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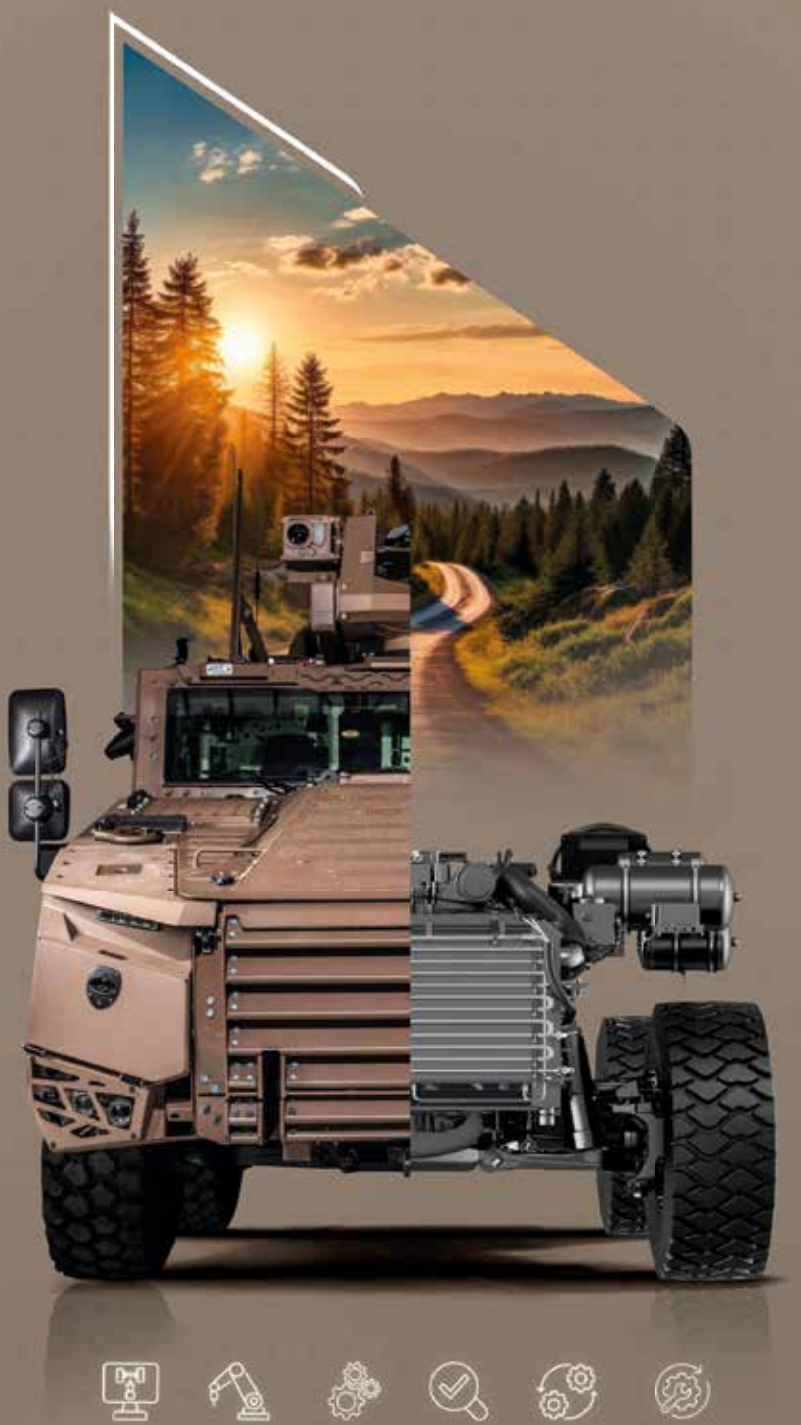

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Europe's tentative first steps toward strategic autonomy

On 19 March 2025, the European Commission published its 'Joint White Paper for European Defence Readiness 2030'. At the outset, many of the threat assessments, security priorities, and capability gaps contained therein are broadly the same as those which have been repeated countless times over the last few years. However, these have now been joined by a newfound urgency and focus in the wake of Europe's recent reacquaintance with the Trump administration's approach to foreign policy.

Highlighting the trans-Atlantic rift in the EU's characteristically diplomatic wording, the paper stated: *"Traditional allies and partners, such as the United States, are also changing their focus away from Europe to other regions of the world. This is something that we have been warned about many times but is now happening faster than many had anticipated",* and later adding, *"the United States, traditionally a strong ally, is clear that it believes it is over-committed in Europe and needs to rebalance, reducing its historical role as a primary security guarantor."*

The remedies advocated in the white paper were largely unsurprising, having been openly discussed by multiple senior figures in Europe since February 2025. Broadly, the paper called for both "collaborative procurement", and a "a massive ramp-up of European defence industrial production capacity". However, the line on how open these efforts would be to non-European companies seemed somewhat contradictory.

On the one hand, parts of the document seemed to encourage industrial cooperation with external partners, including the US. However, one may justifiably ask how Europe plans to external industrial participation with its goal of ramping up European domestic industry, since these approaches would ostensibly be pulling in different directions. Indeed, a reconciliation between these two forces seems unlikely, with the balance of probability favouring European industrial interests, as explicitly stated elsewhere in the white paper: *"the revision process of the EU directive on defence and sensitive security procurement scheduled for 2026 will take into account the Competitiveness Compass recommendation to introduce a European preference",* adding, *"Investing in European defence readiness not only guarantees us the peace of tomorrow; it is also an enabler of our competitiveness ambition for European manufacturing."*

Consequently, the direction of travel suggests Europe will increasingly look internally to meet its defence needs. Europe's industry looks set to reap the benefits, with this shift coming at precisely the time where EU member spending taps are opening, and with the bloc's leadership planning to spend roughly EUR 800 billion on defence by 2030, under the ReArm Europe Plan/Readiness 2030.

What is less clear is where Europe will draw the boundaries in introducing a "European preference". For instance, are foreign subsidiaries to be counted as European domestic industry? Does UK industry count as European for the purposes of this policy? Will foreign companies be required to establish wholly European domestic production and supply chains before they can meaningfully compete for major European programmes? Clearer answers to such questions are needed, especially considering the number of European companies with strong ties outside Europe.

Furthermore, not all of Europe's industrial sectors are equal, and currently there are definite limits to where Europe can look for domestic solutions. In the land domain, Europe has a wealth of very good alternatives to US equipment in tanks, artillery, infantry fighting vehicles (IFVs), armoured personnel carriers (APCs), trucks, and protected patrol vehicles (PPVs). Likewise in the naval domain, Europe likewise has very respectable options for destroyers, frigates, corvettes, submarines, and unmanned vessels. However, the air and space domains are somewhat of a different story. While Europe does have a highly capable aerospace sector, in key areas such as fighter aircraft, research and development efforts are focussed on improving current 4.5 gen and developing future 6th gen aircraft, leaving a domestic gap in the current 5th gen. The elephant in the room here is the F-35 fighter, to which there is currently no direct European equivalent, and to which much of Europe has already committed to procuring. Elsewhere, the white paper listed strategic airlift as a capability gap, and it is unclear how this could be filled by any European solution before 2030, when no real European equivalent to the C-17 transport aircraft exists. A similar story can be seen with European satellite communication and remote sensing capabilities, both of which lag behind those of the US; though in positioning, navigation, and timing (PNT), things look rosier, with Europe's Galileo constellation offering a sovereign PNT capability.

In sum, the current limits of Europe's defence-industrial portfolio suggest the continent will not be able to meet at least some of its capability objectives by 2030 without significant compromise on industrial policy. Indeed, given the sluggish pace of European procurement over the past several decades, along with the need for high-level reforms among many EU members, even Europe's ability to spend EUR 800 billion by 2030 is in doubt. A further factor which may seriously delay progress is the potential for politicisation of procurement, especially in lucrative multilateral collective procurement programmes, and the potential for petty international squabbles it generates. All told, Europe has a Herculean task ahead of it, and one which will likely test its members' ability to put the collective interests of Europe above their own narrow national self-interest.

Mark Cazalet

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ESD [European Security & Defence]
Issue 4/2025, April 2025,
ISSN 1617-7983
www.euro-sd.com

Published by
Mittler Report Verlag GmbH
A TAMM Media Group company

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Cover Photo: An artist's impression of a GPS IIIF satellite orbiting above the Earth. [Lockheed Martin]

Annual subscription rate: €123.80 incl. postage Reduced annual subscription rate for distribution in Germany: €103.80 incl. postage

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Boeing given green light to proceed with NGAD sixth-gen fighter programme

(pf) The US Department of the Air Force has awarded Boeing a contract for the engineering and manufacturing development (EMD) of the Next Generation Air Dominance (NGAD) programme, the centrepiece of which is a sixth-generation fighter.

The EMD contract, which is believed to be worth around USD 20 billion (EUR 18.5 billion), was announced on 21 March 2025 by US President Donald Trump, who declared that the fighter would be designated the F-47. The EMD phase includes maturing, integrating and testing all aspects of the F-47 and will produce a small number of test aircraft for evaluation. The contract also includes competitively priced options for low-rate initial production.

[USAF]

Boeing, in vying with Lockheed Martin to secure the NGAD programme, had already bet big on the project. Both companies had built and secretively flown X-plane demonstrators, but on 26 June 2024 Boeing lifted the lid on a new 1.1 million square-foot factory on which ground was broken at the turn of that year. Expected to be completed in 2026, the USD 1.8 billion factory, which will nearly double the company's manufacturing footprint at its site near St Louis Lambert International Airport, is intended to revolutionise how military aircraft are built and was assumed to be in anticipation of work on NGAD and/or the US Navy's F/A-XX future fighter programme.

However, while the US Air Force (USAF) had released a request for proposals for the NGAD EMD contract in May 2023, with a contract award then expected in 2024, the air force then paused in May 2024 over concerns that a full-blown, sixth-generation NGAD platform would be unaffordable and that a more modest solution might be the best way forward.

A decision over NGAD was thus left for the incoming Trump Administration, which, although currently on a mission to slash government spending across the board, appears to have concluded that only proceeding with NGAD would preserve the US technological edge over a peer-level adversary, ie China.

Announcing the go-ahead for the NGAD programme in the Oval Office of the White House on 21 March, Trump said, "I'm thrilled to announce that, at my direction, the United States Air Force is moving forward with the world's first sixth-generation fighter jet. Nothing in the world comes even close to it, and it'll be known as the F-47.

"In terms of all of the attributes of a fighter jet, there's never been anything even close to it, from speed to manoeuvrability, to what it can have, to payload. And this has been in the works for a long period of time," Trump added. "America's enemies will never see it coming."

The fact that the NGAD fighter platform is being designated the F-47 is somewhat intriguing, given that Trump – who never misses an opportunity for self-aggrandisement – is the 47th president of the United States. Numbers are often taken up by experimental and prototype platforms that ultimately never make it into production – the most recent USAF bomber designations, for example, went from B-2 to B-21 – so the jump from F-35 to F-47 could simply be coincidental.

If, however, the USAF has conceded its designation authority or otherwise moved to allow Trump to associate himself with the NGAD platform, perhaps that will induce the US president to look favourably on the programme as it moves forward.

Relatively little is known about the F-47, which could potentially be the last manned USAF fighter programme. The USAF stated in a press release on 21 March, "As the cornerstone of the NGAD Family of Systems, the F-47 is designed to integrate next-generation stealth, sensor fusion and long-range strike capabilities to counter the most sophisticated adversaries in contested environments. Its adaptability and modular design ensure seamless integration with emerging technologies, positioning it as a dominant platform for decades to come."

Canada reassessing its commitment to buying F-35s in wake of trade war with Trump

(pf) Newly installed Canadian Prime Minister Mark Carney has asked his defence minister, Bill Blair, to review Canada's purchase of the Lockheed Martin F-35 Joint Strike Fighter (JSF) amid the country's ongoing trade war with the US Trump Administration.

The move, initiated on 14 March 2025 just hours after Carney was sworn in and Blair appointed, was confirmed on 16 March 2025 by Canadian Department of National Defence spokesman Laurent de Casanove. The spokesman noted that Canada's F-35 contract remains in place and that Canada has made a legal commitment to purchase an initial 16 F-35As. However, he told the Canadian press that Carney has asked Blair "to determine if the F-35 contract, as it stands, is the best investment for Canada, and if there are other options that could better meet Canada's needs.

[Lockheed Martin]

"We need to do our homework given the changing environment, and make sure that the contract in its current form is in the best interests of Canadians and the Canadian Armed Forces," De Casanove was reported as saying.

Canada initially announced in March 2022 that it would purchase 88 F-35As to satisfy its Future Fighter Capability Project requirement and replace the Royal Canadian Air Force's (RCAF's) current F/A-18A/B Hornet fighters: a fleet that currently stands at around 89 aircraft. On 9 January 2023 the Canadian government announced that a deal had been signed to buy 88 F-35As, with first deliveries expected in 2026 and the first RCAF F-35 squadron to be operational in 2029.

However, prior to Carney becoming Canada's new prime minister, US President Donald Trump had already opened a trade war with the country, even threatening economic coercion to press Canada into becoming the 51st US state: a stance that has sparked anger from both the Canadian government and the country's general population.

Prior to the F-35A being selected by Canada, the other two aircraft vying for the requirement were the Boeing F/A-18E/F Super Hornet – another US contender – and the Swedish Saab Gripen E/F (Dassault and Eurofighter had respectively withdrawn the Rafale and Typhoon from the contest, citing concerns that Canadian interoperability and intelligence-sharing requirements were too extensive).

It is difficult to see how Canada could extricate itself from the F-35 programme without paying significant penalties. As previously mentioned, the country is already contractually committed to buying the first 16 aircraft, which is not a meaningfully sized fleet, and Canada is a Level 3 partner in the JSF programme, meaning that the country's aerospace industry would take a significant hit should it withdraw.

However, Canada is not the first country to reassess how reliable a defence and security partner the United States is under President Trump. On 13 March it emerged that Portugal, which is not a part of the JSF programme but whose air force had expressed a preference for the F-35, was reassessing its options in the wake of Trump's apparent lack of commitment or solidarity with Europe and NATO.

UK chancellor announces defence spending boost, other measures to support defence industry

(pf) Delivering her Spring Statement to the UK House of Commons on 26 March 2025, Chancellor Rachel Reeves outlined a significant immediate boost to UK defence spending and a number of measures intended to turbocharge the UK defence industry.

"In February [2025] the Prime Minister set out our government's commitment to increasing spending on defence to 2.5% of GDP from April 2027 – the biggest sustained increase in defence spending since the end of the Cold War –and an ambition to spend 3% of GDP on defence in the next Parliament," the chancellor noted. "That was the right decision in a more insecure world – we are putting an extra GBP 6.4 billion [EUR 7.68 billion] into defence spending by 2027 – but we have to move quickly in this changing world, and that starts with investment. Today, I can confirm that I will provide an additional GBP 2.2 billion for the Ministry of Defence in the next financial year: a further down-payment on our plan to deliver 2.5% of GDP by 2027."

[Parliament TV]

Reeves additionally stated that 10% of the UK Ministry of Defence (MoD) equipment budget would be spend "on new, novel technologies, including drones and artificial intelligence-enabled technology, driving forward advanced manufacturing production in places like Glasgow, Derby and Newport, creating demand for highly skilled engineers and scientists, and delivering new business opportunities for UK tech firms and start-ups"

She added that a protected budget of GBP 400 million would be established in the MoD, a budget that will rise over time, for UK defence innovation "and a clear mandate to bring innovative technology to the front line at speed".

Perhaps most ambitiously, Reeves asserted, "We will reform our broken defence procurement system, making it quicker, more agile and more streamlined, and giving small businesses across the UK better access to Ministry of Defence contracts – something welcomed by the Federation of Small Businesses."

Furthermore, Reeves stated, "We will provide GBP 2 billion of increased capacity for UK Export Finance to provide loans for overseas buyers of UK defence goods and services. I want to do more with our defence budget, so that we can buy, make and sell things here in Britain. I want to give our world-leading defence companies and those who work in them further opportunities to grow, and to create jobs in Britain, as military spending rightly increases all across Europe. To oversee all this vital work, my right honourable friend the Defence Secretary and I will establish a new defence growth board to maximise the benefits from every pound of taxpayers' money that we spend, and we will put defence at the heart of our modern industrial strategy to drive innovation, which can deliver huge benefits for the British economy."

Other defence-related measures announced by Reeves included a GBP 200 million investment in Barrow and Furness as the heart of the UK's nuclear deterrent capability, the regeneration of Portsmouth naval base and the securing of better accommodation for UK armed forces personnel.

Bundestag vote releases the brake on future German defence spending

(gh) Friedrich Merz, Germany's chancellor in waiting, won a historic vote in the Bundestag on 18 March 2025 to facilitate the country's biggest ever defence spending programme in light of Russian belligerence in Europe.

[DBT/Thomas Köhler]

The Christian Democrat Union (CDU) party leader, who won Germany's 23 February election and is set to form a government with the Social Democrats (SPD), secured the two-thirds majority needed for the constitutional change to unlock new borrowing estimated to exceed EUR1 trillion.

Specifically, the Bundestag passed amendments to Articles 109, 115 and 143h of the Basic Law by 513 votes to 207, putting the financing of German defence spending on an entirely new footing.

In the new Article 143h, the federal government is also authorised to establish a special infrastructure fund with a volume of EUR 500 billion, which does not count towards the country'sdebt brake.

In the government's draft budget for 2025, expenditure totalling EUR 53.25 billion is planned in the Federal Ministry of Defence's individual budget (EPl) 14. In EPl 06 of the Ministry of the Interior a total of EUR 1.4 billion is planned for the Federal Office of Civil Protection and Disaster Assistance, Federal Agency for Technical Relief, Federal Office for the Protection of the Constitution and Federal Cyber Security Authority and EUR 1.2 billion for the Federal Intelligence Service in the Federal Chancellor's EPl 04. EUR 7 billion has been earmarked in EPl 60 for upgrading partner states. This amounts to a total of EUR 62.8 billion. Of this, 1% of GDP (2025: EUR 4,407 billion) is allocated to the debt brake, which is EUR 44.1 billion. This results in a new margin of EUR 18.8 billion for the 2025 budget.

Irrespective of this, the volume of the defence budget is not limited. However, it must not increase by leaps and bounds. The budgeters must consider the EPl 14 and the special assets together and increase the total volume in line with the needs of the Bundeswehr and industry's ability to deliver.

UK MoD announces fully funded plan to mount DragonFire LDEW on Type 45 destroyers by 2027

(pf) The UK Ministry of Defence (MoD) has announced that a fully funded plan is in place to mount the developmental DragonFire laser-directed energy weapon (LDEW) on four of the UK Royal Navy's Type 45 destroyers.

The plan was outlined by UK Armed Forces Minister Luke Pollard on 26 March 2025 and has been facilitated by an announcement by UK Chancellor Rachel Reeves, made on the same day, that an additional GBP 2.2 billion (EUR 2.64 billion) will be made available to the MoD in the next financial year as a further down-payment on the UK government's plan to spend 2.5% of GDP on defence by 2027.

At this stage it is not yet known which Type 45 destroyers will receive the DragonFire installations, but Pollard indicated that the plan is to have them in place by 2027.

The UK MoD had announced on 12 April 2024 that the UK DragonFire LDEW – developed by MBDA in conjunction with Leonardo UK, QinetiQ and the UK's Defence Science and Technology Laboratory (Dstl) – would be installed on Royal Navy warships. At the time, however, the plan was only to install the DragonFire systems from 2027 onwards.

The MoD announced on 19 January 2024 that a DragonFire LDEW demonstrator had successfully conducted firing trials against aerial targets at a range in the Hebrides.

[MBDA]

The UK DragonFire programme leverages MBDA's decades of weapon system manufacturing expertise, Leonardo's position as a world-leading authority in laser technology, electro-optics and advanced targeting, and QinetiQ's experience as the only UK company to successfully develop and safely operate high-energy laser sources in the UK along with coherent beam-combining technology.

DragonFire has been developed through a GBP 100 million joint investment by industry and the UK MoD, working with Dstl. The system has the potential to be a long-term, low-cost alternative to certain tasks missiles currently carry out. It uses a 50 kW-class laser to deliver its effect, with its performance said by the development team to be 'equivalent to hitting a GBP 1 coin from kilometres away', all while the target is moving at speed –with the platform possibly also moving – and while delivering enough dwell time on the targeted point to deliver an effect.

Finland and Ukraine sign defence co-operation MoU as Helsinki announces new aid package for Kyiv

(pf) Finland and Ukraine have signed a memorandum of understanding (MoU) on defence co-operation between the two countries' defence administrations.

[Finnish MoD]

The MoU was signed by the two countries' defence ministers, Antti Häkkänen and Rustem Umerov respectively, as they met in Helsinki on 13 March 2025.

Co-operation under the MoU will be enhanced in a number of fields, including defence materiel, exchange of information, research and innovation, ammunition production, and defence-industrial projects in Finland and Ukraine.

At the defence ministers' meeting Finland also announced its 28th military assistance package for Ukraine.

"For more than three years Finland has supported Ukraine's defence against Russia," the Finnish Ministry of Defence quoted Häkkänen as saying. "We are one of Ukraine's biggest supporters by GDP ratio. Finland and Ukraine are on the same edge of Europe and, drawing from our historical experience, we share a perception of the threat of Russia. Finland is committed to continuing its support for Ukraine. However, the relationship between our countries is not a one-way street but a mutually beneficial partnership. This memorandum of understanding shows that we want to expand and deepen our co-operation for the benefit of both countries."

"Three long years of defence against Russia have honed the Ukrainian armed forces into one of the strongest in Europe. At the same time, Ukrainians have gained extensive experience of how to defend their country against Russia. This means that when we develop our own defence system we must heed head the lessons learned by Ukrainians and make use of their experiences," Häkkänen added.

Finland's latest military aid package for Ukraine, valued at around EUR 200 million, is awaiting approval from the Finnish government and president.

Earlier in January 2025, Finland finalised its 27th defence package for Ukraine, valued at nearly EUR 200 million in replacement costs. In late February 2025, meanwhile, Finland announced an industrial programme worth EUR 660 million that will be used to procure new defence materiel from the Finnish defence industry to help Ukraine. Delivering on these decisions will raise the total value of Finland's materiel assistance to Ukraine to EUR 3.3 billion.

"As before, we will not reveal the details of the [latest] aid package," said Häkkänen. "What I can say is that this time the package contains artillery ammunition, for which there is a great need right now in Ukraine. It is tremendous that there is such a broad political support and national consensus in Finland for supporting Ukraine. Moreover, it is invaluable that we have succeeded in combining support for Ukraine and stronger security of supply in Finland through our new industrial programme."

Damen Naval officially hands over Dutch Combat Support Ship *Den Helder*

(pf) Dutch shipyard Damen Naval has handed over the new Combat Support Ship (CSS) ***Den Helder*** to the Dutch Ministry of Defence's Command Materiel and IT organisation (COMMIT).

During a 24 March 2025 ceremony in Den Helder, the ship's home port, Damen Naval Managing Director Roland Briene and COMMIT Commander Vice Admiral Jan Willem Hartman presided over the official handover of the ship, which will be commissioned on 1 October. An intensive training programme will follow, after which the ship will be ready for operations worldwide in mid-2026.

[Damen Naval]

The handover of ***Den Helder*** marks the first phase in the large-scale fleet renewal programme for the Royal Netherlands Navy (RNLN), with the CSS being an important addition to the RNLN fleet and also to NATO capabilities. It will supply other Dutch naval vessels with fuel, food, water, ammunition and spare parts and will additionally serve as a floating hospital.

Den Helder was built at the Damen Naval yard in Galați, Romania, and departed from there in November 2024 for its first sea trial and the voyage to the Netherlands. The ship arrived on 13 December 2024 in Vlissingen-Oost, where Damen Naval carried out further work. On 22 February 2025 the vessel was christened by Her Royal Highness Catharina-Amalia, Princess of Orange: the heir apparent to the Kingdom of the Netherlands.

On 14 March the CSS departed the Vlissingen yard to continue with sea trials. Various Sea Acceptance Tests (SATs) were conducted, including a replenishment at sea (RAS) with the Rotterdam-class landing platform dock HNLMS ***Johan de Witt***. Now that the ship has been handed over to COMMIT, work

will continue under the responsibility of the Dutch Directorate of Materiel Sustainment (DMI) and Joint IV Command (JIVC), which will begin commissioning the ship's sensors, weapons and command system and manage the hardware-software integration within the ship's combat management system.

RAF says farewell to the Puma after 53 years of operational service

(pf) The end of March 2025 saw the retirement of the UK Royal Air Force's (RAF's) fleet of Puma helicopters after almost 54 years of operational service.

Farewell flights were mounted out of RAF Benson on 26 and 27 March by three Puma HC2 aircraft, visiting numerous US military sites of significance to the Puma's UK service history, which began in 1971. Two flypast flights were also mounted out of RAF Akrotiri on 27 March to mark the Puma's service on Cyprus.

[RAF]

Fifty-three Aerospatiale Pumas were originally procured for the RAF and designated Puma HC1s, 24 of which underwent a mid-life upgrade under a contract signed in September 2009. The RAF returned these modernised aircraft, now designated Puma HC2s, to operational service in 2015.

Published UK MoD data states that the RAF had a total of 20 Puma HC2s in its inventory as of April 2024, of which 17 were in active service.

In March 2021 the UK Ministry of Defence (MoD) announced the New Medium Helicopter (NMH) programme to cover UK rotary-wing requirements including replacing the Pumas. However, the programme appears to have fallen into abeyance and the UK government has meanwhile paused decisions while concentrating on a Strategic Defence Review, which is due to be published some time in 2025.

Royal Navy receives its first autonomous Maritime Mine Counter Measures system

(pf) What prime contractor Thales bills as the world's first end-to-end autonomous maritime minehunting system has been delivered to the UK Royal Navy, Thales announced on 14 March 2025.

The new capability consists of an unmanned surface vessel (USV) – the 12 m long Royal Navy Motor Boat (RNMB) ***Ariadne*** – as well as an advanced towed sonar (TSAM) with a cutting-edge multi-vision sonar (SAMDIS), a remotely operated vehicle (ROV) and a lightweight operations centre (e-POC), all supported by a secure command-and-control system.

Additionally, Thales has developed a sonar analysis application, Mi-Map, that processes sonar data up to four times faster than current systems, allowing even more precise detection and classification of sea floor mines.

The new vessel can be deployed from a coastal base or mother ship to hunt the seabed and water column for mines.

The technology allows mines to be rapidly detected in a more cost-effective and safer manner than previously, greatly increasing operational tempo and eliminating the need for sailors to enter mined danger areas.

The system was delivered under the Anglo-French Maritime Mine Counter Measures (MMCM) programme, which was initiated in 2012 to develop an autonomous system for the detection and neutralisation of sea mines and underwater improvised explosive devices (UWIEDs). Thales was awarded the MMCM prime contractorship in 2015 by Europe's Organisation for Joint Armament Cooperation (OCCAR).

In France the effort is known as the SLAM-F (Système de lutte anti-mines marines du future) programme. The French Navy received its first MMCM/SLAM-F system in December 2024.

According to the UK Ministry of Defence's Defence Equipment & Support (DE&S) organisation, the total contract value of the MMCM for the UK and France is EUR 430 million. The delivery of a first MMCM system to the Royal Navy – the first of four initial systems it will receive this year – is part of the Mine Hunting Capability (MHC) programme led by DE&S, which aims to transition from conventional manned mine countermeasures vessels to maritime autonomous systems.

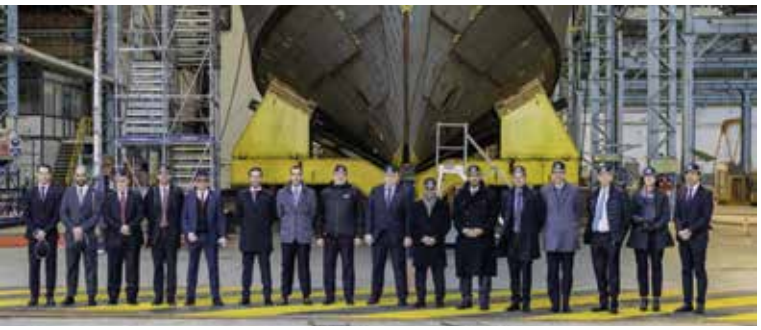
Following the delivery of RNMB ***Ariadne***, Royal Navy personnel will undertake a period of training under Thales' guidance before independently conducting a rigorous operational evaluation of the equipment and beginning to utilise the MMCM system to fulfil operational duties.

In September 2024 a trial of the prototype MMCM vessel, RNMB ***Apollo***, successfully demonstrated the potential for the capability to be deployed flexibly and at pace by the Royal Navy, paving the way for the delivery of RNMB ***Ariadne***. That trial took place in Scotland's Firth of Clyde: a location that proved to be an effective testbed, according to DE&S.

[Thales]

EDGE Group and CMN Naval to create shipbuilding joint venture called AD Naval

(pf) Leading Emirati defence and technology concern EDGE Group and French shipbuilder CMN Naval have formally agreed to create a new Abu Dhabi-based shipbuilding joint venture (JV) called AD Naval, EDGE announced on 19 March 2025.



[EDGE Group]

Leveraging an existing order pipeline worth around EUR 7 billion, the JV will bring together both companies under an exclusivity agreement on the segment of high-value small to mid-size naval vessels including corvettes, offshore patrol vessels (OPVs), high-speed interceptors, trimarans, and landing craft. The move will thus see EDGE significantly expand the scope of its capabilities in the naval domain.

EDGE, holding a 51% stake in the new company, will collaborate with CMN Naval on sales, commercial activities and engineering. It will also establish a design bureau that will assume intellectual property rights for all future designs. The JV will grant EDGE access to CMN Naval's global supply chain and its advanced Integrated Logistics Support (ILS) system and software, enhancing cost efficiency and operational performance through predictive and preventative maintenance, as well as the provision and management of all spare parts.

The scope of the JV will also explore combat systems integration of EDGE's advanced autonomous air, sea and smart weapons solutions onto vessels built by the new company.

Leonardo and Baykar sign MoU to create UAV joint venture

(pf) Leonardo and Turkey's Baykar Technologies signed a memorandum of understanding (MoU) in Rome on 6 March 2025 to establish a joint venture to develop unmanned technologies.

The agreement is based on the industrial synergies and complementarities of the two companies in the unmanned sector. The scope of the joint venture, which will be based in Italy, includes the design, development, production and maintenance of unmanned aerial vehicles (UAVs).

[Leonardo]

"This partnership will leverage Baykar's industry-leading unmanned platforms, which have demonstrated operational effectiveness across various global markets, and Leonardo's expertise in mission systems, payload design, and related aerospace certification in Europe," the two companies stated in a joint press release.

The companies assert that the European market for unmanned fighters, armed surveillance UAVs and deep strike UAVs over the next decade is projected to reach USD 100 billion (EUR 92.4 billion).

BAE Systems and Norwegian shipyard Hamek agree future maritime collaboration

(pf) A memorandum of understanding (MoU) has been signed between BAE Systems and Norwegian shipyard Hamek that will see the two companies collaborate to address Norway's maritime requirements, BAE Systems announced on 24 February 2025.

[BAE Systems]

The signing was completed at an industrial collaboration event at Hamek's Harstad site in northern Norway, where the company plans to invest in its dry-docking and ship facilities. British and Norwegian defence and government delegates attended the event, which took place alongside Royal Navy Bay-class auxiliary dock landing ship RFA *Lyme Bay*.

Subject to the outcome of Norway's future frigate programme, for which the UK's Type 26 design is being considered, BAE Systems and Hamek will explore enhanced ship support and maintenance solutions that could generate further economic benefit in the region.

Leidos appoints new chief executive for its UK and European business

(pf) Technology specialist Leidos has appointed Adam Clarke as its chief executive of Leidos UK & Europe, effective from 31 March 2025, the company announced on 26 March.

Clarke, who brings more than 20 years of experience across the aerospace, defence and security sectors to lead Leidos' European operations, replaces Eric Freeman, who is facilitating the transition before returning to the United States.

Prior to joining Leidos, Clarke was UK managing director for the helicopters division at Leonardo and held senior positions with the company for over two decades, including strategy and competitive analysis director for the electronics division.

Clarke holds a master's degree in manufacturing engineering and operations management from the University of Nottingham and a Master of Business Administration from the INSEAD Business School in Fontainebleau, France.

GPS under threat

Doug Richardson

Since the 1980s, many nations have relied on the Global Positioning System (GPS) for position-finding, missile guidance, and for the precision timing that is essential for many military and civil high-technology systems. So inevitably, this has resulted in the development of corresponding countermeasures.

In 2003, Iraq deployed GPS jammers (probably of Russian origin) in the hope of disrupting the functioning of the US-led coalition's satellite-guided munitions. All six jammers were located and destroyed – in one case by a GPS-guided weapon. Yet the following two decades of development have created jammers of much greater effectiveness.

When first used by Ukraine in the first half of 2023, the GPS-guided BAE Systems/Raytheon M982 Excalibur 155 mm artillery shell was credited with high accuracy, as were other GPS-guided weapons in Ukrainian service, such as the Lockheed Martin M142 High Mobility Artillery Rocket System (HIMARS). Local press reports claimed that Excalibur rounds typically landed not more than 4 m from their planned aimpoint. This success proved short-lived; by August of that year Russian jamming had blunted the effectiveness of Ukraine's GPS-guided weapons.

A total of six GPS Block III satellites are currently in orbit. [USAF]

The GPS constellation

Currently the GPS constellation consists of 31 operational satellites – six Block IIR launched between 1997 and 2004, seven Block IIR-M launched between 2005 and 2009, 12 Block IIF launched between 2010 and 2016, and six GPS-III launched from 2018 onwards. All but the Block IIR transmit M-code. This uses a different waveform with a broader radio frequency range, transmitted at higher power, features that provide greater resistance to jamming. Compared to its predecessors, it also incorporates enhanced signal encryption intended to make spoofing more difficult.

Many of these satellites have exceeded their design lifetime. The oldest Block IIR satellites have exceeded theirs by more than 20 years, with the oldest Block IIR-M more than a decade past their planned lifetime, and the oldest Block IIF are two years past theirs. By these standards, the six GPS-III are comparative youngsters, having been designed for a 15-year lifespan. Production of the first two Block IIIF satellites is now under way, and the first is due to be orbited in 2027. A further eight are under contract, and 12 more are planned.

GPS III satellites have more than eight times the anti-jamming capabilities of earlier satellites. The new IIIF versions will incorporate a further-improved capability designated Regional Military Protection (RMP). This will allow the spacecraft to use a highly-focussed spot beam that will serve ground areas down to 12 km diameter.

AUTHOR

Following an earlier career in engineering, **Doug Richardson** is a defence journalist specialising in topics such as aircraft, missiles, and military electronics.

Despite the advantages of M-code, progress in developing receivers able to exploit it has been slow. According to the US Government Accountability Office (GAO), approximately 700 different types of weapon systems, including aircraft, ground vehicles, and ships, will require M-code-capable user equipment. However, in a September 2024 report it noted that as a result of what it described as years of delay, the first increment of user equipment able to use M-code signals is only now approaching its final series of tests, but the report warned that "discovery of additional deficiencies threatens the program's schedule".

Jamming and spoofing

GPS signals are easy to jam due to their very low power when they reach the Earth's surface. Jamming is fairly easy to detect, but GPS spoofing is a more subtle threat. It involves mimicking the GPS signal in order to make GPS receivers lock on to the signals generated from the spoofing device rather than the authentic GPS satellite signals, causing them to provide false positional and/or time information.

Military-grade GPS receivers are resistant to many forms of spoofing because the (P)Y-code and M-code signals from the satellite constellation are encrypted. However, if an enemy is unable to duplicate this encryption process, spoofing can still be attempted by rebroadcasting a time-delayed copy of the genuine signal without decrypting or altering the data in order to mislead GPS receivers and cause them to generate false location data.

The problems posed by spoofing were well-known even two decades ago, and prompted several potential countermeasures. The strength and elevation angle of the signal being received are two factors that may betray the presence of a spoofing signal. This may not successfully mimic features of the real signal such as changes in signal strength as the receiver changes from receiving from one satellite to receiving from another.

Incidents of global navigation satellite system (GNSS) jamming and spoofing are happening with increasing frequency. The travels of Russian president Vladimir Putin often result in GPS becoming unreliable in the area he is visiting, but less-publicised GPS outages are becoming commonplace. Some are reported to be caused by jamming systems being used to protect Russian oligarchs from drones.

The website *gpsjam.org* displays a daily map showing regions of probable GPS interference that have been derived from aircraft reports of navigation system accuracy. Most of the aircraft reporting bad GPS accuracy are flying near conflict zones where GPS jamming is known to occur, but incidents outside of conflict zones may in some cases be due to testing of military jamming systems.

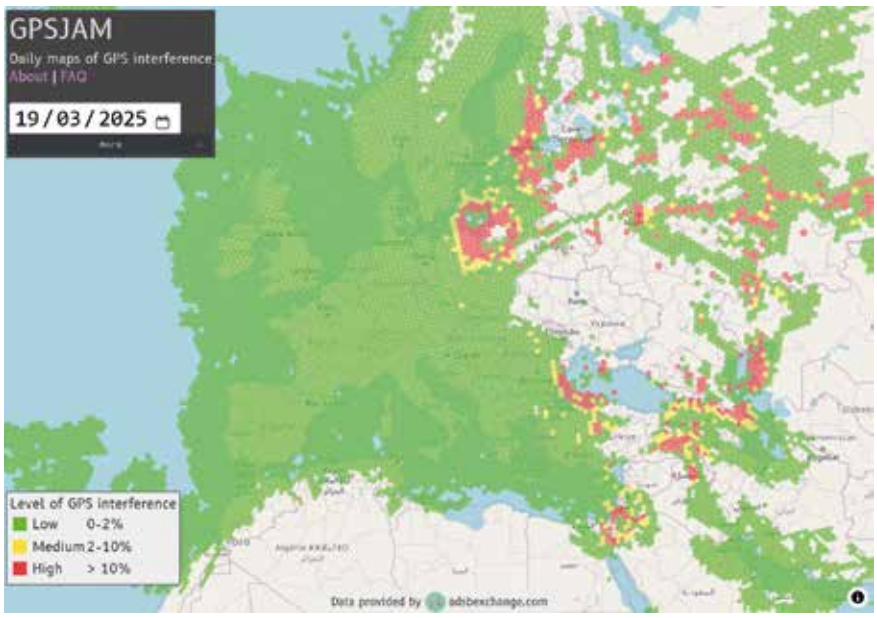
While techniques exist for suppressing jammers that are active across a small frequency range, they are not effective against jammers that can rapidly change their frequency or phase characteristics. In recent years, a team from Aerospace Corporation's Communication System Implementation subdivision has been developing what it terms Blind Interference Signal Suppression (BLISS) technology. This uses a proprietary set of algorithms that estimate specific characteristics of a high-power jammer, which in turn enables it to mitigate their effects. The technology can be implemented with existing receivers, fielded as a standalone device positioned between a GPS receiver and its antenna; and in the future could be integrated into a receiver chipset.

Next-generation spacecraft

The NTS-3 Vanguard programme is intended to demonstrate game-changing position, navigation and timing (PNT) technologies and techniques applicable to the space, ground control and user equipment system segments. The goal of the project is to advance technologies that could mitigate deliberate interference to PNT capabilities, and to increase the system resilience of the GPS system for military, civil, and commercial users.

The spacecraft created by L3Harris Technologies is based on a Northrop Grumman ESPAStar-D spacecraft bus. Its digital on-orbit reprogrammable PNT signal generator will support legacy GPS signals, as well as advanced signals not currently being transmitted. A phased-array antenna will be used to electronically steer signals to a desired geographic region without physically moving the satellite. NTS-3 will test the CHIMERA signal authentication protocol intended to provide robust protection against GPS spoofing for civil users. Different kinds of signals, including future versions of CHIMERA will be uploadable to the satellite at any time after launch. NTS-3 was due to be placed in geosynchronous orbit in 2023, but this date has slipped, and launch is now expected in the second quarter of 2025.

Developed by the MITRE Corporation in partnership with the AFRL Sensors Directorate, the Global Navigation Satellite System Test Architecture (GNSSTA) is a reprogrammable software-defined receiver intended to receive both legacy GPS transmissions, and the advanced signals generated by NTS-3. It explores



Generated by the gpsjam.org website, this diagram shows the regions being affected by the jamming or spoofing of GPS on 19 March 2025. Russia is thought to be responsible for the jamming experienced over the Baltic states and Finland. [gpsjam.org]

the technology needed for future operational receivers with options intended to prevent and respond quickly to threats such as GPS jamming and spoofing.

According to the US Air Force (USAF), recent resilience studies have recommended an additional proliferated fleet of small GPS satellites, Under the Resilient GPS (R-GPS) programme, it plans to augment the existing GPS constellation by deploying up to 20 small satellites capable of transmitting core GPS signals.

Artist's impression of the planned NTS-3 Vanguard spacecraft intended to test the technology planned for future to position, navigation and timing (PNT) satellites. [USAF]

In September 2024, the US Space Force selected Astranis, Axient, L3Harris Technologies and Sierra Space to develop concepts for smaller, more cost-effective GPS satellites based on commercial designs. The programme is intended to produce an initial batch of up to eight R-GPS satellites, with the intention of having these ready for launch by 2028. Following a planned down-select of companies for final design reviews and prototype development, one or more will be chosen to build the initial satellites.

However, the programme has attracted criticism from the US House Appropriations Defense Subcommittee, which rejected the USD 77 million initial funding request during June 2025. The subcommittee did not believe that additional satellites would significantly increase the resilience against jamming, and noted that the programme failed to address vulnerabilities in ground equipment.

Exploiting existing spacecraft

Although designed to provide high-speed internet capabilities, SpaceX's steadily-growing constellation of more than 7,000 mass-produced Starlink small satellites in low Earth orbit (LEO) could become an alternative to GPS. The advantage of a constellation in LEO is that when a satellite's signals reach the Earth's surface, they can be several orders of magnitude more powerful that those from GPS. Although each satellite can serve only a specific geographic area, a constellation of thousands can provide global coverage.

Given a suitable upgrade to the satellite software, the Starlink constellation could provide an alternative to GPS. The data transmission rate from each Starlink satellite is about a thousand times that from a GPS satellite, so individual Starlink spacecraft could provide much more accurate data on their current position, information that would allow a ground-based receiver to calculate its own position with sub-metric accuracy. Since Starlink operates at microwave frequencies, ground-based receiver antennas are much more directional that those used by GPS receivers. This should make it easier to distinguish between the genuine transmission and those from enemy jamming or spoofing.

The US Department of Transportation's Center for Automated Vehicles Research with Multimodal Assured Navigation (CARMEN) at Ohio State University has spent the last decade studying alternatives to GPS, and proposes to exploit the beacon signals transmitted by existing and planned constellations of LEO satellites. Although details of these beacon signals are not available to the public, CARMEN researchers have developed an algorithm able to decipher these.

By 2021, the team was able to use the signals from six Starlink satellites to determine ground position to an accuracy of 10 m. In a 2023 paper for the IEEE/ION Position, Location and Navigation Symposium they described a receiver able to exploit any LEO satellite constellation, and reported tests using Iridium NEXT, OneWeb, Orbcomm, and Starlink satellites. When trialled aboard a moving car, the receiver was able to able to determine its location to within just under 5 m.

Iridium's PNT Division (formerly known as Satelles) proposed a Satellite Time and Location (STL) service based on its current 66-satellite LEO constellation, while other companies have proposed alternative solutions based on constellations of PNT spacecraft planned as commercial programmes. For example, US company TrustPoint is developing a commercial GNSS. Intended for civil and military use, this will exploit the company's planned C-Band LEO satellite constellation. The first technology-demonstration satellite was launched on 15 April 2023, and further satellites are due to be launched by the end of 2025.

In February 2025, Xona Space Systems announced that it had been awarded a USD 4.6 million contract from the Air Force Research Laboratory (AFRL) to demonstrate its planned constellation of Pulsar LEO satellites, the first of which is due to be launched in June 2025. Further launches planned for 2026 are expected to allow initial operational services in 2027. A total of 258 satellites is expected to form the definitive constellation. Other companies are also planning satellite constellations. If fully deployed, these commercial ventures would require a

The sheer size of satellite constellations deployed by companies such as Starlink would make these hard to counter by jamming, spoofing, or direct attack. Conducted on 11 November 2019, this launch orbited a total of 60 Starlink satellites. [USAF]

potential enemy to develop and field suitable jamming or spoofing capabilities, but it remains to be seen how many will prove commercially viable and be fully deployed.

Russia makes no secret of the fact that it possesses anti-satellite (ASAT) capabilities, which it demonstrated on 5 November 2021 by using an A-235 PL-19 Nudol missile to attack and destroy an obsolete Soviet-era Tselina-D SIGINT satellite. Several days after the interception, and only three months before Russia's full-scale invasion of Ukraine, Russian state TV claimed that ASAT missiles could destroy all 32 satellites in the GPS constellation. However, if future satellite-based navaids used hundreds or even thousands of satellite such as the Starlink constellation, most physical attacks on such a large number of spacecraft would be totally impractical.
he only practical kill mechanism able to deal with large constellations would probably be high-powered electro-magnetic pulses (EMPs) generated either by a nuclear explosion or by non-nuclear

electro-magnetic (NNEMP) weapon. The US has developed weapons of the latter type that generate a concentrated beam of microwave energy, and in 2012 successfully demonstrated a missile whose warhead had been created by the Counter-Electronics High Power Microwave Advanced Missile Project (CHAMP). By 2019, the USAF was reported to have deployed at least 20 CHAMP-equipped missiles, and work was under way to develop a smaller and more rugged version under a programme designed the High-Powered Joint Electromagnetic Non-Kinetic Strike Weapon (HiJENKS), which was being tested by 2022.

Possible alternatives to GPS

In November 2023, the USAF released a SBIR (Small Business Innovation Research) solicitation, asking industry to propose "alternative, GPS-independent, navigation augmentation sources of positioning, navigation, and timing (PNT) data for the warfighter, civil and commercial user". These sources could augment GPS or to act as a short/medium-term alternative to GPS if access to the latter is degraded or denied.

Potential solutions listed included *"non-GPS space-based RF [radio frequency] systems including global navigation satellite systems (GNSS), self-contained inertial navigation systems (INS), celestial navigation, computer vision-based approaches, network-based timing approaches, PNT-over-communications, signals of opportunity, and other land-based RF augmentation systems".*

Other recent commercial efforts of potential interest mentioned in the SBIR included *"low cost proliferated LEO (pLEO) communication mega-constellations... machine learning and artificial intelligence, quantum sensing, low cost high data-rate space laser crosslink networks, chip scale atomic clocks, very high density reconfigurable field programmable gate arrays, Graphical Processing Units, as well as the convergence of satellite communications and 5G/6G cell networks."*

Following a planned Phase I study and analysis phase, Phase II was expected to involve contracts intended to provide "an end-to-end capability demonstration in a relevant laboratory operational environment, including initial field testing to prove that the proposed Alt-PNT capability is prepared to move in to limited production and limited operational field testing." Under a Phase-III anticipated for FY2026 or even earlier, the most promising solutions are expected to transition to limited low-rate production of sufficient sub-systems to allow limited operational demonstration in operational environments.

A Government Accountability Office (GAO) report published in August 2022 noted that while the Department of Defense (DoD) was introducing the M-code and technologies such as anti-jam antennas, it warned that "even with these upgrades, vulnerabilities will remain".

According to the GAO, multi-PNT receivers should be capable of integrating multiple sources of PNT data, including GPS M-code and both alternative and future PNT data sources. They should allow a military mission to continue with minimal, or even no degradation in the event that one of the PNT sources becomes unavailable for a period of time. They are expected to exploit information available from other sources on the platform, such as RF antennas or an inertial measurement sensor able to provide acceleration and rotation data. The GAO warned that "current PNT receivers are not designed to easily add in new sources of PNT information... these systems cannot be upgraded affordably".

INSs use sensors such as gyroscopes and accelerometers to track a system's current location from a known starting point. Although small, the inevitable errors in measurement accumu-

Three pieces of USAF jamming equipment sit on display at the 266th Range Squadron, Mountain Home Air Force Base, Idaho, on 27 September 2023. From left to right, pictured is the high power GPS jammer, the single beam track jammer, and the low power GPS jammer. Despite upgrades to GPS, jammers such as these are set to remain a problem for the foreseeable future. [USAF/Senior Master Sgt Joshuia Allmaras]

late over time, and gradually degrade the system's positioning accuracy. Combining information from a GPS receiver with that from an inertial measurement unit (IMU) creates a system that combines the short-term accuracy of an INS with the long-term accuracy of an unjammed satellite navigation (SATNAV) receiver. However, the usefulness of such a combination depends on not having long periods of SATNAV outage.

The August 2022 report was a public version of a report that the GAO had issued in April of that year. The latter had contained information that the DoD deemed to be sensitive, and should be protected from public disclosure. As a result, the August version omitted what the GAO described as "sensitive details about seven of the 11 alternative PNT technology and product development efforts we identified". While little is known about some of these projects, in other cases some information is available.

One project cited by the GAO in its August 2022 report is the US Army's Mounted Assured Positioning, Navigation and Timing System (MAPS), a vehicle-mounted system intended to integrate data from an M-code capable GPS receiver, a receiver for a commercial space-based satellite system (ALTNAV), an inertial sensor, and a high-accuracy clock. A similar array of sources forms the basis of the Dismounted Assured Position Navigation and Timing System (DAPS) intended for use by soldiers on foot.

The US Army's Mounted Assured Positioning, Navigation and Timing System (MAPS) is intended to allow combat vehicles to operate in GPS-contested environments. It integrates a variety of PNT sources, including a receiver for GPS, a receiver for a commercial space-based satellite system (ALTNAV), and an inertial sensor. This soldier indicates the position of a MAPS component on a Stryker vehicle. [US Army]

The Army's Assured Precision Weapons and Munitions (APWM) Project is intended to demonstrate prototype technologies for weapon and munitions components and subsystems in order to ensure the capability to conduct precision attacks in GPS degraded/denied environments.

US Navy (USN) surface ships and submarines use GPS-derived positioning data for navigation, safety at sea, and for weapon guidance. The Navy is updating its GPS-based PNT capability by combining a GPS M-code receiver, precision clock, a receiver for time information from satellites, and automated celestial navigation.

Almost every USN ship currently uses the Northrop Grumman AN/WSN-7 INS. In June 2022, the service awarded Northrop Grumman a production contract for the AN/WSN-12 Inertial Sensor Module (ISM), a key component in the new AN/WSN-12, a replacement system that will occupy the same footprint as its predecessor. The ISM in intended to provide highly accurate positioning data with or without the use of GPS.

The Automated Celestial Navigation System (ACNS) is intended to allow USN operations in a GPS-denied environment by continuously determining a ship's position, and providing data that can be displayed in a ship's pilothouse, or fed directly into the ship's INS. A hardware prototype was developed under a programme begun two decades ago. This involved the design and manufacture of a single-aperture sensor mounted on an equatorial astronomical mount intended to measure the star limiting magnitude and probability of detecting stars, along with a multi-aperture strap down sensor system able to view three areas of the sky separated by 120° in azimuth using a single focal plane array. This hardware is intended to operate by day or by night. The final configuration is expected to consist of an above-deck sensor used to gather celestial data, and a fibre-optic cable that connects this to a Below Deck Unit (BDU) being integrated into Rack 1 of the ship's GPS-based Positioning, Navigation and Timing Service (GPNTS).

The USAF is developing a Resilient-Embedded Global Positioning System/Inertial Navigation System (R-EGI), which will combine an inertial sensor and a GPS M-code receiver, and be compatible with future alternative PNT capabilities. Under current plans, this will initially be fielded on its F-16 fleet.

The magnetic solution

The largest component of the Earth's magnetic field is termed the Core Field, which is responsible for the ability of a compass to point towards the magnetic North Pole. While the Core Field displays very little spatial variation, a second significant component known as the lithospheric or crustal anomaly field is mappable, making it a candidate for use as an aid to navigation. Multiple flight tests have proven the concept, and early sorties conducted at low level demonstrated accuracies of tens of metres over time-scales of hours.
Magnetic navigation is passive, and does not require its host platform to emit any form of signal. Since an unrealistically large amount of energy would be needed in order to create local disruption of the crustal anomaly field, a magnetic navigation system would be unjammable. Additionally, since it has no attackable infrastructure, it cannot be put out of action by an enemy.

In May 2023, the USAF and the Massachusetts Institute of Technology Artificial Intelligence Accelerator (AIA) demonstrated real-time magnetic navigation (MagNav) during flight trials aboard a C-17A Globemaster III transport aircraft. Flying from Travis Air Force Base, California, to Edwards AFB, California, these sorties were conducted under Exercise Golden Phoenix

This experimental MagNav system was flight tested on a USAF C-17A Globemaster III during Exercise Golden Phoenix conducted on 11-15 May 2023. [AFRL]

on 11-15 May. Improvements to the AIA's neural network architecture allowed the removal of magnetic noise generated by the aircraft, allowing the system to derive in-flight position data based on a known magnetic map.

Visual-aided INS

One possible alternative method of providing an INS with accurate positional data is to use optoelectronic sensors such as cameras and Lidar to observe nearby terrain, and compare the gathered data with a stored digital map generated by sources such as satellites or photo-reconnaissance air vehicles. This technique can involve exploiting the whole of the imagery, or by observing specific features of the scene. Terrain features such as buildings can be used as reference points, allowing the IMU-derived position to be corrected at regular intervals.

One problem with this concept is the amount of high-resolution terrain data that is needed, and the computationally-expensive algorithms required by the process of comparing this with the terrain imagery being observed. The UK company NILEQ has developed a navaid which uses imagery from neuromorphic cameras. These do not capture traditional imagery, but record changes in brightness across the sensor's individual pixels. This technique generates much less data than that created by a conventional camera.

Proprietary algorithms developed by the company use this data to create a terrain fingerprint of the tactical area, which is then compared with a stored database of terrain fingerprints that have been generated from satellite imagery. According to the company, terrain fingerprints contain much less data than a conventional terrain database, and the process of comparison requires dramatically less computation.

Although neuromorphic cameras are currently more expensive than conventional cameras, this technique allows the use of less accurate and thus lower-cost inertial hardware. NILEQ's technology is being integrated with a fibre optic-based INS to create a positioning system that could become cheap enough to be installed on low-cost drones.

The US Air Force Life Cycle Management Center (AFLCMC) Positioning, Navigation, and Timing (PNT) Program Office and Integrated Solutions for Systems (IS4S), working in collaboration with AEVEX Aerospace completed a series of six flight tests of a Resilient-Embedded GPS/INS (R-EGI) Modular Open Systems Architecture (MOSA) in early 2025. These flight tests began aboard a Special Operations Command (SOCOM) C-146A Cougar aircraft three weeks after AEVEX Aerospace successfully integrated its LynxVBN Vision-based Navigation System with R-EGI's Mission Capability Navigation (MCNAV) software.

During the airborne tests, R-EGI successfully operated in GPS-denied environments, relying on AEVEX's vision-based updates to navigate accurately. According to IS4S, even with GPS antenna disconnected from the R-EGI GPS receiver, the combined system maintained approximately 10 m of positioning accuracy for up to 2.5 hours.

Artist's visual representation of an aircraft equipped with NILEQ's navaid, which uses a neuromorphic camera to create a terrain 'fingerprint' of the tactical area. [NILEQ]

Quantum technology – a long term unjammable solution?

The position error of an INS accumulates over time and distance due to bias and drift errors inherent in the use of classical sensors. It is therefore essential to reset the indicated position at regular intervals by using an external reference, such as GPS. If inertial measurement accuracy could be increased by orders of magnitude over what is currently possible, this could allow INSs to operate as standalone navaids able to retain accuracy over long periods of time.

One promising potential solution is the creation of quantum INSs that rely on the precision and accuracy possible by measuring properties of supercool atoms. However, a quantum sensor can only operate with a sampling rate of 0.5–2.0 Hz, rather than the 300–500 Hz available from classical inertial sensors. As a result, a quantum sensor is likely to miss rapid changes in acceleration. To avoid the resulting errors, a quantum sensor can be teamed with a traditional microelectromechanical system (MEMS). A sophisticated artificial intelligence (AI) neural network based system can then be used to combine the data from both sensor systems.

In May 2024, QinetiQ conducted flight tests of an experimental quantum-inertial system. When fully developed, this technology will eliminate the gradual build-up of errors experienced with electro-mechanical inertial navigation hardware. [QinetiQ]

In May 2024, the US Defense Innovation Unit (DIU) announced a project under its Emerging Technology - Transition of Quantum Sensors (TQS) programme. This is intended to demonstrate the military utility of quantum sensors.

The problem that researchers face is that current quantum sensors are physically large, typically the size of a domestic refrigerator. Making them practical for many military applications will require a major reduction in both size and power consumption.

In May 2024, the UK announced that a team involving BAE Systems, QinetiQ, and Infleqtion (a company working on quantum technology) had completed a series of test flights of a quantum-based navigation system aboard QinetiQ's BAe 146 Airborne Technology Demonstrator aircraft. According to a member of the BAE Systems team, within five to ten years the hardware might have shrunk to about the size of a shoebox.

Hard-kill solutions

One potentially effective method of countering GPS jammers or spoofers whose position is known is an accurately delivered bomb, or several well-aimed artillery rounds, so it is hardly surprising that GPS jammers have been a potential target during the current conflict between Russia and Ukraine. In early May 2024, the USAF awarded a contract worth USD 23.5 million to Scientific Applications and Research Associates Inc (SARA) for add-on seekers able to be integrated into Joint Direct Attack Munition-Extended Range (JDAM-ER) glide and guidance kits, allowing the upgraded weapon to be used against ground-based GPS jammers. According to the manufacturer, the seeker can operate on the GPS LI and/or L2 frequencies, also Link 16, S-band, and what it coyly describes as "other bands of interest".

The contract called for deliveries to be completed by 1 October 2024, and the seekers were due to be supplied to Ukraine as Foreign Military Sales (FMS) items. In mid-March 2025 the US was reported to be preparing a new shipment of Ground-Launched Small Diameter Bombs (GLSDB) to Ukraine. These weapons were expected to incorporate an upgraded guidance system with increased resistance to Russian jamming.

The way ahead

Inevitably, there is no single or simple solution to the problem of fielding improved navaids. Perhaps the best analogy is the battle between radar and countermeasures. Jammers and other countermeasures have not made radar obsolete, but radars have not been improved to the point where they are invulnerable to jamming. While quantum-inertial systems may replace GPS in many applications, it seems unlikely that the technology can be shrunk in size and cost to the point that it can replace SATNAV-based systems in many front-line roles.

▲ The USAF Research Labs (AFRL) has flight tested the Scientific Applications and Research Associates Inc (SARA) passive RF homing head intended for use against GPS jammers. Seen here mounted on GBU-39/B Small Diameter Bombs (SDB), it is being supplied to Ukraine for use on Joint Direct Attack Munition-Extended Range (JDAM-ER) munitions. [USAF]

New tools for special operations forces

Sidney E. Dean

The intensity and diversity of special operations missions demands top-of-the-line conventional equipment as well as kit specially designed for special operations forces (SOF) requirements. While they are already among the best equipped units of any military, SOF constantly search for new or enhanced tools to provide them with the tactical advantage.

Small arms

The wide range of SOF missions requires the procurement of various weapons optimised for different engagement modes and ranges, as demonstrated by the ongoing modernisation efforts of the German Army and Navy's special operations commands – respectively the Kommando Spezialkräfte (KSK) and Kommando Spezialkräfte Marine (KSM).

Sidearms

At the shortest end of the spectrum, the KSK and KSM are replacing their current pistols with the new Walther P14 and the compact P14K. The procurement contract was announced in May 2024, with a seven year fulfilment period. It covers delivery of up to 6,500 pistols plus accessories, spare parts and training systems. The P14 is based on the Carl Walther AG's 9 × 19 mm Performance Duty Pistol (PDP). The P14/P14K's accessories include sound suppressors, compensators, red dot and laser targeting aids, as well as standard (18 round) and long magazines; these weapons are suitable for maritime environments.

Sniper rifles

At the other end of the spectrum, the KSK recently upgraded the long-range (1,200 m) G22 and G22A1 sniper rifles to the G22A2 standard. The G22A2 features a muzzle brake that cuts recoil by half, reduces trigger pull, with upgraded optical sights which accommodate a night-vision adapter. Other optional accessories include a sound suppressor, a red dot aiming aid, and a ballistic computer with integrated weather meter.

Compact assault rifle

Between these extremes, the KSK and KSM are also procuring two new firearms for short- to medium-range requirements. Heckler & Koch defines the G39 as a compact assault rifle that can be used like a submachine gun (SMG). Based on the HK437, the new "specialised suppressed SOF weapon" will have greater range and stopping power than the MP5D it replaces. It will be chambered for the 7.62 × 35 mm (.300 AAC Blackout) round. In the G39 configuration, it will have a 229 mm long barrel with a retractable stock. The G39 will be equipped with an A-TEC sound suppressor. With a mounted suppressor and fully extended stock it measures 926 mm. Empty weight with suppressor and an empty magazine is 3.3 kg. Overall, the weapon is designed to be highly manoeuvrable in close-quarters battle (CQB) scenarios, while surpassing the MP5 in open-area combat. While H&K cites a typical effective range for an SMG chambered in 9 × 19 mm at around 100 m, an assault rifle firing 7.62 × 35 mm ammunition can achieve a 300 m effective range. Procurement of a first tranche of 176 units was announced in February 2024. While deliveries will begin in 2025, total requirements call for up to 988 units overall.

German Army sniper with the G22A2 rifle. [Bundeswehr/Maximilian Schulz]

Sharpshooter rifle

The G210 is designated as the 'short-range sharpshooter rifle', which is an MR308 A6 variant that H&K developed specifically for the SOF tender of the German KSK. At a max-

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▲ **Representatives of the German defence procurement agency BAAINBw (centre) and Heckler & Koch sign the contract for deliveries of the G210. [Heckler & Koch]**

imum length of 1,010 mm (including a 425 mm barrel) and an empty weight of 4.4 kg, the semi-automatic precision-fire weapon will be suitable for various terrain and urban settings. The order of up to 500 units for the KSK and KSM was announced in August 2024. Per latest H&K statements, the precise delivery schedule is still being negotiated, but is expected to begin in 2025.

Machine gun

The United States Special Operations Command (USSOCOM) was forced to suspend its search for a new extreme-range (2,500+ m) sniper rifle in October 2024 due to budgetary constraints, but has continued other acquisition projects ranging from firearms to missiles.

This includes the Lightweight Machine Gun - Medium (LMG-M), which is designed to supplement the 12.7 × 99 mm (.50 BMG) M2 HB heavy machine gun (HMG), possessing a maximum effective range circa 2,000 m, and the 7.62 × 51 mm M240 general-purpose machine gun (GPMG), possessing maximum effective range circa 800 m, while bridging the capabilities gap between the two. The LMG-M will be chambered in 8.6 × 93.5 mm (.338 Norma Magnum). SOCOM hopes to achieve accurate fire at ranges similar to a 12.7 mm HMG but with the weight and portability of the M240. The requirement traces back to SOF experience in Afghanistan, where enemy fighters deploying non-standard PKM machine guns firing 7.62 × 54R (rimmed) munitions achieved ranges up to 1,500 m, well beyond the M240's capabilities. The new weapon is intended for dismounted SOF as well as for light vehicle and boat weapon mounts.

SOCOM initiated the LMG-M programme in 2017 to ensure future overmatch against enemy forces, and initially hoped to award contracts in the 2021 timeframe. The three remaining competitors for the contract – Sig Sauer, True Velocity (teamed with FN America), and Ohio Ordnance Works – delivered their first prototypes to SOCOM for testing in February 2024. As confirmed by SOCOM in March 2025, the Lightweight Machine Gun – Medium programme is still undergoing source selection. The command intends to make an award announcement in summer 2025.

Glide and loitering munitions

Sometimes, of course, 2,000 m is insufficient. Given the light footprint and mobility requirements for SOF, any long-range weapons must be readily portable either on foot or light vehicles.

To this end, USSOCOM is seeking industry submissions for a precision glide munition that is smaller than the GBU-69 Small Glide Munition and that can be delivered by unmanned aerial vehicles. On 18 February 2025, USSOCOM's technology incubator SOFWERX invited industry to an April 2025 assessment event "to pitch, demonstrate, and/or discuss their solutions." Subsequent evaluations by USSOCOM could lead to research and development agreements and prototype testing. The objective weapon is currently designated as the Gliding Offensive Lightweight Unmanned Munition (GOLUM). The GBU-69 is 107 cm long and weighs 27 kg, including the 16.4 kg warhead; the stand-off range is in excess of 32 km. Objective criteria for GOLUM include a maximum weight of 13.2 kg and a range of 100 km or more, with modular warhead options including airburst, impact, and penetration.

▲ **Concept image of the Hero 120SF. [UVision]**

No target date for introduction of GOLUM or an equivalent system has been made public, but SOF of various nations are acquiring other standoff weapons. In June 2024, UVision USA announced that they, together with Mistral Inc., would jointly provide USSOCOM with Hero 120SF loitering munitions under a USD 73.5 million contract. The 120SF is a modified variant of the Hero 120, and is tailored to specific requirements of special operations forces. To date, only general information regarding the modifications has been made public. The baseline man-portable Hero 120 has a 60 km range and can be launched from a hidden position. According to UVision, the 120SF's enhancements include improved payload capacity with a range of multi-purpose warheads, advanced guidance systems, and increased flexibility for deployment from various platforms. Again according to UVision, the Hero-120SF loitering munition is a mid-range system designed specifically for heavy strikes against armoured targets such as tanks, vehicles, and other hard targets, with minimal collateral damage. Deliveries are expected to be complete by 2029.

Sensors and situational awareness tools

Whether for hostage rescue, direct action or reconnaissance, SOF missions depend on situational awareness. A broad spectrum of tools are required.

Throwable sensors

The Recce360 tactical camera manufactured by Bounce Imaging is designed to capture 360° video and audio in any environment. The spherical camera can be thrown like a baseball and is designed to provide special forces with reliable situational awareness in complex scenarios such as hostage rescue and counter-terrorism operations while keeping personnel concealed. Alternatively, the device can be extended on a pole, lowered on a tether or mounted on a reconnaissance unmanned aerial vehicle (UAV) or unmanned ground vehicle (UGV).

The Recce360 is available in two variants, the Recce360 TW weighing 770 g, and the Recce360 Mini weighing 360 g. Both are equipped with six monochrome cameras arranged evenly over the sphere to ensure complete coverage regardless of how the orb lands. The system is also equipped with a microphone and speaker for two-way communications, and white light distraction LEDs which can strobe to disorient enemies before an assault. Recce360 can be remotely controlled via a tablet or smartphone app and transmit images in real-time to the operator and up to four other team members. Depending on variant, transmission range and battery endurance reach up to 123 m and two hours, respectively.

▲ The Recce 360 throwable sensor and accessories. [Bounce Imaging]

In September 2024, Bounce Imaging announced the addition of the Pit Viper 360 to the company lineup. The firm describes the grapefruit-sized device as "the world's first 360° thermal tactical throwable camera." Unlike the Recce 360 video camera which provides a secondary thermal capability, the Pit Viper combines six thermal imaging cores and an inertial measurement unit (IMU) to create a dedicated thermal video sensor.

Target reconnaissance

For reconnaissance and targeting missions, SOF can choose from various combinations of optical sensors and fire support systems. One solution is Safran Vectronix AG's Sterna True

The Safran Sterna TNF with integrated Moskito optronic device. [Safran]

North Finder (Sterna TNF), which can be paired with a number of the firm's optronic devices to provide accurate targeting coordinates. The Sterna TNF can operate in GNSS-denied environments and in all terrains including indoors. Typical applications include reconnaissance, fire control, close air support, and search and rescue (SAR).

The key capabilities reported by Safran are: determination of own position, non-magnetic true north finding, and accurate calculation of target coordinates. The base system is available in two variants designate as Sterna TNF 45 and Sterna TNF 60. Both are highly portable, with the larger TNF 60 weighing circa 3.2 kg (without the coupled optronic sensor, which can add up to 3 kg). Targeting data is reported with either CAT I or CAT II accuracy, depending on engagement distance to target and the integrated optronic device. The longest-range solution is achieved by integrating Safran's JIM LR multifunction day/night binoculars or the Moskito optical sensor atop the Sterna TNF. Both devices incorporate a laser rangefinder which achieves CAT II accuracy at 10,000 m to target. Coordinates and imagery of targets are relayed via Bluetooth.

Tunnel reconnaissance

On 10 March 2025, USSOCOM posted a request to award a single-source contract for first-person view (FPV) drones, specifically for use in tunnels, caves, and other enclosed spaces. The name of the selected vendor has yet to be released, but SOCOM has stated that only one company is capable of supplying both the required UAVs and the associated operator training. The tender is specifically geared toward SOF (Green Beret) A-Teams operating in the Central Command area of responsibility, although they could be supplied to other SOF as well. "Currently, the absence of dedicated unmanned aerial systems (UAS) for cave clearing operations forces reliance on Military Working Dogs (MWD) or partner forces, significantly increasing risk to both personnel and mission success," SOCOM stated in the request. "Caves present confined, complex spaces with limited visibility and unpredictable terrain, increasing the danger to personnel and potentially hindering MWD effectiveness."

The precise nature of the UAVs to be acquired remains unknown. Fibre-optic cable-guided drones would provide the greatest assurance of unimpeded real-time feedback, since the conditions inside caves and tunnels can interfere with wireless relays from autonomous UAVs. Israeli forces, in particular, have gained considerable experience operating FPVs in extensive labyrinthine tunnel systems which harbour multiple opportunities for booby traps and ambush.

Mobility systems

Maritime SOF have special requirements for covert underwater insertion. In addition to swimmer delivery vehicles (SDVs), this includes personal swimming aids such as Patriot3's Jetboots Diver Propulsion System. According to the producer, the system is in use by forces in 25 nations, including the US Navy, US Marine Corps, and US Army SOF units. In April 2022, USSOCOM ordered additional units via a USD 10

A USMC Reconnaissance specialist prepares to dive wearing Jetboots strapped to his thighs. [USMC/Alexis Betances]

million indefinite-delivery/indefinite-quantity (IDIQ) contract with an ordering period of up to five years.

The system's propulsion battery and control device are strapped around the diver's waist with a belt, and connected by cables to the two thrust nozzles which are fastened to the diver's thighs; the adjustable nozzles are driven by direct current motors with low noise levels. The system allows for speeds of up to 7.2 km/h (3.9 kn) and work down to a maximum diving depth of 92 m. The lithium-ion battery stores sufficient energy for up to six hours of operation, with the actual operational duration depending on the speed.

▲ **The Gladius 2.0 Flex networking system includes an end user device for display and exchange of tactical information. [Rheinmetall]**

Similar to a water sled or scooter, Jetboots reduces the risk of exhaustion during the covert approach of the combat swimmer, while significantly increasing speed and range. Unlike the diving sled, the swimmer has both hands free to manipulate objects or to handle and use weapons and sensors. Mobility and responsiveness are also better compared to water sleds. Jetboots can be integrated with the Dive Tablet 2 device and DiveLog navigation software from Shark Marine Technologies. This allows the diver to continuously monitor battery strength, remaining distance and estimated time of arrival at the target, as well as the current position and water depth via ruggedised tablet.

Protective gear

SOF must deploy prepared for a wide variety of developments without overburdening themselves with equipment. Specifically with regard to protective gear, they must find a balance between force protection and agility. In February 2025, Avon Protection introduced the MITR-M1 half mask as protection against low-to-mid-level respiratory threats. Advantages over full-face counter-CBRN respirators include lighter weight, portability in a pocket or standard pouch. It is designed to work with helmet-mounted retention clips to allow the user to don the mask without removing their helmet. The filter can be worn to either the left or right to minimise interference with weapon sighting. According to Avon, the MITR-PF Compact Particulate Filter used in the mask provides 99.97% filtration efficiency.

The half-mask design is intended to not interfere with other gear such as goggles or night vision goggles (NVGs). Additionally, Avon is developing the MITR-PG1 Powered Goggle to augment the mask. This is essentially a ballistic visor with integrated filter and blower system to continually purge the air within the goggle, to protect the eyes and to prevent misting.

Connectivity

Connectivity of personnel within a deployed SOF unit, and between the unit and headquarters or other military formations, is a force multiplier. Networking is increasingly becoming indispensable, with highly capable systems seeing increasingly adopted for SOF by numerous users.

One example is the Gladius 2.0 Flex system, an SOF-specific variant of Rheinmetall's Gladius 2.0 soldier system. Specifically, Flex is based on the Gladius 2.0 Light variant developed for light infantry and includes the Light base kit consisting of a lightweight plate carrier with scalable ballistic protection, a voice and data radio with integrated GPS-based blue force tracking, a wired/Bluetooth headset for voice communications, and the end-user device which can be either a ruggedised tablet, smartphone or smartwatch capable of displaying tactical maps and exchanging tactical information. Flex adds specific components to support SOF requirements.

As defined by Rheinmetall, this begins with a Smart Hub which integrates the additional components and provides energy and data management for the Gladius 2.0 Flex system. Rather than requiring each system component to have its own batteries, Flex subsystems are powered from a central battery core to simplify logistics. A day/night vision capable helmet-mounted heads-up display uses augmented reality (AR) to display important information. Finally, cable access can connect the soldier system directly to a vehicle, enabling access to power supply, data exchange, vehicle communication, sensors and effectors.

While Rheinmetall's Gladius system has been procured by the German armed forces, similar networked systems are being acquired or developed by numerous armed forces. As high-priority elements, SOF will continue to adapt new technologies that will enhance the situational awareness and communications capabilities which are vital to their success and survival in the field.

Patria's FAMOUS ATV tracked vehicle breaks cover in the Arctic

Mark Cazalet

Patria unveiled a functional prototype of their new FAMOUS ATV tracked platform for the first time, during a 19 March 2025 live fire demonstration at the Rovajärvi firing range, in the northern Finnish region of Lapland.

Patria's new tracked platform is being developed under the joint European Future Highly Mobile Augmented Armoured Systems (FAMOUS) programme, and while it currently does not have an official name yet, it is being referred to by the working title 'FAMOUS ATV' (All-Terrain Vehicle).

A concept demonstrator of this vehicle was previously shown at Eurosatory 2024, however this version was shown with the running gear covered up, and relatively few technical details provided. Now, Patria has shared far more information on what the final version will end up looking like. However, Patria emphasised that the vehicle shown was still a functional prototype, and some differences may end up emerging on the final production version. Indeed, the version shown was just 25 days old at the time it was unveiled. In terms of the timeline ahead, Patria stated that the vehicle was due to be launched as a product at the DSEI 2025 exhibition, and planned to be ready for serial production in 2027.

A first look at Patria's new tracked platform, the FAMOUS ATV. [Mark Cazalet]

Diving into the details

During the live fire demonstration, ESD was provided with more details on the platform from Timo Mennala, the Programme Director for Tracked Vehicles at Patria.

The base platform is 7.2 m long, 2.9 m wide, and 2 m high, and has a nominal ground clearance of 0.55 m. Vehicle weight is dependent on configuration and armouring options selected, but the baseline light armoured APC configuration is notionally intended to run at an empty weight of 11.5 tonnes, with useful payload capacity of 3.5 tonnes, for a total permissible combat weight of 15 tonnes. Regarding how this weight would be used for different configurations, Mennala said that the APC configuration would be expected to sit at a combat weight of 15 tonnes. According to Patria, the vehicle is rated for operating in temperature conditions from -46 °C to +44 °C.

In terms of arrangement, the platform has a front-mounted engine and the driver and commander's compartment directly behind, with the dismount/payload compartment taking up the middle and rear. In the APC configuration, the vehicle seats two crew and 10 dismounts. The driver and commander sit side-by-side at the front, each is provided with a door for access and egress, the commander is also provided with a forward-opening

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View of the rear portion of the FAMOUS ATV, showing dismount compartment door and communications antenna on the hull roof. [Mark Cazalet]

each roadwheel, and allowing the vehicle to adjust its ground clearance from the cab.

Mennala noted that the company opted for a hydro-pneumatic suspension system over torsion bars, because in relative terms the former provides weight savings, along with greater ground clearance, and for allowing clearance adjustment to suit different terrain types. Mennala added that at this stage, the company was testing several hydro-pneumatic suspension systems available on the market, and was also developing such suspension elements with its partners as part of the FAMOUS programme.

single-piece roof hatch, while the driver is provided with a yoke for steering, as well as front and rear cameras – on the production version of the vehicle, these will be day and night capable. The dismounts are seated facing each other in blast-attenuating seats, in an arrangement typical on modern APCs, and provided with a simple door for access and egress.

he Patria FAMOUS ATV is fitted with a Caterpillar 7.1, 7-litre in-line six-cylinder engine, developing 269 kW (360.7 hp), coupled to a Renk HSWL076 automatic transmission. The engine is also provided with a pre-heater for operating in extreme cold conditions. The running gear comprises the drive sprocket at the front, idler at the rear, with six dual rubber-tyred roadwheels and two return rollers, along with Soucy composite rubber tracks (CRTs). For preventing buildup of mud, grit, and snow on the tracks, the vehicle is fitted with track cleaners mounted directly behind the drive sprocket. The suspension system used is a hydro-pneumatic system, providing independent travel at

In terms of mobility characteristics, Mennala stated that the vehicle speed requirement was 80 km/h, but that this had been exceeded, with speeds of 88 km/h recorded under good conditions. The vehicle's range is 600 km on its primary fuel supply, and is also capable of overcoming gradients of 60% (31°), as well as crossing trenches up to 2 m wide. The vehicle is also amphibious with a short preparation (according to Mennala, it takes "just a few minutes" for the crew to prepare the vehicle), and has a swim speed of 4 km/h, propelled in the water by its tracks.

As a relatively lightweight platform with fairly wide tracks at 550 mm, the vehicle achieves a very low ground pressure of 32 KPa (0.326 kg/cm2), allowing it to navigate soft soils, boggy terrain, and snow with relative ease. To put this figure into context, the Russian DT-30PM articulated tracked vehicle, often used as an extreme example of engineers prioritising very high off-road mobility in soft terrain types, has a ground pressure of 29.43

A close-up view of the running gear showing the hydro-pneumatic suspension system, and track cleaner behind drive sprocket. [Mark Cazalet]

Kpa (0.3 kg/cm2). Of course, DT-30PM achieves this largely due to having extremely wide tracks, at 1,100 mm in width per track. Yet overall, the FAMOUS ATV's ground pressure is very close to one of the most extreme offroad military vehicle designs available today. To compare the FAMOUS ATV to an older vehicle in the same class, the MT-LB had a combat weight of around 11.9 tonnes, and used 350 mm wide steel tracks, resulting in a ground pressure of 45.1 KPa (0.46 kg/cm2).

In terms of navigation systems, the prototype shown by Patria was fitted with a global navigation satellite system (GNSS) transceiver, however, Mennala noted that "in this stage the role of GPS is more of testing purposes to collect all possible data and location information. In the near future [the] vehicle will have more advanced INU [inertial navigation unit] and geographic information systems."

In terms of protection, the basic vehicle is rated at a STANAG 4569 Level 1 ballistic and Level 1 mine protection, with an option to go up to Level 2 ballistic protection. However, opting for the higher protection rating would somewhat eat into the vehicle's available payload capacity, which could limit some armament or payload options. According to Mennala, the vehicle can also be fitted with NBC protection if required.

In terms of armament, the prototype vehicle demonstrated was armed with a KNDS France 20 M 621 20 mm automatic cannon, mounted on a SIMA Innovation RM-750 ring mount, with the optional gunner protection kit fitted. However, Mennala noted that multiple different armament options could be accommodated, adding that the NEMO 120 mm mortar turret (weighing 1.2 tonnes) could be mounted, thus giving an approximate indication of the class of turret which would be feasible on this design. Though due to their typical lower weight, and lack of turret basket, remote turrets would be seen as a likelier candidate than manned turrets.

In this vein, and in terms of expectations for the most likely initial candidates for armament solutions, it is worth noting that Kongsberg Defence & Aerospace is both a 49% stakeholder in Patria, a participant in the FAMOUS 2 programme, and has multiple products in its portfolio which would work on this class of platform. Indeed, the FAMOUS ATV demonstrator shown at Eurosatory 2024 featured a Kongsberg remote weapon station (RWS) armed with a M230LF 30 mm automatic cannon along with what appeared to be a 7.62 mm machine gun.

The FAMOUS ATV in context

Having run through its essential characteristics, it is important to explain what this platform is and what it is not. The FAMOUS ATV is not intended to be a medium-weight armoured vehicle geared toward frontline direct fire combat. Rather, it is a lightweight tracked platform which can be used for many different light roles, where the superior terrain trafficability characteristics of tracks over wheels are required. Typically this would mean any role where the vehicle would be expected to spend an extended time operating in soft soils, boggy or swampy terrain, as well as deep snow.

It can perhaps best be thought of as a spiritual successor to the venerable Soviet MT-LB, developed by the Kharkiv Tractor Plant in Ukraine, and in use with the Finnish Armed Forces; or to a lesser extent, the US FMC M113 platform. The M113 and MT-LB first entered service in

A close-up view of the SIMA Innovation RM-750 turret, shown here armed with KNDS France's 20 M 621, a 20 mm automatic cannon. [Mark Cazalet]

View of the left-hand side of the FAMOUS ATV. [Mark Cazalet]

1960 and 1964, respectively, and since then have been adapted into a truly staggering variety of roles. However, since that time, there arguably hasn't been anything similar available to the West, with the majority of tracked vehicle development efforts focussed on either the medium-weight segment typically occupied by IFVs (such as CV90, ASCOD, KF41), or within the articulated tracked vehicle segment (such as BvS10, Beowulf, and Bronco). By comparison, developments focussed on the light tracked platform segment have been very thin on the ground over the last few decades, with a slight exception to this seen in the unmanned ground vehicle (UGV) segment.

While the vehicle shown was notionally configured as an armoured personnel carrier (APC), both MT-LB and M113 were adapted to dozens of different roles by their many users, including command and control (C2), artillery forward observer, very short-range air defence (VSHORAD), electronic warfare, anti-tank missile launcher, mortar carrier, engineering, and various others, demonstrating what is possible for a platform of this class.

As a lightweight tracked platform, FAMOUS is also expected to be significantly cheaper to procure and maintain compared to most typical medium-weight tracked vehicles. The use of Soucy CRTs helps matters further here, by decreasing maintenance requirements compared to steel tracks, both through their longer lifespan between track changes, and through their vibration-damping qualities, which help reduce vibration-related wear and tear on many sensitive vehicle subsystems. Additionally, being lighter than steel tracks, CRTs decrease the unsprung mass of the vehicle, which also provides further savings in the form of lower fuel consumption.

Trending toward commonality

For the FAMOUS (study phase) and FAMOUS 2 (development phase) programmes, Patria has acted as the coordinator for a large industrial consortium of companies from many different countries. Table 1 shows all participant countries and companies within both the European Defence Industrial Development Programme (EDIDP) FAMOUS programme (at a cost of EUR 9.9 million), and the follow-on European Defence Fund (EDF) FAMOUS 2 programme (with an estimated total cost of EUR 122.4 million):

TABLE 1

FAMOUS/FAMOUS 2 Programme Participant Summary

Country	Companies
Finland (lead country)	Patria (Industrial coordinator) FY-Composites Millog Savox Communications Spinverse
Austria	AVL List (FAMOUS 2 only) Steyr Motors Betriebs (Initially joined FAMOUS 2, but then opted out)
Belgium	John Cockerill Defense
Denmark	Integris Composites
France	Arquus KNDS France
Estonia	Cybernetica (FAMOUS only)
Germany	Diehl Defence DST Defence Tracks (FAMOUS only) FFG (FAMOUS only) KNDS Deutschland (FAMOUS only)
Greece	ISD
Latvia	LMT
Norway	Kongsberg Defence & Aerospace (FAMOUS 2 only)
Spain	EM&E Indra Sistemas Piedrafita Sport

View of the right-hand side of the FAMOUS ATV, showing crew compartment. The GNSS antenna housing is visible on the hull roof, just forward of the turret. [Mark Cazalet]

With the FAMOUS ATV, Patria looks set to continue its collaborative approach when it comes to enabling procurement. Looking back over several major milestones, the company secured licence production agreements for their AMV 8×8, most notably with Poland who manufactured the vehicle as the Rosomak, and more recently exemplified by the CAVS programme to procure the Patria 6×6.

With regards to similarities between the CAVS and FAMOUS programmes, ESD spoke to Jukka Holkieri, Patria's Executive Vice President, Global Division. Holkieri noted: *"FAMOUS is the name for the development program, which has also EU money in it, and in our part of this, it materialises on this new armoured tracked vehicle. And obviously what we have seen is, is that the CAVS model seems to work very well. So we ask ourselves, and we ask countries, 'how about doing something similar for the for the track vehicle as well'? Whether it would be within the CAVS, or whether it would be kind of 'CAVS 2', or whatever it could be called, but kind of copying the CAVS model for procurement, also to FAMOUS. CAVS is also a development program. There is, there are these different variants and packages in the R&D*

Frontal view of the FAMOUS ATV. [Mark Cazalet]

agreement. So in that sense, FAMOUS is a little bit different, because it started as a broad development program, whereas CAVS had very few nations to start with, and now it's getting wider, but once we get into the procurement part and the production part, and then the life cycle support part, which is also, by the way, very important, I think the CAVS model could be copy/pasted there, but maybe [with] some modifications, of course."

With regards to some of the key advantages offered by commonality, Holkieri stressed: *"I wanted to take especially the life cycle part, because defence equipment is bought and then it's used for 30 years or even more, and there are several upgrades in that, and you need to take good care of it, not even in peace time, but not to mention the possibility to repair it in in war time. So if that can be done together, that's also a major driver, especially now that in NATO, we are again facing this [threat]. If we are having joint logistics for the same vehicles or same whatever, that helps a lot the warfighting also, and we can different nations, different armies can get support from other countries, units which may be closer by armies, we might have some capability, or some spares that we don't have ourselves. So it's, it's not only the production part. I want to stress that."*

Commonality would certainly seem to be a logical approach for a vehicle in the FAMOUS ATV's class, when considering the potential for different variants. The main drivers behind M113 and MT-LB spawning so many variants in so many different roles was their relative simplicity, and low cost, which allowed them to become near-ubiquitous with NATO and Warsaw Pact armed forces respectively. The FAMOUS ATV looks to be driving into much the same territory, at a time when almost no competitor models in this class exist.

In conjunction with its lack of competitors in its class, there are two other factors worth noting which look likely to work in the FAMOUS ATV's favour regarding adoption. Firstly, this is a European project which is coming to fruition at exactly the same time as Europe's defence spending taps are opening, and where European solutions look to be favoured over US solutions. Secondly, since FAMOUS is a collaborative project, it has generated a large number of stakeholders across many European countries, with a vested interest in helping to push the product forward, at a time where the EU is looking to promote greater defence-industrial cooperation. In sum, this very much looks to be a vehicle whose time has come.

Marketing Report: EVPÚ Defence

Czech defence solutions gain attention in Asia

EVPÚ Defence, a Czech specialist in defence and security technologies, is seeing increasing demand for its systems in Asian markets. To strengthen its regional presence, the company will participate in several major trade fairs in 2025, including DSEI in Japan, Indo Defence Expo & Forum in Indonesia, and Defence and Security in Thailand. This presents an opportunity to build new business relationships and showcase the technological capabilities of European defence solutions globally.

EVPÚ Defence has developed advanced systems to meet the evolving need of armoured vehicle capabilities and equipment. Notably, the GLADIUS range of remote-controlled weapon stations can be integrated with various weapon systems, including a 7.62 mm machine gun, a 12.7 mm machine gun, 40 mm grenade launchers, and a 30 × 113 mm cannon with programmable ammunition.

The GLADIUS systems are compatible with a wide range of mobile or fixed platforms and feature an electro-optical sight equipped with a high-quality thermal imaging camera, essential for low-visibility conditions. The sight operates independently of the gun carriage, allowing effective tracking of fast-moving targets and more precise engagements, particularly in complex environments. These features enhance flexibility, efficiency, and safety on modern battlefields.

The GLADIUS remote weapon station. [EVPÚ Defence]

Another highly sought-after system is the LAWAREC laser and radar irradiation detection system, which detects and locates the emissions of laser and radar sources. Upon identifying a threat, LAWAREC alerts the vehicle crew, indicates the threat's direction, and suggests countermeasures like firing smoke grenades to disrupt enemy targeting. The system can provide comprehensive perimeter coverage.

The next opportunity to meet the EVPÚ Defence team and learn more will be at the DSEI exhibition (stand H5-170) in Chiba, Japan, from 21-23 May 2025.

The increasing necessity of SHORAD

Chris Mulvihill

Increasingly, militaries are pursuing short-range air defence (SHORAD) solutions to prepare for an era of near-ubiquitous unmanned aerial vehicles (UAVs) and loitering munitions, as well as dealing with the continued proliferation of cruise missiles, and rapidly evolving battlefield dynamics.

With concerns over the development of hypersonic weaponry and the introduction of more types of stealth aircraft from new players, it is easier to overlook short-range air defence (SHORAD). As the war in Ukraine illustrates, the ability to counter low-altitude threats – unmanned aerial vehicles (UAVs), loitering munitions, low-flying aircraft and rotorcraft, and cruise missiles – has arguably become more critical than ever before. SHORAD fills in the gap between longer-range and more costly surface-to-air missile (SAM) systems, dealing primarily with the immediate threats that can slip through their defensive coverage. This article explores why SHORAD matters, its evolving role on the battlefield, and the solutions reshaping its future – from truck-mounted cannons to experimental lasers and UAV solutions.

Understanding SHORAD

While some states may not face threats necessitating long- or medium-range air defence systems, they must still be prepared to counter low-altitude threats such as UAVs, loitering munitions, low-flying aircraft, attack helicopters, and cruise missiles, making short-range defences a fundamental necessity. Although threats are numerous at this layer of the air defence umbrella, they do not require the same complex solutions wielded by long- or medium-range systems. As such, SHORAD systems can encompass various types, including man-portable air defence systems (MANPADS), radar- and/or optoelectronically-guided medium-calibre cannons, short-range SAMs, directed-energy weapons, or a combination of one or more of these. It should be noted that traditionally, MANPADS and cannons have been grouped into the very short-range air defence (VSHORAD) category, but are also covered here as their target set overlaps heavily with that of SHORAD.

When employed effectively against certain targets, SHORAD can reduce the consumption of more expensive medium- and long-range SAMs. Short-range air defence weaponry can prove effective against threats including loitering munitions and cruise missiles. The use of MANPADS by Ukrainians has been observed in social media footage in areas surrounding Kyiv, against cruise missiles and one-way attack (OWA) drones such as the Shahed family.

The Ukrainians emphasised the high value they place on having a large quantity of MANPADS distributed to mobile air defence squads. Their use against cruise missiles, OWA drones, and other threats helps preserve Ukraine's smaller stockpiles of high-end, costly munitions for systems such as PATRIOT or IRIS-T SLM. Local modifications to Stinger launchers have also enhanced operators' ability to target aerial threats at night, further bolstering their effectiveness. Ukrainian representatives have often highlighted the struggle to procure or secure donations of MANPADS, despite Ukraine's willingness to accept virtually any type of these systems including systems originating from either European or NATO states.

The Serbian PASARS-16 is a local SPAAG design that is armed with a single 40 mm L/70, can be equipped with indigenous Strela developments and there is a local effort to integrate the recently-purchased Mistral 3ER MANPADS. [Serbian MoD]

Additionally, an appeal has been made by Ukrainian representatives to increase MANPADS production. Despite such calls, the US Army only anticipates Stinger production to rise to 60 missiles per month by this year. Restarting production for a legacy system presents challenges, as many subcomponents are no longer manufactured, necessitating a partial redesign to integrate newer, available components. However, 60 Stingers per month falls short of expectations, especially when considering that these units are also divided between exports to allied countries and domestic consumption in the US.

An increase in conventional SHORAD assets such as MANPADS and anti-air cannons can alleviate excess expenditure of high-end medium-range solutions such as IRIS-T SLM. [Diehl Defence]

Protecting Mobile Assets

The freedom to manoeuvre largely depends on safeguarding mobile units from aerial attacks, both from conventional and evolving threats. This is where the roles of counter-unmanned aerial vehicle (C-UAV) systems and SHORAD converge. Given that 'C-UAV' is still a relatively new term in the defence nomenclature, one potential distinction is that while SHORAD encompasses defence against a wide variety of threats, including UAVs, C-UAV focuses exclusively on UAV defence. However, some C-UAV solutions could double as VSHORAD/SHORAD systems, and vice versa.

For SHORAD, the need to provide coverage for mechanised units is not a new concept. However, defence budgets and manpower are both challenging constraints to navigate. While self-propelled anti-aircraft guns (SPAAGs) have traditionally been a vehicle subclass tasked with accompanying and protecting mechanised units, they have historically relied on tracked platforms – often the only type capable of accommodating heavy twin-gun anti-aircraft turrets. In many cases, these platforms were either unique or adapted from designs distinct from the vehicles they were intended to protect. Even the well-known Gepard, while sharing nearly all of its automotive components with the Leopard 1, is technically not the same hull, being approximately 8 cm longer due to a gap between the third and fourth roadwheels.

For modern armoured fighting vehicles (AFVs), there are already standalone products designed for integration onto various tracked and wheeled platforms, offering organic SHORAD solutions. Modern anti-air turrets are often significantly lighter than the turrets of the 1990s and earlier, typically featuring a single cannon with additional missiles as secondary armament, along with an unmanned turret. Furthermore, some are exploring the use of standard AFV armaments for SHORAD purposes. With the proliferation of programmable air-burst rounds for medium-calibre weapons, there is theoretical potential for armaments originally designed for ground targets to also employ suitable ammunition and competent fire control systems (FCSs) to track and engage aerial targets. As SHORAD and C-UAV roles increasingly overlap in addressing UAV threats – and as such threats proliferate across the battlefield – organic solutions may be trialled and refined, with an emphasis on leveraging readily-available resources rather than relying on bespoke designs.

Mobility and Flexibility

While Ukraine inherited a significant quantity of Soviet-era air defence equipment, being the second-largest country in Europe (after Russia) presented many challenges. Securing the airspace for its many population centres, military installations, and pieces of critical infrastructure requires many assets.

Ukraine has also sought unconventional SHORAD methods by creating a quick-reaction force armed with heavy machine guns and MANPADS that dismount from civilian pickup trucks at locations estimated to provide the optimal interception point for incoming OWA drones. [Ukrainian MoD]

During defence conferences, Ukrainian representatives have expressed that the fundamental question air defence planners must address is what their systems need to protect, and in what concentrations. How far can you spread your air defence systems without creating gaps that allow enemy aerial manoeuvre? How do you counter an enemy concentrating a cruise missile attack on a single defended target, overwhelming nearby air defence systems while those deployed elsewhere remain idle?

As is often inherent in defence, the attacker typically holds the advantage of choosing the time and place for an action, leaving the defender to anticipate a range of possibilities and distribute their systems accordingly. However, defenders can gain an edge by detecting the aggressor's actions early, analysing what is likely to occur and what is required to counter it, and, in the case of air defence, deploying mobile systems that can be swiftly repositioned to meet evolving threats. This hinges on establishing a rigorous command-and-control (C2) network that integrates various sensor inputs, automatically classifies threat information, and rapidly relays targeting data to mobile air defence assets on the ground. To be effective against multidirectional and numerous threats along a wide front, SHORAD air defence systems must be mobile.

From SPAAGs to turrets

It is increasingly rare to encounter SPAAG platforms being marketed as standalone platforms. In truth, such a distinct class of vehicle is no longer purpose-designed as it once was. Largely due to advances in designing lighter weapons and sensors, standalone air defence turrets have become a common SHORAD solution, offering versatility by enabling integration onto user-defined wheeled and tracked vehicles without extensive redesign work.

Rheinmetall's Skyranger 30 and 35 standalone turrets are ready VSHORAD solutions that can be fitted onto a variety of in-service vehicles. The Skyranger 30, chambered in 30 × 173 mm, offers a gun- and missile-based air defence turret weighing between 2.5 and 3.4 tonnes, depending on ballistic protection. Rheinmetall Air Defence claims an effective range of 3 km for the KCE cannon, with a cyclic rate of fire of 1,200 rds/min, although it should be noted that the turret has a capacity of 252 ready rounds. It demonstrates advancements in gun design, surpassing the Gepard's 1,100 rounds per minute with its twin 35 mm Oerlikon KDA cannons.

The cannon also supports the proprietary Advanced Hit Efficiency And Destruction (AHEAD) ammunition, marketed for its C-UAV capability. This munition is time-fuzed, and the way it works is that the round's muzzle velocity is first measured as it has nearly left the barrel, by a sensor close to the muzzle. When the projectile velocity data is combined with data on the target's range, heading, and speed being continuously collected by the turret's optoelectronic or radar sensors, the FCS is able to calculate the time at which the round should initiate for optimal effect at the predicted impact point. This timing data is then programmed into the projectile using an electromagnetic induction programmer located at the end of the muzzle brake; during this process, the round also harvests a small amount of energy from the electromagnetic induction programmer to run the round's on-board electronic timer. The round then leaves the barrel and continues toward its point of aim. Once the electronic timer reaches zero, a small pyrotechnic charge initiates, which pushes the ballistic cap off the round. With the remainder of the round exposed, its payload of numerous tungsten sub-projectiles are dispersed in a spiral pattern toward the target. Dispersal occurs through the centrifugal force of the round spinning (since it is fired from a rifled barrel), rather than explosive force. Numbers of sub-projectiles vary depending on the precise variant of AHEAD used.

Aside from AHEAD, the Skyranger 30 can house a missile pod accommodating up to two MANPADS-class missiles, such as Stinger or Mistral. Following a July 2025 agreement between Rheinmetall Electronics and MBDA Deutschland, an option for pods containing up to nine Small Anti-Drone Missiles (SADMs) is also available.

▲ The Skyranger 30 offers a standalone solution that is unmanned, with the crew located under the turret inside the host vehicle platform. [Rheinmetall Air Defence]

▲ The Skyranger 35 trades missiles such as the Stinger for a cannon-only solution, using the same KDG 35 mm cannon as used on the semi-mobile Skynex system. [Rheinmetall Air Defence]

The Skyranger 35 offers a VSHORAD solution for armies that may prefer the greater range and payload of 35 × 228 mm rounds. This has typically been offered as a cannon-only solution, and can be considered a mobile version of the Skynex system, with which the Skyranger 35 shares its armament. The Skyranger 35 carries the same 252 ready rounds as the Skyranger 30, however the larger KDG cannon provides an effective combat range of 4 km, though this comes at the cost of a heavier turret, weighing around 3.8-4.7 tonnes depending on ballistic protection. Thus far, the Skyranger 35 has not attracted explicit interest. By contrast, the Skyranger 30 has secured orders from Austria, Denmark, Germany, and the Netherlands, mounted on various vehicles, including the Pandur EVO 6×6 for Austria and the tracked Armoured Combat Support Vehicle G5 for the Netherlands.

The reemergence of truck-based SPAAGs

Mounting air defence cannons on trucks is hardly a new concept, but it is a vehicle type experiencing a resurgence of interest, with several manufacturers offering designs based on truck platforms. A likely motivation is cost reduction, achieved by using militarised commercial trucks as base platforms for air defence turrets derived from static or naval systems.

BAE Systems Bofors launched the Tridon Mk2 air defence system at Eurosatory 2024. This system combines the 40 mm Bofors 40 Mk 4 naval turret with a 6×6 Scania G 460 truck chassis. The 'Mk2' designation harks back to a 1990s project that explored a similar concept, featuring variants such as a basic, unprotected Bofors 40 mm L/70 cannon mounted on a Volvo 6×6 all-terrain wheeled vehicle comparable to the Volvo A30D used with the Archer self-propelled howitzer (SPH). Unlike the Mk1's more bespoke chassis, the Tridon Mk2 employs what is essentially a commercial truck for military use. It is equipped with a Chess Dynamics Hawkeye Air Defence optoelectronic sight but lacks an onboard radar detection or tracking system, relying instead on networked data from external assets. A BAE Systems Bofors spokesperson noted that while the turret closely resembles its naval counterpart, the land version includes increased roof armour, despite being unmanned. Its lethality, particularly for the C-UAV role it is marketed for by BAE Systems Bofors, stems from the option of using the 40 × 365R mm (rimmed) 3P programmable ammunition. This round, programmed by induction, offers six modes that are selected based on the target, and include impact, timed, and proximity modes.

Beyond the Tridon Mk2, other manufacturers have also pursued truck-based air defence designs. Serbia's PPT Namenska continues to develop the PASARS-16, which also uses BAE's 40 mm L/70 with the option for 3P ammunition. Unlike the Tridon Mk2, the latest PASARS-16 iteration incorporates RADA's S-band multi-mission hemispheric radar for target detection. Aselsan has showcased a similar concept with its Göker turret (also referred to as the KORKUT 110/35S), armed with a 35 mm cannon, and mounted on a 4×4 truck platform. This 35 mm cannon, essentially a domestically produced Oerlikon GDF by Makine ve Kimya Endüstrisi, is paired with the locally-designed ATOM programmable air-burst ammunition that works similarly to Rheinmetall's AHEAD.

As a candidate for the UK's land ground-based air defence programme, Moog Inc. has offered Reconfigurable Integrated-weapons Platform (RIwP) with the Supacat High Mobility Transporter 6×6, alongside another RIwP application onto KNDS Deutschland's Dingo 3. The RIwP is a modular frame that supports various weapon systems, including machine guns, medium-calibre cannons, automatic grenade launchers, and missiles. Displayed at the IAV 2025 conference in January, the turret featured a single 30 × 113 mm M230LF cannon alongside eight Starstreak High-Velocity Missiles. An open day in late February 2025 highlighted the option to integrate two Brimstone missiles, reducing the Starstreak count to four – a tease on a potential British take on the US Maneuver-Short-Range Air Defense (M-SHORAD).

The Tridon Mk2 offers a flexible solution, being able to use various base platforms depending on the customer requirements. [BAE Systems]

▲ **Supacat HMT with the Moog RIwP turret armed with a 30 mm cannon, Starstreak, and Brimestone. [Supacat]**

This US vehicle is likewise equipped with a RIwP turret, and armed with an XM914 30 × 113 mm cannon (a variant of M230LF which supports programmable air-burst munitions), a pod of four Stingers and a separate pod of two AGM-114L Longbow Hellfire missiles. The Hellfires are gradually being withdrawn in favour of a second pod of four Stingers. Allegedly, the Hellfires did not fare well due to environmental degradation endured while being mounted on exposed launch rails.

Through broader observation, many forces are increasingly favouring wheeled vehicles, with smaller and medium-sized forces in Europe increasingly seeing a higher proportion of their new armoured platforms being wheeled rather than tracked. Consequently, the adoption of truck platforms in SHORAD may reflect a wider trend as forces retire legacy tracked platforms and invest in new wheeled systems. These platforms, while optimised for road networks and requiring less maintenance than tracked vehicles, do not necessarily need to possess the same offroad characteristics as tracked vehicles if the mobile assets they may accompany are also wheeled.

Experimental and alternative solutions

High-energy laser (HEL)-based air defence systems have been in development for decades, yet progress towards a mobile solution remains incomplete in most projects. The closest to entering service for ground applications is Rafael's Iron Beam-M (with 'M' denoting Mobile), with Rafael Advanced Defense Systems as the prime contractor. This laser boasts an output power of 50 kW and is primarily marketed for the C-UAV role. Compared to the static 100 kW Iron Beam, the mobile variant is believed to be a large system requiring multiple vehicles, including the laser weapon vehicles themselves, a command-and-control (C2) post, and possibly also a dedicated surveillance radar, and potentially one or more mobile generators.

While the range of Iron Beam-M is not publicly disclosed, the lighter 10 kW Lite Beam also from Rafael, and designed for integration with vehicles as small as 4×4s, has a stated maximum range of 3 km. Given that the 50 kW class Iron Beam-M would be expected to possess roughly double this range, this would theoretically provide a feasible VSHORAD solution, but with unknown purchase and maintenance costs, and considering the system's reliance on multiple vehicles and a crew of at least a dozen personnel, its practicality remains questionable. Lite Beam offers a more attractive solution, being a standalone vehicle, however with such ranges, it can only be envisaged as potentially being suited against Class I or Class II UAVs, while Iron Beam could offer defence against larger Class III UAVs as well as OWA UAVs and cruise missiles. As prevailing opinion holds, Naval vessels may be the most likely first adopters of laser-based air defence systems, given they are capable of supplying substantial electrical power and already equipped with integrated sensors such as radars.

It is impossible to overlook the experimentation, both planned and impromptu, conducted by Ukrainian forces amid persistent shortages of air defence assets. Widely publicised as of writing, the Magura V5 unmanned surface vehicle (USV) has seen adaptation for air defence with a repurposed R-73 air-to-air missile (AAM) functioning as a SAM. This has disrupted the routes of Russian aerial assets, such as low-flying aircraft and helicopters, which could previously traverse the Black Sea or Sea of Azov with relative impunity in comparison to flying over the mainland. Repurposing the R-73 is not unprecedented but pairing it with the Magura V5 USV at sea, possibly leveraging a more abundant older

▶ **A scale model of Iron Beam-M displayed at AUSA 2024. The beam director and four fixed-face DRS RADA nMHR radars are visible on the roof of the rear module [Mark Cazalet]**

munition, offers a potentially effective area-denial solution. At least one successful hit has been confirmed by the Ukrainian state, with a Russian Mi-8 helicopter shot down in 2024 being attributed to a R-73-armed Magura, with another possibly damaged. While these missiles, originally designed for air-to-air combat, will have lower effective ranges when launched from the ground, nonetheless their deployment has likely complicated Russian route planning and forced higher operating altitudes.

Deliberate or spontaneous attempts to use first-person view (FPV) UAVs to down helicopters have also been documented. At least one instance, shared in August 2024, allegedly showed a UAV striking the tail rotor of an Mi-28 helicopter. The outcome remains unclear to the public, as does whether the UAV was equipped with a specific defeat mechanism (such as an explosive warhead) or simply aimed to damage the tail rotor through collision. Such efforts suggest a potential avenue for developing dual-use or purpose-designed UAVs with sufficient speed to intercept slower conventional targets like helicopters, using manual or automatic targeting. This could provide an alternative countermeasure if MANPADS or anti-air cannons are unavailable.

Parting thoughts

SHORAD will always be an indispensable layer in air defence, underscored by its critical role in countering diverse and evolving low-altitude threats, from UAVs and cruise missiles to helicopters and ground-attack aircraft. The war in Ukraine has demonstrated SHORAD's necessity, not only in preserving higher-end munitions but also in providing flexible, mobile protection for various assets and centres of significance. As threats proliferate across the battlefield, the demand for adaptable solutions has driven a shift from traditional SPAAGs to lighter, standalone turrets and truck-based platforms, such as the Skyranger series and Tridon Mk2, which leverage existing chassis to reduce costs and enhance on road mobility.

This potential evolution reflects a broader trend towards practicality and versatility. Mobility, enabled by lightweight systems and road-exploiting truck designs allows the defender to respond more rapidly to multidirectional and simultaneous attacks, a necessity highlighted by Ukraine's need to balance coverage across vast territories. Meanwhile, programmable air-burst munitions, laser-based systems such as Iron Beam-M, and unconventional adaptations such as the R-73-armed Magura drones and FPV UAV usages signal a future where VSHORAD/SHORAD integrates a greater range of platforms while expanding its range of effectors. While challenges remain, including production limitations and the high costs of advanced systems, the convergence of organic, cost-effective designs with experimental alternatives can ensure a plethora of solutions to forces looking to cover gaps in their air defence networks or expand their SHORAD assets considerably.

Low-cost kinetic effectors for drone defence

Chris Mulvihill

Traditional air defence systems, designed for larger and more expensive threats, struggle to provide a cost-effective countermeasure to widely used micro- and mini-unmanned aerial vehicle (UAVs). The need for affordable countermeasures is urgent, especially as adversaries both state and non-state are increasingly deploying UAVs in coordinated attacks. This article explores the role of low-cost kinetic effectors in countering UAV threats, examining their effectiveness, operational costs, and differing design concepts.

Low cost in the context of UAV defence

For any kinetic counter- unmanned aerial vehicle (C-UAV) system, the initial procurement and long-term operational costs must be carefully weighed. Acquisition costs involve the purchase of weapon systems, initial munition stocks, auxiliary equipment, and support services – often constituting the largest single-time expense during a system's lifecycle. However, operational costs such as future munition purchases, maintenance, spare parts supply, operator training, and logistics are some of the main factors that determine the system's long-term affordability.

According to estimates from the Center for Strategic and International Studies (CSIS), a single PATRIOT battery with five launchers and a typical loadout of munitions (plus two missile reloads) costs USD 400 million for the system and USD 690 million for the missiles. This highlights a critical issue for high-end surface-to-air missile (SAM) systems, whereby the cost for munitions can run higher than the system itself when magazine depth is factored in. Add operator training, spares and maintenance, and money set aside for overcoming future obsolescence, and the cost is even greater.

With UAV threats being constituted in part by cheap commercial-off-the-shelf products, achieving a rough parity in the cost of defeating such threats would be needed in a sustained campaign. The per-shot and per-engagement costs would provide a better metric to evaluate C-UAV systems. The per-shot cost can refer to the cost of a single munition fired against a target. This is a straightforward approach when comparing the unit cost of different munitions. By contrast, the per-engagement cost provides a more holistic measure of effectiveness by factoring in the number of munitions required, along with system maintenance, operational expenses, and manpower costs required per engagement. For a sustainable C-UAV system, the per-engagement cost would ideally need to be within the same range of the cost of the threats it is designed to defeat.

The idea of seeking a cost parity between threat and counter-measure is apparent when the price of adversary threats such as the Shahed-131/136 (and Geran'-1/2 Russian domestic versions) one-way attack (OWA) UAVs in use with Russia have been estimated to cost between USD 20,000 and USD 50,000. Shaheds have become infamous through their usage in the ongoing war in Ukraine, most notably in late-2022. While Ukraine actively organised its air defences to counter a sustained effort against its energy grid from threats including Shaheds, the strategic cost of successful strikes was nonetheless immense, with up to 40% of Ukraine's energy infrastructure being damaged in late-2022 and early-2023. With energy shortages leading to negative economic, social, and political consequences, the lack of effective defensive coverage can cost dearly.

It is critical for procurement officers to strike the right balance for C-UAV defence systems, finding a balance between capabilities and sustainment costs. Such costs go beyond money, with the massive usage of UAVs in conflicts such as Ukraine, C-UAV munitions stockpiles would need to number in the thousands. It is clear that with typical air defence munitions, such stockpiles are beyond the reach of most budgets, which only makes the development of C-UAV systems and munitions all the more important. This article will attempt to briefly examine two C-UAV clusters of effectors: UAV-based interceptors and C-UAV SAMs.

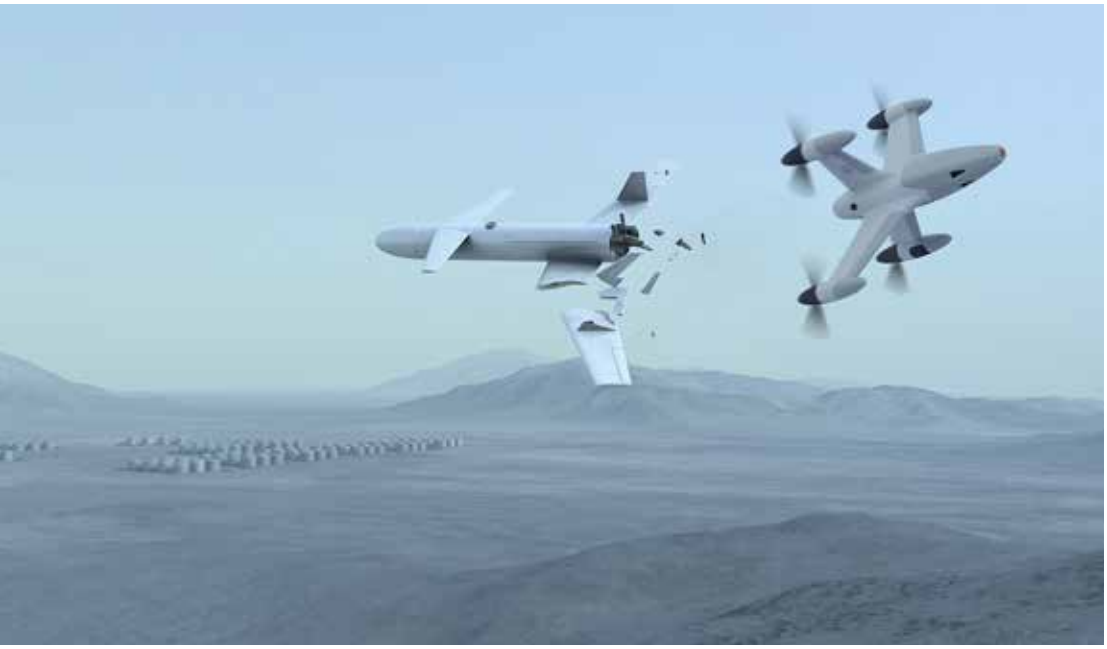
UAV-based interceptors

UAV-based interceptors, encompassing fixed-wing and multi-copter designs, vary widely in capability and are typically pitched as cost-effective alternatives to SAM systems. These

A downed Geran'-2 OWA UAV, this is a license-produced Shahed-136 with additional Russian modifications understood to increase the design's resistance to electronic countermeasures. [GUR]

subsonic platforms, powered by electric motor-driven propellers, are often recoverable if unused post-launch. Their lethality differs by design – some use high-explosive fragmentation (HE-FRAG) warheads, others simply ram their targets, while softer effector options such as net launchers can also be used to effectively disable threats.

A prevalent design is the cruciform quadcopter with an elongated body, which employs speed and mass to strike and disable target UAVs. Unlike hovering-optimised quadcopters (such as the DJI Mavic series), these interceptors focus on acceleration and impact force, delivering sufficient kinetic energy to defeat their target through simple collision.



▲ **MARSS Group's Interceptor-SR in a computer-generated mock-up of a kinetic defeat of a Class II-sized threat. [MARSS Group]**

Several companies have developed UAV interceptors, each tailored to specific threats and operational requirements. MARSS Group offers the Interceptor-SR (short range) and Interceptor-MR (medium range), unveiled at the World Defence Show 2022 in Riyadh and DSEI 2023 in London, respectively. The Interceptor-MR neutralises Class I and II UAVs at distances of up to 8 km, while the lighter Interceptor-SR targets Class I threats at ranges of up to 1 km, both using kinetic impact rather than explosives for reduced cost, weight, and low risk of collateral damage. These autonomous systems rely on external sensors linked to MARSS' NiDAR command and control system for target detection, while tracking targets post-launch with onboard infrared seekers and opto-electronic sensors.

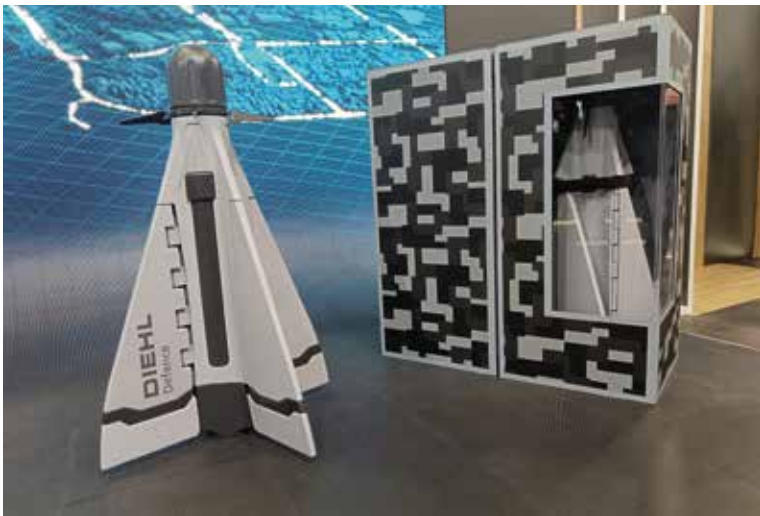
Similarly, Russia's 'Molot' (Hammer), a man-portable interceptor weighing 1.5-2 kg with a 1 km range, also employs kinetic impact, launching from a handheld canister, and using an infrared (IR) homing seeker to engage acquired targets in a 'fire and forget' manner. In contrast, Ukraine's 'Sting' UAV, a larger cruciform design targeting Class III UAVs such as Shahed drones, features an explosive warhead, reaches speeds of 160 km/h, and operates up to 3 km altitude, though its remote-controlled nature limits scalability for mass deployment.

Purpose-built UAV interceptors deliver superior performance and reliability, but generic quadcopter-based systems offer a cheaper alternative. In this vein, MBDA, partnering with Fortem Technologies, have developed a warhead and sensor combination which can be mounted on various user-defined quadcopters, and integrating them with the Sky Warden C-UAV system. The warhead and sensor package features a Doppler-radar and HE-FRAG warhead, with the radar triggering the warhead at an optimal distance from the target. Ukraine has shown commercial UAVs can be repurposed for interception, fitting drones with impact-fused warheads to target enemy helicopters, effectively acting as a 'poor man's short-range air defence (SHORAD) system'.

Anduril Industries, a US newcomer, provides the Roadrunner-M as their entrant into this segment. This is an autonomous, twin-turbojet-powered UAV with vertical take-off and return capability, which is stored in self-contained launch containers and launched vertically. Its turbojets represent a somewhat unconventional choice among UAV interceptors, given that they provide less speed than rocket motors, while being faster but more expensive than electrically-powered propellers.

Diehl Defence has recently presented its Cicada C-UAV concept. The Cicada is designed with a cruciform wing structure and employs a single five-blade propeller mounted around the nose, powered by an on-board battery. Each wing includes actuating fins to enable in-flight manoeuvring. The Cicada features an active radar seeker for terminal guidance, supported by command updates for in-flight adjustments from the ground launch unit. According to Diehl, the Cicacda will

▼ **Like the Roadrunner-M, the Cicada is joins the growing segment of interceptors which are typically slower, but smaller and cheaper, than conventional SAMs. [Mark Cazalet]**



be available with two effector options – a net launcher for the reusable version, and a high-explosive fragmentation (HE-FRAG) warhead version.

The interceptor has reportedly been developed in partnership with Skysec, a company that manufactures the visually similar Sentinel Catch, a net-based interceptor. The Sentinel Catch has a range of 5 km, a top speed of 65 m/s, and weighs 1.8 kg, with a wingspan of 300 mm and a length of 700 mm. Diehl's involvement appears to have taken the base Sentinel Catch design, and further developed it, with the addition of a high-explosive fragmentation (HE-FRAG) warhead. According to Diehl, the Cicaca can be integrated with the Guardion modular C-UAV system, or used as a standalone system. The company has stated that Cicada is slated to be ready for production in 2026.

UAV-based interceptors can offer several advantages, including lower unit costs, faster production cycles, and the use of commercially available components. The trade-off in cost between autonomous, purpose-built UAV interceptors and remotely-operated quadcopters somewhat mirrors the affordability and accessibility of the various threats they are designed to counter.

C-UAV SAMs and hybrid designs

SAMs excel in range, speed, manoeuvrability, warhead mass, and autonomy, functioning as one-way aerial vehicles that navigate – either autonomously or guided by fire-control radar –from launch to intercept. Costing more per shot than UAV-based interceptors due to complex components, they're less economical for targets within 10 km, where simpler, cheaper options such as cannons or man-portable systems may. Though capable of countering UAVs, their high cost drives the use of alternatives or the development of affordable SAMs, spurred by the UAV threat.

BAE Systems offers the Advanced Precision Kill Weapon System (APKWS) guidance kit for the legacy 70 mm Hydra 70 unguided rockets. This uses semi-active laser (SAL) guidance, which relies on an external laser designator (usually found on the launch platform) to illuminate the target. A sensor or sensors then pick up reflected laser emissions off the target's surface which can then be used by the onboard guidance computer to follow a continuously-updated flight path towards a target. The idea of repurposing legacy and specifically 'dumb' munitions breathes new life into old munitions, with an unguided rocket already being a relatively cheap and expendable munition in of itself.

The APKWS II uses an unusual design in the form of a distributed aperture semi-active laser seeker (DASALS). Rather than relying on a single centreline-mounted seeker in the nose of the missile, instead four miniature SAL seekers are mounted in the rocket wings. The wings themselves are also provided with flaps to allow steering. This arrangement allows the use of stock Hydra warheads, with the APKWS guidance section simply slotting in between warhead and rocket motor. With the application of an optional proximity fuse, the end product resembles a small short-range SAM.

L3Harris Technologies has adapted the APKWS kit as the effector for its Vampire C-UAV system. Vampire can use a pod with up to four missiles and is linked to a Wescam MX-RSTA optoelectronic sight, providing day and thermal channels, along with a laser target designator. The system has already seen combat use in Ukraine, reported to have successfully intercepted a Shahed 136. While BAE Systems states a maximum range of 5 km when launched from a rotary-ring platform, with ground-launched range likely substantially lower, and with the idea being to utilise the existing Hydra rocket design, extending this range is unlikely if it is to remain a generic design rather than bespoke.

▲ L3Harris' Vampire C-UAV system can be palletised and be mounted on civilian pickup trucks such as the Toyota Tacoma, making it versatile in terms of mounting options. [L3Harris]

▲ RTX's Coyote Block 2 is designed to be a miniaturised SAM, using a rocket-assisted launch and powered by a turbojet engine. [RTX]

Another interesting low-cost utilisation of unguided rockets is the RP-24 multiple launch rocket system from Hades Defense Systems. The is based on a 57 mm S-5 rocket coupled to a programmable timed-fuse. The launcher can be cued by an in-house HAWK radar which the company states can detect aerial objects with a radar cross section (RCS) of 0.01 m2 at a range of 6 km. The fuse is then programmed to explode at the optimal time to intercept the target, with the rocket itself being unguided, so it relies entirely on the launcher pointing at a precise bearing. This method, while offering an extremely cheap effector, would have a challenge intercepting a manoeuvring aerial threat.

RTX Corporation offers its own small SAM/hybrid C-UAV munition, the Coyote Block 2. The Block 2 shares relatively little with the original Block 1, in that while the Block 1 appears much more akin to a UAV, the Block 2 rather resembles a small SAM. It uses a rocket booster for launch before switching to a small turbojet engine to provided sustained thrust, offering a top speed of 555 km/h. The missile, tested by the US Army as a part of its Mobile-Low, Slow, Small Unmanned Aircraft Integrated Defeat System (M-LIDS) programme, is used in conjunction with the Ku-band Radio Frequency System (KuRFS) fire control radar which provides guidance information to the Coyote. For terminal guidance, the Coyote Block 2 is equipped with a Ku-band active radar seeker. The target defeat mechanism comprises a proximity-fuzed high-explosive fragmentation (HE-FRAG) warhead.

Emphasis on constructing missiles from more generic parts that can be procured or constructed with materials from the civilian market is another emerging trend that seeks to minimise cost, development, and production time for such weapons. Although at an early stage, Estonian firm Frankenburg Technologies is developing the 'Frankenburg Missile Mark 1', which it aims to test in Ukraine sometime in 2025. The missile effector is being designed to engage UAVs flying at a range of up to two kilometres, and at altitudes of a kilometre. Development on the missile has been rapid, with a mock-up pod being showcased on Milrem's Havoc unmanned ground vehicle (UGV) at the IDEX 2025 exhibition in the UAE.

Honourable mentions: remote weapon stations & shotguns

It would be a disservice to overlook remote weapon stations (RWSs) in the discussion of C-UAV. The use of lightened 30 mm cannons mounted on RWSs is an ongoing trend, explored as part of vehicle-focused C-UAV solutions or to provide additional defences for lighter air defence assets. At Eurosatory 2024, KNDS France unveiled a C-UAV variant of the 4×4 VBMR-L Serval equipped with an MC2-Technologies MATIA radar and an ARX 30 RWS featuring a 30×113 mm 30 M 781 MPG cannon. Programmable air-burst munitions were reported to be nearly ready at the time of the unveiling, offering a higher probability of target defeat than conventional munitions, as they can produce a cloud of fragments at an optimal distance from the target. Such solutions are increasingly common at global defence exhibitions.

Conceptual designs have also emerged, claimed to be more cost-effective than 30 mm programmable air-burst munitions. During a visit to the Russian Centre for Unmanned Systems and Technologies by Dmitry Medvedev, a system called 'Titan' was unveiled. It features a 24-barrel shotgun pedestal that can rotate and elevate its barrels, appearing to offer a close-in defence solution for point defence, with what appeared to be a day camera for target tracking. Given the barrel size, the range is likely very limited, but if claims of the Titan's ability to fire salvos are realised, it could provide a last-ditch defence, particularly for vehicle-based C-UAV applications.

Parting thoughts

As UAV technology continues to evolve, so must the capabilities to counter them. The effectiveness of any kinetic C-UAV system is ultimately measured not only by its ability to neutralise threats but also by its cost-efficiency and scalability. While traditional air defence systems remain valuable, the high cost of missile-based interceptors makes them unsustainable for countering vast numbers of inexpensive UAVs. Emerging solutions, such as repurposed guided rockets or UAV interceptors, offer alternatives that balance cost and capability. The development of low-cost kinetic effectors will play a crucial role in ensuring that defensive capabilities keep pace with the rapidly expanding UAV landscape.

A compact radar array for detection, paired with an opto-electrically guided RWS featuring a lightweight 30 mm cannon that fires programmable air-burst ammunition, could provide a counter-unmanned aerial vehicle (C-UAV) solution. This setup can be integrated into existing vehicles without compromising their primary functions. [Chris Mulvihill]

AMASE-ING!

Dr Thomas Withington

Maser technology has been somewhat neglected in defence, however, its ability to detect and produce radio signals with very little noise shows promise.

You have almost certainly heard of lasers and seen them. They are everywhere. From the supermarket checkout to tailoring, eye surgery to welding, our world would be very different without them. Yet you may not have heard of masers, which is a shame because their invention predated lasers by seven years. Like the latter, maser is an acronym, although translated as microwave amplification by stimulated emission of radiation. As with laser, this anacronym is now in everyday use. Despite the age of the technology, military interest in maser technology could increase in the coming years. Masers are interesting because they can be used to generate microwaves, and militaries need microwaves for communications and sensing.

Back in the '50s and '60s

The first maser was built at New York's Colombia University in 1953. One year earlier a trio of physicists – Russia's Nikolay Basov and Alexander Prokhorov, together with America's Joseph Weber – articulated the principle of the maser. Dr Weber did this during the Electron Tube Conference held that year in Ottawa. Half a world away in the Soviet Union, Professors Basov and Prokhorov made a similar presentation. Theirs' took place during the USSR's Academy of Sciences' May 1952 All-Union Conference on Radio Spectroscopy. Another three American physicists – Charles Townes, James Gordon and Hebert Zeiger – would build the first maser in 1953. Professors Townes, Basov and Prokhorov would later win the 1964 Nobel Prize for Physics for their work on masers. Professor Townes would also work with fellow American physicist Arthur Schawlow to lay the theoretical groundwork for the laser.

Masers have since been employed for several tasks. The Harvard and Smithsonian Centre for Astrophysics in Cambridge, Massachusetts says masers can be used to measure the structure and size of the Milky Way. The National Radio Astronomy Observatory in Charlottesville, Virginia notes that masers are used in atomic clocks. Another employment has been space communications. On 28 November 1964, the NASA's Mariner-IV was sent into space from Cape Canaveral, Florida onboard a Convair/General Dynamics Atlas-Agena rocket en route to Mars. Mariner-IV reached the Red Planet on 14 July 1965, performing a flypast which concluded on 15 July and taking 21 full pictures of the Martian surface. At one point, the craft was just 9,846 km (5,316 NM) above the planet. NASA's official history discusses the use of masers to provide a link between the probe and Earth. The technology was very much in its infancy at the time.

NASA's Mariner-IV probe zoomed aloft to head to Mars on 28 November 1964, she reached the Red Planet just over six months later with maser technology integral for communicating with the spacecraft. [NASA]

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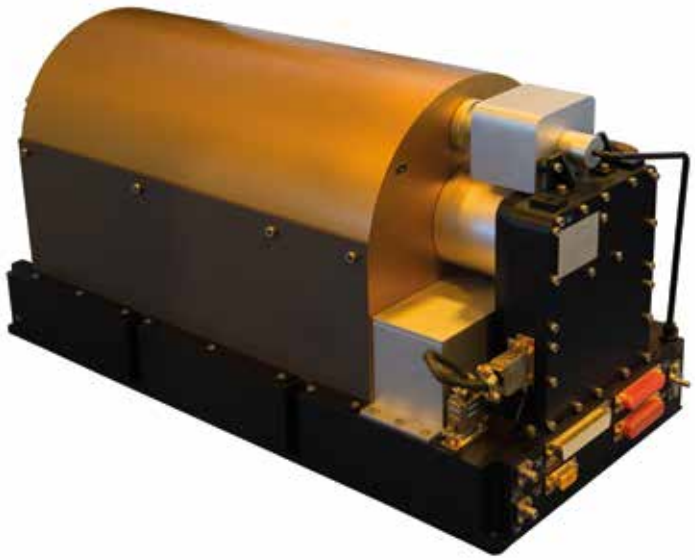
Masers and the spectrum

Before we consider how the maser works, it is worth refreshing our basic physics knowledge. Atoms have a nucleus containing protons and neutrons, which is surrounded by electrons moving at various distances from the nucleus. Radio waves harness electrons to create signals. Radio frequency (RF) radiation was initially produced using vacuum tubes and in the centre is a cathode. When heated by an electric current the cathode emits a cloud of electrons. At one end of the tube is a positively charged electric plate known as an anode. Electrons emitted by the cathode rush towards the anode. A metallic wired grid is placed between the cathode and anode, and a current passed through it. The grid's voltage can be controlled, and it can be negatively or positively charged. A negatively charged grid repels electrons, reducing the flow between the cathode and anode, and vice versa. The vacuum inside the tube is essential as it lets electrons move more freely than they would do in the atmosphere. These generated electrons will form the basis of the signal.

In 1940, British physicists John Randall and Harry Boot, working at the University of Birmingham in central England invented the cavity magnetron. Cavity magnetrons represented a major step forward in radio engineering as they could produce microwave radiation, including RF radiation. The term 'microwave' encompasses electromagnetic radiation stretching from frequencies of 300 MHz to 3 THz. While definitions differ, some classify microwave radiation as occurring in frequencies between 1 GHz and 1 THz.

Cavity magnetrons use a similar cathode-anode arrangement to the vacuum tube. However, in the former, there is a hollow space between the anode and cathode. However, cavity magnetron, The surrounding anode has cavities (known as 'resonating cavities') cut at regular intervals along its internal circumference. Magnets are positioned either end of the hollow space enclosing this, with the anode and cathode in a cylinder. The magnets create a magnetic field inside the hollow space and force the electrons to follow a curved path when inside the space, like people walking up a spiral staircase. As electrons pass by each cavity, this causes electrons within the grooves to move back and forth (known as oscillation). This in turn causes the grooves to alternate between positively charged and negatively charged states. Each cavity is charged with the opposite polarity from its neighbour in a process that causes inductor-capacitor (LC) oscillation, a process by which a direct current voltage is changed into an alternating current (AC). A radio wave is derived from an AC source; a metal loop extracts the oscillation from a single cavity, which is sent to an antenna and transmitted in the form of a radio wave. Oscillations are sustained because the electrons are retained in the magnetron, continually transferring their energy into the cavities and stimulating the LC oscillation.

The problem with streams of electrons, whether generated by vacuum tubes or cavity magnetrons, is that they produce 'noise'. These devices create heat which causes the agitation of free electrons, a process that increases with temperature. Known as thermal noise, this process is largely unavoidable. Thermal noise is problematic because it accompanies an RF signal. Natural and human-made RF noise is also in the atmosphere. These factors can risk drowning out a weak signal as the noise may be too loud, with the strength of the signal compared to the noise, known as the signal-to-noise ratio, being a fundamental part of radio engineering. Noise can be overcome to an extent by amplifying a weak signal, but the process of amplification creates some thermal noise. Thus, the signal may not be as 'pure' as would be desired.



The EU's Galileo global navigation satellite system, like all GNSSs, depends on an accurate timing source to ensure the accuracy of the transmitted PNT signals Galileo users depend on. This is provided by a hydrogen-based maser master clock, an example of which is shown here. [ESA]

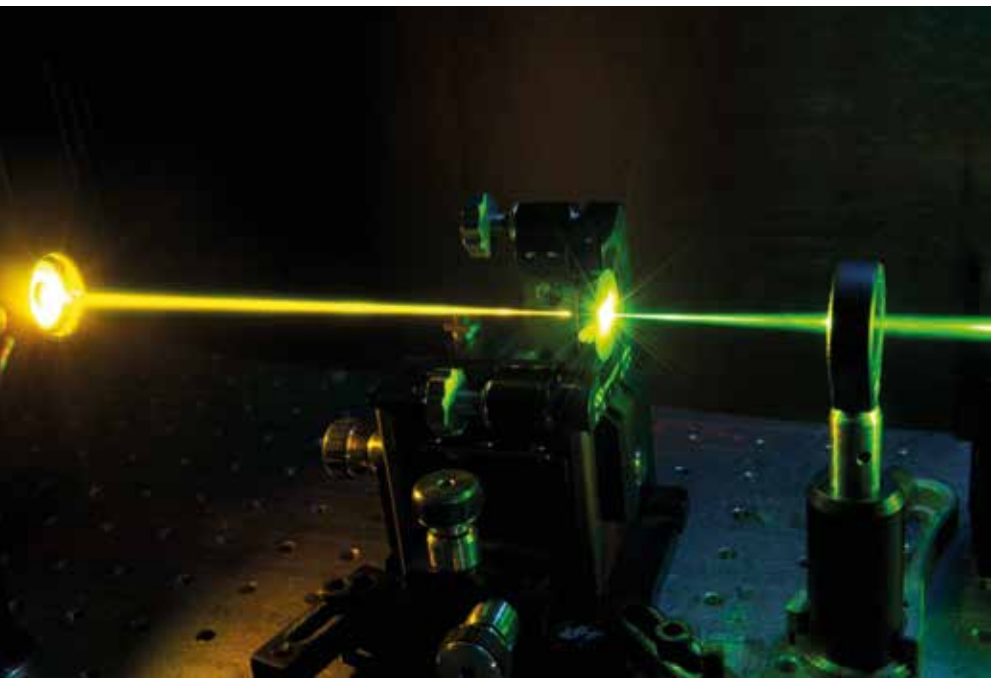
Masers aim to create RF signals without this attendant noise, and they do this by dispensing with streams of electrons as a means of creating AC signals. Instead, oscillations are created through an interaction of light with a material. Masers exploit the principle that every atom will vibrate at a predefined, natural, specific frequency. For example, an Oxygen atom vibrates at a frequency of 370 THz. Atomic and molecular vibration in general typically occurs at frequencies of between 100 THz up to 1000 THz. A maser will employ light, which is fired into a gain medium such as a crystal.

To refresh our memory, atoms comprise protons and neutrons in their nucleus and are surrounded by electrons. These electrons are not at a uniform distance from the nucleus – some are closer than others. The farther away an electron is from the nucleus, the more energy it has and vice versa. Electrons can be persuaded to change their proximity to the nucleus. If they move away from the nucleus, they will use up energy, absorbing a photon, but will lose energy if they move towards it, emitting a photon. Photons comprise light, and indeed are the quanta of the electromagnetic spectrum. Light enters the gain medium, to stimulate the electrons within, causing them to lose energy which is released in the form of photons. This process has a cascading effect: Photons triggered by the stimulated electrons hit other electrons, causing them to lose energy and release more photons, and so on.

Masers and radio waves

Going back to the heady days of 1953 and the first artificial maser created by Professors Townes, Gordon and Zeiger, their efforts focused on using ammonia molecules to provide the gain medium. Usefully, Ammonia molecules have a resonant frequency of 23.79GHz. Resonance occurs when the molecules are subjected to an external force which matches that frequency; in the case of Ammonia, a 23.79 GHz microwave signal. When experiencing this matching external force, the molecules will start resonating at 23.79 GHz, albeit with a higher amplitude compared to the original amplitude of the external force. Put simply, the first maser used a beam of excited Ammonia molecules, pushed through a focuser to separate excited from ground state molecules, with the excited molecules continuing into the resonant cavity. The resonant cavity will have internal dimensions mirroring the resonant frequency of the incoming molecules or atoms; in this case, the wavelength of 23.79 GHz is 12.6 mm. The incoming excite ammonia molecules then decay into their low-energy state, emitting photons at a frequency of 23.75 GHz – which is within the microwave band (300 MHz to 300 GHz). These can be released through an outlet as a coherent microwave signal.

It is worth noting that photons emitted under stimulated emission are of the same frequency as those moving past them, allowing the creating of a very low-noise signal. Some of these photons bounce back and forth within the chamber, inducing other Ammonia molecules to give up their photons; in sufficient quantities, this induces an oscillating electromagnetic field within the cavity. The beauty of the maser is that unlike the vacuum tube and the cavity magnetron, it produces very little noise, as it is not reliant on a stream of electrons. It is noteworthy that quartz oscillators and solid-state electronics which can be used to generate RF energy still produce noise at differing levels.



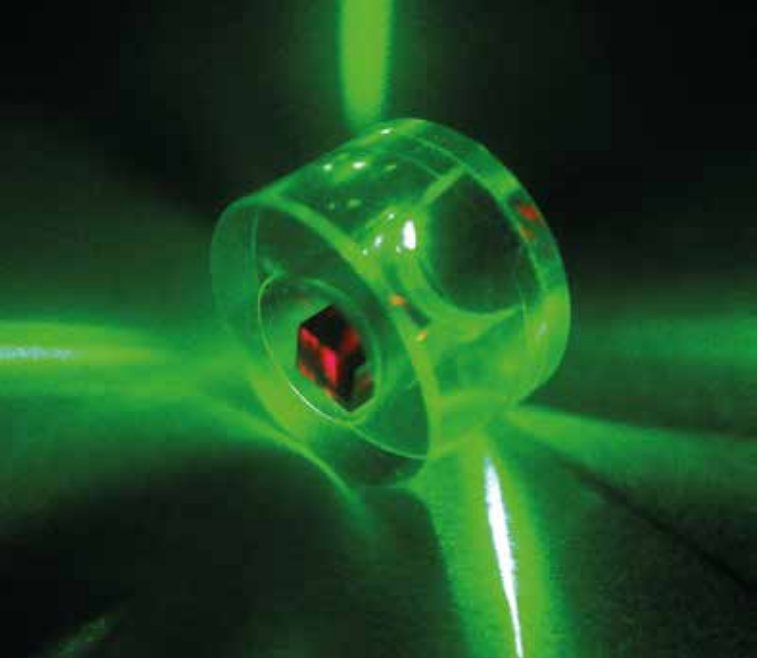
Element Six is one company moving forward with maser research. In the past, the company has developed quantum single-crystal diamond maser technology. [Element Six]

Defence applications

Signal-to-noise ratio (SNR) is a consideration in all aspects of radio engineering, including defence applications. Radars, radio communications and satellite navigation all depend on the transmission and reception of RF signals. The SNR measures the relative strengths of prevailing electromagnetic radiation and the desired signal. The less noise there is, the clearer the signal will be. Likewise, masers can amplify a weak signal with potential benefits for military RF-dependent systems. As noted above, the problem with amplification is that it brings noise; thermal noise from the electrons, and prevailing natural and artificial noise in the ether.

David Stupples, Professor of Electronic and Radio Engineering at London's City University, says that the ability of masers to amplify very weak signals could pay dividends for militaries. Radios and radars increasingly use low probability of interception/deception (LPI/D) techniques to hide signals in the ether. Several articles could be written on the intricacies of LPI/D techniques, but in essence, what they try to do is use the background electromagnetic noise of their environment to camouflage their signals. Electromagnetic noise is ever-present on our planet and indeed the universe at large. Levels of electromagnetic noise vary depending on the environment. For example, a crowded, busy city will have more noise than the sparsely populated countryside: There will be far more people using cell phones, which employ radio waves, in a city compared to rural areas. The prevailing, local level of electromagnetic radiation is known as the 'noise floor', which can be likened to the hubbub of a crowded room. When you walk into the room, you will notice that the different conversations merge into a continuous sound – this is the noise floor. You will not hear someone whispering very quietly to someone else in another part of the room, for example. LPI/D systems try to maintain the strength of their signals below that of the noise floor. Systems can be designed to use techniques to filter out noise to detect LPI/D signals, but there will always be a limit to the faintness of a signal that they can detect. We have the same problem that the system's own activity will produce noise, like electromagnetic tinnitus.

Professor Stupples explained that the advent of LPI/D RF techniques is prompting a renewed interest in masers, particularly for weak signal amplification. As the employment of masers for communications with Mariner-IV showed, the technology has applications for satellite communications too. Signals coming from, or going to, space must travel long distances. Signals are like long-distance runners; the further the run, the more energy they lose. For example, Position, Navigation and Timing (PNT) signals transmitted from space to Earth by Global Navigation Satellite System constellations are very weak by the time they arrive. PNT signals can be as low as -130 dBm (decibels-per-milliwatt) when



A key contribution that maser technology could make to military RF systems is the ability to amplify signals with very little accompanying noise. This could be particularly used when hunting LPI/D transmissions. [UCL Breeze Lab]

they reach Earth; Decibels being a standard measure of signal strength. Figures produced by the US Federal Communications Commission, America's spectrum regulator, say that signals from the US Global Positioning System constellation can have a strength of circa 56.5 dBm when they leave the satellite.

Another application mentioned by Stupples is for directed energy weapons (DEW). A considerable amount of DEW research to date has focused on lasers. Lasers can be used to apply incredible heat in a very precise way against a target, with the United Kingdom's DragonFire DEW being a case in point. A quartet of companies and organisations; MBDA, Leonardo, QinetiQ and the UK's Defence Science and Technology Laboratory, are involved. DragonFire is envisaged as a counter-rocket, artillery and mortar weapon and could enter service from 2027, according to the UK Ministry of Defence (MoD). One problem with certain types of lasers is that they can suffer attenuation, which is a phenomenon by which atmospheric contaminants degrade the strength of a laser beam. Precipitation can absorb and scatter some of the photons comprising the beam, weakening the signal. Smoke and dust can also cause a scattering of the laser light in different directions weakening the signal.

Attenuation is less of a concern for masers: "There is so much attenuation for lasers in the atmosphere, but much less so for masers," according to Prof. Stupples. All-in-all, maser technology has a great deal of potential in the military RF world. The technology has not had the uptake in the defence environment that one might expect, arguably because high-powered radios and radars already work well. Nonetheless, as militaries increasingly embrace LPI/D technology, we may see a greater adoption. After all, as Professor Stupples noted, maser technology "has a great deal of potential."

Soft-kill and maritime air defence: A systems approach

Dr Sidharth Kaushal

With low-cost drones and missiles threatening even well-defended naval assets, this analysis examines a systems approach to integrating electronic warfare that could rebalance the cost equation.

Recent experience of naval combat in theatres such as the Red Sea and Black Sea has illustrated several challenges which navies will face with respect to air and missile defence. First, modes of attack against naval vessels are orders of magnitude cheaper than the interceptors which are often employed against them. For example, the cost of a UAV such as the Samad-2 or a Shahed-136 can be measured in the thousands of dollars. Even more expensive systems such as the now widely proliferated Chinese C-802 missile are comparatively cost effective, with the C-802 costing around USD 500,000.

A YJ-83J air-launched anti-ship cruise missile (ASCM). This model is intended for Chinese domestic service, however it is very similar to the C-802 surface-launched ASCM offered on the export market. [Tyg728, via Wikimedia Commons; CC BY-SA 4.0]

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This poses several challenges for navies. In addition to the obvious issue of cost asymmetries between threat and countermeasure, a rapid rate of expenditure of air defence interceptors will challenge fleets' operational tempo. As has been seen in the Black Sea, where Ukraine was able to successfully attack the Russian Black Sea fleets headquarters within the heavily-defended bastion of Sevastopol with Storm Shadow cruise missiles, even well defended military facilities will be at risk close to the theatre of combat. This, coupled with the fact that vertical launch system (VLS) replenishment at sea remains difficult, will mean that vessels which have expended a large portion of their loadout will need to be rotated to often distant bases for replenishment, limiting the endurance of a fleet in-theatre.

In this context, the ability to engage low-cost targets with systems other than air defence interceptors is of considerable importance. Electronic warfare (EW) capabilities offer particular promise in this respect. Against targets such as UAVs which often use commercial-grade guidance and communications systems, EW capabilities can achieve considerable results. Although steps have been taken by many nations to reduce vulnerabilities, for example by placing some sensitive components within Faraday cages, there are still a number of means of electronic attack which can prove viable against UAVs. In a similar vein, the active seekers of many older cruise missiles, which are not equipped with millimetric wave seekers, are vulnerable to a range of electronic countermeasures (ECM).

None of this is exactly new and EW has been an integral component of naval combat for decades. However, soft-kill systems are still largely employed as either a means of augmenting traditional hard-kill air defence systems, or as a last-ditch defensive capability. The employment of hard- and soft-kill capabilities in an integrated manner, rather than merely in tandem with one another with a marked preference for the former, will be important if navies are to manage the risks posed to them by modern air threats.

The present approach and its pitfalls

There are a number of soft-kill capabilities deployed by navies as things presently stand including shipboard ECM suites and decoys such as the Nulka Digital Radio Frequency Memory

(DFRM) system. What is absent from navies today is not capable existing systems or in-house expertise, but a concept of operations (CONOPS) that integrates hard- and soft-kill components together, rather than treating them as separate but complementary capabilities.

As an example of the phenomenon described we might consider the 2016 attack on the USS *Mason* by Ansar Allah (the Houthis). The *Mason* engaged a salvo of two C-802 cruise missiles launched by the Houthis with a combination of two SM-2 missiles and ESSM and two Nulka decoys. While the outcome was that the Mason was unharmed, the crew appeared to have been initially uncertain as to whether the missiles were engaged by the Mason's SAMs or diverted off course by the Nulka decoys employed. All this would appear to indicate that all possible hard- and soft-kill measures were employed in tandem to maximise the prospects of engaging the missile. This approach, while reasonable against a small number of targets, is unviable against a larger target set. This would correspond with what is known about the workflow in the combat information centre (CIC) suite of a naval vessel where Anti-Air Warfare officers and EW supervisors operate in relative isolation from one another despite operating within the same CIC suite. To be sure, a principal warfare officer (PWO) serves an ultimate coordinating function, but given the compressed time horizon available and strong incentives to employ capabilities which achieve a demonstrated effect (such as missiles), the PWO's incentive structure is likely often biased towards overkill rather than sufficiency.

▲ The guided-missile destroyer USS *Dewey* (DDG 105) launches an electronic decoy cartridge from an MK-234 Nulka Decoy Launching System on 11 July 2018, while participating in the RIMPAC 2018 exercise. [US Navy/MC2 Devin M. Langer]

In theory, an optimal system would be one in which missiles which were being successfully engaged with soft-kill capabilities were removed from the target list of hard-kill air defence. This is, of course, difficult to achieve in practice, not least because some forms of successful electronic attack (such as deceptive jamming) do not necessarily provide visible evidence of success until late in the trajectory of an attacking system. At that point, if success has been misjudged, the outcome can be catastrophic. Nonetheless, there are potential pathways to rendering hard- and soft-kill capabilities more complementary than is currently the case.

A zonal approach

One approach might involve the creation of zones of responsibility, with soft-kill means used first, and threats engaged with hard-kill assets only if they have crossed a given point. This is challenging under current circumstances because EW capabilities often form a final defensive layer rather than an outer zone. For example, the Nulka is launched on a rocket out to a few kilometres from a vessel, while towed decoys such as the AN/SLQ-49 are even closer to the target ship when deployed.

The deployment of EW capabilities, however, could be an immediate role for uncrewed surface vessels (USVs). While the employment of USVs as combat systems capable of holding, for example, vertical launch systems is likely to take some time, many USVs could in principle hold a decoy such as Nulka which, given its relatively efficient thermal battery, would not necessarily draw a great deal of power from the USV's propulsion system.

Another avenue might be the employment of lower-cost converted civilian vessels for tasks such as barrage jamming. A great deal has been written about the potential value that the containerisation of missiles might add to navies as they seek to increase their launch capacity. This is true but another avenue for the employment of civilian vessels would be to utilise their large powerplants to generate the energy needed to power barrage jamming capabilities. Barrage jamming involves an emitting vessel to generate signals on multiple frequencies within a likely spectrum of adversary activity to quite literally drown out useful emissions. Its major disadvantage is that it is highly power-intensive and thus, since range and required power are inversely correlated, difficult to achieve over long ranges. It is also typically a risk to the vessel employing this approach, as it can be readily detected by hostile electronic intelligence (ELINT) and targeted by anti-radiation missiles (ARMs). Large, lightly-crewed vessels which are relatively low-cost might be an optimal platform for barrage jamming capabilities.

An L3Harris Arabian Fox MAST-13 USV sails in the Arabian Gulf on 22 January 2023, during exercise Neon Defender 23. USVs could form a valuable 'outer ring' of defence for naval vessels, through hosting decoys and jammers. [US Navy/MC1 Anita Chebahtah]

The more navies can rely on offboard platforms which can provide EW on a persistent basis at longer distances, the easier it will be to rationalise the employment of SAM systems by allocating them zonally to missiles which cross an outer belt of EW capabilities.

Subdivision by Threat Type

An alternative approach would be the subdivision of allocated assets based on the type of threat detected. Although vessels are challenged by a spectrum of aerial capabilities in the maritime domain, these capabilities can be differentiated based on characteristics such as speed, altitude and trajectory. UAVs, for example, employ considerably different trajectories to cruise missiles.

Given that a major part of the challenge of scale is the threat posed by UAVs, this threat could be one to which EW and close-in weapons systems (CIWSs) were exclusively allocated. On the one hand, UAVs are often particularly susceptible to electronic attack, particularly when they rely on commercial inputs. Moreover, as relatively slow-moving targets, they are more susceptible to gunfire and CIWSs in their terminal phase. Finally, the consequences of a strike with a one-way attack (OWA) UAV with a much smaller payload than the average cruise missile (a Samad-2 has an 18 kg warhead, and by comparison a C-802 has a 165 kg warhead) are considerably lower meaning that some risk can be accepted with respect to close in defence.

The aircraft carrier USS Nimitz (CVN 68) fires a Phalanx Close-In Weapons System (CIWS) during a live-fire exercise. [US Navy/PO2 Jimmy Cellini]

An approach which relied on the subdivision of capabilities based on threat type, with a focus on soft-kill and close in weapons against UAVs would, however, depend to a significant degree on accurate classification. While this is possible based on the characteristics described, there is a risk that an opponent who understood one's targeting approach would employ cruise missiles on higher-altitude trajectories in salvos timed to ensure that faster-moving cruise missiles caught up with slower-moving UAVs to converge on a vessel. The use of fast- and slow-moving targets is something which is discussed by China's PLA for example. This level of coordination is likely to elude many sub-peer opponents, however.

However there may also be technological fixes. For example, airborne sensors both on traditional airborne early warning and control (AEW&C) aircraft and reconnaissance UAVs can help with target discrimination. The discrimination of targets is also an area where artificial intelligence (AI) can be of utility. A mature application of AI is the discrimination of different types of target, something which neural networks built around the principle of accepting bias to reduce variance and thus classifying phenomena based on relatively limited key fragments of data, are very well suited to if properly trained.

Integration

The most radical approach would be to strive for genuine integration between soft- and hard-kill capabilities. This would require a few changes at both the organisational and doctrinal levels. We might, for example, consider the consolidation of the EW petty officer and anti-air warfare officers' roles under the aegis of a single effects coordinator whose work was overseen by the PWO.

Consolidation has its risks to be sure – EW and air defence are both specialised functions which justify specialised roles allocated to each task. However, while operation of systems is a specialised role, the supervision and resource allocation need not be as highly specialised. The supervision and coordination of both functions could be performed by a single officer other than the PWO. An effects coordinator specif-

ically tasked with allocating either EW, hard-kill, or both if necessary, to a given task would represent a means of rationalising their employment relative to a system in which both processes run in parallel.

- **The *Arleigh-Burke* class guided-missile destroyer USS *Stout* (DDG 55) launches an SM-2 during a missile exercise. [US Navy/Lt Laura Radspinner]**

The integration of the software packages underpinning both EW and air defence would also represent a logical step were this approach to be taken, since operators across both EW and air defence would need to be aware of which threats were being allocated to each type of system.

Conclusion

The scope and scale of air and missile threats to vessels at sea provides a considerable incentive for the creation of more synergies between the soft- and hard-kill systems on naval vessels. There are a number of approaches to achieving this, from those which focus more on divisions based either on zonal or altitudinal criteria to those which involve a genuine integration of organisations and functions.

Surface tensions

Dr Thomas Withington

The advent of metasurface technology could herald major benefits for platform protection in the air domain, particularly as a means of reducing visibility to radar.

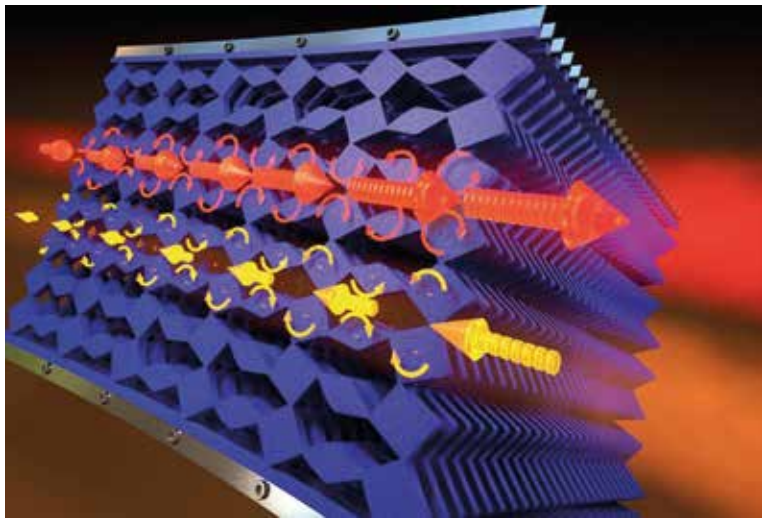
You might not have heard of metamaterials, or indeed metasurfaces, but do not worry, you are not alone. The science of metamaterials of relatively new. In a nutshell, metamaterials exploit the composition of certain materials to manipulate electromagnetic waves. The story of metamaterials dates back to the 19th century. The Scottish mathematician and physicist James Clerk Maxwell (1831 to 1879) helpfully devised several equations. Named eponymously, these equations consolidated existing observations on electricity and magnetism into consistent theories. Maxwell's equations formed part of physics' second great unification with the first unification being from the work of the polymath Sir Isaac Newton on terrestrial and celestial mechanics.

In 1865, Maxwell published his paper 'A Dynamical Theory of the Electromagnetic Field' which posited that light, electricity and magnetism were all the results of the phenomenon of the electromagnetic field. The work of Maxwell and others including Indian polymath Sir Jagadish Chandra Bose (1858 to 1937) reverberates today. These scientists were instrumental in discerning that the interaction of certain materials and physical shapes could have a profound effect on the behaviour of electromagnetic waves. Usefully, the science of radio was developing towards the late 19th century. Maxwell's theories helped pave the way for the work of Italian physicist and engineer Guglielmo Marconi (1874 to 1937), who pioneered radio as a practical technology, transmitting the first transatlantic radio signal in 1901.

Metasurfaces defined

The industry journal Photonics provides a good definition of a metasurface as a "two-dimensional array of subwavelength-scale artificial structures … arranged in a specific pattern to manipulate the propagation of light or other electromagnetic waves at subwavelength scale." What does this mean in practice?

Firstly, these are flat structures and not three-dimensional shapes, giving the metasurface its surface element. Regarding subwavelength-scale artificial structures, all electromagnetic waves have a wavelength. The wavelength is the measure between two peaks or troughs of a wave: A frequency of 1 GHz has a wavelength of 29.98 cm, while a frequency of 233 MHz has a 1.28 m wavelength. The length of these artificial structures within the metasurface can affect the electromagnetic wave's behaviour. A metasurface's ability to influence an electromagnetic wave can affect how that wave moves, or propagates, through a medium. The medium could include the atmosphere of our planet or the vacuum of space. These subwavelength structures are very small – some can be as small as 8 µm in length, others as small as 1,100 nm. Such miniscule dimensions means that metasurfaces can be produced using standard semiconductor manufacturing techniques which are designed to produce tiny structures, such as the microstructures used within modern microchips.



Metamaterials can have fascinating properties as they can filter electromagnetic waves, allowing some signals to pass through the material in one direction, while blocking others. [University of Texas]

Metasurfaces and EW

An instructive film by the United Kingdom metamaterials network; facilitated by the UK's Engineering and Physical Sciences Research Council offers a good overview of how metasurfaces work. Metamaterials can slow, stop or redirect electromagnetic waves. These attributes could make a significant contribution to electronic warfare (EW) in the coming years. EW includes three subdisciplines: electronic attack (EA), electronic protection (EP), and electronic support (ES). The United States Department of Defense *Dictionary of Military and Associated Terms* provides a standard definition of electronic warfare as "military action involving the use of

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electromagnetic and directed energy to control the electromagnetic spectrum or to attack the enemy."

- EA is the subdiscipline which involves "the use of electromagnetic energy … to attack personnel, facilities or equipment with the intent of degrading, neutralising or destroying enemy combat capability."
- EP focuses on "actions taken to protect personnel, facilities and equipment from any effects of friendly or enemy use of the electromagnetic spectrum that degrade, neutralise, or destroy friendly combat capability."
- ES involves actions to "search for, intercept, identify and locate or localise sources of intentional and unintentional radiated electromagnetic energy for the purpose of immediate threat recognition, targeting, planning and conduct of future operations."

These definitions are important in the world of metasurfaces, as their properties are directly relevant to the EP mission. A key tenet of airpower is to perform Offensive Counter Air (OCA) and Defensive Counter Air (DCA) efforts against one's adversary. As US Air Force definitions note, OCA focuses primarily on attack. Blue forces adopt an offensive posture to win and maintain control of the air at the tactical, operational and strategic level from red forces. OCA depends on denying, degrading, dislocating and destroying red force means to counter blue force efforts to win this control. Attacks on ground-based air defence (GBAD), integrated air defence systems (IADS), airfields, command and control (C2) facilities and industrial targets germane to red force airpower all fall within the OCA remit. Offensive counter-air may be fought for using blue force fighter escorts, combat air patrols and suppression/destruction of enemy air defence (SEAD/DEAD) missions. DCA, on the other hand, focuses on using blue force GBAD, IADS, accompanying C2 and fighters to protect friendly airspace against red force OCA efforts.

Radar is a key technology underpinning both the OCA and DCA mission. In its purest form, a radar transmits radio frequency (RF) energy which collides with a target and is re-propagated towards the radar antenna. The radar performs calculations comparing the properties of the repropagated signal to that which was transmitted. Radar signals, like all electromagnetic energy, travels at the speed of light; 299,274 km/s.

Dedicated paints and coatings are integral to combat aircraft radar cross section reduction techniques, although these materials often demand intricate and specialist care to ensure their performance. [USAF]

Suppose we have a radar that transmits a signal with a frequency of 1.25 GHz. It takes the signal 0.26 milliseconds to make the trip from the radar's antenna to the target, and to be repropagated by the target towards the antenna. This is a total distance of 78 km (42 NM). By dividing this distance in half, we determine the target is 39 km (21 NM) from the radar. The frequency of a repropagated radar signal will change slightly if the target is moving towards or away from the antenna. If a target is moving towards the antenna, the frequency of the waves will increase, because waves take progressively less time to reach the antenna, and vice versa if the target is moving away. This phenomenon is known as the Doppler effect, and you have likely experienced it without even realising it. Take for instance the following scenario: If you are standing by a road and a police car drives past with its siren on, the pitch of the siren will increase. Conversely, the siren pitch will decrease as it drives away. The frequency of the siren is always the same, but for an observer it appears to change. To turn this back to our radar scenario, our target, which is 39 km from the radar, is flying at a speed of 481.5 km/h (260 kn). The re-propagated signal will have a frequency of circa 1.2499 GHz. Not much of a change, but enough to tell us the target is moving away from the radar.

The strength of the repropagated signal can tell us more about the target. Signal strength is measured in decibels/dB. Suppose our radar transmit signals with 56.3 dB of power. The radar's antenna has a gain of 32 dB. Gain is a measurement of how much power a radar can focus in a desired direction. Our target in question is a large airliner with a radar cross section (RCS) of 100 m2. RCS is a measure of how large an object will appear to a radar and can be converted into decibels, in this case 20 db. The strength of the repropagated signal will be -0.2dB when it reaches the radar antenna. This is an 88.5 dB reduction in amplification from the original combined strength (transmit power and gain) of 88.3 dB. Despite the apparent weakness of this signal, the radar will be designed to detect and process this.

Matters become more problematic when aircraft are designed to have as low an RCS as possible. The US Air Force's Lockheed Martin F-117A Nighthawk combat aircraft had a reported RCS as low as -30 dB. Using the same radar signal criteria as those above, the repropagated signal from an F-117A will be -5.2 dB. This is 26 times smaller than the strength of the airliner's repropagated signal. Some RCS levels maybe so low that they are comparable with those of birds. This is deliberate. Ground-based air surveillance radars may not need to see and track birds. Such targets may be superfluous to the radar's core tasks, and the radar's processor may be programmed to simply ignore targets with such low RCSs. From a camouflage perspective, it makes sense to design combat aircraft to have as low an RCS as possible.

So-called 'stealth' aircraft like the F-117A Nighthawk shown here represented early forays into the world of metasurfaces. Special paints and coatings helped to reduce radar cross sections and enhance electromagnetic camouflage. [USAF]

It could be argued that aircraft such as the F-117A represented the first meaningful military forays into the world of metasurfaces. RCS reduction is a complex, yet intriguing, subject. Broadly speaking, the process utilises several techniques to reduce an aircraft's visibility to radar. Aircraft with low RCS levels typically use flat and highly angular surfaces to repropagate an incoming radar signal away from the direction of the antenna. Some RF energy will be repropagated back to the antenna. However, the repropagated signal may have a strength so low, it is lost in the prevailing electromagnetic noise. If you throw a bouncing ball at an angle onto the floor, it will bounce off in the opposite angle. Drop it onto a curved surface, and it will bounce back to you. Curved surfaces, such as those seen all over an airliner, are good reflectors of radar signals.

Another useful RCS reduction technique is to mask parts of the aircraft which could enlarge the RCS. Spinning engine fan blades are good RF reflectors which a radar can exploit to determine that it has detected an aircraft. Unlike the wings of a bird, engine fan blades move in a predictable fashion. A standard approach in RCS reduction is to use S-shaped engine inlets which help shield the engine fan blades from the radar's line-of-sight.

Nonetheless, it is the advanced coatings and paints that first-generation 'stealth' aircraft like the F-117A used which were indicative of early metasurface adoption. These coatings were designed to absorb incoming radar signals rather than reflect them back to the antenna. Some coatings use tiny iron balls which resonate when hit by the incoming radar signal. This resonance creates heat which then dissipates, causing very little energy to be repropagated.

Advances in metasurface technology constitute the next step in ongoing work to help protect targets from radar detection. In a recent lecture given by Dr Rafael Licursi, author of the book *Metasurface-Driven Electronic Warfare*, to the Association of Old Crows global electronic warfare advocacy organisation, he said that metasurfaces could be used to scatter incoming radar signals, or to change the signal's polarisation. Much like the RCS reduction technique of using flat surfaces, metasurfaces could be employed to repropagate signals away from the radar antenna. Dr Licursi stated in his lecture that scattering can produce a signal reduction as high as 10 dB in wide RF bandwidths.

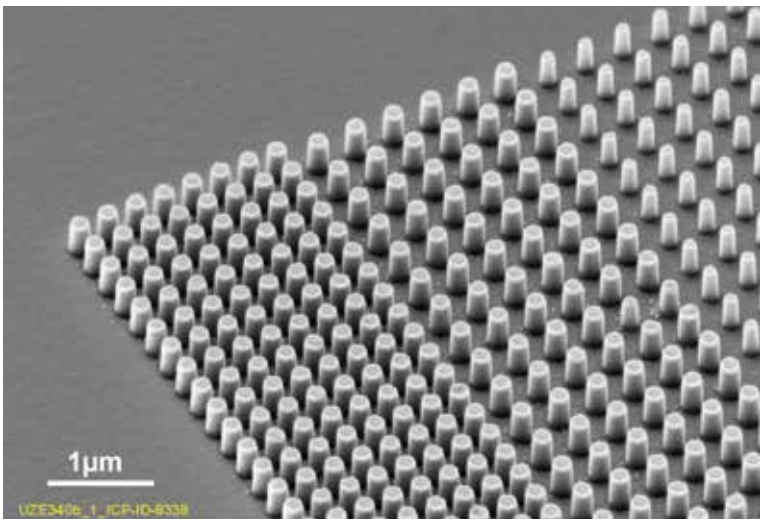
A standard technique used by contemporary combat aircraft to reduce radar detection is to employ a Digital Radio Frequency Memory (DRFM) in their integrated self-defence systems. DRFMs listen for offending radar signals which are then sampled so that these signals can be manipulated. To return to our example, the radar is transmitting on a frequency of 1.25 GHz. The frequency of the signal returned by the target is 1.2499 GHz as it is moving away and causing a phase shift in the returned signal. If the repropagated signal had a frequency of 1.25 GHz, the signal would be in phase, meaning the peaks and troughs are occurring at the same moment. The different frequencies of the incoming and repropagated signal means the latter is out of phase.

After sampling the incoming radar signal, our DRFM creates a false signal with a frequency of 1.250 GHz which will have the same -0.2 dB strength as the real 1.2499 GHz signal. The radar now receives both signals, causing the processor to assume two targets are in the sky. By continuing to alter the fake repropagated signal, the DRFM starts to convince the radar that the fake target is moving at certain speeds and in certain directions. Such techniques pose a dilemma to the radar operator: Which target is genuine, and which is fake? In fact, DRFMs are capable of mind-bending levels of radar signal manipulation.

Advancing the technology

As Licursi noted, even with the onward march of electronics miniaturisation, it may be impractical to outfit size, weight and power-constrained platforms such as small UAVs with DRFMs and accompanying antennas. Instead, a metasurface could collect the energy from the incoming radar signal. The

Minute structures can adorn metasurfaces which can influence and control electromagnetic waves. These structures can be created using semiconductor printing techniques. [Fraunhofer Institute]



signal is then amplified, and a similar phase shift imposed to the one discussed in the DFRM example, before this new signal is transmitted to the radar. The advantage of this approach is that the metasurface material can be under 1 mm thick. Moreover, it does not depend on any digital technology or complex processing.

Metasurfaces can also be used to influence radar signal polarisation. Electromagnetic waves are comprised of an electrical field and a magnetic field perpendicular to one another. If the electrical wave was angled at 0°, it would move from side to side. The magnetic wave would be angled at 90° degrees and would move up and down. This would be classes as a horizontally-polarised radar signal, and will repropagate well from targets with relatively large horizontal surfaces – aircraft wings being a good example. Similarly, a vertically polarised radar signal will repropagate well from a vertical surface. The polarisation of the surface of the target the signal hits negatively or positively influence the strength of the repropagated signal. Licursi said that a metasurface could be used to change the polarisation of the signal it repropagates.

There may well be an unbelievable number of applications in the EW domain for metasurfaces that we have yet to foresee as the technology remains in its infancy. Dr Licursi told this correspondent that metasurfaces have been tested in laboratory conditions, but not yet in operational, real-world scenarios. He says that the technology is probably at about TRL (Technology Readiness Level) three or four. According to European Union definitions, TRL-3 denotes that a design proof of concept has been reached. TRL-4 indicates that the proof of concept has been demonstrated: "The basic components have been tested in laboratories," he says, "but we have only tested the materials, and not yet tested the metasurfaces on platforms." He added that there are already some products available based on metasurfaces, such as those produced by a company called Greenerwave. Furthermore, metasurfaces for stealth aircraft have probably been tested in real-world scenarios by some governments. Information about such endeavours is understandably sparse.

The current state-of-the-art uses Printed Circuit Boards (PCBs) for the construction of metasurfaces. Dielectric laminates have copper on both sides, and Dr Licursi added that "we can etch the copper in a particular way to give the metasurface a specific configuration or property. All we then need to do is to add whatever electronics we might need to produce a particular effect." As discussed above, amplifiers could be added to metasurfaces to control the strength of a repropagated signal. As well as using PCBs, Dr Licursi noted that 3D printing can be employed to build conformal metasurfaces. Bespoke surfaces could be printed to cover the intricate airframe of a small UAV, for example.

Dr Licursi sees a promising future for the employment of metasurfaces with small UAVs which could support specific tasks like facilitating lightweight, multifunction antennas fabricated from these materials. As the Ukraine conflict has illustrated, these aircraft are now largely disposable and relatively inexpensive systems. The *Kyiv Independent* reported in January 2025 that Ukrainian naval units had destroyed over 37,000 Russian UAVs in 2024. However, Licursi believes that metasurfaces will need to reach a price point where they are economical to use on such aircraft. A price tag of USD 100,000 to configure a UAV with a DRFM is simply not feasible given such loss rates. If a UAV could be configured with metasurfaces for circa USD 1,000 then this could become practical, particularly if it helps the aircraft survive numerous missions. As more metasurface adoption occurs, so prices will reduce thanks to economies of scale. Metasurfaces are not going to immediately revolutionise electronic warfare, particularly in the air domain. Instead, expect an incremental adoption as the technology matures over the coming years. Electronic protection improvements heralded by metasurfaces may be similarly incremental, but ultimately profound, over the longer term.

Improving the survivability of small UAVs is another potential application for metasurface technology. While these aircraft are designed to be inherently disposable, improving their survivability is an important force multiplier. [Ukrainian MoD]

Quantum leap

Dr Thomas Withington

Rydberg atom based-sensing could make an important contribution to the enhancement and improvement of radio and radar signal detection.

The city of Halmstad on Sweden's southwest coast has the distinction of hosting the country's first ever International Worker's Day demonstration which took place in 1897. Twelve years earlier, the city's first trade union was formed by textile workers. In 1854, the city became the birthplace of physicist Johannes Rydberg. It was Dr Rydberg who devised his eponymous formula, which would lay the basis for an emerging form of electromagnetic sensing, which harnesses quantum physics.

The work of the Swedish physicist Johannes Rydberg has been instrumental in helping to advance quantum physics, and the Rydberg atom sensing subdiscipline, which is showing promise as a future electronic warfare technology. [The Archives and Museum of the Academic Society]

AUTHOR

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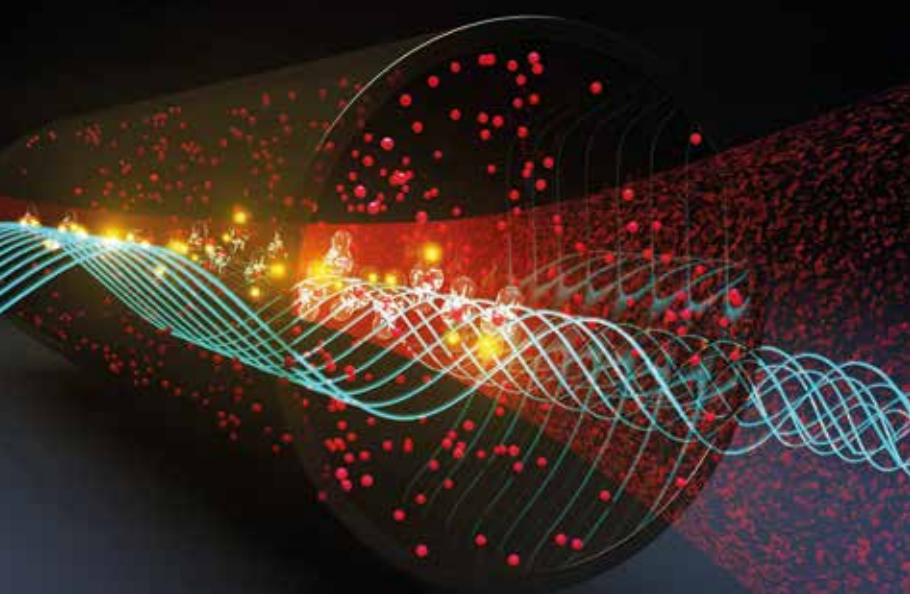
The resultant Rydberg formula predicts the wavelength of light which is produced by an electron moving between energy levels as it orbits an atom. Atoms are comprised of a nucleus, which contains neutrons and protons, with the nucleus surrounded by electrons. The number of electrons possessed by an atom can be determined by a chemical element's atomic number. This number details how many protons are found in the nucleus of each of that element's atoms, with the atomic number equal to the number of electrons surrounding the nucleus. Electrons will orbit the atom's nucleus at different distances. Hydrogen has an atomic number of one and hence a single proton and a single electron. The energy of an electron changes as it moves from one orbit to another. As electrons change their energy state, they release or absorb photons, and photons are the particles of which light is comprised. If an electron moves from a low-energy state to a high-energy state, it absorbs a photon. Conversely, when an electron is moving from a high-energy state to a low-energy state, it emits a photon.

An article published in February 2024 by Forbes magazine, written by Paul Smith-Goodson, entitled 'Quantum Sensing Unleashed: How Rydberg Sensors Will Disrupt Telecom', provides a good introduction to the Rydberg sensing discipline. Quantum sensing is "a cutting-edge technology that harnesses the strange and unique properties of quantum physics to detect tiny changes in the environment with extreme precision," said Bruno Desruelle, Vice President of Photonics at Exail. He added that "[by] manipulating particles like photons or atoms, these sensors measure minute variations with unparalleled accuracy." These properties explain why Rydberg atom sensing are attractive for defence applications like electronic warfare (EW). Joe Spencer, a quantum technology specialist at Global Quantum Intelligence in London, defines a quantum sensor as a "device that can measure or detect the environment in either better ways or new ways than we can currently."

Smith-Goodson's article notes the applicability of Rubidium (Rb) to Rydberg sensing. Rubidium is an alkali metallic chemical element with an atomic number of 37. Rubidium has 36 electrons orbiting consecutive distances from its nucleus. However, its 37th electron is a valence electron, which orbits on its own some distance from the nucleus. As the article notes, the 36 electrons orbiting close to the nucleus act as a barrier, weakening the attraction between the nucleus and this single valence electron. By adding energy to a Rubidium atom using a laser, this single valence electron is moved even further away from the nucleus. Much as the electron's attraction to the rubidium's nucleus is weakening, so its susceptibility to other factors like electromagnetic forces grows. It is these weakly-bound electrons that can be exploited for radio frequency (RF) sensing.



This graphic represents the effect that a wave of light will have on atoms by causing their valance electrons to move away from the nucleus when excited by lasers working at specific frequencies. [US Army]

The properties of atoms vis-à-vis their electrons, and how these electrons behave is denoted by their quantum number. The quantum number essentially describes an electron's position and energy in an atom. Four specific criteria are used to derive a quantum number: principal, angular momentum, magnetic and spin. The principal quantum number escalates in value from one upwards, denoting how far an electron is orbiting from an atom's nucleus. One denotes the electron orbit closest to the nucleus and the numbers increase as you move away. The larger the principal quantum number, the further the electron is from the nucleus. The electron nearest the nucleus will also have the lowest energy state. Add energy to that electron, and it will jump to a higher orbit away from the nucleus and experience an increase in principal number. This process also works in reverse and is known as absorption or emission. As noted above, add energy to an electron and photons will be absorbed, weaken the energy and the electron will emit photons. Angular momentum describes the shape of an electron's orbit around the nucleus. The number of orbits and their orientation is determined by the magnetic quantum number. Finally, the spin quantum number denotes the direction of an electron's spin. A high quantum number will denote that one or more electrons are comparatively further away from the nucleus than a low quantum number. Rydberg atoms have high quantum numbers with at least one electron a comparatively long distance from the nucleus. Dr Spencer said that this atomic quantum state can be vulnerable to alteration by heat or external electromagnetic force. This fragility provides a means of measuring the very factor that may change the state of an atom, such as a magnetic field.

A Rydberg atom's furthest electron from the nucleus will be very sensitive to electromagnetic energy. RF energy, which radios, radars and satellite navigation systems depend on, is a form of electromagnetic energy. The radio segment of the electromagnetic spectrum covers a waveband of 3 KHz to 3 THz. A January 2024 article published in the *EE Times* written by Robert Huntley detailed an approach to Rydberg atom sensing using spectroscopy, which measures the interaction of atoms and molecules with light, which can include visible light as well as ultraviolet, and lasers (coherent light). Light will be absorbed, emitted or scattered by particles as the former interacts with the latter.

Rydberg atoms and RF sensing

How can Rydberg atom sensing help detect RF energy? This process requires spectroscopy, electromagnetically-induced transparency (EIT) and a cell containing a chemical such as Rubidium or Caesium. EIT involves making a medium, such as a specific material, transparent when subjected to a probe field such as a laser beam. The probe field will interact with this medium that is usually opaque, and this process causes the absorption of the light by that material. Initially, when the probe field enters one side of the medium, there will be no transmission of light out of the other side. At this point, the probe field is being entirely absorbed by the medium. However, by applying a second stronger probe field, light from the first probe field can be transmitted through the other side of the medium, making it transparent. This process is possible through the behaviour of the medium's atoms. When the initial probe field is applied, it excites the atoms from their ground state. The ground state is the condition when an atom, and its accompanying electrons, are all at their lowest energy state. Applying the probe field excites the atoms, causing their electrons to absorb photons and preventing any transmission of the probe field through the material. By applying the second, stronger field this process is altered, enabling the transmission of the probe field through medium.

The standard method of sensing RF energy is to use an antenna, much like that which would equip a radio, television or your cell phone. Antennas work well as a means of transmitting and receiving radio signals but have drawbacks: Firstly antennas can have their performance and accuracy enhanced or degraded according to the quality of their con-

Rydberg Technologies has commercialised Rydberg atom sensing through products like its Rydberg Field Measurement System. This uses spectroscopy to collect and characterise RF signals. [Rydberg Technologies]

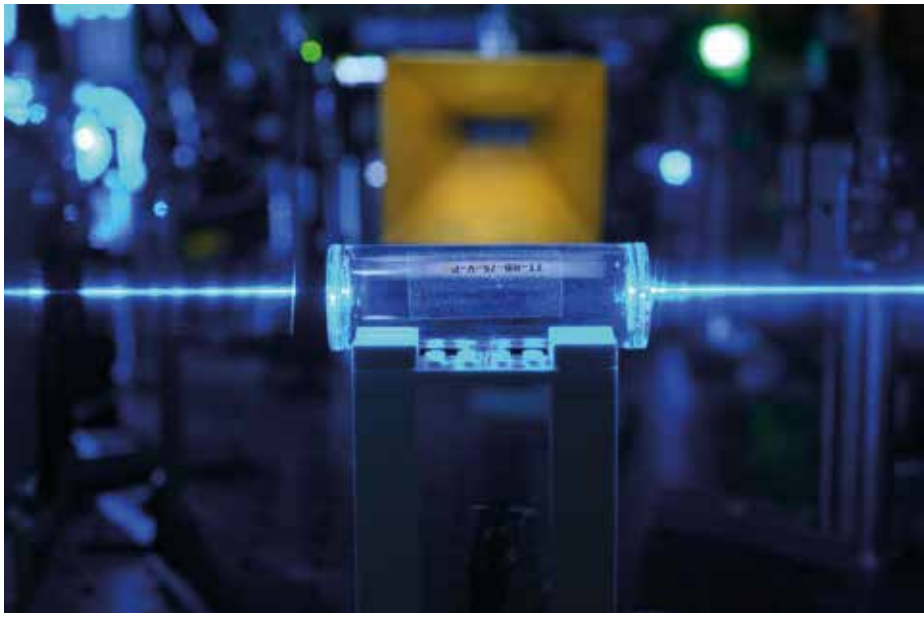
struction. A general rule of thumb in RF engineering is that a dipole antenna, such as metal rod or wire, is one half or one quarter of the wavelength that it is designed to receive and transmit; wavelength is the measurement of the distance between a peak and trough in a radio wave. Antennas must be sited and calibrated to ensure they can work is desired; for example, the higher an antenna is placed, the wider its field-of-view will be, and the better its performance in receiving and transmitting signals. This is why television antennas are placed on top of houses and not in their basements. Moreover, the performance of antennas can change as they age. Environmental factors such as heat may also affect their performance as metal expands and contracts.

Atoms, on the other hand, have specific properties which make them attractive for RF sensing as they have their own accurate properties, and these differ from element to element. For example, the resonant frequency of hydrogen is 1.24 GHz. This means a hydrogen atom will emit a frequency of 1.24 GHz when it transitions from its ground state to a higher energy level and vice versa. As these frequencies are fixed, devices using these mediums for RF sensing are self-calibrating. Importantly, they do not suffer the physical changes experienced by metals. Given that atoms do not need to be size-dependent in a similar fashion to an antenna, they can potentially cover a much larger waveband of frequency detection. Rydberg atoms can be sensitive to external stimuli such as RF energy, as they are very sensitive to microwave electromagnetic energy. Microwaves typically stretch from 300 MHz to 300 GHz. From a military perspective this encompasses the ultra-high frequency (UHF; 300 MHz to 3 GHz), L-band (1-2 GHz), S-band (2-4 GHz), C-band (4-8 GHz), X-band (8-12 GHz), Ku-band (14-18 GHz), K-band (18-27 GHz) and Ka-band (27-40 GHz) wavebands routinely used for convention radio and satellite communications, satellite navigation and radar.

To understand how all these factors come together to detect microwaves, it is necessary to consider the following architecture. An atomic vapour derived from a material such as Rubidium or Caesium is used, precisely because these materials have a single valance atom which can be employed to detect microwaves. Rubidium atoms are excited by lasers using the EIT process described above. The probe laser and strong field, or coupling, lasers will have frequencies of 351.9 THz and 589 THz. The goal is to use these Rydberg atoms to transfer their activity into an optical readout to demonstrate the presence of microwave radiation. The architecture will also need an optical converter to change the incoming RF energy to be analysed to an optical signal. This optical signal can then be used to drive the lasers which will initiate the EIT process. Dr Spencer noted that the components required for Rydberg sensing include a physics package which comprises the atoms that will do the work; "laser systems to control them, photonic circuitry to direct light, detectors to detect signals and feedback systems to maintain atomic states and control the states, and finally a robust housing to shield such a system from unwanted environmental noise."

Next steps

Although Rydberg sensing shows promise in microwave detection, it may be some years until this technology is deployed on the battlefield. As this article has illustrated, much of the work on using Rydberg atoms to aid microwave detection has been confined to the laboratory. It would be reasonable to assume that the technology largely meets a Technology Readiness Level (TRL) of four. US Department of Defense (DOD) and European Union (EU) TRL levels are similar: For both, TRL-4 denotes that the technology has been validated in a laboratory environment. This is just under halfway through the nine US DOD and EU TRL steps that must be taken before an actual system is demonstrated and proven operationally. Relevant operational environments could include representative military exercises or actual battle. The challenge will be developing Rydberg atom sensing to a point where it can equip an Electronic Support Measure (ESM).



The US Army has been experimenting with Rydberg sensing for RF signal detection. In 2018, the US Army Combat Capabilities Development Command's Army Research Laboratory developed the world's first quantum receiver to detect communications signals. [US Army]

ESMs are routinely used by sea, land, air and space forces to detect, locate, identify and characterise RF transmissions from radios and radars. ESMs play a key part in the Electronic Support (ES) mission. EW contains three subdisciplines of Electronic Attack (EA), Electronic Protection (EP) and ES. The US DOD *Dictionary of Military and Associated Terms* defines EA as a division of EW which employs electromagnetic, directed energy or anti-radiation weapons "to attack personnel, facilities, or equipment with the intent of degrading, neutralising or destroying enemy combat capability". EP concentrates on protecting blue forces against EA. ES aids "immediate threat recognition, targeting, planning and (the) conduct of future operations" from an EW perspective.

One of the key contemporary challenges is that ESMs must find and process a Signal-of-Interest (SOI) within what are often very noisy electromagnetic environments. We are continually surrounded by electromagnetic noise which affects the radio spectrum. Some of this noise emanates from space and some occurs naturally on Earth. RF noise is also caused by human activity, cell phone use and broadcasting being two good examples. An ESM's work is further complicated by the fact that military communications and radars transmit RF signals using low probability of detection/interception (LPI/D) techniques. Understandably, users of such equipment are keen for their systems to be as difficult as possible to discover via their radio signals. Once signals are discovered, their source can be pinpointed: Find a signal and you find the soldier, platform, weapon, sensor or base using this radio or radar. Once the source of transmission is determined, coordinates can be derived for the target to be attacked kinetically. Furthermore, a radio signal can be exploited for communications intelligence (COMINT). A radar signal can be similarly mined for electronic intelligence (ELINT). Both ELINT and COMINT provide useful information on the characteristics of these radar and radio signals. By understanding these characteristics, EW cadres can ascertain how these signals could be jammed.

Radar electronic support measures such as L3Harris' ES-3701S naval ESM shown here require large antenna arrays to capture signals of interest which can create engineering challenges. Rydberg sensing approaches could help to reduce reliance on such complex architectures. [L3Harris]

LPI/D adornments for signals are intended to help these signals 'hide' in prevailing electromagnetic noise. One standard LPI/D technique is to make these signals as discreet, or electromagnetically quiet, as possible meaning that the signal will be very weak. In fact, a signal may be so weak that it seemingly disappears within the prevailing noise. An ESM depends on a signal amplifier to strengthen a weak SOI that the apparatus has detected so that this signal can be properly analysed. However, the amplifier's components also produce noise. It may be possible to amplify a very weak signal, but this will see a corresponding amplification of the system noise. As Rydberg sensing is not dependent on an amplifier; an ESM thus equipped may be able to extract the characteristics of a very pure signal with minimal accompanying noise. Such techniques may help cut through LPI/D signal adornments.

NATO interest

Rydberg sensing properties are motivating research efforts in the military domain in the US and France. Rydberg Technologies is one company which is forging ahead with commercialising Rydberg sensing innovation. The company's Rydberg Field Measurement System uses spectroscopy to collect and characterise RF signals. RF signals can also be collected across a wide waveband using the equipment which would ordinarily require multiple receive antennas. Using multiple antennas adds complexity to an ESM as it demands additional hardware and software. Traditionally, ESMs detect signals across wavebands of between 18 MHz and 2 GHz, to 18-40 GHz, depending on customer preferences. Rydberg Technologies has stated that its technology can detect electromagnetic waves from almost 0 Hz to 100 GHz. Such epic wavebands could be very useful in the future as militaries begin to exploit signals above 40 GHz for communications and sensing.

In the public sector, the US Defence Advanced Research Projects Agency (DARPA), has Rydberg sensing as a key part of its SAVANT (Science of Atomic Vapours for New Technologies) effort. Across the Atlantic, the *Agence Nationale de la Recherche* (ANR; ENG: French National Research Agency) has embarked on the 'Cardamone' programme. As the ANR's literature makes clear, Cardamone is examining the potential and limitations of Rydberg sensing technology with an interest in RF sensing. Partners in the Cardamone initiative include Thales, the *Lumière, Matière et Interfaces* (ENG: Light, Material and Interfaces) laboratory at the Paris-Saclay University and the Charles Fabry laboratory at the same institution. Dr Spencer emphasised that "quantum sensors are being tested in the real world right now", although noting that "there is still work to be done to make them fully operational." Johannes Rydberg would no doubt have been pleased to learn about the consequences of his pioneering work over 150 years later.

Unmanned advantage: Russia's drones and the fight for ISTAR in Ukraine

Sam Cranny-Evans

From wedding photographers with DJI Mavics, to Lancets and Z-16 reconnaissance drones, the Ukrainian conflict has witnessed an unprecedented proliferation in drone-based battlefield Intelligence, Surveillance, Target Acquisition, and Reconnaissance (ISTAR), as well as precision strike. This article explores primarily how Russia has rapidly adapted and evolved its drone capabilities, turning drones from less-common support tools into near-ubiquitous critical assets to help their forces can locate, track, and engage targets with high accuracy.

Behind Grandma Hanna's house

As columns of Russian troops poured into Ukraine across the border with Belarus, confusion reigned. Colonel Oleh Shevchuk was commanding Ukraine's 43rd Artillery Brigade which operated three batteries of 2S7 Pions, the fearsome 203 mm howitzer designed during the Cold War to provide counter-battery and tactical nuclear strikes. It can fire its 110 kg ZOF 43 shells out to ranges of 37 km, which meant the three batteries defending Kyiv were uniquely positioned to bring the Russians under early fire, preventing them from advancing and organising as they wished – but only if the commander could figure out where they were. To start with, they received conventional requests for fire from the formations defending Hostomel airfield, but soon civilians who worked as wedding photographers were phoning Shevchuk and offering to find targets with their DJI Mavic drones, sharing the information over WhatsApp and video calls.

In another example, the 43rd Brigade learned that Russian forces were approaching a village within range, but they did not know where. Now, as the story that he repeated to a journalist goes, the targeting team used Google Maps to find the phone number of a shop in the village and contact the owner who confirmed the location of Russian forces in the village. He described one interaction like this, "Good evening, we're from Ukraine! Do you have any *katsaps* [an ethnic slur for Russians] in the village? – Yes. – And where? – Behind Grandma Hanna's house? – And what house does Grandma Hanna have?" The brigade was able to conduct a fire mission based on this information. Using similar contacts, they also corrected unobserved fire by asking people to watch a given area and let them know if a shell exploded there. Working once more with Google Maps, they could adjust their fire based on where the person said the round had landed. It was clear at the time that the Russian forces were struggling to establish the reconnaissance-fire contours that could bring fire down within minutes of Ukrainian guns unmasking.

A 2S7 Pion in service with the 43rd Brigade fires a round against a target. The range of the guns enabled them to strike early and hard against Russian units, despite a lack of persistent ISTAR. [Ukrainian MoD]

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It was several months before the 43rd Brigade received its own drones to conduct fire correction and target detection with. When asked whether his brigade had not had the need for aerial reconnaissance before the war, Shevchuk answered, "The need was always there, but the application was supposed to be different. The plan was like this: the scouts would find the target, dictate its coordinates to us, we would work it out and that was it. But practice has shown that if the shooter cannot see his target, the effectiveness of this shooting is reduced several times." He was referring here to forward observers and reconnaissance teams, elements that can be found in most forces. The principle is fairly simple and has remained similar since indirect fire became possible and useful. An observer who is physically able to see the target area radios coordinates to the supporting artillery and then may correct fire if necessary, although many Western forces work to fire for effect from the first shots. This developed quickly, however, and the growing lethality of both sides led to one Russian commander complaining that his forward observers in Kharkiv refused to leave their bunkers, instead relying on DJI Mavics and similar drones to do their job. As Russia's forces advanced and retreated, and Ukraine's forces adapted, the nature of Russia's ISTAR battle changed, moving from a conventional approach that was enshrined in doctrine, to one that prioritised precision to a far greater degree than any Russian force before it.

Orlan-10 and the ISTAR battle

From the start of the war, both sides have battled for an edge in intelligence, surveillance, target acquisition, and reconnaissance (ISTAR). Russia likely held an advantage in unmanned aerial reconnaissance, but the situation varied depending on the area and units involved. Nonetheless, the Russian MoD indicated that there were 2,000 unmanned aerial vehicles (UAVs) in service in 2018 – many of them the Orlan-10. These UAVs were primarily integrated into Russia's artillery brigades to provide fire correction and reconnaissance in a counter-battery role, and only later made it into wider circulation with other Russian units. This meant that in the opening phases of the war, many Russian artillery units would simply conduct massed fire missions against area targets with little in the way of target confirmation. "They mainly shoot at squares," Shevchuk's chief of staff Colonel Serhiy Ogerenko said, "This is how it was last summer: evening begins, and they go – every forest strip, grove, stream, regardless of whether there are people there, everything is shot through. They had no shortage of ammunition." It was only towards the end of 2022 that most Russian artillery units began correcting their fire with DJI type drones and Orlan-10s.

A soldier carries an Orlan-10 to the rear of its command vehicle during the Slavic Brotherhood exercises in 2018. The Orlan-10 is designed to be assembled and deployed by its crew in close proximity to the frontline. [Russian MoD]

For many reasons, the discussion of drone use in Ukraine has shifted away from the Orlan-10, despite it forming the backbone of Russia's airborne ISTAR. Its continued use makes it worth examining. It is a fixed-wing UAV designed and manufactured by Russia's Special Technology Centre in St. Petersburg, and entered service with Russian forces from around 2013. It would be referred to as a Group or Class 2 UAV in US military parlance, meaning it weighs no more than 16.5 kg, with a base weight of 12 kg, which varies depending on the payload. It has an operational range of 150 km, which can reportedly be extended out to 600 km with repeaters or by other Orlan-10s, and it can fly for at least ten hours with recovery via parachute. The system is typically deployed as a group of two or three UAVs, which can all be operated from a single MP32M1 command and control vehicle.

A Russian soldier from the 150th Motorised Rifle Division prepares to launch an Orlan in 2019 during an exercise. [Russian MoD]

The payload of Orlan-10s varies enormously – some sources indicate there are as many as 11 different variants. One version disassembled by Ukrainian soldiers carried a simple digital camera from Panasonic. However, there are known to be some variants that carry thermal imagers, or digital cameras in gimbal mounts that allow the camera to be moved separately from the drone. There are others still that provide a platform for electronic warfare payloads. Perhaps the most well-known is the RB-341V Leer-3 system, which uses Orlan-10s to intercept and monitor 3G and 4G communications. This was used in Ukraine prior to the invasion to target Ukrainian formations as well as to send messages to soldiers' mobile phones in a bid to undermine morale. Another, less infamous version is known as Shelest (Шелест; ENG: Rustle); an interesting system designed to locate and

support the engagement of counter-battery radars. Supposedly leaked reports from 2016 from the Russian MoD state that it was used to locate AN/TPQ-48 Fire Finder radars through signals intelligence. It was also used to jam or deceive those radars, preventing them from registering the fire that eventually destroyed them.

The Orlan-10 is a relatively simple UAV, even when carrying a thermal imaging payload. This is because it is not equipped to automatically provide actionable coordinates. It is understood to be used in one of two ways; either triangulation of a target, in which case it would essentially be used as if it were a forward observer, or by holding a position above the target. The operator would then use those coordinates to generate a fire request. This approach was fine when ammunition was plentiful and targets concentrated. Artillery can often be an imprecise weapon for several reasons; the flight of a shell is impacted by the temperature of the charge and the barrel, how well the gun is sited in relation to the target, and the wear of the barrel. Once fired, the meteorological conditions begin changing the shell's flight path. The end result is that a howitzer or – preferably a battery – will produce a beaten zone that is approximately cigar-shaped around the target area. This means that if you are trying to destroy a single gun and its crew in the edge of a woodblock, it will likely be necessary to fire dozens of rounds to have an effect. This takes time, depletes barrels and ammunition, and is exhausting for the crew. Precise target coordinates were nice to have but unnecessary for Russian formations, considering that one form of counter-battery engagement was a full salvo from a BM-21 battalion. This would mean 18 vehicles firing 720 rockets each with a 20 kg warhead covering an area the size of four football pitches. So, while ammunition was plentiful, there was little need to improve the accuracy of Russian ISTAR. However, as Ukraine's artillery dispersed to improve its survivability, at times with single guns fighting independently, Russia's ISTAR had to adapt.

Precision strike, needs precision find

Russia has employed a potent mix of counter-battery ISTAR assets to find and engage Ukrainian howitzers. This included the 1L219 Zoopark-1 counter-battery radar, the AZK-7M acoustic artillery ranging system, and the 1B75 Penicillin acoustic artillery ranging and thermal detection system. Between them these systems are able to detect and locate large calibre (152/155 mm and up) artillery fire out to distances of 25 km. Some, like 1B75 Penicillin, can locate fire within five seconds, according to Russian media reports. However, the Ukrainians quickly countered these systems. Zoopark radars have been engaged with anti-radiation missiles, M982 Excalibur 155 mm GPS-guided rounds, and guided rockets. This has changed the unmasking policy around these vehicles; one Russian news outlet conducted an interview with a Zoopark-1 operator who indicated in late 2022 that the system was used sparingly to minimise the risk of it being detected and engaged. These systems worked alongside the Orlan-10 to provide counter-battery ISTAR and they were – and still are – reasonably successful; however, the dispersion of Ukraine's forces and lack of ammunition drove a different approach. Russian strikes had to become more accurate, and to do this, they needed precise location and engagement capabilities. In this vein, from 2023, Russian forces noticeably increased the use of the Orlan-30 and the 3OF39M1 Krasnopol'-M1 laser-guided artillery round to find and engage Ukrainian howitzers.

The view from an Orlan-10's camera as it observes Russian fires. The video feed from the Orlan is fairly recognisable from the crosshair, which changes colour. [Russian MoD]

The Orlan-30 is a larger cousin of the Orlan-10, with a greater payload capacity of 8 kg and a maximum take-off weight of 27 kg, which means it can carry three or more mission payloads simultaneously. Its operational range is up to 500 km using a signal repeater and it has a top speed of 170 km/h with an endurance of eight hours. Like the Orlan-10, its maximum altitude is 5,000 m and it provides a video data link so that footage from its optoelectronic sensors can be received by the ground control station in real time, assuming that it is not jammed or otherwise disrupted. However, the key differentiator between the Orlan-10 and the Orlan-30 is the latter's ability to carry a laser target designator. This means that it can provide more accurate target locations for Russian batteries, or act as a provider of laser guidance for a range of munitions. The Krasnopol' round is a 152 mm round designed to be fired from towed and self-propelled howitzers (SPHs). It has a range of up to 20 km and a 6.5 kg warhead, which makes it suitable for defeating towed and self-propelled howitzers, and in some cases tanks. Russia may have expended its stocks of this munition very quickly in 2022, with some reports indicating they were simply fired without guidance. Nonetheless, by 2023, the CEO of Russia's High-Precision Complexes indicated that production of the Krasnopol' had increased twenty-fold. It was also modified to the M2 standard, with a larger warhead and improved guidance. [Editor's note: Somewhat unhelpfully, Russian industry has previously promoted the 'Krasnopol-M2' as the 155 mm variant of Krasnopol-M1; however, since then, a 152 mm version with the GRAU designation '3OF95' has appeared, also referred to as 'Krasnopol-M2', thereby somewhat muddying the waters.]

Code red to code secure: SATURN's Impact on the future of military communications

As the global military landscape continues to shift, one constant remains: The paramount importance of secure, reliable communication. SATURN, the latest advancement in military radio communications for NATO and its allies and partners, is not just a technological leap, it is a strategic imperative, enhancing interoperability, bolstering security, and reconfiguring the dynamics of modern warfare. Through an in-depth conversation with Thomas Geißler, Head of Sales Defense | Security | Critical Infrastructure Europe, Rohde & Schwarz, we explore the multifaceted impact of SATURN.

Can you explain what SATURN is and its significance in military communications? How does it fit into the broader landscape of secure communication technologies?
SATURN is the new NATO standard for military radio communications, specifically designed to enhance security and reliability in the UHF band. Think of it like a highly secure, special waveform for military forces to communicate, making it much harder for unauthorized parties to intercept or jam their conversations. In the context of military operations, secure communication is not just a luxury, but a necessity. SATURN represents a significant leap forward in this area, addressing the evolving challenges of modern warfare and the increasing sophistication of threats.

How does SATURN improve upon the current system, HAVEQUICK? What were some of the key limitations of HAVEQUICK that SATURN aims to address?
Imagine HAVEQUICK as an older, reliable car. It's served well, but SATURN is like the latest, high-tech vehicle – faster, more agile, and equipped with advanced safety features. HAVEQUICK, while effective in its time, had limitations in terms of its resistance to jamming and its ability to adapt to modern, dynamic battlefield scenarios. SATURN's technology makes it much more resistant to interference and jamming, ensuring that critical communications get through, even in challenging environments. Additionally, SATURN offers enhanced flexibility and interoperability, allowing for more seamless coordination among different units and allies. In a nutshell, SATURN is the digital waveform successor of the analogue HAVEQUICK waveform.

Can you simplify what 'fast frequency-hopping waveform' means in the context of SATURN? How does this technology contribute to the security and reliability of communications?
Think of radio frequencies like channels on your TV. A 'fast frequency-hopping waveform' means SATURN rapidly switches between many channels. This makes it extremely difficult for anyone trying to intercept or disrupt the signal, as they can't keep up with the rapid channel changes. It's like trying to find a specific TV channel that's constantly changing its number. This technology is a game-changer for security because it significantly reduces the window of opportunity for potential eavesdroppers or jammers, thereby protecting the integrity of the communication.

How widespread is SATURN's adoption expected to be, and what does this mean for global military operations? Are there any notable examples or upcoming deployments that highlight SATURN's potential impact?
SATURN is already designated as a NATO Minimum Military Requirement, which means many NATO and allied forces will be adopting this standard. This will significantly enhance interoperability – the ability of different forces to communicate seamlessly with each other, regardless of their country of origin. Imagine a global, secure network for military communications, facilitating smoother, more effective joint operations. We're seeing keen interest from various member states, with several already in the process of integrating SATURN into their military architectures. While specific deployment details are subject to security clearances, it's safe to say that SATURN will play a pivotal role in upcoming international exercises and coalition operations.

What role does Rohde & Schwarz play in this transition, and what expertise do you bring to the table? Can you share any insights into the development process and the challenges overcome?
We're proud to have been a key partner in SATURN's development. Our decades-long experience in creating secure communication solutions, including the predecessor HAVEQUICK, positions us uniquely to support this transition. As an active member of the relevant NATO working groups, we have made a significant contribution to the development and definition of this waveform, procedures and interfaces. We've worked closely with NATO and its allies, leveraging our expertise in software-defined radios, waveform development, and cybersecurity to ensure SATURN meets the most stringent requirements. One of the significant challenges was balancing the need for enhanced security with the requirement for seamless interoperability among diverse military platforms. Our team's dedication and collaborative spirit with our NATO partners were instrumental in overcoming these hurdles. As a reliable partner, we have already successfully implemented a high number of our SATURN-capable radios, enabling the transition to SATURN for our customers.

Paired with the Orlan-30, Russia's counter-battery efforts were able to precisely engage Ukrainian howitzers with a single shell. Krasnopol is not always effective, as low cloud is understood to have disrupted the seeker in some cases, and a wooden shelter above a hide is reportedly sufficient to degrade its effects and at least save a howitzer. However, announcements from Uraltransmash, the design authority for Russia's modern howitzers, indicate the intent to integrate UAVs such as the Orlan-30 directly into the Msta-SM2. This would only be worth doing if the howitzer was carrying laser guided munitions, which may suggest that Russia is planning to empower some guns to fight independently of a battery or battery command post. This is not all for the Orlan-30, however. In September 2023, a series of videos showed precise Russian strikes against bridges in the rear of Ukrainian forces. The bridges were struck, according to Russian sources, by Kh-38ML missiles fired from a Su-34 fighter-bomber jet. The Kh-38ML is a laser-guided missile with a range of 40 km and a 250 kg high explosive warhead; some videos released by Russian channels indicate that the targeting of bridges was provided by an Orlan-30.

Z-16 and Lancet-3

In July 2022, a handful of videos were released via social media showing a white drone with two pairs of cruciform wings streaking into Ukrainian vehicles. This was the first evidence that the Lancet-3 loitering munition from Zala Aero had reached the frontlines. Its use was minimal at first – only 100 uses were logged by pro-Russian website *lostarmour.info* by the end of 2022. However, as with the Krasnopol, the use of the Lancet family of loitering munitions would grow dramatically, and it represented the most significant shift in the ISTAR battle.

The Izdeliye-52 (also known as Z-52, or sometimes as 'Lancet-3'), is a loitering munition in the Lancet family. There have been several versions of this design, and the latest production version is understood to carry the designation Izdeliye-52-3. It has a range up to 30-40 km and a top speed of up to 80-110 km/h. It carries an optoelectronic and infrared camera as standard – while earlier models were understood to simply use a day camera. In a further difference from earlier variants, the latest variant is also fitted with Lidar-based fuzing, enabling it to detonate the warhead at a short distance from vehicles, thereby potentially negating some kinds of protection. It is catapult launched and armed with the KZ-6 3 kg shaped charge warhead, which can penetrate up to 215 mm of rolled homogenous armour equivalent (RHAe). This makes it well-suited to engaging the less-protected areas of a howitzer or tank, often including those used to stow ammunition. Importantly, Izdeliye-52 can effectively strike moving targets.

▲ **The Z-16 -3 is visible here toward the top-left of the image, with the Izdeliye-51-3 below it, and the Izdeliye-52-3 on the right. Comparing the latter two, the Izdeliye-51-3 has larger cruciform wings at the front of the body and smaller one at the rear; this variant of the Lancet family has a longer range than the Izdeliye-52-3, and carries a larger 5 kg warhead. [Mztourist, via Wikimedia Commons; CC-BY-4.0]**

The Krasnopol can also hit moving targets, providing they do not exceed 36 km/h, which is potentially valuable. However, as Western guns entered service, Ukrainian units found they were sufficiently mobile to quickly relocate after unmasking, avoiding counter-battery fire from the likes of a BM-21 battalion or Krasnopol. However, Lancets have proven to be very effective for tracking Ukrainian guns down on the road and engaging them. They are, at times, daisy-chained, meaning the two or three will be launched at a single target to increase the likelihood of a kill. Lancet can provide its own ISTAR, however, with a relatively short endurance of 40 minutes, it is typically only used in this way when the crew is reasonably sure that a target is present – and this is where the Z-16 reconnaissance drone from Zala Aero comes in.

Regardless of their relatively short endurance, Lancets have become a key feature of Russia's counter-battery doctrine. Between July 2022 and February 2025, more than 3,000 uses of these munitions were documented by *lostarmour.info*. The highest usage on a monthly basis occurred in May 2024 as Russian forces advanced into the Kharkiv region. There, Lancets were used 108 times inside a single month within a 133 km stretch of front, the deepest strike extended 50 km from the most forward Russian units, into the Ukrainian rear. Often, the strikes were conducted against vehicles that were rushing to stem the advance, some of them carried on heavy equipment transports, indicating how Russia was able to dominate the ISTAR battle at that time.

tion. It can loiter over a target area searching for Ukrainian artillery either through thermal detection, or by flash spotting. At its typical operational height, the Z-16 provides a viewing range of more than 3,000 m, which is valuable when looking for howitzers hidden in a treeline. It has come to be a regular fixture among Russian formations, supporting the use of Lancets and regular artillery fire support missions with its laser designator. In a reflection of the ISTAR battle in Ukraine, the Z-16 is reportedly also used to detect Ukrainian drone crews and facilitate strikes against them either with Lancets or other munitions as available. It seems that the system is particularly prized for the high quality of its thermal imaging camera. Moreover, it is also understood to be involved in observing and supporting the use of UMPK glide bombs, which have posed a significant danger for the Ukrainian Armed Forces. The Z-16 also appears to have provided targeting coordinates for the 9M723 Iskander-M short-range ballistic missile against Ukrainian military infrastructure and vehicles, indicating that it is potentially resilient to electronic warfare.

Wrapping up

There are of course tens of thousands of drones in use every day in Ukraine. The smaller Mavic-type drones are used for many roles but not covered here. The three primary Russian assets covered in this article are likely to form the backbone of Russian ISTAR in the post-war period. The Russian forces have learnt to use and exploit these assets in both tactical and deep engagements indicating that they are likely to be aggressive and capable in future conflicts. The overall view also suggests that Russia has adapted well since 2022, from a force that was unable to service all of its targeting needs and dependent upon massed fires to make up for the lack of precision, to one that leverages precision extensively, every day. This is only possible because Russia has increased its ability to conduct precision find, and despite losses, maintain enough ISTAR assets along its main lines of effort to apply consistent pressure to Ukrainian forces.

A FAB-3000 with a UMPK glide/guidance kit is released from a Russian bomber. The Z-16 and other drones have been used to facilitate strikes with these weapons, removing previously vulnerable forward air controllers from the frontline. [Russian MoD]

The Z-16 is another series of Class 2 UAVs (around five different versions exist). The baseline model has an endurance exceeding four hours and a range of over 75 km. It has a maximum operational altitude of 5,000 m and a top speed of 110 km/h. It is also claimed to be resistant to electronic warfare by the manufacturer, as well as having a low radar cross section. The Z-16 is lighter than the Orlan-10, with a take-off weight of 10.5 kg including a 1.8 kg payload. It can be fitted with a range of sensors, but typically carries an optoelectronic day and thermal camera combination that is relatively high defini-

The development of unmanned systems in Ukraine

Alex Horobets

The large-scale use of unmanned weapons platforms in Ukraine reflects the rapid evolution of modern warfare, where tactical advantages are often short-lived due to the emergence of countermeasures. With Ukraine ramping up production of long-range unmanned aerial vehicles, this surge highlights Ukraine's growing reliance on unmanned systems for defence. Lessons from the war show that unmanned systems are now integral to military strategies, with success relying on adaptability and innovation.

Production capacity and range is increasing

Ukraine intends to produce nearly 30,000 long-range drones in 2025, according to President Volodymyr Zelenskyy, when he unveiled the plan in late 2024. In October 2024, Ukraine's Ministry of Defence reported that 1.6 million unmanned aerial vehicles (UAVs) of various types had been contracted over ten months, at a value of over UAH 114 billion (approximately EUR 2.55 billion). This number includes reconnaissance drones, long-range strike drones, first-person view (FPV) drones, and various other types. Yet this clearly doesn't represent all UAVs purchased for the Ukrainian defence forces over the past year, since drones are also separately contracted by other defence agencies, including the Security Service, the National Guard, and the Ministry of Internal Affairs. UAVs are also purchased directly on the open market by military units and volunteer organisations, who then hand them over to the military. Speaking of numbers, according to First Deputy Minister of Defence, Ivan Havryliuk, since the start of 2025, the Defence Forces have been receiving approximately 200,000 drones, including FPVs, per month. This marks a staggering tenfold increase year-on-year, with around 20,000 units received monthly in the first quarter of 2024.

However impressive these numbers might seem, as well as progress compared to 2024, under the conditions of large-scale combat, the need for massive supply of UAVs of various types will always remain. Therefore, even with the current statistics, it is likely that the Ukrainian defence forces will continue to ramp up their UAV procurement. Even Russia, when attacking Ukrainian cities far behind front lines, exerting psychological pressure on Ukrainian civilians, most often make use of one-way attack (OWA) drones rather than missiles. Russia is also ramping up production of UAVs, including Shaheds and decoy drones, as the lifespan of its strategic aviation is not limitless. Additionally, ballistic missiles are significantly more expensive than drones, making them comparatively rare choices for precision strikes.

▲ Ukrainian-made ZEUS and HADES FPV UAVs. [Ukrainian MoD]

Russian OWA UAVs are also constantly being modernised, as are the tactics governing their use. Various methods of countering electronic warfare (EW) systems are tested to make drones resistant to spoofing and jamming. Additionally, the Russians are also trying to improve speed and manoeuvrability parameters. Russian manufacturers are also experimenting with payloads, loading drones with large amounts of explosives, various warheads, and other equipment. Meanwhile, the international community is still able to complicate the Russia's domestic UAV production and upgrades, since most spare parts consist of imported components. The situation is different for Ukraine, since it needs to deliver strikes at a range of 500 km or

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even >1,000 km. Certain types of UAVs are specifically used for this purpose, as Ukraine currently lacks other weapons capable of reaching targets at such distances.

Therefore, one key trend from 2024 was the notable increase in the number of different types of unmanned systems employed on the battlefield, on both side of the front lines. We are now at a stage where drones are able to attack Russian oil refineries, defence enterprises, and military infrastructure almost on a daily basis, both close to the border and deep inside the country. A qualitative breakthrough was achieved in 2024 in this regard, since in 2022, Ukraine delivered no such attacks, and in 2023 their long-range strikes rarely involved drones. At present, all Russian territory within 1,500 km of the Ukrainian border is under threat of long-range drone attacks. On the night of 6 November 2024, Ukraine attacked a Russian Navy Caspian Flotilla base in the city of Kaspiysk, nearly 1,500 km from Ukraine, striking several Russian naval missile carriers. Prior to that, the longest-range strikes were expected to cover a range of up to 1,200 km, including one that attacked Russian defence industrial infrastructure in the Republic of Tatarstan. At the same time, Ukrainian Commander-in-Chief Oleksandr Syrskyi said that Ukraine was able to strike targets at ranges of 1,700 km. Throughout 2024, a total of 377 targets in Russia were destroyed. This means there were many more direct OWA UAV attacks on these targets. In 2025, such strikes will remain a significant problem for Russia, since it is simply impossible to deploy effective air defences that cover all critical facilities scattered across Russia's vast territory. Numbers prove the effectiveness of such UAV raids. By the end of 2024, Russia's oil refining capacities had dropped to a 12-year minimum – all due to drone attacks.

Ukraine's UAV portfolio is growing

There are currently estimated to be more than 500 companies engaged in drone production in Ukraine, with more than 240 projects already certified by the Ukrainian MoD. The number of companies undergoing the certification procedure to obtain permission to supply drones to Ukrainian troops is also constantly increasing. Since the beginning of the full-scale war in February 2022, new UAV models have been developed in various categories, including large attack multi-copter designs, analogues of the Chinese Mavic drones, maritime uncrewed systems (known as 'naval drones'), and unmanned ground vehicles (UGVs) to support supply and evacuation. A peculiar advantage for Ukrainian systems is that they can be immediately tested in a live combat environment, and upgraded almost immediately should any shortcomings be exposed. Therefore, such products will potentially be competitive on the international market, boasting higher EW resistance and combat-tested upgrades.

The range of Ukrainian UAV models is quite impressive, but among them, models that have earned most fame should be separately highlighted. Even before the full-scale invasion, Ukraine produced a number of reconnaissance and attack reconnaissance UAVs, including the Leleka-100, designed in 2017 by Deviro. The Leleka-100 is capable of operating amid active EW and a lack of GPS signal, able to remain airborne for up to 4 hours, while covering a distance of up to 100 km. In 2024, the Shark reconnaissance drone developed by Ukrspecsystems was put into operation, representing another EW resistant model, performing reconnaissance missions at a range of up to 80 km. Ukrspecsystems showcased a new variant of the Shark-M UAV with a flight range of up to 420 km and an increased operating time of up to 7 hours. Ukrspecsystems' PD-2 drone has also proven effective, capable of carrying a 3 kg explosive payload in addition to conducting reconnaissance. For tactical reconnaissance, the Valkyrie UAV has been manufactured by Aviation Systems of Ukraine; the model has proven convenient due to its stealth features.

However, battlefield realities have forced manufacturers to focus on rolling out OWA UAVs that had not been developed before the full-scale war. Such drones are now capable of performing high-precision strikes at ranges of over 1,000 km.

▾ **Shark-M during flight. [Ukrspecsystems]**

Shark-D on its launch rail. [Ukrspecsystems]

Among the most famous models is the Antonov An-196 Liutyi drone, which accurately delivers an explosive payload at a distance of >1,000 km. In order to confuse Russian air defence systems and ensure mission success, smaller OWA drones, such as the Rubaka, are employed alongside the Liutyi. These two models are launched simultaneously as part of massed deep strikes. In a single attack, more than 100 different UAVs can be used, some of which are used to confuse Russian air defences.

Other similar Ukrainian projects have also earned acclaim due to high-profile missions carried out, such as the Bober UAV, a long-range loitering munition manufactured by UKRJET. Media reports claim this model has been used in attacks targeting Russia's oil refineries and Moscow.

Another focus of UAV work is the conversion of light commercial aircraft into unmanned systems, designed to carry out precise strikes at distances of >1,000 km. According to open sources, and based on published videos of Ukrainian attacks, these converted aircraft could be the A-22 Foxbat, a light two-seater sports plane capable of carrying a 200 kg payload out to a range of 1,200 km. Further development of such long-range UAVs may involve upgrades to ensure they become reusable rather than used as OWA drones. Eventually, they are expected to release bombs over intended targets before returning to base; for example, this could be a 250 kg FAB-250 bomb. Potentially, and if successful, such strikes will further undermine the operations of Russia's strategic aviation and further reduce the volume of energy generation across Russia.

Trends and new technical solutions

Unmanned systems developed in Ukraine possess significant potential for further modernisation and improvement. In 2024, the Ukrainian MoD simplified the procedures for certifying and testing drones; now, instead of six months, the process can take one month or even less. Thanks to drone testing directly in the combat zone, it is possible to significantly shorten the technological development and upgrade cycle.

The next steps in unmanned system development may involve increasing the number of UGV platforms, introducing AI functions, improving the technical features of UAVs, and developing drone interceptors.

For example, an increase is now observed in the operating range of FPV drones. Previously, commercially produced UAVs flew up to 5 km but now, thanks to repeaters, their range has been extended out to around 20 km. Due to the front line being saturated by EW, the use of fibre-optic controlled drones increased in 2024 (with the most notable uptick seen with Russian forces), and in 2025 they may be supplied even more widely to the Ukrainian Army. Their primary tasks may include attacking hostile jammers to clear the area for radio-controlled UAVs.

Ukrainians have also pioneered the use of drones as interceptors for Russian attack and reconnaissance UAVs. These interceptor drones, which can engage enemy drones mid-flight, are capable of reaching speeds of up to 280 km/h and carrying a 0.5 kg explosive payload; though even lower-tech interception methods have been observed – such as the interceptor UAV aiming a simple wooden stick into the propellers of the target UAV. Such methods of downing Russian UAVs are much cheaper than using traditional surface-to-air missiles (SAMs). Moreover, there is room for cooperation with international partners. In this regard, the Ukrainian innovation project, Brave 1, reported on the testing of the

▲ **Gulliver UGV authorised for use in the Ukrainian Armed Forces. [Ukrainian MoD]**

German-made Tytan interceptor drone, capable of reaching speeds of up to 300 km/h. The manufacturer plans to equip the drone with an automatic targeting system based on machine vision, and is willing to continue cooperation with Ukrainian developers.

After Ukraine's successful missions in the Black Sea, the world learned about Ukrainian unmanned surface vessels (USVs), such as the Magura V5. However, in 2025, we are likely to see the unmanned trend expand in the land domain, with a growing number and higher effectiveness of Ukraine's UGVs used for supplies, mining/demining, medical evacuation, and also for fire support, using machine guns, anti-tank guided missiles (ATGMs), or with a simple explosive warhead for the OWA role. In November 2024, Ukraine's MoD and the Brave1 platform tested 100 Ukrainian UGVs, which are expected to be delivered to combat units soon.

Conclusions

The development and application of unmanned platforms in the Ukrainian Army reveals how quickly the battlefield is changing and transforming under the conditions of full-scale modern warfare. The production and certification cycle is reduced as much as possible since relatively modern models may quickly become irrelevant due to the equally rapid emergence of countermeasures. Tactical advantages are often short-lived as opposing forces continue to search for new solutions, and the longer the hostilities last, the faster this tech race will become.

However, lessons learned from this war show that unmanned platforms have become an integral part of modern warfare, meaning these technologies will be further inscribed into military doctrines and strategies. The key to success on this ever-evolving battlefield will be the ability to quickly adapt and seek innovation, which will increasingly involve AI integration, better autonomy, and higher-quality communications to improve coordination.

Hellenic defence procurement poised to embark on new modernisation plan

Peter Felstead

While Greek defence procurement has been somewhat of a mixed bag in recent years, the Greek Ministry of National Defence (MND) is on the cusp of embarking on a major new modernisation plan.

According to NATO's latest figures for member states' defence spending estimates as a percentage of GDP (the cut-off date for data of which was June 2024), Greece ranks as the fifth-highest country in the Alliance, at 3.08%. Of the top seven spenders, Greece is one of only two nations (the other being the United States) that does not have a direct border with Russia.

In 2022 Greece actually topped the list of NATO defence spenders in terms of GDP percentage, spending 3.88%. For 2025, meanwhile, Greece will almost double its defence spending, which is projected to rise to EUR 6.1 billion. Much of Greek defence spending is spurred by its long-running tensions with Turkey, which has a much greater defence budget in absolute terms.

Within the Greek armed forces' new 'Long-Term Defense Armament Planning' programme, which covers procurement from 2025 to 2037, around EUR 25 billion will be allocated over the next 12 years to a wide range of programmes. The Long-Term Defense Armament Planning programme was set to be presented to the Greek Parliament in early April 2025. Thus, while a number of Greek defence programmes have ostensibly been approved, they are likely to move forward in earnest once the new defence plan has been debated in parliament and agreed upon.

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Air procurement

A major portion of Greek defence spending comes as a result of the country's decision to join the US-led F-35 Lightning II programme.

Eighty-four of the HAF's F-16C/Ds are being upgraded to the F-16V standard. [HAF]

The current backbone of the Hellenic Air Force's (HAF's) combat air capability is provided by a fleet of more than a hundred Lockheed Martin F-16C/Ds, 84 of which are being upgraded to the F-16V standard, as well as a fleet of 24 new and second-hand Dassault Rafales ordered between January 2021 and March 2022, the last of which was delivered in January 2025. However, the air force also operates older types, such as the Dassault Mirage 2000-5 and McDonnell DouglasF-4 Phantom II.

As a seasoned F-16 operator it was a logical progression for Greece to join numerous other European air forces flying the Fighting Falcon to transition to F-35. After Greece initially selected the F-35 in April 2019, the US State Department approved a Foreign Military Sale (FMS) of up to 40 F-35s in January 2024, in an overall package worth EUR 8.6 billion.

Greece then formally signed a letter of acceptance (LOA) for the procurement of 20 F-35As on 25 July 2024 to form an initial squadron. These aircraft are scheduled to be delivered in 2028, but will initially remain in the United States to

facilitate the training of Greek aircrew and technicians. Greece is then expected to subsequently exercise an option to procure an additional 20 F-35As.

While the Greek F-35 programme moves forward, the HAF is moving to extend the service life of its F-16 fleet and maintain operational readiness. In November 2024 the US State Department approved a USD 160 million (EUR 148.75 million) engine support package for the HAF's F-16 fleet.

While the HAF's transport fleet currently consists on paper of eight C-27J Spartans, five C-130B Hercules aircraft and 10 C-130Hs. Less than half a dozen of the C-130s are understood to be operational, which has become a significant issue in relation to the Greek government's ability to respond to natural disasters in the region. With that in mind, in February 2023 the Greek government ordered the purchase of six second-hand C-130J Super Hercules aircraft from Italy. Subsequently, in February 2024, the US State Department gave advanced notice of an intention to transfer two legacy US C-130Hs to Greece as Excess Defense Articles (EDA). The need to modernise the C-27Js has also been identified. The goal set by the Greek Ministry of National Defence (MND) and HAF is to have at least 10 C-130s and C-27s available for operations by 2027, according to reporting by Greek newspaper Kathimerini.

Regarding rotary-wing acquisitions, on 29 October 2024 Lockheed Martin's Sikorsky business received an FMS contract estimated to be worth USD 1.95 billion to supply the Hellenic Army with 35 UH-60M Black Hawk helicopters. The Hellenic Navy (HN) already operates 11 S-70B Seahawk helicopters and is procuring seven MH-60R Seahawks, the last of which is due to arrive in 2025, giving Greece operational and sustainment advantages in terms of fleet commonality.

In April 2021 Israel's Elbit Systems and the Israeli Ministry of Defence were contracted by the Greek government to establish an International Flight Training Centre for the HAF at its 120 Air Training Wing in Kalamata. Here trainee pilots move on from the HAF's fleet of Beechcraft T-6A Texan II turboprop trainers to train on 10 Leonardo M-346 advanced jet trainers. Elbit landed the first M-346s at Kalamata in May 2023 and the first HAF pilot cadets to train on these graduated in December 2024.

The HAF also has upgrading its fleet of four EMB-145H Erieye airborne early warning and control (AEW&C) aircraft as a priority and needs to find new search-and-rescue (SAR) helicopters to replace its obsolescent fleet of 12 AB-205As.

Greece is meanwhile looking to initiate a USD 2 billion programme to develop and field an integrated air and missile defence system to be known as Achilles' Shield. Greek officials have already been talking with Israeli air defence providers, but in March 2025 it emerged that Germany's Diehl Defence, which makes the IRIS-T surface-to-air missile (SAM), is also in discussion with Athens. An air defence system such as IRIS-T SLS could replace Greece's Russian-made 9K33 Osa-M and 9K331 Tor-M1 short-range air defence systems, while Greek newspaper *Kathimerini* has reported that the Israel Aerospace Industries (IAI) Barak MX air defence system is favoured to replace Greece's I-HAWK medium-range and S-300PMU1 long-range air defence systems; the latter of which is being divested and transferred to Armenia's Armed Forces.

A Barak ER SAM launched during trials. IAI's Barak MX system has been reported as being favoured to replace Greece's legacy I-HAWK and S-300PMU1 air defence systems. [IAI]

The Long-Term Defense Armament Planning programme also outlines the need to modernise Greece's PATRIOT air defence systems and acquire new radar systems to replace outdated ground-based radar units.

In terms of its unmanned aerial vehicle (UAV) capabilities Greece has been somewhat behind the curve in developing indigenous UAV capabilities. The HAF's UAV inventory, for example, currently consists of three leased Israeli Aerospace Industries Heron 1 medium-altitude long-endurance (MALE) UAVs and a small number of indigenously-developed Pegasus II MALE UAVs that are now around 20 years old. The Hellenic Army, meanwhile, operates around half a dozen different types of tactical UAV.

On 4 July 2024, the Greek defence minister at the time, Nikolaos Panagiotopoulos, announced to the Greek parliament that EUR 400 million would be allocated to purchase three General Atomics-Aeronautical Systems Inc (GA-ASI) MQ-9B SeaGuardian UAVs, one of which was demonstrated to the HAF and Hellenic Coast Guard in December 2019. However, a firm Greek order for MQ-9Bs does not seem to have been made.

The Hellenic Centre for Defense Innovation (ELKAK), meanwhile, asked in March 2025 for expressions of interest in developing a Greek cargo transport UAV to ensure the rapid and accurate delivery of supplies, particularly in remote or inaccessible areas where the use of conventional means is not feasible or efficient.

Land procurement

Under Greece's Long-Term Defense Armament Planning programme, a significant portion of the funding is allocated to the Hellenic Army, although more than 40% of the funds allocated to the army, amounting to around EUR 1.8 billion, is allocated to the replacement of Greece's Russian-made 9K33 Osa-M and 9K331 Tor-M1 short-range air defence systems.

Beyond this, key programmes include:

- The modernisation of the tank fleet;
- The acquisition of new Israeli multiple rocket launchers (MRLs)
- The upgrade of the army's Czech-made RM-70 MRLs;
- The modernisation of the army's armoured personnel carriers (APCs);
- the procurement of new infantry fighting vehicles (IFVs) after 2030;
- the acquisition of new wheeled general-purpose vehicles;
- the acquisition of electronic warfare systems for the Signal Corps;
- the procurement of loitering munitions (LMs); and
- acquisition of the aforementioned UH-60M Black Hawk helicopters.

The Hellenic Army's main battle tank (MBT) fleet consists of 170 Leopard 2A6HELs, 183 Leopard 2A4s and around 500 Leopard 1A4/5s; all M60A1/A3 tanks appear to have been withdrawn from active service, however, at least some M48A3/A5 MOLF tanks appear to remain in service, according to the Hellenic Army website.

In recent years a number of upgrades to the MBT fleets have been proposed and considered, while Greece has also acquired other armoured vehicles through various means.

In April 2024 Greek company EODH, in collaboration with Belgian-Spanish DUMA and Franco-German armour manufacturer KNDS, presented its proposed Leopard 1HEL upgrade for Greece's Leopard 1A5s, which could be a significant development given that the Hellenic Army is currently holds the largest Leopard 1 fleet. [EODH]

In April 2024 Greek company EODH, in collaboration with Belgian-Spanish DUMA and Franco-German armour manufacturer KNDS, presented its proposed Leopard 1HEL upgrade for Greece's Leopard 1A5s, which could be a significant development given that the Hellenic Army is currently holds the largest Leopard 1 fleet. The upgrade includes mobility improvements that include a new 746 kW (1,000 hp) engine, reinforced suspension, new track system and enhanced driver station with all-weather vision; a new stabilised turret drive system and integrated fire control system; a passive/reactive armour protection package, a sensor suite for active protection, and remote weapon station (RWS); and other enhancements that include a multi-layered communication system, sensor-effector fusion, a battlefield management system and an AI-centric architecture.

In February 2023 Greek defence news website *defencereview.gr* reported that the Greek defence minister at the time, Nikos Panagiotopoulos, had announced the Greek government's approval for the upgrade of 123 Greek Leopard 2A4 MBTs to the Leopard 2A7 configuration as well as the acquisition from Rheinmetall of 250 KF41 Lynx infantry fighting vehicles (IFVs). However, it does not appear that contracts for these deals have so far materialised.

Via Rheinmetall, the German government has already supplied Greece with 40 overhauled Marder 1A3 IFVs from former Bundeswehr stocks through the 'Ringtausch' project, under which the Marders were received in exchange for Greece transferring a similar number of Russian-built BMP-1 IFVs to Ukraine, with the first Marder 1A3s arriving in Greece in late 2022 and all 40 delivered by July 2023.

At Greece's DEFEA 2023 exhibition, held in Athens in May of that year, EODH unveiled its Leopard 2A4 modernisation package. This included the Advanced Integrated Platform Protection System (ASPIS) Modular NG-MBT advanced protection system (which includes both passive explosive reactive armour (ERA) modules as well as active armour modules), improved optical devices, an upgraded fire control system, and a combat control system.

A batch of ex-US M1117 Guardian Armored Security Vehicles arriving at the Greek port of Thessaloniki in July 2022. The US government has transferred 1,202 M117s to the Hellenic Army as EDAs. [US Embassy, Athens]

As the result of a US–Greek intergovernmental agreement concluded in January 2021, Greece has received a total of 1,202 M1117 Guardian Armored Security Vehicles from the US Department of Defense as EDAs, the first of which arrived in December 2021.

While in 2020 Greece had initially planned to acquire 350 M2 Bradley IFVs from US Army surplus stocks to replace its fleet of around 1,860 M113A1/A2 APCs, by October 2024 the Greek MND had rejected the offer of 'free' Bradleys, citing their poor condition and the excessive refurbishment costs required to acquire them. By December 2024 it appeared that the Hellenic Army instead is planning to modernise around 500 M113s as a cost-effective stopgap alternative. Israeli companies Elbit Systems and Rafael have offered proposals for this upgrade, which would likely feature a RWS with a 30 mm armament to increase the APCs' firepower, upgraded armour, a more powerful engine and upgraded communications and electronic systems.

In January 2024 Greek newspaper *Kathimerini* reported that Greece was close to closing a deal with Israel's Elbit Systems to procure 40 Precise & Universal Launching System (PULS) MRLs in a deal estimated to be worth EUR 500-700 million. The PULS can be used to launch a variety of munitions, from 122 mm rockets to 370 mm quasi-ballistic missiles and also Elbit SkyStriker LMs. According to the *Kathimerini* report, the Greek MND plans to buy six types of munitions for the European version of PULS (Euro PULS), with ranges from 35 to 300 km, as well as SkyStriker LMs.

Regarding the upgrade to the Hellenic Army's 122 mm RM-70 MRLs, which are heavier Czech variants of the Soviet-designed BM-21 system, manufacturer Excalibur Army demonstrated the upgrade possibilities to the army in November 2021. The modernisation programme, according to Excalibur Army, would include a new weapon control and aiming system, a fire control system with a ballistic computer, a new inertial navigation with GPS systems, communication and data systems, and the ability to control the weapon system either directly from the vehicle cabin or remotely.

After Greece signalled a desire in mid-2022 to obtain AAV-7 amphibious assault vehicles being phased out by the US Marine Corps, the US State Department approved a USD 268 million FMS package in March 2023 covering 63 AAVP-7A1 personnel variants, nine AAVC-7A1 command variants and four AAVR-7A1 recovery variants. However, according to reporting by *Doureius Ippou*, the Greek budget for the AAV-7 procurement was frozen in late 2023, in part to facilitate the use of US Foreign Military Financing (FMF) credits for the procurement of LMs.

In December 2024 the Greek Government Council for Foreign Affairs and Defense (KYSEA) approved the acquisition of 600 US-made Switchblade 300 and Switchblade 600 LMs via the US FMF programme. With the unit cost of the Switchblade LMs being reduced by the demand for them in Ukraine and elsewhere, it is possible that Greece might acquire additional systems.

Naval procurement

The HN is a mid-sized naval force currently operating 13 frigates, 41 patrol and coastal combatants, 10 diesel-electric submarines, three mine countermeasures vessels and a variety of other vessels such as landing craft and logistics and support vessels. However, the main surface fleet will need to undergo a renewal process within the next decade. Greek naval procurement is thus focused mainly on modernising the HN's fleet by 2032 through a combination of upgrading existing ships and having new ones built, both locally and abroad.

Guided-missile destroyer USS *Momsen* (DDG 92) sails alongside Italian Navy frigate ITS Virginio Fasan (F 591) in the Gulf of Oman, on 13 July 2022. The *Virginio Fasan* is one of two Italian FREMM frigates being offered for Greece. [US Navy/MC 2nd Class Lily Gebauer]

Throughout 2024 the US government had looked to offload four former US Navy Freedom-class Littoral Combat Ships (LCSs) onto Greece. However, due to the US Navy's troublesome history with these vessels, on 14 December 2024 Greek Defence Minister Nikos Dendias appeared to pour cold water on that idea in a speech to the Hellenic parliament – especially to the notion of actually paying for the LCSs, which would requirement significant work, as opposed to being gifted them in a free transfer.

Meanwhile, HN modernisation is focused on six main initiatives, the most important of which is currently the acquisition of a fleet of frigates based on French shipyard Naval Group's Frégate de Défense et d'Intervention (FDI) design for the French Navy. Greece signed an agreement with Naval Group to purchase three FDI frigates, along with an option for a fourth ship, in September 2021. Thus far, two Greek FDI frigates have been launched, on 28 September 2023 and 19 September 2024, with the third scheduled to be launched in June 2025. The first pair of Greek FDI vessels, Kimon and *Nearchos*, are expected to be commissioned in late 2025, with the third, Formion, following in early 2026. The Greek MND has meanwhile confirmed its intention to take up the option to procure a fourth frigate, negotiations for which are reported ongoing.

In September 2024, during launch ceremony for the Nearchos, Defence Minister Dendias announced that, as well as starting procedures to acquire a fourth FDI frigate, Greece is looking to arm the FDI ships with MBDA Missile de Croisière Naval (MdCN) ship-launched cruise missiles. There is also a separate programme to procure a number of Schiebel Camcopter S-100 rotary-wing UAVs to be operated from the Greek FDI frigates.

In March 2025, meanwhile, Greek defence news outlet *Doureios* Ippos reported that Italy had formally notified Greece of the availability of two of its FREMM frigates, *Carlo Bergamini* and *Virginio Fasan*, for potential transfer after 2028. This offer is currently under review by the Greek MND. The HN has also previously shown an interest in acquiring second hand LCF area air defence frigates should they become available.

Another significant HN initiative is the potential acquisition of three new corvettes, again with the possibility of subsequently adding a fourth. The Navy is currently defining its requirements for these vessels, based on lessons learned from current conflicts in its region of operations, but intends for at least two of the corvettes built in Greek shipyards. As part of this effort, Greece is a full member of the EU's Permanent Structured Cooperation (PESCO) project to explore the development of a European Patrol Corvette (EPC).

In June 2024, meanwhile, the Greek Parliamentary Arms Committee approved the HN's participation in the US *Constellation* (FFG-62) class frigate programme, for which a Fincantieri Marinette Marine design based on the Franco-Italian FREMM multi-role frigate was selected in April 2020. As with the future corvette programme, Greece is looking to have some of these frigates built at Greek shipyards. Assuming that an FMS case with the US government proceeds in line with delivering on Greece's requirements with participating in the programme, the result will be a fleet of up to seven FFG-62 frigates that will deliver a significant step-up in the HN's capabilities.

Regarding mid-life update (MLU) programmes, the HN plans to modernise both its four *Hydra* class frigates, which are based on the German MEKO 200 design and entered service from 1992, and its fleet of seven *Roussen* (Super Vita) class fast attack craft – missile (FACMs), which are based on a UK Vosper Thornycroft design, and entered service between 2005 and 2022.

The aim of the *Hydra* class MLU is to extend the service life of the frigates by at least 15 years by addressing obsolescence issues, upgrading current systems and installing new equipment. Discussions on this programme, according to reporting by the *Naval News* website, are proceeding with a consortium comprising Germany's thyssenKrupp Marine Systems (tkms), whose subsidiary Blohm + Voss built the frigates in conjunction with Hellenic Shipyards, and French systems house Thales. *Naval News* reported that Commodore Panagiotis Karavas, Deputy Director of the Armaments Directorate for the HN, estimated that it will take up to four years from the moment a contract is signed before the first modernised frigate begins sea trials.

The Greek Hydra class frigate HS Salamis sailing in the Aegean Sea on 10 May 2022. The Hellenic Navy plans to upgrade its four Hydra class frigates, which are based on the German MEKO 200 design. [US Navy]

The Hellenic Navy fast attack craft – missile (FACM) HS *Roussen*. The Hellenic Navy plans to modernise its fleet of seven *Roussen* class FACMs. [Hellenic Navy]

Regarding the *Roussen* class FACM MLU, Cdre Karavas told *Naval News* that a study is currently awaiting approval, with plans to equip the craft with new sensors and systems to maximise their operational capability and address any obsolescence issues. The commodore also stated that the navy is considering procuring up to nine new FACMs to gradually replace its four Laskos-class (Combattante IIIA) and five Kavaloudis-class (Combattante IIIB) vessels in order to maintain a 16-strong FACM force.

The HN is also moving to bolster it patrol boat force; four former US Coast Guard *Island* class cutters are undergoing repair and upgrade in Greek shipyards, while FMS cases for the procurement of three *Protector* class and two additional *Island* class cutters are progressing. The HN's aim is to operate at eight coastal patrol vessels.
With regard to the HN's submarine fleet, there are plans for the construction of two new submarines, with an option for two more, as well as upgrading the navy's four Type 214 boats. Greece's older Type 209 submarines will presumably be retired as new boats enter the fleet.

Lastly, Greek company Diaplous PHI, formed by a team of former senior naval officers, naval architects and marine engineers, has been developing a special operations craft called the Agenor 18. The first of these entered service with the HN in May 2022, but variants of the design are also being considered for procurement.

Across-the-services procurement

In relation to the Greek MND's intention to procure new wheeled general-purpose vehicles, on 31 March 2025 Greek company Metlen announced that it had signed a memorandum of understanding (MoU) with Italy's Iveco Defence Vehicles (IDV) regarding their joint co-operation to provide military vehicles for the Greek army, navy, and air force. The upcoming programme aims to renew Greece's fleet of both protected and unprotected military trucks across the Greek service arms.

Meanwhile, in April 2023 the Greek MND announced a EUR 370 million procurement of Spike anti-armour missiles for Greek air, land and naval forces. According to available information, 100 Spike-NLOS missiles were to be used to up-arm nine Greek AH-64A attack helicopters, while 17 Spike NLOS systems with 340 missiles would equip Hellenic Army anti-tank units. Four Spike NLOS systems were slated to be fitted to Greek patrol boats and four Spike ER2 systems with 55 missiles were to be assigned to Greek fast patrol boats.

Lastly, in July 2024 the Greek MND issued a request for information (RfI) regarding the acquisition of a Greek military satellite communications (MILSATCOM) solution. The MND's objective is to "develop, manufacture, put in orbit and operate a MILSATCOM satellite capable of hosting primarily military communications payloads in response to national needs while promoting the development of national industry and utilising national assets to the best possible extend [sic]", according to the RfI document, which added, "The main objective is to deploy a [Greek] owned high-end MILSATCOM satellite system which will be fully operated by the Ministry of Defence including the satellite, mission and network operations." Responses to the RfI were due by the end of September 2024.

CBRN defence issues in the Mediterranean

Dan Kaszeta

One of the perils of CBRN defence is that it is all too often seen through the lens of the Cold War. Many assumptions about how CBRN weapons will be used were developed by looking through the prisms of the Cold War with views towards conflict in Central Europe and possibly Korea. Yet ever since the end of the First World War, it can be argued that more interesting CBRN developments have occurred or have the prospect of occurring in and around the Mediterranean Sea.

Personnel assigned to the *Ticonderoga* class guided-missile cruiser USS *Normandy* (CG 60), overview Mission-Oriented Protective Posture (MOPP) procedures, as the ship conducts a CBRN drill, on 25 November 2023. [US Navy/MC 2nd Class Malachi Lakey]

Geography, geopolitics, and climate

The Mediterranean is about 2.5 km2 in surface area. Although there are different methods for determining coastline, the Mediterranean littoral has approximately 46,000 km of coastline spanning three continents. Two EU member states are, in addition, free-standing entities within the sea, Cyprus and Malta. Starting on the western end, from Gibraltar, a British exclave, and working around the north side of the sea, one gets all the way to the Turkish-Syrian frontier. This northern portion comprises almost entirely, NATO member states. The only exceptions are about 4 km of Monaco coastline and a scant 20 km sliver of Bosnia-Herzegovina. The only outlets of this sea are crucial straits at Gibraltar and Istanbul, and the Suez Canal in Egypt.

Yet unlike the Baltic Sea, the Mediterranean is not a NATO or EU lake. The South and East of the Mediterranean have been sources of both trade and conflict for centuries. Spain, France, and Italy all expanded their colonial empires across the sea in ways that still have impacts today. Various countries including Libya, Egypt, Syria, Lebanon, and Israel add to a complex geopolitical environment. Above all else, historically, the Mediterranean Sea has served more as a highway than a barrier. Trade and population, through both sanctioned and unsanctioned means, has always flowed across the Mediterranean Sea since antiquity. In 2023, the UN estimated that 280,000 irregular migrants crossed the sea to Europe. In previous decades, this author would not consider this in the CBRN space, but given the prospects of pandemics, and with thousands of military and paramilitary personnel boarding small boats and rescuing such people at sea, biological PPE needs some consideration.

Beyond the smuggling and trafficking of people, the Mediterranean is also a significant route for smuggling of goods, such a drugs or other contraband. The same routes used for people-smuggling are often used for goods. In theory, the existence of this covert highway could mean a route for CBRN materials. In practice, it means things such as Captagon, Cocaine, and Fentanyl. Regardless, the presence of such materials means military, security, border, and customs officials have to protect themselves from and identify hazardous substances.

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CBRN Aspects of the Region

There is a long history of chemical warfare agent production and stockpiling in the region, with some of it being far more recent than in central Europe. Starting in the West of the region and working around the sea in a clockwise direction, Spain had a chemical weapons programme in the 1920s and used them during the 1921-1926 Rif War in Morocco, pioneering the use chemical weapons in aerial bombs. France had a significant chemical weapons programme from 1915 into the 1980s. Italy had a significant offensive chemical warfare programme before and during the Second World War, giving it up in the aftermath of fascism. Tito's Yugoslavia built on a small pre-war Kingdom of Yugoslavia chemical programme, and the remnants of this programme were eventually disposed of in Bosnia and Serbia after the breakup of Yugoslavia, well within this correspondent's professional career. A small and highly secretive Albanian programme, likely supported by China, existed in the 1960s and 1970s, leading to the embarrassing discovery of tons of Sulfur mustard in 2002, which was declared and disposed of with international assistance. Greece had a small programme in the 1930s, but its stocks were taken by the Germans. Greece had hosted some US tactical nuclear weapons, but they have been withdrawn.

Working around the Eastern end, Türkiye continues to host a small number of US nuclear weapons. Syria has been the site of active chemical warfare use in recent years, and the most likely CBRN scenario would be the discovery or accidental release of former Assad regime stocks. Israel has signed but not ratified the Chemical Weapons Convention (CWC), and whether or not it has any chemical weapons is a bit inscrutable. It does have a nuclear programme. Egypt had a chemical weapons programme, and as one of the few countries to not be a party to the CWC, the status of Egypt and chemical weapons is as opaque as the Israeli one. Libya had a chemical programme and is discussed below. Finally, Algeria should not be overlooked. It was the site of decades of French testing of CBRN weapon systems, including sites that stayed in French control for decades after Algerian independence.

USS *Normandy* personnel conducting a CBRN drill, on 25 November 2023. [US Navy/MC 2nd Class Malachi Lakey]

An uncomfortable truth is that there is a history of chemical weapons in the Mediterranean Sea as well as in the countries surrounding it. In 1944, the retreating Germans, who had both their own chemical stores and had evidently seized Italian munitions, disposed of several thousand tons of chemical agent by dumping them in the Adriatic. The US military similarly disposed of both US stocks and captured Italian weapons in the Mediterranean. A US Army document published in 2001 identified five disposal operations and two significant accidental losses of chemical weapons by the US military in the Mediterranean in the 1945-1946 period. The fate of these materials is, sadly, less well-documented than those in the Baltic or North Sea. Given incidents elsewhere in the world, the risk of chemical weapons being accidentally found at sea, through fishing or other activity, cannot be systematically excluded. Incidentally, the disposal of chemical weapons will be the topic of a forthcoming article in this publication.

Some manufacturers have developed products intended to have lower heat stress, such as the Avon Protection MITR-M1 shown here. [Avon Protection]

Geography and climate influence CBRN defence operations. One aspect of military operations in the Mediterranean Sea and its littoral is climate. It is a generally warm, sometimes punishingly hot climate. High temperatures and brutal sunshine are, broadly, not hospitable for persistent contamination by chemical agents. CBRN personal protective equipment (PPE) intended for use and wear in more temperate climes may pose more discomfort and injury from heat. Decontamination is aided by higher temperatures, and detection equipment may have to operate in conditions that might stress the components in ways not usually seen in more temperate climes.

Some major manufacturers in the CBRN defence industry realise that warmer areas of operation pose more challenges in CBRN protection. In fairness, this has at least as much to do with the lucrative Middle East defence market at least as much as the Mediterranean. A quest for lower heat burden has driven

companies such as OPEC-CBRNe to make successively lighter protective suits. Others, such as Avon Protection (UK), have made design changes to respiratory protection, such as half-face respirators, to seek less operator burden and lower heat stress, albeit sacrificing some level of protection. While some national customers may seek such developments, others are loath to reduce their requirements. Regardless, such equipment is being firmly marketed to Mediterranean customers.

One obvious aspect of CBRN operations in the Mediterranean is the obvious point that maritime affairs are of primary importance. CBRN defence has long been a lesser concern in naval and coast guard circles than on land; an issue last discussed in 2022 in this publication. Within the Mediterranean, naval CBRN defence is not really the Cold War issue of large chemical or nuclear attacks against naval vessels. Maritime operations in the Mediterranean have a strong emphasis on prevention of irregular migration and smuggling. It is a matter of small and medium vessels and crews of navies, coast guards, and border police encountering potential toxic materials when they try to police the transit of illicit materials across the Mediterranean. Boarding parties need to be able to protect themselves and to rapidly assess and identify unknown substances, whether these are CBRN materials or illegal drugs.

As pointed out in numerous previous issues, rapid analysis of powders and liquids is very much the province of a handful of companies in the CBRN space. These include Smiths Detection (UK), Thermo Fisher Scientific (US), 908 Systems (USA), Rigaku (Japan), Serstech (Sweden), and only a handful of other firms. The various maritime forces in the region are avid customers in this segment for the precise reasons highlighted above.

CBRN in Libya

Any discussion of CBRN affairs in the Mediterranean needs at least a passing mention of Libya. The Gaddafi regime tried to acquire nuclear technology and clearly succeeded in making chemical warfare agents and weaponising them. Whether or not they were used in the Libyan-Chad conflict in the 1980s remains an unproven allegation, but by the time the Gaddafi regime, as part of a campaign for international respectability, acceded to the Chemical Weapons Convention, it declared nearly 25 tonnes of Sulfur mustard, and thousands of tonnes of Sarin and mustard precursors, as well as several thousand un-filled aerial bombs.

The OPCW worked with the Libyans to get rid of these items, a demilitarisation campaign that was well underway by the time Libya imploded in 2011. Numerous efforts by the OPCW and Western governments (some of the latter still shrouded in secrecy) sought to locate and destroy the remaining chemical weapons and agents. A variety of efforts between 2011 and 2017 successfully achieved this end, albeit at significant expense and difficulty. The OPCW praised the end of the demilitarisation effort in January 2018. Various conspiracy theories and rumours about rogue bits of Libyan CW being at large have, so far, been groundless. Given the chaos of Libya, it is not impossible that some old materials were not accounted for and CBRN planning in the region needs to keep this possibility under consideration.

CBRN in Italy

The Mediterranean has formed and influenced security and defence policy in Italy longer than Italy has been a unified country, dating back to Roman times. Sometimes, the sea has been referred to as *Mare Nostrum* ("our sea"), indicating a proprietorial sense reflective of Italy's prominence in its centre. As one of the largest forces in this region, and being well-involved in anti-trafficking operations, the Italian Navy has long been more concerned with CBRN defence than most of its Mediterranean counterparts. It should be noted that Italy has, in effect, several navies, with the *Guardia Costiera*, maritime units of the *Carabinieri*, and anti-smuggling vessels and helicopters operated by the *Guardia di Finanza*. All of these services get involved in security operations in the Mediterranean and all can be in the position of confronting CBRN threats. As such, they are a potent market for the CBRN business.

Italian companies have been active in the CBRN space for decades. Foremost in stature, Cristanini s.p.a., mentioned in numerous other articles in this magazine, has established a

Shortly after the Arab Spring and the fall of Muammar Gaddafi, the Defense Threat Reduction Agency (DTRA) deployed teams to Waddan in Libya to build a munitions elimination facility in the Sahara Desert for Libya's declared chemical weapons. [DTRA]

Pictured: Cristanini's RI/CBRN TRAILER. Cristanini, located in Verona, is a core part of the growing CBRN industry in Italy. [Dan Kaszeta]

global reputation in CBRN decontamination. Its products are found around the entire Mediterranean basin. Fincantieri, the giant naval contractor, has worked with detection companies to integrate CBRN systems such as collective protection and detection into naval and coast guard vessels. DPI-Sekur (now part of Leonardo) is a venerable manufacturer of respiratory protection, having spun off from Pirelli Rubber in the early 1990s.

CBRN in Türkiye

If one were to look around the Mediterranean littoral and attempt to write an award citation for 'best attitude towards the CBRN threat', an honest jury would have to grant a prize to Türkiye for both military and civil CBRN preparedness. CBRN in Türkiye is worthy of a full article in its own right, in part because Türkiye sits both figuratively and literally on fault lines. It is a crossing point in many different ways and it sits astride several older and newer conflicts. It is the only NATO member that is in both Europe and Asia, it is the gatekeeper between the Mediterranean and the Black Sea, and it is where, in cultural, religious, and geographic terms, the European world abuts the Islamic and Middle Eastern world. On top of this, it occupies geography that has given it many types of natural disaster. It also faces lengthy and complex security concerns on its borders with Iraq and Syria, both of which have had CBRN issues in recent decades.

This correspondent had serious CBRN-related visits to the Turkish government a decade apart, in 2014 and 2024. The difference between the two was revelatory. In 2014, the Turkish military was still struggling to get beyond a basic Cold War approach to force protection, let alone grasp the emerging chemical conflict on its doorstep in Syria. The civil authorities were working to accept the idea that CBRN terrorism, hazardous materials incidents, and nuclear power incidents, were even phenomena that rated their attention to the same level as earthquakes and severe weather. A positive attitude was in place but not enough of the capacity and capability that a NATO country could be expected to provide.

Flash forward to 2024. The differences, both in doctrine and in practical capability, were stunning. The Interior Ministry's department for disasters and emergencies, AFAD, has built a massive domestic CBRN response capacity from practically nothing in ten years. Equipment, procedures, doctrine, training, and personnel have been dedicated to addressing the CBRN threat to the civilian populace alongside the other natural and technological disasters that AFAD is meant to confront.

The same level of progress can be said for military capability in CBRN defence. Just ten years ago, Türkiye's kit was looking a bit tired and left over from the Cold War. Much effort has gone into force modernisation and today the Turkish military looks far more modern in every respect, and especially so in terms of CBRN equipment. For example, Environics (now Bertin Environics, a Franco-Finnish company) was involved in integrating CBRN sensors into Turkish naval vessels.

The Turkish Armed Forces' CBRN preparedness has come a long way over the past decade or so. [Turkish Land Forces Command]

The third pillar of CBRN in Türkiye has to do with the development of defence industry, which has spawned both local CBRN companies and seen the integration of US and European CBRN goods into Turkish systems. Turkish firms that actively compete in the AFV market, such as FNSS and Otokar, offer various CBRN components into their vehicles and have occasionally marketed CBRN reconnaissance vehicle variants. Various local Turkish SMEs are starting to become players in CBRN, such as STM, Utilis, ARD Defence, and others are starting to pop up not just in Türkiye but at exhibitions elsewhere. The Turkish CBRN sector is clearly one to watch for the future.

European security in the Balkan neighbourhood

Lincoln Gardner

The Western Balkans are at risk of becoming increasingly forgotten amidst a resurgent US policy towards Russia. As the EU frantically races to fill the growing vacuum left by an increasingly uncompromising US foreign policy on Ukraine, some in the region may choose to find their own way and return to the darker side of their recent history.

A Latvian soldier conducts a routine patrol in Northern Kosovo as part of the KFOR mission, on 9 March 2025. With the EU facing an increasingly complex security environment due to deteriorating relations with the US, the Western Balkans looks to be increasingly left to its own devices. [KFOR PAO]

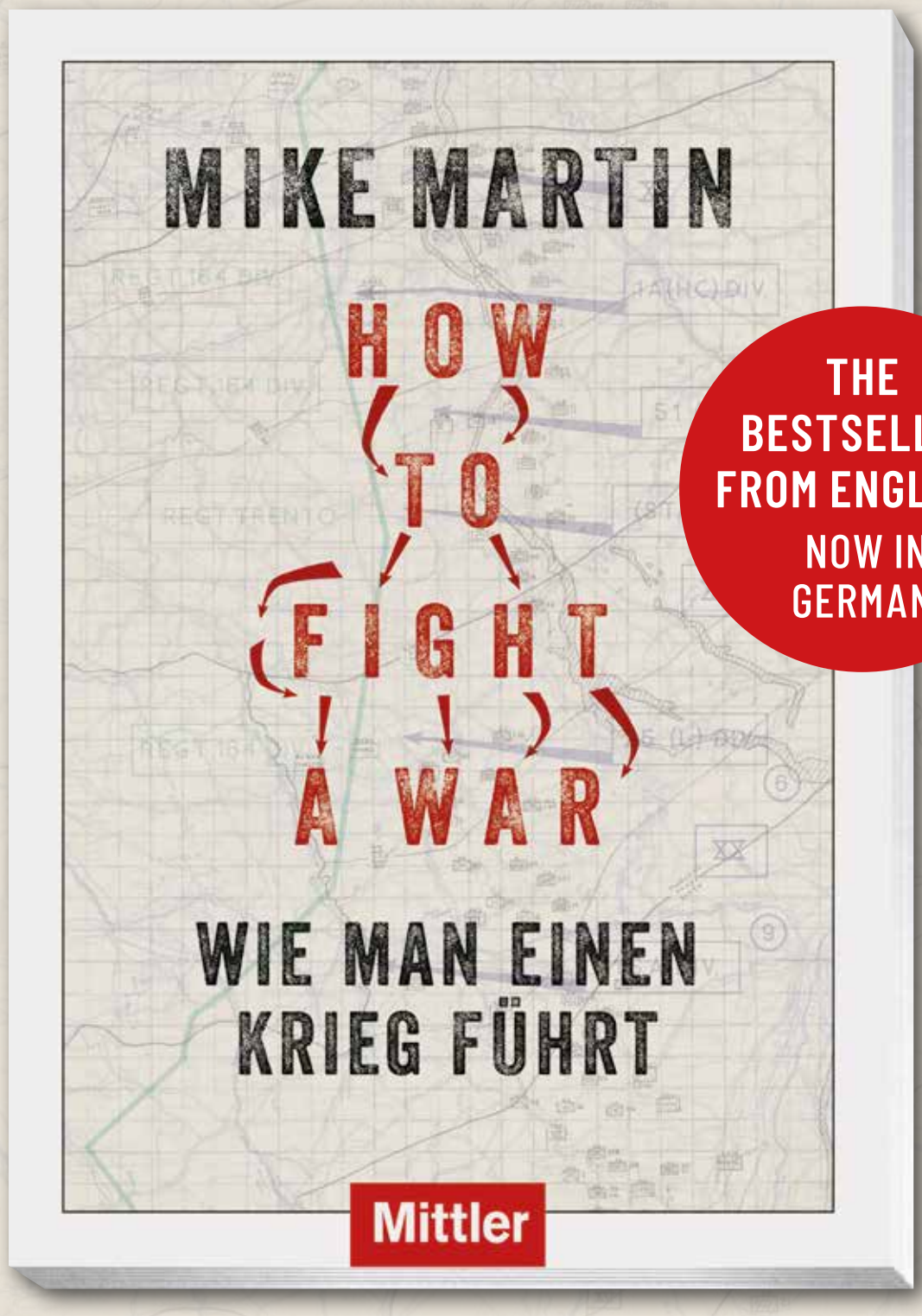
With the second Trump administration wasting no time in flexing its muscles on the international stage, the global order that Europe had become accustomed to has once more been turned on its head. Overnight the victim in Ukraine has become the aggressor, in the process of being bullied into a hasty peace by its former staunch ally. As the world continues its preoccupation with Russia's war against Ukraine (which has recently surpassed three years in duration), the Western Balkans are experiencing a corresponding rise in internal discord and political unrest, coupled with worrying bouts of tension between neighbours.

This fragmented and fragile region, after years of instability following their own bloody and brutal wars in the 1990s, thanks to complex ethnic and historical issues, once again finds itself at critical juncture. While the world waits on Trump's next foreign policy moves, many observers see the Western Balkans being left to cope alone. This article takes a brief look at parts of the region, with a focus on the growing discord and instability in Bosnia and Herzegovina (BiH), the student-led mass protests in Serbia, and increased nationalist rhetoric coming out of Skopje, North Macedonia. The article also explores the changing dynamic in this fractious region, looking at how issues are aggravated by the shift in geopolitical focus by both the US, but also a lethargic EU in this region of Europe. The article reflects the view that with leading global actors – the US and EU – intensively engaged elsewhere (mainly Ukraine), the Western Balkans might increasingly be left to its own devices as it is forced to navigate a worrying period of unpredictability on the European continent.

The Western Balkans

The countries of the Western Balkans might no longer find themselves the first news item or on the front pages as often as other regions (unlike the former State from which almost all of them emerged – the Socialist Federal Republic of Yugoslavia; SFRJ), but the region remains synonymous with political unrest and discord, ethnic tension, and the enduring impact of the violent dissolution of Yugoslavia. Despite lasting peace agreements including the Dayton Peace Accord and the UN Security Council Resolution ending the short and bloody Kosovo conflict in 1999, numerous unresolved questions continue to mould the political environment in ways that still threaten to make the region a dangerous flashpoint on the European continent.

One reason why the region remains a source of instability is the absence of a common approach to democratic good governance. The region also continues to be divided along ethnic, religious, and political lines, shaped by the policies of powerful external players, including, but not only Russia and the EU, but China and Turkey wait eagerly in the wings for more influence should Brussels weaken its interest. Contrary to some views, Russian influence remains strong, most notably in Serbia and the so-called 'Serb half' of BiH, while the EU's enlargement project has been viewed as increasingly dysfunctional, with relatively new EU member states, such as Bulgaria, slowing



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the accession of countries like North Macedonia. As the world watches every move on Ukraine as it fights for survival, many might argue that the international community has begun to ignore the simmering tension in the Balkans, and by so doing, is contributing to an environment where autocratic local leaders are becoming increasingly emboldened to pursue their own ethnic or nationalist agendas.

Bosnia and Herzegovina: Stumbling towards disintegration?

The current situation in Bosnia and Herzegovina (BiH) poses significant challenges to the country's stability in a year when the 30th anniversary of the 1995 Dayton Peace Agreement is commemorated. While this agreement succeeded in halting hostilities, it created a fragile political framework dividing BiH into two separate entities: the Federation and Republika Srpska (RS). This construct was designed principally to safeguard the interests of BiH's three 'constituent peoples' but has also opened the door to the disintegration of the country. One of the most divisive local leaders, Milorad Dodik, RS President, has taken this opportunity and repeatedly advocated for the RS entity's secession from BiH, undermining the very bedrock of the country as established by the Dayton Accords. The situation has recently taken on a new twist, with the sentencing of Dodik by the State Court of Bosnia and Herzegovina to prison (for one year) for "undermining the country's state institutions and violating the BiH constitution" after Dodik's years-long defiance of decisions of state-level bodies and rulings of the international High Representative, German official Christian Schmidt. The sentence highlights the institutional challenges the country faces in administering the rule of law and governance overall. The sentence has also further aggravated divisions, as Dodik's followers see the court's decision as being politically motivated, while his opponents claim it is a step needed to uphold the integrity of the state.

BiH's central authorities have now stepped up efforts mid-March to arrest Dodik as the ongoing crisis threatens to deepen further. The EU-led military force on the ground OP/ALTHEA has temporarily increased its troop numbers by 400 given the heightened tensions. The Court of Bosnia and Herzegovina has issued a nationwide arrest warrant for Dodik, alongside two associates. Meanwhile, Dodik's announcement of plans to establish a separate RS border police force has poured further fuel on the fire; cynically, he has insisted these recent moves would be in line with the Dayton Accords. There are fears of further separatist moves and Dodik has appealed to Russian President Vladimir Putin and Hungarian Prime Minister Viktor Orbán for support. In response to Dodik's actions, EU and US officials have condemned his efforts to undermine the Dayton Peace Agreement, warning that his increasing ties with Russia and defiance of BiH's sovereignty threaten regional stability and peace.

Hungarian Prime Minister Viktor Orbán (left) meets with RS President Milorad Dodik (right) on 24 April 2024. [Office of the President of RS]

Dodik's sentencing serves as a potential flashpoint for new ethnic and political tensions within the country, especially in RS, where he enjoys significant support. There is a concern that should he be arrested and serve a custodial sentence (though this was a first instance verdict with an appeals procedure in place), it could spark real anger in the entity, leading to a highly volatile situation. The Dodik ruling may also strengthen calls from within the entity (led by Dodik) for even more autonomy for RS by creating parallel structures, and even cessation from BiH. Indeed, just recently on 5 March 2025, the RS Parliament passed laws banning the work of BiH judicial and security institutions in RS, thereby violating the country's constitution.

Reacting to the verdict, President Aleksandar Vučić of Serbia leapt to Dodik's defence (even travelling to RS to deliver his message in person), where he sharply criticised the judgement, labelling it a direct attack on the rights of all Serbs in BiH. A long-time Dodik supporter, Vučić claimed that the international community, particularly the EU and the US, targets RS, while ignoring BiH's complex political reality. Vučić's defence of Dodik not only underscores Serbia's role as an ally of RS and defender of Serbs throughout the region, but also highlighted the region's fragile environment. Vučić's kin-state commitment to Serbs in BiH is reminiscent of the outbreak of conflict in the early 1990s and the creation the Serb breakaway 'republic' in Croatia (Republika Srpska Krajina) and the initial founding of the RS in BiH. This has only made efforts to stabilise the country even more complicated, so long after the end of the conflict.

On 31 March 2025, Dodik travelled to Moscow via Serbia, and was received by President Vladimir Putin, in spite of a BiH arrest warrant issued against him, before returning to BiH.

Serbia: Protests, more protests and political polarisation

However, all is not well at home for Vučić either. While he continues to defend the rights of Bosnian Serbs next door in BiH, within Serbia itself the largest protests for many years have taken place on a regular basis across the country, since a tragic collapse of a train station's roof in Novi Sad on 1 November 2024, causing 15 deaths. The deadly incident exposed a deep level of discontent within Serbian society, notably among university students. From the outset, the protests consistently called for accountability for the Novi Sad tragedy and for wider rule of law reforms. Demonstrators believe that Vučić has become emboldened by a Trump victory, combined with a Europe preoccupied with Ukraine, making him increasingly authoritarian; they also note the government's control and manipulation of the media, and the narrowing space for civil society to engage in a meaningful way. The demonstrations therefore signify a larger political crisis, showcasing increasing polarisation between opposing camps.

Participants in a 24 January 2025 protest in central Belgrade. One of the participants holds a banner with the slogan "Samo student Srbina spašava" (ENG: Only students save the Serbs), a play on the slogan "Samo sloga Srbina spasava" (ENG: Only unity saves the Serbs). [SergioOren, via Wikimedia Commons; CC BY 4.0]

On 15 March 2025, Belgrade witnessed the largest protest in the country to date, surpassing even those that preceded the overthrow of Slobodan Milošević, with estimates ranging from 107,000 (Interior Ministry claims) to 350,000-400,000 (per independent sources), with some observers claiming up to 800,000 participants. Despite a significant police presence, only small, isolated incidents were reported, and the anticipated violence thankfully did not materialise. Interestingly, government-paid private 'security' individuals were positioned near the final venue, with many speculating that their goal was to incite violence, thereby discrediting the students' protest movement. Before that could happen however, the protesters dispersed peacefully ahead of the planned time. While no specific next steps were announced, student leaders later stated that the protests would continue until their demands are met. On 16 March, during a Sunday emergency government session, President Vučić confirmed that formal acknowledgment by the National Assembly of Prime Minister Miloš Vučević's resignation would finally happen (which it did on 19 March), thereby triggering a one-month deadline to form a new government. Yet if the government cannot be formed by then, early parliamentary elections could be held in early June 2025. Vučić also acknowledged the 'message' from the massive Belgrade protest on 15 March, stating that the government would need to make changes in response.

Following the 15 March protest, allegations were made by participants that law enforcement used Long Range Acoustic Devices (LRADs), a type of sonic weapon, to disperse the crowds. LRADs emit sound waves that can cause discomfort or disorientation. Serbian authorities initially denied the use of such a weapon, or even possessing such devices, though videos posted online suggested otherwise. Later, on 19 March, the Ministry of the Interior issued a statement admitting that the Government had indeed procured LRADs, but that these were used for "only used for warning, i.e. sending sound messages during large gatherings", and "informing a larger number of people at greater distances". The release also included footage of Interior Minister Ivica Dačić being shown both an LRAD-450XL mounted on a police vehicle and a portable LRAD-100X device during a demonstration. Given the inconsistencies in forming their narrative, the Interior Ministry's explanations did not come across as particularly convincing, and despite government denials, the allegations persist. If true, as video footage and reports from the ground strongly suggest, they demonstrate the lengths the government were prepared to go to disrupt the protest and cause violence.

An LRAD-450XL mounted to the bonnet of a police vehicle, during a 19 March 2025 demonstration to Minister of the Interior Ivica Dačić. [mup.gov.rs]

The ongoing crisis and (thankfully) still-peaceful protests are seen with increasing concern by the international community, most notably by the EU. However, the focus continues to be on Ukraine and how the new Trump administration is handling relations with Moscow, meaning that Serbia's internal problems, including tensions over Kosovo, official corruption, and political protests, are effectively being ignored by the West.

In addition to the ongoing protests, Serbia continues to walk the tightrope between keeping Brussels on board – aligning policies with those of the EU, while nurturing ties with Russia and China. Serbia's main goal may well be EU membership, but its historical relationship with Russia and more recent relationship with China make life more complicated for Belgrade.

An impatient North Macedonia

In North Macedonia, the re-emergence of nationalist rhetoric has become a central feature in the country's political scene. The ruling VMRO-DPMNE party, since its creation, a long-time and consistent supporter of Macedonian identity and nationalism, has remerged as a considerable force since June 2024 under Prime Minister Hristijan Mickoski. Most notably, the VMRO-DPMNE-led government has become increasingly sharp in its public criticism of the EU and especially its accession and integration policy – recently referring to what they see as "double standards" towards EU candidate countries in the region, and most notably regarding neighbouring Bulgaria's veto, which has cited issues related to history and language. This frustration has only encouraged growing anti-EU sentiment in North Macedonia, a NATO member, seeing perhaps they have nothing to lose since EU integration is

often viewed as a pipe dream anyway (Skopje became an EU candidate in 2005). Interestingly, but perhaps not surprisingly, PM Mickoski travelled to Budapest to meet the black sheep of the EU family, Victor Orbán, where he heaped praise on his Hungarian host as an inspirational leader. Both Prime Ministers welcomed the shift in transatlantic relations and were critical of the EU's approach on Ukraine.

On 4 March 2025, Prime Minister Hristijan Mickoski (left) met Hungarian President Viktor Orbán (right) in Budapest. [Hristijan Mickoski X Account]

Just like in Serbia, it has taken a tragedy to put people onto the streets. Protests have recently taken place in the country following the tragic nightclub fire in Kočani (100 km east of the capital Skopje) in the early hours of 16 March 2025, which claimed 59 lives (aged between 15 and 24). As in Serbia, the protesters are indignant at the high levels of corruption rampant in the country, as the nightclub was operating without any licence or safety permits. Local political leaders are among those arrested in relation to the tragedy.

U-turn in relations between the US and the Old Continent: Impact on the Balkans

The new US foreign policy has significant implications for the Western Balkans. Under Trump, the US is rapidly distancing itself from its traditional alliances in favour of more transactional bilateral agreements. This dramatic U-turn will only serve to water down the West's capacity to influence the political paths of countries in the Western Balkans. Moreover, Trump's increasingly Russia-friendly view, combined with an almost total indifference to the EU's enlargement project (for instance with respect to the Western Balkans), has created a situation where local leaders might become even more emboldened to pursue their own agendas, knowing full well no meaningful action or sanction will follow.

While it is true the US continues to be engaged in the region, including with a small military presence in Kosovo, comprising roughly 600 troops serving with the NATO-led Kosovo Force (KFOR), the current situation with Ukraine means that countries such as BiH, North Macedonia and Serbia will no longer enjoy the same levels of attention as before. Many predict that the EU will struggle to maintain a unified approach to the region, since the EU's enlargement process has largely stalled, and with some EU Member States, including Bulgaria, blocking accession paths based on bilateral disagreements; this is nothing new, as previously seen with Slovenia stalling Croatia's EU accession. As a result, unless the EU reassures the candidate countries that their offer of membership is real, there are those who will continue to be frustrated and disillusioned, adding fuel to nationalist tendencies and momentum behind choosing an alternative path.

The US retains a small military force in the region as part of KFOR. However, the Trump administration's recent tensions with European allies, and Europe's focus on Russia, is creating a situation where local leaders may feel emboldened to pursue nationalist tendencies. [KFOR PAO]

Conclusion

The Western Balkans region is at a critical juncture. Internal discord, continuing ethnic tension, political instability, societal frustration with a lack of reforms and widescale corruption, in addition to pockets of rising nationalism, all represent challenges to the region and its stability. The impact of the Ukraine conflict will continue to be keenly felt in the region and with a resurgent US foreign policy regarding that conflict, uncertainty in the Western Balkans will only deepen. Without a stronger hand from Brussels and concrete membership perspectives, many feel the region is increasingly being left alone, and at risk of being forgotten. BiH's brittle state construct and secessionist moves underway, coupled with protests in Serbia (which show no sign of abating), and the sharper, more strident language from Skopje, are all symptomatic of a wider problem – the inability of the Western Balkans' to fully integrate into the European space. This means they are even more exposed to external influence from Russia, and increasingly so from China. As the world's attention is again firmly on Trump and his pledge to bring peace in Ukraine (seemingly at any cost), the Western Balkans are in a vulnerable and increasingly fragile position. European security is far from certain in this part of the Old Continent.

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