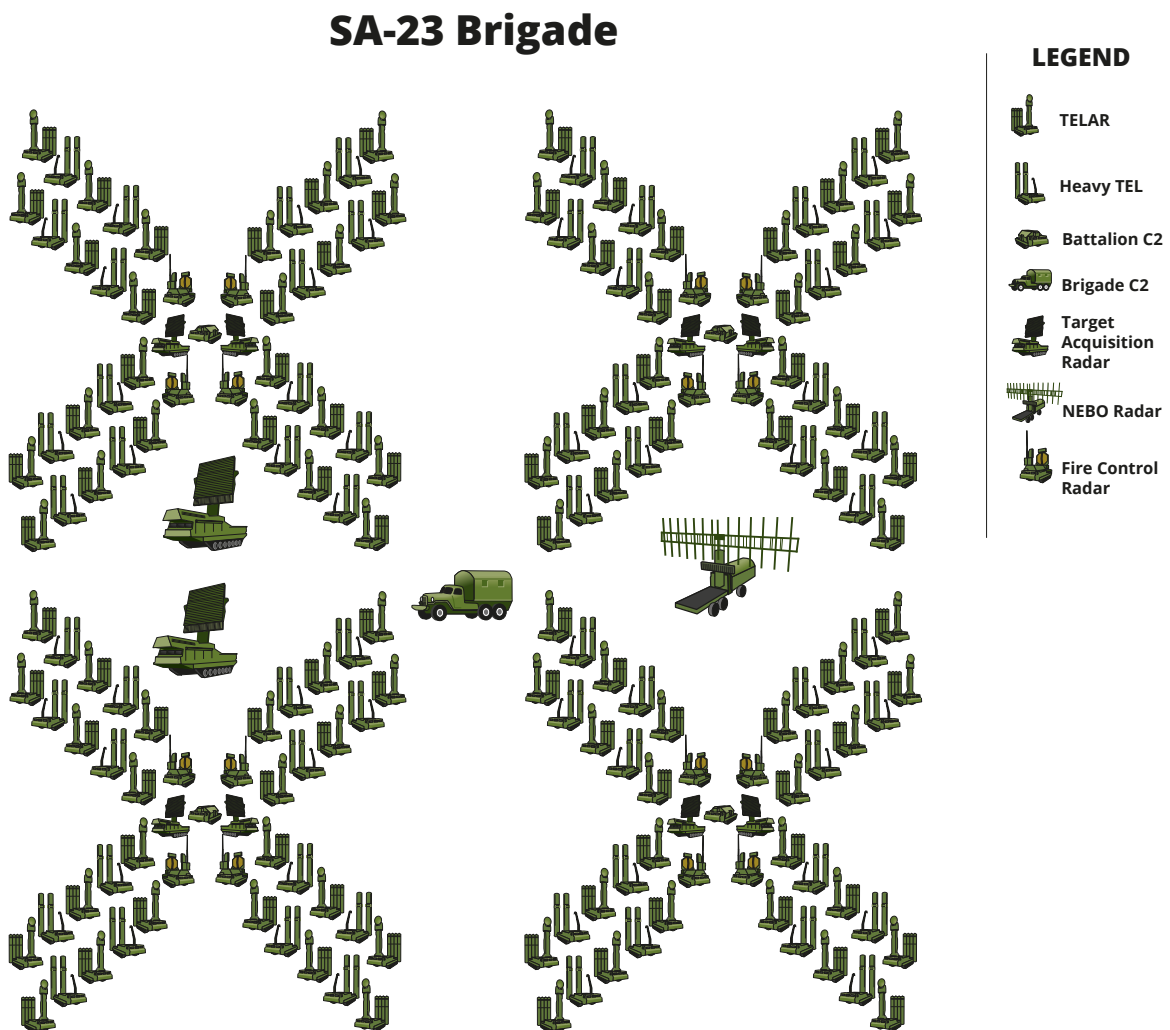
-
5. Author interview with retired Russian SAM system operator, London, 25 February 2016; author interview with civilian expert specialising in Russian SAM systems, Defence Science and Technology Laboratory (DSTL), Portsmouth West, 23 May 2019. See also Peter Mattes, 'What is a Modern Integrated Air Defense System?', *US Air Force Magazine*, 1 October 2019, <<http://www.airforcemag.com/MagazineArchive/Pages/2019/October%202019/What-is-a-Modern-Integrated-Air-Defense-System.aspx>>, accessed 9 December 2019.
 6. Dan Hampton, *Viper Pilot: A Memoir of Air Combat* (New York, NY: William Morrow, 2013).
 7. Author interviews with former US Air Force F-16CJ 'Wild Weasel' pilots, London, 8 March 2017 and Washington, DC, 12 July 2019.
 8. Author interview with US Navy radar specialist, London, 21 March 2019.

Figure 1: SA-23 Battalion.



Sources: Author interviews with retired Russian SAM system operator, London, February–March 2016; author’s own calculations.

Figure 2: SA-23 Brigade.



Sources: Author interviews with retired Russian SAM system operator, London, February–March 2016; author's own calculations.

To properly understand the threat posed by such modern SAM systems, however, it is vital to understand that they are not designed to be fielded and used as standalone units countering all threats. They are designed to fulfil specific and complementary roles as part of an IADS.

The Integrated Air Defence System

A modern IADS is one of the most formidable threats that an air force can be tasked to confront. Given the level of overmatch possessed by NATO against any potential state adversaries in terms of combat aircraft and associated aerial enabling capabilities, it is unsurprising that both Russia and China have invested significant resources into developing ground-based methods to deny Western air forces access to their airspace. Russia, in particular, develops and manufactures the most potent SAM systems in the world and has done so since the mid-Cold War.

When discussing the issue of ground-based air defences and the threat they pose to NATO forces, policy and media discussions typically focus on long-range, so-called 'strategic' SAM systems such as the SA-21 Growler (S-400) due to their ability to project a missile engagement zone (MEZ) over large areas of territory. However, it is crucial to understand that these systems are intended to be deployed as part of a multi-layered IADS rather than in standalone batteries. The SA-23 Gladiator/Giant (S-300VM/4) and SA-21 series are designed as modular systems, able to interface with, control and enhance the capabilities of older, short-range systems in addition to their own organic radar and launcher vehicles.⁹

An SA-23 or SA-21 battalion will include at least one command vehicle, such as the D4M1 Polyana or 55K6E, which functions not only as a command-and-coordination centre for the battalion itself, but also as a data fusion and relay node.¹⁰ These command vehicles are linked to the other IADS elements by multiple radio datalinks and are also able to leverage local infrastructure such as wifi, mobile networks and landlines laid at pre-prepared firing positions to improve C2 resilience.¹¹ The sophisticated fire control and acquisition radars which form part of the battalion can be used to provide longer-range and more accurate target data to older SAM systems such as the SA-20 Gargoyle, SA-17 Buk and SA-5 Gammon that are linked up and controlled via the command vehicle. This technique can greatly enhance the effectiveness of older systems which are limited in terms of performance more by their radar capabilities than the kinematics of their missiles.

On the other hand, this modular architecture also allows SA-23 or SA-21 units to bypass the radar horizon limitations of their own organic radar assets by using radar tracks generated by

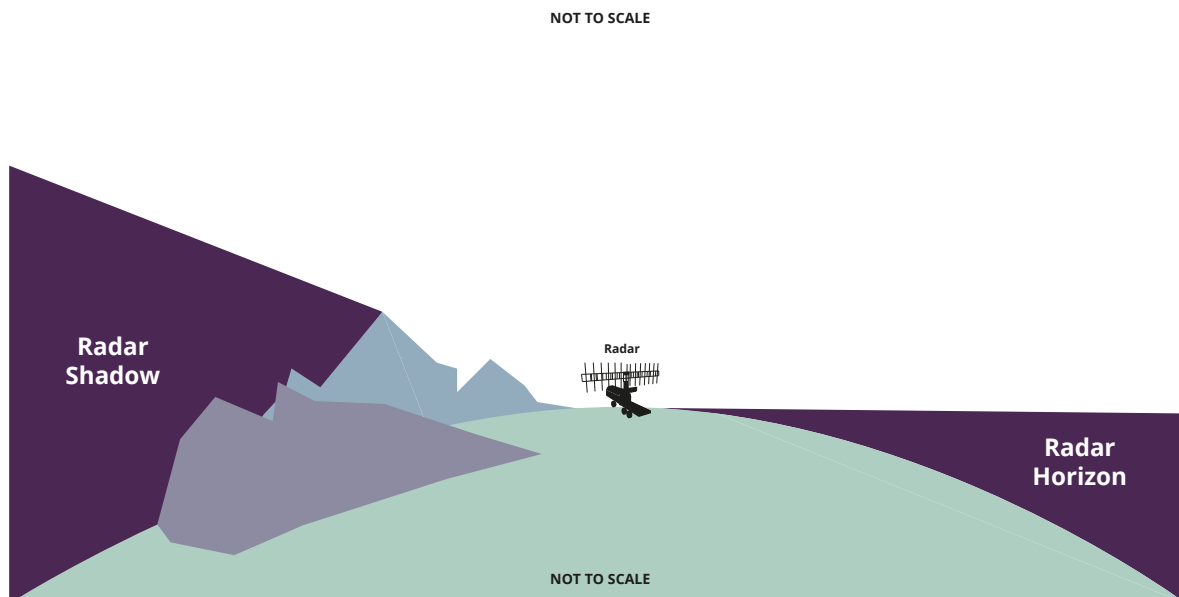
9. Author interview with retired Russian SAM system operator, London, 25 February 2016.

10. Rosoboronexport, 'Polyana D4M1', Air Defence Systems Catalogue, <<http://roe.ru/eng/catalog/air-defence-systems/air-defense-automated-command-and-control-systems/polyana-d4m1/>>, accessed 17 September 2019. For the 55K6E, see Army Technology, 'S-400 Triumph Air Defence Missile System', <<https://www.army-technology.com/projects/s-400-triumph-air-defence-missile-system>>, accessed 19 September 2019.

11. Author interview with retired Russian SAM system operator, London, 25 February 2016; author interview with civilian expert specialising in Russian SAM systems, DSTL, Portsmouth West, 23 May 2019. See also Mattes, 'What is a Modern Integrated Air Defense System?'

third-party sensors.¹² These might be ground based in the shape of medium- or even short-range mobile SAM units such as SA-17 batteries, which are generally sited much closer to potential enemy threats than the strategic SAMs. They might also be from airborne assets in the shape of the A-50M Mainstay and the new A-100 AWACS, or Mig-31BM Foxhound interceptor flights surveying the battlespace from a high altitude and at standoff ranges.¹³ The effect of integrating third-party sensor data into an SA-23/SA-21's situational awareness picture is illustrated in Figures 3 and 4.

Figure 3: The Impact of Raised Terrain and the Curvature of the Earth on Radar Coverage from Ground Level Only.



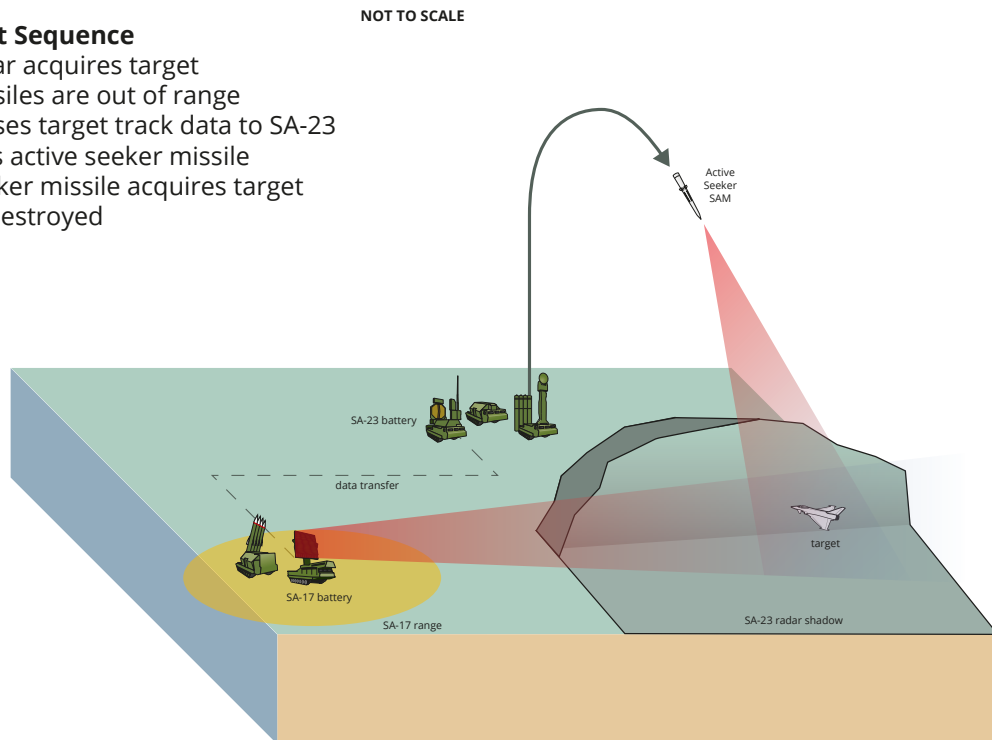
Source: Author generated.

12. Author interviews with former US Air Force personnel and civilian experts on Russian and Chinese air defence system capabilities, Washington, DC, 9–12 July 2019.
13. The effectiveness and reliability of Russian VKS datalinks at the time of writing is extremely difficult to ascertain from open sources. It is likely that reliable cross-domain cooperative engagement capabilities are still far from mature in Russian military service. However, the ability of airborne assets to contribute target position updates to ground-based IADS elements under some operational conditions cannot be discounted.

Figure 4: The Impact of Integrating Multiple SAM Systems for Cooperative Engagements as Part of an IADS.

Engagement Sequence

- 1: SA-17 radar acquires target
- 2: SA-17 missiles are out of range
- 3: SA-17 passes target track data to SA-23
- 4: SA-23 fires active seeker missile
- 5: Active seeker missile acquires target
- 6: Target is destroyed



Source: Author generated.

The first consequence of this radar data-sharing within an IADS is that there are far more potential radar emitters that a SEAD/DEAD task force must consider a serious threat than if each individual battery was only capable of engaging using its own radars. Even if centralised C2 nodes are hit and knocked out, along with large brigade radar assets, individual battalions and even batteries can still pose a serious threat to aircraft. The second effect is that radar horizon-associated blind spots for the strategic SAM systems – equipped with active radar homing missiles and sited further from approaching threats – can, to a large degree, be filled by situational awareness contributed by external ground- and air-based systems. A third effect is that the spatially diverse network of radars operating across multiple different frequency bands can give more precise target information, particularly against stealth aircraft with very low radar cross-sections if all the data can be brought together and cross-referenced in real time by a Polyana, 55K6E or other C2 and data-fusion asset. These properties, as well as the more obvious benefits of mutually supporting defensive fire, make an IADS a vastly more daunting prospect than a standalone strategic SAM system. The ability of the strategic SAMs in an IADS to exchange radar and engagement data with shorter-range systems and airborne assets greatly complicates the task of SEAD/DEAD against these networks.

There are, however, significant questions around the extent to which Russian and Chinese IADS can successfully bring together and make use of the multiple ground- and air-based radar assets theoretically available to them in real time. As the US and its allies have found in multiple conflicts and through projects such as the F-35, Naval Integrated Fire Control – Counter Air and the Advanced Battle Management System, true multi-domain cooperative engagement capabilities (CEC) are highly complex and difficult to master.¹⁴ Latency or system compatibility problems are serious challenges even in a peacetime testing and exercise environment, and would be compounded in a warfighting scenario by heavy use of electronic countermeasures and electronic counter-countermeasures by various systems on all sides, not to mention physical losses of assets in combat. Therefore, it would seem decidedly premature to assume that Russia or China have solved these problems with less advanced military electronics sectors and less experience and funding than the US. China, in particular, continues to have serious problems with joint engagement zone (JEZ) operations to allow SAM batteries and combat aircraft to employ weapons in the same block of airspace simultaneously.¹⁵ Likewise, Russia – whilst undoubtedly pursuing the goal of true JEZ and cross-domain CEC capabilities to help increase the effectiveness of its IADS in Eastern Europe – has struggled with friendly fire and datalink problems even within single services, so it is likely some way off achieving its aim.¹⁶ This does not mean, however, that it cannot effectively share target location and track data between different assets within its IADS on a regular basis, even if full network-wide CEC in real time remains an aspiration rather than a reality at present. Active SAMs mean that target-grade track information throughout the engagement sequence is not required; merely a sufficiently good indication of the heading, speed and altitude of a target or group of targets to get the missile to where it can search for and track them itself.¹⁷

Traditional vs Asymmetric Surface-to-Air Missile System Tactics

In terms of operational-level employment strategies, the traditional role for SAM systems (and for broader IADS) is to deny enemy access to national airspace on an enduring basis by attempting to destroy every hostile aircraft or strike package which enters engagement range. In Vietnam, this approach was applied by North Vietnamese forces using a combination of SA-2

14. For more information, see Justin Bronk, *The Future of NATO Airpower*, RUSI Whitehall Paper 94 (London: Taylor and Francis, 2019), pp. 37–39.

15. Author interview with senior PLAAF expert, National Defence University, Washington DC, 22 February 2019.

16. Author interview with civilian expert specialising in Russian SAM systems at the DSTL, 23 May 2019.

17. For a high-apex missile like the Russian 40N6, the missile seeker's terminal phase search cone can cover a surprisingly wide area. Assuming a standard 60° seeker head field of view, a theoretical vertical scanning cone from 100,00 ft would give a search diameter of 35.17 km (115,400 ft) at ground level, which translates to a radar scan area at ground level of 973 km². The angle of descent during terminal phase, target altitude and terrain would alter this effective search area in a real-world context. Author's own calculations using basic trigonometry.

SAMs and extensive anti-aircraft artillery (AAA) batteries concentrated around major cities, airbases, transportation hubs and other targets. This led to a multi-year battle of attrition between the Vietnamese air defences and US aircraft, with each developing new tactics over time to try and gain the upper hand, and heavy losses on both sides.¹⁸

Traditionally, this full airspace denial approach has been pursued by the Soviet Union (and later, the Russian Federation) and China, with their own networks of SAM batteries and radars, as well as ground-radar guided fighter interceptors. The latter formed the core of Soviet air doctrine, with fighters launched and guided on ground-based radar tracks as part of a system known as 'ground-controlled interception'.¹⁹ The traditional Soviet focus on ground-based missiles and control of interceptors continues to influence Russian thinking on airpower and acts as a centralising influence on C2 and operational practices.

Since the end of the Cold War, there have been several examples of smaller countries using Russian SAMs in a different asymmetric way for subtly different goals. Where a country is not capable of preventing an adversary from routinely fighting its way into its airspace, and/or has already suffered significant damage to its air defences, it may well choose to adopt asymmetric concealment and ambush tactics with its SAMs rather than contesting every incursion. Serbian air defences during the 1999 NATO bombing campaign in Yugoslavia remained camouflaged much of the time, only revealing themselves and launching SAMs against NATO aircraft under particularly favourable circumstances. These tactics contributed to Serb air defences achieving the first kill against a stealth aircraft – destroying a US Air Force F-117 Nighthawk in March 1999.²⁰ More recently, Syrian air defences have taken a similar approach towards contesting Israeli incursions, opting to present a constant danger of well-concealed 'pop-up' SAM threats rather than having radars and SAM batteries destroyed in unequal open confrontations against the Israeli Air Force.²¹ Such tactics make it much harder for air forces to locate and plan coordinated SEAD or DEAD missions against air defences, and forces them to conduct every mission with the ever-present danger of pop-up SAM threats. However, it comes at the cost of much less effective denial of airspace access on the part of the defender than a successful traditional national defence approach.

Most recently in Syria, the arrival of sophisticated Russian SA-21 and SA-23 air defences and the integration of these systems with the Syrian IADS has prompted a shift towards a more

18. Roy M Stanley, *Chasing SAM: My Vietnam War, August 1965–August 1966*, (Indianapolis: Dog Ear Publishing, 2016).

19. Central Intelligence Agency, 'Soviet Air Defence Aviation: Training and Operations', National Foreign Assessment Center Research Papers (Declassified) February 1979, p. iv., <https://www.cia.gov/library/readingroom/docs/DOC_0000969825.pdf>, accessed 9 December 2019.

20. Tyler Rogoway, 'Audio From The 1999 Shoot Down Of F-117 "Vega 31" Over Serbia Is Chilling', *The Warzone*, 24 August 2017, <<https://www.thedrive.com/the-war-zone/13766/audio-from-the-1999-shoot-down-of-f-117-vega-31-over-serbia-is-chilling>>, accessed 26 November 2019.

21. Author interviews with senior Israeli defence officials, Tel Aviv, July 2019.

traditional approach in terms of openly contesting Israeli incursions.²² However, this creates the potential for the development of new asymmetric tactics. Israeli warplanes are highly unlikely to directly strike Russian-manned radar systems due to the political fallout that would ensue, meaning there is little beyond high-level political risk calculations to prevent those same Russian radar systems providing target data to concealed Syrian SAM batteries. This would enable them to more accurately and safely engage Israeli aircraft without having to reveal their own location ahead of launch by turning on their own fire control radars. This tactic does not appear to have been employed in combat by Russian forces in Syria so far, contributing to the comparative ineffectiveness of Syrian forces against Israeli incursions. However, this may well have changed since the accidental, fatal shooting down of a Russian Il-20 electronic warfare and reconnaissance aircraft by a Syrian SAM attempting to respond to Israeli strikes in September 2018.²³ In the aftermath of the incident, Russia expressed its intention to take an active role in upgrading the Syrian IADS, which might well include providing radar and identification friend-or-foe data from their own radars.²⁴

Today, air forces which aspire to field effective SEAD and DEAD capabilities must plan to encounter both IADS adopting a traditional national or battlefield airspace denial doctrine, and forces employing concealment and potentially third-party-supplied targeting information to pose an enduring pop-up threat in a given area of operations. A political inability to target third-party radar sites providing plausibly deniable tracking data to hostile SAMs could become a significant feature of future proxy conflicts, necessitating the development of new SEAD/DEAD tactics or greater political risk appetites. However, the most dangerous strategic-level A2/AD threat remains that posed by IADS operated in a more traditional manner by peer-competitor states as part of a national airspace defence construct.

22. Author interviews with senior Israeli defence officials, Tel Aviv, July 2019; author interviews with senior serving and civilian defence officials, Washington, DC, July 2019.

23. *BBC News*, 'Russia Blames Israel After Military Plane Shot Down Off Syria', 18 September 2018.

24. Vladimir Karnozov, 'Russia Modernizes Syrian Defenses in the Wake of Il-20 Shootdown', *A/IN Online*, 25 September 2018, <<https://www.ainonline.com/aviation-news/defense/2018-09-25/russia-modernizes-syrian-defenses-wake-il-20-shootdown>>, accessed 26 November 2019.

II. How Russia and China Use Integrated Air Defence Systems

Russia's Integrated Air Defence Systems as a Tool of National Power

SINCE THE MID-COLD War, Russia has relied much more heavily than the West on ground-based air defences as a core pillar of its great-power competition strategy. With long land borders to the east, south and west, the Soviet Union and later the Russian Federation saw a multi-layered IADS as essential to its national defence capabilities. As Western dominance in the air environment increased following the end of the Cold War, Russian reliance on its IADS and the priority afforded to continued development and modernisation of the key systems has also increased. The admission of Poland and the Baltic states to NATO following the end of the Cold War, however, has significantly changed the potential importance of these traditionally defensive systems within the context of any standoff with Russia over these countries. The long engagement range offered by modern strategic SAMs allows Russia to threaten NATO's freedom of access to much of the airspace of these Eastern member states without the systems themselves ever leaving Russian territory, especially from the enclave of Kaliningrad.

This capability is provided in large part by two 400-km-class missiles; the 40N6 and 9M82MD, which have been developed for firing by the SA-21 and SA-23 respectively. Both the SA-21 and SA-23 are designed to fire a range of missiles out of common launcher tubes to cover multiple engagement range brackets and target types. For example, the SA-21 uses the 400-km-range 40N6 missile, the 250-km-range 48N6E3, as well as the much smaller and more agile 120-km-range 9M96E2 and 40-km-range 9M96E.¹ This design philosophy allows these strategic SAM systems to save the largest, most expensive missiles for the engagements where extra reach is really needed, using medium- and short-range missiles wherever possible. The smaller size of the medium- and short-range missile types also allows more ammunition to be carried in launch tubes, ready to fire, per battery than if all missiles carried were the very-long-range types.

The Russian Ministry of Defence officially accepted the 40N6 for active service in October 2018, and it has also been sold to China to equip the latter's SA-21 systems which were previously supplied by Russia.² There is much less clarity around the status of the 9M82MD, which may or

1. Army Technology, 'S-400 Triumph Air Defence Missile System'.

2. TASS, 'Advanced Long-Range Missile for S-400 System Accepted for Service in Russia', 18 October 2018, <<https://tass.com/defense/1026630>>, accessed 3 September 2019; Joseph Trevithick, 'Is a Batch of Russia's Most Advanced Surface to Air Missiles Sitting on the Sea Floor?', *The Warzone*, 18 February 2019, <<https://www.thedrive.com/the-war-zone/26540/is-a-batch-of-russias-most->

may not yet have entered service since its acquisition was disclosed in 2016.³ However, since the 40N6 has now entered service it seems fair to assume that Almaz-Antey – the parent company for the design bureaus which manufacture both the 40N6 and 9M82MD – has managed to solve the active seeker guidance, cueing and aerodynamic control issues surrounding this class of hypersonic long-range SAM. Since a long-range equivalent to the SA-21's 40N6 for the SA-23 remains a priority for Russian IADS planners, the 9M82MD will likely enter service soon if it has not already.⁴ Not content with having developed the SA-23 and SA-21 as the backbone of its long-range 'strategic' SAM systems, Russia is actively testing an even longer-ranged derivative with greater anti-ballistic missile capabilities, named the S-500. As if to illustrate Russian long-range SAM design capabilities, a prototype S-500 system successfully destroyed an aerial target from a distance of almost 500 km during testing in 2018.⁵ Due to the radar horizon issues discussed previously – as well as different target speeds, altitudes and headings – the range of these systems in practical terms is often significantly less than advertised. This is especially true against low radar cross-section (RCS), highly agile and aware targets such as fighter aircraft, but this should not distract from the fact that Russian strategic SAMs can project a high-threat MEZ over hundreds of kilometres, especially against enabler aircraft like tankers and AWACS. Radars positioned further forward or on raised terrain can cue in long-range active missile shots, and A-50M Mainstay and Mig-31BM Foxhound interceptors could potentially supply targeting data unaffected by the radar horizon if successfully datalink-connected to the ground-based IADS.

Russia has also been investing heavily in developing and upgrading a wide variety of different radar types, both for use as part of SAM systems, and as standalone systems to feed into the IADS as a whole. In the past fifteen years, most have been specifically designed to improve detection ranges against low-observable (stealth) and low-flying targets including fifth-generation fighters and modern cruise missiles. Any stealth aircraft design is a compromise between aerodynamic properties and visibility from different angles, in various parts of the electromagnetic spectrum. For example, the American F-22 Raptor is extremely difficult to detect from almost any angle in the X-band of the electromagnetic spectrum which is typically used in fire control radars. However, its airframe shaping is less effective at reducing returns when illuminated by radars in the metre and decimetre wavelengths. On the other hand, radars operating at significantly

advanced-surface-to-air-missiles-sitting-on-the-sea-floor>, accessed 3 September 2019; Andrei Akulov, '40N6 Interceptor Added to the Russian Military's Arsenal: A Qualitative Leap Forward in Air-Defense Technology', Strategic Culture Foundation, 2 November 2018, <<https://www.strategic-culture.org/news/2018/11/02/40n6-interceptor-added-russian-military-arsenal-qualitative-leap-forward-in-air-defense-technology/>>, accessed 3 September 2019.

3. Interfax, 'S-300V4 Air Defense Missile System to Get Three Types of Hypersonic Missiles – Almaz-Antey', 9 September 2016, <<http://www.interfax.com/newsinf.asp?id=700340>>, accessed 25 September 2019.
4. Author's own analysis but conclusion supported by senior serving and civilian defence officials during discussions with the author, Washington, DC, 9–12 July 2019.
5. Marc Bennetts, 'New Russian S-500 Prometheus Missile Flies Further Than Ever Before', *The Times*, 26 May 2018.

shorter or longer wavelengths face varying trade-offs in terms of effective range for a given power level, resolution and radar horizon.

The Russian approach has been to develop multiple classes of digital radar operating across a broad range of the radar spectrum, scanning for targets from multiple different angles and ranges to allow the returns to be cross-referenced. The idea is that this multi-static, multi-frequency approach will overcome many of the advantages of stealth aircraft by ensuring a sufficiently high effective resolution to allow detection and tracking at much greater ranges.⁶ A good example of this approach is the 3D Multiband RLM-M Nebo-M Radar which incorporates different frequency transmitter and receiver elements, as well as passive receivers to generate a multi-static, multi-frequency picture in one system.⁷ Naturally, the Nebo-M is designed to feed directly into either SA-21 or SA-23 battalions' command vehicles, and increase the long-range and anti-stealth capabilities of the whole IADS through them. Through this sort of innovative radar technology, it is likely that Russia's IADS in Eastern Europe has a limited capability to detect and track stealth aircraft like the F-22, B-2 and F-35 under certain conditions, albeit at much shorter ranges than traditional combat aircraft.⁸ This does not, however, translate directly into an ability to complete the kill chain by successfully guiding SAMs to intercept those stealth aircraft, which are themselves highly lethal, mobile and designed specifically to destroy, evade or suppress strategic SAM systems. However, Russian radar technology will only continue to improve in this regard and true combat performance for both sides' systems under actual warfighting conditions is almost impossible to predict with certainty.

Russia's IADS is much more than simply strategic SAMs fed by a broad range of early-warning, anti-stealth and fire control radars. The mobile medium-range and short-range SAM systems which form part of every Russian army manoeuvre element are also a vital component. Systems like the medium-range SA-17 and short-range SA-15 and SA-22 ensure that any Russian brigade positioned ahead of a strategic SAM unit presents a formidable initial obstacle to any would-be SEAD mission.⁹ In an Eastern European context, this means that in any scenario where NATO forces were faced with massing or aggressive Russian ground forces, those Russian forces

-
6. 'Multi-static' in this case refers to a radar system which employs several different emitter and receiver arrays set up in physically different locations. This allows a target to be viewed and returns compared from multiple angles, which is an advantage against stealth aircraft and offers inherently improved resolution compared to monostatic or bistatic systems due to simple triangulation.
 7. For RLM-M Nebo-M and over-the-horizon radars, see Konstantinos Zikidis, Alexios Skondras and Charisios Tokas, 'Low Observable Principles, Stealth Aircraft and Anti-Stealth Technologies', *Journal of Computations & Modelling* (Vol. 4, No. 1, January 2014), pp. 153–55.
 8. Confirmed during multiple author interviews with F-22, F-35 and B-2 aircrew in London, Washington, DC and Paris, 2017–19.
 9. For SAM battery numbers and target engagement capacity of Russian battalions and divisions, see Igor Sutyagin and Justin Bronk, *Russia's New Ground Forces: Capabilities, Limitations and Implications for International Security*, RUSI Whitehall Paper 89 (London: Taylor and Francis, 2017), p. 30.

would not only be a challenge on the ground but act as an extension of the IADS. Significant numbers of medium-range SA-17 SAMs near the line of contact and the strategic long-range SA-21 and SA-23 batteries further back would mutually support and enhance each other's capabilities. Meanwhile, the presence of large numbers of short-range SAMs, man-portable air defence systems (MANPADS) like the SA-24 Igla-S and SA-25 Verba series, as well as point-defence systems like the SA-22 would make low-altitude flight extremely hazardous for both aircraft and cruise missiles over a considerable area.¹⁰ The SA-25 Verba MANPADS can be linked to the broader IADS through the system's automated control system, giving the operator helmet-fed indications of approaching enemy aircraft or helicopters before they are visible to the naked eye.¹¹ The presence of MANPADS and radar-guided AAA/point-defence SAMs such as the SA-22 Pantsir and SA-19 Grison make the low-level environment near Russian forces very dangerous for aircraft, whilst the larger SAMs are at their most effective against targets flying at medium altitudes and above. The SA-22 also provides integrated point-defence to SA-21 and SA-23 batteries, deploying with them to shoot down incoming cruise missiles and anti-radiation missiles.¹² This means that in addition to the challenges of finding and getting into weapons-range of an active strategic SAM battery within the IADS, SEAD/DEAD forces would need multiple near-simultaneous weapon deliveries to have a high Pk against each SAM asset. In other words, Russia could use the fact that its ground-force formations are extremely well provisioned with their own SAMs and other air defences such as MANPADS and radar-guided AAA, all of which can interface with the longer-range strategic SA-21 and SA-23 systems, to present a multi-layered challenge to NATO air forces in any Eastern European flashpoint scenario.

This multi-layered physical defence network made up of SAMs and AAA is further strengthened by sophisticated electronic warfare capabilities. The US Department of Defense notes that enemy (in this case Russian) IADS also contain systems designed to 'jam aircraft navigation, communications, target acquisition systems, and precision [guided] weapons'.¹³ Capabilities such as the Krasukha-4 1RL257 broadband jammer, the R-330Zh Zhytel GPS and satcom jammer and the SPR-2M RTUT-BM munitions-fuse jammer ensure that Western aircraft, sensor and

-
10. For the Verba's claimed capabilities and deployment plans, see Alexey Ramm, 'New Verba MANPADS Will Replace Russia's Legendary Igla-S', *Russia Beyond*, 12 September 2014, <https://www.rbth.com/defence/2014/09/12/new_verba_manpads_will_replace_russias_legendary_igla-s_39749.html>, accessed 4 October 2019. For system capabilities of Igla-S, see Rosoboronexport, 'Igla-S MANPADS 9K338', Air Defence Systems Catalogue, <<http://roe.ru/eng/catalog/air-defence-systems/air-defense-systems-and-mounts/igla-s/>>, accessed 4 October 2019.
 11. GlobalSecurity.org, '9M336 Verba (Willow)', <<https://www.globalsecurity.org/military/world/russia/9m336.htm>>, accessed 4 October 2019.
 12. For SA-22 details and capabilities, see Carlo Kopp, 'KBP 2K22/2K22M/M1 Tunguska SA-19 Grison /96K6 Pantsir S1/SA-22 Greyhound SPAAGM', Air Power Australia, 27 January 2014, <<https://www.ausairpower.net/APA-96K6-Pantsir-2K22-Tunguska.html>>, accessed 4 October 2019.
 13. US Joint Chiefs of Staff, *Countering Air and Missile Threats*, Joint Publication 3-01 (Washington, DC: Joint Chiefs of Staff, April 2017), p. 94.

weapons systems would be less reliable and suffer degraded performance compared to normal operational conditions in any operation against Russian forces.¹⁴

In broad strategic terms, this means that Russia can present a sufficiently dense and sophisticated IADS to make sustained NATO air operations over the Baltic states and significant parts of Poland prohibitively costly during the first phases of any military clash in the region. NATO relies very heavily on traditional fast jets such as the F-16, the Typhoon and the Rafale for much of its rapidly deployable firepower. This is a major regional advantage for Russian forces which rely on ground-based artillery and heavily armoured formations for the bulk of their firepower. The IADS coverage would also provide a buffer area of relatively safe airspace for Russian Aerospace Forces' fighters to operate against enemy ground forces during the first phases of any clash, despite said fighters being significantly technically and operationally outmatched by the leading NATO air forces in a head-to-head clash.¹⁵ NATO air forces would be able to mount a viable SEAD/DEAD effort with the help of a combination of stealth fighters like the F-35 and standoff munitions from air-, naval- and ground-based launchers. However, such an effort would need careful coordination as a joint force to achieve 'pulses' of temporary access into the IADS and slow degradation of key radars and C2 nodes. Getting all the required forces (most of them American) into theatre and ready to fight, with the required weapons stocks and enablers in place, would take weeks. The SEAD/DEAD campaign itself would take weeks to degrade the IADS to the extent whereby something like semi-permissive airspace could be established over the area of operations for non-stealth NATO aircraft. Such an effort would also require kinetic strikes on targets on Russian soil to destroy key radars and C2 facilities, with significant political risk and escalation implications.

With the first-mover advantage in terms of mobilisation and a greatly reduced distance for heavy forces to cover compared to US, UK, French or German forces, Russia can outmatch NATO on the

14. For example, see Samuel Cranny-Evans, 'Russia Trials New EW Tactics', *Jane's Defence Weekly*, 14 June 2019; Armyrecognition.com, 'Krasukha-4 1RL257 Broadband Multifunctional Jamming Station', 6 October 2015, <https://www.armyrecognition.com/russia_russian_military_field_equipment/krasukha-4_1rl257_broadband_multifunctional_jamming_station_electronic_warfare_system_technical_data_sheet_pictures_video_10610156.html>, accessed 27 November 2019; Armyrecognition.com, 'Russia Could Deliver Electronic Warfare Systems Moskva-1 and Rtut-BM to Iran', 15 November 2015, <https://www.armyrecognition.com/november_2015_global_defense_security_news_uk/russia_could_deliver_electronic_warfare_systems_moskva-1_and_rtut-bm_to_iran_11511151.html>, accessed 27 November 2019; Armyrecognition.com, 'R-330ZH Zhitel Jamming Cellular Satellite Communication Station', 5 April 2014, <https://www.armyrecognition.com/russia_russian_missile_system_vehicle_uk/r-330zh_zhitel_jamming_cellular_satellite_communication_station_technical_data_sheet_pictures_video.html>, accessed 27 November 2019.

15. For an in-depth examination of the Russian Aerospace Force's fighter capabilities against the leading NATO air forces, see Bronk, *The Future of NATO Airpower*, pp. 9–18.

ground in the Baltic states for the initial phase of any conflict.¹⁶ The strength of IADS for Russia, then, is that they offer a way to keep NATO's airpower occupied and at arm's length for the first weeks of any conflict. With most of NATO airpower committed to SEAD/DEAD efforts and only able to achieve temporary inroads into the defences in large, pre-planned strike packages rather than ranging freely over the battlespace, IADS offer Russia enough potential breathing space to establish a *fait accompli* on the ground. As a result, it helps an otherwise strategically outmatched military power to project a credible military threat to NATO's Eastern flank.

China's Evolving Integrated Air Defence Systems Strategy

From the Korean War until the mid-2000s, China's entire air force and ground-based air-defence capability was heavily dependent on supplies of Soviet and later Russian equipment, specialists and training.¹⁷ However, with the rapid maturation and modernisation of the People's Liberation Army (PLA), the People's Liberation Army Navy (PLAN) and the People's Liberation Army Air Force (PLAAF) under President Xi Jinping, China has begun to exhibit equipment and tactics which are distinct from Russian equivalents.¹⁸

China has procured the Russian SA-21 and continues to import Russian missile and aircraft technology. It has also developed its own equivalent to the SA-20 (S-300), called the HQ-9.¹⁹ Essentially, the HQ-9 is a hybrid design based on a Russian SA-20 but with radar, seeker head and C2 elements heavily influenced by American and Israeli technology. The latter have been acquired through obscure channels but it is likely to involve a mix of cyber theft, conventional espionage and dual-use technology transfer.²⁰ With a significantly more capable domestic micro-electronics industry than Russia, China has been able to rapidly reduce dependency on Russian radar and processing systems, fielding its own systems for early-warning and wide-area surveillance right down to missile seeker heads.²¹ One example is the FT-2000 which is a domestically developed anti-radiation homing SAM, derived from the SA-20 missile series but with a new seeker head reportedly calibrated specifically to home in on the electronic emissions

16. For an in-depth force balance analysis, see Jack Watling, 'The Future of Fires: Maximising the UK's Tactical and Operational Firepower', *RUSI Occasional Papers* (November 2019).

17. Andreas Rupprecht, *Modern Chinese Warplanes: Chinese Air Force – Aircraft and Units* (Houston, TX: Harpia Publishing, 2018), pp. 12–19.

18. Author interviews with Japan Air Self Defence Forces SMEs, Tokyo, 12–13 June 2019.

19. Franz-Stefan Gady, 'China Makes Progress in Induction of Second S-400 Air Defense System Regiment', *The Diplomat*, 27 May 2019.

20. Author interviews with civilian academic and professional Chinese military specialists and military PLAAF experts, Washington, DC, 20–23 February 2019. For more detail on Chinese military and dual-use technology espionage activities, see 'Military and Security Developments Involving the People's Republic of China 2019', Office of the Secretary of Defense Annual Report to Congress, 2 May 2019, pp. 102–104, <https://media.defense.gov/2019/May/02/2002127082/-1/-1/1/2019_CHINA_MILITARY_POWER_REPORT.pdf>, accessed 4 December 2019.

21. Author interviews with Japan Air Self Defence Forces SMEs, Tokyo, 12–13 June 2019.

from AWACS aircraft and the US Navy's specialised EA-18G Growler electronic attack fighter.²² Another is China's development and rapid fielding of a range of active electronically scanned array (AESA) and active phased array radar sensors for ground-based, naval and airborne platforms²³ – something Russia has so far failed to achieve.

The HQ-9 series and its naval variant, the HHQ-9 series, have so far failed to achieve the range and hypersonic performance of the latest generation of Russian SAMs such as the 40N6 and the 9M82MD, being limited to around 300 km with the latest HQ-9B against non-maneuvrable high-altitude targets.²⁴ However, they are starting to benefit greatly from advances in Chinese radar technology compared to their Russian equivalents. AESA radars such as the Type 305A used since the early 2010s with the HQ-9 offer significantly improved resolution, scan speed, multiple simultaneous target tracking and jamming resistance compared to older phased array designs.²⁵

In pursuit of improved anti-ballistic missile defence capabilities, China has also been aggressively pursuing improvements in long-range acquisition and high-resolution tracking of small, fast targets for its upgraded HQ-19 system²⁶ – properties which are likely to contribute to improvements in overall IADS situational awareness and lethality.

China has also been investing extensive manpower and resources in a range of multi-spectral sensors. From metre and decimetre band radars, PCL radar types which rely on detecting reflections of background emissions such as mobile phone networks from targets, to quantum-phenomena radar techniques, China's efforts to uncloak American stealth aircraft are already surpassing those undertaken by Russia.²⁷ PCL has seen significant progress in recent

22. Missile Defense Advocacy Alliance, 'HQ-9', <https://missiledefenseadvocacy.org/missile-threat-and-proliferation/todays-missile-threat/china-anti-access-area-denial-coming-soon/hq-9/#_edn5>, accessed 4 October 2019.

23. Examples of AESA radar-equipped PLAAF platforms reportedly include the J-20A, J-10C, J-16 and KJ-200. Within the PLAN, the Type 055 DDG and latest Type 052D DDGs are also likely to be AESA equipped; Sidharth Kaushal and Magdalena Markiewicz, 'Crossing the River by Feeling the Stones: The Trajectory of China's Maritime Transformation', RUSI Occasional Papers (October 2019), pp. 54–59. The original source of the first PLAN AESA prototype was Ukraine (noted by Sarah Kirchberger, Head of the Centre for Asia-Pacific Strategy and Security, speaking at an Atlantic Council conference on fifth generation air power, Berlin, 7 October 2019).

24. Missile Defense Advocacy Alliance, 'HQ-9'.

25. For details on the Type 305A and other HQ-9 radar types, see Carlo Kopp and John Wise, 'HQ-9 and HQ-12 SAM System Battery Radars', Air Power Australia, <<http://www.ausairpower.net/APA-HQ-9-12-Battery-Radars.html#mozTocId91258>>, accessed 4 October 2019. It is likely that the Type 305A, HT-233 Fire Control Radar and other HQ-9 compatible radar systems have been significantly refined and improved since Copp and Wise completed their Technical Series in 2014.

26. Dave Majumdar, 'Why China's New Air Defense System Could be Quite Dangerous', *National Interest*, 16 July 2018.

27. Author discussions with American radar operational analysis SME, London, 9 October 2019.

years, with real-world tracking tested successfully against low- and high-altitude targets over a wide range in the US, Germany, Italy, and China.²⁸ The frequencies that can be used to track returns in a PCL system cover a much broader part of the electromagnetic spectrum than traditional radar systems, allowing better performance against stealth shapes. Though many of the technologies being explored are unlikely to succeed, China has the resources and focus to ensure that over time, at least some will bear fruit and increase the difficulties posed by its IADS to stealth aircraft. Of course, progress in radar technology also means that legacy types with non-stealth designs will be detectable and targetable at even longer ranges than they are currently.

The PLAN is also a key component of China's IADS in a way the Russian Navy is not. Despite serious issues with inter-service connectivity and joint exercises, China's strategy for its land-based and naval IADS coverage is closely linked.²⁹ SA-21, HQ-9 and other medium-ranged SAM systems like HQ-16 are generally deployed near the coast, especially around the Taiwan Strait, but are also now regularly identified on China's various artificial reef outposts.³⁰ This strategy is coupled with deployments by rapidly increasing numbers of guided missile destroyers such as the Type 052C/D and Type 055 which – like their US Navy *Arleigh Burke* and *Ticonderoga* equivalents – are mobile IADS in and of themselves with powerful, modern radars, HHQ-9, HHQ-16 and various short-range defence systems integrated on each vessel.³¹

China is not yet able to directly link its land-based and naval SAM systems in real time to exploit CEC techniques like the US Navy.³² Moreover, the PLAAF and PLA are unable to operate JEZs where aircraft and SAM units can engage targets in the same block of airspace simultaneously.³³ This means that, for now, the system as a whole is unlikely to be as lethal or resilient against determined SEAD or DEAD efforts as Russia's IADS. However, the combination of a growing PLAN presence, mainland defences and forward reef deployments are creating a dynamic and multi-layered IADS well beyond China's shores towards the First Island Chain. The fact that the various components of China's IADS are not as well networked at present compared to their Russian equivalents may also mean that successful electronic warfare or cyber attacks against one node might do less damage to the functioning of the network as a whole.

28. For more information, see Griffiths and Baker, *An Introduction to Passive Radar*.

29. For more information, see Kaushal and Markiewicz, 'Crossing the River by Feeling the Stones'.

30. For satellite pictures of HQ-9 systems on Woody Island reef, see Thomas Shugart, 'China's Artificial Islands are Bigger (and a Bigger Deal) Than You Think', *War on the Rocks*, 21 September 2016, <<https://warontherocks.com/2016/09/chinas-artificial-islands-are-bigger-and-a-bigger-deal-than-you-think/>>, accessed 4 October 2019.

31. Kaushal and Markiewicz, 'Crossing the River by Feeling the Stones', pp. 54–59.

32. Author interviews with PLA SMEs, Washington, DC, February and July 2019 and Tokyo, June 2019. See also Kaushal and Markiewicz, 'Crossing the River by Feeling the Stones', p. 57.

33. Author interview with Ken Allen, Research Director of China Aerospace Studies Institute, National Defense University, Washington, DC, 20 February 2019.

China is also supplementing its IADS with a much more aggressive and technologically advanced air force modernisation programme than the Russian Aerospace Forces can manage. With three modern AWACS types, operational fifth-generation fighters and the Soar Dragon and Divine Eagle radar-surveillance high-altitude UAVs, as well as experiments with quantum radar, China is casting its technology-experimentation net wide to increase its chances of seriously challenging US aerial dominance within 1,000 km or so of the mainland.³⁴ With the scale and rapid rate of iteration common across the PLAAF and PLAN's equipment modernisation programmes showing no sign of abating, the threat from China's IADS to the US and its allies' military freedom of action in the Pacific will only increase in the coming decade. China can already boast a multi-layered and unpredictable IADS which can threaten modern combat aircraft far from the mainland, and – unlike Russia – is also rapidly building an air force designed to enable aggressive power projection beyond its borders. When, as opposed to if, China can link its ground-based, maritime and aerial assets at a technical and operational level, it will be a formidable challenge for even the US Air Force and US Navy, able to contest airspace over 1,000 km from the mainland.³⁵

In the long term, the Chinese aim seems to be to establish both maritime and aerial dominance within the First Island Chain and provide a buffer zone from which to project power and keep potential enemy forces occupied far from the mainland.

34. The AWACS types are the KJ-2000, KJ-200 and KJ-500. The J-20A is now operational and for details on Divine Eagle and Soar Dragon see Tyler Rogoway, 'China's Reported Plan To Deploy Weaponless Stealth Drones on its Carriers Make Perfect Sense', *The Warzone*, 25 September 2019, <<https://www.thedrive.com/the-war-zone/30020/china-deploying-a-weaponless-stealth-drone-on-its-carriers-makes-perfect-sense>>, accessed 4 October 2019. For debates about the potential viability and capabilities of quantum radar, see Heidi Vella, 'Could Quantum Radars Expose Stealth Planes?', *Engineering and Technology*, 18 April 2019, <<https://eandt.theiet.org/content/articles/2019/04/could-quantum-radars-expose-stealth-planes/>>, accessed 4 October 2019.

35. Author interview with serving and civilian SMEs, Washington, DC, July 2019.

III. Suppression and Destruction of Enemy Air Defences in the Modern World

SEAD IS A term first coined during the Vietnam War, when units of specially modified US Air Force and later US Navy and Marine Corps aircraft were formed with the express purpose of seeking out and destroying North Vietnamese SA-2 SAM sites. As the range, radar performance and countermeasure resistance of SAMs have grown, so the SEAD role has evolved, and there are several different approaches which air forces can take towards the threat posed by air defences in the 21st century. As has already been described in detail, an isolated SAM system is a far cry from the threat posed by the same system operating within an IADS, and the latter poses a much greater threat to aircraft engaged in SEAD or DEAD missions. SEAD involves the suppression of enemy SAMs by various methods, but is generally only aiming to temporarily create the conditions for friendly aircraft to enter defended airspace to conduct a mission. By contrast, DEAD missions aim to physically destroy SAM systems and radars, which can be more difficult but produces a more lasting degradation of an IADS over time.

Before considering the exact SEAD and DEAD approaches available to modern air forces, it is important to clarify that, if possible, most forces will simply opt to avoid known SAM systems rather than attempting to suppress or destroy them. If the SAM is not a threat to ongoing missions, then it is generally safer and cheaper to bypass it. However, with the increasing range of modern SAM systems, as well as their mobility, it is getting harder for aircraft to simply avoid threats. It is difficult to know where these systems are at all times, and their ability to pose a long-term pop-up threat – even if not immediately a problem when first detected – may lead commanders to order their destruction to reduce the risk to later sorties. If SAM systems or a broader IADS is covering strategically or operationally important airspace and ground assets, then SEAD/DEAD may become a necessity.

The first SEAD/DEAD approach to outline is perhaps the most traditional – remaining outside the engagement range of a SAM system or broader IADS and attempting to fire long-range missiles at the most important radars and launchers to suppress or destroy them. Known as a ‘standoff attack’, this method relies on two main conditions being met. The first is that the SAM systems and radars in question can be accurately detected, identified, located and tracked to enable a missile to hit them from beyond their effective engagement range. Radar warning receivers (RWRs) on modern combat aircraft passively ‘listen’ for the radar emissions of enemy systems and then try to identify and, if possible, give bearing and range information. Those on SEAD aircraft are more specifically optimised for detection of SAM radars, and in previous generations multiple aircraft would work together, sharing and cross-referencing bearing information from each to triangulate a SAM’s exact position. More modern aircraft like the F-35 can automatically

calculate changes in bearing over time to enable location and ranging rapidly even with only a single aircraft, whilst the F-35's multi-function advanced data link software allows it to blend both techniques to triangulate extremely accurately when flying in widespread formations.¹

Location fixing was difficult enough when SAMs ranges were limited to a couple of tens of kilometres, but against strategic SAMs like the SA-21 and SA-23 with ranges in the hundreds of kilometres, this is a real challenge. In terms of the ability for aircraft to actively search for SAM radars which are not emitting, it is important to remember that the radar horizon also affects aircraft, meaning that if the on-board sensors (usually radar) are able to see the SAM system, then it can also potentially see them unless they are very-low observable. Likewise, if the aircraft is flying very low to minimise the range at which the SAM system will detect it, then the aircraft's own radar will also be limited by a very short radar horizon. Passive detection, relying on the SAM system's own emissions, is also getting more difficult as Russian and Chinese systems are equipped with modern digital and frequency-agile radars. With modern datalinks, however, aircraft or other launch platforms for standoff missiles (such as ground-based rocket launch systems or naval vessels) can be sent the target coordinates from other assets, such as satellites or other aircraft. This third-party targeting data can enable a standoff launch without a direct sensor view of the target.

The second dependent variable is whether the launch platform can get within range to launch its own missile at the SAM system or radar without being detected, tracked and destroyed first. Missiles have a longer range the higher and faster they are launched, especially if they are rocket powered rather than jet powered. This is because a high and fast launch gives the missile plenty of kinetic energy to start with, and because rocket motors only burn for a short amount of time, accelerating a missile to a very high speed but leaving it to 'coast' for the majority of flight on what energy the initial burn imparted. By contrast, a missile equipped with a jet engine can cruise for long periods but generally at a much slower average speed. The US Navy's advanced anti-radiation guided missile (AARGM) is an example of a modern rocket-powered standoff missile designed to seek out and destroy radars, whilst the MBDA Storm Shadow cruise missile is a modern jet-powered standoff weapon which can be used for SEAD/DEAD but can also hit other fixed targets using multiple guidance methods.² However, jet-powered missiles are slower in flight than rocket-powered ones, which is a factor to consider when attempting standoff attacks against modern mobile SAM systems. If a subsonic cruise missile is launched 400 km away from an SA-21 to ensure they stay completely out of range, for example, then the missile will have a flight time to target in the region of 30 minutes, giving plenty of time for the SA-21 to

-
1. Author briefings by Lockheed Martin operational analysis specialists, Fort Worth, TX, February 2019.
 2. For technical details on AARGM, see Northrop Grumman, 'Advanced Anti-Radiation Guided Missile (AARGM) – Standard and Extended Range', <<https://www.northropgrumman.com/Capabilities/AARGM/Pages/default.aspx>>, accessed 9 October 2019. For Storm Shadow, see MBDA Missile Systems, 'Storm Shadow/SCALP', <<https://www.mbda-systems.com/product/storm-shadow-scalp/>>, accessed 9 October 2019.

move before the missile arrives and avoid the missile's terminal guidance sensor field of view.³ This means that there is an additional requirement when attempting standoff attacks against mobile systems, to be able to pass real-time target position updates to the missile in flight.

An emerging new approach to standoff attacks against air defence systems is to employ large numbers of smaller munitions which are powered by either small jet or propeller engines, have wings and can seek out and destroy targets as a swarm. Loitering munitions such as the Israeli Harpy have been around for decades, but with relatively unsophisticated anti-radiation seekers which simply home in on enemy radar emissions. Today, advances in micro-electronics and seeker head miniaturisation have enabled loitering munitions to combine anti-radiation seekers with electro-optics, GPS guidance and limited target classification and prioritisation capabilities. Examples include the IAI Harop and the UK's upcoming SPEAR 3 mini-cruise missile family.⁴ These systems offer advantages in terms of cost and how many can be carried per launch aircraft compared to large cruise missiles or traditional anti-radiation missiles. However, they are fundamentally constrained in terms of range by their small size, with even the more sophisticated examples like SPEAR 3 and Harop limited to around 140 km compared to well over 400 km for Storm Shadow. On the other hand, if they can be carried close enough to major components of an IADS to be launched without interception, they do offer a potent means of saturating defences with large numbers of small munitions in a very short time. As automatic target recognition, prioritisation and swarm coordination technology improves, this form of standoff SEAD/DEAD attack will continue to get more potent, though range limitations will remain, placing a premium on launch platform survivability well inside the theoretical launch range of most high-threat SAMs.

The second SEAD technique is to use electronic warfare, or jamming, to try to degrade the ability of the radars and missiles making up an IADS to function as intended. As with standoff attacks, identification of the enemy threat systems is usually a prerequisite for successful SEAD through electronic warfare, as the jamming signal must be tailored to the correct frequency and waveforms. Dedicated standoff electronic warfare aircraft such as the US Navy's EA-18G Growler carry advanced RWRs and signal analysis capabilities in addition to their large external jamming pods which emit high-powered jamming signals to disrupt enemy radar and communications systems. Another approach is to use modified cruise missiles or loitering munitions with electronic warfare payloads in place of the usual explosive warhead. Examples include the MALD-X decoy/jammer missile and the upcoming SPEAR-EW.⁵ Such weapons are often known as stand-in jammers, and combine the ability to simulate the radar signature of larger jets in

3. Author's own calculations based on an assumed missile cruise speed of approximately Mach 0.92 at sea level.

4. For more details on the Harop and Harpy, see Yaakov Lappin, 'IAI Announces New Mini Harpy Loitering Munition', *Jane's Defence Weekly*, 19 February 2019. For SPEAR 3 and variants, see Robin Hughes, 'MBDA Discloses Development of SPEAR Variants', *Jane's 360*, 18 April 2019.

5. For SPEAR-EW, see Robin Hughes, 'MBDA Discloses Development of SPEAR Variants'. For MALD, see Raytheon, 'MALD Decoy', <<https://www.raytheon.com/capabilities/products/mald>>, accessed 10 October 2019.

decoy modes, or exploit the fact that jamming is more effective the closer the jamming platform is to the target radar by carrying out targeted disruption against enemy SAM systems from close ranges – often in conjunction with kinetic attacks by traditional standoff munitions.⁶

Both standoff and stand-in electronic warfare systems rely on national or allied signals-intelligence analysis and exploitation capability, to allow new enemy radar emissions to be analysed after being recorded by an EA-18G or another asset. Once the new emissions are identified, specific mission data files need to be written and updated on the electronic warfare aircraft and stand-in jammers to give their systems the ability to recognise and jam that signal in the future. This all takes time and resources, and each time a SAM radar is updated with new radar waveforms or engagement modes, the process must be done again, leading to an almost endless cat-and-mouse game between IADS operators and electronic warfare specialists looking to facilitate SEAD efforts. Given that any advantages gained by either brute-force signal jamming or more subtle electronic attacks to interfere with SAM systems will only be temporary, electronic warfare alone is seldom sufficient for SEAD tasks. However, the ability to degrade enemy radar and seeker head performance is extremely valuable, so electronic warfare remains a vital component of almost all SEAD/DEAD techniques.

Cyber attacks also form part of some states' ability to degrade IADS, at least temporarily. Like jamming, cyber attacks generally aim to degrade or temporarily destroy key radar or C2 nodes to create a temporary opportunity to breach the broader IADS.⁷ However, unlike jamming, cyber attacks use the insertion of malicious code rather than high-energy jamming to disrupt or gain control of key nodes within an IADS. This code can be introduced to the IADS in multiple ways, from covert agents to aerial transmission using specialised AESA radars from aircraft directly to the target radar receiver. Like jamming, however, this technique relies on having an excellent knowledge of the system architecture of the radar, SAM system or command node being attacked, and how it interfaces with the rest of the IADS. Furthermore, once used, the enemy forces will not only work quickly to bring the system back online but will also discover the cyber weapon in their system and patch the vulnerability that allowed it to function effectively – making cyber payloads one-shot weapons with effects that are often only temporary.⁸

The third SEAD/DEAD technique is to employ aircraft with very low observability to radar (stealth) properties to greatly reduce the ranges at which the various components within an IADS can detect them. This does not make aircraft invisible, but by reducing detection ranges dramatically, can open up corridors through the various threat systems within an IADS which would not be viable for conventional aircraft. This can enable stealth aircraft to either get close enough to key radars and other threat nodes in an IADS to attack them directly with their own internal weapons, or at least to use their own sensors to precisely locate, identify and track those radars for standoff attacks by others. When combined with the other two techniques already discussed, stealth aircraft offer a

6. Tyler Rogoway, 'Recent MALD-X Advanced Air Launched Decoy Test is a Much Bigger Deal Than it Sounds Like', *The Warzone*, 24 August 2018.

7. Sharon Weinberger, 'How Israel Spoofed Syria's Air Defense System', *WIRED*, 4 October 2007.

8. Author interview with retired military officer previously involved in the UK's Offensive Cyber programme, London, 21 May 2019.

huge advantage to any SEAD/DEAD force, providing the 'eyes' inside the IADS to guide standoff weapons to their elusive mobile SAM and radar targets and contributing their own direct attacks where possible. Having electronic warfare capabilities to disrupt the enemy IADS only increases the ability of stealth aircraft to get closer to threats with a low probability of detection, and the F-35, in particular, also has potent electronic warfare capabilities of its own to bring to the fight.⁹

It is important to remember that even with modern stealth aircraft like the F-22, F-35 and B-2, thorough mission and strike package planning and coordination, supported by in-depth standoff analysis of the IADS, is essential for SEAD/DEAD missions against a modern IADS. Successfully coordinating all the elements required for successful SEAD/DEAD necessitates not only the right equipment, but also forces which are well trained, have exercised regularly as a coalition in realistic conditions and are given the requisite political freedom of action to carry out strikes on enemy territory. Given the size and complexity of Russia's and China's IADS, and the limited availability of air-launched standoff munitions in NATO's inventories, long-range precision fires contributed by naval and ground forces would significantly improve the ability of NATO forces to rapidly degrade these networks. However, as with air-launched standoff munitions, ground-launched or naval precision strikes would still require real-time target location and track data to reliably hit elusive, mobile SAM radar targets. These will have to be mostly supplied by air forces, adding a networking requirement to be able to pass track-quality target data from air assets inside the IADS to friendly joint force assets without revealing their position.

It is also worth remembering that while the scenario of having to fight into a modern IADS as a joint force can seem like a remote possibility in the context of a war against Russia or China, these systems are proliferating rapidly around the world, with Iran, Turkey, Algeria, India, Egypt and Venezuela having acquired SA-21s or SA-23s in recent years.¹⁰ Many of these states also either already operate or are acquiring a range of medium- and shorter-ranged SAM systems and even capable electronic warfare systems. Fundamentally, IADS are a comparatively cheap way to raise the costs of intervention by airpower-dependent hostile powers so they are likely to continue to be a tool of choice for near-peer and sub-peer states over the following decades. In other words, having to fight against a modern IADS may soon be the theatre-entry standard for intervention operations around the world, rather than solely a spectre of peer conflict against great powers.

9. Author briefings from Lockheed Martin SMEs, Fort Worth TX, 18 February 2019.

10. For example, see IsraelDefense.co.il, 'Egypt Receives First S-300VM Air Defense Missile System from Russia', 6 August 2017; Hannah Lucinda Smith, 'Turkey Tests Russian S-400 Missile System on US-Made F-16 Jets', *The Times*, 26 November 2019; Franz-Stefan Gady, 'India Makes \$800 Million Advance Payment for Russian S-400 Air Defense Systems', *The Diplomat*, 20 November 2019; *Times of Israel*, 'Iran Gets First Missile Shipment for S-300 System', 18 July 2016.

Conclusion

DESPITE BEING COMPOSED of similar SAM systems and sensor capabilities, the long-term threats posed by the IADS fielded by Russia and China are subtly different. Russia has more capable long-range SAMs at present, and its IADS is better integrated to allow different elements to mutually support each other in offence and defence, and to cross-cue missile shots to overcome radar horizon limitations. The use of a variety of multi-static, multi-frequency radar systems to feed data into the IADS has probably given Russia a limited ability to detect and track NATO stealth aircraft at close ranges and from certain angles. However, it is highly unlikely that this translates into an ability to complete the kill chain against such targets, assuming the latter are competently flown, at least for now. For Russia, the IADS is a fundamentally static construct composed of mobile elements. It is designed to defend Russian airspace and to give the Kremlin an ability to threaten aircraft with long-range missiles some distance inside neighbouring countries' airspace and in the Baltic from behind a multi-layered and sophisticated network of medium- and short-range SAMs. It is also a critical part of the Russian Ground Forces' plans to be ready to fight or coerce NATO forces in Eastern Europe, by forcing NATO's air forces to spend the first critical weeks of any conflict engaged in a protracted, costly and politically high-risk SEAD/DEAD campaign rather than attacking ground forces and strategic objectives inside Russia.¹ The IADS also offers the otherwise heavily outclassed Russian Aerospace Forces a window to operate against NATO ground forces in the Baltics or Poland during those crucial first few days and weeks without being completely overwhelmed by superior NATO air superiority patrols. For NATO states, having answers to the Russian IADS is, therefore, a central part of any militarily coherent plan for the defence of Eastern European members of the Alliance during any conflict with Russia.

The Chinese IADS is a different problem, and one which is closely linked to China's wider military ambitions to be able to restrict freedom of action for the US and its regional allies to the airspace and maritime territory within the First Island Chain. Despite slightly inferior SAM technology compared to the latest Russian SA-21, the Chinese are now pulling ahead in terms of radar and sensor technology. They are also better placed to pursue true multi-spectral sensor fusion than Russia due to a much larger and more advanced domestic electronics industry. Advances in sensor technology are being supported by a creative and wide-ranging approach to new platform applications including fighter aircraft, AWACS, high-altitude UAVs and space-based systems. While not able to combine maritime-, air- or land-based sensor and shooter platforms in joint engagements yet, China is able to project a more varied and geographically extensive IADS than Russia. This is thanks to a mixture of mainland coastal SAM sites, sites on artificial reefs throughout contested maritime areas, and a rapidly growing and increasingly capable PLAN task group presence inside the First Island Chain. Coupled with the rapid modernisation

1. Andrei Afanasevich Kokoshin, 'Strategic Nuclear and Nonnuclear Deterrence: Modern Priorities', *Herald of the Russian Academy of Sciences* (Vol. 84, No. 2, March 2014), pp. 59–68.

and professionalisation of the PLAAF, the ability for the US and its allies to project airpower within 1,000 km of China's mainland shore in a conflict will shrink dramatically on current trends through the 2020s.

IADS are not impenetrable, however. When employed correctly, stealth aircraft, standoff munitions and electronic attacks can suppress and degrade an IADS for a finite period of time in a limited area to enable strike packages to get through to their targets. However, completely rolling back an IADS the size, depth and complexity of those of Russia or China would most likely take weeks and possibly months of full-scale warfighting. Furthermore, the experience of SEAD campaigns against Serbia and Syria would suggest that eliminating pop-up threats from isolated SAM systems altogether would be almost impossible without victory on the ground.

No state except for the US can afford to field all the potential force elements required for high-end SEAD/DEAD missions against Russian or Chinese IADS. However, the threat to the credibility of NATO's collective defence capabilities in Eastern Europe is sufficiently severe that European NATO members should take urgent steps to improve the quantity and readiness of the force elements within their national air forces optimised for this crucial mission set. The Alliance is highly unlikely to change the dynamic of heavy dependence on airpower for warfighting credibility, and so needs to have more comprehensive answers to the challenge posed by Russia's IADS to its aerial freedom of action in the event of a crisis. Likewise, for the US, China's increasingly capable and far-reaching IADS presents a serious challenge to its decades-long air and maritime strategy in the Asia-Pacific, and hence will be a major driving force behind US Air Force and US Navy modernisation efforts.

Modern IADS, as capable as they are, will not be able to prevent successful SEAD/DEAD in the long term in most conflict scenarios. However, their influence over future force structure planning and military options for the airpower-dependent West in the initial phases of any great-power conflict makes them a critical phenomenon to understand for defence planners and policymakers.

About the Author

Justin Bronk is a Research Fellow for Airpower and Technology in the Military Sciences team at RUSI. He is also Editor of the *RUSI Defence Systems*. Justin has written on airpower issues for the *RUSI Journal*, *RUSI Defence Systems*, *RUSI Newsbrief*, *Journal of Strategic Studies* and the *RAF Air Power Journal*, as well as contributing regularly to international media.