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Regenerating Warfighting Credibility for European NATO Air Forces

Justin Bronk



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*Cover image: Mechanics re-arm a JAS 39-C Gripen at dispersal airstrip
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Executive Summary

- The UK armed forces and other European militaries have been sized, equipped and organised around the assumption that air superiority will be quickly achieved and leveraged to defeat state opponents.
- Russia will remain an adversary for the foreseeable future and is likely to continue to rearm and rebuild large-scale conventional forces once the fighting in Ukraine ceases. It is in China's geopolitical interests to split US and European resources and attention away from the Indo-Pacific. Therefore, China is likely to help Russia rearm once there is some form of ceasefire in Ukraine. This would significantly increase the level of threat Russia can pose in the medium term.
- The Chinese military threat means fewer US military assets available to reinforce Europe in a crisis. A notable risk is that Russia will take advantage of a conflict between the US and China in the Indo-Pacific to renew aggression against European NATO members or Ukraine.
- The likelihood of an enduring military threat from Russia and, increasingly, US commitment to the Indo-Pacific mean that European NATO air forces must take steps to urgently regenerate credible warfighting capability against Russian forces. Medium-term deterrence requires it.
- However, almost all European air forces, including the RAF, currently lack many of the critical capabilities required to credibly be able to gain and exploit air superiority against Russian forces, or indeed any state opponent with modern ground-based air defence systems and long-range strike capabilities.
- The first major area of concern is the vulnerability of air forces that have, due to decades of efficiency-saving measures, ended up in a position where their combat aircraft and the maintenance capacity to support them are concentrated in a small number of main operating air bases with limited hardened shelters or ground-based missile defence systems. This makes them highly vulnerable to Russian long-range strike capabilities and so undermines their deterrence credibility and survivability in any potential conflict.
- Remedying this will require a combination of dispersal, hardening and ground-based air defence protection. The optimal combination will vary depending on each air force's current laydown, equipment and resourcing. Sweden and Finland both provide examples of air forces that currently maintain a much less vulnerable posture than most European NATO air forces. Not all aspects of their equipment or practices can be universally adopted, but there is much that could be learned.
- The second major concern is a lack of currency and proficiency for high-intensity mission sets among aircrew and other key personnel across most air forces in Europe. The tactics and procedures required to be effective against a state adversary like Russia are very different from those required for peacetime air policing or close air support against insurgent groups.
- To regenerate proficiency in high-end warfighting mission sets, air forces must reduce discretionary commitments such as counterterrorism and international diplomacy-

focused deployments. At present, with the scale of ongoing activity, most air forces, including the RAF, lack the necessary maintenance, spares and aircrew capacity to conduct focused warfighting training at scale. Overstretching fast jet fleets by trying to do everything is resulting in increasing problems with aircraft availability, and significant numbers of the most critical experienced instructor pilots and senior engineers are becoming burnt out and resigning.

- The third major area of concern is that no European NATO air forces currently have sufficient expertise or the required munitions stocks to conduct suppression and destruction of enemy air defences (SEAD/DEAD) at scale. The lethality of mobile surface-to-air missile (SAM) systems on both sides in Ukraine is a vivid reminder of the consequences of an inability to conduct SEAD/DEAD at scale. Without such capacity, European NATO air forces cannot credibly achieve and exploit control of the air over a battlefield contested by Russian forces or even by near-peers such as Iran.
- Weapons and aircraft already exist that are well suited to SEAD/DEAD; most notably, in terms of weapons, the GBU-53/B StormBreaker, SPEAR 3 and AARGM-ER, and in terms of aircraft, the F-35. However, these are all expensive capabilities that must be fielded in significant numbers and regularly trained and exercised at scale as part of the joint force if they are to be operationally credible. This means that European air forces that do so will pay a significant opportunity cost in terms of other potential mission sets and capability areas that will need to be disinvested in to generate financial headroom and capacity.
- It is, nonetheless, vital that at least a few of NATO's larger European air forces do regenerate a SEAD/DEAD capacity at scale against modern, mobile SAM systems. The key warfighting bottleneck standing in the way of generating sustainable European deterrence credibility against Russia (or other regional near-peer threats like Iran) is an inability to credibly establish air superiority due to lack of SEAD/DEAD capacity. Fixing this deficiency should, therefore, be seen as a matter of urgent priority.
- The only alternative – accepting that air superiority is not attainable over future battlefields contested by Russia or another adversary nation – would require a total redesign of NATO's joint forces towards a force that relies on massed artillery, armour and infantry as the core of its fighting power, rather than air-delivered firepower. That alternative implies demographic, political and financial costs that far outstrip the costs of regenerating warfighting credibility for NATO air forces.

Introduction

THE RUSSIAN INVASION of Ukraine and fears of a Chinese invasion of Taiwan have forced the US, the UK and other NATO nations to once again plan for high-intensity peer warfighting as a core task for the first time since the end of the Cold War. At the same time, experience from the ongoing conflict in Ukraine has reminded air forces everywhere of many often forgotten or ignored features of peer warfare.

First, Russia's long-range precision strike campaign and successful Ukrainian strike and sabotage operations have confirmed that large fixed air bases are key targets and will be struck with accurate missile barrages during any force-on-force clash.¹ Second, the poor performance of the Russian Aerospace Forces (Vozdushno-Kosmicheskoye Sily, or VKS) due to systemic deficits in aircrew, doctrine, planning and command-and-control (C2) staff competence has graphically illustrated the importance of regular realistic training, not only for aircrew, but for the whole airpower enterprise.² Third, the war in Ukraine has graphically illustrated that the scale of weapon use in peer warfighting at scale would rapidly and dangerously deplete Western stockpiles and far outstrip existing surge production capacity.³ Finally, the mutual denial of air superiority for both the Ukrainian Air Force and VKS by ground-based air defence (GBAD) assets has graphically illustrated the consequences of not being able to conduct suppression and destruction of enemy air defences (SEAD/DEAD) at scale.⁴

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1. See, for example, Michael Holden, 'Half of Russia's Black Sea Fleet's Combat Jets out of Operation, Western Official Says', *Reuters*, 19 August 2022; *AirLive*, 'Ukrainian Air Force MiG-29s Have Been Destroyed at Ivano-Frankivsk Airbase', 27 February 2022, <<https://www.airlive.net/ukrainian-air-force-mig-29s-have-been-destroyed-at-ivano-frankivsk-airbase/>>, accessed 23 November 2022; Bethany Dawson, 'Russia Strikes Ukrainian Airbase, Destroying Aircraft and an Ammunition Depot, Say Reports', *Business Insider*, 9 April 2022, <<https://www.businessinsider.com/russia-strikes-ukrainian-airbase-destroying-aircraft-and-ammo-depot-reports-2022-4?r=US&IR=T>>, accessed 23 November 2022.
 2. Author interviews with Ukrainian Air Force fighter fleet and air defence commanders, Ukraine, October 2022. For more details, see Justin Bronk with Nick Reynolds and Jack Watling, 'The Russian Air War and Ukrainian Requirements for Air Defence', *RUSI*, 7 November 2022, pp. 6–21.
 3. Alex Vershinin, 'The Return of Industrial Warfare', *RUSI Commentary*, 17 June 2022, <<https://www.rusi.org/explore-our-research/publications/commentary/return-industrial-warfare>>, accessed 23 November 2022.
 4. 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, <<https://rusi.org/explore-our-research/publications/rusi-defence-systems/getting-serious-about-sead-european-air-forces-must-learn-failure-russian-air-force-over-ukraine>>, accessed 23 November 2022.

The Western way of warfare relies on having air superiority over any potential battlefield to provide ISTAR capabilities and precision firepower at scale through close air support and interdiction. However, if SEAD/DEAD cannot be conducted, then air superiority is impossible to attain, an inconvenient and expensive truth for air forces that have been largely optimised for operations in permissive and semi-permissive airspace for decades, and whose high-end warfighting capabilities are largely air-to-air focused. This mission-based deficit is closely linked to both aircrew training and munitions stockpile challenges, since SEAD/DEAD is a highly demanding mission that requires specialist skills and weaponry to accomplish.

The gap between pre-invasion expectations and the actual performance of both the Russian and Ukrainian armed forces will also have significant long-term implications for deterrence between major powers. The logistics, operational planning and training deficiencies that initially hamstrung the Russian army are likely to make all militaries more inclined to weight assessments of such factors more heavily in future when considering the conventional military capabilities of any would-be adversary. Essentially, Russia has reminded the world quite how difficult it is to plan, execute and provide logistical support and enablement on the scale required for warfighting against a peer nation. As such, in future, states are likely to be less deterred by front line force structures that conspicuously lack realistic training and exercise schedules, enabler support, logistics provision and stockpiles for spares and ammunition. Re-establishing deterrence credibility with conventional military forces, therefore, will require not only regaining key warfighting skills such as SEAD/DEAD, but also regenerating the stockpiles and realistic exercise programmes and training tempo needed to avoid hollow front line forces. For non-US NATO air forces, these challenges are much more severe than for the US since the US Air Force (USAF), US Navy and US Marine Corps all still field airpower on a large scale with a global footprint and large munitions stocks. However, the Pentagon is heavily focused on the Indo-Pacific and the threat from Chinese forces that increasingly pose a major threat to US military freedom of action.⁵ The result is that there will be far fewer US forces available to help defend Europe in any future war with Russia. This would be especially problematic for European powers if Russia took the logical step of coordinating any future armed aggression to coincide with the US being occupied by a war or serious armed standoff with China.⁶

In Europe itself, whether the current phase of the war in Ukraine ends in a Ukrainian victory on the ground or a protracted stalemate and eventually an uneasy ceasefire, Russia will remain a serious military threat in the three-to-five-year timeframe. The Russian political leadership class has completely committed to an ideological, and in their view existential, confrontation with the Western-led global order. Military setbacks in Ukraine have led to more extreme rhetoric and

5. Valarie Insinna, 'The New National Defense Strategy Keeps the Pentagon's Focus Locked on China', *Breaking Defense*, 27 October 2022, <<https://breakingdefense.com/2022/10/the-new-national-defense-strategy-keeps-the-pentagons-focus-locked-on-china/>>, accessed 2 December 2022.

6. Confirmed during interviews between the author and senior US military officers and national security officials in Washington, DC, 9–15 November 2022

demands, and partial national mobilisation rather than withdrawal or moderation.⁷ At the same time, Russia's economy has been badly hit by comprehensive sanctions and the demographic impact of mobilisation, mass casualties and emigration of young people.⁸ Its energy supply leverage over Europe is rapidly waning as Germany and other key customers urgently diversify their gas and oil supplies away from Russia.⁹ Political parties and media organisations that once took significant Russian funding now face public backlash in most Western countries. All these factors mean that most of the Kremlin's so-called 'grey-zone' tools for competition and influence have been dramatically weakened for the foreseeable future. This will logically increase its reliance on military power to compete, and so rearmament and reconstruction of its conventional forces after the immediate end of hostilities in Ukraine will almost certainly be a priority. In this, Russia is likely to be heavily supported by China in both economic and technical terms. The Chinese government remains extremely uncomfortable with Russia's war in Ukraine, and has shown limited willingness to provide overt support while hostilities are ongoing.¹⁰ However, once the shooting pauses, the fact that it is in China's geostrategic interest to have Russia continue to tie down US and European military forces by posing a threat in Europe suggests that Beijing will support Russian rearmament efforts at scale.

To ensure that Russia does not have an opportunity to re-establish the conventional capability to threaten them, European NATO members must urgently regenerate the warfighting credibility of their armed forces. Although the US remains far and away the most powerful NATO member, China will force it to keep the bulk of its forces postured towards the Indo-Pacific in the coming decades. Since the air domain is where the bulk of NATO's conventional firepower and lethality sits, deterring Russia requires European NATO air forces to regenerate warfighting capabilities so that they can defend NATO airspace and ground forces.¹¹

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7. See, for example, Vladimir Putin, 'Signing of Treaties on Accession of Donetsk and Lugansk People's Republics and Zaporozhye and Kherson Regions to Russia', speech, 30 September 2022, <<http://en.kremlin.ru/events/president/news/69465>>, accessed 2 December 2022; Emily Ferris, 'Putin's Speech Offers a Way Out of This War ... For Now', *RUSI Commentary*, 4 October 2022, <<https://rusi.org/explore-our-research/publications/commentary/putins-speech-offers-way-out-war-now>>, accessed 2 December 2022.
 8. Jeffrey Sonnenfeld et al., 'Business Retreats and Sanctions are Crippling the Russian Economy: Measures of Current Economic Activity and Economic Outlook Point to Devastating Impact on Russia', Yale University, 19 July 2022, <https://papers.ssrn.com/sol3/Delivery.cfm/SSRN_ID4179598_code3324709.pdf?abstractid=4167193&mirid=1&type=2>, accessed 2 December 2022.
 9. European Council, 'Infographic: Where Does the EU's Gas Come From?', <<https://europa.eu/!Ry4j3d>>, accessed 2 February 2023; *BBC News*, 'Germany Says it is no Longer Reliant on Russian Energy', 18 January 2023.
 10. Stuart Lau, 'Putin Admits China has "Questions" and "Concerns" About Ukraine War', *Politico*, 15 September 2022, <<https://www.politico.eu/article/putin-admits-china-has-questions-and-concerns-about-ukraine-war/>>, accessed 2 December 2022.
 11. Jack Watling, 'The Future of Fires: Maximising the UK's Tactical and Operational Firepower', *RUSI Occasional Papers* (November 2019).

This paper examines three areas of challenge for European NATO air forces facing this task. Chapter I looks at the vulnerability of NATO air bases and the options for hardening or dispersal according to various existing models. Chapter II provides an analysis of NATO aircrew training and exercise practices. Chapter III looks at the twinned challenges of munitions stockpiles and SEAD/DEAD requirements. Finally, the Conclusion lays out several broad recommendations for European NATO air forces in the short, medium and longer term.

I. Reducing Air Base Vulnerability

IN THE 30 years since the end of the Cold War, all NATO air forces have significantly reduced the number of aircraft, bases and personnel they operate.¹² This has, however, been accompanied by a significant increase in the theoretical combat power of most air forces, due to dramatic improvements in precision-guided munitions, targeting pods, sensors and avionics. Essentially, the aircraft and weapons have become much more capable and lethal, while also becoming more expensive and complex to maintain. This, combined with declining defence budgets, has led almost all NATO air forces to dramatically reduce the number of air bases from which they operate, and to centralise maintenance and logistics support on the remaining main operating bases to improve cost efficiency.¹³ This made sense in the absence of a credible strike threat to those air forces on their bases. However, with the return of Russia as an active adversary, European NATO air forces must confront the fact that their current force laydowns involve potentially very lethal, but nonetheless comparatively small, numbers of fast jets and enabler aircraft on a small number of main operating bases, often alongside the deep maintenance and sustainment facilities for each fleet.

This is a major issue for the conventional deterrence credibility of NATO's airpower, since it means that much of it is very vulnerable to destruction by Russian long-range precision strike capabilities in the event of any direct clash. Throughout the invasion of Ukraine, Russia has fired thousands of ground-, sea- and air-launched cruise and ballistic missiles against a range of Ukrainian targets with consistently sufficient accuracy to hit individual buildings from standoff ranges.¹⁴ The challenge for the UK and other European air forces is not necessarily that Russia would open any clash with a massive strike wave against NATO air bases (although it could,

12. For example, the RAF has contracted from 90,000 regular personnel in 1990 to just under 30,000 in 2022. Ministry of Defence (MoD), 'FOI2017/04440', 28 April 2017, <https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/628180/2017-04440.pdf>, accessed 25 November 2022; HM Government, 'Quarterly Service Personnel Statistics 1 January 2022: Full-Time Trained Strength (RN/RM & RAF) and Full-Time Trade Trained Strength (Army)', 15 September 2022, <<https://www.gov.uk/government/statistics/quarterly-service-personnel-statistics-2022/quarterly-service-personnel-statistics-1-january-2022#full-time-trained-strength-rnrm--raf-and-full-time-trade-trained-strength-army>>, accessed 25 November 2022.

13. For example, see *BBC News*, 'RAF to Pull Out of Leuchars as RAF Lossiemouth Stays', 18 July 2011, <<https://www.bbc.co.uk/news/uk-scotland-14182729>>, accessed 25 November 2022. Aside from RAF Leuchars, other RAF front line flying stations closed since the end of the Cold War include RAF Wattisham, RAF Coltishall, RAF Kinloss and RAF Cottesmore.

14. Author interviews with senior Ukrainian Air Force aviation and GBAD officers, and intelligence officers, Ukraine, October 2022. For an in-depth analysis of the Russian long-range strike campaign, see Bronk, Reynolds and Watling, 'The Russian Air War and Ukrainian Requirements for Air Defence', pp. 25–34.

depending on the perceived stakes and risk on both sides). Rather, the risk is that NATO could be deterred from using its airpower to start degrading Russian IADS (integrated air defence system) coverage and attriting ground forces during any future Russian aggression against an Eastern European NATO member state, due to the chronic vulnerability of its combat air fleets to return strikes. Since most joint-force ISTAR capacity and precision firepower across the Alliance is delivered by air, and Western armies have very limited GBAD capabilities, this is a serious problem.

There are essentially two potential approaches GBAD air forces can take, and in some cases already are taking, to reduce the vulnerability of their air bases. The first is hardening (which can include deploying integrated GBAD capabilities) and the second is dispersal. Both present challenges and have practical limitations and significant extra costs associated with them. Neither are a silver-bullet solution in themselves, but both offer ways to significantly reduce the attractiveness of air forces as targets for finite Russian (or other state) long-range precision strike and sabotage capabilities. Therefore, they are an essential component for NATO air forces trying to reorientate towards great-power deterrence once more.

Hardening involves using both passive and active defences to render air bases and the aircraft, weapons stockpiles, fuel and facilities on them less vulnerable to strikes. Passive Cold War staples such as hardened aircraft shelters (HASs) (see Figure 1) and command facilities have been replaced on many bases by commercial-grade buildings or light shelters that provide no blast protection. Even where they have been retained, the concentration of fleets on small numbers of bases means that generally there are not nearly enough HASs for all the aircraft to be so protected.¹⁵

15. Confirmed during author visits to front line NATO fast jet stations including: RAF Coningsby, UK, 6–7 July 2021; French Air and Space Force (Armée de l'air et de l'espace, or AAE) Orange-Caritat, France, 18 August 2021; RAF Lakenheath, UK, 23–24 September 2021; CFB Bagotville, Quebec, 24–27 May 2022; Laage-Rostock Air Base, Germany, 16 August 2022; and RAF Lossiemouth, UK, 28–30 November 2022.

Figure 1: RAF Squadron Buildings with Hardened Aircraft Shelters



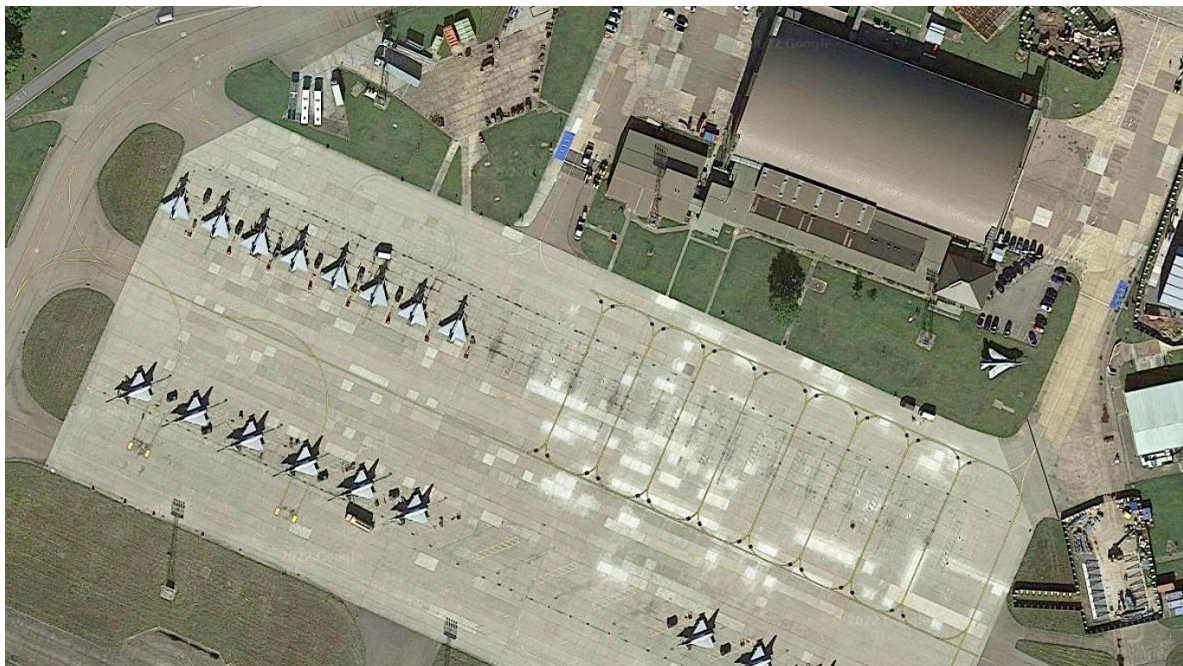
Source: Google maps satellite image, retrieved 1 December 2022, © 2022 Airbus, CNES/Airbus, Getmapping plc, Maxar Technologies, Map Data © 2022.

One of the reasons why HASs have gone out of fashion since the Cold War is that precision-guided munitions with unitary warheads can defeat HAS protection with direct hits. However, in the context of long-range Russian missiles, as opposed to comparatively cheap Western laser- or GPS-guided bombs dropped from aircraft, they still provide very significant levels of protection, for several reasons. First, destroying multiple aircraft protected by HASs requires at least one, and sometimes multiple, direct hits with penetrating, unitary warheads on each shelter.¹⁶ This means that a lot of accurate, long-range and therefore expensive munitions are required for an adversary to destroy even a moderate number of aircraft using conventional strikes. Second, it is difficult to tell if a HAS is in use at any given time using overhead or orbital surveillance. Therefore, if there are more HASs than aircraft on a base, an enemy will be forced to assume that they will waste at least some weapons on empty shelters during any strike, and it will also be more difficult to track the dispersal of aircraft both on the air base and off-site for targeting purposes. This effect would dovetail extremely well with the use of realistic decoy aircraft and other deception measures to greatly increase the number of missile strikes Russia would have to plan on to achieve a given level of effect. HASs are also very useful for reducing vulnerability to more unconventional threats, since inside them aircraft are well protected against the light warheads that can be carried by small UAVs and loitering munitions, and are harder for infiltrated saboteurs to reach in general.

16. For examples, see Carlo Kopp, 'Airbase Hardening in the Western Pacific', *Defence Today* (Vol. 9, No. 4, 2012), pp. 12–15, <<http://www.ausairpower.net/PDF-A/DT-Hardening-Mar-2012.pdf>>, accessed 2 December 2022.

By contrast, aircraft parked under unprotected sun shelters, in non-hardened hangars or on hardstands (see Figure 2) are vulnerable to being destroyed or disabled in significant numbers by sabotage or a single missile carrying a large high-explosive fragmentation warhead or submunitions. They are also much easier to find and target using small UAVs or loitering munitions. The risk is heightened further if aircraft parked on hardstands or in hangars are not separated by raised berms to deflect horizontal blast, shrapnel and the spread of fire or secondary explosions. Even with revetments for horizontal blast protection, multiple aircraft can be destroyed or rendered unflyable by both conventional missile strikes and/or special forces using UAVs to drop explosives and cause secondary fuel fires. This was graphically illustrated by the destruction of at least eight Su-30SM and Su-24MR jets from Russia's Naval Aviation forces at Saki Air base in August 2022 by a combination of as-yet unattributed primary and secondary explosions and fire.¹⁷

Figure 2: RAF Squadron Hangar with Aircraft Parked on Hardstand Area



Source: Google maps satellite image, retrieved 1 December 2022 © 2022 CNES/Airbus Get Mapping.plc, Infoterra Ltd and Bluesky, Maxar Technologies, Map Data © 2022.

The construction of HASs is a relatively expensive activity, made more so by the increased space requirements for a given number of aircraft compared to large hangars, and the need to provide the requisite ground support equipment in multiple locations around a squadron site. Line maintenance also becomes more labour-intensive for ground crews if aircraft are to undergo routine maintenance tasks in dispersed HAS sites, rather than in a large central hangar

17. Samuel Oakford and Joyce Sohyun Lee, 'At Least Six Explosions Hit Crimea Air Base in Nearly an Hour', *Washington Post*, 14 August 2022.

or on hardstands. However, compared to the cost of combat aircraft themselves, it is relatively efficient to construct HASs when doing so will significantly improve their survivability. As an example of the rough cost and continued appeal for air forces who take high-intensity conflict seriously as a planning requirement, in July 2020 the Republic of Korea Air Force and USAF completed a joint programme to construct 20 new third-generation HASs at Kunsan Air Base for a total cost of \$125 million.¹⁸ This is around the cost of one modern Western fighter aircraft, including engine and initial servicing contract. The relatively small size of most NATO fighter fleets, and the fact that some HAS capacity still exists at many bases, suggests that resilience against long-range missile and UAV strikes could relatively affordably be significantly improved by national or multinational HAS construction and renovation programmes.

Another crucial element of passive hardening to make air bases more resilient in the face of standoff attacks is the ability to rapidly defuse unexploded munitions, fill in craters and resurface runways that have been damaged. Multiple runways or the ability to take off from taxiways provide additional resilience but ultimately, to remain active under fire, an air force must retain the ability to repair runways rapidly, so that an opponent would have to fire an uneconomical number of missiles on a sustained basis to keep aircraft grounded. Under existential threat from the People's Liberation Army's long-range missile arsenal, the Republic of China [Taiwanese] Air Force has long maintained rapid runway repair teams and equipment at each base, and the Israeli Air Force does the same to avoid being grounded by Hizbullah rocket strikes.¹⁹ However, in most European air forces the specialist engineering support units that provided a rapid runway repair capability during the Cold War were disbanded in the 1990s and 2000s due to the lack of an obvious threat.

It is far more expensive to harden C2 facilities, munitions and fuel bunkers. This is not only because they are larger, but also because they need to be assured to a greater degree than each individual HAS due to their value as targets for limited stocks of expensive ballistic missiles able to penetrate significant depths of concrete. Providing such defence requires burying these facilities under large amounts of earth and reinforced concrete. As such, dispersing these functions across smaller, more numerous nodes with reduced signatures may be more viable than buried hardening as a route towards reducing their vulnerability within the budgets available. It is also significantly more difficult to provide HAS protection for large enabler aircraft like tankers and AWACS than for fighters, meaning that a greater reliance on dispersal (including potentially at civilian airports) and active hardening through air defence systems at main operating bases may be a better route for reducing the vulnerability of these critical assets.

Active hardening for airpower on the ground involves the ability to intercept and shoot down incoming missiles, in addition to traditional ground-based force protection such as that provided

18. Will Bracy, 'Hardened Aircraft Shelters Constructed at Kunsan', US Indo-Pacific Command, 5 August 2020, <<https://www.pacom.mil/Media/News/News-Article-View/Article/2301725/hardened-aircraft-shelters-constructed-at-kunsan/>>, accessed 2 December 2022.

19. Ian Easton, 'Taiwan, Asia's Secret Air Power', *The Diplomat*, 25 September 2014, <<https://thediplomat.com/2014/09/taiwan-asias-secret-air-power/>>, accessed 4 December 2022.

by the RAF Regiment for the UK against infiltration or special forces attacks. Integrated air and missile defence (IAMD) requires a layered and seamlessly interconnected system of sensors to provide early warning and tracking of incoming threats, and shooters to intercept the missiles.²⁰ For the defence of facilities in the homeland, IAMD capabilities also require assured and seamless deconfliction with civilian air traffic activities and other military flying. These integration and networking requirements drive up cost and personnel demands on top of the sensors and interceptor systems, which are themselves very expensive. For example, Bahrain recently paid \$2.5 billion for 60 Patriot PAC-3 missiles, 36 Patriot PAC-2 GEM missiles, nine M903 launchers and two AN/MPQ-65 radar sets, along with control stations and other associated equipment. This would be roughly sufficient to protect one site from a large-scale ballistic missile attack, or two sites from a smaller-scale attack.²¹ In terms of air defence systems focused on cruise missiles, a contract to produce six batteries of medium-range NASAMS systems for Ukraine was valued at \$1.2 billion in 2022.²²

The high cost of providing modern GBAD, particularly in layered form, has itself become a driver of further air base consolidation in recent years. The Royal Norwegian Air Force is closing Air Force Base Bodø and concentrating its F-35 fleet on only one main operating base (Ørland) and one forward base (Evenes).²³ The logic is that with a limited number of bases to begin with, it is better to concentrate forces on one base around which more effective layered air defence can be sited.²⁴ It is certainly the case that an active hardening approach using layered ballistic and cruise missile defence systems is easier to finance, deploy and sustain if it only has to provide protection to a small number of main operating bases.

However, since Russia has a significant arsenal of advanced ballistic missiles with terminal manoeuvring and decoy-launching capabilities, and the air-launched hypersonic Kh-47M2 Kinzhal and naval hypersonic 3M22 Zircon missiles, even layered defences that have a high degree of efficiency against traditional cruise missiles and less advanced ballistic missiles cannot fully protect air bases.²⁵ On the other hand, modern advanced quasi-ballistic and hypersonic threats are available to Russia in relatively limited quantities, rely on valuable and scarce launch platforms to get within range of many Western European targets, and would be in demand for a wide range of target sets. The demonstrated ability of modern Western medium- and short-

20. Sidharth Kaushal, Archer Macy and Alexandra Stickings, 'The Future of NATO's Air and Missile Defence', *RUSI Occasional Papers* (July 2021), pp. 13–27.

21. Jen Judson, 'State Dept. Clears \$2.5 Billion Sale of Patriot Missile Defense System to Bahrain', *Defense News*, 3 May 2019.

22. Jen Judson, 'Raytheon Wins \$1.2 Billion Surface-to-Air Missile Order for Ukraine', *Defense News*, 1 December 2022.

23. Astri Edvardsen, 'The Norwegian Armed Forces Will Keep Shelters for Fighters in Northern Norway', *High North News*, 4 November 2022, <<https://www.highnorthnews.com/en/norwegian-armed-forces-will-keep-shelters-fighters-northern-norway#>>, accessed 2 December 2022.

24. Author discussions with the chief of the Royal Norwegian Air Force, Copenhagen, 3 May 2018.

25. CSIS Missile Defense Project, 'Kh-47M2 Kinzhal', last updated 19 March 2022, <<https://missilethreat.csis.org/missile/kinzhal/>>, accessed 1 December 2022.

range air defence systems like NASAMS and the IRIS-T SLM to achieve a very high probability of kill against even advanced Russian cruise missiles like the Kh-101 and 9M728 in Ukraine shows what could be achieved in terms of threat reduction against the bulk of Russia's long-range firepower with even a single battery at each major air base.²⁶

The second major approach to reducing the vulnerability of air forces on the ground is dispersal. At the most basic level, this involves increasing the number of targets an opponent has to try to hit, and complicating their targeting process by moving assets between air bases and support facilities regularly. Among European nations, Sweden has taken the dispersal approach the furthest in terms of the ability to operate away from main operating bases for sustained periods under realistic combat conditions.

With a medium-sized fleet of 95 operational Gripen C/D fighters, and 60 new Gripen E jets on order, the Swedish Air Force operates from five home operating bases, but for its wartime posture maintains the ability to operate from 11 main bases, 12 forward operating bases and 21 reserve bases.²⁷ To further increase dispersal options it also maintains highway strips, and some bases have multiple runways with redundant taxiways connecting them to multiple hardstand areas. Sweden also maintains GBAD capabilities to further increase resilience against Russian strikes. However, this ability to operate dispersed requires an air force and aircraft designed for that purpose from the ground up. The ground support equipment set for a Gripen fighter wing such as F 21 is supplied in 20-ft shipping containers that can be attached to a hangar to form part of a home base maintenance facility, but can also be loaded onto medium-sized trucks in minutes and dispersed at short notice along with the aircraft themselves.²⁸ The Gripen itself sits relatively low to the ground and has access panels that can be opened with push toggle locks with winter gloves on, greatly facilitating maintenance by ground crews without ladders or specialist tools in dispersed locations. The auxiliary power unit on the aircraft allows it to be started up from cold without ground power if required, and most major operations, including loading weapons and engine changes, can be conducted outdoors with universal winch tools known as 'fishing rods'.²⁹ Fuel and ammunition dumps and hides are required at the forward and reserve bases, and must be transported to and loaded on highway strips as needed. To ensure that these sorts of armed flight operations all over the country can be certified and assured from an explosive and flight safety point of view, this must be practised with reasonable regularity.

26. Author interviews with Ukrainian air defence commanders, Ukraine, October 2022. See also Phil Stewart and Idrees Ali, 'NASAMS Air Defense System have 100% Success Rate in Ukraine – Pentagon Chief', *Reuters*, 16 November 2022.

27. Author visits to Swedish Air Force F 21 Fighter Wing at Luleå and interviews with senior aircrew and maintenance chiefs, 29 September 2022 and 31 January–1 February 2023.

28. *Ibid.*

29. *Ibid.*

Figure 3: Swedish Conscript Mechanics Rearm a JAS-39C Gripen Between Sorties at a Remote Dispersal Airstrip, 1 February 2023



Source: Swedish Air Force (reproduced with permission).

For most NATO air forces, however, that fly fighter aircraft not designed specifically with sustained operations from dispersed locations in mind, the Swedish model is difficult to copy. The European air force with the most advanced dispersed basing model that flies non-Swedish fighters is the Finnish Air Force, which has many similarities to its Swedish counterpart and notably makes even more regular use of highway strips for flight operations, with 19 highway strips and the ability to use a range of other civilian airfields and airports for military operations.³⁰ Due to the higher frequency of drills, the Finnish Air Force has even more recent experience and currency than the Swedish Air Force in flying from dispersed locations.³¹ However, Finland's maintenance and logistics support equipment is more concentrated than Sweden's, and its 55 F-18C/D Hornet fighters are based in two main operating bases (Rovaniemi and Kuopio) in peacetime.³² The F-18 Hornet has landing gear designed to cope with hard, short landings on less than ideal surfaces, can take arrestor cables to further reduce landing runs, and is designed to be forgiving to land

30. Military Airfield Directory, 'Finland: Air Bases and Military Airfields', <<https://www.mil-airfields.de/fi-finland/air-bases.html>>, accessed 4 December 2022. For an example, see Clement Charpentreau, 'Finland Closes Major Highway to Conduct Air Force Drill', *Aerotime Hub*, 30 October 2022, <<https://www.aerotime.aero/articles/32293-finland-highway-dispersed-operations>>, accessed 4 December 2022.

31. Author discussions with Finnish and Swedish Air Force officers, Santahamina, Finland, 31 October 2022.

32. For F-18C/D fleet size, see Flight Global, 'World Air Forces 2022', 2021, p. 18, <<https://www.flightglobal.com/download?ac=83735>>, accessed 4 December 2022.

at high angles of attack and relatively slow speeds due to being designed for operations on US Navy aircraft carriers. Likewise, compared to land-based aircraft, the ground support equipment for the Hornet and other navalised fighters must be relatively compact and transportable to maximise the space available in the cramped hangars onboard aircraft carriers. Therefore, it is logical to expect that Finland can disperse its logistics and maintenance chain relatively easily compared to most Western air forces, even though the F-18 was not designed from the outset for such operations on land like the Gripen was.

For most NATO air forces, however, which fly aircraft such as the F-16, F-15, F-35, Typhoon and Rafale, dispersing maintenance and conducting sustained operations away from main operating bases is more challenging. The ground support equipment, spares packs and tool sets required to diagnose and fix faults, conduct engine changes, load weapons and process mission data from the aircraft for each sortie are generally bespoke and extensive. This is because, with the partial exception of the F-35B, these aircraft were designed around the assumption that they would operate from large, well-equipped bases. Perhaps more significantly, many NATO air forces have contracted a significant part of their line maintenance and fleet support arrangements to civilian industry. This has allowed fighter fleets to be maintained with a lower uniformed personnel headcount by using civilian engineers rather than military ones, and enabled lower operating costs.³³ However, it has also driven further centralisation of maintenance and logistics, often in commercial-standard buildings. Civilian maintainers working for industry also generally have more restrictive hours in their working day and are more expensive to deploy away from home than military personnel. Availability-based maintenance contracts that undertake to simply provide an air force with a given number of airframes and flying hours at main operating bases also tend to lack the flexibility to rapidly generate dispersed operations at short notice or for sustained periods.

33. For example, see MoD, 'MOD Set to Save Over £500M and Sustain Hundreds of UK Jobs with New Typhoon Support Deal', 12 July 2016, <<https://www.gov.uk/government/news/mod-set-to-save-over-500m-and-sustain-hundreds-of-uk-jobs-with-new-typhoon-support-deal>>, accessed 5 December 2022.

Figure 4: Spanish Air Force Maintenance Personnel Working on a Spanish Eurofighter at Albacete Air Force Base, Spain, 2015



Source: Cynthia Vernat, Wikimedia Commons Licence.

Consequently, there is a practical limit to the length of time air forces equipped with such aircraft can operate sustainably away from established bases, even when supported by teams and equipment carried by large transport aircraft like the C-17 or the A400M. To ameliorate its air base vulnerabilities, the USAF has developed its Agile Combat Employment (ACE) strategy, initially for the Indo-Pacific and subsequently with an increased focus on ACE exercises in Europe since the invasion of Ukraine began.³⁴ The doctrinal definition of ACE is ‘a proactive and reactive operational scheme of manoeuvre executed within threat timelines to increase resiliency and survivability while generating combat power’.³⁵ In other words, it is not about power projection or deployment over distance per se, but rather about being able to move fast jets between bases faster than a peer opponent’s targeting cycle can follow in order to improve the survivability of a force while still flying combat sorties. While tied to large facilities for deep and regular line maintenance, US Air Forces Europe (USAFE) trains its fighter wings to conduct multi-day deployments to operate from dispersed forward-operating locations at 24 hours’ notice.³⁶ When this occurs, large numbers of fighters disperse to Allied air bases throughout

34. For more details, see Patrick Mills et al., *Building Agile Combat Support Competencies to Enable Evolving Adaptive Basing Concepts* (Santa Monica, CA: RAND Corporation, 2020).

35. For a detailed description, see USAF, ‘Agile Combat Employment’, Air Force Doctrine Note 1-21, 23 August 2022, <https://www.doctrine.af.mil/Portals/61/documents/AFDN_1-21/AFDN%201-21%20ACE.pdf>, accessed 4 December 2022.

36. Author discussions with F-15E weapons instructors, RAF Lakenheath, 23–24 September 2021.

Europe that have been designated as forward-operating locations or additional landing sites, and then draw on a combination of pre-positioned supplies, host nation support and deployable air base systems moved by C-17.³⁷ The US currently has an unmatched global logistics system including heavy lift and pre-positioned stocks, and can also afford to spend far more money than other individual nations in NATO on conducting ACE at scale and on a regular basis. Even so, US fighter wings remain tied to their main operating bases for maintenance purposes, and C2 functions – especially targeting cells – are still largely centralised in Air Operations centres. Therefore, despite the impressive ability to rapidly disperse fighter aircraft, crews and maintainers to forward-operating locations around Europe, large-scale Russian strikes on USAFE bases and command centres still pose a serious threat to each fighter wing's ability to conduct warfighting at scale on a sustained basis.

When considering how to reduce the vulnerability of European air forces on their air bases, it is important to prevent the lack of a perfect solution being seen as a reason not to make improvements to the situation as it currently exists. While no affordable hardening or dispersal measures can completely remove the vulnerability of any one air force or location to a concentrated long-range precision strike campaign by Russia, it is still possible to greatly increase the number of weapons required to have a decisive effect. For Russia to undertake a major strike campaign against NATO airpower on its home bases, its military commanders would have to have a reasonable degree of confidence that it would destroy enough combat airpower to justify the resulting political escalation and military retaliation. A combination of active and passive hardening and dispersal/ACE exercises could with reasonable efficiency make NATO's main operating bases much less attractive targets than they currently are, thus reducing both the temptation to conduct a strike campaign and the credibility of threats to do so.³⁸ The Russian military has shown the capability to fire large numbers of standoff missiles with acceptable accuracy against Ukraine. However, it only has a limited number of long-range launch platforms, and most would have to expose themselves to at least some risk to reach many key targets in Western Europe.³⁹ Therefore, presenting Russia with targeting dilemmas and reducing the efficiency of any given successful strike would significantly increase the deterrence value and warfighting credibility of NATO airpower. For most NATO air forces, the practical solution is likely to be a combination of limited investment in hardening main operating bases, investing in more deployable spares kits and forward-operating location exercises, and purchasing small numbers of GBAD assets such as NASAMS or Sky Sabre to provide cruise missile defence at each main operating base.

37. For an in-depth examination of the requirements for ACE, see Matthew Crowley, Carissa Deeney and Adam Potter, 'The Case for A.C.E Infrastructure in EUCOM', Air University, 8 March 2022, <<https://www.airuniversity.af.edu/Wild-Blue-Yonder/Articles/Article-Display/Article/2949295/the-case-for-ace-infrastructure-in-eucom/>>, accessed 5 December 2022.

38. See Mark Gunzinger et al., 'Towards a Tier One Royal Air Force', Center for Strategic and Budgetary Assessments, 2019, pp. 43–44, <https://csbaonline.org/uploads/documents/RAF_Final_Report_WEB_1.pdf>, accessed 5 December 2022.

39. For an in-depth analysis of the Russian long-range strike campaign, see Bronk, Reynolds and Watling, 'The Russian Air War and Ukrainian Requirements for Air Defence', pp. 25–34.

Of course, any increased spending to increase the survivability of air forces on the ground will come at an opportunity cost, both in terms of money and the capacity of the force to conduct other activities. HAS construction, maintenance and support, and C2 arrangements and exercises to enable ACE-type dispersal, particularly GBAD, are expensive. However, the primary reason why combat air is an extremely expensive business remains the complex sensors, weaponry, defensive systems and high performance required to ensure the aircraft themselves can survive against enemy threats while remaining effective and lethal in the air. Given that most NATO air forces (rightly) judge it essential to pay these costs to be able to contest control of the air, it would seem prudent to also spend the significantly lower sums required to credibly give the aircraft and the maintenance and logistics systems that support them a degree of survivability on the ground. After all, they are much easier for Russia to target on the ground than in the air, and the ground is where they unavoidably spend most of their time.

II. Aircrew Training and Exercises

FAST JET AIRCREW, or ‘fighter pilots’ in layman’s terms, remain the most vital human component of any modern air force. However, the skills that combat-ready fast jet crews require to be combat-effective are poorly understood by the majority of non-specialists in the wider military and policy community. The costs and timescales involved in generating the tactical leadership skills essential for fast jet combat operations are widely underestimated, as are the minimum fleet size and flying activity thresholds required to do so on a sustainable basis. Part of this is because producing a cost estimate that can be relied on for use as a rule of thumb is a complex undertaking due to the number of variable factors involved, and because precise figures are seldom deemed suitable for public release due to political and commercial sensitivities.⁴⁰

From the outset, it is important to understand that being good at physically flying the aircraft is one of the least important factors distinguishing a capable modern fast jet pilot. Basic airmanship skills are an important prerequisite, not least from a flight safety perspective, but these are supposed to be largely ingrained in newly trained pilots by the time they graduate from basic fast jet flying training and move on to advanced fast jet flying training. The modern fly-by-wire flight control systems make most advanced fourth- and fifth-generation fast jets comparatively easy to fly from a traditional ‘stick skills’ perspective. An ability to recognise and/or diagnose and then safely cope with a wide range of potential mechanical and software failures in flight remains essential, and requires a mix of synthetic and live flying experience to develop. However, the main focus during advanced fast jet flying training, and subsequently on an operational conversion unit (OCU), is not physical flying skills or airmanship, but rather learning how to tactically operate the many sensors, weapons systems and avionics that will be used on the front line.

The most critical task for the modern fighter pilot is to harness the different sensor and communications systems on their aircraft to generate an accurate and detailed understanding of the battlespace around them in real time. They must then continuously interpret this situational awareness picture and react so as to optimally position their aircraft to survive against known and potential threats, and employ their weapons and sensor capabilities against aerial and ground-based targets. This task is made hugely more challenging by the fact that it must be done while moving at high speeds in three dimensions, often under significant g-forces, dealing with transiting complex airspace boundaries, international borders and weather conditions, and potentially managing a wider formation or even a complex strike package.⁴¹

40. The author contacted the RAF Air Staff for an estimated cost for training an RAF fast jet pilot from service entry to entry to a front line process, but a publicly releasable figure could not be obtained.

41. Examples of these frictions were observed by the author during an RAF Typhoon training sortie from RAF Coningsby, 7 July 2021, and a Swedish Air Force low-level multirole sortie from Luleå, Sweden, 31 January 2023.

These challenges become far greater for missions against a peer adversary like Russia, which can disrupt communications and threaten bases, enablers and fighter aircraft themselves from long range using ground-based and airborne assets. Against a state threat such as that posed by Russia, missions must be planned to include complex, mutually supporting elements working in tandem to detect, suppress and destroy threats. As such, one of the core qualities of a successful fighter pilot is an ability to multi-task and make rapid life-and-death decisions based on information that is often simultaneously overwhelming in volume and incomplete. This is a skill set that is partly affected by innate ability, but is primarily a function of proficiency in the core tasks of flying and navigating the aircraft. As a pilot gains proficiency and currency, the tasks of flying the aircraft, navigating and employing weapons require less mental capacity to perform. This leaves more capacity for communication, tactical awareness building, decision-making and, eventually, formation leadership functions.

As such, it is important to understand that a fast jet pilot is of limited value in most combat scenarios at the point when they first finish training and join a front line unit, due to lack of experience and qualifications. They will start out flying as wingmen in a pair or four-ship formation, providing support to and learning from a formation leader. In most Western air forces, pilots will progress through initial combat readiness in their primary role and later multirole mission sets, night operations and formation leader qualifications during their first tour.⁴² Nevertheless, one of the key fighter pilot mantras is that one never stops learning; it takes multiple tours, specialist training courses, a wide range of operational experiences and the right mindset and aptitude to become an effective combat leader in the fast jet world.⁴³ As such, it is difficult to define exactly what the true cost is to generate multirole-capable front line fast jet pilots, but what is certain is that it costs many millions of pounds, takes the better part of a decade and requires a significant amount of input from existing qualified instructor pilots. Moreover, the skill sets and competencies that make a truly effective multirole fighter pilot also fade rapidly without regular practice, since so many things must become all but second nature for a person to have sufficient mental capacity to be tactically effective as a formation leader.⁴⁴

The poor performance of the VKS fighter fleet during the invasion of Ukraine in 2022 underscores how vital fast jet pilot competency and currency are to effectiveness. In the years leading up to the invasion, VKS (and Russian Naval Aviation) fighter crews were typically flying around 80 hours per year, and had limited access to high-fidelity simulators for synthetic training.⁴⁵

42. Author interviews with fast jet weapons instructors at RAF Coningsby, 6–7 July 2021, AAE Orange-Caritat, 18 August 2021, RAF Lakenheath, 23–24 September 2021, CFB Bagotville, 24–27 May 2022, Laage-Rostock Air Base, 16 August 2022, and RAF Marham, 20 September 2022.

43. *Ibid.*

44. *Ibid.*

45. Ministry of Defense of the Russian Federation, 'В командовании Военно-воздушных сил ВКС подвели итоги за 2018 год' ['The Command of the Air Force of the Aerospace Forces Summed Up the Results for 2018'], 4 December 2018, <https://function.mil.ru/news_page/country/more.htm?id=12206756@egNews>, accessed 11 February 2022; Justin Bronk, 'Developments in Russian Combat Air Spending and Likely Operational Implications', in Pentti Forsstrom (ed.), *Russian*

Furthermore, a significant proportion of the flying hours being flown by Russian fast jet crews were relatively simple sorties involving navigation, unguided weapon deliveries on ranges, and target simulation for GBAD operators.⁴⁶ Consequently, many Russian aircrew had limited skills across the primary mission set assigned to their aircraft type (fighter, frontal-bomber, ground attack), let alone all the weapons, tactics and procedures involved in potential secondary mission sets. As a result of this, the core VKS inventory of around 350 modern, multirole fast jet aircraft has been shown in practical terms to be fairly inflexible in terms of mission sets, with very limited tactical interoperability between fleets.⁴⁷ Though the inability of the VKS to conduct a successful air campaign against Ukraine so far is a positive from a NATO point of view, the difference between the capabilities of the Russian fighter force on paper and its capabilities in practice should be a wake-up call for aircrew training and readiness standards for most European air forces.

Throughout the 2000s and 2010s, annual flying hours accrued by Western fast jet aircrew fell dramatically, with most getting somewhere between 80 and 120 hours per year, as air forces attempted to maintain fleet sizes as far as possible in the face of continued budget cuts.⁴⁸ As a result, most Western air forces today have modern, multirole fast jet fleets but risk falling into the same trap as the Russian VKS; failing to invest in sufficient flying hours and the infrastructure required to conduct realistic, complex training sorties. Pilots interviewed for this paper from multiple NATO air forces consistently emphasised that they were permanently ‘behind the drag curve’, with too few flying hours available for both instructor and student pilots, and that this was causing an overall degradation of skills currency and multirole capabilities.⁴⁹

Spreading out smaller aircraft fleets to maintain the appearance of a larger number of front line units has exacerbated the issue, since with fewer aircraft per squadron it is often difficult to reliably generate enough available jets to fly the four-ship formations required to practise the complex tactics required by most warfighting mission sets.⁵⁰ The smaller unit complements of aircraft are, the more vulnerable regular realistic training flying is to disruption due to inevitable maintenance issues, depot cycles and operational deployment requirements.

Concept of War, Management and Use of Military Power (Helsinki: Finnish National Defence University, 2022), pp. 89–101.

46. Author interviews with Finnish fast jet aircrew and intelligence officers, Helsinki, 15–16 February 2022.

47. Author interviews with Ukrainian Air Force fighter fleet and air defence commanders, Ukraine, October 2022. For more details, see Bronk, Reynolds and Watling, ‘The Russian Air War and Ukrainian Requirements for Air Defence’, pp. 6–21.

48. Author interviews with fast jet weapons instructors at RAF Coningsby, 6–7 July 2021, AAE Orange-Caritat, 18 August 2021, RAF Lakenheath, 23–24 September 2021, CFB Bagotville, 24–27 May 2022, Laage-Rostock Air Base, 16 August 2022, RAF Marham, 20 September 2022, and RAF Lossiemouth, 29 November 2022.

49. *Ibid.*

50. Author interviews with pilots and maintenance officers at RAF Lossiemouth, 29 November 2022.

Another commonly expressed theme from pilots across European NATO air forces is that quality and realism in live flying training have been systemically sacrificed on the altar of flight safety, largely due to a refusal at the duty-holder and senior leadership levels to sign off on and hold risk. This was expressed succinctly by one German Eurofighter weapons instructor who stated that: ‘the German approach to training and flight operations is geared towards fulfilling NATO flying hour targets as safely as possible, but with no real concern for how to make us lethal [as fighter pilots].’⁵¹ The lack of any serious peer threat since the end of the Cold War has permitted air forces throughout NATO to focus on maximising flight safety at the expense of pushing aircrew, aircraft and weapons systems to their limits during realistic training sorties and major exercises. The cost of the latter approach during the Cold War was a steady drumbeat of fatal crashes, especially during low-level training sorties in bad weather or at night. However, against the Soviet Union such tactics were seen as the only viable option for penetrating Warsaw Pact air defences, and so to ensure the operational credibility that was seen as essential to conventional and nuclear deterrence, the risks inherent in realistic regular training at low level in low-visibility conditions were seen as necessary.⁵² The dissolution of the Soviet Union and the breakup of the Warsaw Pact removed the threat that justified regular aircrew deaths and losses of airframes, so it was not only inevitable but also morally right that a greater emphasis be placed on flight safety during training.

Furthermore, the intervention and counterinsurgency campaigns of the 2000s and 2010s saw almost all combat operations conducted from 12,000 ft or above to remain clear of the anti-aircraft fire and man-portable air defence systems (MANPADS) that formed the only realistic threat. They also generally involved close air support against enemies who were often fighting in civilian areas and/or very close to friendly forces. Consequently, training for these medium-level operations generally focused on performing the difficult task of conducting close air support as safely and accurately as possible to minimise collateral damage and friendly fire risks.⁵³ As a result, aircrew training for combat operations has been focused on flight safety and operations in permissive or semi-permissive airspace for more than a decade. Even among air forces like the RAF and the French Air and Space Force (L’Armée de l’air et de l’espace, or AAE), where a significant proportion of pilots have live combat experience, that combat took place under permissive conditions very different from those they would face against Russia or another serious state adversary.

To return non-US NATO air forces to a state where they are ready and capable of performing realistic combat missions against Russia will require significant changes to the focus of training

51. Author interview with weapons school instructors at Tactical Air Wing 73 ‘Steinhoff’, Laage-Rostock Air Base, 16 August 2022.

52. Nigel Walpole, *RAF and East German Fast-Jet Pilots in the Cold War: Thinking the Unthinkable* (Barnsley: Pen & Sword Books, 2020), pp. 32, 230, 237.

53. For an overview of the complexities inherent in close air support, see USAF, ‘Counterland Operations’, Air Force Doctrine Publication 3-03, 21 October 2020, pp. 8–14, <https://www.doctrine.af.mil/Portals/61/documents/AFDP_3-03/3-03-AFDP-COUNTERLAND.pdf>, accessed 12 December 2022.

and exercises and to the policies around how risk is managed, and above all a reduction in operational tempo compared to the current situation. Retraining aircrew for warfighting tasks requires those aircrew to have time, capacity and flying hours to dedicate to developing proficiency in both core and advanced skills that they either have not practised in a long time or in some cases may have never been qualified in before. Furthermore, the tactics employed in most high-intensity mission sets generally require larger numbers of aircraft, supporting enablers and planning to accomplish. To generate competence in them, aircrew must have their capacity and flying hours synchronised to fly exercises together at the same time.⁵⁴ Unfortunately, in several NATO air forces (including the RAF), pilots are currently completely overstretched by the concurrent requirements for multiple ongoing operational deployments in the Middle East and Eastern Europe, major exercises and basic currency flying.⁵⁵ The same goes for maintenance crews, who are struggling to generate jets reliably to meet the operational and training tempo demanded.⁵⁶ This means that there simply is not currently enough capacity, either in terms of aircrew or aircraft availability/maintenance personnel, to conduct large-scale complex warfighting training sorties on a regular basis for most non-US NATO air forces.

The underlying problem is that while most NATO nations have accepted the political need to pivot defence planning towards Russia and a return to state-on-state deterrence as a core planning assumption, few pre-existing deployments or operational commitments have been stopped to generate the capacity for fast jet crews and the maintenance personnel who keep them flying. Instead, the demand signal has been to keep doing everything, while flying additional deterrence and reassurance operations and deploying for new exercise activities. Overstretching fast jet fleets leads inexorably to poor morale across the force, increasingly poor aircraft availability for regular training, and the atrophying of aircrew skill competencies. It also leads to an increase in aircrew and engineers leaving the military, which in the case of experienced personnel creates shortfalls that take many years to rectify.⁵⁷ In addition to the expense and time it takes to replace aircrew and experienced engineers who leave air forces due to an unsustainable operational tempo, their loss increases the burden felt by those who remain, since the same workload must be tackled by a smaller cadre of experienced personnel.

54. For this reason, the USAF generally flies sorties in waves of eight–12 fighters per squadron (of 20–24 aircraft) during regular front line training, so that complex tactics can be regularly practised. Observed by the author on visits to the USAF's 492nd, 493rd and 494th Fighter Squadrons at RAF Lakenheath, 20 May 2019 and 23–24 September 2021.

55. Confirmed in author visits to multiple air bases including: RAF Coningsby, 6–7 July 2021; RAF Lakenheath, 23–24 September 2021; CFB Bagotville, 24–27 May 2022; RAF Marham, 20 September 2022; and RAF Lossiemouth, 29 November 2022.

56. *Ibid.*

57. *Ibid.*

The Critical Role of Weapons Instructors and Balancing Live Versus Synthetic Training

Arguably the most critical personnel cadre for any combat-focused air forces are weapons instructors (or their equivalents, for the few air forces who do not use that specific role title). Weapons instructor pilots are generally responsible for leading formations in combat and coordinating complex missions in the air. Within each squadron they are also responsible for leading the tactical mission planning, briefing and debriefing stages of any mission. Essentially, while standard instructor pilots are responsible for training and certifying pilots to fly their aircraft in a variety of conditions safely, weapons instructors are responsible for the tactical training and combat effectiveness of a squadron and its pilots. The process to train such instructors is complex and varies somewhat between air forces, but it remains essential for credible combat capability.

In the RAF, pilot conversion to front line fighters such as the Eurofighter Typhoon and F-35 Lightning II takes place at the OCU, alongside basic combat readiness qualifications prior to assignment to a front line squadron. 29 Squadron is the OCU for the Typhoon force, and it is also the unit that conducts qualified flying instructor (QFI) and qualified weapons instructor (QWI) training courses. The process of training new QFIs and QWIs requires a significant pool of pre-existing and experienced QFIs and QWIs; consequently, 29 Squadron has the largest number of instructor pilots of any RAF squadron.⁵⁸ Dependence on experienced instructors is one of the hidden fragilities within any air force. If the number of instructors drops below that required to both serve the requirements of front line squadrons and simultaneously train a steady supply of sufficiently qualified new QFIs and QWIs, one process must be truncated at the expense of the other, and the overall pilot training ecosystem will break. If this happens, it is generally extremely difficult and time consuming, or even impossible, to fix without resorting to a dependence on partner-nation training pipelines to shore up numbers.⁵⁹ As air forces have become smaller, it has become progressively harder for them to balance recruitment, training, career management and retention to ensure that enough suitably qualified and experienced personnel are retained where needed.

To provide adequate live flying hours for the OCU, QFI and QWI courses, 29 Squadron has by far the largest number of aircraft and maintenance and support personnel of any RAF squadron, with approximately 24 airframes and 300 people, respectively. Nevertheless, the training requirements for both new junior pilots and the instructor cadre, coupled with supply chain disruption caused by the Covid-19 pandemic and Britain's exit from the EU, have created considerable problems with spares and airframe availability.⁶⁰ To try to compensate for the expense and scarcity of live flying hours at all levels of the training pipeline and on the front

58. Author interview with Wing Commander Jim Calvert, Commanding Officer, 29 Squadron, 6 July 2021.

59. Many NATO air forces now struggle to run weapons instructor courses, due to personnel shortages, and in some, the number of individuals who can examine and certify new patch wearers can be counted on one hand.

60. Author interview with Wing Commander Jim Calvert, Commanding Officer, 29 Squadron, 6 July 2021.

line, RAF senior leadership has pushed reliance on synthetic training in simulators further than have other NATO air forces.

At present the RAF Typhoon force average sits somewhere between 50% and 70% synthetic flying hours compared to live flying (with significant variation depending on squadron, location and operational deployments).⁶¹ The RAF's long-term strategy plans to increase that to around 80/20% synthetic/live.⁶² There are significant benefits to relying heavily on the synthetic environment for some aspects of training fast jet pilots. Simulators that are linked together to allow at least four aircrew (and ideally more, from multiple bases) to train together simultaneously are an excellent way to efficiently practise complex high-end tactics and mission sets. In the case of certain threat systems, advanced tactics and electronic warfare (EW) techniques, there are aspects of training for high-end warfighting that can only be practised regularly in the simulator due to airspace, security and financial constraints. However, every fighter pilot interviewed for this study thought that 80% was too high as a proportion of synthetic to live flying, and that the simulator should be used to enhance rather than replace the value of live flying training. Despite the benefits of conducting many complex training tasks primarily in the simulator, from an operational effectiveness point of view, the universal view was that if the planning priority were warfighting readiness, then the synthetic/live flying balance across European air forces would be different.⁶³

The effects of bad weather, visibility while night flying, the effect of sustained high g-forces when manoeuvring to defeat incoming missiles and the dangers of low flying were all regularly cited by interviewees for this paper as vital elements of flying training for state-on-state mission sets that cannot be replicated accurately in a synthetic environment. Perhaps even more significantly, the psychological and physiological effects of adrenaline and fear caused by sudden spatial disorientation, and the risk of accidents during tactical flying or from enemy action, are almost impossible to accurately train for in the simulator.

Perhaps even more crucially, when missions are not exercised regularly in real life but instead are only practised in simulators, only the aircrew are getting any training value. The maintenance crews are not getting practice generating large numbers of jets for complex sorties or loading live air-to-air and standoff air-to-ground weapons, the logistics chain is not being realistically tested, and none of the practical clearance and authorisation steps are being carried out. In other words, synthetic training does not allow end-to-end testing of the air force as a whole. This also applies for multi-domain or joint warfighting effects. If new doctrinal and tactical assumptions rely on synchronising capabilities from multiple services in real time to solve

61. Author interviews with RAF Typhoon squadron commanding officers, RAF Coningsby, 6 July 2021, and RAF Lossiemouth, 29 November 2022.

62. *RAF News*, '£274-Million Training Boost for RAF', 27 May 2021, <<https://www.raf.mod.uk/news/articles/274-million-training-boost-for-raf/>>, accessed 8 December 2022.

63. Author interviews with fast jet weapons instructors at RAF Coningsby, 6–7 July 2021, AAE Orange-Caritat, 18 August 2021, Laage-Rostock Air Base, 16 August 2022, RAF Marham, 20 September 2022, and RAF Lossiemouth, 29 November 2022.

operational challenges, then to be credible, all the required joint force elements and support structures must be regularly exercised together in real life, from the planning stages through to execution, debriefing and lessons learned.

The picture is different for USAFE, where the practical training and planning focuses more heavily on traditional high-intensity warfighting readiness and credibility than in most European NATO air forces. A key advantage that the USAF has over European air forces is the scale at which it routinely operates in a training and exercise context. Most bases host a fighter wing composed of between three or four squadrons of fast jets, each with between 20 and 24 aircraft. On some bases a typical day will see each squadron launch two or even three waves of eight–12 aircraft in rapid succession.⁶⁴ As such, the training airspace used by some USAF fighter wings will regularly be in use by 30 or more fighters simultaneously, usually supported by tankers and sometimes big-wing ISR enablers such as the E-3G AWACS.⁶⁵ This in turn means that in locations where they are well resourced, such as RAF Lakenheath, US fast jet aircrew train daily as part of large formations in complex air environments – conditions which most other Allies can only generate for periodic large-scale exercises. Maintenance crews, logistics chains, planners and air traffic and airfield traffic management personnel are also constantly trained to handle operations at a realistic scale for most warfighting scenarios. The resultant complexity of day-to-day training means that USAFE fighter aircrew tend to develop tactical expertise faster than other Western air forces, but as a result may not spend as much time concentrating on technical flying finesse *per se*.⁶⁶

The philosophy within the F-15E community at RAF Lakenheath on live/synthetic training for new pilots is that skills can be introduced, familiarised and practised through cheap, safe repetition in the simulator, but they must be validated by instructors and then regularly practised during live sorties.⁶⁷ The USAFE fighter community in general tends not only to fly more than the RAF or the AAE but also to be significantly less comfortable with the prospect of very heavy synthetic training over live training ratios. Senior instructor pilots noted that newer pilots joining the squadrons with significantly lower live flying hours in basic and advanced flying training had good tactical skills and system knowledge but also generally displayed a poor standard of basic airmanship.⁶⁸ This meant that they had to be given significant live flying training time before their airmanship skills were judged to be of an acceptable standard. From a budgetary perspective, this implies the need to compensate for live flying hours in relatively cheap trainer aircraft sacrificed for cost saving during basic training by flying an increased number of live

64. Observed by the author on visits to the USAF's 492nd, 493rd and 494th Fighter Squadrons at RAF Lakenheath, 20 May 2019 and 23–24 September 2021.

65. Author interviews with the USAF's F-15E and F-35 weapons officers at RAF Lakenheath, 23–24 September 2021.

66. Interview with senior USAF F-15 and F-35 weapons officer with experience as an exchange officer on the RAF Typhoon force, RAF Lakenheath, 24 September 2021.

67. Author interviews with USAF F-15E and F-35 weapons officers at RAF Lakenheath, 23–24 September 2021.

68. *Ibid.*

hours in expensive front line jets once at squadron level. It also meant that a lower proportion of live flying hours could be devoted to combat-relevant training tasks.

In the USAF, with the luxury of significantly greater resources than most other NATO air forces, fighter pilots are expected to progress to being qualified to fly as the leader of a two-ship formation around the end of their first year on a front line squadron. For an F-15E Strike Eagle squadron this typically equates to around 250 flying hours, with the higher-than-usual average being accounted for by deployments on combat operations in the Middle East.⁶⁹ The general intent is to bring almost all pilots to a stage where they are qualified as four-ship leaders during their first three-year front line tour. There is no hard and fast rule on when this happens, with individual aptitude and temperament, as well as individual squadron situations, influencing how fast each pilot is able to progress. The most promising may begin the process of upgrading almost as soon as they are qualified as a two-ship lead, but for most this typically happens around the one-and-a-half- to two-year mark, with around 500 hours flown. However, these rosy flying hour totals are not representative of the current USAF as a whole. According to General Mark Kelly, speaking at the International Fighter Conference, the average US fighter pilot flew only 81.5 hours in 2021, although other sources suggest that for active-duty fighter pilots, the figure was marginally over 120 hours.⁷⁰ It is also vital to note that not all flying hours are created equal, especially in relation to readiness for peer warfighting. For example, a sortie to provide a combat air patrol on NATO's eastern border with Russia might involve long transits and several hours maintaining a combat air patrol, giving the pilots involved four to six hours in the air, but with little to no tactical training value.⁷¹

During their second front line tour, many USAF pilots will be expected to train as instructor pilots – able to teach those fresh from the operational training units how to fly the type in question, and conduct basic check flights to assess competency. However, those who are perceived as having a sufficiently advanced grasp of tactical issues and sufficient technical airmanship and operating acumen will be selected for training as weapons officers – the USAF equivalent of RAF QWIs. The selection process is sufficiently robust that by the time aircrew reach 'weapons school', the pass rate is very high, despite the complexity and demanding pace of the training. The course involves intense academic study over four to five months, especially on the subject of the aircraft, avionics, weapons and tactics used by both Allied and potential adversary air forces. Actual flying time at weapons school can be as low as 30 hours, with many

69. Author interview with F-15E weapons instructor pilots at RAF Lakenheath, 23–24 September 2021.

70. General Mark Kelly speaking at the International Fighter Conference, Berlin, 21 September 2022. See also John Venable, 'US Air Force', Heritage Foundation, 18 October 2022, <<https://www.heritage.org/military-strength/assessment-us-military-power/us-air-force>>, accessed 7 December 2022; John A Tirpak, 'Air Force Flying Hours Decline Again After Brief Recovery', *Air and Space Forces Magazine*, 1 June 2022, <<https://www.airandspaceforces.com/air-force-flying-hours-decline-again-after-brief-recovery/>>, accessed 7 December 2022.

71. Author interviews with multiple fast jet aircrew with operational experience at RAF Lakenheath, 23–24 September 2021, CFB Bagotville, 24–27 May 2022, RAF Marham, 20 September 2022, and RAF Lossiemouth, 29 November 2022.

of the higher-level tactical training and learning exercises necessarily being carried out in the synthetic environment.

Just as in the RAF, when USAF weapons officers, known as ‘patch wearers’, return to the front line they are expected to act as the primary source of tactical and operational knowledge in their squadron, and to lead on planning and operational activities. At first, a weapons officer will act as a Tier 1 patch wearer, and will focus on leadership at the tactical level in the air and often fly as the lead and command ship during complex exercises or combat operations. They are also expected to lead debriefings after each complex sortie to ensure that all mistakes or areas for improvement are identified, dissected and drilled into all pilots. Between a year and 18 months after rejoining the squadron as a Tier 1 weapons officer, a pilot may be upgraded to Tier 2 and be given the primary planning responsibility for complex operations at the squadron or wing level. A Tier 2 weapons officer is expected not only to be an expert on almost all aspects of the aircraft and weapons systems that his or her squadron operates, but also to act as the bridge between the tactical and operational levels of war.

This relationship between experienced fast jet pilots and operational planning and leadership places weapons officers at the core of the USAF’s ability to provide credible warfighting capability. It is a deeply ingrained concept that operational expertise at the planning and policy advice level is based on and relies on extensive tactical understanding. As such, the live flying training and combat flying experiences of aircrew are seen as essential for developing leaders of sufficient calibre to ensure that the USAF can plan and execute complex joint operations, especially in a contested environment.

French fast jet pilots also take around a year from the end of their flight training to achieve basic combat readiness for single-role duties. However, the AAE takes longer than the USAF to qualify front line pilots as combat leaders. There is some variation according to individual aptitude, but around three years is the average to become certified as a two-ship flight lead, and another year after that to become a four-ship leader. AAE fast jet crews typically fly around 150–180 hours per year.⁷² The amount of simulator training compared to live flying varies by type, with Rafale crews taking advantage of more modern synthetic training aids to conduct around a 50/50 synthetic/live mix, while the Mirage 2000 crews with more limited simulators fly more at approximately 20/80 synthetic/live.⁷³

The AAE is somewhat unusual among NATO air forces in that it has not traditionally had weapons instructors per se. Instead, four-ship leaders have tactical leadership responsibilities when on operations and in training. As part of the four-ship qualification process, pilots must take a course at centres of excellence for their aircraft type and write a paper on a tactical subject that will be analysed and critiqued by senior pilots and brigade-level staff members. In addition, the most experienced four-ship lead pilot in any given squadron will be the appointed expert

72. Author interviews with Mirage 2000 pilots and instructors at AAE Orange-Caritat, 18 August 2021, and with a Rafale instructor pilot, London, 15 December 2021.

73. *Ibid.*

in air-to-air or air-to-ground tactics and will oversee tactical training in each squadron.⁷⁴ With a smaller aircrew pool than the USAF, the AAE has traditionally sought to bring as many four-ship lead pilots to a required tactical proficiency standard as possible, and to create a written tactical debate and database of analytical writing on which all squadrons can draw, rather than concentrating on creating an elite cadre of weapons instructors.⁷⁵ In any case, France's more strategically independent foreign and defence policy stance compared with other NATO countries explicitly prioritises the ability to act independently against near-peer threats, and the AAE also retains a regularly exercised and modernised airborne nuclear deterrent role. Therefore, it has retained a greater focus on hardening, electronic attack and self-protection suites, GBAD and live training for high-intensity missions than many other air forces since the end of the Cold War. The AAE has also recently started to consider moving to a more formalised weapons instructor course and role for aircrew.⁷⁶

The ability to sustain truly dispersed operations places specific demands on aircrew training and tactics. Consequently, Swedish fighter pilots train to be capable of operating in a very independent way compared to most NATO air forces. For any air force to continue to be operationally effective when operating from a widely dispersed posture, even two-ship formation leaders must be highly capable. To meet these requirements, Swedish fighter pilots take around three years to become two-ship leads.⁷⁷ This is because they are expected to be capable of conducting mission planning at remote locations with heavily disrupted communications; executing high-intensity mission sets; diverting at short notice into reserve bases, civilian airports or highway strips; conducting rapid turnarounds; and still coming together with other force elements in the air with precise timing to concentrate force in larger formations such as four-ships as required.⁷⁸ All Swedish fighter pilots train to be air-to-air mission-capable first and foremost, and then train for additional tasks with priorities set according to the secondary mission specialisation of their particular fighter wing, which might be EW, anti-ship strikes or interdiction. It takes around six years on a front line squadron before Swedish pilots generally qualify as four-ship leads, and at least 10 years before they may be selected to train as either weapons instructors or mission planners.⁷⁹

This much slower progression rate compared with other Western air forces is mostly due to the much greater complexity of mission planning and execution required to be combat-effective against Russian forces from a truly dispersed footprint on a sustained basis. It is also due to the harsh weather requirements of operations in Northern Europe and the Arctic, such as the

74. Author interviews with Mirage 2000 pilots and instructors at AAE Orange-Caritat, 18 August 2021, and with a Rafale instructor pilot, London, 15 December 2021.

75. *Ibid.*

76. *Ibid.*

77. Author interviews with Swedish Air Force F 21 Fighter Wing weapons instructors and mission planners, Luleå, 29 September 2022.

78. *Ibid.*, and observed during a multirole Gripen sortie to a dispersal base location with F 21 Wing, 31 January 2023.

79. *Ibid.*

need to be qualified and current to lead four-ship formations in beyond-visual range and close-in air-to-air combat in full instrument-flying conditions, including launch from and recovery to dispersed highway strips.⁸⁰ To allow the development and maintenance of such specialised dispersed warfighting aircrew skills, Swedish (and Finnish) pilots are not rotated every three years between units and other non-flying posts like pilots in most NATO air forces, but instead are expected to stay for 15–25 years with the first squadron, or at least wing, that they join.⁸¹ This gives them reduced career variation and exposure to other parts of their services compared to other Western aircrew. However, this approach also improves pilot retention by allowing more family stability and facilitates a depth of learning and specialist skills development that is hard to match. The latter is further improved by the lack of an expeditionary posture for either the Swedish or Finnish Air Force, which has reduced the operational burden and mission breadth that pilots and ground crews have to meet, allowing a much greater focus on fielding credible deterrence capabilities against Russian aggression.

Regardless of the way in which aircrew, maintenance crews and the other ground trades are managed in terms of training and career management, there are clear trends that are key for regenerating warfighting credibility among the European NATO air forces where it has been allowed to decay. First and foremost, the development, incentivisation and retention of weapons instructors or equivalent tactical experts in every squadron is vital. If more of these individuals can be trained and retained in flying posts, the workload on each individual will be lower and the air force's tactical expertise, internal training, planning and operational warfighting leadership capacity will be more resilient. Second, if personnel are not regularly trained in representative live missions, the capacity across the force to credibly generate and execute a given capability will rapidly degrade. As noted above, when practice for complex warfighting mission sets is relegated to the simulator, only the aircrew get the training value; the vital maintenance crew, logistical tail, other joint force elements, ground and airspace traffic management and regulatory/permissions aspects are not practised and so will atrophy. Third, no serious increase in aircrew training quality, exercise frequency and thus warfighting readiness and skill sets will be possible without reducing current operational tasking levels. Some fighter forces have already been pushed well beyond a sustainable operational tempo, leading to degrading aircraft availability, worsening retention of key aircrew and maintenance personnel, and fragile morale. Training for warfighting requires capacity, especially when the additional complications of dispersal or ACE-type activities are factored in. It is not a task that can just be added on to existing commitments.

80. Author interviews with Swedish Air Force F 21 Fighter Wing weapons instructors and mission planners, Luleå, 29 September 2022.

81. *Ibid.* and 31 January–1 February 2023; author discussions with senior Finnish Air Force commanders and instructor pilots, Santahamina, 31 October 2022.

III. The Need for SEAD/DEAD and Munitions Stocks

IN TERMS OF the medium-term threat to Western deterrence and warfighting credibility, it is worth noting that the two components of Russian military power that have performed consistently well during the invasion of Ukraine are its GBAD systems, and its long-range precision strike capabilities.⁸² Both are significant for the operational credibility of Western air forces, and they collectively mean that comparative performance between Western fighters and their VKS equivalents is not the key criterion that will determine the potential combat effectiveness of airpower against Russia (or any other peer opponent). Hardening against long-range precision strike capabilities is discussed in Chapter I. However, the need for SEAD/DEAD capabilities is another critical point, and one that has been underlined not only by the highly lethal capabilities of Russian surface-to-air missile (SAM) systems in Ukraine, but also by the striking effectiveness of Ukraine's much less sophisticated and numerous GBAD capabilities.

One of the defining features of the Russian invasion of Ukraine has been the inability of either side to reliably locate, identify, track and destroy the other's SAM systems. This has resulted in a mutual denial of the ability to effectively use airpower to shape the war on the ground. Even when not acting as part of a well-coordinated IADS, Ukrainian mobile SA-11 (Russian designation 9M38M1) 'Buk' and SA-8 (Russian designation 9K33) 'Osa' SAMs have proven sufficiently lethal to deny the much larger and technologically superior VKS the ability to operate above very low altitude inside Ukrainian-controlled airspace.⁸³ This is despite the fact that the VKS began operations against Ukraine with well over 350 genuinely modern fast jets, a wide range of standoff precision-guided munitions, and potent and widely deployed ground-based and aerial EW capabilities.

The inability to use airpower effectively on the battlefield has significantly limited Russia's tactical and operational options, and greatly facilitated Ukrainian challenges. However, the Russian and Ukrainian armies are both designed to rely on massed artillery and tanks for the vast majority of their firepower. The Russian army invaded Ukraine with 2,433 tube artillery systems and 3,547 multiple-launch rocket systems, while the Ukrainian army fielded 1,176 and 1,680, respectively.⁸⁴ Both the number of artillery pieces and the ammunition quantities involved dwarf NATO stocks, largely because NATO forces (with the partial exception of the US military) are designed around assumed air superiority and the delivery of aerial precision fires

82. For more details see Bronk, Reynolds and Watling, 'The Russian Air War and Ukrainian Requirements for Air Defence', pp. 6–21, 25–34.

83. *Ibid.*, pp. 6–21.

84. Mykhaylo Zabrodskiy et al., 'Preliminary Lessons in Conventional Warfighting from Russia's Invasion of Ukraine: February–July 2022', RUSI, 30 November 2022, p. 2.

at scale over any contested battlefield.⁸⁵ However, at present this assumption is deeply flawed against Russia (and China) due to an inability to credibly deal with their IADS in most likely future flashpoint scenarios.

Western planners have been aware of the serious challenge to airpower posed by the IADS deployed by Russia and China for years, especially in terms of very long-range SAM systems such as the SA-21 (Russian designation S-400) and the HQ-9B, linked to advanced radar systems such as the RLM-ME Nebo-M and the 59N6 Protivnik-GE.⁸⁶ However, the lesson from Ukraine's air defence performance against Russia in the air domain is that even successfully degrading an enemy IADS to the point that it stops performing as a unified system is insufficient to allow control of the air over contested areas.⁸⁷ The threat posed by mobile medium- and short-range SAM systems such as the SA-17 (Russian designation 9M317) and SA-15 (Russian designation 9K330) 'Tor' would still render medium- and high-altitude penetrations unacceptably dangerous for the non-stealth platforms that will continue to make up the vast bulk of NATO's combat aircraft inventory for the foreseeable future.⁸⁸ To be able to establish air superiority, therefore, NATO air forces must be able to not only conduct SEAD but also hunt down and conduct DEAD at scale against mobile and aware medium- and short-range SAMs.

The SEAD/DEAD task requires specialist aircrew training, weapons and sensors that no European air force currently fields at anything like the scale required. Even during the supposedly European-led Libya intervention in 2011 against a largely static and completely outdated air defence system, other NATO partners were dependent on the US to conduct SEAD/DEAD before they could operate effectively.⁸⁹ The challenge that would be faced from a near-peer such as Iran, let alone against Russian forces in Eastern and Northern Europe, is almost incomparably more serious, with layered long-, medium- and short-range SAM coverage provided by highly mobile systems linked to a range of multi-static and multi-frequency radar systems by modern C2 vehicles and communications architectures.⁹⁰ To give an idea of the threat, Ukrainian fighter pilots have been shot down while flying at altitudes as low as 15 ft by SA-21 SAMs fired from over 150 km away, enabled by active-seeker terminal guidance on the missile itself coupled with launch-cueing and mid-course guidance from a 48Ya6-K1 'Podlet' all-altitude radar

85. For more details on ground-based firepower comparisons, see Watling, 'The Future of Fires'.

86. For more information, see Justin Bronk, 'Modern Russian and Chinese Integrated Air Defence Systems', *RUSI Occasional Papers* (January 2020).

87. For a detailed analysis of how to degrade an IADS, see Jack Watling, Justin Bronk and Sidharth Kaushal, 'A UK Joint Methodology for Assuring Theatre Access', *Whitehall Report*, 4-22 (May 2022).

88. Confirmed in author discussions with F-15E, F-16, A-10C, Eurofighter Typhoon and Gripen weapons instructors at CFB Bagotville, 24–27 May 2022, RAF Marham, 20 September 2022, SwAF Luleå, 29 September 2022, International Fighter Conference, Berlin, 17 November 2022, and RAF Lossiemouth, 29 November 2022.

89. Deborah C Kidwell, 'The US Experience: Operational', in Karl Mueller (ed.), *Precision and Purpose: Airpower in the Libyan Civil War* (Santa Monica, CA: RAND Corporation, 2015), pp. 119–26.

90. For more information, see Bronk, 'Modern Russian and Chinese Integrated Air Defence Systems'; Watling, Bronk and Kaushal, 'A UK Joint Methodology for Assuring Theatre Access'.

relayed through the standard SA-21 battalion 55K6 command vehicle.⁹¹ Russian SA-15 and SA-22 (Russian designation Pantsir-S1) short-range systems also regularly shot down incoming precision munitions, including the AGM-88 HARM and sometimes even the Tochka-U short-range ballistic missile.⁹²

At the individual aircraft level, European NATO capabilities are more impressive than in 2011, especially since many European nations have purchased the F-35 to replace previous F-16 and Tornado fleets.⁹³ The F-35 was designed specifically to be able to operate against modern SAM systems in both the penetrating strike and SEAD/DEAD roles. Its stealth and EW capabilities allow it to operate much closer to hostile SAM systems than non-stealth aircraft for a given level of risk.⁹⁴ Just as importantly, the F-35's superlative active and passive sensor suite can rapidly and precisely geolocate SAM systems when they illuminate their radars, especially when the aircraft is being operated in a four-ship formation.⁹⁵ However, despite these very impressive capabilities, simply fielding the F-35 is not sufficient as an answer to European NATO's SEAD/DEAD problem in itself.

One of the key limitations for some F-35 operators, like the RAF, in the SEAD and more specifically the DEAD role, is a lack of suitable munitions. The radar performance of Russian systems and the overlapping coverage when deployed as intended means that even with its stealth features, the F-35 is likely to be at significant risk if it has to get close enough to drop free-fall bombs. The ability of the SA-15 and SA-22 to intercept incoming munitions also means that free-fall and even glide weapons are likely to have limited survivability when attacking the medium- and long-range SAM units that these short-range systems are designed to protect. Furthermore, anti-radiation seekers such as those found on traditional SEAD weapons such as the AGM-88 HARM will lose the SAM once it stops emitting radar energy, and even if they can store a fairly accurate position fix and hit that, accuracy is usually insufficient to reliably destroy armoured SAMs, and they cannot be tracked if they are moving. Anti-radiation munitions can modify SAM operators' behaviour and engagement periods to avoid being hit, but they have a very poor track record of achieving hard kills. They are, for the most part, SEAD rather than DEAD weapons.

91. Author interviews with senior Ukrainian Air Force commanders and intelligence officers, Ukraine, October 2022. See also Bronk, Reynolds and Watling, 'The Russian Air War and Ukrainian Requirements for Air Defence', p. 12.

92. *Ibid.*

93. For a list of current F-35 operators and customers, see Lockheed Martin, 'The Global F-35 Enterprise', <<https://www.lockheedmartin.com/en-us/products/f-35/f-35-global-partnership.html>>, accessed 14 December 2022.

94. Author interviews with senior F-35 engineers, test pilots and sensor experts, Fort Worth, 20 February 2019, and with F-35 instructor pilots at RAF Lakenheath, 24 September 2021, and RAF Marham, 20 September 2022.

95. Author interviews with senior F-35 engineers, test pilots and sensor experts, Fort Worth, 20 February 2019, and with F-35 instructor pilots at RAF Lakenheath, 24 September 2021.

EW effects are also a vital component of both the threat (since Russia deploys advanced electronic attack assets at scale) and any NATO SEAD/DEAD strategy. Due to the sensitivity of detailed information on EW capabilities, a detailed discussion of their effects and potential is difficult within the bounds of this paper. However, in general terms they can be tailored to offer responsive and much more cost-effective suppressive effects than kinetic munitions against the radars that provide situational awareness and guidance for hostile SAM systems.⁹⁶ Doing so requires advanced electronic intelligence collection capabilities to stay up to date on the latest enemy system frequencies and operating patterns, and a responsive mission data-programming capability. It also requires assets capable of delivering the electronic attack (or jamming) effects, such as the US Navy's standoff EA-18G Growler aircraft, the stand-in F-35, the MALD-X air-launched decoy/jammer, or the proposed MBDA SPEAR-EW missile.⁹⁷ However, EW effects are generally temporary, even if certain enemy systems must be reset or components replaced to restore functionality. Therefore, while EW is a vital component of SEAD efforts, it cannot create the conditions for lasting air access in airspace contested by modern air defence systems alone. Instead, it must form part of the mix of SEAD capabilities that can open temporary access opportunities for key strike operations. Only the destruction of a significant portion of the ground-based SAM threat will provide Western airpower with the sustained access it needs with the majority of its conventional aircraft to attain control of the air.

For the DEAD mission, Western air forces need weapons that can first be launched from standoff and can navigate to a SAM's approximate location using either positional data provided by an advanced sensor suite such as the F-35s, or by homing in on emitted radar energy using an anti-radiation seeker. Then to reliably hit and destroy the SAM during the terminal phase, the weapon must incorporate millimetric radar homing or possibly infra-red imaging-seeker capabilities to find and accurately hit that SAM even after it has stopped emitting radar energy and is on the move to reposition. They also need to be available in sufficient numbers to seriously attrite the multi-layered Russian IADS quickly, both in terms of overall stockpile, and carriage capacity per aircraft. This is an expensive combination of traits and requires specialised designs.

There are three clear options for NATO air forces at present. The first is the Raytheon GBU-53/B StormBreaker glide bomb, which includes a millimetric seeker for terminal target acquisition and precision guidance, and if launched from high altitudes and speeds can strike moving targets

96. For more information, see John A Tirpak, 'Dominating the Spectrum', *Air and Space Forces Magazine*, 22 February 2022, <<https://www.airandspaceforces.com/article/dominating-the-spectrum/>>, accessed 25 January 2023.

97. For more information, see *Naval Technology*, 'EA-18G Growler Electronic Attack Aircraft, US', 12 April 2022, <<https://www.naval-technology.com/projects/ea-18g-growler/>>, accessed 25 January 2023; John Keller, 'Lockheed Martin and BAE Systems to Integrate Electronic Warfare (EW) into F-35 Fighter-Bomber Avionics', *Military and Aerospace Electronics*, 23 November 2021, <<https://www.militaryaerospace.com/sensors/article/14214394/electronic-warfare-ew-f35-fighterbomber-avionics>>, accessed 25 January 2023; MBDA Missile Systems, 'SPEAR-EW: Network Enabled Electronic Warfare Capability', 2021, <https://www.mbda-systems.com/?action=force-download-attachment&attachment_id=20573>, accessed 25 January 2023.

over 70 km away.⁹⁸ This offers much greater lethality and survivability for launch aircraft than free-fall bombs, but is likely to require multiple weapons per target to saturate SA-15 and SA-22 defences. Another option is MBDA's similarly sized SPEAR 3 miniature cruise missile, which also offers a millimetric radar seeker capability but with a jet engine that allows a much greater standoff range (especially when fired from lower altitudes and speeds), faster flight time to target and a higher likelihood of each weapon getting past terminal defences.⁹⁹ The cost is a significantly higher price per weapon and, therefore, a correspondingly lower number that any air force can purchase. The third SEAD/DEAD weapon option is the Northrop Grumman AGM-88G Advanced Anti-Radiation Guided Missile Extended Range (AARGM-ER).¹⁰⁰ The AARGM-ER is a significantly larger, rocket-powered missile with an anti-radiation seeker and millimetric radar terminal homing capabilities that can be fired from even further away than the SPEAR 3 and travels much faster.¹⁰¹ Its high peak speed of around Mach 4 results in less time for SAMs to reposition once fired upon at any given standoff launch range, and should also make it more difficult for point defences to intercept the AARGM-ER than other SEAD/DEAD weapons. The downside is a much higher per-weapon cost and, if carried internally on an F-35, being restricted to only two weapons per aircraft per sortie, as opposed to up to eight GBU-53/Bs or SPEAR 3s.

An important alternative option would be to build in a much greater doctrinal reliance on long-range ground-based firepower for DEAD effects, with location and targeting supplied by air assets like the F-35. Long-range rocket artillery systems such as the Guided Multiple Launch Rocket System (GMLRS) and High Mobility Artillery Rocket System (HIMARS) systems have been used to impressive effect in Ukraine against Russian logistics and vehicle targets in the deep battle area and could potentially offer significant lethality against SAM batteries many tens of kilometres behind the hostile front line. However, there are various requirements to be satisfied before this represents a viable core of a SEAD/DEAD strategy. First, GMLRS/HIMARS systems would require ammunition with appropriate warheads for reliably destroying or disabling mobile, combat-spaced and armoured SAM systems, such as the M30E1 GLMRS – Alternate Warhead (GMLRS-AW).¹⁰² These are not currently fielded by European operators of GMLRS or

98. Raytheon Missiles and Defense, 'StormBreaker Smart Weapon', <<https://www.raytheonmissilesanddefense.com/what-we-do/air-warfare/air-to-surface-missiles/stormbreaker-smart-weapon>>, accessed 14 December 2022.

99. Author discussions with MBDA subject-matter experts, Stevenage, 23 September 2022. See also MBDA Missile Systems, 'SPEAR', <<https://www.mbda-systems.com/product/spear/>>, accessed 14 December 2022.

100. Joseph Trevithick, 'Our Best Look Yet at the Navy's New Air Defense Busting Missile', *War Zone*, 30 August 2022, <<https://www.thedrive.com/the-war-zone/our-best-look-yet-at-the-navys-new-air-defense-blasting-missile>>, accessed 14 December 2022.

101. *Ibid.*; John Keller, 'Navy Orders AGM-88E2 AARGM Anti-Radar Missiles with GPS/INS Guidance for the Government of Australia', *Military + Aerospace Electronics*, 14 October 2022, <<https://www.militaryaerospace.com/sensors/article/14284185/antiradar-missiles-guidance>>, accessed 14 December 2022.

102. US Army Department of Test and Evaluation, 'FY14 Army Programs: Guided Multiple Launch Rocket System – Alternate Warhead (GMLRS-AW) XM30E1', 2014, <<https://www.dote.osd.mil/Portals/97/>>

HIMARS, so would need to be procured. More to the point, these systems would need to be present in theatre with the ammunition available and political permissions to fire into hostile territory as part of the early stages of any clash when the SEAD/DEAD mission would be most critical. They would also need a secure, common and interoperable communications and data exchange architecture to allow real-time targeting information to be passed from assets such as national and Allied F-35s to GMLRS/HIMARS batteries.¹⁰³ This multi-domain approach does offer a route towards greater DEAD lethality, but it also imposes additional training, exercising and resource allocation challenges.

For example, in the UK the British Army is currently attempting to reconstitute its warfighting capacity, and long-range precision fires renewal is a key component within the operational testing and resource allocation planning process. The RAF might decide to doctrinally rely on Army GMLRS systems forming a key component of DEAD lethality in future joint operations. However, for that to work, detailed discussions on ammunition stockpiles and warhead/guidance requirements, assumed fire mission capacity allocations, airspace deconfliction, wartime and deterrence deployment sequencing and logistic support assumptions must happen urgently before key Army procurements are fixed. Furthermore, just as with other aspects of air operations, if multi-domain SEAD/DEAD approaches are not properly resourced, regularly exercised in realistic scenarios and trained for as a primary task by all the joint elements involved, they will not work in practice when needed. In terms of weapon cost, the notion of relying on ground-based long-range fires simply transfers cost liability to another service in balance sheet terms (assuming they agree) but does not avoid the overall requirement to spend more on munitions to regenerate a SEAD/DEAD capability at scale.

Whichever weapons are chosen, the cost per weapon is likely to mean that, with the possible exception of the GBU-53/B, stockpiles will need to be purchased and held specifically against the SEAD/DEAD mission. The capabilities that these weapons require mean that they are unlikely to be economical as multipurpose utility weapons for lower-threat target sets and missions. However, the quantities required to give a credible DEAD capability will mean that air forces which buy into this mission set will have to accept a high opportunity cost in terms of other potential purchases forgone. Furthermore, even with such weapons, the SEAD/DEAD mission set in a high-intensity Russia scenario is an extremely complex task that will require joint force planning, enablement and deconfliction, as well as specialist aircrew skills and competencies. In other words, European air forces will have to specialise in order to be good at SEAD/DEAD. For small F-35 operators, with fleets sized only to be able to generate perhaps two four-ship waves per day on a sustained basis, this would likely have to be the primary mission focus for training, exercises and operational deployments. Not every air force in NATO needs to specialise in SEAD/DEAD to unlock the problem set of how to regenerate a viable and credible airpower

pub/reports/FY2014/army/2014gmlrs.pdf?ver=2019-08-22-110519-813>, accessed 25 January 2023.

103. For more details, see Watling, Bronk and Kaushal, 'A UK Joint Methodology for Assuring Theatre Access'; Justin Bronk and Samuel Cranny-Evans, 'Building the Capacity to Conduct Joint All-Domain Operations (JADO): Considerations for the UK', *RUSI Occasional Papers* (November 2022), pp. 13–18.

posture to deter Russian military aggression in the medium term. However, with the US ever more overstretched trying to deter burgeoning Chinese capabilities in the Indo-Pacific, it is not a discretionary requirement for at least some of Europe's air forces to step up to the task.

If a viable European SEAD/DEAD capability is not regenerated at scale, European NATO states will be unable to establish control of the air in any scenario where the US is either unable or unwilling to commit major resources to doing so itself. This is not simply an issue for deterring Russian forces, but also for maintaining military options against near-peer states such as Iran, or even a state such as Algeria, which fields modern air defence systems at scale. The alternative to regenerating SEAD/DEAD capacity is a requirement to regenerate massed infantry, artillery and armoured forces to beat the Russians at their own game. This would also mandate procuring massed ammunition stocks and recruiting sufficient personnel to run all the enablers needed to deploy and sustain large land forces where needed. Massed land armies such as those fielded by Russia and Ukraine also imply the acceptance of far greater casualties in any war than the current airpower-heavy Western model. Therefore, while regenerating viable SEAD/DEAD capacity at scale is an expensive task, the alternative is far more expensive and more politically problematic.

Conclusion

SINCE THE EARLY years of the Second World War, the Western way of warfare has relied heavily on the precision, reach and sheer lethality of airpower for its warfighting and deterrence credibility. This has brought a wide range of advantages, not least the ability to retain military overmatch sufficient to deter or defeat most potential and actual adversaries without having to field massed land armies optimised for high-casualty, massed firepower battles of attrition as seen in Ukraine since February 2022. In short, the ability to rapidly establish and exploit air superiority has allowed NATO to be the pre-eminent military alliance in the world since at least the 1980s with comparatively efficient and small standing military forces. However, lacking any serious challenge to its air superiority in discretionary conflicts since 1991, most NATO air forces have allowed their warfighting credibility against peer threats such as Russia and China to atrophy.

The platforms remain, for the most part, highly capable individually. However, the number of bases has been dramatically reduced and, in many cases, the hardening measures at the remaining main operating bases are either inadequate to house the squadrons now stationed there or have been demolished to make way for non-hardened buildings and open hardstands and sun shelters. GBAD capabilities have been retired and/or only replaced in small numbers in many countries. Meanwhile, expensive but resilient networks of dispersal bases, and regular exercises and the maintenance arrangements and equipment required to credibly use them, have been dropped in the name of efficiency savings. It is worth noting that war is an inherently highly inefficient business, and an area where layers of redundancy are essential for credible capability, especially in a peer conflict. These factors mean that the threat posed by Russian long-range missile capabilities is serious, and the survivability of NATO combat air platforms in the air is not matched by their survivability on the ground.

In the air, flying hours are lower than ever in most NATO nations. While modern simulators can compensate for or even improve on live flying training for some advanced threats and tactics, synthetic training does not exercise or test the whole air force and cannot realistically account for real world risks and weather conditions. Furthermore, the capacity is simply not there in most NATO air forces to 'add' serious training at scale for warfighting mission sets to existing deployments, operational commitments and exercise schedules. Training and maintaining the aircrew skills, especially tactical leadership skills, as embodied by weapons instructors, is just as vital for credible warfighting capabilities as having the right aircraft and weapons. However, generating and sustaining such talent requires not burning people out so that they leave after one or two front line tours, and giving them sufficient high-quality live and synthetic training hours to develop and maintain the required skills and deep tactical knowledge. Flying enough of the right sort of training hours requires additional operational funding for engineering capacity and spare parts availability for jets. However, in many heavily tasked NATO air forces it also requires both senior air force commanders and political leaders to significantly reduce ongoing

discretionary taskings, such as legacy counterterrorism, or diplomatic and industrial influence deployments, to free up force capacity.

Another key issue that needs urgent attention if European NATO air forces are to regenerate warfighting credibility is munitions stocks. It is not simply that the invasion of Ukraine has served as a stark reminder of the scale of munitions expenditure required to stop a determined Russian (or Chinese) military force; it has also shown that many of the existing weapon types developed and purchased for operations in permissive air environments are not relevant in contested airspace. The SEAD/DEAD mission is non-discretionary for achieving air superiority over not only Russian or Chinese forces in a contested area, but also against near-peer or sub-peer states with moderately advanced GBAD capabilities. The dedicated munitions required to allow even advanced aircraft like the F-35 to engage modern mobile SAM systems sustainably, with a high probability of kill, are expensive. To enable non-stealth platforms to either provide supporting fires for F-35 and other penetrating assets from a safer distance or engage themselves, these weapons must have not only the terminal seeker performance to find and strike the target without direct designation, but also significantly greater standoff range. All these requirements can be met, but cost per munition is correspondingly high, and tactics and therefore training to use them effectively must also be developed and regularly practised.

The bottom line is that the way that Western military forces have been sized, equipped and organised to fight as a joint force requires air superiority to be achieved relatively quickly to defeat peer or near-peer opponents. Russia will remain an adversary of the West for the foreseeable future and is likely to continue to rearm and rebuild large-scale conventional forces once the fighting in Ukraine ceases. China has a great deal to gain from helping Russia rearm, in terms of splitting US and European resources and attention to prevent full concentration on the Indo-Pacific, and so is likely to do so once there is some form of ceasefire in Ukraine. The same Chinese threat means that the US will be able to spare fewer and fewer military assets to reinforce Europe in a crisis, especially if such a crisis is timed to coincide with a conflict in the Indo-Pacific. Therefore, European NATO air forces must take steps to urgently regenerate the credible capability to achieve air superiority over an area contested by Russian forces; medium-term deterrence requires it.

Doing this will require reducing the vulnerability of air forces on the ground to long-range precision fires, refocusing aircrew and whole force training on warfighting mission readiness, and acquiring the specialised weapon stocks and skills sets to prosecute a SEAD/DEAD campaign at scale. The cost, and opportunity costs in terms of discretionary capability sets and commitments, will be considerable. But if NATO's European air forces cannot credibly gain and exploit control of the air in the event of a conflict with their most likely non-discretionary threat actor, then they are not fit for purpose.

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