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The Russian Air War and Ukrainian Requirements for Air Defence

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Executive Summary

- Russian Aerospace Forces (VKS) conducted significantly more extensive fixed-wing strike operations during the first days of the invasion than has been previously documented, while Ukrainian ground-based air-defence (GBAD) capabilities were suppressed by initial attacks.
- During this period, Ukrainian fighter aircraft inflicted some losses on VKS aircraft but also took serious casualties due to being totally technologically outmatched and badly outnumbered.
- Russian fighters have remained highly effective and lethal against Ukrainian aircraft near the frontlines throughout the war, especially the Su-35S with the R-77-1 long-range missile and, in recent months, the Mig-31BM with the R-37 very long-range missile.
- From early March, the VKS lost the ability to operate in Ukrainian-controlled airspace except at very low altitudes due to its inability to reliably suppress or destroy increasingly effective, well-dispersed and mobile Ukrainian surface-to-air missile (SAM) systems.
- Russian GBAD has also been highly effective since March, especially the long-range S-400 SAM system supported by the 48Ya6 'Podlet-K1' all-altitude long-range surveillance radar system.
- Numerous man-portable air-defence systems (MANPADS) provided to Ukrainian troops and later mobile air-defence teams meant that low-altitude Russian fixed-wing and rotary penetrating sorties beyond the frontlines proved to be prohibitively costly during March, and ceased by April 2022.
- Throughout the war, most Russian airstrikes have been against pre-designated targets with unguided bombs and rockets. The Su-34 fleet has regularly also fired standoff missiles such as the Kh-29 and Kh-59 against fixed targets, and Su-30SM and Su-35S fighters have regularly fired Kh-31P and Kh-58 anti-radiation missiles to suppress and target Ukrainian SAM radars.
- Without air superiority, Russia's attempts at strategic air attack have been limited to expensive cruise and ballistic missile barrages at a much more limited scale. These failed to achieve strategically decisive damage during the first seven months of the invasion. However, the latest iteration is a more focused and sustainable bombardment of the Ukrainian electricity grid, blending hundreds of cheap Iranian-supplied Shahed-136 loitering munitions against substations with continued use of cruise and ballistic missiles against larger targets.
- The West must avoid complacency about the need to urgently bolster Ukrainian air-defence capacity. It is purely thanks to its failure to destroy Ukraine's mobile SAM systems that Russia remains unable to effectively employ the potentially heavy and efficient aerial firepower of its fixed-wing bomber and multi-role fighter fleets to bombard Ukrainian strategic targets and frontline positions from medium altitude, as it did in Syria.

- It follows that if Ukrainian SAMs are not resupplied with ammunition, and ultimately augmented and replaced with Western equivalents over time, the VKS will regain the ability to pose a major threat.
- In the short term, Ukraine also needs large numbers of additional MANPADS and radar-guided anti-aircraft guns, such as the Gepard, to sustain and increase its ability to intercept the Shahed-136s and protect its remaining power infrastructure and repairs to damaged facilities.
- In the medium term, Ukraine needs cost-effective ways to defend itself against the Shahed-136. One option could be compact radar and/or laser ranging and sighting systems to allow numerous existing anti-aircraft guns to be much more accurate and effective against them.
- The Ukrainian Air Force fighter force needs modern Western fighters and missiles to sustainably counter the VKS. Russian pilots have been cautious throughout the war, so even a small number of Western fighters could have a major deterrent effect.
- Any Western fighter supplied in the short–medium term needs to be capable of dispersed operations using mobile maintenance equipment and small support teams, and flying from relatively rough runways, to avoid being neutralised by Russian long-range missile strikes.

Introduction

WHEN RUSSIA BEGAN its full-scale invasion of Ukraine on 24 February 2022, it initiated the first large-scale peer conflict in Europe since the Second World War. The stakes are extremely high, as the outcome of the war will define not only the future of Ukraine and of Russia, but also the global geopolitical system.

Unsurprisingly, therefore, there has been an unprecedented degree of sustained global public, political, military and media interest driving external analysis of the war. Since the start of the invasion, military analysis in both public and professional communities has focused heavily on Russia's employment of ground forces.¹ This is logical since the Russian Ground Forces have done by far the most damage, possess most of Russia's conventional firepower and are the most important component of Russian military capability. By contrast, Russian Aerospace Forces' (VKS) fixed-wing and helicopter operations during the conflict have remained more sparsely documented and only partially understood outside those Ukrainian Air Force, Navy and Army personnel directly involved in countering their operations day-to-day.

External analysts, including the lead author of this report, have so far focused on trying to explain the apparent absence of a large-scale air campaign or strategically significant results achieved by the VKS.² The pervasive use by both sides of small unmanned aerial systems (sUAS) – usually called 'drones' – and UAVs – also usually called 'drones' – carrying modern cameras, and the ubiquitous presence of smartphones among troops, has ensured that detailed footage of the

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1. For examples, see Jack Watling and Nick Reynolds, 'Ukraine at War: Paving the Road from Survival to Victory,' RUSI Special Report, 4 July 2022; Michael Kofman and Rob Lee, 'Not Built for Purpose: The Russian Military's Ill-Fated Force Design', *War on the Rocks*, 2 June 2022; and assessments and maps updated each day at Institute for the Study of War, 'Ukraine Conflict Updates', <<https://www.understandingwar.org/backgrounder/ukraine-conflict-updates>>, accessed 24 October 2022.
 2. For example, Justin Bronk, 'Is the Russian Air Force Actually Incapable of Complex Air Operations?', *RUSI Defence Systems*, 4 March 2022; Phil Stewart and Idrees Ali, 'What Happened to Russia's Air Force? U.S. Officials, Experts Stumped', *Reuters*, 2 March 2022; Thomas Newdick, 'After An Abysmal Start, Here Is How Russia's Application of Airpower in Ukraine Could Evolve', *War Zone*, 10 March 2022, <<https://www.thedrive.com/the-war-zone/44634/after-an-abysmal-start-heres-how-russias-application-of-airpower-in-ukraine-could-evolve>>, accessed 20 October 2022; Justin Bronk, 'Getting Serious About SEAD: European Air Forces Must Learn from the Failure of the Russian Air Force over Ukraine', *RUSI Defence Systems*, 6 April 2022; Dan Parsons, 'Ukraine Situation Report: 80 Percent of Kyiv's Airpower Remains Intact', *War Zone*, 20 September 2022, <<https://www.thedrive.com/the-war-zone/ukraine-situation-report-surface-to-air-missiles-have-wreaked-havoc-on-russian-aircraft>>, accessed 20 October 2022.

ground war has been captured and broadcast in unprecedented detail throughout the war.³ By contrast, the combat air environment is inherently much harder to film due to the speeds, distances and altitudes involved. Consequently, much of what is known about the air war over Ukraine has been gleaned from isolated clips filmed from the ground, and carefully selected footage collated and released by both the Ukrainian and Russian Ministries of Defence as part of information operations.⁴ Therefore, while analysts have been able to observe fragments of the air war, and to track competing kill/loss claims and count wreckage on both sides, there has so far been very little granular information available in the public domain about the actual Russian air war over Ukraine.⁵

This report sets out to start the process of uncovering how Russia's VKS has operated over Ukraine between the start of the invasion in February and late October 2022. It is based on fieldwork conducted in Ukraine in August and October 2022, which included interviews with Ukrainian Air Force officers working in both the aviation and air-defence branches, interviews with senior intelligence officers and military scientists, and examination of captured and recovered Russian weapons systems. To protect sources, the interview subjects have been anonymised and precise dates and locations are not disclosed. The interviews were, of necessity, conducted with Ukrainian officials and officers but not Russian ones and, consequently, they represent an incomplete view from only one side of the air war. To guard against over-reliance on single sources, most of the interviews were conducted with multiple individuals representing different parts of their services. Where possible, information has also been cross-referenced between different interviews, and also evaluated against externally available footage and existing open-source intelligence data.

Chapter I provides details of the operations undertaken by the fixed-wing fighter, fighter-bomber and attack aircraft of the VKS. There were significant changes in objectives, tactics, operational intensity and weapons use at various phases of the war, so this chapter takes a chronological approach to explain their evolution over time. Chapter II examines Russian attack

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3. For example, Alex Horton and Samuel Oakford, "'Ammo! Ammo!'" Video Shows Close Combat in Ukraine Offensive', *Washington Post*, 10 September 2022; WarLeaks - Military Blog, 'Watch How This Single Ukrainian Tank Takes On An Entire Russian Column In Extraordinary Combat Footage', YouTube, 6 April 2022, <<https://youtu.be/BfTrQiFkWyk>>, accessed 28 October 2022; The Sun, 'Ukrainian Special Forces Take Out Russian Tanks in Aerial Bombardments over Donetsk', YouTube, 3 October 2022, <<https://youtu.be/popjKLSfhG8>>, accessed 28 October 2022.
 4. For example, WarLeaks - Military Blog, 'Ukrainian Su-24 Jets Drop Unguided Bombs On Russian Positions', YouTube, 28 September 2022, <<https://youtu.be/wWj-ql05IUg>>, accessed 28 October 2022; Gareth Jennings, 'Ukraine Conflict: Ukrainian MiG Shown Firing HARM Missiles', *Janes*, 30 August 2022; Zenger, 'War In Ukraine: Russian Su-35 Fighter Jets Bomb Ukrainian Targets', YouTube, 23 May 2022, <<https://youtu.be/3xfURpbFbJs>>, accessed 24 October 2022.
 5. The most comprehensive publicly available database on Russian aircraft losses in Ukraine is: Stijn Mitzer with Joost Oliemans, 'List of Aircraft Losses During the 2022 Russian Invasion of Ukraine', *Oryx*, 20 March 2022, <<https://www.oryxspioenkop.com/2022/03/list-of-aircraft-losses-during-2022.html>>, accessed 20 October 2022.

aviation (helicopter gunship) operations during the war. Chapter III examines the Russian long-range precision-strike campaign, looking at the patterns of use, targets and some characteristics of the cruise and ballistic missiles Russia has used to bombard Ukraine. It also provides some analysis of the Iranian-supplied Shahed-136 (called Geran-2 by Russia) loitering munitions (often inappropriately called 'kamikaze drones') that have been extensively used against Ukrainian infrastructure since September 2022. Finally, the report concludes with an analysis of the main priorities for aid that Ukraine needs from its international partners to improve its air-defence capabilities. There are several areas that are already becoming critical requirements if Ukraine is to sustain the battlefield momentum that it has won over Russia at such a devastating cost since February 2022.

The report deliberately avoids giving detailed descriptions of Ukrainian air combat and ground-based air-defence (GBAD) tactics, operations and losses to protect Ukrainian operational security. As such, it does not attempt to give a comprehensive or final account of the air war, but rather to usefully increase Western understanding of the use of Russian airpower during the conflict within the bounds of what can be verified and publicly discussed at this stage.

I. Russian Fixed-Wing Combat Operations

THE IMPACT OF hundreds of Russian cruise and ballistic missile strikes across Ukraine and the ill-fated air-assault operation at Hostomel Airport dominated the external view of Russian air operations during the initial week of the invasion.⁶ Ukrainian fast jets flew several visible combat air patrols (CAPs) over Kyiv and other cities, but various viral pieces of footage claiming to show air-to-air combat between Russian and Ukrainian jets were quickly recognisable as fakes created using commercial flight simulator software.⁷ This led several commentators, including the lead author of this paper, to put forward various theories for the apparent absence of VKS activity during the first week of the invasion.⁸ The VKS had deployed a fast-jet force of around 350 modern combat aircraft for operations in Ukraine; so the lack of a publicly visible air campaign came as a major surprise to most analysts.⁹ The tentative conclusions reached by this author in March about the lack of VKS capacity to mount complex, large-scale operations still hold today, but early analysis was wrong about the lack of significant Russian air activity in the early days of the war.¹⁰ This chapter explains how, in fact, the VKS mounted significant strike and offensive counter-air operations during this period, and the Ukrainian Air Force engaged in numerous air-to-air clashes to oppose it.¹¹

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6. For example, Natalia Zinets and Aleksandar Vasovic, 'Missiles Rain Down Around Ukraine', *Reuters*, 25 February 2022; and David Hambling, 'Russia Invades Ukraine: Missiles And Misinformation', *Forbes*, 24 February 2022.
 7. For example, see links in Joe Skrebels, 'Video Game Footage Falsely Presented as Videos of Ukraine War', *IGN*, 25 February 2022.
 8. Justin Bronk, 'The Mysterious Case of the Missing Russian Air Force', *RUSI Commentary*, 28 February 2022.
 9. For VKS modern aircraft numbers and capabilities, see Justin Bronk, 'Developments in Russian Combat Air Spending and Likely Operational Implications', in Pentti Forsström (ed.), *Russian Concept of War, Management and Use of Military Power* (Helsinki: Finnish National Defence University, 2022), pp. 89–101. For VKS unit deployment patterns in the lead-up to the invasion, see Thomas Newdick, 'How The Russian and Ukrainian Air Forces Stack Up Against Each Other', *War Zone*, 23 December 2021, <<https://www.thedrive.com/the-war-zone/43603/face-off-over-donbas-how-russian-and-ukrainian-air-forces-stack-up>>, accessed 30 October 2022.
 10. Analysis presented in Bronk, 'Is the Russian Air Force Actually Incapable of Complex Air Operations?' largely holds up while the lack of activity underpinning the analysis in Bronk, 'The Mysterious Case of the Missing Russian Air Force' was flawed due to incomplete information.
 11. Author interview D, with four senior Ukrainian Air Force commanders representing the aviation branch of the service, Ukraine, October 2022; author interview G, with three senior Ukrainian Air Force commanders representing the ground-based air-defence branch of the service, Ukraine,

During the first week of the invasion, Russian electronic warfare using jamming equipment and E-96M aerial decoys were highly effective in disrupting Ukrainian GBAD.¹² S-300 and SA-11 'Buk' radar-guided surface-to-air missile (SAM) systems were particularly badly affected in the north of the country, especially to the north of Kyiv along the Hostomel/Irpin and Chernihiv axes.¹³ Cruise and ballistic missile strikes had also damaged or destroyed multiple long-range early warning radars throughout the country, and destroyed various Ukrainian SAM sites in Kherson and Zaporizhzhia oblasts in the south. The physical destruction, along with the electronic disruption and suppression of SAM systems in the north and northeast, left the Mikoyan Mig-29 and Sukhoi Su-27 fighters of the Ukrainian Air Force with the task of providing air defence over most of the country for the first few days of the war.¹⁴ The Ukrainian air defences progressively recovered as jammed and damaged radar systems were reset and assets were rapidly repositioned during the second and third days. After that, the Air Force and air defence infrastructures worked in tandem. Deconfliction between aircraft and GBAD was coordinated by time until 3 March, after which deconfliction began to be coordinated by space because of friendly fire incidents.¹⁵ In other words, SAM systems and combat aircraft sorties began to be deconflicted by being allocated separate operational areas.

While Ukrainian GBAD units were electronically degraded and trying to reorganise and recover from physical strikes, Russian GBAD units inside Ukraine were also suffering from major limitations. Mobile air-defence assets, such as the short-range SA-15 'Tor' and medium-range SA-17 'Buk', had been sent into Ukraine with no functional communications plan. They were also advancing out of sequence and often separated from the formations that they were supposed to protect; and they were operating under very restrictive rules of engagement which instructed them to assume anything flying was Russian.¹⁶ The inability of radar-guided SAMs on either side to perform as anticipated during the first week and a half meant that fixed-wing aircraft on both sides had remarkable freedom to penetrate significant distances across the rapidly changing frontlines. This would quickly cease to be the case from early March, when both sides' GBAD reorganised and became far more effective.

At the start of the invasion, Russian Sukhoi Su-34 'frontal bomber' and Su-30SM and Su-35S multi-role fighter aircraft flew around 140 sorties per day, conducting fighter sweeps and strike

October 2022; and author interview H, multiple in-depth discussions with technical experts from the Ukrainian Military Scientific Institute, Ukraine, October 2022.

12. Author interview D; and author interview H. See also Jack Watling and Nick Reynolds, 'Operation Z: The Death Throes of an Imperial Delusion', RUSI Special Report, 22 April 2022, pp. 2–3.

13. Author interview D; and author interview J, with senior officer from the Ukrainian Air Force lessons learned team, Ukraine, August 2022.

14. Author interview D.

15. Author interview J.

16. Author interview D; and author interview G.

sorties up to 300 km inside Ukrainian territory at altitudes of between 12,000 ft and 30,000 ft.¹⁷ During the first three days, the primary targets of these VKS strikes were Ukrainian air defences. Over 100 fixed long-range radar installations, bases, munitions storage sites and positions occupied by mobile long- and medium-range SAM systems were attacked, with Russian fixed-wing sorties concentrating their activities along the routes intended to be used by airborne and helicopter assault forces.¹⁸

Notably, all the medium- and high-level strikes were conducted against pre-designated locations that had been extensively mapped by Su-24MR reconnaissance bombers. The Ukrainian Air Force observed that the latter constantly flew two–four sorties per day at medium to high altitude along Ukraine’s borders from early February to the end of April.¹⁹ Su-34s carried out the bulk of the strikes with multiple unguided FAB-500 and OFAB-250 bombs, and, during the first week, typically operated at medium altitudes of around 12,000 ft.²⁰

Most of these medium-level daylight strikes were carried out by single aircraft, with fewer than 25% of strikes conducted by pairs or larger formations; and none were observed that involved more than six aircraft in a strike package.²¹ This contributed to inconsistent damage results as well as inefficient battle damage assessment (BDA), meaning that follow-up strikes were seldom carried out.²² Nevertheless, VKS fixed-wing air strikes were effective in the south, where, in conjunction with cruise and ballistic missiles, attacks badly degraded the limited Ukrainian Air Force and Naval air-defence capacity deployed in the Kherson and Zaporizhzhia regions.²³ However, most of the targets hit were static radars and outdated S-125 (SA-3) SAM sites, and the only serious damage was to Ukrainian mobile SAM systems against trailer and truck-mounted S-300PS/PT units that either received too little warning to be able to move, or were stuck due to lack of spare parts.²⁴

Russian Su-35S and Su-30SM fighters flew numerous high-altitude CAPs at around 30,000 ft in support of the medium-altitude Russian strike aircraft operating widely during the first three days. They scored multiple air-to-air kills against Ukrainian Mig-29 and Su-27 fighters, as well

17. Mykhaylo Zabrodskiy et al., ‘Preliminary Lessons in Conventional Warfighting from Russia’s 2022 Invasion of Ukraine’, RUSI Special Report, forthcoming November 2022.

18. *Ibid.*

19. Author interview J. Also featured in *ibid.*

20. Author interview D. This matches loadouts seen being flown with by multiple VKS Su-34s in footage released by the Russian Ministry of Defence in March 2022. See Republic World, ‘Russia’s Defence Ministry Releases Video of Sukhoi-34 Bombing Ukrainian Military Infrastructure’, YouTube, 6 March 2022, <<https://youtu.be/YmaUOVXgSYY>>, accessed 28 October 2022.

21. Author interview D. Also featured in Zabrodskiy et al., ‘Preliminary Lessons in Conventional Warfighting from Russia’s 2022 Invasion of Ukraine’.

22. Author interview J.

23. Author interview D.

24. *Ibid.*; author interview G; and author interview J.



Circuit boards and tail fin from an R-77-1 air-to-air missile.
Courtesy of Jack Watling

as against low-flying Su-24 and Su-25 attack aircraft that were conducting strikes with unguided bombs and rockets against Russian military convoys on the Kyiv axes.²⁵

Ukrainian pilots confirm that Russia's Su-30SM and Su-35S completely outclass Ukrainian Air Force fighter aircraft on a technical level. The long range and good look-down, shoot-down performance of their N011M Bars and N035 Irbis-E radars, and the much longer reach and active-radar guidance capability of the R-77-1 air-to-air missile compared with the semi-active R-27R/ER available to Ukrainian fighters, are the most important aspects of this technical overmatch.²⁶ Throughout the war, Russian fighters have frequently been able to achieve a radar lock and launch R-77-1 missiles at Ukrainian fighters from over 100 km away.²⁷ Even though

25. Author interview D.

26. *Ibid.*; author interview H; and inspection of recovered R-77-1 and R-27 missiles, Ukraine, October 2022.

27. Author interview D; and author interview G. Supported by footage released by the Russian Ministry of Defence showing three R-77-1s being launched by an Su-35 flying at Mach 1.1 and around 33,000 ft with a launch acceptable region (LAR) indicator on the heads-up-display showing around 75 km at the start of the clip. Since missile effective range is proportional to launch altitude and speed, as well as target aspect and speed, an Su-35 flying faster than Mach 1.1 at, for example, 40,000 ft+ (well within its performance capabilities) could easily have an LAR in excess of 100 km against a low-flying closing target. Footage accessible at Fighter Bomber, Telegram, 1 June 2022, <https://t.me/fighter_bomber/7432>, accessed 30 October 2022. Alternatively, see Rob Lee, 'Video of a Russian SU-35S fighter launching R-77 air-to-air missiles at an aerial target', Twitter post, <<https://twitter.com/RALee85/status/1532831958757261313?s=20&t=I12-hY07Jky1C4dTnfeWTg>>, accessed 30 October 2022.



Internal view of R-77-1 air-to-air missile section showing rear fin control actuators. *Courtesy of Jack Watling*

such shots have a low probability of kill, they force Ukrainian pilots to go defensive or risk being hit while still far outside their own effective range, and a few such long-range shots found their mark. Furthermore, the R-77-1's active radar seeker, combined with the modern N011M and N035 radars, give Russian fighters the ability to launch missiles in track-while-scan (TWS) mode, meaning that Ukrainian pilots are unlikely to get warning from their radar-warning receivers (RWRs) that they have been launched on until the missile itself goes active a few seconds before it hits.²⁸ In contrast, the R-27R/ER missiles that Ukrainian fighters are armed with require a single target track (STT) lock to be maintained by the launching fighter's own radar throughout a missile engagement.²⁹ This means that Russian pilots receive an RWR warning when a Ukrainian pilot launches a radar-guided missile at them, and that if the Ukrainian fighter even briefly loses radar lock during missile flight, due to either side manoeuvring, deploying countermeasures or electronic warfare, then the missile will miss.

This deeply unequal radar and missile performance compared with Russian fighters, as well as being tactically outnumbered by up to 15:2 in some cases, forced Ukrainian pilots to fly extremely low to try to exploit ground clutter and terrain masking to get close enough to fire before being engaged.³⁰ This was still highly dangerous, and flying low further increased the range discrepancy between the effective ranges of Russian and Ukrainian air-to-air missiles,

28. Author's own analysis. For more detailed information, see Justin Bronk, 'Russian and Chinese Combat Air Trends: Current Capabilities and Future Threat Outlook', *RUSI Whitehall Report*, 3-20 (October 2020), pp. 6-9.

29. *Ibid.*

30. Author interview D.



Section of casing from R-77 warhead showing expanding rod and pre-formed shrapnel sections. *Courtesy of Jack Watling*

since Russian fighters were at higher speeds and high altitude, giving their missiles much more energy at launch.³¹

Despite these disadvantages, aggressive Ukrainian tactics and good use of the low-level terrain during the first days of the invasion led to multiple claims and several likely kills against Russian aircraft, although Ukrainian fighters were often shot down or damaged in the process.³² After three days of skirmishing in which both sides lost aircraft, there was a notable pause in Russian strike and fighter sorties venturing deep behind Ukrainian lines, which lasted for several days. As such, during the latter half of the first week, Su-34 and Su-35S pairs instead conducted

31. For more detailed information, see Justin Bronk, 'Russian and Chinese Combat Air Trends', pp. 6–11.

32. Author interview D. There is significant uncertainty about the number of kills scored during air-to-air engagement in this period since overclaiming on both sides undoubtedly occurred and some aircraft would have come down in areas controlled by Russian forces in remote wooded areas or in water. As such, they were not confirmed at the time. However, as Ukrainian forces liberate more territory, Russian aircraft wrecks continue to be discovered, such as an Su-30SM fighter with tail number RF-81773 (bort number 'Red 62') was also discovered near Izyum in September. See Ukraine Weapons Tracker, Twitter post, 12 September 2022, <<https://twitter.com/UAWeapons/status/1569275480343281665?s=20&t=V2EClykC9C6E8oxlaZaqfA>>, accessed 30 October 2022. Another example is an Su-34 frontal bomber with tail number RF-81852 (bort number 'Red 09') discovered near Lyman in early October. See Ukraine Weapons Tracker, Twitter post, 2 October 2022, <<https://twitter.com/UAWeapons/status/1576565672838303745?s=20&t=Y2306EbNHHYJP5YTcJyUIQ>>, accessed 30 October 2022.

numerous standoff launches against suspected Ukrainian radars and bases using Kh-31, Kh-58 and Kh-59 missiles.³³

In early March, however, Russian SAM defences rapidly became much better coordinated and the threat from long-range S-400 'Triumph' SAM systems based in Belarus and Crimea forced Ukrainian aircraft to fly at extremely low altitude – below 100 ft – for most of their sorties on the northern and southern axes.³⁴ The threat from these long-range SAMs was compounded by the presence of a Russian S-band 48Ya6 'Podlet-K1' all-altitude radar in Belarus covering the Kyiv axis, and another in the south (which was later destroyed near Nova Kakovkha).³⁵ These mobile radar systems were introduced in 2018, and have allowed Russian forces to track Ukrainian fixed-wing and rotary sorties at altitudes as low as 15 ft at well over 150 km.³⁶ Given the method of operation of the Podlet-K1, it is unlikely to be capable of successfully supplying the high-resolution data required for terminal guidance illumination of low-flying targets at longer ranges. The success on various occasions of low-flying Ukrainian fighters in ambushing Russian high-altitude patrols during the first week of the war in areas covered by the Podlet K-1 system would suggest it only gives a relatively low-resolution tracking capability. On the other hand, this may simply indicate a poor dissemination of surveillance information from the radar to the Il-20M 'Coot' airborne command post and relay aircraft passing information from ground networks to patrolling Russian fighters.³⁷ However, Podlet-K1 was designed to allow modern S-300 variants and the S-400 system to fire long-range missiles at a detected target, relay mid-course updates on the target movements to the missiles while in flight, and hence guide the missile close enough to detect and lock on to the aircraft in question with its own active radar seeker head as it descends from a high apex. The confident Ukrainian attribution of the loss of several aircraft to S-400 missile engagements while flying at very low altitude and at significant distances would, therefore, seem to suggest that longer-ranged missiles fired by these SAM systems do indeed possess a post-apex lock-on capability as previously theorised.³⁸

On the Donbas front and in the south, a similar task was performed by A-50M/U Mainstay AWACS aircraft which flew an average of two–three sorties per day, providing higher-resolution

33. Author interview D; and author interview G.

34. Author interview D.

35. For more information on the 48Ya6 K1, see US Army Training and Doctrine Command (TRADOC), '48Ya6-K1 Podlet K1 Russian Mobile Long-Range High-Altitude Surveillance Radar', <https://odin.tradoc.army.mil/mediawiki/index.php/48Ya6-K1_Podlet_K1_Russian_Mobile_Long-Range_High-Altitude_Surveillance_Radar>, accessed October 2022. For the destruction of the Podlet K1 near Nova Kakovkha, see Ukraine Weapons Tracker, Twitter post, 19 July 2022, <https://twitter.com/UAWeapons/status/1549458529752432641?s=20&t=4DvqEg72sd_YtliXfC6r0Q>, accessed 30 October 2022.

36. Author interview D; and author interview H.

37. On the presence of Il-20M as an airborne command and control post, see Zabrodskyi et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

early warning and vector information on low-flying Ukrainian aircraft in those sectors.³⁹ However, the effectiveness of A-50M as a force multiplier has been limited throughout the war by two factors. First, Ukrainian forces have found A-50 to be fairly easy to degrade via electronic attack, and report consistent success in doing so.⁴⁰ Second, because the Russian air operation is subordinated to the Ground Forces, surveillance information is not typically relayed directly between A-50M and fighters on CAP or to long-range GBAD units such as S-400 batteries. Instead, information is normally relayed via the military district command post or a combined arms army command post, then either directly or via an Il-20M relay aircraft to the GBAD units and fighter patrols.⁴¹ This significantly slows the rate of data transfer and limits the VKS's ability to use A-50M/U to directly guide weapon engagements by GBAD assets or fighters.

Following the first chaotic week of the invasion, it was becoming increasingly clear that Russian ground forces on the Kyiv and Kharkiv axes had become bogged down amid fierce Ukrainian resistance and Russian logistics difficulties. The airborne assault on Hostomel Airport had been repulsed by Ukrainian rapid reaction forces, and suddenly Russian forces had to adapt to a new plan.⁴² However, they had no coherent communications plan; many units had not exchanged encryption keys and had a shortage of trained radio operators. Furthermore, some radios were found to contain cheap Chinese substitute components lacking military-grade encryption, and so jamming resistance became a critical issue.⁴³ The electronic warfare capabilities that had been initially very effective in degrading Ukrainian SAM systems were also causing serious electronic fratricide problems and thus compounding an increasingly critical communications breakdown among Russian ground force elements.⁴⁴

Russian ground forces being unable to effectively communicate now became a greater threat to the Russian operation than Ukrainian SAM systems, so their electronic warfare assets began to greatly scale back their operations after the first two days. This allowed newly relocated Ukrainian SAM systems to regain much of their effectiveness, although it took time to repair or adapt to much of the damage to key radar systems for early warning and long-range missile guidance. In the first week of March, however, Ukrainian SAMs began to inflict significant losses on Russian attack sorties.⁴⁵

39. Zabrodskiy et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

40. Author interview D.

41. Zabrodskiy et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

42. James Marson, 'Putin Thought Ukraine Would Fall Quickly. An Airport Battle Proved Him Wrong', *Wall Street Journal*, 3 March 2022.

43. For more detailed analysis on early Russian communications difficulties, see Sam Cranny-Evans and Thomas Withington, 'Russian Comms in Ukraine: A World of Hertz', *RUSI Commentary*, 9 March 2022.

44. Author interview G.

45. Author interview D; and *ibid*.

The most effective Ukrainian SAMs against Russian fixed-wing aircraft have consistently been SA-11 'Buk' systems operating transporter-erector launcher and radar (TELAR) vehicles as individual pop-up threats rather than as formed batteries alongside the usual target-acquisition radar and command vehicles.⁴⁶ Alongside the longer-ranged S-300PS/PT and S-300V SAMs that had escaped destruction during the initial wave of strikes, the SA-11s quickly made Russian medium- and high-altitude operations prohibitively dangerous on the Kyiv and Kharkiv axes. At the same time, the VKS received new targeting priorities as it was swiftly becoming clear to the Russian leadership that the original military plan to rapidly seize Kyiv and other key cities and overthrow the Ukrainian government had failed.⁴⁷ Therefore, the main VKS air effort was switched from attacks on Ukrainian air-defence capabilities to attempts to support the ground forces directly.

With Ukrainian GBAD capabilities rapidly recovering from initial suppression and damage, they took over as the primary arm responsible for repelling the VKS near the frontlines from 3 March. The failure of Russia's initial strike campaign to destroy the bulk of Ukraine's medium-range SA-11 and SA-8 SAMs meant that as the VKS was re-tasked to attack Ukrainian Army positions in aid of the ground offensive, its pilots were forced to abandon flying at medium or high altitudes when penetrating Ukrainian airspace. At very low level, radar-guided SAM systems have a comparatively short effective range due to clutter and the curvature of the earth blocking their radar field of view to the target. Therefore, the final days of February and the first week of March saw the VKS conduct around 140 sorties per day, using Su-25, Su-30SM and Su-34 aircraft to conduct strikes at 500 ft or below using unguided bombs and rockets on Ukrainian positions.⁴⁸ Once again, the sorties were flown as singles or pairs rather than larger formations.⁴⁹

While flying low did reduce losses from radar-guided SAMs, it also brought Russian jets into the range of the thousands of man-portable air-defence systems (MANPADS) that had been widely issued to Ukrainian troops. The results were predictable, with at least eight assorted Su-25, Su-30 and Su-34 jets being shot down by MANPADS in a week.⁵⁰ These strikes were also significantly less accurate than the medium-level bombing that had been conducted in the first few days and in Syria, since they were also conducted with unguided bombs and rockets.⁵¹ At

46. Author interview D; and author interview G.

47. Zabrodskiy et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

48. Author interview D; author interview G; and author interview J. See also *ibid.*

49. Author interview D; and author interview G. This fits with available footage such as OP Info, 'Russian Su-34 Bombers Operate in the Kharkiv Region', YouTube, 28 February 2022, <<https://youtu.be/hneCGWKAuKw>>, accessed 30 October 2022.

50. Author interview G. See also Joseph Trevithick, 'The Russian Air Force Just Had A Terrible Day Over Ukraine', *War Zone*, 7 March 2022, <<https://www.thedrive.com/the-war-zone/44602/the-russian-air-force-just-had-a-terrible-day-over-ukraine>>, accessed 25 October 2022. For geolocated early crashes, see Mitzer with Oliemans, 'List of Aircraft Losses During the 2022 Russian Invasion of Ukraine'.

51. Author interview D; and author interview J.

very low levels pilots have only seconds to visually acquire, identify and then manoeuvre their aircraft to accurately drop weapons on targets.⁵² In this case, the targets were Ukrainian forces which were frequently well dug in and operating many of the same vehicles and weapons as Russian forces. A lack of up-to-date maps also compounded low-level navigation and target-recognition difficulties for Russian pilots.⁵³ Consequently, penetrating daylight low-level strikes achieved little serious damage against Ukrainian forces and the concept of operations was rapidly judged to be unsustainable by experienced VKS fixed-wing pilots, who quickly began to refuse to fly missions beyond Ukrainian lines.⁵⁴

In response, the VKS shifted its penetrating sorties to night attacks from 9 March 2022. Since most Ukrainian MANPADS operators lacked night-vision goggles at this time, initial VKS losses were greatly reduced by operating in darkness.⁵⁵ However, the only one of its fast jet fleets with cockpit equipment and appropriate training for contested low-level night operations was the Su-34s.⁵⁶ Consequently, the Su-34 fleet bore the brunt of the remaining penetrating strike operations flown by the VKS before they were curtailed in April. As before, the primary armament remained heavy loads of FAB-500, or mixed OFAB-250 and OFAB-100 unguided bombs, although the Kh-29T/L standoff missile and Kh-31P anti-radiation missile (ARM) began to see increasing use for specific targets and suppression of enemy air defences (SEAD).⁵⁷ With the difficulties of target acquisition and accurate attacks at low level compounded by flying at night, the general targeting profile also changed. Unable to accurately hit Ukrainian military units, the VKS defaulted to simply bombarding besieged cities as it had in Syria, except at night and from low level. Chernihiv, Sumy, Kharkiv and Mariupol were all heavily bombed by the Su-34s during this period, since Russia was desperately looking to make symbolic progress as the Battle for Kyiv increasingly swung in Ukraine's favour.

52. For detailed information on the difficulties of low-altitude ground attack against dug-in troops, see Jerry Pook, *RAF Harrier Ground Attack Falklands* (Barnsley: Pen and Sword Aviation, 2007), pp. 190–93.

53. Author interview G; and author interview J. This fits with widespread reports of Russian ground forces being sent into Ukraine with maps that are often decades out of date. See, for example, Nicholas Cecil, 'Putin's Troops Using "Antiquated" Maps from 1970s Are Missing Targets in Ukraine, Say Western Officials', *Evening Standard*, 29 April 2022.

54. Author interview D; and author interview G.

55. Author interview D.

56. Justin Bronk, 'Russia Likely Has Local Air Superiority in Donbas, but it May Not Matter', *RUSI Defence Systems*, 19 April 2022.

57. Author interview D; and author interview H. The use of FAB-500s is supported by the recovery of multiple examples of these bombs from an Su-34 shot down in Chernihiv on 5 March. Ukraine Weapons Tracker, Twitter post, 5 March 2022, <<https://twitter.com/UAWeapons/status/1500074221665505285?s=20&t=Q0jHtXOjLNG8eqh0LOo8TA>>, accessed 30 October 2022. Further, this was seen from Izyum on 28 February. OSINTtechnical, Twitter post, 28 February 2022, <https://twitter.com/Osinttechnical/status/1498285547097407497?s=20&t=k_KszkHoziw6pC46J2essQ>, accessed 30 October 2022.

Throughout March, Su-35S and Su-30SM fighters continued to conduct CAPs between 30,000 and 50,000 ft, but generally without entering Ukrainian-controlled airspace. Instead, they acted as a deterrent to Ukrainian attack sorties, but were also tasked to conduct SEAD operations. To this end, their CAPs were used as bait to try to make Ukrainian SAM systems turn on their radars to fire at them. If SA-11s or other SAMs did try to engage them, the Flankers would fire Kh-31P and, later, older Kh-58 ARMs at long ranges to home in on the radar emissions, and then turn away.⁵⁸ Meanwhile Su-25 singles or pairs flown by experienced crews would fly in at low altitude to try to find and kill the SAM with rockets while it was suppressed.⁵⁹ However, there were few Russian pilots capable of low-level destruction of enemy air defences (DEAD) sorties in an Su-25 with unguided rockets, and those that could frequently paid for their bold tactics by being hit with MANPADS from Ukrainian troops.⁶⁰ Ukrainian Air Force aviation and air-defence commanders confirmed in multiple interviews that while Ukraine has lost a number of SA-11 and SA-8 SAMs to the many Kh-31P and Kh-58s fired since the invasion, none of the low-level Su-25 DEAD rocket attacks was successful.⁶¹

After the collapse of the Kyiv axes in April, Russian forces were reorganised and concentrated against Ukrainian positions in Donbas and in the southeast in the surrounded city of Mariupol. This allowed far better coordination of Russian aircraft, long-range strike capabilities, electronic warfare assets and GBAD with ground operations. Alongside continued heavy use of Kh-31P and Kh-58 ARMs by VKS fighters, Russian troops also began to effectively coordinate operations with hunting complexes of Orlan-10 UAVs to force Ukrainian SAM systems to unmask and then suppress them for long enough using electronic warfare attack to designate individual SAMs for accurate artillery and missile strikes.⁶² This rapidly forced medium-range Ukrainian Air Force SA-11 'Buk' and short-range Ukrainian Army SA-8 'Osa' SAM systems to operate further back from the frontlines to reduce loss rates, and allowed Russian aircraft a significant degree of freedom to operate at medium and high altitudes in the vicinity of the frontlines.⁶³ Nevertheless, actual

58. Author interview D; and author interview G. Also supported by Russian Ministry of Defence footage of Su-35S sorties flying with and launching Kh-31P. See, for example, Kirill Kunetsky and Nikolay Varanov, 'В МО РФ показали кадры применения Су-35 в ходе спецоперации на Украине' ['The Ministry of Defence of the Russian Federation Showed Footage of the Use of Su-35 During a Special Operation in Ukraine'], *Zvezda*, 7 March 2022, <<https://tvzvezda.ru/news/202237820-suPZe.html>>, accessed 30 October 2022.

59. Author interview D; author interview G; and author interview J.

60. Author interview D; and author interview G.

61. Author interview D; and author interview G.

62. Author interview B, with Ukrainian former military, now defence industry UAV and counter-UAV specialist and designer, Ukraine, October 2022; and author interview H. Also see inspection of captured Orlan-10s including electronic warfare, sensor-ball/laser designator and basic reconnaissance payloads, Ukraine, October 2022. For continued use of Su-35 with Kh-31P supported by Russian Ministry of Defence, 'Su-35 Fighter Crews Launch Air Attacks at AFU Military Infrastructure and Equipment', *Telegram*, 22 June 2022, <https://t.me/mod_russia_en/2355>, accessed 30 October 2022.

63. Author interview G.

penetrations of Ukrainian lines to conduct strikes with fixed-wing aircraft on targets other than Ukrainian Army positions rapidly decreased due to persistent losses during even low-altitude night-time operations by Su-34s against cities such as Kharkiv, which involved very limited penetration distances. Instead, the Su-34 fleet began to regularly employ Kh-29T/L tv/laser-guided missiles for standoff attacks from medium altitude at distances of 8–15 km against fixed targets from mid-April.⁶⁴ During this period, Russia also used 16 Tu-22M3 ‘Backfire’ bombers to drop heavy unguided bombs on the besieged Azovstal steel works in Mariupol from medium altitude by day on 21 April, in addition to repeated attacks by Su-34s carrying sticks of heavy FAB-500 unguided bombs.⁶⁵

A notable feature of VKS fixed-wing strike operations from February to April was that BDA was poor. The primary assessment metric was whether crews reported hitting the target upon landing, and orbital imagery assessment was used to then confirm damage observed as expected.⁶⁶ This meant that in most cases where damage was only superficial or had actually failed to hit the intended targets, follow-up sorties were not flown. A marked tendency to overstate successes has been a consistent feature of Russian intelligence and military BDA and planning cycles during the period leading up to and then during the 2022 invasion of Ukraine.⁶⁷ This is an almost unavoidable consequence of the way that the Russian political system works, where reporting what seniors wish to hear, reinforcing their previous decisions and inflating successes, is an absolute prerequisite for promotion to higher rank.⁶⁸

In the war to date, Russian Su-25SM/SM3 ground-attack aircraft have been used differently from the rest of the VKS fixed-wing fleet, being generally tasked with operations against Ukrainian Army targets at grid locations supplied by friendly assets on or near the frontlines. The deepest recorded strikes using unguided lofted rocket attacks by Su-25 formations were less than 100 km from the Russian frontlines, and most involved far shorter penetrations of Ukrainian lines.⁶⁹ Su-25 sorties remained almost exclusively at low altitudes below 1,000 m and often at less than 100 m, especially close to the frontlines during rocket attacks or if patrolling for targets.⁷⁰ MANPADS have been the primary threat for the Su-25, due to the need to regularly cross parts

64. Zabrodskyi et al., ‘Preliminary Lessons in Conventional Warfighting from Russia’s 2022 Invasion of Ukraine’.

65. Author interview G. See also Zabrodskyi et al., ‘Preliminary Lessons in Conventional Warfighting from Russia’s 2022 Invasion of Ukraine’.

66. Author interview J.

67. Author interview D; author interview G; and author interview J.

68. Author interview C, with three senior officers from Ukrainian intelligence agency 1, October 2022.

69. Author interview G. See also Zabrodskyi et al., ‘Preliminary Lessons in Conventional Warfighting from Russia’s 2022 Invasion of Ukraine’.

70. Author interview D. This fits with multiple examples of footage including MARKAZ, ‘Russian SU-25s Avoid Two Ukrainian Anti-Air Missiles During Combat Sortie Over Ukraine’, YouTube, uploaded 11 September 2022, <<https://youtu.be/HJx7D9jeCgQ>>, accessed 2 November 2022; WarLeaks - Military Blog, ‘Russian SU-25 Combat Sortie Over Ukraine’, YouTube, 14 June 2022, <<https://youtu.be/ATwkpH9mSql>>, accessed 28 October 2022.

of the frontlines during such operations.⁷¹ However, their defensive aids suites have performed consistently well against most MANPADS; the losses have come from repeat exposure in areas with high concentrations of MANPADS teams, rather than a high probability of kill during individual engagements.⁷²

From September 2022, the launch of the Ukrainian counter-offensive in Kherson and subsequent counter-offensive in the Kharkiv region in the northeast granted Ukraine the initiative and has forced the Russian Army to go on the defensive across almost the whole of its remaining frontlines. In the air too, Ukraine has been able to significantly attrit and subsequently impose a degree of suppression on Russian GBAD using the Western-supplied AGM-88 High-Speed Anti-Radiation (HARM) missile.⁷³ As such, Ukrainian Su-25 and Su-24 attack aircraft have become increasingly active, conducting regular standoff rocket attacks and even bombing runs against Russian positions in Kherson and Kharkiv. This has forced the VKS to adopt an increasingly defensive posture. The VKS has divided the Ukrainian/Russian lines into eight zones and maintains a regular posture of a pair of Su-35S fighters or Mikoyan Mig-31BM interceptors in each one.⁷⁴ Without regular tanker support – which the VKS does not provide to fighter units due to limited capacity and prioritising the strategic bomber force – times on station for these CAPs are unlikely to exceed two hours, so at minimum this posture requires around 96 sorties per day to sustain in daylight.⁷⁵ However, these patrols have proven highly effective against Ukrainian attack aircraft and fighters, with the Mig-31BM and R-37M long-range air-to-air missile being especially problematic. The VKS has been firing up to six R-37Ms per day during October, and the extremely high speed of the weapon, coupled with very long effective range and a seeker designed for engaging low-altitude targets, makes it particularly difficult to evade.⁷⁶ The long range of the R-37M, in conjunction with the very high performance and high operating altitude of the Mig-31BM also allows it significant freedom to menace Ukrainian aircraft near the frontlines from outside the range of Ukrainian defences. The VKS has also started employing the R-37M from at least a few of its Su-35S fighters, which not only increases the reach of the latter in combat but may also suggests Russian stocks of the R-37M are in little danger of running out.⁷⁷

71. Author interview D; and author interview G. Supported by multiple examples of footage, including WarLeaks - Military Blog, 'Russian Pilot Ejecting From Shot Down SU-25 At Extreme Low Altitude', YouTube, 23 October 2022, <<https://youtu.be/34-4D-MmR4I>>, accessed 28 October 2022; Global Intel, 'Watch A Russian SU-25 Jet Getting Shot Down By Ukrainian MANPAD', YouTube, 7 September 2022, <<https://www.youtube.com/watch?v=m1tbOKfppNY>>, accessed 28 October 2022.

72. Author interview H.

73. Author interview D; and author interview H.

74. Author interview D; and author interview G.

75. Author's own calculations.

76. Author interview D. In addition, the author conducted an examination of recovered R-37M missile sections that had been recently fired in Ukraine, October 2022.

77. Guy Plopsky, Twitter post, 1 November 2022, <https://twitter.com/guyplopsy/status/1587338111562174464?s=61&t=BXBcQfw_Pb1cMBeLxBMcbw>, accessed 2 November 2022.



MiG-31 BM carrying R-77-1 and R-37M missiles taking part in operations in Ukraine. *Courtesy of Ministry of Defence of Russia*

Despite the demands for close air support from the Russian Army which has been forced to retreat from Kharkiv oblast and parts of Luhansk and Kherson, the strike tempo being flown by the VKS Su-25 and Su-34 fleets has not noticeably increased.⁷⁸ The Su-25 force continues to conduct regular standoff rocket attacks, but these are only capable of producing a barrage effect in a rough area. The lack of targeting pods and multi-role expertise across the Russian fighter fleets leaves the Su-34 fleet as the only VKS element theoretically capable of conducting effective standoff dynamic targeting against Ukrainian forces moving in the open.⁷⁹ The VKS is almost certainly anxious to minimise further losses of these expensive and complex aircraft, after losing at least 17 since February.⁸⁰ Therefore, footage of Su-34s conducting unguided bombing runs over the frontlines at low level – exposing them to a high degree of risk from MANPADS and ground fire – suggests a degree of desperation.⁸¹ It may be that stocks of Kh-29T/L and other standoff missiles are running low, or that the Su-34s are struggling to accurately find and hit Ukrainian battlefield targets without coming in very low and getting close enough to visually identify them. There have also been several crashes in the VKS Su-25, Su-30 and Su-34 fleets during non-combat-related accidents since early September.⁸² Each one may be individually

78. Author interview D; and author interview G.

79. For more details, see Bronk, 'Developments in Russian Combat Air Spending and Likely Operational Implications', pp. 89–101.

80. For the 17 confirmed losses, see Mitzer with Oliemans, 'List of Aircraft Losses During the 2022 Russian Invasion of Ukraine'. For overall Su-34 numbers and capabilities see *ibid.*, pp. 89–101.

81. For example, 'Военный Осведомитель' ['Military Informant'], Telegram, 28 October 2022, <<https://t.me/milinfofive/92576>>, accessed 30 October 2022; Lamp of Knowledge, 'Risky Dropping of FAB 500 Bombs by Su-34 Aircraft in Ukraine', YouTube, 15 September 2022, <<https://youtu.be/CYUfzziraPo>>, accessed 30 October 2022.

82. For example, Ukraine Weapons Tracker, Twitter post, 12 September 2022, <<https://twitter.com/UAWeapons/status/1569302325533020160?s=20&t=A08sidaE5kZiDDQiSxSudg>>, accessed 28

explained by bird strikes, pilot error or technical failures. However, collectively they suggest that eight months of war have taken a toll in terms of accumulated airframe and aircrew fatigue. Tired aircrew, ground personnel and continuing operational demands for support from the ground forces that force normal maintenance, leave and overhaul periods to be ignored are all likely to be contributing factors. In particular, the ground-attack-focused Su-25 and Su-34 fleets have both taken much heavier losses than the fighter fleets, with 23 of the former and 17 of the latter confirmed lost from pre-war fleets of around 110 modernised Su-25SM/SM3s and 130 Su-34(M)s.⁸³ This will have further increased the burden of an operating tempo far in excess of peacetime expectations on the aircraft and pilots that remain.

In summary, the VKS conducted a more significant fixed-wing strike campaign during the initial days of the invasion than has previously been documented by external analysts. The ground-based Ukrainian air-defence network was initially suppressed by electronic attacks, decoy use and physical strikes, and this allowed Russian aircraft to attack more than 100 targets deep inside Ukraine. Ukrainian Air Force fighter aircraft bore the brunt of the air-defence task until the SAM systems and radars of the GBAD network had been relocated and reset sufficiently to take over primary responsibility at the beginning of March. The great disparity in technical capabilities and numbers between Ukrainian Air Force fighters and Russian ones meant that while Ukrainian fighter pilots were able to inflict some losses on Russian aircraft using aggressive low-level tactics, they also took many losses in return. However, once the SA-11 and S-300 SAM systems began to operate effectively, Russian strike aircraft were forced to operate at low altitudes when penetrating Ukrainian-controlled airspace, and Russian fighters had to stand off to patrol at high altitudes. Russia's inability to effectively conduct DEAD against Ukrainian SAM systems has so far denied them the ability to control the airspace over most of Ukraine. The VKS has used Kh-29 and Kh-59 missiles to hit fixed targets from standoff ranges, usually using the Su-34 fleet. It has also used the Su-35S and Su-30SM fleets to fire large numbers of Kh-31P and Kh-58 anti-radiation missiles to suppress Ukrainian radar-guided SAMs, though this has failed to produce many actual kills. However, Russian close air support efforts have generally been limited to low-level unguided bombing runs and unguided rocket barrages, which have failed to inflict decisive damage on Ukrainian ground forces and have led to sustained losses to MANPADS among the Su-25 and Su-34 fleets. On the other hand, Russian high-altitude fighter CAPs with Su-35S and more recently with Mig-31BM interceptors are continuing to shoot down significant numbers of Ukrainian ground attack aircraft near the frontlines from distances that render them all but immune to return fire.

October 2022; Breaking Aviation News & Videos, Twitter post, 24 October 2022, <<https://twitter.com/aviationbrk/status/1584513851092963328?s=20&t=A08sidaE5kZiDDQiSxSudg>>, accessed 28 October 2022; Intel Mule, Twitter post, 23 October 2022, <https://twitter.com/Intel_Mule/status/1584151898164457472?s=20&t=A08sidaE5kZiDDQiSxSudg>, accessed 28 October 2022.

83. For confirmed losses, see Mitzer with Oliemans, 'List of Aircraft Losses During the 2022 Russian Invasion of Ukraine'. For Su-34 numbers and capabilities, see Bronk, 'Developments in Russian Combat Air Spending and Likely Operational Implications', pp. 89–101.

II. Russian Attack Helicopter Employment and Performance

A LONGSIDE THE SU-34 frontal bomber fleet, the dominant ground-attack platform in the Russian air campaign has been the Ka-52 'Alligator' attack helicopter. Alongside Mi-28 'Havok' and Mi-24/35 'Hind' gunships, the Ka-52 fleet conducted aggressive hunter-killer sorties at very low altitude against Ukrainian forces during the early months of the war.⁸⁴ These sorties were generally flown in pairs and used a combination of unguided rockets and cannon fire against troop concentrations and soft-skinned vehicles, and anti-tank guided missiles (ATGMs) against armoured vehicles and other hardened targets. In Kherson and Zaporizhzhia oblasts in the south, where Ukrainian air defences took particularly heavy damage in initial strikes on 24 February, hunter-killer sorties from Ka-52s were observed penetrating up to 50 km into Ukrainian-controlled territory during late February and into early March.⁸⁵ Ka-52s and Mi-24s also escorted the Mi-8/17 transport helicopters carrying Russian airborne troops into Hostomel Airport on the first day of the invasion, with at least one Mi-24 being shot down by a Javelin anti-tank missile used in direct attack mode and a Ka-52 force landing after taking small arms fire.⁸⁶

During the battle for Kyiv, Mi-24 and Mi-28 gunships operated alongside the Ka-52 in the hunter-killer role at night, as well as in daylight. However, typically night operations of this kind have been flown by the Ka-52 fleet due to their superior night-vision equipment.⁸⁷ It is also likely that the doctrinally established role for Ka-52 – to provide support to Russian special operations forces including in adverse conditions and at night – meant that a much greater proportion of Ka-52 aircrew were trained and current in low-level night operations compared with in the Hind and Havok fleets. However, following the Russian retreat from Kyiv in April, penetration distances and the number of hunter-killer sorties began to diminish rapidly across all the gunship fleets. Heavy losses taken during daylight operations, especially among experienced crews,

84. Author interview D; author interview G; and author interview H.

85. Author interview G.

86. Footage of the Mi-24 shoot down can be found at Bloomberg, 'Video Reportedly Shows Russian Choppers Shot Down', YouTube, 1 March 2022, <<https://www.youtube.com/watch?v=ZLkNyEEcR5o>>, accessed 21 October 2022. The Ka-52 forced landing can be seen at WarLeaks - Military Blog, 'Ukraine War - Russian KA-52 Emergency Landing During Combat Sortie At Hostomel Airport', YouTube, 19 March 2022, <<https://youtu.be/oLa3fZD1vXs>>, accessed 28 October 2022.

87. Author interview H. Supported by footage of Ka-52s conducting night operations during this period. For example, The Sun, 'Russian Z Ka-52 Helicopters Night Operations', YouTube, 8 March 2022, <https://youtu.be/V8v7yIfJ_uA>, accessed 30 October 2022.

created a dynamic whereby Russian rotary crews became very hesitant to cross the Ukrainian frontlines from April.

Russian helicopter (and fixed-wing attack jet) defensive aids suites combining missile-approach warning sensors and countermeasures-dispensing programmes have functioned reasonably well throughout the conflict, succeeding in decoying many incoming missiles.⁸⁸ However, the sheer number of MANPADS fired at them during penetrating sorties ensured that many hits were still scored. Furthermore, at several points during early March and later in Donbas, Russian helicopters failed to dispense flares when engaged by MANPADS.⁸⁹ This suggests that either they had run out already during that sortie, or potentially supply chain issues were forcing crews to fly with their defensive aids suites set to semi-automatic or manual modes to reduce consumption rates at the cost of reduced effectiveness. The British Starstreak and the American Javelin anti-tank missile (used in direct-attack mode) have been particularly effective against all Russian helicopters as they are immune to being decoyed by flares or chaff countermeasures.⁹⁰ However, these weapons require a significantly greater level of operator training and are more expensive and scarcer than normal MANPADS. Javelin has also largely been saved for attacks on Russian tanks.

After heavy initial losses, Russian helicopters almost solely engaged in attacks with unguided rockets from behind the Russian frontlines during the Russian offensive in Donbas between April and July, and in defensive operations against Ukrainian counter-offensives in Kherson and Kharkiv since September. During these indirect rocket attacks, Russian helicopters typically approach a target area while flying at below 200 ft, then pitch up to between 15 and 30 degrees and fire S-8 and S-13 unguided rockets in a lofted trajectory against known concentrations of Ukrainian forces in a general grid square.⁹¹ Immediately after firing all their rockets in a salvo, they turn away while dropping countermeasures without crossing their own lines. The accuracy that can be obtained using these tactics is generally poor, sufficient only to force Ukrainian forces in the open to take cover, or to fix dug-in units in place until the impacts subside. In Donbas, both Ka-52 and Mi-24s also regularly conduct these indirect attacks at night to keep Ukrainian troops awake.⁹² In general, however, Russian helicopters have struggled to conduct low-altitude sorties at night outside the areas of Donbas, occupied by Russian proxy forces since 2014 and thus well known to them. Russian maps of most of Ukraine as provided to all troops

88. Author interview D; author interview G; and author interview H.

89. Author interview G; and author interview H.

90. Author interview G; and author interview J. Footage of a successful Starstreak engagement against a Mi-28 can be seen at The Sun, 'Dramatic Moment Ukrainian Troops Shoot Down Russian Helicopter Using British "Starstreak" Missiles', YouTube, 2 April 2022, <<https://youtu.be/rXnjQmoV2D8>>, accessed 30 October 2022.

91. Author interview D; and author interview J. See also Thomas Newdick, 'Russian Attack Helicopters Are Now Wildly Lobbing Rockets Over Ukraine (Updated)', *War Zone*, 18 March 2022, <<https://www.thedrive.com/the-war-zone/44803/russian-attack-helicopters-are-now-wildly-lobbing-rockets-over-ukraine>>, accessed 30 October 2022.

92. Author interview H.

are often decades out of date and helicopter crews are no exception, making low-level flight at night very hazardous since obstacles are unlikely to be mapped.⁹³

ATGMs are sometimes also used by gunships to attack Ukrainian positions, or vehicles that can be spotted and identified without crossing the lines. However, Russian gunships face a notable disadvantage when operated in this manner since they have very poor vibration dampening.⁹⁴ This means that the gyro-stabilisation of internal optics struggles to produce a clear picture at high magnification levels, making acquisition, positive identification and precise laser or command-wire guidance at longer ranges very challenging.⁹⁵ This limits the practical range of Russian helicopter-launched ATGMs, and forces them to expose themselves to potential attack by MANPADS, Javelin in direct attack mode, and ground-launched ATGMs by firing from close to the frontlines. The final penetrating hunter-killer sorties were conducted by Ka-52s in June 2022.⁹⁶

Confirmed losses of Russian gunships at the time of writing, where wreckage has been positively identified, include eight Mi-24/35 'Hind', six Mi-28 'Havok' and 23 Ka-52 'Alligator' helicopters.⁹⁷ The true total is undoubtedly higher, but Stijn Mitzer and Joost Olieman's numbers in the Oryx blog also include several helicopters destroyed on the ground or in accidents, and the overall proportions are likely to be fairly representative. What stands out is that the Ka-52 fleet has taken a disproportionate number of losses compared with the other gunship types operated by Russia.

There are several reasons that are likely to have contributed to this. First, the Ka-52 has seen more intensive use than the other fleets, both by day and especially at night, on all fronts in Ukraine.⁹⁸ Second, the Ka-52 has notable deficiencies in armour protection compared with other Russian attack helicopters, especially the engine compartments, which have no armour plating at all – leaving them potentially vulnerable to damage from even small arms fire.⁹⁹ Third, the Ka-52 uses a different ATGM from the Mi-28 and Mi-24/35; the 9K121 Vikhr uses a laser beam-riding guidance system with the seeker on the missile mounted at the rear facing backwards rather than in the nose like a traditional laser seeker. In other words, the seeker on the Vikhr looks back at the helicopter to 'see' the laser guidance beam, rather than looking for a laser spot reflected off the target. This makes it almost impossible to jam in flight and also

93. Author interview D; and author interview G. See also Cecil, 'Putin's Troops Using "Antiquated" Maps from 1970s Are Missing Targets in Ukraine, Say Western Officials'.

94. Author first-hand practice with Russian gunship ATGM targeting system in flight, October 2021. See also Thomas Newdick, 'Russia's Ka-52 Attack Helicopters Have a Serious Vibration Problem', *War Zone*, 16 May 2022, <<https://www.thedrive.com/the-war-zone/russias-ka-52-attack-helicopters-have-got-a-serious-vibration-problem>>, accessed 30 October 2022.

95. Author first-hand practice with Russian gunship ATGM targeting system in flight, October 2021.

96. Author interview H.

97. Mitzer with Oliemans, 'List of Aircraft Losses During the 2022 Russian Invasion of Ukraine'.

98. Author interview D; author interview G; and author interview H.

99. Author interview H. An example can be seen in WarLeaks - Military Blog, 'Ukraine War - Russian KA-52 Emergency Landing During Combat Sortie At Hostomel Airport'.



S-8 unguided rockets ready for loading on to a Kamov Ka-52 attack helicopter for standoff attacks against Ukrainian positions. *Courtesy of Ministry of Defense of Russia*

cheaper than comparable traditional ATGMs. However, it also means that the Ka-52 cannot drift more than a few degrees per second to the left, right, up or down while guiding the missile in flight, or the laser beam from the helicopter will move outside the field of view of the seeker and guidance will fail. The result has been that Ukrainian troops have been able to shoot down Ka-52s using wire-guided Stugna anti-tank missiles on several occasions, when the helicopters were hovering almost stationary attempting to identify and guide their Vikhr missiles to targets near the frontlines.¹⁰⁰

Multiple Ka-52 airframes have also been recovered after being shot down in a condition that suggests poor maintenance and crew training are problems. Modern encrypted radio sets have been found without the encryption keys needed to use them, and in others the radar and other sensors have been found either in the stowed position or with pins or covers still fitted that prevent them from working.¹⁰¹

In summary, the Russian attack helicopter fleet was initially used to conduct aggressive hunter-killer sorties behind Ukrainian frontlines, with penetration depths of up to 50 km relatively common. However, losses to MANPADS were heavy and so Russian tactics shifted during March, with penetrating sorties becoming less and less common; they were replaced by rocket 'lofting' attacks from a safe distance. Since April, Russian attack helicopters have been used extremely cautiously, with a heavy reliance on standoff rocket attacks rendering them little more than flying rocket artillery assets. Despite this cautious approach, they continue to be shot down regularly by Ukrainian frontline units using MANPADS, Javelin and, occasionally, ATGMs.

100. Author interview H. See also War Leaks, 'Ukraine War - Ukrainian Forces Shoot Down Russian Helicopter With STUGNA-P ATGM System', Youtube, 5 April 2022, <<https://youtu.be/MT8Um69fbHA>>, accessed 21 October 2022.

101. Author interview G; and author interview J.

III. Russia's Long-Range Strike Campaign: Cruise Missiles, Ballistic Missiles and Loitering Munitions

THE RUSSIAN INVASION began with a heavy cruise and ballistic missile barrage, the opening salvo in a sustained long-range precision-strike campaign which averaged around 24 missiles per day for the first three months of the war.¹⁰² From 24 February to the end of May, more than 2,000 3M-54 Kalibr, Kh-101, Kh-55, Kh-555 and other cruise missiles were fired into Ukraine, usually in salvos of 4–12 at once.¹⁰³ The Kalibrs are fired from naval ships and submarines in the Black Sea, while the Kh-101, Kh-55 and Kh-555 are typically launched from Tu-95 strategic bombers from inside Russian airspace.¹⁰⁴ Around 240 9M720 and 9M723 ballistic missiles were also fired from Iskander-M ground-based launchers at around 160 targets.¹⁰⁵

Russian land-attack cruise missiles and ballistic missiles have performed well throughout the conflict, with most impacting within 3–10 m of their intended aiming points, except when degraded by Ukrainian electronic warfare assets. Furthermore, during the initial strikes, Ukrainian air defences were themselves degraded by electronic warfare and most were relocating during the early salvos to avoid being destroyed so only succeeded in intercepting a small proportion of the incoming cruise missiles. Intercepting Russian Tochka-U and Iskander ballistic missiles has proven very difficult throughout the conflict due to a lack of suitable interceptor missiles and the short range of potential coverage for each system against such threats. Iskander 9M723 is especially problematic for Ukrainian air defences due to its quasi-ballistic manoeuvring capabilities and the fact that it launches six penetration aids to generate additional radar returns and electronic warfare effects during its terminal phase.¹⁰⁶

102. Author interview D; author interview G; and author interview H.

103. Author interview F, with multiple senior officers from Ukrainian intelligence agency 3, October 2022; and author interview G.

104. Author interview H; and author interview I, with senior representatives from Ukrainian Defence Industry, Ukraine, October 2022.

105. Zabrodskiy et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

106. Author interview G; and author interview H; and author examination of numerous recovered 9M723 Iskander missiles, including intact penetration aids, Ukraine, October 2022.

The primary Russian long-range strike objective during the first three days was to degrade and destroy Ukrainian air-defence capabilities.¹⁰⁷ As such, Russian strikes overwhelmingly targeted air-defence sites including fixed radars, fixed S-125 (SA-3) SAM sites, command centres, airbases, ammunition storage sites and known long-range S-300 mobile SAM sites.¹⁰⁸ Most of these represented fixed targets that Russia had been able to identify and integrate into a strike plan during the months leading up to the invasion. Conventional methods for locating targets included orbital reconnaissance and electronic and signals intelligence (ELINT and SIGINT) aircraft such as Su-24MR 'Fencer-E' and Il-20 'Coot' aircraft conducting standoff reconnaissance flights to map Ukraine's defences.¹⁰⁹ However, perhaps Russia's most important source of targeting information for the opening and subsequent stages of its strike campaign remains human intelligence (HUMINT). The Russian 'special services' including the Foreign Intelligence Service (SVR), Federal Security Service (FSB) and Main Directorate of the General Staff (GU) run active teams and officers who control networks of recruited assets, including important regional and national politicians and military officers inside Ukraine.¹¹⁰ Controlling Ukraine has been one of Russia's longest running foreign policy goals, and thorough penetration of its government and security apparatuses has been a task for the Russian special services ever since the collapse of the Soviet Union.¹¹¹ As such, Russia has had access to detailed information about the workings of the Ukrainian state and military for decades, which provides a rich source of data for planning and targeting long-range strikes against fixed defence sites, bases and important infrastructure nodes.

Despite detailed Russian target lists and heavy firepower, Ukrainian air defences were on alert on the 24 February and, after receiving urgent warnings from partner states, relocated most of their mobile air-defence systems shortly before their positions were struck by the first wave of Russian missiles.¹¹² Consequently the losses among mobile assets were light, consisting of a number of S-300PS/PT SAM transporter erector launchers (TELs) that could not be moved in time due to insufficient warning and poor chassis serviceability. However, many static early warning radars were hit and at least temporarily knocked out. Several older static SA-3 SAM sites were destroyed.¹¹³ The Russian missile (and fixed-wing) strikes were most effective in the southern Kherson and Zaporizhzhia regions where warning times were lower than in Donbas or

107. Author interview D; and author interview G. Also see author interview J; and Zabrodskiy et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

108. Author interview D; and author interview G.

109. Zabrodskiy et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

110. Author interview C; author interview G; author interview E, with two senior officers from Ukrainian intelligence agency 2, October 2022; and author interview F.

111. Author interview A, with a senior officer in Ukraine intelligence agency 4, Ukraine, October 2022. See also Jack Watling and Nick Reynolds, 'The Plot to Destroy Ukraine', RUSI Special Report, 15 February 2022.

112. Author interview G.

113. *Ibid.*



Penetration aid from a Russian 9M723 Iskander ballistic missile. *Courtesy of Jack Watling*

in the north and many units had older, less serviceable equipment.¹¹⁴ Strikes on Ukrainian Air Force airbases and ammunition stowage also caused limited damage due to timely dispersal of airworthy Ukrainian aircraft to smaller bases and relocation of most ammunition stocks in the hours prior to the invasion.¹¹⁵

The opening salvos exhibit one of the clearest features of Russia's long-range strike campaign against Ukrainian military targets during the war. The Russian military and intelligence services collectively demonstrated an ability to collect detailed information about Ukrainian air-defence target locations.¹¹⁶ This was then used by each Military District command centre to develop a coherent target list according to the overarching plan at the operational level, which was then used to assign targets to individual strike assets serving each of the four main operational directions. The missiles themselves generally hit the aiming points assigned to them with sufficient precision, and the opening salvo was well coordinated with electronic warfare effects to ensure almost all of them got through the largely blinded and suppressed Ukrainian air defences.¹¹⁷ However, in many cases the targets of each strike had moved by the time the missiles hit their designated aiming points.

After the initial salvos failed to destroy Ukrainian air-defence capability on 24 February, the Russian target detection, tracking and fire-mission assignment process was not fast enough to stay ahead of continued Ukrainian dispersal and shoot-and-scoot tactics. For example, HUMINT

114. Author interview D; and author interview J.

115. *Ibid.*

116. Author interview F.

117. Author interview D.

on a Ukrainian air-defence position located by GU assets would be passed into the 'Akatsiya' strategic command architecture in Moscow, then integrated into the next 24 hours strike plan at Military District command-centre level, and assigned to a strike asset.¹¹⁸ This process takes at least 48 hours and sometimes significantly longer to result in a strike.¹¹⁹ As such, when used against mobile targets the Russian long-range strike complex has consistently generated accurate strikes using expensive cruise and ballistic missiles (or long-range rocket artillery) on the exact positions long since vacated by Ukrainian systems.¹²⁰

Having failed to achieve a quick military victory in the first few days, Russian long-range strike assets were re-tasked in early March from Ukrainian air-defence sites to infrastructure and government targets.¹²¹ These included transmission towers for Ukrainian television and radio in Kyiv, Vinnytsia and other cities, and attacks on internet and mobile phone infrastructure.¹²² These strikes were coupled with a significant increase in the already-intensive Russian offensive cyber campaign against Ukraine. There were also sporadic strikes on government buildings and symbolic civilian targets such as Kharkiv University, which caused many civilian casualties and increased refugee flows out of the country.¹²³ The primary aim appears to have been to degrade Ukrainian government public messaging and coordination capacity in the hope that Ukrainian resistance and political unity might still fracture and allow a pro-Russian takeover. Targeting buildings with governmental, security and cultural importance in cities with large cruise and ballistic missile warheads also served to increase the pressure on President Volodymyr Zelensky and the Ukrainian public by raising the spectre of massive damage and civilian casualties in besieged cities if fighting continued. Strikes were also directed at important Ukrainian defence industry factories to reduce the capacity to produce, maintain, modernise and repair domestically manufactured equipment, as well as targeting a training and assembly base for Western volunteer fighters in Lviv on 13 March.¹²⁴ While significant damage was done, it did not have decisive results due to the scale of Western support, the volume of captured Russian military equipment, ammunition and spares available to Ukrainian forces, and the rapid dispersal of many previously centralised facilities to reduce their vulnerability to further attacks.

The weight of fire that Russia could sustain limited the overall effectiveness of this approach, since aside from large broadcast towers, physically destroying a critical mass of communications equipment in a country the size of Ukraine would require attacking a huge number of relatively small targets. By mid-March the VKS fixed-wing fleet was flying almost no penetrating sorties by

118. Author interview F; and author interview G.

119. Author interview F; and author interview J.

120. Author interview G; and author interview J.

121. Author interview G.

122. *Radio Free Europe / Radio Liberty*, 'TV Tower In Kyiv Hit As Zelenskiy Again Calls for NATO to Impose No-Fly Zone', 1 March 2022.

123. For example, *Sky News*, 'Ukraine Invasion: University and Government Buildings Are Struck in Missile Attack in Kharkiv', 2 March 2022.

124. Andrew R C Marshall, 'Bloodied but Alive after Russian Air Strike in Western Ukraine', *Reuters*, 13 March 2022.

day, and those that were being flown were exclusively low-level flights to drop unguided bombs on area targets in support of the ground forces. Large-scale cyber attacks also failed to have a decisive effect as Russia had been conducting sustained cyber warfare against Ukraine since 2014, so most key networks were heavily defended, with attention given to backing up critical data with help from allies.¹²⁵ This left only Russia's cruise and ballistic missile arsenals available to conduct deep strikes across most of Ukraine.

Russia also relies heavily on its long-range precision-strike arsenal for conventional and tactical nuclear deterrent capability against NATO under the doctrine of non-contact warfare.¹²⁶ With the Russian Army increasingly bogged down and overstretched in Ukraine, and a strategy of brinkmanship from President Vladimir Putin predicated on intimidating the West into abandoning or at least limiting its military assistance, Russia cannot afford to fire its entire stockpile. Therefore, Russia's military leadership began to plan for a new set of targeting criteria that could deliver a greater strategic effect with the limited number of total missiles available.

The next major Russian bombardment strategy was instigated in June, with several weeks of daily strikes against Ukrainian fuel storage facilities, refineries and key railway infrastructure.¹²⁷ This could potentially have had a very serious effect on the Ukrainian population and the war effort over time if it had been conducted on a large scale from the outset.¹²⁸ However, two major factors conspired to reduce its impact to a manageable level.

First, Ukrainian air defences had, by this stage, been reorganised and redeployed to provide much more effective coverage against cruise missiles around key cities and facilities. Whereas during March and April interception rates had been around 20–30%, by mid-June they were roughly 50–60%.¹²⁹ The SA-11 'Buk' SAM systems provided the bulk of the anti-aircraft threat near the frontlines to keep Russian fast jets and helicopters flying low or further back behind Russian lines.¹³⁰ The long-range S-300PS/PT and S-300V1 SAM systems are more capable against cruise missiles and Tochka-U ballistic missiles than SA-11, and provide coverage over a wider area. They are also more valuable and less mobile than SA-11 so it made less sense to risk having them destroyed by Russian SEAD/DEAD efforts by deploying them close to the frontlines. Therefore, Ukraine's S-300 systems were primarily deployed to defend cities and infrastructure, and have proven highly effective against all types of Russian cruise missiles, especially when supplied with early warning information of launches from either Ukrainian sensors or partners.¹³¹

125. Bill Echikson, 'Ukraine Is Winning the Cyber War', CEPA, 29 September 2022, <<https://cepa.org/article/ukraine-is-winning-the-cyber-war/>>, accessed 24 October 2022.

126. RUSI, 'The Russian Way of War: Missile Strike Capabilities | Dr Sidharth Kaushal', YouTube, 11 February 2022, <https://youtu.be/b_sF6G0rEv4>, accessed 24 October 2022.

127. Author interview G. See also Mykhaylo et al., 'Preliminary Lessons in Conventional Warfighting from Russia's 2022 Invasion of Ukraine'.

128. Author interview A.

129. Author interview J.

130. Author interview D; and author interview G.

131. Author interview G; and author interview H.



Second, Russia was already running uncomfortably low on missile stocks given its requirements to maintain a contingency stockpile to deter NATO and the heavy expenditure from February to June. Despite benefiting from an impressive degree of component modularity and commonality between different missile types, including between cruise missiles such as 3M-54 Kalibr and ballistic missiles such as 9M723, Russian industrial production capacity is very limited compared with the rate at which they have been expended.¹³² For example, the modernised 9M723 Iskander production line has a monthly output capacity of six missiles.¹³³ Effective sanctions enforcement to complicate Russian acquisition of Western micro-electronics would make their sustainment problems considerably worse given the heavy reliance on US, Taiwanese and other Western chips in all their standoff missiles.¹³⁴ As a result of these shortages, firing rates of Russia's standard long-range land-attack missiles were lower from June to September than the 24 per day average in the first three months of the war.¹³⁵ In combination with a revitalised Ukrainian air-defence capability, this lower rate of fire has hampered the ability of Russian long-range strikes to prevent Ukraine steadily gaining the initiative in the war during this period. However, during this period Russia's stockpile limitations and inadequate production capacity for traditional cruise and ballistic missile types led to several significant actions on the part of the Russian military leadership.

132. Author examination of internal components from 9M720, 9M723, Kh-101 and multiple 3M-54 variants; and author interview H.

133. Author interview H.

134. Author examination of internal components from 9M720, 9M723, Kh-101 and multiple 3M-54 variants, Ukraine, October 2022. See also James Byrne et al., 'Silicon Lifeline: Western Electronics at the Heart of Russia's War Machine', RUSI, August 2022.

135. Author interview G.



9M723 Iskander ballistic missile remains with penetration aid (decoy) dispenser tubes visible. The R-77-1 air-to-air missile is also visible (left). *Courtesy of Jack Watling*

First, Russian forces began firing large numbers of other long-range missile types in the land-attack role. Older Kh-22 ‘Kitchen’ anti-ship missiles have been fired into Ukraine throughout the conflict, but as early as mid-March Russia also began launching the relatively new, supersonic and hugely expensive P-800 ‘Oniks’ anti-ship missile from its ‘Bastion-P’ systems in Crimea.¹³⁶ However, the radar-guided terminal-homing capabilities of anti-ship missiles are not optimised for attacking ground targets, and so offer not only reduced precision compared with dedicated land-attack weapons when used in that role, but can also sometimes home in on the wrong target once they go active. One likely case was the devastating attack on a shopping centre in Kremenchuk in July 2022 where a Kh-22 apparently missed its intended target nearby and instead homed in on the large radar reflection of the shopping centre’s flat metal walls and roof.¹³⁷ Russia also began to regularly use its S-300V1 and S-300VM tracked long-range SAM systems in the land-attack role, especially in the south near Kherson. Both versions fire the 5V55 missile which was designed to have a secondary land-attack capability for self-defence of the S-300V1.¹³⁸ In the land-attack role, it has a ballistic trajectory with a maximum range of 82 km. Its high supersonic speed makes it impossible to intercept with current Ukrainian air-defence

136. Author interview G; and author interview H. See also Thomas Newdick, ‘Russia Claims It Launched Bastion-P Anti-Ship Missiles Against Ground Targets in Ukraine’, *War Zone*, 23 March 2022, <<https://www.thedrive.com/the-war-zone/44891/russia-claims-it-launched-bastion-p-anti-ship-missiles-against-ground-targets-in-ukraine>>, accessed 24 October 2022.

137. Author interview J. See also Jack Taylor and Adam Parker, ‘What CCTV and Satellite Images Tell Us About Shopping Centre Missile Strikes in Ukraine’, *Sky News*, 6 July 2022.

138. Author interview H. See also CSIS Missile Defence Project, ‘S-300’, CSIS, 6 July 2021, <<https://missilethreat.csis.org/defsys/s-300/>>, accessed 24 October 2022.

systems and it delivers a large 130-kg high-explosive fragmentation warhead.¹³⁹ However, it is a very inaccurate weapon, being purely ballistic with no terminal homing capabilities against ground targets, and so Russian forces generally use them as indiscriminate bombardment weapons against cities – especially Mykolaiv.¹⁴⁰ Russian industry has also opened a new production facility to recondition and return old stocks of Tochka-U ballistic missiles to usable condition to supplement dwindling 9M720/723 Iskander-M stocks and production capacity.¹⁴¹

The second significant consequence of Russia's ineffective (albeit very destructive) initial standoff missile campaigns and limited remaining stockpiles was a deal with Iran to supply large numbers of Shahed-136 loitering munitions and Islamic Revolutionary Guards Corps (IRGC) support to teach Russian units to assemble and use them. The first Shahed-136 (Russian name, 'Geran-2') attacks were recorded by Ukrainian air defenders in mid-September, with attacks against Odesa alongside Iranian-supplied armed Mohajer-6 UAVs.¹⁴² An IRGC training group protected by an FSB security detail was identified and monitored by Ukrainian intelligence services, and destroyed with a precision artillery strike in Kherson around this time.¹⁴³ Unfortunately this did not end the Russian acceptance and ramp-up process for large-scale Shahed-136 use as a long-range strike weapon.

The Shahed-136 itself is a propeller-powered missile with a warhead capacity of 20–40 kg, depending on fuel load, desired range and consequent centre of gravity limitations.¹⁴⁴ It has a maximum range of well in excess of 1,000 km and typically cruises at around 150–170 km/h.¹⁴⁵ Guidance is provided using a mixture of inertial navigation and civilian GPS receivers with some features to improve jamming resistance, allowing it to hit fixed aiming points, but not moving targets.¹⁴⁶ The accuracy is sufficient to produce multiple hits on a single building, and the Shahed-136 can also bank to circle around a target upon arrival to perform a steep (>70-degree) terminal dive from a specific bearing programmed before launch.¹⁴⁷ A modified version equipped with

139. Author interview G; and author interview H.

140. *Ibid.*

141. Author interview H.

142. Author interview G. See also Ukrainian Ministry of Defence, 'A Video Featuring the Destruction of the Iranian Shahed-136 UAV in Dnipropetrovsk Region Appeared', 24 September 2022, <<https://mil.in.ua/en/news/a-video-featuring-the-destruction-of-the-iranian-shahed-136-uav-in-dnipropetrovsk-region-appeared/>>, accessed 30 October 2022; and Dylan Malyasov, 'Ukrainian Soldiers Seize Iranian-Made Mohajer-6 Drone', *Defense Blog*, 4 October 2022, <<https://defence-blog.com/ukrainian-soldiers-seize-iranian-made-mohajer-6-drone/>>, accessed 30 October 2022.

143. Author interview A.

144. Author inspection of nearly complete unexploded Shahed-136; and author interview H.

145. *Ibid.*

146. *Ibid.*; author interview B, with a former Ukrainian Armed Forces and current Ukrainian industry UAV and counter-UAV specialist, Ukraine, October 2022; author interview G; and author interview H.

147. Author observation of Shahed-136 flight pattern and impact during air raid, Ukraine, October 2022.



Wing-tip section from a destroyed Shahed-136. *Courtesy of Jack Watling*

specialist seeker heads and datalinks can apparently hit moving targets if designated by a more sophisticated UAV such as the Orlan-10, although these modifications significantly increase the price and are not common.¹⁴⁸ The basic Shahed-136/Geran-2 is a relatively simple, cheap and precise weapon for use against fixed targets for which Iran can supply components and Russia could license manufacture in very large quantities. This makes it an important medium- and long-term component in Russia's current long-range strike strategy against Ukraine.

The new Russian strategy opened with a barrage of cruise missiles and ballistic missiles against targets in multiple Ukrainian cities, including in central Kyiv on 10 October. This time, cruise missiles were launched alongside tens of Shahed-136 loitering munitions. More than half the total incoming weapons were shot down by Ukrainian air defences, but those that got through still inflicted serious damage and multiple civilian casualties.¹⁴⁹ Despite Putin claiming that the strikes in cities were a one-off retaliation for an explosion on the Kerch Bridge the previous week, the new strategy – to target electricity infrastructure – was already being prepared before the bridge was bombed.¹⁵⁰ On 9 October a new commander of the Russian military campaign against Ukraine, General Segey Surovikin, was appointed.¹⁵¹ Notorious for the brutality of the campaign he ran in Syria in his previous role as the commander of the VKS, Surovikin was appointed to implement a strategy that many of the more extreme Russian political and media

148. Author interview B.

149. Author interview D; and author interview G.

150. Author interview A.

151. Megan Fisher, 'General Sergei Surovikin: Who Is Putin's Hard-Line New Commander in Ukraine?', *BBC News*, 12 October 2022.

commentators have been urging for months – to deprive the Ukrainian civilian population of light and heating as winter approaches via large-scale strikes on infrastructure.

Since 10 October, Ukraine has seen multiple daily waves of Shahed-136s fired against electricity substations, infrastructure-control offices and facilities across most of the country.¹⁵² The relatively small warhead is less suitable than cruise missiles or ballistic missiles for destroying large or hardened targets. Therefore, the expensive Kh-101 and Kalibr cruise missiles and 9M723 Iskander, drawn from increasingly depleted stocks, have been simultaneously used to hit power stations and other large electricity-related targets.¹⁵³ Most of the Shahed-136s that are launched are being shot down by Ukrainian fighters, SAMs, MANPADS teams and anti-aircraft gunfire. However, they are being used in large enough numbers already – with more than 400 fired since mid-September – that they are draining Ukraine’s air-defence missile stocks in an alarming way, and still each day some get through to their targets.¹⁵⁴

In summary, Russia’s long-range missile campaign has gone through several phases. The opening salvoes targeted Ukrainian Air Force air-defence capabilities and stockpiles. Strikes subsequently focused on Ukrainian defence industry, communications infrastructure and small numbers of symbolic buildings in key cities. After the Russian ground campaign refocused on offensive operations in Donbas, fuel storage, refineries and railway infrastructure became primary targets for long-range strikes. However, in each of these cases Russia was unable to generate a critical concentration of strikes to have decisive effects on Ukraine’s ability to continue fighting. Under General Surovikin the strategy has changed again. Iranian-supplied loitering munitions and more expensive traditional precision-strike weapons are now being used in tandem to systemically target critical civilian electricity infrastructure. The multiple daily air-raid alarms disrupt work and sleep patterns and cause fear and anxiety for people who had hoped the threat to their homes was receding.¹⁵⁵ More worryingly, temporary blackouts that grow more frequent each day across many of Ukraine’s key cities after just three weeks of this new strike campaign suggest that it poses a major threat to Ukraine’s ability to keep its people warm and safe during the coming winter months.¹⁵⁶ It is unlikely to change Russia’s battlefield fortunes in Ukraine, but the latest iteration of Russia’s long-range strike efforts is causing major problems and generating new requirements for Ukrainian air-defence equipment.

152. Author interview A; author interview B; author interview D; author interview G; author interview H; and personal author observation, Ukraine, October 2022.

153. Author interview D; and author interview G.

154. *Ibid.*

155. Author observations and interviews in Ukraine, October 2022.

156. Author interview A. See also *BBC News*, ‘Ukraine War: Russia Deploys Dozens of Drones in Two Days – Zelensky’, 28 October 2022; and Henri Astier and Yaroslav Lukov, ‘Ukraine War: Massive Russian Strikes Target Energy Grid – Zelensky’, *BBC News*, 23 October 2022.

IV. The Need for More Western Aid to Improve Ukrainian Air Defence

AFTER THE SUCCESS of the Ukrainian counter-offensive in Kharkiv, its subsequent recapture of Lyman and continued pressure in Luhansk and Kherson, Russia is faced with the prospect of military defeat on the ground in 2023.¹⁵⁷ Partial Russian mobilisation will take several months to produce even barely competent new troops to augment battered regular units, let alone entire new formations. The task will be especially difficult given that the instructors and experienced officers Russia would normally count on to train new conscripts are largely either stuck trying to hold the frontlines in Ukraine or have become casualties. In response to the lack of viable options on the ground, Russia's leaders have turned to renewed long-range bombardment against civilian critical utilities. The plan is to cause enough civilian suffering that the Zelensky government is either forced to negotiate ceasefire terms or face major civil unrest that delays preparations for a renewed counter-offensive push to liberate the remaining occupied territories of Ukraine in spring 2023.

Russia's air and missile strike operations between February and August 2022 failed to produce decisive effects against Ukrainian target sets that ranged from air defences to communications, military industry, transport and fuel infrastructure. The failure of the VKS to mount an effective SEAD/DEAD campaign in the face of effective, dispersed Ukrainian Air Force GBAD operations cost it the ability to operate above very low altitude in Ukrainian airspace.¹⁵⁸ This was critical in allowing the Ukrainian Air Force fighter and ground-attack fleets to survive and continue to contest control of the air and attack Russian ground forces, despite being completely outmatched at a technical level.¹⁵⁹ Meanwhile, the large number of MANPADS provided to Ukrainian troops and later mobile air-defence teams near the frontlines meant that even very low altitude VKS fixed-wing penetrations proved prohibitively costly in March, and ceased by April 2022.¹⁶⁰ In consequence, Russia has not been able to effectively employ the potentially heavy and efficient aerial firepower of its fixed-wing Su-34 'frontal bomber' and multi-role fighter fleets by bombing Ukrainian strategic targets, except during the first few days of the invasion. Instead, Russia's attempt at strategic air attack has been limited to expensive cruise and ballistic missile barrages at a much more limited scale. These barrages have nevertheless caused major damage and have killed many Ukrainian citizens. Fortunately, Russia's limited stockpiles and production capacity

157. Jack Watling and Nick Reynolds, 'Ukraine at War: Paving the Road from Survival to Victory,' RUSI Special Report, 4 July 2022.

158. Author interview D; author interview G; and author interview H.

159. Confirmed in author interview D.

160. Author interview D; and author interview G.

of standoff missiles prevented adequate concentration or sustainment of effects against communications, transport or fuel infrastructure target sets. However, this should not lead to Western complacency about the need to urgently bolster Ukrainian air-defence capacity.

The Russian adoption of the Iranian Shahed-136 as a cheap weapon able to conduct large-scale, sustained precision strikes on civilian infrastructure and other fixed, non-hardened targets marks a key change in the character of the air war. Ukrainian air defences are currently shooting down the majority of incoming Shahed-136s and around half of the cruise missiles fired by Russia using a combination of SAMs, fighters with R-73 air-to-air missiles, mobile MANPADS teams and anti-aircraft guns.¹⁶¹ However, most of these interceptions use munitions that are far more expensive and are available for Ukraine in more limited quantities than the Shahed-136 is likely to be for Russia. Western SAM systems that have been supplied so far have proven highly effective against incoming cruise missiles, including the stealthy Kh-101, but have been supplied with inadequate ammunition for Ukrainian usage rates even though they are not being used against Shahed-136.¹⁶² MANPADS are effective and relatively efficient against Shahed-136 and cruise missiles when they pass within range of mobile air-defence teams.¹⁶³ However, the numbers required are large due to short range and the need to defend cities and infrastructure across Ukraine, in addition to protecting frontline troops from Russian attack aviation and UAVs. Due to its relatively small size, shape, low altitude flight and low speed, legacy Soviet and Russian self-propelled anti-aircraft guns (SPAAGs) such as Shilka and Tunguska also struggle to reliably shoot down the Shahed-136, although the German Gepard is highly effective.¹⁶⁴ After two weeks of sustained Russian attacks on electrical infrastructure, new deliveries of equipment and systems specifically tailored to efficiently providing defence against Shahed-136 attacks are already one of Ukraine's top priorities in terms of support from its international partners. The weapon is simple and not especially difficult to intercept, but most of the current means of doing so are too expensive or draw on unacceptable numbers of weapons required for other defence tasks to provide an adequate medium-term solution.

In the short term, therefore, Ukraine urgently requires deliveries of large numbers of additional MANPADS for mobile and static air-defence teams, and many modern SPAAGs such as the Gepard, LvKv 90 or Skyranger as possible. It also requires additional supplies of night-vision goggles to enable MANPADS teams to operate effectively at night.¹⁶⁵ Additional ammunition and more launchers for the highly effective IRIS-T SLM and NASAMS systems are also critical to enable the Ukrainian Air Force to defend remaining electricity infrastructure and protect repair work from higher-end cruise missile attacks. With rolling blackouts already affecting much of the country and the weather already getting cold, the urgency of these requirements is hard to overstate. Neither MANPADS or SPAAGs should be considered politically sensitive as they are fundamentally defensive weapons needed to protect civilian infrastructure that do

161. Author interview B; and author interview G.

162. *Ibid.*

163. Author interview G; and author interview H.

164. Author interview B; and author interview G.

165. Author interview G.

not require the absolute latest in cutting-edge technology to be effective. Rapidly gifting even small inventories of stored MANPADS and SPAAGs currently offers European states that wish to support Ukraine but face political difficulties in delivering longer-ranged offensive weapons or heavy armoured vehicles to make a real difference now.

In the medium term, Ukraine needs a way to produce or at least procure and operate efficient defence systems against Shahed-136 and other UAVs at scale. Countries that have significant experience defending against multiple relatively slow loitering munitions and UAVs such as South Korea, Saudi Arabia and Israel would make sense in terms of potential sources of ideas and subsystems, even if politically they were unwilling to directly supply Ukrainian forces. In general, gun systems are preferred over missiles where possible due to the much lower cost per engagement and higher availability of ammunition compared with SAMs and MANPADS.¹⁶⁶ A relatively simple new product that combined a small counter-UAV AESA radar with an attachable predictive aiming reticule sight is one option that, if possible, would offer a way to significantly enhance the capability of Ukraine's many traditional anti-aircraft guns such as ZSU-2-23 and 14.5-mm/12.7-mm heavy machine guns against Shahed-136.

Ukraine also needs a way to resupply its Soviet-made and domestically upgraded S-300 and SA-11 'Buk' SAM systems in both the anti-missile and battlefield anti-aircraft/counter UAV role. Eight months of high-intensity combat have consumed unprecedented and unforeseen quantities of interceptor missiles, and Western allies have few ways to supply more directly or indirectly. Western militaries have invested very little in production of medium- and short-range GBAD systems since the end of the Cold War due to overwhelming air superiority in every conflict since then. This means that production is now having to ramp up from a very low level and existing inventories are too small to meet Ukraine's needs. This will make it impossible to replace the large number of remaining S-300, SA-11, SA-15 'Tor' and SA-8 'Osa' systems operated by Ukraine directly in the medium term, let alone expand coverage. Therefore, it would seem sensible for Ukrainian industry to work with industrial partners in Western countries to set up new manufacturing lines as fast as possible for key SAM system ammunition such as the 5V55 missile for S-300PS/PT and S-300V1, and the 9M38 missile for the SA-11 'Buk'. This would have the side benefit of greatly improving Western familiarity with missile families that in various derivations are still in widespread use by adversaries including Russia, China and Iran.

If Ukrainian SAMs are allowed to run out of ammunition, then not only will Ukrainian infrastructure and other key target sets become dramatically more vulnerable to Russian missile strikes, but the Russian VKS fixed-wing fleet would suddenly again be able to start penetrating deep into Ukrainian-controlled airspace at medium and high altitudes. Russian fighters retain the capability to dramatically overmatch Ukrainian ones if allowed to roam freely at high altitude, as has been shown by their lethality against Ukrainian Air Force jets conducting low-level operations against Russian positions in Kherson in recent weeks.¹⁶⁷ In addition to the radar performance and missile range advantages that have always been a factor, the VKS Su-35S and Mig-31BM fleets

166. Author interview A; and author interview G.

167. Author interview D.

can now draw on a lot of live air-to-air combat experience from conducting continuous CAPs close to Russia's own borders. As such, the underwhelming VKS fighter performance during the first days of the invasion is unlikely to be repeated if Ukrainian SAMs are starved of ammunition to the point that they can no longer deter Russian fixed-wing incursions. Furthermore, despite the relatively poor operational-level coordination between different Russian fast-jet fleets, and limited close air support capabilities against organic battlefield targets in contested environments, the experience of rebel groups and the Islamic State in Syria should remind those quick to dismiss the VKS of how much firepower they can and regularly do apply to fixed targets if allowed to operate freely at medium altitudes.¹⁶⁸ The inability of the Russian Air Force to coordinate large-scale complex SEAD/DEAD operations to neutralise Ukraine's ground-based air-defence network has been the key factor that has prevented it from being one of the main threats to Ukraine's war effort so far.¹⁶⁹ It is vital that the West does not lose sight of the fact that it must help Ukraine to keep that air-defence network supplied and reinforce it, otherwise that situation could change fairly rapidly in the coming months.¹⁷⁰

The Ukrainian Air Force also urgently needs more Western weapons that can enhance the standoff lethality of its existing attack jet fleet in a similar manner as the AGM-88 HARM was integrated to allow SEAD strikes against Russian SAMs. Due to the very serious threat from Russian long-, medium- and short-range GBAD systems and Russian fighter patrols, Ukrainian attack aircraft must fly very low when anywhere near the frontlines and still regularly suffer losses. Very low-level approaches to target areas make detecting and designating for laser-guided weapons or achieving electro-optical or infra-red lock-on against targets almost impossible due to the very short period and range within which they appear within the pilots' field of view. Clearly, the more standoff range can be offered, the more losses will be minimised. Candidate weapons must be able to be programmed with the release and target parameters before being loaded onto the jet, since Western smart munitions are unlikely to be able to exchange data directly with existing Ukrainian aircraft avionics.¹⁷¹ They would need to have sufficiently capable automated target detection and attack capabilities to reliably detect and destroy Russian ground vehicles themselves when delivered roughly to the right target area. Since these weapons would primarily be needed to counter Russian mass as mobilised formations appear on the frontlines in spring 2023, suitable munitions would also need to exist in Western stockpiles in large numbers. Such a demanding list of criteria leaves a very small number of potential options, with the American CBU-105 Sensor Fused Weapon being one potential option worth exploring.¹⁷² If it could be released by Ukraine's Su-24 bombers in a lofted profile from a fast

168. For example, see Human Rights Watch, 'Russia/Syria: War Crimes in Month of Bombing Aleppo', 1 December 2016, <<https://www.hrw.org/news/2016/12/01/russia/syria-war-crimes-month-bombing-aleppo>>, accessed 24 October 2022.

169. Bronk, 'Getting Serious About SEAD'.

170. Author interview A; author interview D; and author interview G.

171. Author interview D; and author interview I.

172. N R Jenzen-Jones, 'US CBU-97/CBU-105 "Sensor Fuzed Weapon" Cluster Munition', Armament Research Services, 5 August 2017, <<https://armamentresearch.com/us-cbu-97cbu-105-sensor-fuzed-weapon-cluster-munition/>>, accessed 24 October 2022.

low-altitude pop-up delivery, then guided to a more precise aim point by pre-programmed GPS coordinates, the multiple anti-armour homing skeet submunitions would be devastating against Russian vehicle concentrations.

In the medium term, Ukraine needs new fighter aircraft able to meet Russian fighters on more equal terms as soon as possible, especially if providing sufficient ammunition to maintain frontline SAM coverage proves difficult. The enduring threat from Russian long-range S-400 SAMs, especially when cued in by radars capable of tracking them at low altitudes from long ranges such as the 48Ya6 Podlet-K1, is likely to force Ukrainian fighters to operate at low level as part of standard tactics.¹⁷³ The effective range of air-to-air missiles is inherently tied to launch altitude and speed of both the aircraft firing and its target.¹⁷⁴ As such, any new fighter for the Ukrainian Air Force needs to come equipped with a missile capable of offering the greatest possible effective range under low-altitude, subsonic launch conditions. Electronic warfare capabilities to reduce the effectiveness of Russian radars at longer ranges would also be highly beneficial, as would a radar designed to be resilient against the Khibny jamming pods that Russian fighters typically fly with over Ukraine. Aside from improved air-to-air performance, the main Ukrainian operational priority is for an aircraft capable of operating from dispersed, relatively basic airbases to prevent them being located and rapidly destroyed by Russian long-range missile strikes.¹⁷⁵ This entails an ability to be serviced with limited personnel and heavy equipment, and to operate from relatively rough and short runway surfaces. Anti-shipping capabilities are also required.¹⁷⁶ Any new fighters also need to be able to generate high sortie rates from both an availability and affordability perspective, since the Ukrainian economy has been devastated by the Russian invasion and new fighters are competing with a huge range of other requirements. As a long-term plan, the Ukrainian Air Force wants to operate a split fleet of a single engine light multi-role fighter and a longer-ranged twin engine fighter for greater air-defence persistence.¹⁷⁷ However, in the short term, even a tiny number of modern Western fighters would be a huge boost to Ukraine's ability to continue deterring the VKS from penetrating its skies.

The decision to supply a Western fighter would inherently be heavily influenced, and most likely ultimately decided, by political factors. In the long term, US-supplied aircraft are likely to form a large part of the Ukrainian Air Force inventory due to political, industrial and financial considerations. However, while Ukrainian airbases are still at high risk of Russian missile strikes, the long, high-quality runways and large hangars with extensive ground support equipment required to operate most US fighters would be difficult to build without being observed and hit. It is worth noting that of the currently available Western fighter aircraft that could possibly be supplied, the Swedish Saab Gripen C/D offers by far the most suitable candidate in terms of operational requirements. It was designed from the outset for ease of maintenance, and can be refuelled, re-armed and given basic maintenance by teams of just six ground crew using two

173. Author's own analysis. Supported by author interview D.

174. For more detailed information, see Bronk, 'Russian and Chinese Combat Air Trends', pp. 6–9.

175. Author interview D.

176. *Ibid.*

177. Author interview D.

vehicles on small airbases or highways in cold weather.¹⁷⁸ Moreover, only one of each crew needs to be a highly trained maintainer; the rest can be conscripts or even troops.¹⁷⁹ Conceptually, the Swedish Air Force has always emphasised low-level air superiority tactics from dispersed bases, in a similar manner to how the Ukrainian Air Force currently operates, and so the Gripen was designed with ground support equipment and maintenance requirements compatible with that approach. The electronic warfare suite on the Gripen C/D is also optimised specifically for countering Russian fighter and SAM radars. Other factors that make Gripen particularly suited to Ukrainian operational needs are that it can fire the very long-range European Meteor missile, which, thanks to its ramjet propulsion design, is less adversely affected by being launched from low and slow than traditional rocket-powered missiles such as R-27 or AIM-120 AMRAAM, and Gripen was also designed from the outset with an anti-ship capability.

Since April, VKS pilots have been extremely reluctant to aggressively fight their way into Ukrainian airspace due to the losses taken during early attempts. The threat of Ukrainian SAM and MANPADS engagements has shaped the behaviour and constrained the effectiveness of Russian pilots significantly. Therefore, even a few modern Western fighters with long-range missiles able to meet the Russians on technically equal or even superior terms would likely have a disproportionate deterrent effect.

Western military aid has quite rightly concentrated on equipping and supporting the Ukrainian ground forces until now. Ukraine has so far managed to hold its own in the air domain, largely using its own equipment. However, there is a real danger that this success leads to Western complacency about the threat that the VKS can still pose to Ukrainian forces, infrastructure and cities if given an opening. Ukraine now needs rapid deliveries of SAM launchers and missile ammunition, SPAAGs and ideally Western fighter aircraft to prevent a sustained strike campaign that could, if unopposed, thwart the dominant battlefield momentum that Ukrainian troops have fought so hard to win.

178. Author interview with Swedish Air Force maintenance chief and senior ground crew personnel, F.21 Fighter Wing, Luleå Airbase, Sweden, 29 September 2022.

179. *Ibid.*

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Cover image: A Russian fighter jet flies above a railway junction on fire following recent shelling in the course of Russia-Ukraine conflict in the town of Shakhtarsk (Shakhtyorsk) near Donetsk, October 2022. *Courtesy of Reuters / Alamy Stock Photo*

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