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Pondering C-UAV trends

Over the past two years, the trend of developing and procuring Counter-UAV (C-UAV) systems has steadily accelerated, in large part as interest has spiked with the extremely heavy use of small drones seen during the War in Ukraine. While a plurality of options exist today, and even more are in development, it is worth considering where things look to be heading over a longer timescale.

To start with, electronic warfare (EW), is widely recognised as perhaps the most cost-effective C-UAV tool given the current threat landscape, capable of both detecting and jamming drones. However, along with this comes a recognition that as drones and loitering munitions (LMs) become increasingly autonomous, measures such as jamming will eventually need to be supplemented or replaced by effectors capable of dealing with autonomous drones and LMs. Yet EW is unlikely to be replaced altogether in the C-UAV role – while 'soft kill' jamming may not be effective against individual autonomous drones and LMs compared to 'hard kill' effectors, EW is nonetheless likely to have a major part to play in the anti-swarming role.

What can be thought of as 'true' drone swarms (as opposed to cruder coordinated saturation attacks) need to stay in constant communication with one another for coordination and cohesion. As such, disrupting their ability to communicate with one another – and thus degrading the cohesion of the swarm – is an obvious job which will have to remain for EW going into the future, even as platforms gain increasing autonomy.

Looking to 'hard-kill' solutions over the longer term, prospective users are presented with a range of possibilities. Here, there is a gradual consensus emerging that traditional kinetic solutions such as missiles and cannon munitions, while effective, could incur unacceptably high ammunition costs over the course of their service life. This seems particularly valid when looking at the War in Ukraine, where drones and loitering munitions have been used by the tens of thousands by both sides, with losses estimated in the thousands each month. In such a target-rich environment, and with their logistical costs and risks factored in, traditional kinetic options do not look as economically appealing as their directed energy weapon (DEW) alternatives.

The two primary varieties of DEW being developed right now are high energy lasers (HELs) and high power microwave (HPM) systems. In the future C-UAV role, HPMs in particular look to be a favourite, owing to their superior anti-swarming potential when compared to HELs. While HELs defeat targets one at a time, with a typical beam 'dwell time' of several seconds on each target (depending on the range), HPMs can target a patch of sky, potentially enabling them to engage multiple targets at the same time – a useful capability in a swarming scenario.

Having said that, much of what we understand about swarming threats today is based on assumptions and estimates rather than real operational experience. As such, there is still much we do not know about the swarming threats which will actually be faced on future battlefields. For instance, solutions which work against an assumed 'compact swarm' may not work as effectively against a highly dispersed swarm. If operating a highly dispersed swarm, with each platform operating far from its closest swarm members, HPM engagements would be expected to take longer than against a compact swarm, as the system will either be forced to engage more patches of sky with a given beam width, or perhaps use a wider, less-concentrated beam.

While HELs currently appear less useful than HPMs against swarms, they seem more immediately useful against a variety of other common threats, such as mortar bombs, artillery shells and rockets, and also provide the possibility of dazzling or burning out the sensors of infrared seekers or cameras – though it should be noted in the latter case, damaging sensitive electronic equipment is also possible with HPMs.

In terms of where the market appears to be headed right now, both HEL and HPM development efforts are receiving considerable interest, though HPMs appear to be enjoying a slight advantage in terms of their possibility for smaller form factor, permitting more platform mounting options. As a case in point, thus far at least two manufacturers have unveiled a UAV-based HPM effector – something which is unlikely to be replicated on the HEL side. This advantage, along with the potential for synergy or crossover with research into waveforms on the EW side, may be enough to swing the trend over to HPMs.

However, as always in conflict, the enemy gets a vote. Here, an indicator of which DEW becomes favoured will be whether the efforts of UAV and LM developers to counteract HPMs and HELS bear fruit. Likely efforts here would include hardening electronic systems against HPM attack, and developing lightweight thermal coatings to protect against HELs, at costs which still allow for mass production at vast scales. Depending on the effectiveness of such efforts, preferences could still swing either way, or users could be tempted to hedge their bets, and get both.

Mark Cazalet

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Cover Photo: US Army AH-64D Apache Longbow attack helicopter assigned to 1st Battalion, 25th Aviation Regiment Attack Reconnaissance Battalion (ARB) under an Aurora sky at Fort Wainwright, Alaska, on 13 January 2019.

Credit: US Army/CW2 Cameron Roxberry

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Swedish flag raised at NATO Headquarters in Brussels

(pf) A flag-raising ceremony was conducted at NATO Headquarters in Brussels on 11 March 2024 to mark Sweden becoming the 32nd member of the alliance. Flag-raising ceremonies took place simultaneously at Allied Command Operations (SHAPE) in Mons, Belgium, and Allied Command Transformation in Norfolk, Virginia, in the United States.


Credit: NATO

Sweden officially became a NATO member on 7 March when Swedish Prime Minister Ulf Kristersson formally handed over the country's accession documents to the US State Department in Washington, DC, where the NATO charter is held.
Ahead of the flag-raising ceremony in Brussels, NATO Secretary General Jens Stoltenberg welcomed Kristersson to NATO Headquarters and thanked the Swedish prime minister for his strong personal leadership and commitment in leading Sweden into NATO. "Sweden has taken its rightful place at NATO's table under the shield of Article 5 protection: the ultimate guarantee of our freedom and security," said Stoltenberg. "All for one and one for all.
"Sweden's accession shows again that NATO's door remains open," Stoltenberg added. "No one can close it. Every nation has the right to choose its own path, and we all choose the path of freedom and democracy."
The final path to Sweden's membership of NATO was cleared after the Hungarian National Assembly voted 'yes' on 26 February 2024 in relation to Sweden's application to join the alliance.
Both Sweden and Finland, which officially joined NATO on 4 April 2023, had formerly been neutral nations: Sweden since 1812 and Finland since the end of the Second World War. However, Russian President Vladimir Putin's invasion of neighbouring Ukraine in February 2022 irrevocably altered the military-geopolitical climate in Europe. With broad support in the Riksdag, the Swedish government applied for NATO membership on 16 May 2022 and on 5 July 2022 all NATO member countries signed the Accession Protocol for Sweden.
Overall, Putin's goal of limiting the size of NATO and retaining a 'buffer zone' between Russia and the alliance must be regarded as a failure. While many Eastern European nations demonstrated a natural proclivity to join the security and economic frameworks of the West once free of their communist governments after the Cold War, Putin's military interventions – in Georgia in 2008, Crimea in 2014 and most obviously in the whole of Ukraine since 2022 – have only served to compound gravitations toward the West.
When Putin officially became Russian president in March 2000 there were 19 NATO allies and Russia shared a border with just one of them: Norway. Now, with 32 allies in the alliance, Russia shares a border with five NATO nations – Norway, Finland, Estonia, Latvia and Poland – while Georgia and Ukraine also have aspirations to join the alliance.

Diesel-electric Barracuda design selected to replace Dutch navy's Walrus-class submarines

(pf) France's Naval Group has been selected by the Dutch Ministry of Defence for the Replacement Netherlands Submarine Capability project, based on the group bidding a conventional diesel-electric-powered variant of its Barracuda-class nuclear-powered attack submarine design, the company announced on 15 March 2024.


Credit: Naval Group

The French design was selected ahead of bids from a Damen and Saab teaming, offering a derivative of Saab's A26 design, and ThyssenKrupp Marine Systems, which was offering its Type 212 design. There will now be detailed negotiations intended to lead to the signature of a contract.
"Naval Group is honoured by the award decision expressed by the Netherlands Ministry of Defence (MoD)," the company stated in a press release. "This decision commits the group to implement a full-scale strategic partnership with the Netherlands aimed at supporting the Royal Netherlands Navy submarine service and at intensifying co-operation with the Netherlands' MoD, industry and R&D partners."
The programme will replace the Royal Netherlands Navy's Walrus-class submarines, four of which entered service from April 1990, with four new boats that will be known as the Orka class and will be named *Orka, Zwaardvis, Barracuda* and *Tijgerhaai*.
Only three boats of the Walrus remain operational – *Zeeleeuw, Dolfijn* and *Bruinvis* – after *Walrus* was decommissioned in October 2023.
The Orka class are due to enter service from 2034.

The Turkish Aerospace Kaan future fighter makes its maiden flight

(pf) The Turkish Aerospace Kaan fifth-generation fighter, otherwise known as the National Combat Aircraft (MMU) and formerly called the TF-X, made its maiden flight on 21 February 2024.


Credit: SSB

The Kaan took to the skies out of Turkish Aerospace's production facilities near Ankara, escorted by a Turkish Air Force (TAF) F-16D. The aircraft was airborne for 13 minutes, reached an altitude of 8,000 ft (2,438 m) and achieved a speed of 230 kt (426 km/h), according to Turkish Aerospace.
The company's website specifies the aircraft's intended performance as achieving a speed of Mach 1.8 at 40,000 ft, a service ceiling of 55,000 ft and g limits of +9/-3.5 g. With a length of 21 m and a height of 6 m, the aircraft has a wingspan of 14 m.
The Kaan has been developed as a multi-role fighter to meet Turkish requirements from around 2030 by replacing the TAF's fleet of F-16 fighters and is intended to be in service until the 2070s.
The TF-X development programme was initiated when Turkish Aerospace received a con-

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tract from the then Turkish Undersecretariat for Defence Industries (now the Defence Industry Agency - SSB) on 5 August 2016.
The Kaan prototype conducted its first taxi and ground tests on 16 March 2023 and was officially named in a ceremony on 1 May 2023. Although Turkish Aerospace indicated last year that the aircraft might fly by the end of 2023, the centenary year of the modern Turkish state, its maiden flight on 21 February nevertheless puts the aircraft's development ahead of schedule as it was originally planned to make its first flight in 2025.
Development of the Kaan has become more significant for Turkey since the country was ejected from the US-led F-35 Joint Strike Fighter programme in July 2019 after refusing to cancel a programme to buy Russian S-400 air defence systems, which would have compromised the F-35's stealth characteristics.
Although indigenously designed and built, the Kaan prototype is currently powered by two US-sourced General Electric F110-GE-129 turbofans each delivering a thrust of 131.2 kN on full afterburner. On 2 July 2022 the SSB published an invitation to tender for the domestic development of a powerplant for the Kaan.

Houthi campaign against Red Sea shipping inflicts its first fatalities

(pf) The campaign waged by the Yemen-based Houthi militia against commercial shipping in the Red Sea region has inflicted its first fatalities.
"At approximately 11:30 am (Sanaa time) March 6 an anti-ship ballistic missile (ASBM) was launched from Iranian-backed Houthi terrorist-controlled areas of Yemen toward M/V *True Confidence*, a Barbados-flagged, Liberian-owned bulk carrier, while transiting the Gulf of Aden," US Central Command (CENTCOM) stated in a press release on 6 March 2024. "The missile struck the vessel, and the multinational crew reports three fatalities, at least four injuries, of which three are in critical condition, and significant damage to the ship."


Credit: US CENTCOM

CENTCOM added that the crew of *True Confidence* abandoned the ship and that coalition warships had responded and were assessing the situation.
"This is the fifth ASBM fired by Houthis in the last two days," CENTCOM stated. "Two of these ASBMs impacted two shipping vessels – M/V MSC Sky II and M/V *True Confidence* – and one ASBM was shot down by USS *Carney* [a US Navy Arleigh Burke-class destroyer]."
According to reporting by *The Times* newspaper in the UK, the ship's operators said the vessel was struck about 50 nautical miles (92.6 km) southwest of the Yemeni port of Aden. *The Times* reported that there were 20 crew and three armed guards on board, who included 15 Filipinos, four Vietnamese, two Sri Lankans, an Indian and a Nepali national.
Writing on the X/Twitter social media channel on 6 March, UK Foreign Secretary Lord Cameron stated, "We condemn the Houthis' reckless and indiscriminate attacks on global shipping & demand they stop. We will continue to stand up for freedom of navigation and back our words with actions."
However, the fatalities on *True Confidence* only served to confirm that, despite numerous attacks by the forces of US CENTCOM, sometimes in conjunction with UK Royal Air Force (RAF) Typhoons operating out of RAF Akrotiri on Cyprus, the Houthis' offensive capabilities have not been degraded to a significant degree.
Even after the attack on *True Confidence*, CENTCOM reported that "At approximately 7:14 pm (Sanaa Time) March 6 United States Central Command conducted self-defense strikes against two unmanned aerial vehicles in a Houthi-controlled area of Yemen that presented an imminent threat to merchant vessels and US Navy ships in the region."
The threat of Houthi attacks is forcing international shipping companies to avoid the Red Sea/Suez Canal route and to reroute their vessels around Africa at considerable extra time and expense.
Meanwhile, CENTCOM attacks against Houthis targets in Yemen cannot negate the threat while the Houthis continue to receive further supplies of war materiel from their backers in Iran.
Hostile Houthi action against international shipping in the Red Sea region began November 2023 in response to the Israel Defense Forces' campaign against Hamas militants in Gaza following Hamas' terrorist attack on southern Israel on 7 October 2023.

Singapore adds eight F-35As to its order for 12 F-35Bs

(pf) The Republic of Singapore Air Force (RSAF) is to acquire eight Lockheed Martin F-35A Lightning II conventional take-off and landing (CTOL) Joint Strike Fighters (JSFs) to complement the 12 F-35B short take-off/vertical landing (STOVL) JSFs Singapore has already ordered.
The additional F-35 order was announced by Singaporean Defence Minister Ng Eng Hen on 28 February 2024 during a partiamentary debate on the Singaporean Ministry of Defence's (Mindef's) budget and was first reported by The Straits Times.
Singapore ordered four F-35Bs in 2020 and then another eight of the type in 2023. Delivery of the first four F-35Bs is expected in


Credit: USMC

2026, with the other eight in 2028, said Ng, while the eight F-35As now ordered are due to arrive around 2030.
Explaining the rationale behind the F-35A purchase, Ng stated, "The F-35As are designed for greater endurance; they have the ability to carry payloads of higher capacity. They complement the F-35Bs' short take-off and vertical landing capability ... which provides more operational flexibility [in land-scarce Singapore]."
While Ng did not say how much the eight F-35As will cost, he noted that Mindef and the Singapore Armed Forces might have to deprioritise other programmes to make the purchase. "But we have done our calculations, and we think this is the best time to put in the order for F-35As," he added.
The current 'flyaway' cost of an F-35A averages around USD 82.5 million (EUR 75.4 million) across its latest three production lots, compared to around USD 109 million for an F-35B.
The RSAF currently operates a fleet of 60 Lockheed Martin F-16C/D Block 52 fighters (20 F-16Cs and 40 F-16Ds) delivered from 1998 and 40 Boeing F-15SG strike fighters delivered from 2009. The F-35s are intended to progressively replace the F-16s.

Dutch to replace LPDs and OPVs with one class of Amphibious Transport Ship

(pf) The Dutch Ministry of Defence (MoD) has announced plans to replace the Royal Netherlands Navy's (RNLN's) two landing platform dock (LPD) ships and four Holland-class offshore patrol vessels (OPVs) with a single class

of six 'Amphibious Transport Ships'.
The vessels are intended to be suitable for wartime scenarios as well as other types of amphibious operations and are planned to be introduced from 2032, Dutch Defence Secretary Christophe van der Maat told the Netherlands House of Representatives on 6 March 2024.
The cost of the programme has been put by the Dutch MoD at between EUR 1 billion and EUR 2.5 billion.
The RNLN uses its LPDs, HNLMS *Rotterdam* and HNLMS *Johan de Witt*, for amphibious operations, most obviously the landing of Netherlands Marine Corps units, while the Holland-class OPVs are mainly designed for low-intensity operations, such as drug interdiction missions in the Caribbean.
However, the Dutch MoD stated on its website, "Although these tasks differ considerably from each other, both classes are combined within this project. They grow closer in terms of needs.
"For example, modern amphibious doctrine calls for light, rapid and dispersed action, with light logistical support," The MoD explained. "The new generation of ships is therefore smaller in size than the current LPDs. This could, for example, lead to multiple Amphibious Transport Ships being deployed simultaneously. The OPVs, on the other hand, are not currently designed for tasks high on the violence spectrum. Due to the deteriorated international security situation, the navy needs ships that are suitable for war conditions."


Credit: Wiki_CC BY-SA 2.0

The MoD additionally noted that both the LPDs and the Holland-class OPVs will reach the end of their operational lives at around the same time, facilitating their replacement by a single class, and that procuring one type of ship for multiple missions produces economies of scale in purchasing, training and maintenance.
To maintain the RNLN's capacity the inflow of the new Amphibious Transport Ships and the outflow of the current two LPDs and four OPVs will be co-ordinated and will require a new vessel to be operationally deployable every year from 2032, with the last vessel entering service in 2038. This is actually too late for HNLMS Rotterdam, which is set to reach the end of its service life in 2028, and so the MoD is looking at what measures might be necessary to keep the LPD in service until at least 2032. The outflow of the other ships, meanwhile, roughly corresponds to the end of their operational lifespans.
The Dutch MoD noted that, as the new class is being procured, it is co-ordinating with the UK MoD, given that the two countries have bilaterally operated the UK/NL Amphibious Force for over 50 years.

Hungarian MoD orders four more Saab Gripen C fighters

(pf) The Hungarian Ministry of Defence (MoD) signed a contract with the Swedish Defence Materiel Administration (FMV) on 23 February 2024 for four additional Gripen C fighters, manufacturer Saab announced the same day.


Credit: Saab

The Hungarian Air Force currently operates a fast jet combat fleet consisting of leased Saab Gripens, comprising 12 JAS 39C single-seat fighters and two twin-seat JAS 39D conversion trainers. These aircraft entered service in 2006 and will be owned by Hungary once the lease deal expires in 2026.
"With the Gripen fighter, Hungary has one of Europe's most capable air forces," Saab President and CEO Micael Johansson was quoted as stating in a Saab press release. "We look forward to continuing our close collaboration with the Hungarian government and defence industry," he added.
Saab additionally noted that it has a contract with the FMV regarding support for Hungary's Gripens and is ready to provide additional upgrades and support for the Hungarian fighters beyond 2035.
In January 2022 Hungary reached a deal with the FMV to upgrade its Gripen C/Ds to the latest MS20 Block 2 standard, increasing the aircraft's combat and communication capabilities and widening the range of weapons that can be integrated onto them.
Saab and the Hungarian MoD have also signed a memorandum of understanding regarding the development of high-tech industrial areas and fighter capabilities. The co-operation includes support for the establishment of a centre of excellence for virtual reality technologies in Hungary.

Russian-intercepted Luftwaffe call leads to awkward questions for Berlin

(pf) A conference call involving the chief of the Luftwaffe, Lieutenant General Ingo Gerhartz, has led to awkward questions being asked of the German government after it emerged that the conversation had been intercepted by Russia.
During the call high-ranking air force officers including Gen Gerhartz discussed German military policy in relation to the country's support for Ukraine in its conflict against invading Russian forces. The call, however, was made using standard webex video conference software that was therefore not encrypted. The recorded 38-minute conversation, which was subsequently posted online on 1 March 2024 by the head of Russia's state-backed RT media channel, has been confirmed as genuine by the German Ministry of Defence.
Most crucially the content of the leaked conversation included a discussion around how to covertly supply Ukraine with Taurus air-launched cruise missiles (ALCMs) that revealed how the UK and French military handled supplying Ukraine with Storm Shadow/SCALP ALCMs. The conversion revealed that the UK armed forces had people on the ground in Ukraine to both transfer the missiles and help integrate them onto Ukrainian aircraft and even revealed that British personnel used Ridgback protected patrol vehicles to transport the missiles.
The conversion also discussed the potential targeting of the Kerch Bridge, which links Crimea with Russia, using Taurus ALCMs and how many missiles would be needed to attack it, with one of the speakers noting that the bridge "is akin to a runway. Therefore, it may require more than 10, or even 20 missiles" to destroy it.


Credit: Bundeswehr

German Chancellor Olaf Scholz has not yet approved the supply of Taurus ALCMs to Ukraine, while the German government's distinct resistance to allowing any military advisors into Ukraine was one of the issues the Luftwaffe conversion was addressing.
The fallout from the leaked conversation has erupted on multiple fronts. Most obviously it has embarrassingly revealed the Bundeswehr

as an organisation with lax security protocols and painted Germany as an ally that cannot be trusted to hold close the secrets of its allies. The revelations from the conversations will no doubt force the UK and France to change their procedures for delivering ALCMs to Ukraine.

Former UK defence secretary Ben Wallace told The Times newspaper, "We know Germany is pretty penetrated by Russian intelligence, so it just demonstrates they are neither secure nor reliable."

The leaked call has also led to a diplomatic spat between Moscow and Berlin, with Russia claiming the conversation was evidence that Germany was preparing acts of war against Russia. Dmitry Peskov, the spokesman for Russian President Vladimir Putin, was quoted as saying that the recording "suggests that the Bundeswehr is discussing substantively and specifically plans to strike Russian territory".

Germany, in turn, has pointed to an aggressive Russian spying operation designed to sow discord among NATO's allies and, given the timing of the released recording, to offset the negative publicity in Russia surrounding the death of imprisoned dissident Alexei Navalny.

The ultimate loser in the episode, however, may be Ukraine, which is now arguably much less likely to receive the Taurus ALCMs it has been requested from the German government for some time.

Ukrainian USVs claim Russian patrol ship *Sergei Kotov*

(pf) The Ukrainian military has claimed the destruction of another vessel of Russia's Black Sea Fleet, this time the 1,700-tonne Project 22160-class patrol ship *Sergei Kotov.* As with previous strikes, the attack was conducted using multiple bomb-laden Magura V5 unmanned surface vessels (USVs).

The Main Directorate of Intelligence (HUR) of the Ukrainian Ministry of Defence stated on its website, "On the night of March 4-5 2024, Group 13, a special unit of the Defence Intelligence of Ukraine, attacked the Russian patrol warship Sergei Kotov. The operation was carried out in co-operation with the Navy of Ukraine and with the support of the Ministry of Digital Transformation of Ukraine.

"As a result of the strike by Magura V5 marine drone[s]," the HUR added, "the Russian warship *Sergei Kotov* of Project 22160 suffered damage to the stern, port and starboard sides.

The HUR stated that the ship was attacked "in Ukraine's territorial waters near the Kerch Strait", claiming that "the cost of the sunken ship is about USD 65 million [EUR 60 million]".

Infra-red footage of the attack from the Magura V5 USVs, posted by the HUR on its website and on YouTube, showed the ship suffering multiple explosions.

Project 22160-class patrol ships typically have a crew of up to 80, with the HUR claiming that Russian casualties in the *Sergei Kotov* attack "amounted to seven irrecoverable losses and six sanitary losses [personnel who have lost their combat capability]". The HUR added that the Russians "probably managed to evacuate 52 crew members who were on the ship".

The Ukrainian military have now sunk several significant vessels of the Russian Black Sea Fleet.


Credit: HUR

The first significant ship sunk by Ukraine was the Tapir-class landing ship *Saratov*, which was sunk or scuttled on 24 March 2022 in the port of Berdiansk after sustaining missile damage. Ukrainian forces then famously sank the Russian Slava-class cruiser *Moskva* using Nepture anti-ship missiles on 13 April 2022.

Air-launched Storm Shadow missiles then destroyed the Ropucha-class landing ship Minsk on 13 September 2023 and struck another Ropucha-class vessel, *Novocherkassk*, on 26 December 2023, probably destroying the ship.

The Russian Tarantul-class corvette *Ivanovets* was sunk on the night of 31 January/1 February using bomb-laden USVs, which also accounted for the sinking of the Ropucha-class landing ship *Caesar Kunikov* on 14 February 2024.

Other major naval vessels, including a 'Kilo'-class submarine, have been significantly damaged, possibly beyond repair, and numerous smaller vessels sunk.

Australian government releases blueprint for larger and more lethal RAN surface fleet

(pf) The Australian government released its blueprint for a larger and more lethal surface combatant fleet for the Royal Australian Navy (RAN) on 20 February 2024. Its publication follows Canberra's consideration of the recommendations of an independent analysis of the surface combatant fleet, commissioned in response to the government's 2023 Defence Strategic Review.

Although the blueprint calls for fewer Hunter-class frigates than planned, it nevertheless envisages a more than doubling of the size of the RAN's surface combatant fleet compared to the former government's plan.

"The independent analysis of [the] navy's surface combatant fleet lamented the current surface combatant fleet was the oldest fleet navy has operated in its history, and emphasised the need for immediate action to boost [the] navy's air defence, long-range strike, presence and anti-submarine warfare capabilities," the Australian Department of Defence (DoD) noted in its press release.

The DoD's future plans consequently call for a RAN fleet that includes 26 major surface combatants consisting of:

- Three Hobart-class air warfare destroyers with upgraded air defence and strike capabilities;
- Six Hunter-class frigates to boost the RAN's undersea warfare and strike capabilities (a reduction from the previous plan for nine such ships);
- 11 new general-purpose frigates that will provide maritime and land strike, air defence and escort capabilities;
- Six new Large Optionally Crewed Surface Vessels (LOSVs) that will significantly increase the RAN's long-range strike capacity;
- Six remaining Anzac-class frigates from the current eight-strong fleet (with the two oldest ships to be decommissioned as per their planned service life).

The blueprint also accepted the independent analysis' recommendations to have 25 minor war vessels to contribute to civil maritime security operations, including six offshore patrol vessels (OPVs).

The Hunter-class frigates will be built at the Osborne shipyard in South Australia, the construction of which will be followed by the replacement for the RAN's Hobart-class destroyers, which will meanwhile be upgraded at Osborne with the latest US Navy Aegis combat system.

Construction of the new general-purpose frigates will be accelerated to replace the


Credit: BAE Systems Australia

Anzac class, meaning their Transition Capability Assurance (TransCAP) upgrades are no longer required.

"These new general-purpose frigates will be modern, capable and more lethal, requiring smaller crews than the Anzac [class]," the DoD stated.

Consolidation of the marine industry precinct located at Henderson in Western Australia is currently underway, as recommended by the Defence Strategic Review.

"Successful and timely consolidation will enable eight new general-purpose frigates to be built at the Henderson precinct and will also enable a pathway to build six new Large Optionally Crewed Surface Vessels in Western Australia," the DoD stated.

"The Albanese government is committed to continuous naval shipbuilding in Australia and the design of [the] navy's future fleet will provide a stable and ongoing pipeline of work to the 2040s and beyond," the DoD added.

In order to implement the recommendations of the independent analysis, the Australian government has committed to funding the planned acquisition and sustainment of the future surface fleet. This will see the government inject an additional AUS 1.7 billion (EUR 1.03 billion) over its Forward Estimates and AUS 11.1 billion over the next decade in defence overall for an accelerated delivery of the RAN's future surface combatant fleet and to expand Australia's shipbuilding industry.

This comes on top of the government of Australian Prime Minister Anthony Albanese investing an additional AUS 30.5 billion to the DoD's Integrated Investment Program out to 2032-33.

F-35A Lightning II certified as nuclear weapon carrier

(gh) The Lockheed Martin F-35A Joint Strike Fighter (JSF) has been certified for the use of the B61-12 thermonuclear gravity bomb, news portal Breaking Defense reported on 8 March 2024, citing a spokesman for the F-35 Joint Program Office (JPO), Russ Goemaere.

The nuclear certification of the conventional take-off and landing (CTOL) JSF variant was achieved on 12 October 2023, months ahead of an undertaking made to NATO allies that the certification would be in place by 2024.

This will make the F-35A a "dual-capable" fighter that can carry both conventional and nuclear weapons, Breaking Defense quoted Goemaere as saying.

Credit: F-35 JPO

In December 2022 the then German defence minister, Christine Lambrecht, officially sealed the procurement of the F-35A for the Bundeswehr by signing the letter of acceptance for the aircraft, the Bundeswehr wrote on its website at the time. The certification of the aircraft as a nuclear weapon carrier was an important selection criterion in order to secure the Bundeswehr's continued NATO 'nuclear sharing' mission. The F-35A is to take over the nuclear role, previously assigned to the Luftwaffe's Tornado strike aircraft, without interruption until it is decommissioned. After around 50 years in Luftwaffe service, the Tornado will reach the end of its service life in 2030.

The B61-12 is the 12th version of a nuclear gravity bomb that was introduced in 1968.

According to the National Nuclear Security Administration (NNSA), it can be used as a ballistic or guided weapon. The 375 kg bomb has been given more precise GPS/inertial navigation with a life extension program. Production was scheduled for 2020 to 2025. The first B61-12 from series production was handed over on 20 December 2021. Version 12 will replace versions 3, 4, 7 and 10. According to unconfirmed information, the adjustable explosive force will be between 0.3 and 50 kilotons.
According to information from the International Campaign to Abolish Nuclear Weapons in Germany, the nuclear warheads stored in Europe are to be replaced by the B61-12 from the beginning of 2023.

UK MoD plays down failed test of Trident II SLBM

(pf) The UK Ministry of Defence (MoD) has played down the significance of the recent failed test launch of a Trident II (D5) submarine-launched ballistic missile (SLBM).
The test failure, first reported by *The Sun* newspaper, occurred on 30 January 2024, when the nuclear-powered ballistic missile submarine HMS *Vanguard* tested an unarmed Trident II SLBM off the coast of Florida. It has been reported that the missile's first-stage boosters did not ignite, leaving it to drop into the ocean nearby. The missile was supposed to have flown for around 6,000 km before entering the sea between Brazil and West Africa.


Credit: USMC

The test was intended to be the final hurdle for HMS Vanguard, one of the Royal Navy's four SSBNs, to re-enter service following a GBP 500 million (EUR 584 million) overhaul.
UK Defence Secretary Grant Shapps, who was on board HMS Vanguard for the launch, issued a written statement to the UK Parliament on 21 February 2024 that read, "The test reaffirmed the effectiveness of the UK's nuclear deterrent, in which the government has absolute confidence. The submarine and crew were successfully certified and will rejoin the operational cycle as planned. On this occasion an anomaly did occur, but it was event specific and there are no implications for the reliability of the wider Trident missile systems and stockpiles. Nor are there any implications for our ability to fire our nuclear weapons, should the circumstances arise in which we need to do so."
Tobias Ellwood, the former chairman of the House of Commons Defence Committee, told GB News that the failure was caused by test equipment strapped to the missile and that "the actual rocket didn't fire because of the testing equipment".
However, the failed test is the second successive launch failure for UK Tridents. In 2016 another unarmed Trident II, launched from the SSBN HMS *Vengeance*, suffered a serious malfunction that saw it travel in the wrong direction and automatically self-destruct.
The Trident II SLBM has been the sole weapon of the UK's nuclear deterrent since the WE.177 freefall nuclear bomb was retired from UK service in 1998.

Saab signs EUR 1 billion Carl-Gustaf M4 deal with Poland

(pf) Saab signed a contract with the Polish Ministry of National Defence's procurement authority on 4 March 2024 for delivery of Carl-Gustaf M4 weapons, ammunition and training equipment, the Swedish manufacturer announced the same day.
The order value corresponds to SEK 12.9 billion (EUR 1.15 billion), according to Saab, which expects to book the order and make the contract effective before the end of this year's second quarter, "subject to the fulfilment of certain external conditions", Saab noted.
The contract period is 2024-2027.
"I am proud of our close relationship with the Polish armed forces and that Saab can continue to strengthen Poland's ground combat capability and national defence with our world-leading Carl-Gustaf system," Saab CEO and President Micael Johansson was quoted as saying in a Saab press release.
Saab's ubiquitous Carl-Gustaf 84 mm recoilless rifle is a man-portable, multi-role weapon system that allows dismounted


Credit: Saab

soldiers to effectively deal with multiple challenges on the modern battlefield. The Carl-Gustaf M4 is the latest iteration of the weapon, offering a number of advantages over its predecessors, such as being shorter than 1 m long and weighing less than 7 kg, thus less cumbersome to carry and use. Although the M4 is backward-compatible with all legacy Carl-Gustaf ammunition, it is also compatible with programmable ammunition and advanced fire control devices. Addressable targets include armoured vehicles, bunkers, obstacles and even enemy troops in defilade.

Austrian MoD orders 36 Skyranger 30 air defence systems for its Pandur 6×6 Evo fleet

(pf) The Austrian Ministry of Defence (MoD) is procuring Rheinmetall Skyranger 30 turreted air defence systems to install on 36 of the Pandur 6×6 Evolution (Evo) wheeled armoured vehicles it recently ordered from General Dynamics European Land Systems – Steyr (GDELS-Steyr), Rheinmetall announced on 23 February 2024.
The order is worth a figure in the mid-three-digit million-euro range, according to Rheinmetall, with deliveries to begin in 2026.


Credit: Rheinmetall

Under the project Rheinmetall is serving as a subcontractor of GDELS-Steyr, which announced on 19 February that the Austrian MoD had ordered 225 Pandur 6×6 Evo vehicles, representing a fourth batch of these vehicles for the Austrian Army. A hundred Pandur Evos have previously been ordered: 34 in 2016 and delivered by 2020, 30 in October 2020 and delivered by 2023, and a third batch of 36 in September 2022 that is currently in production and delivery.
The 36 Pandur 6×6 Evos to receive Skyranger 30 turrets will thus give the Austrian Army a significant mobile air defence capability. Skyranger combines state-of-the-art sensors with a high-performance 30 mm automatic cannon and surface-to-air missiles, which in the Austrian case will be Mistrals.

EDGE Group to join Fincantieri in shipbuilding joint venture

(pf) United Arab Emirates (UAE) defence entity EDGE Group and Italian shipbuilder Fincantieri have agreed to launch a joint venture (JV) to capitalise on global shipbuilding opportunities with a focus on the manufacturing of a broad range of sophisticated naval vessels, the companies announced on 21 February 2024.

EDGE will hold a 51% stake in the venture, which has a commercial pipeline valued at approximately EUR 30 billion, with management direction provided by Fincantieri. The Abu Dhabi-based JV will be awarded prime rights to non-NATO orders, especially leveraging on the attractiveness of Emirati government-to-government arrangements and export credit financing packages, along with a number of strategic orders placed by select NATO member countries.

The agreement, which was formalised at a recent event at Palazzo Marina in Rome attended by senior Italian defence officials, was signed by Hamad Al Marar, managing director and CEO of EDGE Group, and Pierroberto Folgiero, CEO and managing director of Fincantieri.

The agreement grants the JV a strong mandate to market its products to navies worldwide, underlining its global ambition and commitment to developing joint intellectual property and future designs. The deal significantly enhances EDGE's ability to design and build frigates and other large vessels, broadening its range of operations and marking a crucial advancement in the diversification of its maritime solutions portfolio. The JV also harbours ambitions to develop an underwater programme for mid-sized submarines.

The incorporation of the JV is subject to a series of conditions customary for an agreement of this kind.

"The JV will concentrate on sales, commercial operations, and engineering for design and service, taking charge of developing shared intellectual property and retaining exclusive rights to all future designs," the companies jointly stated. "Furthermore, the JV will set up a dedicated design authority, opening up opportunities for highly skilled Emiratis, and drawing in international expertise to support this innovative and strategic initiative."

"Through this transformative joint venture with Fincantieri, we are not just expanding EDGE's diverse capabilities in shipbuilding but setting a new benchmark for collaboration and knowledge exchange in the global maritime industry," Al Marar was quoted as saying. "This partnership embodies our commitment to innovation, leveraging Fincantieri's unmatched expertise to explore opportunities in the global market. This venture is a testament to our strategic vision of growth through collaboration, promising a future of technological advancements and enhanced naval defence solutions."

Folgiero added, "We are honoured and eager to join forces with EDGE Group with the aim of creating a unique industrial platform able to address with maximum entrepreneurship and distinctive competencies the sizable market opportunities originated in the UAE and from the UAE to the international markets."

Embraer and ST Engineering sign accord to further co-operation in Asia and South America

(pf) Embraer Defense & Security announced an agreement with ST Engineering on 14 March 2024 to jointly explore alternatives for future collaboration in key identified areas such as engineering, maintenance and support service activities for Embraer's C-390 Millennium multi-mission transport aircraft in the Asia Pacific region.

In addition, both companies will co-operate on products and services, including radars and land systems, C4ISTAR systems, border security, simulation and advanced production methodologies, in support of ST Engineering's portfolio of capabilities in South America.

The co-operation is based on a memorandum of understanding (MoU) signed in February during the Singapore Airshow 2024.

"We see strong synergies between ST Engineering's capabilities in defence and the MRO [maintenance, repair and overhaul] sector and Embraer Defense & Security's complete line of integrated solutions and we look forward to fostering stronger ties with ST Engineering," Bosco da Costa Junior, president and CEO of Embraer Defense & Security, was quoted as saying in a company press release. "The C-390 Millennium is a flagship product for Embraer Defense & Security and it received a lot of attention at the recent Singapore Airshow. We look forward to growing our customer base in the region."

In addition to Brazil, the C-390 has been selected by South Korea, the Czech Republic, Austria, the Netherlands and Portugal. The fleet of C-390 aircraft currently in operation has accumulated more than 11,500 flight hours, with operational availability of around 80% and mission completion rates above 99%, according to Embraer.

ST Engineering's defence capabilities, meanwhile, cover a wide range of solutions from engineering aircraft and avionics upgrades to designing and building proven battlefield mobility platforms, soldier systems, ammunition and naval vessels.

As an authorised service centre for several original equipment manufacturers, ST Engineering's Defense Aerospace business provides a comprehensive range of maintenance support and solutions, including aircraft modernisation for global customers, supporting platforms including combat aircraft, transports and trainers as well as helicopters.

EDGE Group and Indra form joint venture to create UAE-based advanced radar house

(pf) EDGE Group of the United Arab Emirates (UAE) formalised a new joint venture (JV) agreement with Spain's Indra Sistemas (Indra) on 4 March 2024.

The agreement, signed at the Ministry of Defence in Madrid by EDGE Managing Director and CEO Hamad Al Marar and Indra CEO Jose Vicente de los Mozos, will see the new Abu Dhabi-based JV develop and manufacture next-generation radar systems in the UAE, opening a pipeline of orders for approximately 300 advanced radar solutions. The new business will be granted prime rights for current and future non-NATO and non-EU orders awarded to Indra.

Al Marar said during the signing ceremony, "This new joint venture with one of Europe's top three defence technology players in this sector will enable EDGE, in partnership with Indra, to significantly expand and diversify the scope of its offerings through knowledge sharing and the development and manufac-

Credit: Embraer

Credit: EDGE Group

ture of advanced radar systems to customers around the world."

"In line with our strategy for growth through mutually beneficial partnerships, we are fully committed to this venture, which will be built on both companies' existing reputation for excellence, and which will enable us to combine our strengths to drive innovation, develop sovereign capabilities, and expand market reach, while contributing to the technological advancement and economic growth of the UAE and Spain," Al Marar added.

EDGE stated in a press release that the JV "will place a strategic focus on the continued development of sophisticated technologies, innovation, and global market expansion by targeting untapped and fragmented non-NATO markets outside of the European Union. EDGE will bring its commercial strength and technology building blocks, while Indra will enhance the new company's capabilities by transferring technology, and shifting some engineering, commercial, and manufacturing capabilities to the JV."

H E Faisal Al Bannai, Chairman of EDGE Group, was quoted as saying, "We see tremendous value in building relationships that will spur growth and bring tangible benefits to all parties. Our new joint venture with Indra, as a global market leader in the field of advanced radar technologies, will enable us to combine the strengths of both companies to create an entity that will become a major industry player in this sector. We are confident that this strategic partnership will prove to be a highly successful one."

Marc Murtra, chairman of Indra, added, "This agreement between the two companies can create one of the world's leading players in the field of radar technology and is a step forward in Indra's international expansion strategy. With strategic initiatives such as this, we are making decisive steps in key vectors of our Strategic Vision 2024-2026: technological leadership, international growth and partnerships building."

José Vicente de los Mozos, CEO of Indra, said: "The JV between Indra and EDGE Group will be recognised for its capacity for innovation and the use of the most sophisticated technologies. This JV will help us to expand our geographical reach and our international mindset in our defence business and will increase our proximity to the global clients. We in Indra are convinced that this JV will create new significant business opportunities in new markets."

On 6 March Indra published its industrial and strategic plan 'Leading the Future', which it described as a "decisive strategic transformation milestone for Indra" of which the JV with EDGE will be a significant part.

The JV will also focus on building a team of highly qualified personnel in the UAE, particularly in sales and engineering roles, by leveraging local Emirati as well as global talent, to ensure "sustainable operational excellence and innovative output".

Babcock and ST Engineering team to offer land systems solutions

(pf) UK-based Babcock International Group and Singapore Technologies Engineering (ST Engineering) have signed a collaboration agreement to offer capabilities across the land domain, Babcock announced on 5 March 2024.

Credit: Babcock

The agreement, which will have an initial focus on mortar systems, brings together the companies' skills, technology, products and integrated solutions to pursue opportunities in defence markets of joint interest, combining the benefits of Babcock's long-standing systems integration experience and close working relationship with the British armed forces with ST Engineering's extensive land systems portfolio.

"This announcement formalises an exciting relationship with ST Engineering, ensuring ST's unique land systems capabilities are embedded in the UK in order to serve our customers' emerging and complex needs," Chris Spicer, managing director of engineering and systems integration at Babcock's Land business, was quoted as saying in a company press release. "By partnering, our organisations can offer complementary skills, technologies and truly transformative solutions to enhance the delivery of our customers' critical and complex missions."

Tan Pek Tong, head of international business for ST Engineering's Land Systems business, added: "We are pleased to partner Babcock in exploring opportunities in the UK and other markets. We believe the synergistic capabilities offered by ST Engineering and Babcock can offer compelling operational requirements to deliver mission critical outcomes for our customers."

DIMDEX 2024: Aselsan and Barzan Holdings sign two MoUs

(pf) Turkey's Aselsan and Qatari company Barzan Holdings signed two memoranda of understanding (MoUs) at DIMDEX 2024, Qatar's biennial maritime defence exhibition, which was held in Doha from 4-6 March.

The MoUs signify further collaboration between Aselsan and Barzan Holdings on possible future agreements for the procurement of Aselsan solutions and services by the Qatari end users. Aselsan will also directly contribute to the growth of Qatar's indigenous defence industry as part of the strategic alliance with Barzan Holdings.

The first MoU encompasses the transfer of production and technology for laser guidance kits (LGK), while under the second MoU Aselsan and Barzan Holdings solidify their commitment to strengthening land forces capabilities by initiating collaboration on cutting-edge electronic warfare (EW) technology.

"Qatar focuses on investing in highly advanced systems, which creates a competitive arena for the leading defence and security brands who compete on providing excellence," Ahmet Akyol, Aselsan's president and CEO, was quoted as saying n a company press release. "We as Aselsan, being a well-trusted defence and technology company, are excited for the new opportunities together with our valued partner Barzan Holdings to strengthen Qatar in this challenging sector."

Abdulla Hassan Al Khater, CEO of Barzan Holdings, added, "We at Barzan Holdings are excited to strengthen our partnership with Aselsan through these MoUs. These agreements aim to support the integration of innovative defence technologies, contribute to the development of Qatar's military, and promote knowledge transfer. We look forward to this collaboration and its role in bolstering our country's security forces."

Credit: Aselsan

Armoured Fury: Analysing Large Calibre Ammunition in the Ukraine Conflict

Sam Cranny-Evans

Tanks provide a vital form of fire support in Ukraine, which means that both sides rely extensively on high explosive (HE) and guided ammunition natures.

If you watch enough videos and read enough reports, you will get a sense of the vast scale of Ukraine. It is more easily appreciated by driving; even the relatively populated route from Lviv to Kyiv will travel through hundreds of kilometres of open fields. The occasional settlement breaks up what is otherwise uninterrupted terrain that is mostly flat with some large hills. The country has a total land area of 579,330 km^2, with another 24,200 km^2 of water – this makes it twice the size of Italy, not much smaller than France, and about 14 times the size of the Netherlands. Much of Ukraine is made up of similar terrain except for the Carpathian Mountains that form a natural barrier with Romania, Hungary, and Slovakia. The Dnipro River is one of Ukraine's most dominant features, it runs from north-to-south and empties into the Black Sea, it averages 80 – 400 m along its length, and has a maximum width of 7 km near a dam in Zaporizhzhia. Forests cover around 16.7% of Ukraine, but their distribution is uneven. The northern and western regions boast higher proportions of woodland, while the southern and eastern regions transition into steppe landscapes with little to no woodland. The northern and western regions are home to most of Ukraine's wetlands, with others located in river floodplains; this accounts for another 1.7% of Ukraine's land.

Author

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Credit: National Guard of Ukraine, via Wikimedia Commons

A tank from the Azov brigade fires at Russian troops from a T-64BV. From the angle of the gun, it is possible that this is a long-range shot.

In theory, this is the type of topographical description that lends itself to large meeting engagements of tanks and armoured vehicles. In fact, during World War II, Germany's 1st Panzer Group met the Soviet 5th and 6th Armies around Brody in 1941. Some estimate that there were 5,000 tanks involved in that battle, which ultimately ended in favour of the 1st Panzer Group. Yet during Russia's war against Ukraine, there have been remarkably few sweeping advances, and even fewer meeting engagements between massed ranks of armour. There are many reasons for this; the persistent ISR of both sides with effective and short artillery targeting cycles make attempts at concentrating armour ill-advised. Equally, the prevalence of anti-tank guided missiles (ATGMs) means that infantry are more easily able to break up and absorb an armoured advance than their WWII predecessors. In some areas, Russian forces did advance with relative speed at the start of the war. In those areas that had been fought over since 2015, however, they were slowed by Ukrainian fortifications and resistance. The scale mentioned above, combined with extensive attrition, also seems to lead to a lack of available armour.

This means that Russian and Ukrainian tanks rarely meet, and if they do, engagements are between a few vehicles and short. As a result of this, the armour piercing fin stabilised discarding sabot (APFSDS) rounds that have shaped and defined armour-on-armour engagements for a generation, are not the most important large-calibre nature used by armoured vehicles in the war. That title belongs firmly with the HE rounds and gun-launched ATGMs (GLATGMs).

Accurate, immediate, and deadly

Tanks have come to play a key role in Ukraine through the provision of fire support against fortified positions, snipers, and vehicles. The Russian's had explored this tactic prior to the invasion by pairing Orlan-10 drones with tanks to create a tactical reconnaissance-fire capability. The majority of fires are conducted at low angles, making it essentially direct fire. The primary ammunition used for this type of mission is HE, the Soviet era tanks employed by both sides may have access to the 125 mm 3VOF36 round, which consists of the 3OF26 high explosive fragmentation fin-stabilised munition, a V-429E or V-429V fuze; and either a 4Zh40 or a 4Zh52 rear propelling charge. The 3OF26 projectile has a weight of 19.4 kg and can be fired to a maximum range of 10 km. It has a steel body, and carries 3.4 kg of A-IX-2 explosive material, constituting 14.8% of the projectile's total weight. The fuze is a point detonating type but it can be set to delayed activation. A-IX-2 is a Russian explosive that consists of 73% RDX, 23% aluminium powder, and 4% wax as a phlegmatiser, which is used to stabilise the RDX and make it less sensitive. The four fins at the rear impart a slow rate of spin, but this spin is not involved in arming the fuze.

The 3OF26 will deviate up to 0.23 m from the line of shot for every 1,000 m it travels. However, one Russian source from 2005 indicates that the round is much less accurate, with sufficient dispersion at 2,000 m that makes it difficult to use reliably. The round is also made from a steel alloy that lends itself to 'hot stamping' for production, but inefficient creation of fragmentation. The author uncharitably referred to the 3OF26 as 'technology from the 30s'. He also noted that the impact fuze was limited and could not be used during rain or hail. An alternate fuzing system was developed for use with the Aynet fire control system in the T-90K and T-80UK tanks. It employed the 3VM17 and 3VM18 electric fuzes that were programmed as the round was loaded, enabling the crew to fire high explosive rounds with an airburst detonation. The Russian author noted, however, that the fire control system was not capable of reliably producing the kind of accuracy needed for this, as shells would have a 0.001 second window in which to detonate above an enemy trench.

The theoretical outcome, or supposed outcome of combat based on assessment of the technology in a vacuum is not always an accurate reflection of the real world outcomes, however. The following is an account of a Western volunteer fighting in Ukraine in 2022:

"I had [taken] a position with the PKM just to the right of everyone else in a small little 'L' shape type of trench. Every so often we would hear enemy drones flying over us and not long after would hear tank rounds getting fired. There [were] some [which] were hitting in a field not too far from us. About 5 minutes after that I could hear the sound of a drone coming towards us. It was right over me and I was expecting it to carry on moving, but this time it never did. I heard the drone get loud as it hovered over me and within about 10 seconds I heard the sound of a tank fire. Next thing I see was a red flame and hear a loud bang. I got instant ringing in my ears I couldn't hear nothing [sic]. 'Are my friends okay?' is the

Credit: National Police of Ukraine, via Wikimedia Commons

This image shows damaged buildings in Avdiivka. Direct fire from tanks using HE rounds has been important in many wars, and that role has continued in Ukraine.

Credit: Russian MoD

Two Russian tankers prepare 125 mm HE 3VOF36 rounds to be loaded into their T-72B3 in 2020. The HE nature has proven very valuable in the type of fighting that predominates in Ukraine.

first thing I thought. At first I thought shrapnel had went into my left hand, I felt the impact from the blast hit my left side. I knew I needed to get to a better trench, so I ran to a trench [which] had better cover for me."

There are many accounts of Russian tanks employing high explosive shells in this way. Some reveal startling accuracy – first round strikes against a few isolated personnel, rounds bursting through walls of buildings that tear helmets from heads and shower infantry in fragmentation. It is also understood that tanks are used in conjunction with drones to improve their accuracy. Some accounts indicate that tank rounds are especially demoralising, because they provide no indication of their approach like artillery shells. Direct fire support is conducted at distances of 2 km from Ukrainian positions. With a muzzle velocity of 850 m/s, the 3OF26 will reach a target in around 3 seconds. Russian forces will fire large quantities of rounds at a target and relocate before return fire is generated. In many ways, the 3OF26 is one of the most important tank rounds for the Russian armed forces, it is valuable in an urban fight, as well as against fortifications.

Advanced types

The Russians are not alone in using tank armaments for fire support; Ukraine has made use of its Soviet-era tanks as well as newer platforms from the West in this role. Ukraine operates a veritable zoo of armoured vehicles, so it is not possible to explore every type of ammunition that they may have been provided. However, there is evidence of Ukraine receiving the 120 mm DM11 high explosive round with a programmable fuze from Germany. This is arguably one of the more advanced HE natures in use in Ukraine. It contains 2.17 kg of HE filler and 6,000 tungsten balls located in the tip of the warhead, all surrounded by a strong steel casing that enables the round to be used against bunkers and walls. It has a muzzle velocity of 1,000 m/s when fired from the L55 gun of a Leopard 2A6 and a programmable fuze in the base of the munition. The munition is stabilised by four folding fins at the rear and is provided as a single piece round with propellant attached. It was required to have a range of 5,000 m and be lethal to lightly armoured vehicles like BTRs, and capable of disabling 50% of an infantry squad in a wedge formation with two shots. Upon detonation the DM11 generates a total of 13 kg of fragments including the tungsten balls. If a fuze programming kit is not fitted, the Rh31 round can be used as an alternative to DM11. This uses the same warhead as DM11, but the round is only fitted with a point detonating fuze, and has a lower effective range of 3,500 m.

Russia has developed its own air-bursting round for tanks, which is designated 3VOF128 Tel'nik and was reported to be in use with Russian forces in October 2023. It is fitted with the 3VM18 fuze, has a total projectile weight of 23 kg, including 3 kg of explosive filler and a 1.6 kg fragmenting element designed to disperse the 450 pre-formed fragments in a cone pattern. Of the tanks used by Russia in Ukraine, Tel'nik can only be fired by the T-90M, as it requires the use of a compatible fire control system and ballistic computer for programming of the fuze.

Russian and Ukrainian tank crews have also made use of GLATGMs for precise strikes against ground-based ATGM teams and other isolated targets. The missiles provide greater range and accuracy than other forms of tank-fired munition, which makes them a valuable weapon to stay beyond the reach of weapons such as Javelin. The 9M119M Invar is one example of a GLATGM employed by Russian forces. The complete system is designated 9K119M Refleks-M, and it consists of the guided 9M119M Invar projectile, and the 9Kh949 ejector which pushes the missile out of the barrel, as well as a guidance system inside the tank turret. It employs laser beam riding for its semi-automatic command to line-of-sight (SACLOS) guidance, employing an encoded laser beam to send guidance corrections to a receiver located on the base of the missile in flight. Refleks-M has a range of 5 km, and takes 14 seconds to reach its maximum range, powered by a solid propellant motor. The warhead weighs 4.5 kg and is a tandem high explosive anti-tank (HEAT) nature, designed to penetrate tanks protected by explosive reactive armour (ERA). Like the 3OF26, GLATGMs are used against defences and stationary positions too, their accuracy providing a form of precise fire for frontline units.

Credit: Bundeswehr-Fotos, via Wikimedia Commons

This image shows a Leopard 2A6 in service with the Bundeswehr. The type has been used in Ukraine and has been observed providing fire support against Russian trenches and emplacements.

Credit: Vitaly Kuzmin, via Wikimedia Commons

The 9M119M Invar GLATGM is shown here with its specialised 'pusher', which expels it from the gun before the rocket motor takes over. It can take 15 seconds or more to reach its full range, but it – and other munitions like it – are still a valuable tool for tank crews fighting against emplaced positions.

Indirect fire; a waste of time?

Soviet tankers were taught indirect fire as far back as WWII, on various tanks such as T-34 and IS-3. Each tank was equipped with an indirect fire azimuth indicator that had to be dismounted for use, as well as an elevation quadrant mounted on the gun carriage. The azimuth and elevation devices were used to measure gun orientation and elevation for indirect fire, and the gunner would conduct calculations to get the rounds onto a target. They considered anything beyond 2,500 m to be a valid indirect fire target and the command sequence to fire would begin with the azimuth, elevation, and type of ammunition. The commander might also give instructions on the type of fire – three round volley fire for instance.

In later designs such as the T-72, a turret azimuth indicator is included inside the turret and used to provide a precise indication of the turret's orientation for indirect fire. The sighting system on the standard T-72s provides fire control solutions and ballistic calculations out to 4,000 m for direct fire. Indirect fire at ranges beyond this is likely closer in methodology to the aforementioned T-34 scenario. This form of fire is relatively ineffective and produces a wide dispersion of impacts. However, it appears to be used to some extent in Ukraine as a means of generating harassing fire or of supporting artillery fire. This is especially the case where Russian units are lacking artillery. Ukrainian units have also reportedly made good use of indirect fire from tanks and employed digital methods of fire correction.

In sum

Perhaps past battles in WWII, the 1973 Arab-Israeli war, or the 1991 Gulf War are responsible for the impression that tanks should be fighting other tanks? There are many wars where tank-on-tank combat has formed a minor, almost unimportant role for heavy armour. Most recently, Chechnya, Syria, Iraq during the 2003 invasion and again during the fight against ISIS, their primary role has been in fire support of infantry operations. In that sense, the weight of history suggests that we should have expected tanks to primarily provide fire support with high explosive and other ammunition natures rather than being limited to high intensity combat against other tanks with APFSDS rounds. ■

Counter-UAV: meeting emerging threats

David Isby

The proliferation of unmanned aerial vehicles (UAVs) is transforming conflicts, both ashore and afloat.

Unmanned aerial vehicles are increasingly used for kinetic and non-kinetic attacks, along with their primary intelligence, surveillance and reconnaissance (ISR) mission. Attack UAVs – in function effectively cruise missiles – have been extensively used in the Red Sea, Syria and Iraq, Nagorno-Karabakh and Ukraine; a United Kingdom Ministry of Defence intelligence update on Ukraine on 1 November 2023 described them as "one of the most effective new capabilities". The counter-UAV (C-UAV) target set is often slow, low-observable, operating at low altitude and often amid ground clutter, and, above all, cheaper and easier to deploy than the surface-to-air missiles (SAMs) that can intercept them. Then-Marine General Kenneth McKenzie Jr., commanding US Central Command (CENTCOM), said in a speech to the Middle East Institute in Washington on 7 February 2021, "The growing threat posed by these systems, coupled with our lack of dependable, networked capabilities to counter them, is the most concerning tactical development."

C-UAV is not limited to niche or specialised assets, but overlaps with integrated air and missile defence (IAMD) and indirect fire protection capability (IFPC), the latter focussing on the counter – rocket, artillery and mortar (C-RAM) mission. All three mission areas focus on active defence – defeating threats after launch – but also include attack operations and passive defence, all made possible by BM/C4I (battle management/command, control, communications, computers and intelligence). As with IAMD and ICPC, no single, affordable 'silver bullet' solution for C-UAV is possible. Rather, an effective architecture integrates disparate systems across service and national lines.

Credit: USMC/Sgt Melissa Marnell

Early version of LMADIS is visible in the background, while a Low Altitude Air Defense (LAAD) Officer operates a drone during C-UAV training in the Kingdom of Saudi Arabia, on 12 June 2021. This version of the system used the RPS-42 radars and CM202 mast-mounted sight, both of which were replaced on the version of LMADIS shown in 2023.

In the US and worldwide, "the production for counter-UAS [has] to go through the roof," Bill LaPlante, Under Secretary of Defense for Acquisition and Sustainment, said during the Reagan National Defense Forum in California on 3 December 2023. Maximising system capabilities, sustaining high production rates and expanding magazine size – and minimising the associated cost – is critical to fielding effective C-UAV systems. He said, "Everything I said has to be affordable; if it costs USD 1 million a round and you're going against a USD 100,000-or-less cheap UAS – they've won".

In FY 2023, the US Department of Defense (DoD) allocated USD 668 million for C-UAV research development test and evaluation (RDT&E) programmes and at least USD 78 million for procurement. Even though procurement funding increased to USD 365 million in the Army's FY 2024 request, "It is mostly RDT&E because they are prototypes," LaPlante said. "We've got to move that to production…counter-UAS capabilities, at scale. We need lots of money…we need production lines to go fast." The Army, as the lead service for the C-UAV mission, is planning on introducing a dedicated C-UAV funding line in the FY 2025 budget request, due in March 2024.

In 2019, the DoD established the Joint C-small UAS Organization (JCO) with responsibility to enable the defeat of UAVs in Group 1 (UAVs weighing up to 9 kg, flying under 457 m at less than 185 km/h), Group 2 (11–25 kg, up to 3,500 feet and 250 kn) and Group 3 (up to 600 kg, 1,067 m and 463 km/h). The US Army has made defence against UAV Group 3 – including many attack UAVs – the responsibility of air defence units. All combat and support units will be trained and capable of defending against widely proliferated Group 1 and 2 UAVs.

The US effort has parallels in international RDT&E programmes, such as the UK's Project Synergia, which was declared to reach initial operational capability (IOC) in 2020. The first of the now-annual NATO C-UAS Technical Interoperability Exercises (TIE), in 2021, brought together over 70 systems and has expanded since then. In 2023, NATO moved towards issuing its first C-UAS doctrine document and adopted the UK-developed SAPIENT (Sensing for Asset Protection with Integrated Electronic Networked Technology) protocol developed as an open standard for the fusion and integration of sensor data into a single integrated picture.

Author

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C-UAV technologies

Sensor technology – to detect, identify, classify and track UAVs – includes radars with active electronically scanned array (AESA) and pulse Doppler technologies, though the latter can be problematic in filtering out slow-moving UAVs in ground clutter. Longer-range radars, such as the Lockheed Martin AN/TPQ-53 radar, with upgrades since FY 2016, can be networked through the US Army's Northrop Grumman Forward Area Air Defense (FAAD) command and control (C2) system, which the JCO has mandated as a joint service C-UAV C2 system. Optronic/infrared, acoustic (using networked sensors) and radio frequency sensors (analysing the electromagnetic spectrum to detect and locate UAV activity) have proven valuable in the conflict in Ukraine. Artificial intelligence (AI) and machine learning (ML) technologies are being applied to the C-UAV mission. Identification Friend or Foe (IFF) and airspace deconfliction issues remain problematic, especially for non-specialist units carrying out self-defence C-UAV – an attack UAV succeeded against US troops in Jordan in January 2024 reportedly because US forces mistook the hostile drone for a friendly one.

Credit: US ANG/Spc Everett Sharp

M-LIDS engages an aerial target during training at Fort Bliss, Texas, on 24 October 2022.

Integrated C-UAV systems: LIDS and MADIS

Integrated, deployable systems include the US Army's Fixed Site-Low, Slow, Small UAV Integrated Defeat System (FS-LIDS), which is mounts the system components on transportable pallets and tripods. Its mobile version is the Mobile-Low, Slow, Small UAV Integrated Defeat System (M-LIDS) Increment 2 mounted on a pair of Oshkosh M-ATV light trucks integrated by Leonardo DRS, one configured for kinetic effects and the second for electronic warfare (EW).

These LIDS systems share many components, including the FAAD C2 system, the Syracuse Research Corporation (SRC) Counter-Small UAV Electronic Warfare System Direction Finding (CUAEWS DF) system to provide direction finding and jamming capabilities, and an optronic sight with day and infrared (IR) channels.
The primary kinetic effector used for FS-LIDS/M-LIDS is the Raytheon Coyote Block 2 disposable anti-UAV munition (effectively a subsonic, rocket boosted, turbojet-powered SAM). The available radars for

Credit: US Navy/Neil Mabini

The MADIS Mk1 (left-most and right-most vehicles) and MADIS Mk2 (middle two vehicles) configurations shown in 2023, during a system integration test at Yuma Proving Grounds in Arizona, on 27 September 2023.

use with FS-LIDS/M-LIDS are the Raytheon Ku-band Radio Frequency Sensor (KuRFS) radar and the SRC AN/TPQ-50. The US Army awarded a USD 426 million contract for AN/TPQ-50 radars for use with its FS-LIDS configuration on 4 December 2020. Later the Army awarded RTX two contracts – a USD 207 million contract on 10 October 2022, followed by a USD 237 million contract on 19 April 2023, both for KuRFS radars and Coyote family effectors, for use with FS-LIDS/M-LIDS.

The M-LIDS kinetic effects vehicle mounts a Moog Reconfigurable Integrated-weapons Platform (RIwP) armed with a Northrop Grumman XM914E1 30 mm Bushmaster chain gun and a co-axial M240 7.62 mm machine gun (MG). The electronic warfare vehicle is armed with a M2 12.7 mm heavy machine gun (HMG) provided with a Ballistic Low Altitude Drone Engagement system (BLADE) specialised C-UAV sight. While the M-LIDS Increment 2 configuration is based on two M-ATV 4×4 protected patrol vehicle platforms, M-LIDS Increment 3 seeks to combine the kinetic and EW M-LIDS capabilities onto a single armoured vehicle.

The Army had planned to equip 10 divisions with five M-LIDS sets each. Major General Sean Gainey, head of the JCO, said in a talk in Washington D.C. on 15 November 2023, "Every division will have a counter-UAS battery manned by air defence soldiers." In December 2023, when two divisions had started to receive M-LIDS, the Army announced its intention to expand the programme. M-LIDS is currently deployed to the Central Command (CENTCOM) area of operations.

The Army has asked industry for information on enhancing its Maneuver Short Range Air Defense (M-SHORAD) Increment 3 programme with upgraded C-UAV capability, incorporating the Coyote Block 2+ and non-kinetic capabilities into the Stryker series of wheeled AFVs used in the current M-SHORAD Increment 1. BAE Systems has developed a version of its Advanced Multi-Purpose Vehicle (AMPV) tracked AFV platform, mounting a RIwP turret, configured as on the M-LIDS kinetic effects vehicle. In January 2024, this vehicle carried out live-fire testing at the Big Sandy Range in Arizona.

The US Marine Corps' three new Littoral Area Air Defense (LAAD) battalions will use the AN/MSY-2 Marine Air Defense Integrated System (MADIS) Mk1 and Mk2 vehicles, based on the Joint Light Tactical Vehicle (JLTV). As with the M-LIDS, the MADIS Block I operates as a two-vehicle set. Both vehicles use the SAIC Multi-Environmental Domain Unmanned Systems Application Command and Control (MEDUSA C2) system, which is being made interoperable with FAAD C2.

The MADIS Mk1 is fitted with a Kongsberg Defense Protector RS6 remote weapon station armed with a 30 mm chain gun, an M240 7.62 mm MG, and two FIM-92 Stinger family missiles. The vehicle also carries a mast-mounted gimballed sight in the form of the Ascent Vision Technologies CM262. The MADIS Mk2 appears to feature the same equipment as Mk1, but is additionally fitted with that appear to be four RADA aCHR (RPS-62) radars, along with a fairing for an antenna on top of the turret, thought to be part of an EW system. The two vehicles are intended to operate together and complement each other's capabilities. In December 2023, MADIS successfully carried out live-fire systems integration testing at the Yuma Proving Ground. It entered low-rate initial production (LRIP) in June 2023 and is planned to enter full-rate production in FY 2024.

Light MADIS (LMADIS) versions, using Polaris vehicles, started initial operational testing and evaluation (IOT&E) in October 2022. LMADIS is a two-vehicle system, with one vehicle carrying the sensors, including four RPS-62 radars, and CM262 sight, and the second understood to carry an SNC Modi II EW system. On 17 July 2019, a developmental variant of LMADIS aboard the amphibious warfare ship USS Boxer was reported to have been involved in the downing of an Iranian UAV during the Boxer's transit through the Strait of Hormuz, reportedly downing the UAV via EW.

Low-cost multi-mission interceptor: VAMPIRE

By early 2023, the US had reportedly sent Ukraine such a large quantity of Stingers that it would require 13 years' worth of production at recent levels to replace them. This demonstration of the scope of missile consumption has been given additional impetus by the rise of C-UAV requirements. To provide a low-cost multi-mission C-UAV capability, in 2023, the US Navy's Naval Air Systems Command (NAVAIR) developed, and L3Harris integrat-

Credit: L3Harris

VAMPIRE shown with optronic sensor mast extended.

ed, the Vehicle-Agnostic Modular Palletized ISR Rocket Equipment (VAMPIRE), a bolt-on combination of mast-mounted optronic sensor and a quadruple launcher firing the BAE Systems AGR-20 APKWS (Advanced Precision Kill Weapon System), a semi-active laser (SAL) guided 70 mm rocket, which is also offered in a variant fitted with an L3Harris/TSC radio frequency (RF) proximity fuze for the C-UAV role. Tested for use against Group 2 and 3 UAVs at Yuma Proving Ground in 2022, 14 truck-mounted versions have reportedly been supplied to Ukraine.

Deploying APKWS for C-UAV operations, the US Army has integrated a quadruple launcher with the Commonly Remotely Operated Weapon Station II (CROWS II) from Norway's Kongsberg Defense, which can be mounted on a range of vehicles or static sites. The US Army has tested other international systems including the Thales Lightweight Multi-Role Missile (LMM), dubbed 'Martlet' in Royal Navy service. This is a semi-automatic command to line-of-sight (SACLOS), laser beam-riding missile fitted with a proximity fuze. In 2023, the Royal Navy tested the missile in the C-UAV role, during which it was launched from the Wildcat helicopter platform.

SAM-like effectors: Coyote and Roadrunner

The Raytheon Coyote Family is intended to be able to be launched from UAVs, helicopters and ground vehicles, and is designed to defeat Group 1–3 UAVs. The Block 2 version, which achieved IOC in 2019, was greatly redesigned compared to the Block 1B variant, fitted with a turbojet engine for propulsion in place of a pusher prop, and with upgraded with improved sensors, increased air speed of 370 km/h (200 kn), extended loiter time, greater range (10–15 km). The munition is fitted with a two-way datalink for communication and command updates, and a high explosive fragmentation (HE-FRAG) warhead.

The Coyote Block 2 was first used in combat in January 2023, defending US forces in Syria. By 2023, the Army had procured over 1,200 Coyotes and, in December 2023, announced plans to procure, during FY 2025–29, some 6,000 Coyote missiles, 252 fixed and 25 mobile Coyote launcher systems along with 118 fixed and 33 mobile KuRFS radars.

In the same category of SAM-like munitions is the Anduril Roadrunner-M, which received research and development funding in FY 2024, to meet a US Special Operations Command (SOCOM) requirement to defeat Group 3 UAVs. Earlier Roadrunner versions have already been deployed for operational evaluation. Unlike Coyote, the jet-powered Roadrunner is recoverable, allowing it to land and be retrieved for later re-use if it does not engage the target.

Technology: HELs

High-energy lasers (HEL) have been under development for decades. The proliferation of UAVs has provided an impetus to deploy these systems, offering low-cost interception and now capable of putting sufficient power on target to destroy UAVs. Static HEL systems include the 100 kW class Israeli Iron Beam, developed in cooperation with the US, which carried out live-fire testing in March 2022, and is reportedly due to enter service in 2025.

The US has deployed multiple C-UAV-capable HEL systems, though these have not yet reportedly been used in combat. In 2014, the US Navy introduced the shipboard 33 kW Kratos AN/SEQ-3 Laser Weapon System (LaWS) on the USS Ponce. This was followed, in 2019, by the Lockheed Martin High-Energy Laser with Integrated Optical Dazzler and Surveillance system (HELIOS) as Increment 1 of the Surface Navy Laser Weapon System (SNLWS) programme. The company has stated that during factory testing, HELIOS "routinely demonstrated full power operation above 60 kW" and the company has stated that HELIOS could be scaled to 120 km or higher within existing space, weight and power (SWaP) allocations for laser weapon systems on Navy vessels. A HELIOS Mk 5 Mod 0 version, mounted on the destroyer USS Preble in 2021, has been integrated with the ship's Aegis combat system.

The US Navy envisions an SNLWS increment 2, with a beam power of 150-300 kW, which would be capable of defeating anti-ship cruise missiles (ASCMs) flying as crossing targets. This is planned to be followed by SNLWS increment 3, which is intended to be capable of defeating an ASCM flying directly at the host vessel.

In 2019, the US Marines deployed the 5 kW Boeing Compact Laser Weapon System (CLWS), capable of being mounted on a tripod or a Joint Light Tactical Vehicle (JLTV), or a Stryker. Boeing had previously developed a 10 kW class laser for the High Energy Laser Mobile Test Truck (HELMTT) demonstrator, and are developing the 100

Credit: Raytheon

A Raytheon Coyote Block 2 interceptor being launched. FS-LIDS palletised components are visible in the background, while an M-LIDS kinetic effects vehicle is visible in the middle foreground.

Credit: US Army/C. Todd Lopez

A MEHEL Stryker fitted with a 5 kW CLWS laser weapon during MFIX-17 at Fort Sill, in April 2017.

kW class Tactical Laser Weapon System together with General Atomics-Electromagnetic Systems (GA-EMS).

Developed in a 10-month programme by the Army's Rapid Capabilities and Critical Technologies Organization (RCCTO) and integrated by SAIC, the Blue Halo LOCUST palletised HEL was developed for the JCO. It has a 2-20 kW scalable power output, and is intended to defeat Group 1 UAVs and C-RAM targets. The system was live-fire tested at Yuma Proving Ground in 2022. According to the manufacturer, the system was operationally deployed overseas. In April 2023, the US Army awarded Blue Halo a USD 45.7 million contract to develop a prototype of the system mounted on an Infantry Squad Vehicle (ISV), for the Army Multi-Purpose High Energy Laser (AMP-HEL) programme.

Part of the High-Energy Laser Weapon System (HELWS) programme, four Raytheon 10 kW HELs have been delivered – the first in October 2019 – to the Air Force Research Laboratory (AFRL). These are intended for overseas airbase defence, three mounted on MRZR all-terrain vehicles (ATVs) and one mounted on a pallet.

Not yet deployed overseas, the M-SHORAD Increment 2 Multi Mission High Energy Laser (MMHEL) Guardian system, developed by the RCCTO, is a General Dynamics Land Systems Stryker-series wheeled vehicle armed with a Raytheon/Kord Technologies 50 kW laser. The first four-vehicle platoon of prototype vehicles was delivered in September 2023. In live-fire testing at Fort Sill and the Yuma Proving Ground, they destroyed Group 1–3 UAVs. The MMHEL is scheduled to reach IOC in FY 2025.

Work on developing a near-term 300 kW HEL is being carried out by four companies: Lockheed Martin, Northrop Grumman, General Atomics and nLIGHT/Nutronics, intended for the Navy's High Energy Laser Scaling Initiative (HELSI) and the Army's Indirect Fire Protection Capability-High Energy Laser (IFPC-HEL) programme, dubbed 'Valkyrie'. Deliveries of Valkyrie prototypes are scheduled to start in 2024.

China, Germany, Israel, Russia and the United Kingdom are among the countries known to have ongoing HEL programmes. China's Poly Technologies Silent Hunter HEL, with a power output estimated between 30 Kw and 100 kW, has reportedly been used in combat by Saudi Arabia. The Rheinmetall Skyranger 30 HEL, announced in February 2022, integrates a 20 kW HEL (with planned output of 50 kW planned for the first phase, and provision for a follow-on 100 kW version) into an integrated C-UAV system. In 2023, Germany completed a year-long test of the MDBA Deutschland/Rheinmetall ARGE shipboard HEL. The UK's DragonFire 50 kW class HEL, initiated in 2017 and integrated by an MBDA-led team with Leonardo and QinetiQ participating, successfully destroyed a target drone in live-fire testing in January 2024.

Technology: HPM

High power microwave (HPM) technology has the potential to defeat multiple or swarming UAVs simultaneously, while individual HELs must engage one target at a time. As with HELs, the US has deployed C-UAV HPM systems operationally, but has not reportedly used them in combat. The US plans on using HELs and HPMs together.

BAE Systems – in partnership with Leidos, Verus Research, and the AFRL – integrated a government-developed HPM into the prototype Tactical High Power Microwave Operational Responder (THOR) technology demonstrator, deployed for airbase defence to AFRICOM and CENTCOM, starting in 2020. It demonstrated its ability to defeat a Group 1 UAV swarm at 2,000 m range in tests at Kirtland AFB New Mexico in 2023. AFRL stated that a deployable prototype of the follow-on system, the Leidos Mjolnir, was slated for delivery in 2023.

As part of the Directed Energy Frontline Electromagnetic Neutralization and Defeat (DEFEND) programme, the Raytheon Counter-electronic High-Power Microwave Extended-Range Air Base Air Defense (CHIMERA), designed for longer-range engagements, completed a three-week field test at White Sands Missile Range New Mexico in January 2024. Previously, the US Air Force had tested the Raytheon Phaser HPM system in the close-range C-UAV role.

Leonardo DRS's Specialized Portable Electromagnetic Attack Radiator (SPEAR) HPM was one of four systems the US Army tested against swarming UAVs in April 2022 at Yuma Proving Ground,

Credit: Lockheed Martin

CG render of a HEL system for the IFPC-HEL programme.


Credit: AFRL

CHIMERA HPM system prototype.

along with Epirus' Leonidas HPM. Four trailer-mounted prototype systems were ordered by RCCTO in January 2023, with the first delivered in December 2023. They will be tested as part of the Indirect Fire Protection Capability-High-Power Microwave (IFPC-HPM) programme. Capable of being paired with the IFPC-HEL, IFPC-HPM may transition to a programme of record in FY 2025. In addition, the Leonidas is currently being integrated with the Stryker 8×8 platform, enabling it to be paired with the HEL-armed M-SHORAD Increment 2, mounted on the same vehicle and also using FAAD C2. This is due to be tested in 2024–25. In addition to the towed and Stryker-based variants, a miniaturised pod-mounted version of Leonidas, dubbed 'Leonidas Pod', capable of being carried by a relatively small UAV, has been developed for SOCOM.

To defeat swarming UAVs, the Coyote Block 3 SAM has been tested with a "non-kinetic effector", referring to either an EW or HPM payload, according to the company it defeated a 10-strong UAV swarm during testing in 2021. In a similar vein, Lockheed Martin's Mobile Radio Frequency-Integrated UAS Suppressor (MORFIUS), a tube-launched, fixed-wing UAV, uses HPM to defeat hostile UAVs.

Technology: direct fire weapons

Guns remain the most widespread kinetic C-UAV technology. The challenge is to enable both a high rate of fire and proximity kills without ammunition costs and collateral damage concerns limiting their use. The US Army's 30 mm XM1211 High Explosive Proximity (HEP), evaluated starting in 2023, and the XM1198 High Explosive Dual Purpose (HEDP) ammunition natures are intended to provide enhanced C-UAV capability for the XM914 30 mm chain gun mounted on the M-SHORAD Stryker. The follow-on XM1223 Multi-Mode Proximity Airburst (MMPA) is a HEP round being developed for FY 2027 as part of M-SHORAD Increment 3. Multiple guided 30–40 mm rounds with airburst capability have been proposed or developed for the C-UAV mission.

International gun systems are a mainstay of C-UAV active defence. The self-propelled twin 35 mm Gepard system has reportedly been highly effective in a C-UAV role in Ukraine. Rheinmetall established an ammunition production line, delivering an initial batch of 30,000 rounds to Ukraine in 2023. With regards to Germany's efforts in this area, the Boxer 8×8 mounted Skyranger 30 A1, armed with Rheinmetall's Oerlikon KCE-ABM 30 mm × 173 revolver cannon, carried out its first-live firing in December 2023, at the manufacturer's proving ground in Ochsenboden, Switzerland. Germany has so far ordered 18 Skyranger 30 vehicles in a EUR 595 million contract in February 2024, with a prototype to be delivered by the end of 2024.

Technology: Non-kinetic

Non-kinetic active defence systems include radio frequency jammers, and/or spoofers. The former aim to disrupt the command links between UAVs and operators, or to disrupt UAV satellite navigation. Spoofing involves sending false signals, such as incorrect positioning information or commands. In the US, in 2020, JCO selected, among other non-kinetic systems, the US Navy's Northrop Grumman Drone Restricted Access Using Known EW (DRAKE); the system is a low-cost software-defined jammer, originally designed for vehicle use, that is now operational on warships.

In the European theatre, the Titan Blue Halo has been used in European Command (EUCOM) by SOCOM, and the AFRL's Negation of Improvised Non-State Joint Aerial Threats (NINJA), capable of jamming and spoofing UAVs, has also been integrated


Credit: Lockheed Martin

Lockheed Martin's tube-launched MORFIUS can use its HPM warhead to defeat UAV swarms that may be out of range of terrestrial HPM systems.


Credit: US Navy/Specialist 3rd Class Aislynn Heywood

Sailors aboard the Nimitz class aircraft carrier USS George Washington (CVN 73) train on the DRAKE UAV jamming system, on 26 August 2021.

with the Royal Air Force's (RAF's) ORCUS C-UAV system. Another notable European effort is the German Guardion system, a collaboration between Diehl Defence, ESG, and Rohde & Schwarz. This is a highly tailorable system which can incorporate a range of different sensors including radar, direction finders, optronic, acoustic sensors, and the possibility of multiple effectors ranging from various forms of jamming to kinetic and directed energy effectors.

While non-kinetic defeat technologies have the advantages of low costs and low footprint – in terms of systems deployed to forward areas – it is potentially vulnerable to changes in UAVs. Increased autonomy in flight operations and the use of automatic target recognition (ATR) guidance have already been reported in Ukraine, where UAVs have been modified to make it more difficult to be jammed or spoofed.

Tactics:
Attack operations and passive defence

Attack operations and passive defence make it possible for active defence systems to limit the threat from UAVs. Ukraine's armed forces have found that attack operations – locating controllers by triangulating on their signals and calling in artillery fire – are perhaps the most effective counter to the UAV threat.

The importance of passive defence has been reflected in the appearance of appliqué overhead protection on armoured vehicles in Ukraine and Gaza. Hardening, camouflage and frequent displacement are necessary for survival on a battlefield shaped by widespread UAV use. Combat lessons from Ukraine, along with NATO and US exercises, have shown the importance to troops of being alerted to UAVs in their immediate vicinity, to take cover, move, or engage.

Future C-UAV

C-UAV is being developed by fielding service-specific capabilities, yet effective operational architectures will be, of necessity, joint-service and multinational. While all types of forces – not just specialists – must be trained for and capable of C-UAV, how they conduct active defence without disrupting their own operations remains uncertain. While, looking at US experience, there has been significant success in demonstrating network connectivity, this is still far from the seamless linkages envisioned by the DoD's Joint All Domain Command and Control (JADC2) concept.

Effective C-UAV has been demonstrated in Ukraine, in CENTCOM and in the Red Sea. These experiences have all underlined the importance of magazine depth at the point of need, which, in turns, emphasises cost and ability to be mass-produced. Complicating these requirements are the need for overlapping capabilities. A HEL that would be effective in the blue skies above the Red Sea may not be so during the storms and fog common to the Barents Sea.

The US approach to C-UAV shows examples of the extensive range of technologies being applied, with many solutions coming from outside major players in US industry. The need for near-term C-UAV capabilities has provided openings for international partners. However, integrating diverse systems and recent combat lessons into C-UAV architectures remains challenging, both for the US and internationally.

In the US, the JCO has provided funding and expertise so that services can procure, deploy and operate C-UAV systems, operating the Joint C-UAS Training Academy, currently at Yuma Proving Ground – but due to move to Fort Sill, Oklahoma in 2024. While an Army organisation, reporting to an Army three-star General, the JCO has emphasised joint service and international cooperation. Whether the JCO will be able to move capabilities forward at a time of static – at best – expenditures and Congressional dysfunction delaying new start programmes, remains uncertain. Especially in the wake of the January 2024 UAV attack on US troops in Syria, the importance of the overall C-UAV mission will likely be reflected in the US and many other countries globally. ■


Credit: US Army/Brandon Mejia

The P-HEL palletised high energy laser at Yuma proving ground.

Nano-UAV and micro-UAV developments

Sidney E. Dean

The introduction of very small unmanned aerial vehicles (UAVs) has provided small infantry units with a new and potent reconnaissance and combat tool. Armed forces and industry are working to enhance their performance by improving range, endurance and payload capacity.

In the past, infantry forces frequently had no choice but to advance with limited situational awareness of the immediate terrain, accepting the concomitant risk of ambush or forcing them to attack with less-than-optimal intelligence. While these risk factors still exist, nano- and micro-UAVs have proven to be the proverbial 'game-changer' in many ways. They provide units down to the squad or fire team level with integrated short-range intelligence, surveillance, targeting and reconnaissance (ISTAR) capabilities. Actionable intelligence can be relayed directly to the operator in real-time and this information can then be used directly by the small unit, or relayed to an upper echelon to feed into the force's common situational awareness picture.

These micro-aircraft are controlled via hand-held consoles or via laptop, tablet or cell phone apps. Depending on the system and mission, payload options can include optronic sensors, signals intelligence sensors, and/or sensors to detect chemical, biological, radiological, or nuclear (CBRN) threats. They are also useful in scenarios where there is limited line-of-sight, such as urban and woodland settings. Nano-UAVs are generally considered the smallest category of UAV suitable for military operations, with a maximum weight (not counting payload) of circa 250 g. Micro-UAVs constitute the next larger category, with an aerial vehicle weighing up to 2 kg.

Given their very small size, nano-UAVs have an extremely small acoustic, thermal and visual signature; this permits them to approach enemy positions virtually undetected and even enter structures or caves to conduct tactical reconnaissance. Information regarding hostile force dispositions, as well as the location of primary mission targets, can be wirelessly relayed back to the controller, or the UAV can simply return to its operator for manual download of intelligence data. They can also be carried in a standard ammunition pouch and are usually launched by hand. Being somewhat larger, micro-UAVs have superior payload capacity, and generally also outperform nano UAVs in terms of range, endurance and service ceiling. Payload options can include not only sensors but explosives as well. They can be deployed and retrieved by hand or via special launch platforms.

Systems and capabilities

Modern nano- and micro-UAVs display impressive capabilities, especially for aircraft of their size. A representative survey of operational and soon-to-be operational systems illustrates the spectrum of their capabilities.

Bug 4.1

The Bug UAV was developed by British firm Uavtek in collaboration with BAE Systems. The original variant weighs in at 196 g or – as the manufacturer points out – approximately as much as a cell phone. The battery permits a 2 km operating range, or approximately 40 minutes of flight endurance. The British Army received the first batch of 30 in 2020 and since then, Uavtek has continued to refine the system. The latest iteration, the Bug 4.1, weighs less than 350 g and has a range of 3 km. The UAV is launched and recovered by hand. The lossless HD zoom camera incorporates a thermal imaging capability, with data transmitted to the operator via a secure wireless link or encrypted SD card.

Additional payload options include microphone/listening device, loudspeaker, various lights (white/red/infrared), a mapping system and a distraction device. Sensor data can be simultaneously transmitted to multiple locations; qualified receivers include mobile phones, laptops, tablets and the Android Team Awareness Kit (ATAK). An integrated GPS follow-the-leader kit prepares the Bug 4.1 for

Credit: Uavtek

The Bug 4.1 nano-UAV system.

UAV swarm deployment. Flight endurance is 30 minutes at a maximum speed of 80 km/h; however, potential mission endurance is considerably longer as the drone can land at its target site and continue to transmit sensor data for several hours. While the vehicle's overall dimensions are 25×20.5×7.5 cm (LWH), the firm continues to classify it as a nano-system, likely in part due to its low weight.

Ninox 40 MT

The Ninox 40 MT (micro tactical) developed by the Israeli firm Spear UAV is launched from a 40 mm tube, grenade launcher, or a baton-sized hand-held capsule/launcher; in flight, it is controlled via tablet. This nano-UAV is the smallest member of the Ninox family of nano-/micro-UAVs, weighing less than 250 g, and with a flight endurance of 35 minutes. Like most small UAVs, it requires only minimal training to operate.

Artificial intelligence controls the integrated day/night camera system and enables automatic tracking of objects of interest. Sensor data is relayed via a commercial-off-the-shelf (COTS) secure two-way datalink, with the launch capsule functioning as the wireless router connecting the drone with the tablet. The navigation system combines global navigation satellite system (GNSS) and inertial navigation system (INS) guidance to ensure continued operations even in signal-denied environments. Mesh networking and swarm capabilities are integral to the system, including the ability to feed targeting data to Spear UAV's Viper loitering munitions. The Ninox 40 MT has been demonstrated to US armed forces and is assumed to be in service with the Israeli military.

Black Hornet 4 PRS

US-based Teledyne FLIR unveiled the Black Hornet 4 Personal Reconnaissance System (PRS) in October 2023. Compared to older variants of the Black Hornet family, this newest member features enhanced range, endurance, signature and imagery data. Capabilities of the 70 g UAV include a 30 minute flight endurance, more than 2 km range, and the ability to operate in 13 m/s (25 kn) winds, in addition to a maximum speed of 36 km/h. An improved battery and a new obstacle avoidance system enhance flight performance with the system also able to operate in GNSS-denied environments.

Credit: Teledyne FLIR

The Black Hornet 4 nano-UAV is optimised for small unit covert reconnaissance.

On the latest model, sensors have also been upgraded. The Black Hornet 4 is equipped with five cameras providing a combined 270° field of view (FOV). These include three low-resolution day cameras for navigation and obstacle avoidance, a new 12 MP forward-looking low-light capable HD day camera with a 125° FOV, and a thermal camera with 650×512 resolution and a 78° FOV (the world's smallest thermal camera, according to Teledyne FLIR); and an ultrasonic sensor. Black Hornet 4 is configured for use by dismounted personnel, although it can also be deployed by hand through the hatch of a vehicle. The nano-UAV and the dedicated controller (which includes the joystick controller as well as a video screen which displays the camera feed in real time) are carried in a hardened pouch or 'hangar' attached to the operator's vest or webbing. The complete system – including extra batteries being charged in the hangar – weighs less than 1.3 kg. The aircraft can be deployed within 20 seconds, permitting immediate ISR when a tactical situation arises. An optional 'zipline' mode permits the UAV to continue flying on a straight path while rotating its body to direct its forward-facing cameras in various directions.

Credit: Spear UAV

The Ninox 40 MT nano-UAV can be carried in a baton-shaped launcher attached to the soldier's belt or vest.

Anafi

French drone-maker Parrot designed its Anafi micro-UAV for the defence and internal security sector, but also sells the system on the civilian market. It is manufactured in Europe as the 'Anafi Ai' and in North America as the Anafi USA. The Anafi USA MIL variant is marketed internationally to military and security forces. Defence and government users include the armed forces or coast

The Anafi USA MIL variant.

guards of Finland, France, Japan, Spain, the United States and the United Kingdom. The UAV weighs 515 g and can be folded for carriage. Unfolded, the flight-ready dimensions are 28×37×8.4 cm. Flight endurance is 32 minutes per battery charge; the system is sold with three interchangeable batteries to enable quick turn-around times. The Anafi's body and propellor blades are constructed of polyamide reinforced with carbon fibre and streamlined using hollow glass beads, which minimises the system's weight while enhancing structural integrity. According to the firm, the broad rotor blades were inspired by the pectoral fins of humpback whales; these blades optimise lift and simultaneously minimise acoustic signature.

The satellite navigation system can operate using GPS, GLONASS, and GALILEO. Sensors include a barometer and magnetometer, as well as ultra-sonar for terrain and obstacle detection. The most impressive element of the Anafi is the camera suite. It includes two 32× continuous zoom day cameras for 21 MP still imagery and 4K video, and a FLIR Boson 320 infrared camera with 320×256 resolution. The day cameras allow for detection of human-sized targets at 2 km, and read licence plates from an altitude of 130 m. Zoom is variable with resolution, allowing lossless 5× zoom in 4K, 10× zoom at 1080p, and 15× zoom at 720p, or 27× zoom at 480p. The onboard image management system can combine thermal and visual camera inputs into a single image.

In February 2024, Parrot announced the latest enhancement to the system. The SmartCam3D produced by Rapid Imaging is being integrated, which will permit real-time overlay of geospatial data onto video captured and streamed by the Anafi's day camera. This data can include street names, points of interest, and territorial boundaries in order to enhance situational awareness during time-critical missions.

Wolverine

The Wolverine micro-UAV developed by Israeli firm Xtend offers advanced capabilities beyond ISTAR. The multi-mission UAV's forward- and downward looking sensors include a 40× zoom day/low-light capable camera as well as a FLIR Boson thermal camera. The vehicle's onboard AI capabilities evaluate the imagery in real time, identifying and categorising vehicles and humans, as well as highlighting armed personnel; a top speed of 70 km/h makes the Wolverine a very fast micro-UAV, and permits short-term pursuit of moving vehicles. This 1.3 kg UAV is equipped with a robotic gripper which can carry up to 2 kg of payload or manipulate objects during the course of its mission. The vehicle has an endurance of 30 minutes, or a maximum line-of-sight (LOS) range of 7 km.

The Wolverine can also carry and precisely deposit surveillance devices, such as the Xaver 100 through-wall life detector, strobes and homing devices, small supply payloads, and even explosive charges. The latter is especially useful for neutralising mines and IEDs ahead of advancing soldiers without sacrificing the drone. Conversely, the Wolverine can retrieve small items or sling loads (up to its payload limit) from the field. The rotary propulsion system enables the Wolverine to access and hover even in small or hard-to-access areas.

Black Recon

Most nano- and micro-UAVs are optimised for use by dismounted personnel (although they can be deployed through open windows or vehicle hatches). Teledyne FLIR is currently working on a new system which will provide mounted crews with their own beyond-line-of-sight aerial reconnaissance, surveillance and target acquisition capabilities. The Black Recon concept was unveiled in September 2023 at the DSEI exhibition in London, and the idea comprises three UAVs carried in a hardened launch box atop a vehicle. Soldiers would be able to deploy and recover these UAVs from moving vehicles while remaining secure

The Wolverine micro-UAV equipped with a claw manipulator.

The developmental Black Recon deployment system's cradle-arm autonomously recovers drones and seats them in the carriage box to recharge.

under armour. Among other benefits, this would provide the ability to conduct en-route terrain evaluation and threat assessments ahead of the vehicle, potentially permitting ground forces to advance more quickly.

The box weighs less than 80 kg, measures 68×65×45 cm, and can accommodate a wide variety of UAVs. According to the firm's press release, Teledyne is currently developing a completely new micro-UAV configured to withstand the physical rigours of travelling on combat vehicles. The UAVs will carry optical and thermal sensors, and operate in signal-denied environments. They will weigh circa 350 g each and have a 45 minute mission endurance. The operational profile envisions a service ceiling of 3,600 m and within a temperature range of -20°C to +49°C.

Black Recon replaces the Black Hornet Vehicle Reconnaissance System which FLIR Systems introduced in 2018, but which ultimately proved too light to satisfy mission requirements. Development of Black Recon began in 2020 with the support of the Norwegian Defence Research Establishment. Teledyne FLIR expects to begin marketing the new system in mid-2024, with deliveries beginning in early 2025.

Future capability enhancement

While today's nano- and micro-UAVs display significantly greater capacity than earlier systems, there are still limitations regarding speed, endurance, range and payload capacity. Improvements in any or all of these areas would enable forces to collect even greater and more detailed actionable intelligence prior to advancing or striking. This would permit optimised mission planning and have the potential to reduce casualties and improve the probability of successful mission execution. The two prime factors which could influence these performance parameters are enhancement of the propulsion and energy system, and weight reduction. New composite materials promise to make UAVs lighter and more resilient, enabling even current motors to lift heavier payloads or improve mission range and speed. Batteries continue to be a major weight factor. Current research at MIT suggests that using a solid ceramic electrolyte rather than a liquid electrolyte could produce solid-state Lithium batteries with greater energy density than current Li-ion batteries, allowing for greater mission range and endurance on platforms which use them. Additional research conducted at Monash University in 2023 suggests that Lithium-Sulphur (Li-S) batteries could ultimately provide a lighter and more powerful alternative to Li-ion.

Mission systems also offer abundant room for performance enhancement. The cameras in the UAVs reviewed above all surpass the capabilities of previous generation sensors. Moreover, the future will see continued upgrades of sensor performance. In addition to video, thermal and audio, additional sensor payloads including NBC detection and signals intelligence capabilities may become more widespread. Offensive electronic warfare capabilities as well as laser targeting systems to illuminate targets for semi-active laser (SAL) guided weapons will constitute major additional enhancements to nano- and micro-UAV capabilities. Lethal payloads will increasingly become possible for even the smallest UAVs, enabling their deployment as loitering munitions or attack drones.

Elbit Systems has taken a first step here, introducing the Lanius in November 2022. The roughly 1.25 kg system can carry a 125 g close proximity high explosive charge for targeted strikes, or non-lethal payloads to support special operations and hostage-rescue missions. Alternatively, it can deploy as a standard reconnaissance and area-mapping system. The UAV's 29.4 x 29.4 x 16.7 cm dimensions permit passage through open doorways and windows, pipelines and sewage systems as well as tunnels, making Lanius suitable for operations in urban or restricted terrain. While flight endurance is only seven minutes, mission endurance can be considerably longer if the UAV lands and transitions to surveillance mode. It can also launch and revert to attack mode upon command or upon identifying an emerging target; the sprint speed of 72 km/h increases the odds of a successful surprise attack.

Of course, all UAV missions depend on reliable communications and navigation. Secure two-way command, control and communications systems will remain a focal point of research and development. The same holds for AI progression in order to ensure accurate navigation and enhance the UAV's ability to autonomously classify targets and accurately complete missions in the event of communications disruption. ■

Up to three Lanius micro-UAVs can be transported closer to the target by a 'mothership' UAV.

Power junkies: UAV propulsion challenges and trends

Tim Mahon

The war in Ukraine ensuing conflict has brought drone warfare into sharp focus. Though not new by any stretch of the imagination – unmanned systems have been used in conflict around the world since the turn of the century – the execution of drone warfare in Ukraine has given the issue new prominence, raised more challenges than ever before, and given birth to considerable innovation on both sides.

While Russian losses of equipment and manpower to drone attacks have been staggering, Russia's own drone strikes on Ukrainian infrastructure have caused immense damage to buildings, factories and equipment, along with causing considerable harm to Ukraine's civilian population in general. The loss of drones – particularly of the first-person view (FPV) genre most in vogue currently – has risen to an unprecedented level. Indeed, the Royal United Services Institute (RUSI) in London postulated that drone losses between the two sides are running north of 10,000 units per month. Meanwhile, drone production continues apace, with claim and counter-claim as to which side will be the first to produce 1 million drones per annum.

Against this background, the technology of unmanned systems has been progressing in leaps and bounds. Many tactical limitations unearthed in early operations have been overcome with technology insertion, the issue of attrition has been partially assuaged by altered tactics and the methodologies adopted to counter drone strikes through effective counter-UAV tactics and equipment are beginning to have an effect – though the provision of counter-UAV systems at the scale required remains an issue for both parties.

One area not much discussed in open sources, largely because it is not as 'exciting' as new advances in autonomy, sensor improvements or enhanced weapons effects – is the improvement performance brought about by alterations in UAV propulsion.

Author

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Credit: Steadicopter

Pictured: Black Eagle 50H. There is an increasing move towards hybrid fuel/electric propulsion for UAVs, in an effort to reduce consumption of fossil fuels and provide an interim solution until pure electric drives that overcome current limitations can be developed.

The first and, perhaps, most obvious improvement in propulsion systems has been the further development and enhancement of electric drives. While this was originally the preserve of the lighter, more agile Class I and II drones, there is evidence of serious work being done in making Class III drones all-electric as regards propulsion. This is particularly the case in Israel where, incidentally, there is also considerable effort being devoted to hybrid propulsion for larger UAVs that may be more vulnerable to counter-UAV capabilities as a result of their size and visibility. Fuel cells, solar power and several even more esoteric methods of propulsion are under examination, though do not look likely to enter serial production on Class III drones in the immediate future. Nonetheless, UAV propulsion is an area of development – both industrial and operational – that occupies a good deal of current attention.

The issue of speed – at tactical and strategic levels – is one that continues to trigger fierce debate in sections of the UAV community. Is the need for speed paramount, or should it give way to the stealth benefits deriving from near-silent propulsion units? Take the Iranian-manufactured Shahed-136 loitering munition for example, which Russia is now manufacturing under licence in quantity under the designation 'Geran-2'. The versions used in Ukraine thus far have been powered by a simple turboprop, and the distinctive noise it makes has gave rise to its nickname of 'the Moped'. Indeed, the ability for defensive assets to be alerted and even cued to the approach of a Shahed attack may well have been a motivating factor in Ukraine's development of a network of acoustic sensors, which is proving so effective that the US military announced in January 2024 it was looking at testing the system to determine its efficacy for US counter-UAV operations.

Turbojets are becoming an increasingly popular propulsion system of choice for new UAV designers and developers, with more turbojet-powered UAVs appearing on the development continuum from drawing board to prototypes in test chambers. They bring with them the advantages of tactical speed and 'dash speed' – the latter exhibited successfully by the Anduril Industries Roadrunner-M loitering munition intended for the counter-UAV role. This is launched from an 'automated hangar' called 'Nest', and can use its high subsonic dash speed for a limited period to intercept relatively fast-moving UAVs or slower, low-altitude manned aircraft. Although the Roadrunner-M's development is atypical of the direction in which other companies are moving (with the partial exception of RTX's Coyote), informed observers suggest that more and more attention will be paid in the future to the provision of high speed as a key operational benefit. This will almost inevitably mean more effective turbojet engines.

Prvni brnenska strojirna Velka Bites, a. s (PBS Velka Bites) of the Czech Republic has specialised in the development of turbojets specifically designed for use in unmanned aircraft for over 20 years, featuring thrust from 400 N to 1,500 N. Currently in the closing stages of development is the latest iteration of its family of turbines, the PBS TJ200, which will be the most powerful turbine yet produced by the company. The compact fuel-lubricated turbojet features a brushless DC starter-generator, an electric metering fuel pump and a full authority digital engine control (FADEC) electronic control system. With an outer diameter of just 246 mm and length of 730 mm, the 28 kg engine lends itself particularly well to mid-sized UAVs. In terms of performance, the engine develops 2,280 N of thrust, allowing speeds of up to 326 m/s (Mach 0.95), and operating at altitudes of up to 10,000 m.

Credit: Iranian State Media

Experience gained with the Shahed 131, which Russia designated the Geran-1, led to the licence manufacture of the Shahed 136 (pictured) under the designation Geran-2. The Shahed 136 features an uprated engine – but one that still replicates much of the distinctive noise that characterises the earlier variant.

The smaller but still compact and powerful PBS TJ150 has been designed with smaller UAVs and high-speed target drones particularly in mind. Sharing many characteristics with its larger, younger sibling, the 17.1 kg TJ150 also offers an excellent thrust-to weight ratio – producing 1,500 N and offering top speeds up to 309 m/s (Mach 0.9) at altitudes up to 10,000 m. Several of the





Credit: PBS Velka Bites

PBS Velka Bites has spent two decades developing turbine engines specifically for UAVs, with power steadily increasing with each new member of the family.

company's engines feature pyrotechnic ignition and selected others are capable of being reused even after immersion in salt water, as may occur if the host platform lands in the sea.

Germany's Sky Power GmbH, on the other hand, focuses its efforts from its Bad Homburg headquarters on a range of conventional two stroke combustion and Wankel rotary engines for UAV applications towards the lower end of the weight spectrum. The company makes considerable capital of the 'Made in Germany' nature of its engines, and has made significant inroads of late into providing engines for new and innovative programmes. A case in point is the Polish MADDOS VTOL 600h, a hybrid engine development of the VTOL 350e. In addition to the four electrically-powered rotors that provide the VTOL component of the 600h's performance, the aircraft has been fitted with a pusher prop powered by a Sky Power SP-210 TS ROS two-stroke carburettor engine. The engine develops 12.6 kW (17.1 hp) at 6,000 rpm from a 210 cc displacement, and is offered with starter generator and generator for power production. The implementation of both forms of propulsion on the MADDOS VTOL 600h permits the platform an endurance of up to 10 hours and a maximum speed of 138 km/h.

Increasingly, power providers are offering complete packages, especially for electric and hybrid fuel/electric UAVs. Companies such as ePropelled in Lowell, Massachusetts, tempt designers and operators with packages that include motors, starters/generators and intelligent power management systems for holistic solutions, thereby offering the user lower energy consumption and enhanced range and endurance. A range of motors from 750 W to 12 kW of constant output leads to lighter, more efficient UAVs and, coupled with lightweight electronic speed controllers, contributes to enhanced size, weight, and power (SWaP) optimisation.

In addition to speed, a compact nature and extended endurance or loiter time, UAV users are increasingly demanding very high degrees of reliability from their aircraft. The eight-rotor Chinese Tianlong UAV, for example, has been designed as a firefighting asset capable of hovering and deploying 'fire-extinguishing bombs' into a conflagration with great precision and flexibility at an affordable cost. The operational concept is to remove human operators from hazardous situations and reduce potential casualties – but success depends on a very high degree of reliability and, according to the developers, this is best achieved by very close control of engine output. As application scenarios become more complex and critical, so increased emphasis is being placed on propulsion system reliability.

As if all these desired capabilities and features were not enough to present engine developers with interesting enough challenges, the careful balancing of propulsion versus power generation adds a further layer of complexity. For almost any UAV, ranging in size from the Black Hornet personal reconnaissance system to the US Navy's Triton high-altitude long-endurance (HALE) UAV, the propulsion system is the core provider of power to the aircraft – and therefore a powerful determinant of its ability to prosecute its mission(s) successfully. Whether conventionally fuel-powered, hybrid electric or pure electric, the engine is perhaps the most vital component of mission capability.

Traditional fuel propulsion offers distinct advantages in the form of higher payload capacity, extensive ranges and long-endurance, as well as rapid resupply. However, concerns over environmental impact, depletion of fossil fuels and political pressure have forced attention to focus more and more on hybrid and purely electric propulsion solutions – with the former widely seen as a stepping stone to the latter. Hybrid systems currently offer average savings of some 30% in fuel consumption compared with conventionally-powered aircraft.

There can be little doubt that electric propulsion is the direction in which the commu-

Credit: USN

At the larger end of the spectrum, high-altitude long-endurance UAVs such as the Triton, in service in the US and Australia, are less concerned with SWaP aspects of their propulsion systems than with reliability and flexibility.

Credit: Airbus

The Airbus Zephyr UAV, entirely solar-powered, achieved a continuous operational time of 26 days during trials in 2018. The search for effective solar-powered propulsion systems continues for platforms destined for long-endurance missions in largely uncontested airspace, though combat missions make such solutions less than optimal.

nity is headed, but there are some subtleties and some as yet unproven technologies that may accelerate or impede progress. Both fuel cells and solar photovoltaic cells, offer viable alternatives to the Lithium-ion batteries in common usage. In Britain, the solar-powered Zephyr high-altitude UAV achieved a very creditable aloft time of 26 days in 2018, and in China similar efforts have manifested in the CH-T4 and Qimingxing-50 solar-powered UAVs. American forays into solar powered unmanned aircraft include the Solara 50, Apusduo and Aquila platforms.

There are alternatives, of course. Further improvements to engine technology would enable developers to maximise the energy derived from fossil fuels. More research and development time and resources are required to investigate the potential for superconducting motors to effectively solve the issues of power and heat dissipation in electric motors. The prize for cracking that particular puzzle will be significant improvements in SWaP optimisation and commensurate increases in range, endurance and, perhaps, other aspects of airframe performance.

What does the future hold? A lot of work, a great deal of argument and debate and a host of divergent R&D projects – that much is certain. It is already clear, however, that a number of paths to the Holy Grail of efficient propulsion systems are revealing themselves. Among the technologies to be pursued will be: high-density energy storage – to overcome the inherent volume/weight penalties of hydrogen fuel cells; high-power density motor technology, which will have immense impact across a swathe of application challenges; high-efficiency and high-power density converters; and, perhaps above all, efficient heat management technology.

Credit: Hyundai

Although this article focuses on the development of UAV propulsion for military and security applications, it should not be forgotten that massive investment is being made in parallel and pertinent technologies for civil applications – in which reliability and passenger safety are key drivers.

A rapid canter through some of the current and future aspects of UAV propulsion technology reveals a lively and vibrant developer ecosystem. There are all sorts of other avenues being pursued, too, such as supersonic UAV flight or even the recharging of UAVs from space via microwave link. That may seem fanciful, but in 2023 the Microwave Array for Power-transfer Low-orbit Experiment (MAPLE) test proved the concept of wirelessly beaming power through space, and was even able to direct a detectable amount of energy back to Earth. It may be some time in the future, but meanwhile there is the prospect of using air refuelling UAVs, à la MQ-25 Stingray. All things are possible but, it has to be said that, despite the critical nature of propulsion to the sensible evolution of UAVs, further development will, for the foreseeable future, play second fiddle to more imperative requirements. From the perspective of operators, these include: more reliable autonomy, better sensors, as well as enhanced weapon effects and capabilities.

Drone Challenge – Training Riposte

Trevor Nash

The adoption of uncrewed aerial vehicles (UAVs) such as the MQ-9 Reaper continues but this family of weapon platforms has now grown to include 'hobbyist' drones. Such systems create a demand for effective training both for users and those trying to counter them.

In 1953, the British military strategist Basil Liddle-Hart said that "…the most epoch-making changes in history [are] determined by changes in weapons and tactics – especially the latter." Never has this observation been truer than when considering the growing adoption of UAVs and the tactics needed to counter them. The arrival of platforms such as the US General Atomics MQ-1 Predator in the mid-1990s and Elbit Hermes 450 in 2003 marked a transition process where UAVs acquired an attack capability to supplement their original reconnaissance and surveillance functions. Such platforms have been increasingly adopted by national air forces all around the world.

More recently technologies, most notably GPS, more powerful processing, miniaturised high-resolution optics and guidance systems have become more widely available to enable the construction of lower-cost UAVs. These systems are being used by state and non-state actors alike to create an arsenal of both reusable attack UAVs and disposable loitering munitions (often called 'kamikaze drones'), that are being deployed in conflicts around the world. They are cheap, easy to produce and creating "epoch-making changes" to tactics and military doctrines throughout the world by providing a kinetic air power asset to all.

Such systems were first brought to the public's eye in 2019 when Houthi rebels used 'drones' to attack oil refineries in Saudi Arabia. The following year drones were used to great effect in the Nagorno-Karabakh War. The expansion in the use of such systems is evidenced in current conflicts, notably in the Red Sea and Ukraine. This adoption and the need to counter these platforms has serious implications for training.


Credit: Ukrainian MoD

A Ukrainian soldier launches an FPV drone carrying an explosive warhead.

In the Red Sea, Houthi rebels are using Iran Aircraft Manufacturing Industries Corporation (HESA) drones to attack shipping. HESA also supplies a number of platforms to Russia that are being used in Ukraine alongside Russian manufactured platforms. Compared to major UAVs such as the Hermes 900, MQ-9 Reaper or RQ-4 Global Hawk, HESA's Shahed-136 and Samad-3 are presenting lower-level but still significant threats. Other threats are presented by so-called 'hobbyist' platforms such as the Chinese manufactured First-Person View (FPV) Mavic and Matrice drones. Costing anything from hundreds to a few thousand dollars, these platforms are causing losses to armoured vehicles, air defence systems and parked aircraft that run into millions of dollars.

This feature will address three components of the training challenges that are being generated by this growth of UAVs. The first is the training that is available for mainstream or conventional UAVs; the second for the FPV/Mavic-type family of drones and finally, for counter-drone operations.

Mainstream training

Although the world's media is highlighting the proliferation and capabilities of the 'hobbyist' kamikaze drone, mainstream platforms such as the MQ-9, RQ-4 and Hermes 900 should not be forgotten. These systems have a major impact "at the tactical, operational and strategic levels of military engagement," Jim Chittenden, CAE's Director of Strategic Business Development told ESD. The frequent need to transition between these levels during the same mission adds another layer of complexity to the training requirement.

"Historically, the RPA [remotely piloted aircraft] crew was seen as the pilot and sensor operator – specifically tasked with controlling and operating the aircraft and its systems," explained Chittenden. "Now, RPAs are completely integrated into the intel and C2 operational structure. Personnel in those fields using and exploiting the fruits of the RPA crew's labour are, by extension, part of the operational RPA crew" and this generates a requirement for more inclusive collective training.

Author

Following a career in the British Army specialising in air defence, **Trevor Nash** (PhD) spent four years in the training & simulation industry before becoming defence journalist concentrating on training, simulation technology and air power studies.


Credit: Trevor Nash

The MQ-9 Reaper epitomises the modern UAV, with its surveillance, reconnaissance and attack capabilities.

This demand for a holistic UAV training environment has also been identified by the UK's Inzpire that has been providing UAV training for over 10 years. In addition to supplying its own platform specific Compact Agile Simulator Equipment (CASE) training devices the company started to offer "theory-based foundation courses for RPAS/UAS [remotely piloted aerial system/uncrewed aerial system] education and UAS integration for collective training," explained Andy Bain, Head of Inzpire's ISR Division. With the UAV "market exponentially growing" the company has increased "its team of experts and [is] diversifying to bring in tactical experience from the land and maritime domains."

Bain also notes that with nations procuring smaller UAVs – the so-called Small Uncrewed Aerial Vehicle (SUAV) platforms such as SilentEyes and ScanEagle – "the need for training services has increased. Where experience is limited, there is a training need." This is reflected in the work conducted by the company for a number of customers including the British Army, Latvian Air Force and Belgian Ministry of Defence (MoD).

Paradoxically, Bain highlights that although there is currently an upwards trend in UAV training, "increased reliance on autonomy and, to an extent, the integration of AI in the future" could lead to a situation where "UAS could be handled by individuals who are less skilled in manual UAS operation," therefore reducing the amount of training required. "This could sound like a downturn in training requirements, but with the expected increase in UAS applications, the need for training will remain high."

Another tactic that could increase UAV training requirements is the use of surrogate unmanned platforms working in conjunction with manned aircraft. The Airbus-led Future Combat Air System (FCAS) provides such an example. "Looking to the future, this will certainly extend to the development and employment of Collaborative Combat Aircraft – which will have various elements of automated and remotely piloted capabilities," opined CAE's Chittenden.

Training for the world's major UAV platforms are either conducted by the manufacturer, by the military in conjunction with a contractor or by a designated training service provider. One of the largest and most experienced users of UAVs is the US Department of Defense (DoD) and in particular, the US Air Force (USAF). The major training load for its MQ-9 crews is undertaken at Holloman Air Force Base (AFB) in New Mexico, home of the MQ-9 Formal Training Unit (FTU) where training is provided by the USAF in conjunction with a commercial contractor. The current industrial incumbent is Crew Training International Inc. which took over from CAE in 2019.

Although Holloman, along with its satellite facilities at Creech AFB, March Air Reserve Base and Hancock Field Air National Guard Base, provide the USAF with its core MQ-9 training capabilities, the "dilapidated" and "structurally unsound" facilities at Holloman have been criticised over many years. This has resulted in the decision to replace the current FTU buildings, and this programme is nearing contract award. As the world's leading exponent of UAVs, the USAF continues to face a number of training shortfalls, most notably, the need to train sufficient aircrew to operate its UAV fleet. In basic terms this training pipeline has seen students' complete initial flight training on the Diamond DA-20 aircraft before undertaking an RPA Instrument Flight Qualification Course.

This is followed by an RPA Fundamentals course that introduces students to planning operational missions and operating the platform prior to attending the FTU at Holloman for the MQ-9 or Beale AFB for the RQ-4. The USAF is now amalgamating the instrument and fundamentals courses


Credit: Airbus

The FCAS project envisages operating surrogate drones and this will add another layer to the training challenge.

Credit: Trevor Nash

A crew are put through their paces at the MQ-9 FTU, Holloman AFB.

into a single course under the banner of the RPA Learning Next. The aim of the new course "is to create a competency-based training concept where instruction is driven by the student's capabilities and instructional needs. Instead of the entire class moving through the course together, some students may transition through the pipeline quicker and others may stay longer if needed to adequately develop their skills," explained Delaware Resource Group that is working closely with the USAF on this initiative.

One of the leading providers of UAV training is CAE. Cutting its teeth at Holloman on the MQ-9, the company has now expanded its MQ-9 training footprint as the training partner for the platform's designer and manufacturer, General Atomics Aeronautical Systems, Inc. (GA-ASI). CAE supplements GA-ASI's Flight Test and Training Center (FTTC) in Grand Forks, North Dakota and has built turnkey MQ-9 training centres in Italy, UAE, UK and in the future, Canada.

CAE's efforts are mirrored by Elbit in training crews for its Hermes 450 and 900 platforms. The company produces its own virtual simulators that are available in "two configurations: a dedicated training-only version…a high-end Mission Simulator (MISSIM), and an embedded version on the real console, that is switchable between training and flight-operation modes, the Embedded Operator Proficiency Trainer (EOPT)," explained company spokesperson, Nimrod Karmi. These simulators are used for familiarisation training that the company provides at its factory in Israel or at the customer's facilities. More complex tactical training for the integration of UAVs into the wider battlespace is provided at the IDF's UAV Mission Training Center at Palmachim airbase.

Drone wars

Current conflicts in Ukraine and in the Middle East have highlighted the growing use of the FPV drone, a cheap and easily available platform that with modification can become a credible weapon delivery device or surveillance asset. The sheer scale of this market can be gauged by Ukrainian President Zelensky's widely reported call in the media in December 2023 for one million such devices to enter service in 2024. This has major implications for training and has driven the creation of the Ukrainian 'Army of Drones' programme to train upwards of 10,000 drone operators.

Training drone pilots in Ukraine is challenging and varies according to the model of drone and mission profile. One of the established training centres is Ukraine's 'Dronarium'. By early 2024, this organisation had graduated over 7,000 drone pilots from its training facilities in Kyiv and Lviv with an additional 500 students graduating every month. The Dronarium is supplemented by around 30 additional training facilities – such as those provided by Victory Drones and Kruk – that offer courses lasting a few days to a few weeks depending on the complexity of the drone platform and its mission profile.

The procurement of drones and the training provided in Ukraine is mainly generated by crowd funding and one of the training facilities created by this initiative is the Army Drone School (ADS). According to ADS, "Drone School specialises in training [the] military who go on the front line in two weeks to combat operations. Training is conducted in small groups with an emphasis on quality training, practise and flying. The theory is also kept to a minimum."

The ADS has graduated approaching 400 drone pilots and offers a number of different courses. The basic course teaches how to fly a drone, operating in ECM environments and some basic military skills such as camouflage and concealment. The advanced course is aimed at pilots who have completed an operational tour and focuses on dropping ordnance, using thermal imagers, directing artillery fire and advanced tactics.

The final offering that is provided by the ADS is the FPV impact course for the so-called 'kamikaze' drones. According to ADS, "the training consists of several weeks of theory and a minimum of 20 hours of practice on the simulator."

Credit: Dronarium

Four graduates from Ukraine's Dronarium drone school.

The threat from the FPV drone is significant and its use in Ukraine may be viewed as a warfighting game-changer. This is not only because this new medium provides its users with a low-cost air power capability that can undertake reconnaissance, surveillance and kinetic attack, but that such low-cost systems can destroy enemy weapon systems costing millions of dollars more than the attacking drone. The cost of training FPV pilots is also many orders of magnitude cheaper than training crews for conventional weapons. According to Ukraine's Minister of Digital Transformation, Mykhailo Fedorov, Ukrainian drones had destroyed 1,280 "pieces" of Russian equipment over three months in late 2023, including 246 MBTs, 69 self-propelled artillery vehicles and 75 air defence system components.

Credit: MVRsimulation

MVRsimulation provides its VRSG visualisation system as part of the US Air Force's MQ-9 appended MALET-JSIL training package.

Training to counter

Conventional UAVs are countered by using current air defence weapons but smaller FPV platforms present different challenges. As well as their reduced radar cross section, these devices use concealment to approach their targets. The main counter is to jam the command signal and for more capable drones and loitering munitions, the satellite navigation source such as GLONASS.

As the use of UAVs and FPV drones has grown, so too has the adoption of counter-UAV systems. Last year, Elbit sold its ReDrone system to the Netherlands as part of a USD 55 million contract that also included training. The system comprises Elbit's DAiR radar, SIGINT sensors and the COAPS-L optronic sight as well as jammers.

Systems such as ReDrone and the Ukrainian Piranha 20BSP are automated and require very little training, but in the US, counter-UAV training and awareness is being taught at all levels. In 2023 a counter-UAV academy opened at Fort Sill, Oklahoma "to train soldiers on how to effectively defend against the rapidly-evolving threat of drones." Training here covers 'soft-kill' systems such as ReDrone and 'hard-kill' systems that detect and then kinetically engage the target. An exemplar of the latter is provided by the Israeli company Sharpshooter with its Smash Hopper system.

"We don't have five years to wait for the perfect system. We have to rapidly innovate with what's possible now and keep getting better, because even when we figure it out, they're going to make a countermove," Army Futures Command's Gen James Rainey said. The aim is to graduate 1,000 soldiers each year from the Joint Counter Small Unmanned Aircraft University that can then provide counter-drone experience at unit level.

The US Army is also conducting counter-UAV exercises with its allies. The most recent were carried out in Saudi Arabia and the Republic of Korea. The latter exercise included using the DroneDefender jamming system and according to US Eighth Army's Maj Joshua Gompert "this combined and joint experimentation will increase the readiness and interoperability of the ROK-US Combined Joint Force."

As this feature has shown, the growth of UAVs and hobbyist drones converted for military roles have expanded exponentially. This has resulted in an increased focus on training platform operators as well as soldiers to counter such threats. In addition to providing 'air power to all,' these technologies are causing military forces to redefine tactics and operational doctrine.

Blue water submarines: capabilities and requirements

Conrad Waters

Despite the ever-increasing number of navies harbouring 'blue water' naval ambitions, the total of those with the means to field this capability underwater is limited. The nuclear-powered submarine's combination of speed and endurance continues to provide an unrivalled capacity to undertake long-range, oceanic deployment. However, few nations have either the technological base or financial resources to acquire such vessels. As a result, the acquisition of long-range diesel-electric boats remains the default option for many of these fleets. This article examines the major programmes that are currently underway for both submarine types.

Blue water submarine capabilities

Although precise definitions of a 'blue water' navy differ, most commentators agree that the capacity to deploy and sustain naval power at distance across the world's oceans lies at the term's heart. In the underwater domain, this capability is closely associated with a submarine that can transit at high speed across long distances to the desired operational area. Here, it has to be capable of sustaining its mission for a considerable period; a requirement that inevitably has significant implications in areas such as endurance, habitability and the amount of weaponry that needs to be carried.

The conduct of oceanic underwater operations is not new in naval warfare. The Kriegsmarine's U-boat offensive during the Battle of the Atlantic and the US Navy's devastating submarine campaign against Japanese shipping in the Pacific are good examples of strategic campaigns carried out by submersibles operating at distance from their home bases. However, such offensive potential has been a secondary consideration for many past and current submarine operators, whose primary focus has been built around a more defensive mindset that emphasises deployments closer to home. Whilst the current generation of modern

Credit: Crown Copyright 2022

The prototype Russian Project 885 'Yasen' class submarine RFS Severodvinsk seen whilst being shadowed by a British frigate in 2022. Series production of the Project 885M variant is now well underway.

diesel-electric boats – often equipped with air independent propulsion (AIP) – are well-suited for such missions, they typically lack the speed and size optimal for operations at longer range.

Given this backdrop, it is unsurprising that the major navies configured largely for expeditionary warfare have tended to focus on the nuclear-powered attack submarine (SSN) as the centrepiece of their underwater fleets. The US Navy quickly reached the conclusion that the qualities of nuclear-propelled craft were so far in advance of diesel-electric alternatives for their chosen missions requirements that they should dispense entirely with the latter, a decision subsequently followed by the United Kingdom and France. Meanwhile, both Russia and China operate a mixture of nuclear-powered and diesel-electric boats. Notably, this virtual monopoly of nuclear-powered submarine operators corresponds with the five permanent members of the UN Security Council in a reflection of the financial, political and technical hurdles that all need to be overcome to acquire the type.

Existing operators

The US Navy is the largest operator of SSNs today, with around 50 of the type in service as of early 2024. Current construction is dominated by the *Virginia* (SSN-774) class. This was initially developed after the end of the Cold War as a more cost-effective alternative to the previous Seawolf (SSN-21) design. A total of 22 of the class had been commissioned between 2004 and the end of 2023, with a further 16 authorised to date. The boats are powered by a SG9 reactor that utilises highly enriched uranium and is intended to serve throughout a ves-

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sel's life without the need for refuelling. The Virginias have been procured in various 'Blocks' and have benefitted from progressive improvement. Assembly is shared between General Dynamics Electric Boat at Groton in Connecticut and Huntington Ingalls Industries at Newport News in Virginia.

Increased tensions in the Asia-Pacific region mean that submarine procurement is a high priority for the US Navy, which is also experiencing downwards pressure on force numbers as the remaining Cold War-era attack submarines decommission. There is also a need to increase weapons-carrying capacity given that the four Ohio class strategic submarines which were reconfigured as cruise missile-carrying boats (SSGNs) also face imminent retirement. This requirement is being met by the insertion of a *Virginia* Payload Module (VPM) – a 25.6 m (84 ft) hull plug – in most of the boats procured from Block V onwards. Each VPM contains four large diameter vertical launch tubes that can carry 28 Tomahawk cruise missiles, increasing total payload in the order of 75%. Current acquisition cost of a *Virginia* class submarine equipped with a VPM is in the region of USD 4.4 Bn (EUR 4.1 Bn) per boat.

Despite some problems ramping up production of *Virginia* class boats to a sustained level of two units each year, the tried and tested design is well-suited to the US Navy's requirements as it attempts to stabilise and then expand SSN numbers to at least 60 vessels over the next 30 years. It should be noted that the official target for US Navy attack submarine numbers is 66 but various alternative force structures are under consideration. Current plans therefore envisage continued construction of the class until the mid-2030s when procurement of a replacement SSN(X) design will commence. Early US Navy pronouncements suggest that this new class will be configured to "…provide greater speed, enhanced horizontal payload capacity, improved acoustic superiority and higher operational availability…" than existing boats.

Turning to Europe, the British Royal Navy is currently well-advanced with renewing its SSN flotilla with its *Astute* class design. Also a product of the immediate Cold War era, delivery of these new boats was badly impacted by the erosion of the defence industrial base that accompanied this new environment. However, five out of a planned total of seven vessels are now in service and construction of the remaining pair by BAE systems at Barrow-in-Furness is well advanced. HMS *Astute* is broadly similar in size and concept to the *Virginia* class's original configuration, utilising a PWR2 reactor that also has a 'full life' core. However, the British submarines lack the vertical launch capability of their American counterparts, utilising conventional torpedo tubes to deploy their cruise missiles. Work is now underway on the follow-on SSN-A design, which will commence deliveries in the late 2030s as part of the AUKUS programme (see further below).

Credit: Crown Copyright 2021

The Astute class SSNs form an important part of the British Royal Navy's blue water capabilities. This photograph shows the lead boat of the class during the CSG-21 global carrier strike group deployment.

The French equivalents of the British Astutes are the *Suffren* class, of the 'Barracuda class' design. The first unit of a planned six-strong class commenced construction at Naval Group's Cherbourg facility in December 2007 and became operational in mid-2022. A sister, FS *Duguay-Trouin*, was delivered in July 2023 and the remaining boats are at various stages of construction for delivery through to the end of the decade. Although intended to perform similar duties to the American and British SSNs, the French boats are considerably smaller and have a reduced weapons load-out in consequence. This compromise may reflect the importance of the confined waters of the Mediterranean to French operational requirements. Another important difference is the use of low enriched uranium in the class's K15 reactors. Whilst necessitating refuelling every ten years, this provides valuable synergies with France's strong civilian nuclear sector. The *Suffren* class

Credit: Naval Group

The French counterparts of the British Astute class are the 'Barracuda' or Suffren class submarines. This picture shows FS Suffren at the time of her official launch ceremony.

are also notable through being capable of operating in stealthy turbo-electric drive; a capacity that is of growing importance as anti-submarine warfare detection capabilities continue to advance.
Russian naval forces were badly downgraded in the Cold War's aftermath, but the fleet's underwater capabilities have always been accorded a relatively high priority. In addition to playing an important role in nuclear deterrence, submarines have played an important role countering the 'West's' superiority in carrier aviation and surface combatants. After a period of considerable disruption, blue water requirements are now being met by series production of the Project 885M or 'Yasen M' class by the United Shipbuilding Company's Sevmash subsidiary at *Severodvinsk* in Northern Russia. Derived from the sole Project 885 boat RFS *Severodvinsk*, the 'Yasen M' design is generally classified as a nuclear-powered cruise missile submarine (SSGN). It has many conceptual similarities with the VPM-equipped *Virginias* but its ability to deploy 3M22 'Tsirkon' hypersonic cruise missiles provides a capability currently absent from NATO equivalents. Three 'Yasen M' series submarines have been commissioned to date and a further five are under construction. Open source information suggests that a total of between 10 and 12 Project 885/885M boats is ultimately envisaged.
Although China had deployed SSNs since the 1970s, it has only been since the emergence of the People's Liberation Army Navy's (PLAN's) blue water ambitions in the current millennium that the type has gained its present importance. Even now, the series of current Type 093 boats are believed to lag behind foreign contemporaries in key areas such as acoustic stealth. Perhaps in consequence, they are only being built in limited numbers by Bohai Shipbuilding Heavy Industry at Huludao. The yard delivered two Type 093 and four Type 093A class submarines from 2006 onwards and is now outfitting at least two improved Type 093B variants. Whilst firm details are scarce, it has been widely reported that the design benefits from Russian technology acquired after the Cold War came to an end. If the previous trajectory of Chinese surface combatant construction can be relied upon, it would seem that the Project 093 class submarines are essentially prototypes for an improved design that is often referred to as the Project 095. This is due to enter rapid series production once developmental work is concluded.

Table 1: Specimen nuclear-powered attack submarine (SSN) designs

Country:	USA	USA	UK	France	Russia	China
Class:	***Virginia***	***Virginia VPM***	***Astute***	***Suffren***	**Project 885/885M [1]**	**Type 093**
Entered Service:	2004	tbc	2010	2020	2014	2006
Number:	22+8	tbc	5+2	2+4	4+6	6+2
Displacement:	7,800 tonnes	10,200 tonnes	7,800 tonnes	5,300 tonnes	14,000 tonnes	6,500 tonnes [est.]
Dimensions:	115×10×10 m	140×10×10 m	93×11×10 m	100×9×7 m	130×14×9 m	107×11×8 m
Payload:	26 torpedoes; 12 missiles	26 torpedoes; 40 missiles	38 torpedoes/ missiles	24 torpedoes/ missiles	30 torpedoes; 32 missiles [est.]	n.k.

Note: 1) Officially classed as SSGN. The design includes one prototype Project 885 'Yasen' vessel built to slightly different dimensions and the series-built Project 885M 'Yasen M' class.

Blue water aspirants

In addition to existing operators, the expansion of navies developing blue water capabilities means that there are a growing number of aspirants to the exclusive 'SSN club'. Of these, only India currently has actual experience of operating nuclear-powered attack submarines, having leased Russian-built Project 670 and Project 971 class boats in the past. At the current time, its only operational nuclear-powered boat is the highly secret INS Arihant, lead unit of a class of four planned strategic submarines. There are longer term ambitions to field a flotilla of six Project 75 Alpha SSNs that, like the strategic boats, would be built at the Naval Shipbuilding Centre at Visakhapatnam. Although preliminary clearance for the programme was granted in 2015, it is likely to be well over a decade before the new class enters service. In the interim, it has been reported that India will lease another Russian Project 971 class boat to increase its experience of SSN operations.
Brazil is another country with longstanding ambitions to operate SSNs. However, its rationale for acquiring the type is somewhat different than for other operators focused on blue water power projection. The Brazilian Navy's own requirement is driven more by a desire to safeguard the extensive wa-

Credit: Indian Navy

The Indian Navy has leased nuclear-powered submarines from Russia on two occasions and has plans to build its own Project 75 Alpha SSNs. This is the Project 971 boat INS Chakra seen during her time on lease.

Credit: Huntington Ingalls Industries

USS Arkansas (SSN-800) pictured under construction at Huntington Ingalls Industries' Newport News shipyard. She will be the 27th member of the Virginia SSN class. Some of the later boats in the class are receiving a hull plug to increase their missile-carrying capacity.

ters of its exclusive economic zone (often referred to as the 'Blue Amazon'), a mission for which the speed and endurance of nuclear-powered units are well-suited. Work to develop a SSN commenced as early as the 1970s but it is only in recent years that this has gained traction.

The Brazilian Navy's current plans are focused on combining its long-term research into developing an indigenous nuclear reactor with the broader submarine technology transferred from France as part of local construction of the diesel-electric 'Scorpène' design under the huge 'PROSUB' submarine development programme. This approach leverages the substantial investment made in the infrastructure to build and support submarines at the vast Itaguaí industrial complex west of Rio de Janeiro developed with the assistance of Naval Group following signature of a series of contracts in 2009. The facility has already delivered two of a quartet of 'Scorpènes' and will progressively transition to the construction of the planned SN-BR. Fabrication of a test section of the new boat, to be named Álvaro Alberto in honour of the father of the navy's nuclear programme, commenced in October 2023. It is hoped that she will eventually be delivered in the early 2030s as the prototype of an extended class.

The most recent country to embark on SSN acquisition is Australia. It plans to acquire a flotilla of nuclear-powered submarines under the trilateral AUKUS security partnership with the United Kingdom and United States that was announced in September 2021. The procurement owes much to the country's desire to be able to deploy submarines to counter Chinese naval expansion in South East Asia; a requirement that emphasises speed and endurance. It was previously intended that procurement of large, diesel-electric submarines derived from France's *Suffren* class would provide this capability. However, the attractions of nuclear propulsion ultimately became irresistible as the cost/capability balance of the resultant 'Shortfin Barracuda' or Attack class programme started to look increasingly unattractive.

Current Australian plans envisage a phased transition to SSN operation under which increased deployments of British Royal Navy and US Navy submarines to Australia and an associated ramp-up in training will be followed by transfers of *Virginia* class submarines from the latter's inventory. This will ultimately pave the way for introduction of a class of new AUKUS (SSN-A) nuclear-powered attack submarines that will be developed for Australia and the United Kingdom under a joint programme that will also benefit from the input of US technology. Deliveries of the Australian submarines will commence in the early 2040s after assembly at the Osborne Naval Shipyard in Adelaide, South Australia utilising PWR-3 reactors produced by Rolls-Royce in Derby, United Kingdom. The ability of American and British industry to produce whole-life reactor cores is seemingly an important enabler of the Australian programme, enhancing the security of nuclear material in compliance with the requirements of the international nuclear non-proliferation regime.

The conventional alternative

Although Australia's experience is indicative of the superiority of nuclear propulsion for blue water submarine deployments, the hurdles that need to be overcome to acquire this capacity are substantial. In addition to the considerable expense involved in procuring and operating SSNs, the technological and political obstacles to adopting nuclear propulsion are also significant. Indeed, the AUKUS programme is the first

Credit: Navantia

An unusual overhead view of the Spanish S-80 class submarine Isaac Peral taken whilst she was being floated out in 2021. She is a large diesel-electric submarine equipped with AIP and well-suited for extended deployment.

Credit: Saab AB

A Saab-Damen partnership is offering the C718 variant of Saab's Expeditionary Submarine to meet the requirements of the Royal Netherlands Navy's Walrus class replacement programme.

occasion on which a non-nuclear weapons state has acquired nuclear reactors to power submarines. As such, the acquisition of large, diesel-electric submarines remains the only practical option for many fleets wishing to expand their expeditionary underwater capabilities.

Within Europe, the best example of a modern, conventionally-powered 'blue water' submarine is probably Spain's new S-80 Isaac Peral class. The lead boat was commissioned in November 2023 after a protracted construction period resulting from the original design turning out to be overweight. Three additional boats are currently under construction at Navantia's Cartagena shipyard. The design is based on staff requirements that emphasised global naval power projection both across the oceans and into the littoral. The latter mission set is reflected in an ability to deploy land attack cruise mis-

Credit: JMSDF

JDS Taigei (SS-813) is the first of a class of new Japanese diesel-electric submarines equipped with lithium-ion batteries.

siles and the specification of an advanced AIP plant incorporating bioethanol reformer-based technology. It should be noted that the first two boats will be fitted 'for but not with' this capability. The design is relatively unusual as a large, diesel-electric submarine suitable for extended deployment. This could make it an attractive proposition for other navies seeking this capability.

The Royal Netherlands Navy's longstanding requirement to replace its existing *Walrus* class with submarines capable of extended deployment has revealed other potential options. The Dutch Ministry of Defence (MoD) considered three proposals from:

- **Naval Group:** A diesel-electric variant of the nuclear-powered 'Barracuda' class broadly similar in concept to the 'Shortfin Barracuda' previously offered to Australia.
- **Saab (in partnership with Damen):** A C718 variant of Saab's C71 expeditionary submarine concept, itself derived from Sweden's A26 Blekinge class.
- **thyssenkrupp Marine Systems:** A stretched expeditionary ('E') variant of the new Type 212CD design that has already been ordered by Germany and Norway.

All these boats have a submerged displacement in excess of 3,000 tonnes, offering extended range and a significant weapons-carrying capacity. On 15 March 2024, the Dutch MoD announced their decision, selecting Naval Group's diesel-electric Barracuda design.

Beyond Europe, the demands of operations over the vast extent of the Pacific have driven the adoption of large diesel-electric submarines by a number of navies across the region. Australia's existing Swedish designed *Collins* class were an early example of this trend, but it is the Japan Maritime Self-Defence Force (JMSDF) that has greatest experience of developing the type. Its latest *Taigei* (SS-513) class are large vessels with a submerged displacement of over 4,000 tonnes. Construction is shared between Kawasaki Heavy Industries and Mitsubishi Heavy Industries at the two companies' shipyards in Kobe. An interesting innovation is their use of Lithium-ion batteries, which were first introduced in the final members of the preceding, Soryu (SS-501) class. Their higher energy density compared to many other battery types potentially offers the ability for greater sustained speeds, bridging some of the gap with nuclear-powered boats. It has also been reported that the JMSDF's next submarine class will incorporate vertical launch systems for use with the Tomahawk cruise missiles, which the country is in the course of acquiring.

Developments in Japan are being closely mirrored by those in neighbouring South Korea. The initial batch of three submarines completed to its latest KSS-III design by Hanwha Ocean at Okpo and Hyundai Heavy Industries in Ulsan incorporates vertical launch cells for submarine-launched ballistic missiles. A second batch will also be equipped with lithium-ion batteries for greater underwater endurance and speed. Together, this combination provides significant capabilities to support the Republic of Korea's growing blue water naval ambitions, which also extend to aircraft carrier acquisition. However, the class's primary function is seemingly to act as part of the country's 'Three Axis' deterrent against potential North Korean aggression, providing the means of undertaking a powerful conventional response to any nuclear strike.

The future

Whilst the capacity of nuclear-powered submarines to sustain blue water operations remains unchallenged, it seems likely that the numbers of fleets adopting this type will remain limited. Only six navies have operated SSNs in the seventy years since the first, USS Nautilus (SSN-571), was commissioned on 30 September 1954 and only one or two additions are likely in the decades ahead. Whilst developments in the field of diesel-electric submarine technology will likely narrow the performance gap with their nuclear counterparts, operators of the 'true' blue water submarine will remain an exclusive club for the foreseeable future.

Table 2: Specimen large diesel-electric submarine (SSK) designs

Country:	Japan	South Korea	Spain
Class:	*Taigei*	KSS-III (Batch 1)	S-80 *Isaac Peral*
Entered Service:	2022	2021	2023
Number:	tbc	3	4
Displacement:	4,300 tonnes [est.]	3,800 tonnes	3,000 tonnes
Dimensions:	84×9×10 m	84×9×8 m	81×12×7 m
Payload:	n.k.	n.k.	19 torpedoes/ missiles

AUVs and ROVs make key contribution to seabed warfare

Dr Lee Willett

Providing sustained presence on station at depth below the surface is a role that sits neatly with uncrewed underwater vehicles. For emerging operational requirements such as seabed warfare, autonomous underwater vehicles and remotely operated vehicles combine to generate surveillance and response for this task.

Seabed warfare is a new element to the maritime underwater domain, or perhaps even a new domain altogether. Whether to secure or attack critical undersea infrastructure (CUI) such as oil and gas pipelines or communications/data/power cables, whether to secure or exploit seabed resources, or whether to use the seabed to search for or deploy sensors or weapons when shaping the operational battlespace, uncrewed underwater vehicles (UUVs) will provide core capabilities for navies. There are two primary UUV types – remotely operated vehicles (ROVs), and autonomous underwater vehicles (AUVs).

In February 2024, reports emerged that several CUI cables running from Saudi Arabia to Djibouti across the southern Red Sea's seabed had been disrupted. The Red Sea is of course currently a focus for high-intensity naval operations. Multinational naval forces are assembled to provide air-defence and anti-surface warfare cover for commercial and naval shipping transiting the Gulf of Aden/Bab-el-Mandeb Straits/Red Sea corridor under the threat of air and surface attack from Yemen-based Ansar Allah (Houthi) rebels launching ballistic and cruise missiles along with uncrewed aerial vehicles (UAVs) and uncrewed surface vessels (USVs).

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Credit: IAI

The BlueWhale AUV, developed by IAI. AUVs such as this one are capable of undertaking a range of missions, including intelligence-gathering above and below the sea surface, as well as detection of underwater targets such as submarines and naval mines on the seabed.

Senior military officers have also asked whether a small but prominent uptick in Somali piracy in the Gulf of Aden may be linked to Houthi activities across the water. Similarly, defence analysts have asked whether the Houthis themselves might have developed the capability to conduct seabed operations using UUVs, and have been responsible for these latest attacks.

The current Russia-Ukraine and Israel-Hamas wars, alongside the Red Sea shipping crisis, are all demonstrating not only the use of uncrewed systems – something not even major navies have yet done with any regularity and mass – but their use in innovative ways.

As regards seabed warfare and the role of UUVs, operating on the seabed itself – including at depths down to 6,000 m – is a significant technological and operational challenge. However, the increasing availability of technologies such as UUVs (including both AUVs and ROVs), is opening up the prospect that both state and non-state actors could operate to significant effect on the seabed, in either littoral or blue-water operational contexts.

The Red Sea cable incident is the latest in several high-profile events involving disruption to seabed CUI. In October 2023, the Balticconnector gas pipeline running between Estonia and Finland, plus a nearby telecommunications cable, were disrupted by what was widely reported as a Chinese commercial vessel dragging an anchor across the seabed. In September 2022, the two Nordstream gas pipelines that dissect the Baltic Sea were ruptured by explosions. NATO and countries in the region attributed the incident to sabotage.

Credit: US Navy

US Navy sailors are pictured working with a REMUS 100 AUV off Denmark in 2019. AUVs have become a core capability for navies focused on tackling seabed warfare threats.

In January 2022, at the northern end of the maritime dividing line between the Norwegian and Barents seas, fibre-optic cables connecting the SvalSat Satellite Ground Station on Norway's Svalbard archipelago to the Norwegian mainland were damaged. Local media reports said that Norwegian investigations indicated human involvement.

In November 2021, it was reported that a sub-surface environmental sensing network on the seabed off the Lofoten peninsula, in northern Norway, had been taken offline due to more than 4 km of its fibre-optic sensing cable being ripped out. The Lofoten peninsula sits at the southern end of the Norwegian/Barents seas maritime junction, and would be a busy location for submarines seeking to slip around the North Cape at the bottom of the Bear Island Gap. The sensor network, owned and operated by the Norwegian Institute of Marine Research's civilian Lofoten-Vesterålen (LoVe) Ocean Observatory, likely could detect maritime traffic as well as monitoring environmental matters.

The range of causes potentially relevant in these five different incidents includes the possible use of explosives (as in the Nordstream and Red Sea cases), with such explosives potentially deployed by an ROV; an anchor dragged, accidentally or otherwise (as in the Balticconnector case); and a UUV – likely an ROV – used to damage a cable (as in the Svalbard case), and to grip and drag a significant length of cable, including ripping it from concrete moorings (as in the Lofoten case).

Instances where a cable or pipeline may have been blown up or ripped out indicate potentially the involvement of a UUV fitted with a manipulator arm that can conduct, effectively, 'ditch or retrieve' manoeuvres.

Across these five incidents, water depths range from: tens of metres to over 400 m through the Bab-el-Mandeb straits at the southern end of the Red Sea; to around 200 m in the Baltic Sea and off the Lofoten peninsula; to as deep as 2,700 m off Longyearbyen, Svalbard.

Some Western navies are developing the capacity to conduct seabed warfare operations at depths of up to 6,000 m. The ability to operate at such depths means these navies can conduct seabed operations across the North Atlantic almost in its entirety.

Twin requirements

The Baltic and Red Sea incidents related to CUI. The two incidents in Norwegian waters related to commercial sensor and communications cables that could gather and transmit information that could in turn be used to shape situational awareness for Norway and its allies. For example, according to media reports, data gathered by the LoVe Ocean Observatory is shared with the Norwegian Ministry of Defence (MoD).

These two separate types of incident reflect navies' own operational requirements prospectively to conduct two separate types of seabed warfare. The first type would be to secure commercial and military CUI from a defensive perspective – operations which may likely take place in national territorial waters or exclusive economic zones. The second type would be to monitor and sanitise – or 'de-louse' – the seabed, looking for sensors or ordnance that may have been placed to threaten naval freedom of manoeuvre, or looking to deploy sensors or ordnance to threaten another navy's freedom of manoeuvre. The latter type of operations could occur wherever a navy's area of interest might be around the world. By way of example, at the Portuguese Navy/NATO Maritime Command co-led 'REPMUS'/'Dynamic Messenger' maritime uncrewed systems (MUS) exercise in southern Portugal in September 2023, a UUV was used to conduct over-the-horizon intelligence, surveillance, and reconnaissance (ISR) in support of a mine counter-measures (MCM) operation intended to 'de-louse' a seabed 'corridor' to enable an amphibious assault ashore. The operation needed to be conducted covertly, so as not to signal the impending amphibious operation: UUVs – especially AUVs – play a critical role in generating such covert access, and doing so at distance with the required level of autonomy. The UUV used was a Teledyne Gavia AUV, taken to the exercise by the Royal Danish Navy.

Credit: US Coast Guard

A Teledyne Gavia AUV was used to conduct long-range sanitisation of an amphibious assault corridor during the 'REPMUS'/'Dynamic Messenger' maritime uncrewed systems exercise off Portugal in September 2023. A Gavia AUV is pictured here onboard a US Coast Guard vessel, during a previous exercise in the Arctic Ocean.

Credit: Canadian Armed Forces

A Royal Canadian Navy Kingston-class maritime coastal defence vessel operates a containerised HUGIN AUV during the USN-led 'RIMPAC' exercise in 2016. Containerising capability is a key operational concept for navies in deploying AUVs and ROVs.

Developing seabed warfare capability, for either defensive or offensive operations, is something navies can sometimes be sensitive to talking about, reflecting the fact that navies operating regularly in the opaque underwater world prefer to mask their activities there. However, one navy talking openly about, and demonstrating in operations, how it is looking to conduct seabed warfare (both defensive and offensive) and around the world (in both littoral and blue-water contexts) is the French Navy.

Calliope Operations

In October 2022, the French Navy established a new, bespoke seabed warfare operation called 'Calliope'. Four 'Calliope' deployments – what the navy refers to as Maitrise des Fonds Marins (MFM) operations, or deep-sea control – have now taken place, the most recent of which occurred in October 2023 in the Atlantic Ocean. The navy conducts 'Calliope' operations in conjunction with France's defence procurement agency, the Delegation Générale de l'Armaments (DGA).

In a 15 October 2023 social media post on X (formerly Twitter), the French navy said the latest 'Calliope' operation built on developments carried out in the three previous activities, relating to the use of AUVs and ROVs. Rear Admiral Cedric Chetaille, the navy's deputy chief for operations and the senior officer responsible for seabed warfare operations and capabilities, discussed the latest 'Calliope' deployments and the wider seabed warfare context in two posts on X, on 10 October and 16 October 2023 respectively. First, he noted that the seabed is a new domain for hybrid conflict and other matters that can have strategic outcomes; second, regarding 'Calliope', he said "the French Navy continues with the successful development of its capacity to monitor the deep sea and to act on the seabed."

Back in February 2022, the French Navy published its seabed warfare strategy, in which it stipulated the requirement to deliver capability to operate on the seabed at depths of up to 6,000 m by 2026. Requirements such as this as set out in the strategy are shaping the developmental focus of the 'Calliope' operation. In a short report published in November 2023, the French MoD said "The freedom of action of our forces at sea therefore depends heavily on our ability to control the depths."

In the report, Rear Adm Chetaille outlined the core contributions of AUVs and ROVs in seabed operations and control, encompassing the development of knowledge of the seabed, plus the capacity to monitor and to act. AUVs help build knowledge and surveillance; ROVs provide capability to surveil and react, the admiral explained.

In the first 'Calliope' activity, in October 2022, the oceanographic and hydrographic survey vessel FS Beautemps-Beaupré deployed to the Bay of Biscay carrying onboard a Kongsberg Maritime HUGIN Superior AUV. The AUV, which has the design capability to deploy down to 6,000 m, was tested down to 4,500 m during 'Calliope'. In the first half of 2023, two 'Calliopes' occurred. The first, off the coast of Brest on France's west coast, involved the offshore support vessel FS Garonne. The second, in the Mediterranean Sea, involved deploying the Exail A18-D AUV down to 3,000 m.

Within the context of the navy's seabed warfare strategy and under France's latest Loi de Programmation Militaire (LPM), which is covering the 2024-30 period, the navy is aiming to manufacture its own AUVs and ROVs by 2026, based on the systems it has been testing in 'Calliope'. Such systems, the MoD report said, will be designed to give France sovereign capabilities for controlling the seabed.

The report noted that France's research institute for maritime exploration has been working with Exail to develop the capabilities of the ULXy deep-water AUV, adding that the system could meet the capability and operational requirements for France's deep-water AUV with its capacity to deploy down to nearly 6,000 m.

Exail Technologies – formed when ECA Group and iXblue joined forces in 2022 – refers to A18-D as a mid-sized AUV (with a 5.5 m maximum length, and a 690 kg maximum weight) designed for deep water applications down to 3,000 m, optimised for CUI survey work, and able to perform autonomous missions with a 24-hour endurance. Sensing capability includes a sub-bottom profiler, side-scan and forward-looking sonars, and a multi-beam echo sounder; its flexibility in sensor payloads is demonstrated by the fact that it has an option to fit a synthetic aperture sonar (SAS), too. The system is air-transportable (via shipping container, with this containerized capability including the AUVs' command-and-control [C2] link), is deployed via launch-and-recovery system (LARS) to deliver autonomous underwater recovery, and comes with data processing software installed.

Kongsberg's HUGIN Superior's capabilities for monitoring the seabed include a sub-bottom profiler, SAS and multi-beam echo sounders in its sensor package; autonomous pipeline tracking via the SAS capability; enhanced positioning through its High Precision Acoustic Positioning (HiPAP) system; automatic target recognition capability; and long endurance on station and/or wider seabed coverage. According to the company, the AUV's seabed imagery coverage rate is roughly 4.5 km^2 per hour. Kongsberg added that the system's level of autonomy means its host platform can be released to conduct concurrent activities. The 6.6 m, 2,200 kg HUGIN Superior is deployed with C2 and LARS systems, plus post-mission analysis software.

Containerised capability

France's approach to developing seabed warfare capability that can be containerised and rapidly deployed where and when required reflects the wider approach of other NATO countries, and NATO itself, to develop capability that can be used to deter and defend against the seabed warfare threat.

At 'REPMUS'/'Dynamic Messenger', alongside testing the utility of AUVs in sanitising forward operating areas to enable the entry of follow-on forces, NATO navies also tested the utility of AUVs and ROVs in deterring and defending against risks to CUI. In a scenario demonstrated at sea during the exercise's Distinguished Visitors' (DV) Day, a layered collection of uncrewed systems was tasked to respond to a state-based threat to seabed cables that involved the use of some hybrid warfare tactics. NATO's integrated response layers in the exercise included UAVs conducting surveillance of the operating area, USVs deploying AUVs, and several ROVs and AUVs that were present to sense and respond to the CUI threat.

A senior NATO official told a media briefing at the DV Day that the results of the live scenario and the wider testing of UUVs during the exercise may feed into the development of concepts and capabilities that could form part of a containerised CUI protection 'system of systems' that could be generated as a deployable, rapid-response option.

NATO and its member-state navies have already developed and deployed containerised capability for MCM operations, with both AUVs and ROVs included here. Other areas of focus for developing containerised capability include humanitarian assistance and disaster relief (HADR) and anti-submarine warfare (ASW) – the latter again including UUVs.

One navy developing a platform designed specifically to embark AUV and ROV capabilities for seabed warfare, and particularly in containerised format, is the UK Royal Navy (RN), through its Royal Fleet Auxiliary (RFA) vessel Proteus.

Proteus is one of two dedicated platforms the RN is procuring under the multi-role ocean surveillance ship (MROSS) programme to provide capacity to address CUI threats. While the second ship in the programme could be either custom-built or market-bought, *Proteus* (formerly named *Topaz Tangaroa*) was procured off-the-shelf from the commercial offshore support vessel market to enable delivery of such capability into service as soon as possible. Following the announcement of the planned procurement, the ship arrived in January 2023, was commissioned in October 2023, and is currently completing customisation as an RFA asset: it sailed from the Cammell Laird shipbuilding yard on 12 March 2024, and arrived at HM Naval Base Devonport two days later.

"The UK is being really clear that we're procuring a vessel that is capable of protecting our sovereign CUI," RN Second Sea Lord Vice Admiral Martin Connell told the annual Combined Naval Event (CNE) conference in Farnborough, UK in May 2023.

Capacity to carry containers and deploy AUVs and ROVs onboard *Proteus* is enabled by the ship's design. According to *Janes Fighting Ships*, relevant spaces, systems, and equipment for the embarkation and operation of containerised AUV and ROV capabilities include a 120 tonne offshore crane; a 1,000 m^2 working deck; a large hangar; a moonpool; and dynamic positioning capability. While the RN has not said much publicly about the kinds of capabilities *Proteus* will embark, in September 2023 it was announced that the UK MoD had contracted Danish subsea engineering company Eiva to supply its ScanFish L remotely operated towed vehicle (ROTV).

According to a statement released by the company, ScanFish L will be part of the RN's 'system of systems' approach for seabed warfare, with the system bringing together a collection of acoustic sensors and other instruments that can be deployed from different platforms. The statement noted that ScanFish L's particular contribution to this 'system of systems' is, broadly, oceanographic survey and data collection, including: seabed mapping; wide-area search; CUI monitoring such as pipeline inspection and cable route survey; and MCM operations. To conduct these and other operations, the ScanFish L sensor package includes Sonardyne's SPRINT-N inertial navigation system/doppler velocity log, and two Voyis systems – the Observer Pro optical camera, and Insight Pro laser scanner.

Credit: Eiva

The ScanFish L, shown here in its containerised configuration, will contribute to the Royal Navy's seabed warfare 'system of systems'.

The ScanFish L capability will be provided to the RN in containerised format, using a modular container from Danish company SH Defence. The container will come fitted with two dedicated workstations, meaning ScanFish can be fully integrated and operated without needing to be plugged into the ship's C2 system. According to Eiva, "This solution will provide integrated and enhanced operational capabilities for the RN, demonstrating both modularity in the ScanFish setup and flexibility of employment through the containerised solution."

Containerisation is a core concept supporting the effective embarkation, deployment, and operation of AUVs and ROVs at sea. Containerised concepts have been developed by navies for two primary reasons. Containerising capability provides navies with an opportunity to bring a ship into port mid-mission to add a capability the ship may need in response to an urgent operational requirement, or a ship can be fitted out with a container prior to deploying for a mission to provide it with a capability not carried organically.

Both approaches generate the option for navies to deploy AUVs and ROVs relatively rapidly in response to operational requirements, and to spread such capabilities across naval force structures without needing to embark them organically on every ship.

Credit: Crown Copyright 2023

The UK Royal Navy's first dedicated seabed warfare platform RFA Proteus, pictured in London during its service of dedication in October 2023, can deploy AUVs and ROVs in a variety of ways.

Finding the edge: sonar technologies and programmes

Tim Fish

As submarines become quieter and operations shift towards the littorals, high-end sonar systems are needed in order to better detect and identify targets in the water column, especially in a cluttered environment. This article examines the latest technologies being used to improve sonar performance and the new products on the market that meet emerging naval requirements. It also identifies the latest sonar programmes and their importance for submarines and anti-submarine warfare operations.

The return of high-intensity peer-on-peer competition has raised the stakes in the underwater domain. The ability to control the sea lines of communication and exploit that control in the littorals has returned as a priority area for investment. Submarines perhaps represent the ultimate platform for sea control; their ability to gather information about the underwater environment in order to either hunt for submarines or to improve submarine operations is outstanding.

Naval requirements for sonar systems are evolving to improve submarine detection, underwater navigation and the tracking of underwater objects. With the addition of quietening technologies, modern submarines are becoming extremely difficult to detect; there is therefore a drive towards improving sonar systems and integrating them as part of a wider enhancement of the anti-submarine warfare (ASW) effort.

These efforts include bringing sonar systems into the combat network and integrating sonar data with other sonar and sensor system data; using the network to increase the use of multi-statics; adapting products to make them more modular and capable of integrating with drone operations; and utilising data processing enhancements such as artificial intelligence (AI), machine learning (ML) and data aggregation.

Author

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Credit: L3Harris

Active Low Frequency Towed Array Sonar (ALOFTS) from L3Harris combines a high-powered, active source in a variable-depth towed body. A directional towed array receives active and passive signals.

Multi-statics

Multi-statics is all about getting more sensors into the water to improve the ability of sonars to detect and localise targets. It means using an active sonar (often off-board) to generate a 'ping', with multiple passive sonar devices acting as listening posts to detect the sound bouncing off the target and allowing the target and its location to be found.

Unlike the air domain, where communications networks can easily be established linking sensors through the electro-magnetic spectrum in the air and via cables over land, this is not so easily achieved underwater or through the air-surface gap.

For multi-statics to work, it means that an active sonar source, such as from a helicopter dipping sonar will have to be networked with ships, aircraft, sonobuoys and submarines to collate the information. Multi-statics becomes more important in shallow littoral waters where active sonar is refracted and reflected creating false contacts among the clutter, thereby making it less effective – this means more sensors are needed to help identify targets.

The addition of autonomous underwater vehicles (AUVs) and uncrewed underwater vehicles (UUVs) fitted with sonars is part of the solution to have more sensors in the water and provide a more persistent surveillance of more challenging underwater environments. This can be realised with a more effective underwater communications system able to link AUVs and UUVs and crewed submarines together, and also with command centres.

Distributed acoustic sensors connected by fibre-optic cables also have the capability to continuously monitor larger underwater areas and provide real-time information.

There are several potential sonar developments that could prove to be game changers. These include the integration of sensors, such as passive and active sonar to enhance detection, and the fusion of contact data from different sources

BlueWhale – A True Submarine Force Multiplier

The seventh annual REPMUS* and Dynamic Messenger naval exercises, organized and led by the Portuguese Navy and NATO, were held over a three week period in September 2023. Over two hundred representatives of security and defense industries, military forces, and academia from thirty countries around the globe witnessed the operation of **"Blue-Whale"**, a unique system with on-board capabilities beyond anything seen before on an uncrewed underwater asset.
In fact, these representatives likely witnessed the first **successful deep-water submarine detection by an uncrewed underwater vehicle** (UUV). Developed by IAI's ELTA division, BlueWhale is a stealthy, long-endurance, large displacement uncrewed underwater vehicle (LDUUV) designed to complement conventional submarines and naval task forces by performing a wide array of important covert missions.
Exploiting IAI-ELTA's expertise in systems and sensors design, together with a modular hull design, **BlueWhale** can be configured to effectively perform a wide range of critical missions: **Anti-Submarine Warfare** (ASW); **Intelligence, Surveillance and Reconnaissance** (ISR); **SEABED warfare; Mine Counter Measures** (MCM); **Acoustic Intelligence** (ACINT); **Forward SIGINT scout for Special forces**, including real time video support for landing missions; **Forward SIGINT scout for naval task force; and piracy, terrorism and illegal immigration detection.**
Special attention has been paid to ASW. To maximize the platform's Warfare (ASW) capabilities in this critical area, IAI-ELTA teamed with ATLAS ELEKTRONIK, a world leader in the underwater domain, to integrate the company's Towed Array Sonar (TAS) with **BlueWhale**. The synergy between these systems has produced a truly "game changing" solution.
Using Bi-static and Multi-static external active sonar sources, the system delivers the revolutionary ability to extend a submarine barrier over areas that were previously impossible to monitor in an efficient way. Operating undetected with a passive array to a dive depth of 300 meters, **BlueWhale** creates a real challenge for enemy submarine forces. This important capability was demonstrated to tremendous effect on a daily basis as part of NATO task force during the three weeks of REPMUS23 and DYMS23.


Credits: IAI-ELTA (3)

BlueWhale in Portugal, REPMUS 2023

In addition to TAS, the sub-surface sensor suite includes active and passive Flank Array Sonar (FAS) for the detection of surface vessels and submarines, Synthetic Aperture Sonar (SAS) for mine detection and high-resolution sea bottom mapping, and magnetic sensors for mine detection and verification. On top, **BlueWhale** features a patented, purpose designed collapsible mast configured with an advanced suite of high-performance surface payloads, including staring radar, electro-optics/IR, R-ESM, and low signature Broad Band SATCOM for real-time data exchange.
BlueWhale brings entirely new capabilities to MCM. For example, the covert autonomous survey of a coastal area before amphibious landings, close inshore to the enemy coast. No other solution available today can accomplish this task stealthily.

In fact, **BlueWhale** was the only "eye on the target" before and during special forces amphibious landing exercise at REPMUS23, which took place in a very shallow and complex area of operation.
Underwater systems team lead, Captain (Ret.) EE, an experienced naval officer with over twenty-five years at sea in command positions, explains that **BlueWhale**'s mission capabilities, proven over 2,000 diving hours encompassing a range of successful autonomous missions, add a new dimension to subsurface warfare and make it the first LDUUV to effectively complement larger crewed platforms.

BlueWhale is operated and managed via a highly developed Command & Control (C2) system, which facilitates a continuous Situation Awareness Picture, Call-to-Action commands, events blogger, remote operation and more. A user-friendly Human-Machine Interface (HMI) enables the system to be efficiently operated by only two personnel, a LDUUV operator and a payload (sonar) specialist.
The ability of **BlueWhale** to complement conventional submarine forces by performing critical missions with complete autonomy reduces crew workload, saves lives, and improves mission performance. This, together with the fact that **BlueWhale** is less costly to acquire and operate than conventional submarines, make the system a true force multiplier.

to provide a comprehensive situational awareness picture.

Advances in signal processing with algorithms that can better filter and analyse sonar data will reduce false alarms and improve accuracy of threat detection, while the use of AI and machine learning (ML) can enhance the automated processing of that data to enable faster and more effective decisions.

Sonars also need to be adaptive so they can adjust their operational parameters based on the environmental conditions and the specific characteristics of the underwater domain. For example, there is a need for enhanced sonar to operate more effectively in icy environments that can address the challenges of the Arctic and sub-Arctic regions. This can be enabled with advances in environmental sensing technologies to provide a better understanding on how sonar performance is impacted by underwater conditions.

Credit: Thales

Hull-mounted sonar devices are common on most warships with different variants selected to provide higher or lower levels of capability. Thales BlueWatcher has been chosen for the French Navy's new OPVs, with BlueHunter set to be fitted on French and Greek FDI frigates and Polish Miecznick frigates. BlueMaster will also be fitted to Spanish Bonifaz class (F110) frigates.

Passive/active approaches

According to a spokesperson from Thales Underwater Systems: "The new trend for anti-submarine warfare systems is to use a combination of both passive and active sonar for a more complete and effective underwater surveillance capability, depending on environmental conditions and missions."

The Thales spokesperson told *ESD*: "Nowadays, there is a growing operational need for both improved active and passive capabilities so that surface ships can fulfil their various [mission types]. For submarine sonars, the focus is more on passive sonars, however high frequency active sonar remains useful for Mine and Obstacle Avoidance Sonar (MOAS) for instance."

Passive and active sonar technologies have different uses. The Thales spokesperson said that different principles apply to each. Advances are required in both technologies. Active sonars use acoustic transducers and power for sound output, with algorithms designed determine the distance, direction and characteristics of targets depending on the acoustic returns. The Thales spokesperson noted that, "The development of advanced signal processing techniques to improve target discrimination and reduce the impact of background noise in active mode is essential", adding, "The implementation of adaptive sonar technologies with the use of the most appropriate ping parameters such as frequency, pulse lengths, and types, as well as other parameters based on environmental conditions, is also a key differentiator."

Meanwhile passive sonars use hydrophones for listening. These rely on detecting and analysing acoustic signatures from the environment. Improved signal processing algorithms are needed for improved detection and classification of those signatures. Sonar resolutions are increasing, and with them the volume of data needing to be analysed, which means that technologies to help with processing and networking are becoming increasingly important.

For a more collaborative form of ASW to be achieved with integrated sonars and interconnected sensors, the use of modern digital technologies such as AI, ML and Big Data will be vital for sonar operators to help make sense of the acoustic environment and find threats. The Thales spokesperson said that as an example, these could be used in classification and database management.

The Thales spokesperson concluded that, "For submarine sonars, the technologies enabling the management of large quantities of data are being investigated. Trustable IA and ML are also possible tools for the sonar operators, but only under operators' supervision." The spokesperson added, "They are important to alleviate the operators' workload and enable them to focus on their main tasks."

Sonar programmes

The number of programmes for new sonar systems and for upgrades to existing sonar systems is increasing for both ship- and submarine-mounted equipment.

In July 2023, the UK MOD announced a GBP 30 million (USD 38.4 million) contract with Ultra Electronics for the supply of five Type 2150 hull-mounted sonar (HMS) for the Royal Navy's Type 26 frigates adding to the three already contracted. The 2150 is part of the company's Sea Searcher range of sonar already being fitted to the Type 23 frigate as part of a wider programme to replace the Type 2050 HMS developed in the 1980s. Deliveries are expected to be completed by 2032.

Ultra stated that the 2150 incorporates digital control of the outboard array to minimise interference and reduce cabling. Under a USD 19 million contract from Lockheed Martin awarded in October 2022, Ultra is delivering an HMS for the Type 26 frigates being built under the Canadian Surface Combatant programme. The HMS will allow the ships to passively or actively detect submarines and extend the time between maintenance periods for the sonar.

The Type 26 frigates are specialist ASW frigates using the Sonar 2087 low-frequency active/passive variable depth

Credit: Thales

The CAPTAS-4 sonar suite is in service with the navies of France, Italy, Morocco, and Egypt on their FREMM frigates, and other recent customers include the US Navy for its Constellation class frigates, Greece's Hellenic Navy for its FDI frigates, the Spanish Navy for its F110 frigates.

towed sonar array. Sonar 2087 is the Royal Navy's name for the CAPTAS-4/ UMS 4249 product from Thales and is the service's primary ASW sensor. The company is providing a series of enhancements to the Type 2087 sonars fitted to the Type 23 frigates under a GBP 110 million contract awarded in September 2022 for the Sonar 2087 Design Authority Capability Insertion Project (DA-CIP). Under the DA-CIP, Thales is incorporating new technologies into the system for enhanced detection and tracking, faster processing, better displays and controls that will allow it to retain operational capability in the underwater spectrum and operate well into the mid-2030s.

In the United States, during July 2021, Lockheed Martin was awarded a USD 80.2 million contract for the provision of a technical insertion-20 (TI-20) for the AN/SQQ-89A(V)15 surface ship undersea warfare combat systems and AN/SQS-53C hull-mounted sonar. The system is fitted to the US Navy's *Arleigh Burke* class destroyers and Ticonderoga class cruiser; it uses both active and passive sensing to detect and track underwater objects.

The AN/SQQ-89A(V)15 upgrade includes improved automation for torpedo detection and sophisticated sonar processing and performance prediction. It also has a redesigned display to alleviate operator loads and integrates training and logistics. The AN/SQS-53C is a digital HMS, and compared to earlier variants it provides a longer detection range, relying on less power and offers more detailed contact information. Deliveries will be completed by June 2026. The AN/SQQ-89A(V)15 receives regular upgrades and in September 2022, Lockheed Martin underwent a contract modification worth USD 253.89 million for the inclusion of Technical Insertion-22 (TI-22) hardware and new TB-37A multi-function towed array components.

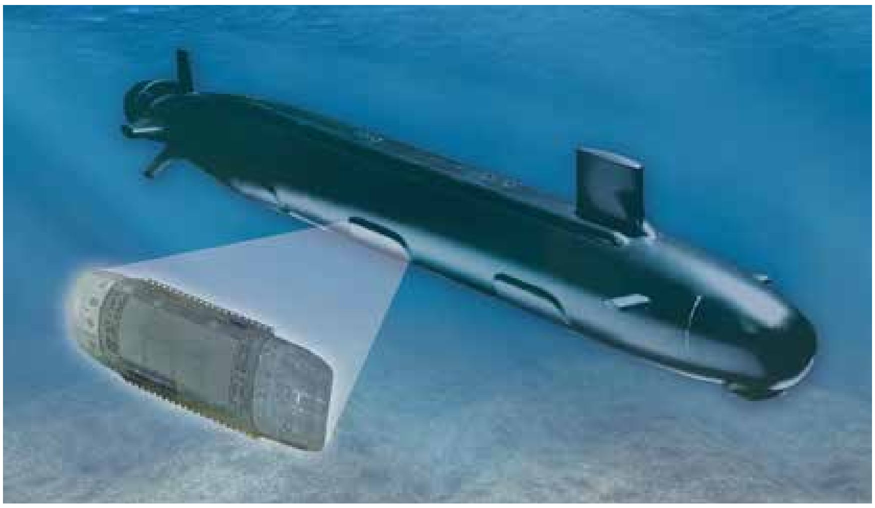
Meanwhile Thales announced in February 2024 that its subsidiary Advanced Acoustics Concepts (AAC) had delivered the first CAPTAS-4 Variable Depth Sonar to the US Navy in October 2023. CAPTAS-4 is to be fitted to the Constellation class frigates under a contract signed in May 2022. Four Constellation class vessels have been ordered so far, and the Navy's present plans call for up to 20 in total. This first CAPTAS-4 is due to be fitted to the first-of-class vessel shortly, but Thales also announced that a new CAPTAS-4 production facility is being built at the AAC site at Uniontown, Pennsylvania for the final assembly, integration and acceptance testing of the next systems expected.

Submarine sonar

Unlike surface ships, submarines require a range of different sonar systems not just for detecting threats, but also for navigation and obstacle avoidance. These are mainly passive sensors because the submarine's main asset is stealth.

On US Navy submarines, L3Harris Chesapeake Sciences Division is providing a new TB-34X fat-line tactical towed sonar array that includes more hydrophones, improved towing mechanisms and with less internal noise generated by the system. It also produces the new TB-29A Compact Towed Array for operations in shallow water, where a slower vessel's speed means longer towed array systems may risk coming into contact with the propeller. The TB-29A also has a reduced power and space requirement. L3Harris is also delivering the six acoustic panels that are used on the Lightweight Wide Aperture Array (LWWAA) flank array sonar fitted to the US Navy's *Virginia* class submarines. These are lighter and smaller than previous panels, which means the LWWAA offers nuclear attack submarines (SSNs) more buoyancy whilst maintaining sonar sensitivity.

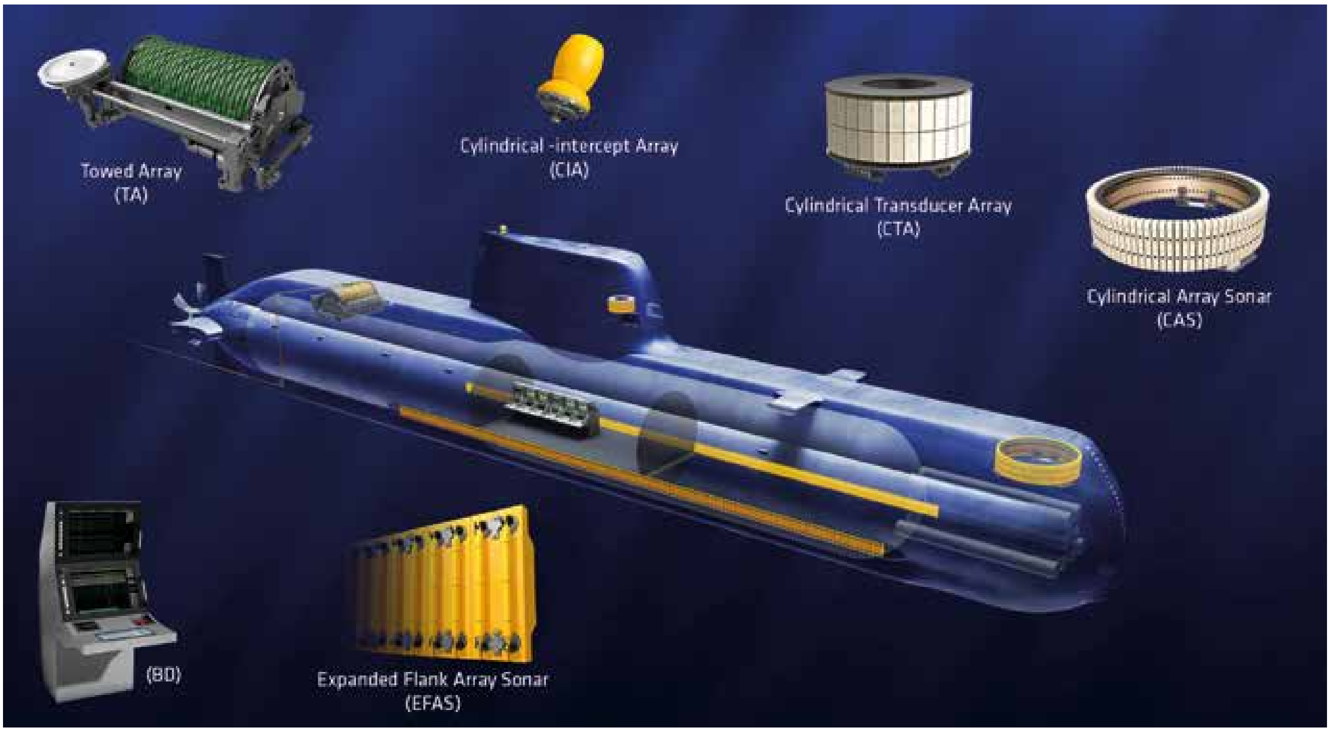
For the French Navy, Thales is providing a new sonar suite for the Sous-Marin Nucléaire Lanceur d'Engins de Troisieme Génération (SNLE 3G) third generation nuclear-powered ballistic missile submarines (SSBNs), and for modernising the second generation boats (SNLE 2G) – *Triomphant* class. The suite will include bow sonar, flank array, and towed arrays with optical technology, intercept array and echo sounders. Thales was awarded the contract from the DGA, the French defence procurement authority, in July



Credit: Northrop Grumman

Northrop Grumman's Lightweight Wide Aperture Array (LWWAA) flank array sonar for the US Navy's Virginia class submarines form part of the Acoustics-Rapid Commercial Off-the-Shelf Insertion (A-RCI) sonar system used on USN submarines.

Credit: Atlas Elektronik



Improved detection ranges and accuracy are a feature of the ISUS 100 sonar suite that can include large acoustic aperture long-range flank arrays and a reelable thin line extended towed array.

2023. A spokesperson said: "The new arrays will be bigger, with [higher performance] sensors will require big-data algorithms to be deployed on more powerful processors. This will be the first implementation of ALICIA [Analyse, Localisation, Identification, Classification Intégrées et Alertes] architecture."

ALICIA is a data processing system designed to handle the significantly larger volumes of data that will be generated by the new sonar suite. It will include intuitive user interfaces to optimise operator workload and provide decision support. The company is also completing a sonar retrofit on the French Navy's two *Améthyste* class SSNs that is due to be completed later in 2024.

ELAC Sonar is developing a new sonar system for the Italian Navy's two new U212 Near Future Submarines under a EUR 49 million contract from prime contractor Leonardo. The Spanish Navy's new S-80A Plus submarines will have the Lockheed Martin Submarine Integrated Combat System (SUBICS) sonar suite that includes a bow, flank, passive ranging and mine and obstacle avoidance sonar (MOAS). Sweden's *Blekinge* class (A26) submarine will be fitted with new bow, flank and HF intercept sonar arrays by Atlas Elektronik, along with the SA9510S MOAS and bottom navigation systems including an EM2040 multibeam echo sounder, side-scan sonar, sub-bottom profiler and hydrographic echo sounders.

In terms of materials science, textured ceramics is one technology that promises to improve acoustic transducer performance, further enhancing sensitivity, and potentially also reducing weight and power requirements in sonar systems. Improvements in construction methods can also improve the conduction of sound to the sensor, reducing the ambient noise. Textured ceramic-based transducers are being incorporated into the product lines of a number of sonar manufacturers.

Uncrewed capabilities

Solutions are being developed to address uncrewed ASW assets. At DSEI in Septem-

Credit: UMS Skeldar

Screenshot from a UMS Skeldar concept video showing the Skeldar V-200 VTOL UAV being used for dispensing sonobuoys and data relay.

ber 2023, UMS Skeldar and Ultra Marine showcased a new ASW sonobuoy dispenser that could be mounted on a Skeldar V-200 rotary-wing vertical take-off and landing (VTOL) unmanned aerial vehicle (UAV). It was developed under a defence innovation contract from the Canadian Department of National Defence awarded in October 2022. The intention is for the UAV to provide a rapid sonobuoy dispensing capability to supplement that provided by fixed-wing maritime patrol aircraft and dipping sonar mounted on a ship's helicopters. It rapidly adds more sensors into the water that can contribute to a multi-static sensor network, for the detection of submarines. A prototype is being developed under phase 2 of the contract, with a live flight demonstration expected should the project progress to a third phase.
Meanwhile, the UK MoD is seeking to develop, demonstrate and deliver new uncrewed deployable ASW capabilities under Project Charybdis. It is part of the wider Royal Navy ASW Spearhead programme in which the Submarine Delivery Agency is delivering phase 1 – to identify technologies ripe for application and awards contracts for concept studies. This project includes autonomy, robotics, AI and ML that be harnessed in uncrewed platforms to enhance their capability and provide a persistent and deployable uncrewed ASW capability alongside existing assets. The service wants this new capability to be able to deploy across wide areas of ocean, detect dangerous object, classify them, localise and track them and report contacts to allied units.
With the project underway, almost 30 companies have received small contract awards to develop concepts. Phase 2 is for the demonstration of technologies, and this is due to start during FY2024–25. This second phase will build on initiatives already begun and provide evidence for new work and develop essential elements to each project, including shore infrastructure, regulatory approaches, training and support. The intention is to find solutions that could be fielded within five years.
The Thales spokesperson said that under Project Charybdis, the company "defined two ASW Surveillance concepts with a blend of UxVs [uncrewed surface/underwater vehicles] within the solutions. We are waiting for the customer to advise on the next steps for Phase 2, but the intention is to prototype capabilities from the phase 1 concepts".

Conclusion

Sonar systems remain the key to unlocking the underwater domain. The two key improvements are firstly to enhance the performance of the sonar systems and process the data faster and more effectively, and secondly to connect larger numbers of sonar systems and into the wider military network to enable multi-static detection of targets.
Sonar developments aim to increase sensitivity to detect, classify and localise targets at longer range and apply greater processing power to manage the data loads and present information to speed up decision-making.
This technology can then also fuse sonar data with data from other, multi-static, sources via robust communications systems, that will offer a much clearer understanding of the acoustic environment across a wider area, and the ability to rapidly identify and classify targets in the water column in different environments.
As sophisticated sonar capabilities such as these develop and proliferate, submarines will find it ever more difficult to remain hidden. ■

Patrol pairing

Dr Lee Willett

The arrival of uncrewed systems into force structures and operations is providing navies with an opportunity to harness the capabilities these systems can add to those of crewed platforms. This new force package is combining to generate force multiplying operational effects. However, there are still challenges to be worked through, including in both conceptual and technological terms.

Maritime uncrewed systems (MUS) are increasingly present in Western navies' inventories and operations in all three primary maritime domains: air, with uncrewed aerial vehicles (UAVs); surface, with uncrewed surface vessels (USVs); and sub-surface, with uncrewed underwater vehicles (UUVs). There are two types of UUV: remotely operated vehicles (ROVs), which are controlled by a human operator onboard the ROV's host platform; and autonomous underwater vehicles (AUVs), which operate independently.

An ROV is, in some senses, a very simplistic example of what is known today as 'manned/unmanned teaming', or MUM-T, with a human operator controlling the system in a manner, and perhaps in an environment, designed to exploit what can be done without a human operator onboard.

In practice, MUM-T concepts, capabilities, and operations are somewhat more complex than that. In a 2020 paper published in NATO's Joint Air Power Competence Centre's (JAPCC's) monthly journal, Italian Army lieutenant colonel Livio Rossetti defined MUM-T as "a relatively new technology which aims to synchronize the employment of the actors involved". "The innovative concept of action could revolutionize the planning and conduct of warfare in the future," Lt Col Rossetti added.

In maritime terms, MUM-T can perhaps be considered in two ways. First, it encompasses the integration of crewed and uncrewed

Credit: US Navy

A US Navy (USN) P-8A Poseidon maritime patrol aircraft (MPA) takes off from Sigonella Naval Air Station, Sicily, Italy in January 2024. The USN intends to operate MQ-4C Triton uncrewed aerial vehicles (UAVs) from Sigonella too, increasing options for P-8A/MQ-4C manned/unmanned teaming (MUM-T).

platforms at a tactical level, for example a maritime patrol aircraft (MPA) operating in partnership with a UAV to augment a navy's sustained, wide-area surveillance capacity. Second, it can also include the development of a crewed platform – most likely a surface ship – as a host asset deploying uncrewed assets exclusively (whether they be AUVs, USVs, or UUVs).

While navies are actively looking to deploy and integrate uncrewed capabilities across all three primary domains, it is in the air where developments have perhaps proceeded more quickly. Moreover, while navies continue to work out the optimum role and use for the range of uncrewed systems of different capabilities they aim to develop in each domain, initial focus has fallen on tasks where such uncrewed capabilities can – in the first instance, at least – have the most prominent impact. Here, Western navies have been concentrating on using uncrewed capabilities to undertake what are termed the '3-D', or 'dull, dirty, and dangerous' tasks, for which deploying complex, expensive, crewed platforms for extended periods may not be an operationally efficient use of resource, particularly when there may be risk to the platform and thus to the lives of its crew.

When combined with the fact that the increasing operational challenge at sea for Western navies posed by the return of state-based competition and conflict mandates greater coverage across what are large expanses of both littoral and blue water regions to build maritime domain awareness (MDA), the focus on '3-D' tasking means that most such navies are prioritising the development of surveillance capability from a technology perspective, and surveillance capacity from an operational perspective.

The Russo-Ukraine war, which erupted in February 2022, has featured prominent maritime campaigns in both the Black and Baltic seas. In the Black Sea, this included extensive use of traditional operations like

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mine warfare, and emerging technologies like USV attacks, both conducted to generate sea denial. In the Baltic Sea, this included the apparent use of 'grey zone' hybrid warfare operations, including targeting critical undersea infrastructure. The consequences of these maritime campaigns have seen NATO build greater at-sea presence from the High North to the Eastern Mediterranean, in order to enhance maritime surveillance and broader MDA. It is in this surveillance task where initial, operational-level progress in MUM-T can be seen most clearly. Moreover, it is also in the air where such maritime MUM-T is most visible.

Patrol profile

The US Navy's (USN's) Boeing P-8A Poseidon MPA is arguably the premier air-based maritime surveillance platform. The USN's operational requirement is for an inventory of 128 P-8As: 118 have been delivered to date, and 12 operational squadrons have been established (plus two in reserve); four squadrons are forward-deployed around the world, meeting the operational need to generate 28 aircraft deployed at all times, Captain Clay Waddill, the USN's Plans, Training, and Requirements Branch Head for its Maritime Patrol and Reconnaissance Force under the Commander Patrol and Reconnaissance Group (CPRG), told the SAE Media Group Maritime Reconnaissance and Surveillance Technology (MRST) conference in London in late January 2024.

According to the USN, CPRG is the fleet sponsor for the navy's MUM-T integration concept work. Having the P-8A forward deployed "gives us that 24/7 rapid responsiveness", said Capt Waddill. Pairing it with uncrewed platforms enhances the capabilities and effects it can bring – either when responding rapidly in tandem, or with the uncrewed platform providing a baseline of surveillance presence against which the P-8A can focus on issues of interest as, when, and where they arise.

The USN forward deploys P-8A squadrons on rotation to Sigonella Naval Air Station, Sicily, Italy. Notionally, 11 USN P-8As are deployed there. The P-8A also has a wider, multinational footprint across the region. The Norwegian and UK air forces operate P-8As across the Euro-Atlantic theatre (with Norway having five aircraft, and the UK nine). Germany will be the next European-based P-8A operator, and in late 2023 upped its planned buy from five to eight airframes. Canada is planning to buy 14 P-8As, and is likely to deploy aircraft to the Euro-Atlantic theatre regularly – just as it does with its in-service Lockheed Martin CP-140 Aurora MPA. In a presentation given by the Italian Air Force at the MRST conference, the P-8A was listed as a possible option for Italy's own future MPA platform. Thus, the P-8A Euro-Atlantic presence – which is already significant – seems set to keep growing. This continuing expansion in NATO's collective MPA 'ORBAT' remains timely, too. Russian naval activity from NATO's northern flank in the High North to its southern flank in the eastern Mediterranean and Black Sea region remains significant, despite Russia's relatively slow offensive progress ashore in the war; not to mention the sustained attacks its Black Sea Fleet is suffering from Ukrainian uncrewed vehicles, within what appears to be an effective sea denial campaign.

Across the Euro-Atlantic maritime theatre, Russian naval activity is particularly prevalent in the underwater domain. This is where the P-8A's capabilities arguably are needing to be brought to bear most significantly. While being a highly capable MPA when it comes to intelligence, surveillance, and reconnaissance (ISR), its capabilities are required particularly in terms of anti-submarine warfare (ASW). Thus, the P-8A's operational effects can be enabled, and in fact multiplied, by partnering it with UAV capabilities in particular, with the UAVs taking on some of the burden for wide-area maritime surveillance: in this context, the P-8A is a primary example of the requirement for, and benefits of, MUM-T.

Captain Bryan Hager – Commodore of the USN's Sigonella-based Commander Task Force 67 (CTF-67) and Commander, Fleet Air Sigonella – underscored this point to the MRST conference audience. CTF-67 delivers the USN's regional maritime patrol presence, with the P-8As based in Sigonella but with a need to cover the Arctic down to the Gulf of Guinea, "We can't do it with just aircraft," said Capt Hager. With the Arctic/Gulf of Guinea coverage spread being just one instance of the vast maritime areas the USN (for example) from an MDA perspective, must cover interoperability between systems, he explained. A particular partner the USN is preparing to pair with the P-8A is the Northrop Grumman MQ-4C Triton high-altitude/long-endurance (HALE) UAV.

Credit: US Coast Guard

A P-8A flies above three US Coast Guard fast response cutters, during joint training in the Gulf in April 2023. Given the amount of surveillance data Poseidon is now bringing onboard, the USN is looking at how to off-board that data more quickly so that other platforms can exploit it.

Credit: US Marine Corps

A USN MQ-4C Triton UAV assigned to Unmanned Patrol Squadron 19 (VUP 19) departs from Marine Corps Air Station Iwakuni, Japan, in October 2022. VUP 19 is the first unit to deploy an operational MQ-4C capability – the USN's first Triton 'orbit', forward deployed out of Guam.

According to the USN, "The MQ-4C Triton is an autonomously operated system that provides a persistent maritime ISR capability using multiple maritime sensors." While providing such ISR persistence as its primary function, the data it gleans is fed back to a ground control station crew numbering five personnel – an air vehicle operator, tactical co-ordinator, signals intelligence (SIGINT) co-ordinator, and mission payload operators (two). Triton operates as a remotely piloted air system (RPAS).

"[Triton] was originally procured by the Navy to take over that ISR capability, with electro-optical/infra-red [EO/IR] imagery and radar data, to alleviate that task for the manned aircrew, so [the P-8A] can focus on the things that … [it's] really there for, which is ASW," said Capt Waddill. "Triton will be that first line of defence," he added, noting that the MQ-4C will be forward based around the world in three deployable locations – which are known as 'orbits'. The first 'orbit', operated by Squadron VUP 19, has been established in Guam.

The MQ-4C system capabilities that are already being demonstrated are showing great potential, said Capt Waddill. Such capabilities include sustained time on station, for example. Triton can bring maritime surveillance capability for up to 18 hours at a time, Capt Hager explained, with the UAV operating effectively as an "unblinking eye" that provides persistence not even a P-8A can generate. The MQ-4C is now a central, integrated element of the USN's plan for conducting long-endurance air-based maritime surveillance missions, demonstrating the importance of the MUM-T approach.

Yet Triton's focus on surveillance capability underlines the requirement for its MUM-T integration with the P-8A in particular. "The critical part of this is Triton can't do anything other than look. What is the other piece of this? This is where MUM-T comes in," said Capt Hager.

Here, he explained, the P-8A brings responsiveness and agility, the ability to operate at low level if needed, capacity to capture high-resolution imagery, and the ability to deliver weapons. "So, whenever we get that cue from Triton, we can launch the P-8A out to be able to go and do further prosecution: that's how that MUM-T works."

Data from both aircraft is fused at a ground control station. A future line of capability inquiry for the USN is how to get what are increasing amounts of data off both aircraft

Credit: US Navy

A Triton UAV, assigned to VUP 19, is pictured in 2021 in Jacksonville, Florida. The USN plans to set up three forward-deployed Triton 'orbits'.


Credit: US Navy

P-8A Poseidon aircrew assigned to Patrol Squadron 30 (VP 30) are pictured during a training flight. Underlining the integration between Poseidons and Tritons, VP 30 provides training to aircrew flying both aircraft types.

more quickly, so the data can be filtered, synchronised, and turned into information that is ready to be exploited.

Triton was procured to replace the capability provided by the Lockheed Martin EP-3E Aries SIGINT aircraft. The MQ-4C programme passed through its initial operating capability (IOC) milestone in September 2023, and all aircraft will be delivered by 2030, said Capt Waddill. As well as providing broad surveillance capability, SIGINT and optronic/IR capabilities will be added to the aircraft in a series of upgrades planned for implementation in the 2024-27 timeframe, Capt Waddill added. Such capability upgrades will help improve the aircraft's ISR coverage.

As the USN develops its Triton MQ-4C capability, just as with the P-8A this capability will always be forward deployed. In February 2024, the second Triton vehicle was delivered to Sigonella NAS, building capability in the Euro-Atlantic theatre in advance of the USN completing the development of procedures and processes to enable operations to take place within the theatre. Basing the Euro-Atlantic Tritons at Sigonella underlines the potential to develop a high level of integrated MUM-T operations, with Triton and Poseidon operating from the same facility.

In 2025, the USN will set up its second Triton Unmanned Patrol Squadron (VUP), VUP 11. This squadron will operate one of the three 'orbits': however, Capt Waddill explained, it is not yet determined which one. VUP 19 will operate the other two.

The second and third 'orbits' themselves are also set to be established by 2025, and will cover areas including the US Fifth Fleet's Middle East area of operations (AOO) as well as the Euro-Atlantic theatre. A Triton 'orbit' includes four aircraft, and is designed to provide capacity to maintain continuous surveillance of the respective AOO.

The MQ-4C operators include P-8A-qualified USN personnel, Capt Hager said. Capt Waddill added that a cycle is developing of personnel moving back and forth between Poseidon and Triton postings. This all underlines the level of MUM-T integration generated across and within the Poseidon/Triton package.

As noted, one challenge the USN is looking at keenly in technology terms is that the P-8A/Triton pairing is generating increased amounts of data. This underlines the need to find a way to offload that data mid-mission more quickly so that decision-makers may exploit it more rapidly, said Capt Hager. Capt Waddill added that a next step in this process is a procedural one, preparing the data in a 'first pass' analysis so that it is ready for use and action by the decision makers.

Wider teaming

The USN is not the only navy making progress in delivering MUM-T for air-based maritime surveillance. The French Navy has developed extensive experience of operating its Dassault Atlantique Mk 2 (ATL2) MPA with UAVs, Lieutenant Commander Maxence Combas – an MPA tactical co-ordinator, currently posted to the navy's Maritime Surveillance and Intervention Patrol centre of excellence (CENTEX PATSIMAR) – told the MRST conference.

The ATL2 aircraft have been integrating with tactical UAVs to conduct ISR and close air support missions, Lt Cdr Combas explained. Here, for each aircraft, the navy has learned how to use such integrated co-operation to exploit respective strengths and mitigate respective weaknesses. Lt Cdr Combas underlined the particular role UAVs play in providing sustained ISR, and in being able to operate in contested environments were air- and surface-based threats to crewed aircraft may be especially prevalent.

A challenge the French Navy is looking to address to further enhance MUM-T is communications connectivity between the two platform types, said Lt Cdr Combas. Such connectivity is something that is being contested ever more acutely in contemporary naval operations.

Transport aircraft: a survey of future trends

Sidney E. Dean

Armed forces are currently evaluating mid- to long-term technology innovations with the goal of improving speed, reach and survivability of transport aircraft.

Farther. Faster. Better than they used to be. While reminiscent of a 1970s television series, these words describe current military planners' aspirations regarding the next generation of transport aircraft. On the one hand, this reflects the desire to utilise emerging technologies and materials to enhance performance, simplify maintenance, and – if possible – reduce operating costs.

On the other hand, the developing geostrategic environment and corresponding changes to concepts of operation will require military airlift to adapt in order to fulfil mission profiles. The practice of modifying civilian transport aircraft for military applications may no longer be viable in tomorrow's threat environment. The development of longer-range air defence systems and air-to-air weapons will impose greater risk for transport aircraft operating in warzones; these aircraft will require 'stealth' level signature reduction as well as integrated defences to enhance survivability while supporting frontline forces. Longer-range enemy rocket and missile artillery will hold airbases in combat theatres at risk; as a result, the ability to operate transport aircraft from austere secondary airfields and even provisional landing sites will be increasingly valuable. Increased speed and range will also improve the ability to support forces operating across large theatres such as the Indo-Pacific region.

Given the recent trend toward distributed military operations rather than deployment of large, massed ground combat formations – especially when considering operations in the Indo-Pacific theatre – armed forces are also recognising the need for a more diverse fleet including both large and small transport aircraft. General Mike Minihan, Commander of the US Air Force's (USAF's) Air Mobility Command (AMC), clearly stated in July 2023 that his service's Next Generation AirLift (NGAL) programme should lead to a family of systems. These would not only replace AMC's very large airlifters (C-5, C-17) and mid-sized tactical transports

Credit: Airbus

Model of an Airbus BWB concept aircraft displayed at the 2022 Berlin ILA international air show.

(C-130), but also introduce smaller aircraft better suited to delivering smaller loads to dispersed units. General Kenneth Wilsbach, then Commander of the US' Pacific Air Forces, echoed Minihan's remarks, advocating for a larger number of (potentially unmanned) small transports capable of simultaneously taking a limited number of people or set of supplies to numerous locations. Minihan for his part also declared that unconventional technologies such as vertical take-off and landing (VTOL) or unmanned aircraft are being considered as possible solutions to future requirements.

To achieve these goals, governments and industry are investigating lighter but stronger materials, more aerodynamic designs, alternate assembly processes, innovative operating concepts and alternate fuel options. Next-generation and 'generation-after-next' transport aircraft are expected to present 'revolutionary' rather than evolutionary designs and capabilities in order to deploy and survive in high-threat environments. That being said, many of the technologies envisioned are dual-use, creating an incentive for industry to invest in research that will also flow into more efficient and cost-effective future commercial aviation platforms.

Blended wing body design

Enhanced aerodynamics to reduce friction and drag will be a major goal for future transport aircraft designs. One promising approach is the blended wing body (BWB) design. As the designation implies, the fuselage and high-aspect-ratio wing of a BWB form a unit, presenting a broader and uninterrupted silhouette. A blended wing aircraft thus generates lift with the fuselage as well as the wings. This arrangement promises significant improvements in airspeed and range while reducing fuel consumption by an estimated 30–50%. A BWB's extra lift allows for operations from much shorter runways than equivalently-sized conventionally-designed 'tube and wing' airframes. Moreover, the broader fuselage accommodates larger payloads than conventional aircraft of the same length.


Credit: JetZero

Concept image for USAF's large blended wing body demonstrator.

Various government and industry teams are jointly investigating this technology, including the Pentagon's Defense Innovation Unit, the USAF, and NASA. To date, the blended wing concept has only been tested at small scale or in wind tunnels. In August 2023, the USAF selected California-based JetZero (in partnership with Northrop Grumman and Scaled Composites) to build a large blended wing body demonstrator aircraft suitable for the cargo or tanker role. The full-scale technology demonstrator will be the size of a large narrow-body commercial aircraft, but is forecast to be 50% more fuel efficient. The firm's Z5 design which forms the basis for JetZero's proposal is supposed to achieve a 9,260 km (5,000 NM) operating radius and carry 250 passengers, while weighing half as much as today's equivalent capacity airliners. Flight testing is expected to take place in early 2027. While JetZero has voiced confidence that an operational variant could be ready as early as 2030, many aviation experts consider this too optimistic given the challenges of testing and validating an as yet unproven design.

Other firms researching the blended wing concept include Airbus, which has presented a concept for a BWB aircraft under its 'ZEROe' (Zero Emissions) series of hydrogen-powered concept aircraft. According to the company, the BWB aircraft would have a 3,704 km (2,000 NM) range and the capacity to carry under 200 passengers. While conceived primarily for the civilian market, this design could ultimately be adapted for military transport requirements. As aircraft concepts and propulsion technology are refined, the performance characteristics of an Airbus BWB can be expected to improve.

While not specifically considered a 'stealth' design, the more unitary form of a BWB aircraft achieves a notably reduced radar cross section (RCS), with concomitant benefits for survivability. Given the inherent stability of the form, some BWB designs require no tail. Engines can either be mounted atop the aircraft or be embedded into the body; the latter configuration further reduces the aircraft's radar, thermal, and acoustic signatures.

Boeing introduced its own concept for a BWB tactical transport aircraft in January 2023. The firm specifically designed its model as a stealth aircraft. Beyond the standard benefits of the BWB form, the Boeing model features numerous low-observability elements such as obscured engine inlets, chined edges, a relatively sharp, beak-like nose, and a splayed tail. The internally-mounted engines and top-facing, relatively flat exhaust nozzles further reduce the radar and heat signature. The firm emphasises that the design is still in an early concept stage, with considerable room for change; in early 2023, Boeing postulated that it could be developed into an operational transport within the next 10 to 15 years.


Credit: Boeing

The top-down view of Boeing's BWB stealth design clearly displays the internal engine carriage and the top-mounted exhaust system.

Ground effect aircraft

The US Defense Advanced Research Projects Agency (DARPA) is investigating several unconventional concepts under the Liberty Lifter programme and the Speed and Runway Independent Technologies (SPRINT) programme. Unlike the blended wing, these concepts do not rely on signature reduction, but utilise other approaches to minimise detection and targeting. Both concepts are fully independent of runway or landing strip infrastructure.

Liberty Lifter is a ground effect aircraft concept. The USAF awarded competing prototype design awards to Aurora Flight Sciences and General Atomics-Aeronautical Systems Inc (GA-ASI) in January 2023. Phase two of the programme is set to begin in mid-2024. It will downselect to a single vendor who will conduct advanced design work leading up to construction and flight of a full-scale demonstrator aircraft. DARPA states that the first flight of the demonstrator is planned for late 2027 or early 2028. The agency's requirements include the ability to fly close to the sea surface over long distances using the ground effect (also known as the wing-in-ground effect), as well as conventional flight at altitudes up to 3,100 m. The aircraft must be able to take off and land on the ocean surface during Sea State 4 conditions, and perform sustained on-water operations in Sea State 5. Cargo capacity must meet or exceed that of the C-17.

The aircraft would be optimised for delivering personnel, large equipment, or significant amounts of supplies in littoral zones or along island chains, at speeds exceeding existing sea lift platforms. Given these characteristics, it appears strongly slanted to the requirements of the Indo-Pacific theatre. DARPA's 1 February 2023 press release speaks of ultimately partnering with DoD and international partners to develop an operational aircraft. However, it remains unclear whether the concept will ever progress beyond the X-plane demonstrator stage, given cheaper options also

Credit: GA-ASI, via DARPA

General Atomics' Liberty Lifter concept presents a dual-hull connected by a third wing-segment.

under consideration, such as fitting removable pontoons to C-130 Hercules airlifters to enable surf-zone deliveries.

VTOL transport aircraft

VTOL systems are also under consideration in order to supply forward operating units which have no access even to ad-hoc runways such as roads or level fields. Such capabilities are of course already operational in the form of helicopters and tiltrotor aircraft such as the V-22 Osprey. Future VTOL aircraft must exceed current operational systems in terms of speed, range and survivability. In this context, General Minihan has specifically referenced DARPA's SPRINT programme. The programme seeks to develop a jet-speed aircraft capable of cruising at 741-833 km/h (400–450 kn; which is 278-370 km/h (150–200 kn) faster than the V-22 Osprey), and transitioning to vertical mode when required to land at austere sites with no suitable runway.

According to the agency, the SPRINT X-plane is intended to be a proof-of-concept technology demonstrator, not necessarily the precursor to an actual development and acquisition programme. Instead, DARPA states that the flight test programme seeks to validate enabling technologies and integrated concepts that can be scaled to different sized military aircraft. Four firms – Aurora Flight Sciences, Bell Textron, Northrop Grumman and Piasecki Aircraft – were awarded initial concept design contracts. The agency is granting the firms great leeway regarding such factors as payload capacity or manned versus unmanned operations. Initial design reviews are due in May 2024, followed by elimination of one or more of the contenders. Another downselect is planned for late summer 2025, followed by flight tests of a demonstrator aircraft in early 2027.

In addition to DARPA's SPRINT programme, other VTOL cargo programmes are being pursued, including civilian cargo drones currently entering service. San Francisco-based Elroy Air has already secured 500 orders for its Chaparral UAV, which can carry up to 136 kg over a distance of 500 km at a cruising speed of 232 km/h (125 kn), and land within a 5 m^2 area. The hybrid-electric propulsion system consists of eight vertical lift fans and four electric propellers for horizontal flight with an onboard gas-turbine generator helping to recharge batteries in flight, thereby contributing to the aircraft's endurance and range. The payload is carried in underslung pods which can be deposited or picked up autonomously. While Chaparral is aimed primarily at the civilian airfreight market, Elroy has also received research and development funding from the USAF. An aircraft of this configuration would fill a gap between smaller UAVs and manned aircraft, making it suitable for resupply of dispersed platoon and company sized units. Chaparral can itself be transported into a theatre of operations by tactical cargo aircraft or in a 12 m container. The system is due to complete flight testing and begin deliveries during the course of 2024, with full-scale deliveries to commercial customers beginning in subsequent years. Being relatively low-cost and able to be procured in larger numbers than crewed equivalents, aircraft such as this would be suited for use in high-risk contested zones where losses are more likely to occur, and could provide an interim solution ahead of more sophisticated technology being introduced.

Bell announced in 2021 that it was pursuing a family of three High-Speed Vertical Take-Off and Landing (HSVTOL) aircraft ranging from a 1,800 kg unmanned vehicle to a 45,500 kg manned aircraft approaching the size and capacity of the C-130. Each unit would feature a dual-propulsion system consisting of tiltrotors for vertical flight, and jet power for horizontal flight. Cruising speeds of more than 741 km/h (400 kn) are expected. Signature reduction technology, as well as electronic and infrared countermeasures would enhance survivability. For transport missions, aircraft with such a capability profile would be best suited for relocating personnel and supplies into highly contested areas. Evaluation of component technologies has been conducted through early 2024 at Holloman Air Force Base, New Mexico.

Credit: Bell Textron

Bell's heavy, medium and light HSVTOL concepts. The C-130 and V-22 in the background provide scale.

Credit: Elroy Air

Elroy Air's Chapparal UAV is being tested by the USAF.

Unmanned/optionally manned

Almost every category of aircraft is currently being tested for suitability as an unmanned platform; cargo planes are no exception. China's Tengden Technology company announced the maiden flight of its Scorpion D cargo drone in October 2022. The dual-use capable aircraft has a 1.5 tonne or 5 m³ payload capacity, and appears suitable for short or austere landing sites. Western firms are pursuing similar capabilities across the spectrum from small to large aircraft.

London-based Droneliner has presented designs for two concepts, the DL200 and DL350, with 182 and 318 tonne payload capacities, respectively. With an anticipated unrefuelled range of 12,038 km (6,500 NM) and an aerial refuelling capability, the designs promise to enable next-day worldwide cargo delivery. Depending on the model, the fully-automated roll-on, roll-off airframes are planned to be capable of accommodating up to 40 (in the case of DL200) or up to 80 (in the case of DL350) lightweight versions of standard 6 m ISO shipping containers. Faster loading and unloading times as well as a favourable 4:1 payload-to-fuel ratio (enabled through use of fuel-efficient engines) promise to reduce airfreight costs by 70%, according to the firm.

While Droneliner is primarily aiming for the civilian airfreight market, the firm's designs include options for remote-controlled airdrop capability. That capability aside, a wide-bodied unmanned airlifter could quickly ferry equipment and supplies from North America or Europe to safe logistic hubs in the theatre of operations, for transfer to tactical airlifters. This could reduce pressure on human aircrews, freeing up pilots and loadmasters for warzone supply missions – a potentially significant consideration given many nations' current difficulties recruiting and retaining flight personnel. Developing fully autonomous transport aircraft will require progress in artificial intelligence. In the short to medium term, it is questionable whether the military would entrust a large cargo of vital wartime supplies to a fully robotic aircraft, while using unmanned aircraft as troop transports seems even more unlikely. As an alternative, increased automation could reduce the human workload in the cockpit, permitting a single pilot to fly the aircraft. The USAF is already considering just such an option for the KC-46 tanker aircraft.

Credit: Droneliner

The DL200 unmanned transport's design features electric propulsion and a capacity of 35–40 ISO containers.

Alternate/renewable energy propulsion systems

New propulsion options are another area receiving attention. While this is largely an industry focus targeting the civilian carrier market, armed forces are also interested in the potential for greater fuel efficiency and reduced reliance on imported oil, as well as lower emissions. Research and development generally falls into one of two categories: alternate fuels (also known as sustainable fuels) and electric power.

Hydrogen currently appears to be the most promising option for replacing hydrocarbon fuels. There are three different concepts for hydrogen propulsion. The first, hydrogen combustion, simply replaces hydrocarbon-based fuels with liquified hydrogen; this requires modification of fuel

Credit: Airbus

Airbus is pursuing zero emission, hydrogen powered propulsion for various transport aircraft configurations, from standard tube-and-wing to BWB designs.

injectors, but overall the propulsion process remains virtually unchanged. The second method uses hydrogen fuel cells to power electric motors; this electric propulsion system would constitute a radical change from current systems. The third option combines hydrogen-burning gas turbine engines with hydrogen fuel cells to form a hybrid propulsion system.

Numerous firms are researching these technologies, mostly on smaller airframes. Airbus has emerged as a global leader in applying the technology to larger aircraft with the firm working simultaneously on three hydrogen-fuelled aircraft concepts under the canopy of the ZEROe programme. This includes the aforementioned BWB concept, two conventional airframes (one turbofan and one turboprop) utilising hybrid hydrogen-electric systems, as well as one electric prop concept powered by hydrogen fuel cells. The firm hopes to market the world's first fully hydrogen-powered commercial carrier by 2035. As an intermediate step, Airbus plans a 2026 demonstration flight of an A380 passenger jet converted to hybrid propulsion combining hydrogen-burning turbines and hydrogen fuel cells.

However, challenges remain. Notably, Airbus' expectations regarding passenger capacity and range of their first generation ZEROe concepts are significantly lower than comparable hydrocarbon-powered Airbus transports. By weight, liquified hydrogen has a significantly higher energy value than hydrocarbon fuels, but this advantage is more than neutralised by the fact that hydrogen is significantly less dense. As a result, it requires more storage space aboard an aircraft. It also requires specialised (and often heavy) storage containers. Adding fuel cells to the configuration imposes an additional weight penalty. With time, solutions will likely be found for these challenges. However, industry analysts postulate that even if hydrogen-powered aircraft begin to enter service circa 2035, it will be closer to 2050 before they become fully established. It seems unlikely that military airlift will be a trailblazer for alternative fuels, so revolutionary propulsion systems will likely appear with the 'generation after next' military transports.

Suborbital transport

The most revolutionary concept of all is cargo insertion via suborbital flight. In principle, the concept falls outside the topic of transport aircraft, as it envisions the use of rocket-borne cargo capsules, but merits discussion here given the serious consideration it is receiving. To qualify as suborbital, the carrier would have to reach the Kármán line 100 km above the Earth's surface, then re-enter the atmosphere and land.

While suggestive of science fiction, suborbital transport has been actively studied and pursued by the USAF for years. "I don't think anything is off the table, in terms of creative thinking for space," said the then Assistant Secretary of the Air Force for acquisition, technology, and logistics, Will Roper, in November 2020. "When you can launch an austere airbase in a space capsule, that's frickin' awesome! Just to be able to just have it come down, halfway around the world, with everything you need to be able to main-

Credit: SpaceX

Concept of the Starship reusable spacecraft.

tain and operate a small fleet of airplanes — refuel it, rearm it and get it back in the fight", Roper told reporters during a Pentagon briefing. His words echoed a statement by the then commander of the US Transportation Command, General Stephen Lyons, one month earlier: "Think about moving 80 short tons, the equivalent of a C-17 payload, anywhere on the globe in less than an hour. We should challenge ourselves to think differently about how we will project the force in the future, and how rocket cargo could be part of that." In 2021, the USAF elevated the Rocket Cargo programme to a high-priority project.

In pursuit of this objective, the USAF Research Laboratory (AFRL) has signed cooperative research and development agreements (CRADA) with five firms to study the potential for suborbital 'point-to-point' delivery. The Starship launch vehicle under development by SpaceX is receiving especially close attention. The Starship's upper stage is powered by six engines, three of which can be used for performing a controlled 'soft' landing, once the stage has performed a 'belly-flop' manoeuvre to align itself for landing after the initial phase of re-entry. Alternately, payloads can be jettisoned in flight. According to SpaceX, the reconfigurable cargo section has a capacity of 100–150 tonnes. The ongoing study initiated in 2022 plans to analyse data collected during commercial launches and landings of SpaceX's Starship rocket, evaluate the compatibility of the spacecraft's cargo bay with US military container systems, and culminate in a demonstration of the launch and landing of a cargo-loaded Starship system. According to Greg Spanjers, AFRL chief scientist for the Rocket Cargo programme, this flight testing could occur as early as 2026.

However, a successful test would not signal that the concept is nearing operational maturity. Many challenges remain, including development of standardised cargo containers which would protect equipment and supplies during launch and re-entry, while remaining compatible with conventional military ground and air vehicles for further transport. Another cost-intensive complication is the need for multiple dedicated spaceports, located in the US and overseas, for launching the rockets. Recovery of the reusable upper stage from far-flung and isolated landing sites also seems questionable, especially under wartime conditions. Many experts agree that realising the concept remains a matter of decades. Ultimately this could be a good thing, given the risk that adversaries might mistake a supply mission for a nuclear attack and launch a counterstrike.

Credit: US ANG/Tech Sgt Brigette Waltermire

Rapid Dragon demonstration at Andøya Space Defense Range, Norway, on 9 November 2022. While Rapid Dragon envisaged use of cruise missiles, various other air-launched effects could be included, including decoys and UAVs.

Most likely to succeed

The most important considerations for next-generation and generation-after-next transport aircraft will be: agility; survivability; the ability to supply dispersed operating locations with minimal reliance on infrastructure; and relatively low operating costs. Lightweight, but strong composite materials are now available or being developed which will permit construction of new, more aerodynamic and reduced-RCS airframe types, such as the BWB. In addition to signature reduction, these materials will also contribute to reduction of airframe weight, thereby enhancing fuel efficiency as well as range and potentially speed.

Open architecture will permit maximum adaptability of aircraft to meet new operating environment conditions or accept additional responsibilities on top of their primary mission. In February 2024, General Minihan doubled down with more details about the USAF's aspirations regarding future mobility platforms, whether tankers or airlifters. Mentioned options include acting as communications nodes or adding a command and control/battle management capability. "We've got an enormous amount of real estate on these airplanes to do connectivity and serve a greater cause [...] without bankrupting the Air Force" he said during the Air & Space Forces Association Warfare Symposium in Colorado. What holds for the United States will surely hold for other nations' military air fleets as well. Survivability enhancement, at least for airlifters operating in contested environments, will likely also include defensive (and potentially offensive) electronic warfare suites as well as the capability to control armed unmanned escort aircraft. Adding electronic support measures would permit airlifters to gather electronic intelligence during their routine transport missions.

Cargo and cargo-capable tankers will also be used as auxiliary weapons carriers. The USAF began testing the Rapid Dragon concept – launching palletised cruise missiles from C-130 and C-17 aircraft – in 2021. US Allies quickly expressed interest, leading to a demonstration of the concept during a NATO exercise in 2022. In February 2024, General Minihan announced plans to test launch 100 UAVs from an air-mobility aircraft in July or August of 2024. Again, these concepts are viable for any nation with medium to large cargo aircraft, enabling forces without a bomber fleet to launch significant numbers of long-range weapons or smart munitions.

The more sophisticated the technology, the more expensive the aircraft will be. The most likely outcome for future airlift fleets will be a tiered set of aircraft forming a transport relay chain. Some will be equipped with very advanced survivability measures, up to and including low-observable coating and VTOL capabilities, suitable for frontline missions in highly contested environments. They may be deployed in tandem with manned or unmanned escorts, and may potentially be unmanned themselves. For in-theatre operations less close to the front lines, larger manned aircraft equipped with defensive electronic countermeasures and potentially kinetic or directed energy weapons will ferry supplies and soldiers to hub bases. Blended wing designs and other technologies will permit these aircraft to operate from short or austere landing fields. For the most permissive environments, large-capacity and fuel-efficient transport planes will continue to ferry equipment and personnel into theatre, utilising full-fledged military and civilian airfields. ■

Viewpoint from Paris

Photo: author

The new French Army Command structure

Jean François Auran

In 2023, the Army initiated a vast transformation plan toward 'a war fighting Army.' This transformation is the answer to the deep evolutions of the strategic context. The objective is to produce more power through better organisation, for increased responsiveness. Due to its operational contract, the Army must be capable of deploying a two-brigade division along with its supporting elements within 30 days by 2027. The idea is to generate units adapted to multi-field multi-domain (M2MC) requirements and more reactive commands. According to the reform's promoters, the new structures will be incubators of critical capabilities for high-intensity operational engagement. By the summer of 2024, these new commands will be fully operational and interact closely with the Corps and Divisions headquarters. Under the authority of Army Headquarters (EMAT), the Force and Land Operations Command (CFOT) remains the central piece of the command system. The HQs located in Lille include the operational Land HQs (EMOT) and the Land Command for operations in Europe (CTE), which has just been established recently. Specialised divisional commands created with the 2016 'Au Contact' model will be transformed into specific mission-oriented organisations.

Reorganisation of divisional-level headquarters

The Deep Actions and Intelligence Command (CAPR), which includes three brigades – air combat, intelligence, and artillery – will coordinate units operating in the 50 km to 500 km zone. The objective is to create a more responsive intelligence-fire loop. It will include the Strasbourg Intelligence Brigade and the 19 Artillery Brigade, which will be recreated in summer 2025 in Lyon. The Theatre Support and Logistics Command (CALT) will oversee the rear area of operations and logistics. It will combine the current logistics command and the Land forces maintenance and a recreated Engineer Brigade. The command will include the 19, 31 Engineer Regiments, 25 RGA, 28 Geographic Group, 2nd Dragoon Regiment (CBRN), and the 132 Regiment (canine unit).
The newly created Digital Support and Cyber Command (CATNC) operates in communications, cyber security, and data management. The objective is to integrate a hardened, structured cyber capability into the joint manoeuvre force. The Army has bet on digitalising all combat platforms and creating a combat cloud as part of collaborative combat. The Digital and Cyber Support Brigade (BANC) combines the five Signal regiments (28, 40, 41, 48, 53). In 2025, the brigade will encompass a cyber battalion composed of the 807 and 808 companies based in Rennes. Special forces are also evolving with the emergence of a Land Special Actions Command (CAST) for Military influence and indirect actions. In addition to the Special Forces units, the attachment of the Centre for Operational Military Partnership (CPMO) and the Joint Centre for Environmental Actions (CIAE) is effective.
We can also mention the Combined Arms Combat Training Command (COMECIA), which ensures the preparation of forces, which is vital in the context of the new Military Programming Act. The transformation will impact the two fighting divisions. The Third Division will oversee prevention and influence and, as such, focus on 'operational military partnerships' in the Indian Ocean and Africa. First Division in Besancon will focus on Europe, especially on the Eastern Flank. The combined arms brigades (BIA) will be the central element of deployable engagements, with a force of 5,000 soldiers each. The order of battle will be modified to incorporate support capabilities, such as cyber and maintenance, to gain autonomy and responsiveness quickly. The transformation will allow brigades to better respond to the tightening of operations and their unpredictability, as well as to be more efficient in daily business. In this vein, the 9 Marine Infantry Brigade is in the process of integrating the 5 Overseas Interarmes Regiment (RIAOM) based in Djibouti.
In conclusion, air-land engagement seeks to dominate and destroy the enemy, but it also serves to build, conquer, and stabilise. This reform should be inspired by the principle of the 'Joint Air-Ground Integration Center' (JAGIC) of the US Army established ten years ago. C2 is one of the key factors of Western operational superiority, and this reform aims to maintain it. At the army staff level (EMAT), the future Combat command (CCF) will be in charge of speeding up unit adaptation, with new adaptations expected to arrive more quickly than in the past.

Medium support helicopters

Tim Fish

The enduring importance of medium helicopters to military forces has been highlighted by the initiation of three acquisition and development programmes in Europe – the UK's New Medium Helicopter (NMH), NATO's Next Generation Rotorcraft Capability (NGRC) and the EU's Next Generation Medium Helicopter (NGMH). This article examines the emerging requirements for new helicopters in this market that are designed to ensure these platforms are able to operate in an increasingly contested environment and meet the new conditions of warfare; it also explores the latest developments and trends in the medium helicopter sector market.

Medium support helicopters have multirole capabilities and are able to meet a variety of military requirements, including for transport, utility, medevac, vertical replenishment, close air support, search and rescue, firefighting and more. They are also dual use with many military designs based on commercial helicopters, which means reduced acquisition and support costs. This is unlike specialist platforms, such as attack helicopters, that have completely different designs and capabilities.

The three aforementioned programmes – the UK's NMH, NATO's NGRC and the EU's NGMH – as well as the US' Future Long-Range Assault Aircraft (FLRAA), will be part of this growth in the short and long term and will be the main programmes driving forward innovation in new architectures and capabilities. While speed is one important new factor, a spokesperson from Leonardo Helicopters, a European rotorcraft manufacturer, told ESD that navigation, protection, connectivity, autonomy, digitisation, and integration with uncrewed assets, are also important, as well as range, endurance and altitude requirements that go beyond the limits of conventional rotorcraft platforms.

Further, faster, and lethal

The need for increased levels of performance in terms of speed, range and altitude is because there are many more long-range precision weapons on the battlefield. This can compromise the role medium helicopters have in providing close support for ground forces. The take-off and landing zones for helicopters would usually be located relatively close to what would traditionally be considered the 'front line', though extended range artillery could now target them from further away.

A spokesperson for Airbus Helicopters told ESD that helicopters "need to be able to take off from a longer distance in safe areas", and explained: "The ability to fly further and stay longer in the air is a significant advantage. Medium and heavy helicopters offer long-range capabilities, in excess of 500 NM [926 km]. Helicopters will have to be able to operate from dispersed bases."

Higher speeds and longer ranges would be useful for search and rescue (SAR), special forces insertion and troop transport. The ability to fly low is also crucial for helicopter survivability, along with modern autopilots and avionics that can improve flight safety, reduce crew workload and enhance the platform's stability for observation or firing weapons.

Military operators want to add heavier weapons onto medium helicopters, including gun systems, guided rockets and missiles. Airbus has developed the modular HForce weapon system that can fit on its H125M, H145M, H225M helicopters. This system includes a fire control system, helmet-mounted monocular sight and display for gunner and pilot targeting, an optronic sight for target identification and fire control, and weapon pods with the option for machine guns, cannons, rockets, or air-to-surface, and air-to-air missiles.

Credit: Airbus

In German service, the H145M is expected to take on a light attack role fitted with the HForce weapon system. In the troop transport and utility roles, the increased cabin volume means the helicopter can host two pilots and up to 10 troops; with low noise levels and infrared signature, the H145M can undertake ISTAR missions.

Author

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"With these weapons packages, medium and heavy helicopters can be used as long-range strike platforms combining the long-range/payload capabilities of a medium/heavy helicopter and the firepower of the weapons," the Airbus spokesperson said.

Communications is also essential for any modern military platform and medium helicopters are no exception. SATCOM is being introduced on some heavier helicopters but there is a need to protect against the jamming of communications and GPS signals to ensure that navigation, positioning and connectivity can be maintained. "In this domain, electronic warfare systems are being improved to cover a larger spectrum of threats," the Airbus spokesperson added.

However, according to Leonardo's spokesperson, the main concern is that "clear requirements are needed" to allow industry to fully understand which technologies can best meet them.

Credit: Sikorsky

Besides increasing flight safety and reliability, the MATRIX system will improve an aircraft's chances for survival in dangerous environments, in poor weather conditions – when human pilots could become tired or disoriented – and for long missions, such as surveillance missions.

Autonomy and uncrewed aspects

US company Sikorsky believes that autonomy in helicopters is becoming increasingly important. It has developed its Matrix suite of technologies that improve the safety of flight, especially for helicopters that fly close to the ground, and allows aircraft to be optionally piloted.

In 2022, in cooperation with the US Defense Advanced Research Projects Agency (DARPA), Sikorsky demonstrated the control of an uncrewed Black Hawk helicopter using its Matrix technology to perform a logistics/resupply mission.

Jay Macklin, Sikorsky's business development director for Army and Future Vertical Lift told ESD: "With Matrix technology, an aircraft with no humans on board can operate safely in complex terrain and in degraded visual environments, while performing high-value missions, such as intelligence, surveillance, reconnaissance, contested logistics and medical resupply/casualty evacuation."

The ability to operate uncrewed systems from helicopters is also a growing requirement for military operations. Airbus Helicopters has been developing its Manned-Unmanned Teaming (MUM-T) capabilities using an H145M helicopter. In the summer of 2022, the H145M participated in the Multi-Domain Flight Demo, a large-scale flight demonstration that linked up fighters, helicopters and drones as part of the Système de combat aérien du future (SCAF) programme. The company is also developing a generic European MUM-T system under the EU's Project Musher. Demonstrations are expected later this year.

On all of its platforms, US company Boeing is exploring the leveraging of existing technologies, with a company spokesperson telling ESD, "You're seeing increased importance of Manned-Unmanned Teaming across all rotorcraft to give the pilot more situational awareness," before adding, "The AH-64 Apache has been operating with MUM-T capability for nearly 10 years, so we've done quite a bit of work already."

Boeing also has expertise in autonomous systems with uncrewed vehicles but understands that it is not the complete solution. "We also know that nothing truly replaces the eyes and ears of a human pilot. The future of autonomy, at least in the near term for rotorcraft, is a combination of the two," the Boeing spokesperson added.

UK helicopter renewal

The UK's NMH programme is intended to replace the Westland-Aerospatiale SA 330E Puma HC2, Bell 212, Bell 412, and Airbus AS365 Dauphin II helicopters used by the British Army, rationalising the fleet of rotorcraft that it supports from four to one, and potentially fulfilling a fifth rotary requirement. Up to 44 new helicopters are required under NMH, with a budget of about GBP 1 billion allocated.

A pre-qualification questionnaire (PQQ) stage saw the down-selection of four companies: Airbus offering the H175M, Leonardo with the AW149, Lockheed Martin with Sikorsky's S-70M Black Hawk and Boeing, which initially offered a ser-

Credit: Leonardo

Leonardo's AW149 was unveiled in 2006 at the Farnborough Air Show, offered as an alternative to the UH-60 Black Hawk. With a cruising speed of 287 km/h, the helicopter has a range of about 800 km. Operators include Poland, Egypt and Thailand.

vices, support and training solution but has since teamed with Airbus.

"The partnership with Airbus Helicopters in the UK allows Boeing Defence UK (BDUK) to best leverage its localised training expertise and capabilities," the Airbus spokesperson said. BDUK already supports the British CH-47 Chinook and Apache helicopters. The H175M team also includes Babcock, Spirit AeroSystems, and Pratt & Whitney Canada. Design work would take place in Belfast, with manufacturing at Broughton in Wales and support provided from Scotland and on bases across the UK.

Meanwhile, Leonardo says it can deliver the AW149 in less than 24 months, built at its factory in Yeovil, Somerset. A Leonardo spokesperson said that an initial production capability at the site included the manufacturing and commissioning of jigs, fixtures and tooling with 50 skilled engineers trained to build the aircraft. "We are also able to draw from a wider pool of several hundred highly skilled engineers in Yeovil that could be readily trained in AW149 specifics," the spokesperson added.

Sikorsky is leveraging the international success of the Black Hawk with variants in service with 35 nations. It is teamed with StandardAero in Gosport where the aircraft will be assembled. Other team members include Martin-Baker, Curtiss-Wright, Chelton, Inzspire, Nova Systems, CAE and Ascent Flight Training.

A contract for NMH was expected in 2023, but this has not materialised. However, an invitation to negotiate was released in February 2024, so companies will now prepare their offers, which will be evaluated through 2025, with platform selection and contract to follow. On this timeline it is unlikely that an entry into service from 2025 can still be achieved, therefore the UK's Pumas are likely to need a life extension upgrade to last until the late-2020s.

The true prize

However, the British project is small in comparison to the NATO NGRC programme that will deliver a new medium helicopter to many countries across the Alliance that could see orders in the thousands of units. Launched in 2020 with a letter of intent signed by five countries (France, Germany, Greece, Italy, and the UK), the programme plans to provide a new medium-lift helicopter for entry into service from 2035. Still in the concept phase, the NGRC now includes The Netherlands, with Canada also showing interest.

A three-year concept phase was launched with a Memorandum of Understanding signed in June 2022 alongside initial funding of EUR 26.7 million. It includes five separate studies that will develop requirements, concepts of operations, doctrine, disruptive technologies, trade-offs and a preliminary design review. In December 2023, the NATO Support and Procurement Agency (NSPA) awarded a third study contract to Lockheed Martin for a study into open systems architecture under the NGRC effort.

Sikorsky's Macklin said that the company was "actively participating" in NGRC and in February 2024 was awarded a contract to develop an Open Systems Architecture concept for future rotorcraft. "We are currently preparing to bid on the NATO NGRC Integrated Platform Concept Study which will pull together results from all other studies conducted to inform NATO and assess next-generation rotorcraft capabilities against their requirements," Macklin said.

Countries are trying to align their requirements and industrial capacity, while in the meantime, several bidders could be contracted to offer design solutions when the concept stage is completed. With increased speed a primary requirement, Airbus intends to offer a new tactical helicopter concept for the NGRC programme that includes speed as a key factor. It has already developed a prototype called Racer that the Airbus spokesperson said will "soon demonstrate the added value of a hybrid concept in flight", adding, "We aim to achieve the best trade-off between speed, cost-efficiency and mission performance… that can be adapted for military missions."

The Racer has two laterally-mounted pusher props, one fitted on a double wing strut per side, in addition to the traditional main rotor and a low drag fuselage. This allows the platform to achieve high speeds of up to 400 km/h. In a similar vein, Leonardo is developing a Next Generation Civilian TiltRotor (NGCTR) aircraft that can reach around 500 km/h. These will be able to deliver something closer to the 556 km/h achieved by the V-280 Valor tiltrotor aircraft from Bell Helicopter, which won the Future Long Range Assault Aircraft (FLRAA) competition that is part of the US Army's Future Vertical Lift (FVL) programme.

"The United States has decided to replace part of their tactical helicopter fleet with a high-speed platform. This shows that there is a need for a high-speed rotorcraft for some military operations," the Airbus spokesperson said. Yet the need for conventional helicopters is still essential. "A mix of high-speed rotorcraft and conventional helicopters would ensure that armed forces will be able to execute both high-end operations and day-to-day military transport and logistics missions," the Airbus spokesperson added.

Credit: Airbus

The Airbus Racer demonstrator was developed as part of the European Clean Sky 2 research programme. It could be a harbinger of things to come for medium weight helicopters in the future with a hybrid metallic-composite airframe designed for low weight, 30% fuel savings in cruise mode and lower acoustic footprint.

Credit: Bell Helicopter

With a cruising speed of 526 km/h and a range of 2,100 km, the V-280 Valor tiltrotor design has built on the success of the earlier V-22 Osprey from Boeing. However, unlike the V-22, the V-280 only tilts the rotors and drive shaft, whilst leaving the engines in place.

With Valor

Bell Helicopter's V-280 Valor tiltrotor aircraft was selected in December 2022 for the FLRAA part of the FVL programme to replace the US Army's Sikorsky UH-60 Black Hawk medium support helicopter, beating the SB-1 Defiant bid from a joint Sikorsky–Boeing team. Some 2,000+ Black Hawks will be replaced when the V-280 enters service from the early 2030s.

The V-280 is designed to meet US Army requirements for a new fleet of helicopters that can operate at higher cruising and maximum speeds, and achieve a longer range than existing rotorcraft. This is to meet evolving battlefield conditions; using a Modular Open System Architecture approach will allow for the rapid integration of new technologies in the V-280 as they emerge.

A Bell spokesperson told ESD that the company was 10 months into the Weapon System Development Contract. "So far, we have completed the Delta System Requirements Review/System Functional Review. This review established the requirements and functional baseline for the FLRAA Weapon System and ensures that we are developing the capability our warfighters need," the spokesperson said. "Bell and the FLRAA team are continuing to move forward with preliminary and detailed design activities. We are currently preparing for the Weapon System Delta Preliminary Design Review, which will lead to Milestone B," the spokesperson added.

In February 2022, the US and UK signed an agreement to share information on the Future Vertical Lift (FVL) programme to accelerate cooperation on rotorcraft development between the two countries, known as the 'Future Vertical Lift Cooperative Program Feasibility Assessment' project. The Netherlands also signed a similar agreement in July 2022. Although FVL now only includes the FLRAA component, its timelines align with the NATO NGRC, raising the potential for the V-280 to have wider utilisation across the NATO alliance.

"We are staying aligned with our Army teammates and the appropriate authorities from our government team to ensure that exportability is considered now, during design to ensure the US Government has the ability to conduct FMS in the future," the Bell spokesperson said.

Black Hawk remains essential

Although Sikorsky lost out on the FLRAA, the company will continue to provide a huge number of helicopters to the US Army as it will still need Black Hawk for the foreseeable future. In 2022, the company signed a multi-year contract that continues production through to 2027 with Macklin saying that he was "encouraged" by Army plans to extend production beyond this for deliveries through to 2033.

"The US Army has stated the Black Hawk will be in front-line service another 40-60 years [and] operate well into the 2070s alongside the US Army's FVL aircraft," Macklin said. Therefore modernisation and upgrades of the aircraft will be continually rolled out to support the fleet and improve its capabilities.

Sikorsky is providing upgrades that align the Black Hawk fleet with open architectures that can maintain relevance in multi-domain environments and increase the aircraft's reach, survivability, lethality and sustainment. It is integrating a new Modular Open Systems Approach (MOSA) cockpit into the optionally piloted vehicle Black Hawk demonstrator.

Credit: Sikorsky

The S-70M is the latest Black Hawk variant built by PZL Mielec in Poland, a Sikorsky subsidiary. Based on the S-70i design, the S-70M has a digital cockpit, GE 701D engines delivering a cruising speed of 276–300 km/h, range of 460 km, and cabin space for about 11–12 troops.

European ambition

Meanwhile in May 2023, the European NGMH was launched under the EU's Permanent Structured Cooperation (PESCO) framework that aims to bring together countries and align requirements and industrial capabilities for major defence projects. Under NGMH, France, Italy, Finland and Sweden are examining future rotorcraft needs and technologies and developing new solutions for installation in existing helicopters, such as the NH90 as upgrades, or into new aircraft.

NGMH follows on closely from the European Next Generation Rotorcraft Technologies (ENGRT) that was launched in December 2022 to develop technologies and concepts of operations for future military helicopters. It includes France, Germany, Greece, Italy, The Netherlands, Spain and Sweden. NGMH will provide solutions for helicopters through to the 2040s when it is expected that under ENGRT, a new helicopter platform will be developed, jointly led by Airbus and Leonardo Helicopters, including a host of smaller industry partners, and/or a more comprehensive NH90 Block 2 upgrade.

The first phase of ENGRT is worth EUR 40 million and will last until the 2025 timeframe. It is looking at developing concepts of operations, developing new systems, airframes and propulsion systems. A second phase worth EUR 100 million will follow that will seek to mature technologies, implement an open systems architecture, enhance platform survivability, and secure connectivity. Development of a high-speed rotorcraft will take place from 2027 with a new aircraft qualified around 2035.

Asian developments

At the ADEX Exhibition in October 2023, the Korean Air Aerospace Division unveiled a new Future Vertical Launch concept similar to the V-280. So far however, it remains a conceptual design to analyse technologies and designs in anticipation of a potential requirement from the South Korean military.

At the Paris Air Show in 2023, Turkish Aerospace Industries showcased a model of its new T925 medium utility helicopter. Developed with help from the Turkish military, it is expected that a prototype will fly later in 2024. A naval variant is also under development.

In 2021 in Japan, the Ministry of Defence announced the completion of development of the new UH-2 multirole medium helicopter for the Japan Ground Self-Defense Force. Built by Subaru (formerly Fuji Heavy Industries), the UH-2 leverages the Subaru–Bell 412EPX design following collaboration between the two companies announced at the Farnborough Air Show in 2018. Up to 150 are to be delivered, with the first examples handed over in June 2022.

The order book grows

Over 2023, it was announced that Brazil has requirements for 16 new medium helicopters, along with Croatia securing approval to buy eight more UH-60M Black Hawk helicopters under US Foreign Military Sales (FMS). The Australian Army is ditching its entire fleet of 39 NH90 helicopters and replacing them with 40 UH-60M Black Hawks. Greece has also ordered 49 Black Hawks with a Letter of Acceptance signed in 2024 and a contract award expected shortly.

Moreover, in early 2023, the Iraqi Army put in an FMS request for 16 Bell 412M and four Bell 412EPX medium-lift helicopters to replace Russian models. The Czech Republic has also taken delivery of eight Bell UH-1Y Venom helicopters. Since 2021, Bell has delivered nine Bell 412EPI helicopters to Indonesia, which are customised locally by Indonesia's PT Dirgantara Indonesia (PTDI) before handover to the Army.

Meanwhile, Leonardo is delivering 32 AW149 helicopters to Poland and in January 2024, North Macedonia ordered four AW149 and four AW169M helicopters. In November 2023, Leonardo received an order from Slovenia for six AW139M helicopters.

In December 2023, the German Bundeswehr ordered 82 H145M helicopters, its largest ever order. This followed a contract in November 2023 from the UK MOD for six H145 helicopters for its bases in Cyprus and Brunei. Airbus continues to deliver both variants of the NH90 helicopter to customers worldwide, with over 500 handed over so far. Airbus' H160M has been selected by France to replace older fleets of aircraft. The military variant is currently under development and slated to be fitted with HForce. Elsewhere, Airbus' new H175M helicopter was demonstrated in Saudi Arabia as recently as September 2023.

Closing thoughts

Procurement plans for new next generation medium helicopter platforms are not expected to come to fruition until the end of the decade. It means that the full spectrum of capabilities that the addition of new technologies can offer will not be seen in an operational platform before then.

However, existing helicopters will incrementally receive some of these capabilities both in the delivery of platforms and through modernisation and upgrade programmes. In the meantime, the market for medium helicopters remains highly competitive, with orders coming thick and fast.

Credit: Airbus

The H175M has recently completed testing in Saudi Arabia. On the larger side of the spectrum – Airbus calls it a 'Super-Medium' helicopter – it has a large internal cabin of 12 m³ with space for 16 troops, internal fuel tanks providing a range of up to 1,111 km, and an integrated Electronic Warfare capability.

Viewpoint from Kyiv

Credit: Author

The war drones on

Alex Horobets

Over the past six months, the War in Ukraine has been reshaped due to both sides widely using various types of uncrewed aerial vehicles (UAVs). In 2022, Ukraine had the upper hand in this regard, but in 2023, Russia caught up, employing a variety of reconnaissance drones and disposable loitering munitions (often referred to as 'kamikaze UAVs'). Now both warring parties have announced plans to ramp up their UAV output in the coming years.

This suggests that the use of first-person view (FPV) drones and reconnaissance UAVs at the tactical level has already changed warfare as we know it. FPV drones are cheaper than conventional 155 mm artillery shells, while still being capable of destroying equipment worth millions of dollars. Moreover, drones are highly accurate, and they can also film their strikes ensure they hit their mark, or a neighbouring drone can film the strike to confirm target defeat. Russia's large-scale employment of drones was one of the reasons that Ukraine could not apply NATO-style tactics in its counteroffensive during the summer of 2023. The Ukrainians were no longer able to use large armoured groups for a quick breakthrough, since their survivability was reduced by the presence of drones. At the same time, in the context of ammunition shortages, in part due to delays in US assistance, drones have become an effective tool for Ukraine to creatively deter Russian offensive efforts. Drones have now become an important factor that commanders take into account when planning infantry or armoured assaults. In fact, drones allow their users to effectively detect the movement of even small assault groups, at which point loitering munitions often come into play. The sheer availability of UAVs has pushed commanders to put the burden of most assault efforts on the shoulders of the infantry, though even they often find themselves attacked by loitering munitions.

It should be kept in mind that drones are effectively disposable given the intensity of ongoing battles, and they are frequently downed. Consequently, large numbers of UAVs are required in order to have a significant impact on all sections of the front line. As such, numerous UAV production campaigns have been launched at the state level in both Ukraine and Russia.

In Ukraine, at the core of FPV drone production were volunteers who primarily used off-the-shelf components purchased from China. Gradually, the effort has become more coordinated, which involved setting up production lines for UAV components in Ukraine. At the same time, Ukraine established cooperation with international investors and manufacturers to this end. A year on, more than 200 Ukrainian firms are involved in UAV production. Now a coherent approach on the part of Ukraine's government is required to both support private initiatives and increase output at the national level. President Volodymyr Zelenskyy set an ambitious goal for Ukraine to produce 1 million drones in 2024, and also ordered the creation of a separate armed forces branch, the Unmanned Systems Forces.

Once the front lines become even more saturated with drones, the survival rate for both manpower and equipment is expected to decrease further. Footage on social media has shown various Russian weapon systems being hit at relatively longer distances than usual beyond the line of contact. Recent examples include the TOS-1A Solntsepyok thermobaric rocket artillery system and a launch vehicle from the Tor family air defence system. So far, the leap in FPV development has been so rapid that the warring parties are yet to deal with delivering enough quality anti-drone systems to the battlefield.

The surge in the development and upgrade of unmanned systems in both Ukraine and Russia was dictated by ongoing combat operations; since other nations have not faced similar conditions, the range and quantities of drones produced is generally much smaller. However, Europe and the US are starting to catch up in this regard.

The next step in UAV development, which we may witness sooner than expected, is the extensive application of artificial intelligence. The UK, along with the US and other governments, has expressed interest in sending Ukraine thousands of swarming-capable AI-driven UAVs that could coordinate with each other and attack Russian targets simultaneously. Potentially, the use of autonomous drone swarms would pose an even greater threat to Russian Forces, though the Kremlin has also taken up the development of such systems. It is important to note that UAVs are not seen as a panacea, nor as a replacement for aviation and artillery. However, they are a very useful combat element, and amid shortages of many other weapons systems, drones have significantly contributed to maintaining Ukraine's defensive capabilities.

Rotary wings – developments and market trends

Tim Guest

From recce to troop transport, medevac to close air support, spec ops, search-and-rescue (SAR), and maritime roles, the versatility of helicopters makes them indispensable workhorses on today's battlefields.

The war in Ukraine is a case in point, where the high-profile use of helicopters by both sides, of often aged, though formidable, Soviet-era airframes flying nap-of-the-earth (NOE) over the battlefields, often in stand-off attack roles, illustrates the many scenarios in which the helicopter plays a core operational role. With Ukrainian forces increasingly tactically dispersed in response to the threat from Russian missiles and long-range precision fires, the helicopter has also been crucial in transporting troops and equipment considerable distances. The war has, however, also revealed helicopter vulnerabilities and their corresponding need to be equipped with latest defensive systems, along with other advanced sensors, if they are to survive the modern battlefield.

This article explores the latest rotary-wing developments, some in response to current conflict, with reference to, and comment from, certain leading manufacturers.

Credit: Ukrainian Helicopters

Being able to repurpose a platform quickly to perform a different, urgent, critical mission is exactly what Ukrainian Helicopters has done with its Mi-8MTV-1 modernisation. The helicopter can be quickly reconfigured by the aircrew is just 40 minutes to fly reconnaissance/rapid response, SAR, MEDEVAC, troop transport, or cargo missions, all of which have been flown in the war against Russia.

Constant innovation, constant demand

With the right upgrades and new avionics, flight controls, smart displays, self-protection systems and more, crucial improvements to rotary-winged flight through a lessening of pilot and crew burden are being achieved by helicopter makers, ensuring manned helicopters will be in constant demand in military operations and critical for decades to come. Exactly what some of those upgrades need to be in the face of changing battlefield tactics, the advent and use of more unmanned aerial vehicles (UAVs), and other operational changes, can be seen in industry developments currently underway.

Airbus Helicopters, for example, which designs and manufactures light and heavy platforms in attack/reconnaissance, utility/transport, as well as maritime categories, integrates most of its helicopters with guided weapons, such as rockets and missiles, and, in some cases, with longer-range, stand-off weapons that can hit targets over 15 km away. The company believes all categories of helicopter are complementary to one another, with military customers needing to have the choice from standard combat helicopters for conventional force operations, to more specialised platforms offering specific capabilities to meet extreme demands such as those of special forces.

According to Patrick Bréthous, military advisor to the CEO of Airbus Helicopters, and himself a former French Army Light Aviation (ALAT) combat helicopter pilot and retired Major General, agility is also key factor for military customers, who want helicopters that can fly low and are agile enough to follow the terrain to avoid being seen, or detected, as much as possible. He said this in the context of the conflict in Ukraine, which has also shown how important self-protection systems are, with increasing military requirements for electronic warfare (EW) systems and flare launchers. In addition, military users in such high-intensity ops need to be able to fly in difficult weather conditions, either by day, or by night, in order to retain an element of surprise, and here there is increasing demand for advanced avionics, sensors and flight controls to enable such operational capabilities. Reducing crew workload to allow them to focus on their mission is also a key factor, one for which advanced onboard mission systems can now help pilots prepare and conduct missions. In addition, reliable and robust onboard connectivity is critical, to ensure any helicopter involved in operations is fully integrated into any, or

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Credit: Airbus

Patrick Bréthous, Military Advisor to the CEO of Airbus Helicopters: "Manned-unmanned teaming will progressively become a standard feature for military helicopters."

all, military command and control systems. Crews must have good vision and as full an understanding of the tactical situation around them as possible. In this context, manned-unmanned teaming (MUM-T) – between the manned helicopter and UAV assets – is, according to Bréthous, also increasingly requested by customers as a prerequisite capability for any prospective purchase, and will progressively become a standard feature for military helicopters, one that will not only allow a crew to access data gathered by UAVs, but also enable them to control one, or more, drones in flight, themselves.

MUM-T broad agreement

These MUM-T requirement and other sentiments were echoed by Boeing's Mark Ballew. He said that with rotorcraft demand remaining strong worldwide, as well as the rise in UAVs, the company was working with its own customers to offer different and more advanced technologies to improve efficiency, and help ensure helicopter crews have the best chance to accomplish missions and survive. He added that the company was exploring autonomy as a capability on all of its enduring and future platforms, leveraging technology that, in part, already exists across the enterprise. He cited as an example the increased importance of MUM-T across all helicopters, in order to give pilots more comprehensive situational awareness (SA) of the whole battlespace. He noted that the AH-64 Apache had been operating with MUM-T capabilities for nearly 10 years, adding that the company's experience in autonomy and unmanned vehicles, which operate in multi-domain operations over land, sea and in the air, as well as beyond Earth's atmosphere, included the Boeing Insitu ScanEagle, MQ-25 Stingray, and MQ-28 Ghost Bat, as examples of the kinds of unmanned craft with which helicopters would collaborate. While recognising that autonomy is part of the future of flight, Ballew emphasised that nothing can, as yet, truly replace the eyes and ears of a human pilot, so the future of autonomy, at least in the near term for helicopters, will be a combination of the two.

Leonardo Helicopters, which also recognises a rapid increase in the uptake of UAVs, expects the balance between manned and unmanned military rotorcraft will shift in favour of unmanned in the coming decades. In the meantime, the company has conducted its own trials of MUM-T, (what it calls Crewed-UnCrewed Teaming – CUC-T), over the past four years, including of UAVs integrated with the mission system aboard one of its AW159 helicopters. This allowed the helicopter crew to control the drone from their cockpit, as if it was one of the chopper's own onboard sensors. In general, while improving overall mission effectiveness, the company sees key benefits of MUM-T in also reducing the risk to aircrew in high-threat scenarios through improving their SA, and thereby allowing pilots to remain central to a mission without increasing their workload.

A company statement also underpinned the increase in operational range that can be achieved using MUM-T, due to the unmanned asset being able to operate with 'high persistency' beyond the horizon of the manned helicopter's own onboard sensors, while at the same time providing valuable data to the pilots of the crewed aircraft. With that, also comes increased mission efficiency, an overall cost reduction of an operation, with the more expensive crewed asset used only when necessary, and greater reliance placed on the UAV. This combination, in an era where aircrew fatigue is a serious limiting factor, MUM-T ensures that greater overall operational persistence is possible.

Commercial-military confluence

As one might expect, there are a number of influences from the commercial helicopter sector with potentially favourable impact on the military market; platform configurations, as well as onboard technologies are often relevant to both sectors. A civil-sector air ambulance, for example, configured as an emergency medical service platform, might have considerable influence on the final configuration and onboard equipment carried by a casualty evacuation (CASEVAC) chopper on the battlefield. Several other areas of overlap also exist and include aspects such as those of noise and safety. The former sees demand in the civil market for reduced noise levels from aircraft and is well reported, relating particularly to light and medium helicopters operating in urban environments.

Credit: Leonardo

UAVs have proliferated, as seen on the battlefields of Ukraine. Pictured: CG render of the NHI NH90 (left) and Leonardo's AW249 combat helicopter (right), which is said to be interoperable with all air and ground assets, including UAVs.

Credit: Leonardo

Pictured: Italian Air Force AW139M. This is the military version of the commercial AW139, an example of the overlaps between the commercial and military helicopter sectors.

By modifying the tail rotor, for example, and enclosing it in a fenestron – first developed in the 1940s – manufacturers can reduce rotor noise levels; typically, instead of the two to four blades of a conventional rotor, a fenestron-encased tail rotor may have 7-18 blades. Numerous aircraft have sported fenestrons over the years, with the Boeing-Sikorsky RAH-66 Comanche stealth helicopter, along with Airbus' UH-72B variant of its established Lakota; of which the first new variant was delivered to the US Army's National Guard in September 2021. The benefit of lower noise levels to the military customer, making helicopters more discreet, is, perhaps, more important than ever in the face of today's enemy forces, which are more likely than not to be equipped with advanced acoustic sensors and listening devices.

On the issue of safety, this is where the civil world drives innovation, with standards often higher than those for purely military aircraft. As a result, military helicopters, especially when derived from civil-certified platforms, often benefit from improved levels of safety.

And while not directly an airframe component, one on-the-ground civil helicopter fleet development, with potential for beneficial operational impact on the military helicopter ecosystem, warrants a mention. This is in the area of maintenance, repair and operations (MRO), where civil helicopter operators, in the quest for faster turnaround times, greater aircraft availability, and less 'dead time' on the ground for their aircraft, are turning to the use of interactive 3D technical publications by their MRO teams. These 3D publications provide complex-equipment, product documentation that offers easy-to-use digital troubleshooting tools, connected services and support, all of which gives technicians the information they need in a digital format to be able to maintain aircraft efficiently, to the highest standards, and without compromising safety. It also enables MRO to be conducted quickly. Such an approach will be of direct operational benefit to military customers/users, particularly in conflict, where, with simplified maintenance plans, reduced maintenance workloads and less time on the ground for aircraft, more helicopters will be in the air, more of the time.

A current example of this civil-military confluence is the work between Boeing and Leonardo on the Grey Wolf programme, with the multi-mission, MH-139A Grey Wolf, essentially a militarised version of Leonardo's AW139 helicopter. The reconfigured aircraft is replacing legacy USAF UH-1N Iroquois helicopters and will protect intercontinental ballistic missile installations, as well as transport security and US Government personnel. The first four Grey Wolf test versions were delivered to the USAF in August 2022.

Avionics and onboard tech

Innovations in avionics and onboard flight technologies are many across both the commercial and military helicopter sectors, and tend to focus, particularly in the military domain, on reducing crew workload and increasing SA, as well as improving safety. At the same time, many proven, exceptional military aircraft, such as the Chinook, have had manufacturers working tirelessly to upgrade and extend their lifetimes, and typically include many new onboard innovations.

Of these, Airbus' Bréthous said that glass cockpits were currently available with new large displays that can be reconfigured to allow the crew to access critical information at the right time. He also said there had been a focus on the human machine interface (HMI), ensuring crew are able to navigate easily within a helicopter's latest avionics system, with touch screens progressively being introduced and integrated aboard some aircraft alongside new avionics and mission systems, with those same screens either used to display information related to the flight and the aircraft, or tactical information from the battlespace. With connected avionics, a helicopter's crew can exchange information not only with other aircraft and troops on the ground and command centres, but also, in the context of MUM-T, with unmanned systems.

With two of the biggest challenges – improving SA and reducing crew workload – facing today's helicopter operations and

Credit: Boeing

MH-139A Grey Wolf is essentially a militarised version of Leonardo's AW139 helicopter. The first four Grey Wolf test versions were delivered to the USAF in August 2022.

driving innovations in avionics and cockpit technologies, a system developed in response to these two drivers is Leonardo's HELIAWARENESS Mission Management System (MMS), which is intended to enhance mission effectiveness by providing crews with a single integrated picture of the operational environment. The MMS fuses data from sensors, such as radar, optronic and automatic identification systems, with relevant information extracted and combined into a common, real-time picture intended to make the crew's life significantly easier.

Continuous upgrade

When it comes to upgrades and extensions, at Airbus Helicopters, the company applies a continuous improvement policy to its entire range, with new features tested regularly and new sensors and weapons integrated as they become available, a policy, Bréthous said, which also focuses on increasing safety standards and reducing maintenance workload. Bréthous added, "A good example is the H145M; new weapons are being integrated thanks to the open architecture of the HForce weapons system. The Spike ER2 missile is currently being integrated following a customer request and will be available for future operators. The H145M has also been used to experiment MUM-T with various scenarios, and a 17 inch foldable display is under development." It is understood that the H225M helicopter also benefits from that policy; its maximum take-off weight has been increased by 160 kg and the aircraft is now equipped with what the company claims are the largest cockpit displays on the market, together with a new interface.

For Boeing, upgrades to maintain and extend existing airframes are highlighted by latest developments with Chinook Block II and Apache aircraft. Mark Ballew said that the US Army recently announced they were moving toward full production of the CH-47F Block II programme, a decision which will benefit the global Chinook user community and those interested in acquiring Chinooks for the first time. International operators will see improved affordability, but they will also be maintaining critical interoperability with the US Army when either undergoing modernisation efforts, or purchasing aircraft for the first time.

"The beauty of the Block II programme," Ballew continued, "is that it provides both a near-term and a long-term solution for our heavy-lift customers." The Block II configuration provides enhanced capabilities, including a reinforced airframe, an improved drivetrain and redesigned fuel tanks, all of which enable the Chinook to lift more and fly further. Looking long term, Block II provides structural and design improvements that allow customers the ability to easily integrate further enhancements, such as a more powerful engine.

Of Apache, Ballew added that the focus was on modernising the aircraft for the future. "Beyond MUM-T, we're working on making Apache compatible with the modular open systems architecture (MOSA) ecosystem, improving performance and adding additional flight control assists to reduce operator workload."

Importance of HMI

Last November, Airbus announced it had successfully tested a new simplified HMI along with advanced autonomous features, through a project code-named Vertex. Bréthous explained the Vertex demonstrator that was tested on their Flightlab, consisted of a fully automated flight, controlled by a pilot via a tactile tablet, during taxi, take-off, cruise, approach, and final landing.


Credit: Boeing

Chinook Block II programme provides both a near-term and long-term heavy-lift solution with enhanced capabilities, including a reinforced airframe, an improved drivetrain and redesigned fuel tanks. The US Army recently announced the move towards full production of the CH-47F.

Credit: Airbus

Airbus has tested a new simplified HMI flight control system that replaces the traditional cyclic/collective/pedal controls, under a project code-named Vertex. A touchscreen tablet plays a central role in mission preparation and management.

Bréthous said, *"The objective of the demo flight was twofold: to carry out a demonstration of a fully-automated flight from take-off to landing, and to increase the maturity of the different techno-bricks. Vertex aims to enhance helicopter safety by increasing SA through automatic obstacle detection and reducing pilot workload through a simplified flight control system, thus enabling helicopter pilots to focus on high-level decisions."* The overall concept of the demonstrator is to let the system take over as much as possible from the pilot to simplify the mission; the aircraft flies along a predefined trajectory, although the pilot remains in control and can take over whenever necessary. Bréthous added, *"The system is interesting, as it could improve the safety of low-level helicopter flights when helicopters are close to obstacles such as pylons, power cables, bridges, or terrain. The project took the technology to technology readiness level, TRL, 4."*

It is understood from Boeing's Ballew, that the company is working on a similarly simplified flight control system for helicopters, moving away from the traditional cyclic/collective/pedal controls. Ballew noted that human factors engineering, and flight interface control development have been a focus, with the company always looking at ways to reduce operator workload and make the vehicles more responsive, easier and safer to fly. *"For example, for modernised Apache,"* he said, *"the flight control system will help with small adjustments to keep the vehicle level and oriented correctly, while the pilot makes larger manoeuvres, manually."*

Operational lessons

With some final comments on how operational trends and lessons from Ukraine might be driving developmental trends, Patrick Bréthous said, *"Airbus Helicopters' military experts keep a close eye on what is going on in Ukraine, but also in other military operations across the world; a lot of lessons learned can be underlined. The first, is obviously the massive arrival of UAVs on the battlefield, which means that combat helicopters must be able to cooperate with this new asset, at least to be coordinated in flight, though the best being to operate with them."*

He added that recent operations had shown that helicopters can be vulnerable when flying in daylight and if they fly too high, he emphasised that high speed can help with agility for NOE flights, as well as the ability to fly by night – all key to a helicopter's survival over the battlefield. He also stressed that operations in Ukraine have demonstrated that helicopters must be equipped with precise stand-off weapons and advanced self-protection suites, and that in such high-intensity conflict they will likely suffer combat damage; anything that can help repair them quickly and easily makes sense, if a high level of fleet readiness and availability is to be ensured, factors which echo earlier sentiments on the advantages of employing advanced digital 3D MRO procedures from the civil sector, in the field.

Technological advances are pushing and pulling at the fabric of military helicopter development. Whether from sophisticated surface-to-air weaponry and targeting systems, making the skies above Ukraine and other theatres dangerous places for any kind of rotary-winged craft and requiring manufacturers to respond by equipping platforms with effective self-protection systems and avionics, or simply because the competition has a lead on, say, a flight control development. In the latter case, development may, one day, see the cyclic, the collective, and pedals all disappear, to be replaced by a single, control – what is certain is that the manned, military helicopter, configured, or specifically developed for a particular application, is here to stay for the foreseeable future, even with the advent of UAVs. For now, UAVs actually look like being the manned helicopter's best friend – as long as it's one of their own. ■

Credit: Boeing

Boeing is making Apache compatible with the modular open systems architecture (MOSA) ecosystem, improving performance and adding additional flight control assists to reduce operator workload.

Modern ceramic armour for personal and vehicle protection

Gerhard Heiming

In response to the growing market for body and platform protection, Nurol Teknoloji, a major Turkish manufacturer of ceramic protective elements, is expanding its capacities, both qualitatively and quantitatively. The most recent step was the acquisition of the German ceramics specialist Industriekeramik Hochrhein (IKH) and its integration into the production process.

Long-range weapons mean that forces and their platforms in the theatre of operations and beyond are in constant danger of being hit by bullets and fragments. The growing importance of protection, and in particular individual protection, has led to a boom in protective elements of all kinds. Two basic requirements are at odds: high protection and low weight. High weight reduces mobility and reduces the willingness to wear body armour.

Modern armour-piercing projectiles, improvised explosive devices (IEDs), unmanned aerial vehicles (UAVs) and a range of new challenges underline the need for robust protection solutions. In response to the changing dynamics on the battlefield and the resulting increased demand for protection against the multitude of threats, protection solutions are being developed to anticipate and mitigate the evolving threats facing armed forces today and, in the future, ensuring the safety of operators in a dynamic operational environment.

Different threats require different protection technologies to ensure the required level of protection against each threat. Different technologies often have to be combined in order to realise the best possible protection. Today, ballistic body protection is primarily based on panels made of ceramic materials.

Production of ceramic protective plates

Nurol Teknoloji, part of Nurol Holding, is one of the most important manufacturers of protective ceramics in Turkey. Since 2008, the company has been manufacturing ballistic protection products for personal, platform, and structural protection (safety cabins, containers) at several production sites in Ankara. High-performance technical ceramics are used for this purpose. The product range of ballistic ceramics includes Boron carbide (B4C), silicon carbide (SiC) and Aluminium oxide (Al2O3).

According to Nurol's description, Boron carbide is the third-hardest known material, surpassed only by diamond and cubic Boron nitride. Not only is it exceptionally hard, but it is also one of the most demanding materials in the world to manufacture. Its combination of hardness and relatively low density of 2.5 g/cm^3 (compared to around 7.85 g/cm^3 for steels) make Boron carbide among the lightest choices for high-end ballistic protection – thereby making it a good choice for personal protection ballistic plates. In addition to its role as an armouring material, Boron carbide is used in nozzle production due to its high wear resistance and in the nuclear industry due to its exceptional neutron absorption.

With the acquisition of IKH, Nurol Teknoloji has strengthened an essential element of ceramic production. IKH is a German specialist in the production of ceramic powder, the base material for protective plates.

The ceramic powders are produced in complex chemical-physical processes. Precise adherence to the process parameters is a prerequisite for the high and consistent quality of the raw materials. The raw materials are finely ground and mixed according to the product specification. According to IKH, the ceramic powder produced in this way is dimensionally stable during the sintering process with good pressing properties. This allows a high sintering density to be achieved, with the optimal physical and chemical properties.

The powder produced at IKH is mainly transported by lorry to the Nurol Teknoloji production facility in Ankara. In the next step, the ceramic powder is pressed into moulds at high pressure to shape the material toward its intended purpose, for instance as body armour plates or tiles for vehicle platforms. These blanks are then sintered at high temperatures. The properties of the IKH powder and the associated physical and chemical processes give the material a hardness and toughness that goes beyond the required resistance to high-end ammunition.

Credit: Gerhard Heiming

Three stages in the production of Boron carbide body armour: (right to left) powder, sintered Boron carbide plate, completed plate (showing ballistic damage). The completed plate comprises a fabric layer at the front, sintered Boron carbide plate in the middle, and backing at the rear to dissipate projectile energy and prevent splinters from reaching the body.

The direct sintered Boron carbide plates, are currently among the top products for body armour, with a claimed weight saving of around 25% compared to other Boron carbide body armour solutions. The picture shows the starting product Boron carbide powder with the protective plate blank on the right and the finished, already coated body armour element on the left, with the fabric layer in front, the protective plate in the centre and the backing behind it. The latter distributes the penetrating energy and prevents splinters from reaching the body.

Nurol Teknoloji continues to invest in high-temperature sintering furnaces to increase capacity for direct sintered Silicon carbide and Boron carbide, to meet the increasing demand for the lightest possible personal and vehicle protection solutions.

The UK NMH programme: a marathon as opposed to a sprint

Peter Felstead

The UK Ministry of Defence (MoD) finally issued an invitation to negotiate for its New Medium Helicopter requirement in February, but the history of the programme suggests that the fruits of this procurement initiative could still be years away.

On 27 February 2024 the starting gun was fired on the next phase of the UK's New Medium Helicopter (NMH) programme when the UK MoD issued an invitation to negotiate (ITN) for the requirement, with responses to the ITN due to be received by 30 August.

The ITN downselected three contenders – Airbus Helicopters UK with the H175M, Leonardo Helicopters UK with the AW149 and Lockheed Martin UK offering the S-70M Black Hawk – for a requirement that is now largely a programme to replace the Puma HC2 fleet currently operated by the Royal Air Force (RAF). The aim of the NMH programme, according to the MoD's 27 February statement, is to "deliver up to five rotary-wing requirements using a single aircraft type", although the MoD did not specifically state what those five requirements are.

While the ITN was welcomely received as a sign of progress in the programme, the bidders are likely to believe that the race to fulfil the NMH requirement will continue as a marathon rather than a sprint.

The original NMH requirement

When the NMH programme was first announced by the UK MoD in March 2021, the MoD announced that it was to procure up to 44 aircraft in a contract worth GBP 0.9-1.2 billion (EUR 1-1.4 billion) that "intends to rationalise existing multiple rotary-wing requirements into one platform type, maximising commonality in order to improve efficiency and operational flexibility.

Credit: Crown Copyright 2023

An image taken to mark the British Forces Cyprus transition from the Griffin HAR2 to the Puma HC2 on 31 March 2023. Both types were originally to be replaced by a single type under the NMH requirement, but Airbus H145s have been selected to ultimately take over the RAF missions in Cyprus and Brunei, assuming the UK MoD and Airbus can agree a contract.

"NMH, the MoD stated, "will provide a common medium-lift, multi-role helicopter, fitted for, but not with, specialist Mission Role Equipment and able to operate in all environments in support of defence tasks."

NMH at the time covered four distinct rotary-wing requirements. As well as replacing the fleet of 23 RAF Puma HC2s operated by No 33 and No 230 squadrons out of RAF Benson in Oxfordshire from 2025, the programme was also intended to replace five Bell 212s serving with the Army Air Corps' (AAC's) No 667 Squadron in Brunei, three Griffin HAR2s operated by the RAF's No 84 Squadron out of RAF Akrotiri on Cyprus (tasked with search and rescue), and six special-forces-roled AS365 N3 Dauphin IIs operated by the AAC's No 658 Squadron from the Special Air Service (SAS) barracks at Credenhill in Herefordshire.

Beyond procuring aircraft, the NMH contract was also to "include the provision of training capabilities and a maintenance/spares package as well as design organisation scope", according to the MoD. The relatively ambitious in-service date for the new helicopters was given as 2025, suggesting that an already-existing airframe was likely to be chosen.

Following the initial issuing of the NMH requirement in March 2021, it was not until 18 May 2022 that the MoD released its NMH 'Contract Notice and Dynamic Pre-Qualification Questionnaire' (PQQ), with a deadline of 20 June 2022 for responses. The emerging bidders that passed the PQQ stage of the requirement in November 2022, in addition to the three types ultimately downselected in February 2024, also included Boeing, which was expected to offer a version of its MH-139 Grey Wolf. Offers from Bell, which was initially keen to pitch its 525 Relentless as an NMH contender, and low-cost, non-OEM contender AceHawk Aerospace, which was offering remanufactured Black Hawks featuring the Garmin G5000H digital cockpit, did not pass the PQQ.

No discernible NMH progress was then made until 13 November 2023, when the MoD published a notification of intent to procure six Airbus Helicopters H145 aircraft, along with three years of support services, to serve British forces operating in Brunei and Cyprus. This procurement, which was stated to have a value of GBP 140 million excluding VAT, thus covered two of the NMH programme's original four requirements, with the H145s intended to enter service from 2024.

Selection of the H145 for these roles made sense from a logistical and training perspective, as three of the type are already operated under the UK armed forces' contractor-operated Military Flying Training System regime, where the H145s are known as Jupiter HT1s.

ESD understands that, should ongoing negotiations to procure the Airbus H145s reach a satisfactory conclusion, this will allow aviation support to UK defence facilities in Brunei and Cyprus, where Puma HC2s took over from the three Griffin HAR2s on 31 March 2023, to be formally extracted from the NMH programme, allowing the ongoing NMH requirement to focus on the remaining defence tasks requiring medium rotary-wing lift support.

The three NMH contenders

The S-70M being offered by Lockheed Martin UK is based on the S-70i 'International' Black Hawk manufactured by Sikorsky subsidiary PZL Mielec in Poland. With a maximum take-off weight (MTOW) of 10 tonnes, the S-70M is powered by two General Electric T700-GE-701D turboshafts each developing 1,450 kW and has a top speed of 361 km/h, a range of 460 km with a 20 minute fuel reserve, a service ceiling of 6,100 m (20,000 ft) at a gross weight of 8,165 kg, and can accommodate up to 12 troops in addition to a crew of four. It has an underslung load capacity of 4,082 kg.

Credit: PZL Mielec

The S-70M being offered for the NMH requirement by Lockheed Martin UK is based on the S-70i 'International' Black Hawk manufactured by Sikorsky subsidiary PZL Mielec in Poland.

In bidding the Black Hawk, Lockheed Martin/Sikorsky can point to an impressive heritage for the type that includes more than 15 million flight hours flown (including five million in combat conditions), 35 user countries and a user base of more than 5,000 aircraft worldwide. The latest S-70M, moreover, features new technology that includes digital avionics and composite wide-chord rotor blades.

While the Lockheed Martin website asserts that "today's Black Hawk platform has better survivability and situational awareness, and can fly higher and carry more than its predecessors and competitors ever did", the perceived weak point in the S-70M bid is that it is based on a US helicopter when the NMH adjudication is most likely to favour a solution with a high degree of UK content and value to the domestic defence industry.


Credit: Leonardo

If selected for NMH, the Leonardo AW149 will continue the tradition of UK helicopters being built at 'the Home of British Helicopters in Yeovil'.

To counter this perception, in September 2023 Lockheed Martin UK launched its Team Black Hawk of UK industry partners that include Gosport-based StandardAero, Martin-Baker in Denham, Curtiss-Wright in Christchurch, Chelton in Marlow, Inzspire in Lincoln, C3iA Solutions in Poole, Nova Systems in Filton, and Ascent Flight Training & CAE at RAF Benson.

Speaking to the press at the time, Lockheed Martin UK CEO Paul Livingston asserted that around 40% of the overall value of the NMH programme would be supplied from within the UK should the Black Hawk prevail. He additionally pointed out that having a Black Hawk production line already hot in Poland would allow Lockheed Martin to "pivot more quickly to set up in the UK".

Leonardo, meanwhile, in bidding the AW149, has the heritage of the UK's Westland Helicopters at its Yeovil site in southern England to burnish its NMH credentials, along with the UK armed forces' long history with the current fleet of AgustaWestland AW101 Merlin helicopter variants. The company has already assembled a supply chain of more than 70 UK companies as part of its bid and committed to at least 60% of total AW149 production occurring in the UK at "the Home of British Helicopters in Yeovil".

In fact, at the UK's Farnborough Air Show in July 2022 Leonardo announced that it had already started to establish an AW149 manufacturing facility at its site at Yeovil. Noting this was "a demonstration of our commitment", Mike Morrisroe, head of UK campaigns for Leonardo Helicopters, stated at Farnborough in 2022 that the "jigs, tools and fixtures are already in place" and that Yeovil engineers are already training in Italy". Leonardo is pledging a capability to deliver military off-the-shelf aircraft from Yeovil within 12-14 months of any contract signature.

Emphasising its position as "the UK's only helicopter manufacturer, building military aircraft since 1947", Leonardo points out that "more than 50% of the UK armed forces' current frontline helicopter fleet came from Leonardo's site in Somerset, which employs 3,300 people".

Pointing to export potential, Leonardo has stressed as part of its bid that it has "generated GBP 6.6 billion in helicopter exports from the UK to customers in North America, Asia-Pacific, Europe and North Africa, and that it sees "an addressable export market for more than 500 medium multi-role helicopters that could be satisfied with UK-made AW149s".

Military certified in 2014 and already in service with the Egyptian Navy, Royal Thai Army and Polish Land Forces, the AW149 has a maximum gross weight of 8,600 kg and the capacity to carry 16 fully equipped troops in addition to its crew of two, or a useful load of at least 3,800 kg, as well as an underslung load capacity of 2,800 kg, according to the Leonardo website. Powered by two Safran Aneto-1K turboshafts each developing 1,715 kW (or General Electric CT7-2E1s), the AW149 has a maximum speed of 313 km/h and a range of around 1,009 km at its maximum gross weight at 1524 m (5,000 ft) when powered by CT7-2E1s (or 913 km when powered by Aneto-1Ks). A service ceiling figure is not published on the Leonardo website but it does specify a hover out of ground effect (ISA, at a weight of 8,300 kg) at 2,893 m (with CT7-2E1s).

Regarding the AW149's battlefield survivability, Leonardo points to key features such as a crashworthiness design allowing the helicopter's crew and occupants to survive in 90% of all survivable crashes (according to the DEFStan 00-970 crash case specifications); a run-dry transmission that enables 50 minutes of continued flight after suffering total oil loss; and an exhaust infrared (IR) suppression system to minimise targeting by man-portable air defence systems.

Other salient AW149 features stressed by include a single-pilot, NVG-compatible, low-workload 'glass cockpit' and an open systems architecture that enables the rapid and low-cost integration of new equipment to meet changing military requirements.

Meanwhile, in offering the H175M – a military variant of the Airbus H175 civilian type, which entered service in 2015 – the company is continuing what they state is a "highly successful record over many years in developing dual civil and military variants of the same helicopters, evidenced by the enviably balanced market share achieved [by Airbus] in the two sectors".

Credit: Airbus Helicopters

Developed from the H175, which entered service in 2015, the H175M continues the tried-and-tested Airbus strategy of developing military variants of its civilian helicopters.

Airbus describes the H175M as "a high-capability, low-risk solution with outstanding technical and safety specifications, already operating successfully in a range of demanding roles and environments". With an MTOW of 7,800 kg and powered by two Pratt &Whitney PT6C-67E turboshafts, the H175M can carry up to 16 fully equipped troops, or a useful load of 3,000 kg, and has a cargo sling load capacity of 2,700 kg. It has a cruising speed of 278 km/h, a service ceiling of 4,572 m (15,000 ft) and a maximum range of 1,111 km with a standard fuel tank.

An Airbus spokesman told ESD on 18 March that, "if selected by the UK, the H175M will be made and serviced in Britain by the H175M Task Force" that includes Airbus, Boeing Defence UK, Babcock, Spirit AeroSystems and Pratt & Whitney Canada. "Design work will be performed in Belfast, it will be made at Broughton in North Wales, and supported in Scotland and at military bases, creating hundreds of jobs and helping to drive competition and innovation in the UK helicopter industry," said the spokesperson, adding that the programme "will act as a catalyst for strong export sales, enhancing the UK's global reputation and bringing hundreds of millions into the economy".

A key differentiator in the H175M bid is the aircraft's Airbus-proprietary Helionix avionics suite: precisely the same systems used by the Juno HT1 (Airbus H135) and Jupiter HT1 (Airbus H145) helicopters employed for the UK's contractor-operated Military Flying Training System regime, offering significant savings in time and cost on training. This advantage will become even more relevant if Airbus successfully concludes negotiations with the UK MoD to provide the six H145 helicopters selected to serve British forces operating in Brunei and Cyprus.

Beyond this, Airbus stresses that, among its other features, the H175M's 12 m3 of cabin space is the largest on the market for a helicopter of its size, while the aircraft's dual-duplex, four-axis automatic flight control system (AFCS) "ensures safe final approaches (particularly at low heights for prevention against terrain collision), along with a hands-off one-engine failure management mode".

More delays in the wings?

As the three NMH contenders push their bids in earnest following the February 2024 ITN, it looks increasingly likely that this long-drawn-out programme will only get longer as the UK heads into a general election. With the latest indications suggesting the election will not be called by the ruling Conservative government until some time in the second half of 2024, the NMH programme appears likely to be delayed further by the pre-election 'purdah' period, which will stymie any major programme decisions once an election date is called. If, as most polling predictions strongly indicate, the Labour Party will prevail in the upcoming election, a decision on the NMH programme will most likely land on the desk of a new Labour UK defence secretary, possibly causing further delays to a programme that, while largely intended to be a military off-the-shelf procurement, has already been running for three years.

The NMH programme, as originally announced in 2021, was intended to bring new medium-lift helicopters into service in 2025, yet according to the most optimistic projections from the bidders it will take at least a year from contract signature to the delivery of any aircraft. It therefore appears inevitable that the RAF Puma HC2 fleet will have to soldier on beyond its intended service life; in September 2023 the UK MoD issued a contract to Airbus Helicopters to extend support for the Puma HC2 until March 2028.

A venerable but dwindling fleet

The RAF's original fleet of 48 Puma HC1s first entered operational service in June 1971 – almost 53 years ago, making it the oldest rotary-wing platform in RAF service – while the first of an eventual 24 upgraded Puma HC2s was delivered back to RAF Benson for operational trials in August 2013. The final Puma HC2 was rolled out in December 2014, before the RAF returned the upgraded Puma fleet to operational service in 2015, intended to serve until 2025.

According to UK MoD figures accurate as of 1 April 2023, the RAF had a total of 18 Puma HC2s at that point, of which 13 were in service. The clear concern is that, if the number of available Pumas dwindles, the HC2 fleet's taskings (which now also include the Cyprus mission) will have to be supplemented by other types, most likely RAF Chinook heavy lift helicopters, with a resultant strain on the serviceability of those replacement aircraft.

The Chinook fleet may have gained some respite with the announcement on 31 March 2023 that the UK MoD had finally agreed a deal with the US government under which 14 new Boeing H-47 Chinook Extended Range (ER) helicopters will be procured. However, with the extended-range capabilities of these aircraft, they are most likely to be earmarked for a special forces role, while deliveries of the new Chinooks will not occur before 2027.

Thus, the RAF and support partner Airbus will have to do their utmost to keep as many as possible of the venerable Pumas flying beyond 2025 and probably until 2028.

Sensor fusion: The future of land ISTAR?

Sam Cranny-Evans

As sensor fusion and AI begin to enter the networked warfighting space, armed forces have been experimenting with and implementing some of the new possibilities these technologies can provide.

In 2020 a data centre at Joint Base Lewis McChord in the US began to receive data from a number of low earth orbit satellites and an MQ-1C Gray Eagle drone. The data was processed with the assistance of artificial intelligence (AI) before being passed onwards to Yuma Proving Ground. There, a targeting solution was created and passed to a specially designed howitzer, which loaded an XM1113 rocket assisted projectile fitted with a precision guidance kit (PGK), and fired. The whole process reportedly took less than 20 seconds. No forward observers, no tactical drones, no radars – except for the ones used to track the guided munitions. As it happened, the XM1113 projectile landed near the target but failed to detonate, but that was sort of the point. This engagement was not part of a live conflict, but an element of Project Convergence, the US Army's experimental framework designed to explore multi-domain operations (MDO). It was unique because a long-range engagement was conducted using only space-based and strategic intelligence, surveillance, target acquisition and reconnaissance (ISTAR) assets. The data was interpreted and analysed with the help of AI and used to carry out an attempted engagement.

This approach may reflect the future of ISTAR for land warfare. Not so much the specifics – but the fusion of multiple sensor outputs into a coherent operational picture to generate non-traditional targeting cycles.

Author

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Credit: US Army/Ana Henderson

The US Extended Range Cannon Artillery programme was designed to develop long-range precision strike capabilities from a tube artillery system and increase the quantity of effectors capable of exploiting the benefits of sensor fusion.

The nuts and bolts

"Fusing information and then taking action has always been key to winning on the battlefield. It's just that in the past, these sensors were human beings, information was passed verbally or in writing, and the fusion happened inside a commander's head," Will Blyth, co-founder and CEO of Arondite, a defence tech start-up building AI and autonomous systems told ESD via email. "The emerging ISTAR paradigm shifts the human up the value chain" he added, which means that the outputs from multiple external sensors can be fused into a single operational picture by AI and then presented to the human.

This is one of the core challenges of driverless cars, which must take the inputs from multiple sensors of different types and fuse them into a single understanding of the surrounding world. The car can then make decisions based on its understanding of that world. While it is likely that a driverless car will receive sensor data from external systems – a satellite navigation network for instance – the bulk of the computing will be done on the vehicle with its sensors. It is, in that sense, computing at the edge. Military systems will always require the outputs from multiple external sensors to be fused into a single operational picture. This requires design decisions about where computing should be done. In the ISTAR chain of direct, collect, process, disseminate; AI and sensor fusion are applicable to all stages. However, the primary consideration here will begin with collect, and proceed through process, and disseminate.

For example, it is possible to install a computer loaded with AI algorithms onto a drone. As the drone records imagery of the world around it, the algorithms would go

to work on that imagery feed and generate outputs. The algorithms might be trained for image recognition or navigation, for example, and feed that data back to the operator on the ground. It is also possible to provide that data onwards to another system, a fire control system for example, which is where the application becomes exciting. An alternative solution is to retain the AI computing power away from the edge, on the ground control station of a drone, or at a command post, for example. This allows for greater computing power but may require more communications bandwidth to transmit live video data or signals intelligence before the computing is carried out and outputs created.
There is also the question of algorithms. It is likely that most military applications will require multiple sets of algorithms trained for different purposes. For example, a drone fitted with a camera and an edge-processing capability might have one algorithm for image recognition, which has several applications such as identifying camouflaged vehicles, or artillery flashes. It may feed its outputs to a sensor fusion algorithm that compares and collates the information it receives from the drone's sensor before distributing that information to other systems. The same camera and computer may include a navigation algorithm, which uses terrain matching and image recognition to understand where it is, and where it is going in a GNSS-denied environment. Combined, several algorithms can be used to autonomously generate targeting coordinates for an effector.

Credit: PEO Missiles & Space

The IBCS from Northrup Grumman shown here was designed to provide a sensor fusion capability to air defence. It has been tested using various radars and sensors from the air and land. It is in production for the US Army and various other users.

Credit: АрміяInform, via Wikimedia Commons

A Leleka-100 drone carried by a soldier near Avdiivka. Ukraine has brought a trend to the fore that has been emerging for some time, the spread and proliferation of tactical reconnaissance assets. This increases the potential benefits of sensor fusion.

But why?

AI is often touted as something between the necessary future of defence, and a solution for all of defence's problems. The reality is that it is probably something between these two extremes. It can generate new capabilities by helping to fuse sensors and shooters ever closer together. It can also solve challenges presented by declining force and equipment levels; where in the past a human team would be sent for reconnaissance, a machine can be sent in their place and AI used to bring all of the outputs together. For land ISTAR, sensor fusion offers new capabilities such as the use of space-based assets for target engagements. It can also be used to generate different routes to an outcome. For example, the US Integrated Battle Command System (IBCS) demonstrated an air defence capability that combined a PATRIOT battery with AN/TPS-80 G/ATOR radars from the USMC and two F-35s. The system shared targeting data between its assets, something not normally possible, and conducted a successful intercept against a cruise-missile like target. In theory, if this kind of technology were realised at scale, it could unlock the potential to include almost every sensor on a battlefield in an air defence network and fuse the bewildering array of outputs that would result into a single air defence picture. "By shifting the human up the value chain, you reduce cognitive burden, but there is also a requirement to place our values at the heart of how we deliver this chain," Blyth explained. "This means ensuring that development of AI for the battlefield needs to be explainable and auditable, retaining the human as the decision maker," he added.

In surface-to-surface applications, some challenges of ground-based observation include duplication or 'double-counting,' and developing a shared understanding across a battlespace. With AI, it is theoretically possible to identify a platform and maintain an understanding of that platform between sensors, thereby minimising the risk of duplication. For example, a T-72B3 emerging from a forest could be identified by one drone, which would share its understanding of that tank with an armoured reconnaissance vehicle through a battle management system. As the tank came into view of the reconnaissance vehicle and its sights, the tank would be re-identified and confirmed to be the same tank that the drone had spotted earlier. This understanding could be shared across a formation using pixel-sized identifiers that only AI can spot. In an alternate scenario without sensor fusion, it is possible that this tank would be identified and reported twice as two different vehicles, which complicates the task of establishing situational awareness.

Edge computing capabilities, with a small AI-enabled computers installed on each platform within a formation would enable this kind of capability and create a shared understanding of the battlespace and an adversary's movements between each operator as well as reduced duplication of reporting. There are many applications for this type of sensor fusion; consider for example the challenges of operating in Ukraine or Afghanistan. In both conflicts, the force footprint is and was relatively low for the area of operations.

RUSI estimates from February 2024 indicate that there are some 470,000 Russian troops in Ukraine, while on 9 September 2023, Ukraine's Defence Minister Rustem Umerov claimed a total of 800,000 members of the Ukrainian armed forces – though it is estimated the majority of are not deployed on the front line. These are ostensibly large numbers, but very few when considered against the 1,000 km long frontline. The frontline numbers for Ukraine may be closer to 200,000. Deployments are often conducted at a section-level, with 10 – 15 personnel occupying and operating over a frontage of a few kilometres. It is not possible for a small section to control an area this large in a high intensity war. It seems likely that the extreme dispersion in Ukraine is at least part of what drives the mass use of drones – one for every section.

However, the way that the data collected by drone operators is fused together is often very slow. It may include team calls on a virtual meeting suite and the cumbersome sharing of targeting data through extraction of screen shots. To reduce this time lag, it seems that drone operators are often co-located with an artillery system to provide real time fire adjustment. It works, but the process could be more efficient.

In Helmand province, Afghanistan, the British Army's peak strength was around 10,000 personnel, to patrol and contest an area of 58,560 km^2. Helmand represents an area slightly larger than Croatia, populated by 1.4 million people. The UK's troops were routinely split up into small sections and deployed to isolated forward operating bases. They made extensive use of fixed-wing and rotary-wing air power to provide firepower that compensated for the lack of mass. Artillery also played a key role and armoured rapid reaction forces were maintained to intervene in the event of a contact that involved multiple casualties, or one that could not be resolved by infantry and airpower alone. This did not help to make the battlespace any smaller, however, and the British forces filled the gap with a rapid and extensive expansion of ISTAR assets. The Hermes 450 drone was deployed alongside MQ-9s and larger surveillance assets like the Shadow R1

Credit: RLW-E, via Wikimedia Commons

Forward observers have been important for artillery fire control since indirect fire was first realised. However, as sensor fusion capabilities are realised, the nature of their role may change significantly.

(a modified Beechcraft King Air 350CER) as well as space-based assets and static surveillance balloons.

Many of these systems flew almost continuously from the moment they were deployed generating thousands of hours of footage that had to be processed and analysed – up to nine Hermes 450s were eventually deployed, they had flown 86,000 hours by 2014. Their findings would be communicated manually over radio and in some cases the video footage itself would be beamed directly to troops on the ground using ROVER terminals. The British armed forces required an extensive communications network and spent millions on satellite communications for the duration of their deployment to Afghanistan as a result.

In both scenarios, it is possible to see that sensor fusion with edge-based AI would provide uplifts in situational awareness by automatically combining the outputs of multiple sensors from several domains. As an additional bonus, AI can condense its outputs into metadata packets that are much smaller than live-streamed video and can be distributed across a battle network more easily requiring less bandwidth.

Leading by example

Under Project Convergence the US Army has experimented with FIRes Synchronisation To Optimise Responses to Multi domain operations (FIRESTORM), an AI decision agent used to process huge quantities of data and provide targeting recommendations to a human operator in tenths of seconds. The same process without AI would supposedly take a human tens of minutes. It is reportedly capable of maintaining a clear understanding of the operational picture and matching sensors to shooters. FIRESTORM does not work alone, it receives data that has been turned into a

Credit: USAF/Staff Sgt Allison Payne

The F-22 was the first operational aircraft to combine supercruise, supermanoeuvrability, stealth and notably sensor fusion in a single weapons platform. It is now joined by the F-35 and the US is exploring various means of introducing greater sensor fusion into its armed forces.

common language by Rainmaker, another AI algorithm that works across all sensors and the communications network to ensure that data is received in a format that can be interpreted and processed by a machine. Rainmaker may also play a role in rebuilding the communications network to ensure that data can progress through a mesh network should a node be degraded through jamming.

It is understood that Rainmaker then forwarded data to Prometheus, another algorithm responsible for finding targets within Rainmaker's data. Identified targets are then forwarded on to FIRESTORM, which matches the targets to shooters based on one of a number of decision-making protocols. In Convergence 2020, it found six sensor-shooter combinations, this had expanded to 21 by the time the exercise was conducted in 2021. A final algorithm – SHOT (Synchronized High Optempo Targeting) was used to assign the target to a sensor-shooter pair and disconnect all other pairs so that further target engagements could be undertaken. Prometheus was also used at this point to conduct battle damage assessment.

The Israeli Defence Forces have at least two systems for sensor fusion. The strategic 'knowledge factory', which ingests intelligence from all of the country's services and employs AI algorithms such as Gospel to analyse it. Gospel is actually the final algorithm, it provides targeting recommendations to a human operator in much the same way as FIRESTORM does for the US Army. Other algorithms are used to fuse and analyse the data before it reaches Gospel. It is said to be capable of generating 200 targets in 10 – 12 days, which is around 50 times faster than a team of 20 analysts doing the same work. Another system is more tactical and known as Fireweaver. Fireweaver connects sensors and shooters in a network together in an integrated sensor-to-shooter system. It provides a commander with targeting recommendations based on the positioning and effects of every shooter. Gospel and its supporting algorithms have been used operationally in Gaza; it is also likely that Fireweaver has been deployed too.

In the UK, sensor fusion for land ISTAR is to be realised through project ZODIAC. A contract for ZODIAC was signed with Roke at DSEI 2023 that will cover two further years of ZODIAC delivery. Roke is the delivery partner for the programme, which is expected to provide an underlying systems architecture, that will be used to ingest and fuse data from a variety of sensors. The system is expected to be capable of taking data from all sensors, analysing it, and distributing the resulting intelligence to battlefield users across all domains. It will also provide the foundation for the British Army to deploy AI in its efforts to interpret and understand data.

"For most militaries, AI will be spirally developed and integrated into existing kit, as well as integrated into future product. This will require a closer more innovative approach between primes, defence tech companies and the frontline," Blyth said. Some, like the US and Israel, have started early and gained a lead in sensor fusion development. For others such as the UK, programmes have been initiated and there are companies vying to produce products to meet anticipated needs. However, the future of the British Army's funding is far from clear, despite the geopolitical realities that the force is currently facing.

Looking ahead

At a theoretical level, the advantages of sensor fusion are relatively clear. It enables a force to generate targets quickly and potentially with a more complete understanding of the battlefield. This should lead to better prioritisation of targets – a force cannot hit everything it is presented with at once – which will be beneficial in attacking an enemy's network at an operational level. However, human elements should always be thought of alongside the excited talk of sensor fusion for land-based ISTAR. Few in the West thought that Russian troops would continue fighting in Ukraine after suffering such heavy losses. Many over-estimated the capabilities of Western weapons in the close and deep fight. Nobody could accurately predict the amount of resistance Hamas would generate, despite being faced with completely overwhelming firepower and superior ISTAR resources. Suffice to say, sensor fusion provides the means to engage an opponent more efficiently, but a lot more needs to happen in a battlespace to translate this into victory.

Detecting illicit drugs: Technology and products

Dan Kaszeta

If you declare war on something, industry will make goods to sell to the warriors. This has been the case since antiquity. The so-called 'War on Drugs' is no exception.

A variety of techniques and technologies have come into use in the worldwide struggle against smuggling, manufacturing, and sale of dangerous drugs. The substances of immediate concern shift with the times. At various points, heroin, cannabis, cocaine, methamphetamine have been and continue to be of concern. Fentanyl is a more recent threat. Regardless of substance, the need to detect traces of drugs to guide investigations and searches, as well as the need to characterise suspicious substances, are valid operational requirements. It should be noted that an area of active law enforcement and border protection concern is the detection and identification of various precursor substances used to make illegal drugs. Furthermore, there is a serious overlap with explosive detection and identification, both in end-user and in hardware.

Non-electronic methods

Snoop dogs

Drug detection started with non-electronic methods. Old techniques are still valid. Euphemistically referred to as 'manual search techniques', border guards, custom inspectors, and police can and do tear things apart searching for drugs. This is crude, but effective. A thorough physical search is very good at finding drugs. However, it is time-consuming, alienates the public that the authorities are trying to protect, and is prone to abuse. Tearing apart every car and searching every box in every cargo container is not only unwise, it is logistically impossible, and mankind has long ago enlisted dogs to help. In the time it would take to disassemble a car thoroughly enough to find a small parcel of hidden drugs, a trained dog and handler could screen hundreds of cars.

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Dogs are a time-honoured approach to detecting hidden drugs. Well-trained drug detection dogs are in use around the world. When well-trained and used by a skilled handler, they are highly sensitive at detecting drugs. They also work much faster than many electronic techniques. Trained dogs paired with trained handlers can screen at speed and often can lead the search team to the exact location of a drug stash. A good dog can lead the handler to a drug stash, a task which automated devices can rarely perform.

Detection dogs are not without their issues. They are expensive and need a well-trained handler. The dogs need to be looked after and a skilled handler knows how to maintain the correct work-rest cycle. Overworked dogs do not perform well, and they are, like their handlers, prone to distraction in adverse environments. Dogs have been known to get sick or injured. Various experts point out the hazards of injury to dogs from inhalation of drugs or precursors. Likewise, inadvertent exposure to caustic chemicals, some of which are used in clandestine drug production or even found normally as household substances, can temporarily or even permanently damage a dog's nose. Furthermore, a dog will not be able to tell you what drug it has detected.

Wet chemistry

The other major category of non-electronic drug detection is wet chemistry. All of the major categories of illegal drugs are easily detectable by a range of traditional chemistry techniques. Although chemical processes in actual laboratories have been around for well over a century, and field techniques are often back-stopped by forensic analysis in laboratories, rather a lot of chemical reactions are easily achieved with simple hardware in field environments with far less training needed. Many chemical reactions that show a visible colour change

Credit: USMC/Carlos Guerra

Dogs are still one of the best detection methods.

can identify, at least by broad class, all of the major drugs of concern. Because of this, industry has ensured that a bewildering array of kits, swabs, vials, detector papers, ampoules, and related paraphernalia are available at reasonable prices. This market is highly fractionated and well served by a global web of specialist small and medium enterprises (SMEs). In some countries, kits are even available for household use, with packaging aimed at concerned parents.

Credit: G. Climer

Drug detection test kits are even available commercially in the USA.

Wet chemistry techniques and products have drawbacks. They are primarily designed for users with a sporadic requirement. You would burn through a lot of consumables doing lots of tests every day. They will not help you find hidden drugs and are generally meant for identifying a sample of visible product. In other words, they are there to answer the 'is this substance a narcotic?' question, not the 'which car contains the drugs?' and the 'where are the narcotics hidden in this car?' questions.

Electronic techniques

IMS

The most commonplace electronic means for detecting illegal drugs is ion mobility spectrometry, often known by its acronym IMS. Readers of this magazine will have seen this technology mentioned in articles about chemical weapons detection, where IMS is one of the leading technologies for rapid electronic detection. The same technical approach, which uses some sort of ionisation source to ionise a vapour sample, can detect molecules of various drugs. By ionising a sample of vapour and measuring the behaviour of this sample, the molecular weight of the compound can be deduced, and the substance identified. This same approach works for many types of explosives as well, and the products in this area are often configured for both explosive and drug detection.

Unlike many toxic industrial chemicals and most chemical warfare agents, illegal drugs tend to have extremely low volatility. This means that merely sniffing the air is not likely to be the most useful way to identify traces of drugs. A typical operating principle for an IMS drug detector is to use a swatch or swab of a special cloth or paper, which has been rubbed on an area of interest, such as a door handle, the outside of a suitcase, or something similar. The sample swab is inserted into the IMS detector, which heats up the sample to make the drug traces (or explosive traces) more likely to evaporate into a gaseous form that can be ionised and analysed.

A number of firms are active in this marketspace, often marketing the same or nearly identical product configurations for both explosive and drug trace detection. Smiths Detection (UK) has long held a large share in this market, with its Ionscan series of desktop-sized systems and Sabre series of portable systems. Their long-term rivals Bruker (DE) and Rapiscan (USA) field IMS trace detection production of comparable scope and specifications. Several other manufacturers are also active in this space such as Autoclear (Canada), Nuctech (China), and Securscan (Italy).

nology does have some aspects that can be seen as operational drawbacks. Many of them have some sort of radioactive isotope as their ionisation source, which means that

Credit: USAF/Airman 1st Class Rhonda Smith

IMS detectors, such as this Smiths Detection Ionscan 600, typically use swabs of cloth or paper rubbed on a given surface, in order to detect a target substance.

they come under radiation safety and licensing regimes, thus increasing training, maintenance, and paperwork burden. While the sensitivity of an instrument – its ability to detect a small number of molecules– is an advantage in many ways, the high sensitivity of IMS devices can also pose issues.

For starters, they are trace detectors, not bulk-sample identifiers. Many devices are calibrated to be very sensitive to detect small traces and can be overloaded by a strong sample. A system swamped with a strong sample of opiates or cocaine might take many hours to clear down, being out of service until it can cleanse itself. In practice, some detectors could be so overwhelmed that they would need factory servicing. Cross-contamination can also be a problem, and operators who do not follow correct procedures may cause numerous false positives. For example, the floor of a rental van that had held some drugs might give a positive reading days or weeks after it has been hired out to someone else. For these reasons, training is very important with IMS devices. They are best used as a follow-on to other search techniques.

Shine a light

There are several technologies that are designed for broad-spectrum analysis of unknown solids and liquids. By necessity and design, devices designed for interrogating unknown materials will give some utility in detection of drugs, precursors, and common cutting agents. Two of these are Fourier Transform Infrared (FTIR) spectroscopy and Raman Spectroscopy.

FTIR is absorption spectroscopy. Infrared light is introduced to a sample of material, and the device determines which wavelengths are absorbed and which were not absorbed. If you do this to something such as bare metal or a chunk of salt, you get a bad result. However, if you do this to an organic chemical (such as drugs and explosives), you get interesting information by looking at this absorption spectrum. The spectrum will serve as a chemical fingerprint. In theory, it can detect basically every illegal drug. In practice, you get a lot of blends as drugs often are 'cut' with various substances. However, you can add all of these blends to a library, algorithms can interpret the data for a non-specialist operator, and you can send a spectrum reading to a chemist who can help understand the spectral data. Once large, expensive instruments that were the province of laboratories, devices as small as a shoebox or a briefcase are now routinely used. Training is denominated in hours, not weeks. Such a device can answer the 'is this white powder a drug or a baking product?' question.

Credit: USAF/Airman 1st Class Rhonda Smith

The Smiths Detection HazmatID is one of a number of FTIR chemical identifiers.

A Raman device works in a related manner. Organic molecules will have a 'Raman' spectrum, named after the discoverer of the technology, C.V. Raman. A low-energy laser is fired into a sample of material, and the light scattered from the sample is examined. This Raman spectrum also works as a chemical fingerprint and can be compared to vast libraries. As with FTIR, this technology has gotten much smaller. Typically, Raman devices are now smaller than their FTIR cousins, and handheld systems are commonplace. However, because they introduce energy into a compound, one has to be careful. More than once, a Raman device has caused a fire in a suspected clandestine drug laboratory. Again, this is largely a training and operating concept issue, not an inherent drawback to the technology. Finally, because the sensor never comes into contact with the sample, it is easy to avoid cross-contamination. It should also be noted that technologies such as gas chromatography and mass spectrometry (GC/MS) are also useful in this role, but often represent a higher-end solution that is more expensive and complicated than necessary for most users.

A variety of manufacturers are present in the FTIR and Raman space. Smiths Detection (UK) has long fielded a family of FTIR devices under the 'HazmatID' tradename. They have gained extensive market penetration over the last two decades and have a reasonable reputation in the law enforcement and border protection fields. Thermo Fisher, the US conglomerate, has a number of offerings in this segment and good market penetration in the North American market. RedWave (USA) has FTIR products that are visibly quite similar to the Smiths offerings. Several other companies including Serstech (Sweden), Rigaku (Japan), and 908 Devices (USA) are strong players in Raman detection.

Backscatter: Straight outta Compton

We should not neglect the venerable technology of X-rays in the struggle to detect smuggled drugs. X-ray systems have a variety of uses in this field. Medical X-rays have long been an investigative tool to help detect whether someone has swallowed or otherwise secreted balloons or similar containers of drugs. Conventional and computed tomography X-ray imagery is not likely to detect drugs directly, but they can be useful investigative tools to find containers and items that have been modified, thus leading to suspicion. This is an area where algorithms and machine learning may be useful. If a computer has looked at 25,000 X-ray images of televisions or car radiators, image 25,001 with something slightly different may be an indicator to look for contraband. Large X-ray systems could find void spaces in vehicles or cargo containers. Due to radiation safety concerns, a lot of training, regulation, and precautions are necessary with X-ray systems. Smiths and Rapiscan are two of the leaders in this space.

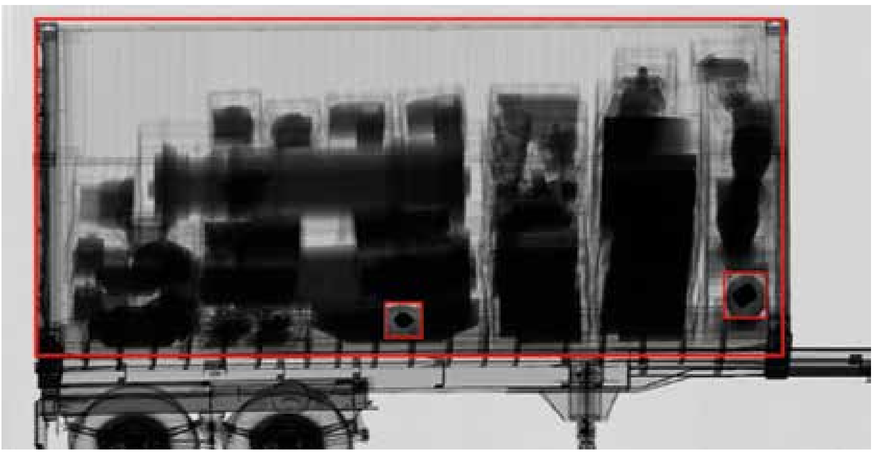
X-ray technology has advanced beyond simply providing images. The way X-ray photons interact with matter can actually derive some information. Backscatter technology uses so-called 'Compton' scattering to determine the presence of organic matter. This can be used to locate possible quantities of drugs, and has been used on body scanners. X-ray diffraction is another technique. When combined with computed tomography (CT) techniques, various types of drugs can be detected in baggage. This particular segment is the most likely one to watch for future developments.

Operating concepts are key

What none of these products, techniques, and technologies will do is to give an operational end-user a useful concept of operations to make it all work together. None of the technology works as a magic wand to detect drugs from a distance. Indeed, fraudsters preying on the ignorant and corrupt have gone to prison for selling fake devices that purported to be basically magic wands – most notable being the infamous ADE-651 scandal. Since no technology or technique is ideal, a system-of-systems approach is almost always needed.

Depending on the type of operation, a blend of tactics and technology are needed. For a low-volume prison operation, physical pat-downs and manual searches may still be the best. For a high-volume land border crossing, or a major port, manual searches are the absolute last resort, and saved for the most necessary operations. Dogs, trace detection, wet chemistry kits, x-rays, and FTIR/Raman devices can all be used in a logical way and in a rational hierarchy in order to have a high probability of detection and to rationally allocate sparse manual search assets

The drug threat does evolve, but the good news is that most of the techniques here are amenable to easy adaptation, except for dogs, which are not easily upgraded with software patches. Yet the electronic instruments all use adaptable libraries and new threat information can be rapidly provided to end-users as part of routine software upgrades. ■



Credit: Rapiscan

X-ray systems can examine entire cargo containers. Software algorithms can then rapidly analyse images to detect contraband.

Nuclear weapons at sea – is their use viable?

Sidharth Kaushal

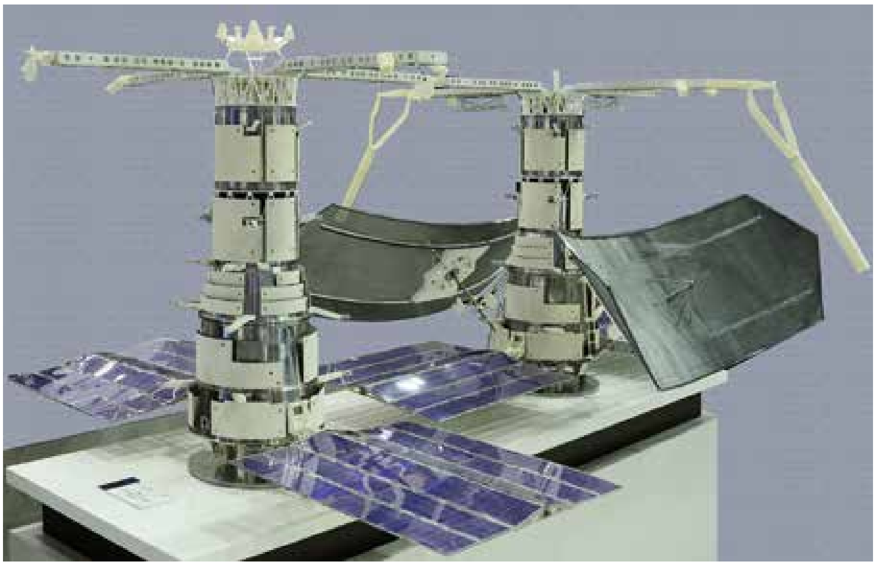
Against the background of the War in Ukraine, the spectre of nuclear conflict has re-emerged from the wilderness of a Cold War past where it has spent the last three decades. While the use of nuclear weapons has remained a prospect all should wish to avoid, it has nonetheless remained a stubborn strategic possibility. As such, it is worth examining the topic from the standpoint of nuclear weapon employment in a modern-day naval conflict.

Throughout much of the 20th century, a presumption that warfare at sea could involve the employment of nuclear weapons underpinned force design. The staying power of vessels against missile attacks, for example, was deprioritised partially because of an assumption that on a nuclear maritime battlefield, should vessels fail to intercept incoming targets, they would largely become non-survivable. Nuclear-armed mines and depth charges were also an important part of the arsenals of both sides during the Cold War as a means of achieving area effects against elusive targets such as submarines.

For much of the Cold War, official US policy was that nuclear use against American assets at sea would be treated as being no different from a nuclear attack anywhere else. However, at the time some scholars questioned whether this was indeed a credible deterrent – after all, unlike tactical nuclear use at scale on land, the use of nuclear weapons at sea would inflict only military casualties. Against a continental power such as the USSR the challenge was that most forms of nuclear retaliation which would be damaging enough to be credible would necessarily have to target the Soviet homeland and would represent strategic nuclear use rather than the tactical employment of nuclear weapons.

The theory that battlefield nuclear employment at sea could be deterred by the threat of strategic escalation was never tested but there are reasons to believe that this threat was not regarded as credible. This has ramifications for both the conduct of nuclear deterrence under contemporary conditions and the employment of naval forces in the emerging operating environment.

Thinking about nuclear conflict at sea, at least in public discourse, has largely receded with the assumption often being that in the event of a nuclear escalation the character of a conflict has altered to the point where previously held assumptions about warfighting no longer hold. In effect, all nuclear use is to be treated as strategic, with the ramifications that this entails being part of what is expected to deter an opponent. While there is something to be said for strategic ambiguity as a deterrent strategy (insofar as this leaves an opponent without clear consequences to plan against and mitigate) there is some evidence that, at least in the European theatre, this may not be sufficient.



Credit: Vsatinet, via Wikimedia commons

Scale models of the Lotos-S (left) and Pion-NKS (right) satellites, developed for the Liana ELINT programme.

Russian Naval Planning

It is of note that Russia's planning document 'Fundamentals of the state policy of the Russian Federation in the field of naval activities for the period until 2030' explicitly identifies "the capability of the Navy to damage an enemy's fleet at a level not lower than critical with the use of non-strategic nuclear weapons" as a core naval function.

It is in many respects unsurprising that this should be the case. On the one hand, Russia has demonstrated that its capacity for conventional targeting at sea is limited at best, particularly in what the Russians identify as the areas beyond their coastal defensive zones (out to slightly over several hundred kilometres from Russia's coasts). Russia has largely failed to replace the Soviet era Tselina and Legenda electronic intelligence (ELINT) and radar-equipped satellite constellations. The Pion and Lotos satellites which collectively form Russia's Liana constellation have only been launched in limited numbers, meaning that Russia can expect only intermittent situational awareness at long distances beyond its coastlines. Other methods of surveillance such as the use of commercial satellite imagery or data from over the horizon (OTH) radar such as the Polsodnyukh and Kontainer are limited

either by latency or a lack of granularity. The margin of error on the average OTH radar against maritime targets, for example, is up to 40 km.
Many of these limitations have been visible during the ongoing conflict in Ukraine. Over the course of this conflict, Russia failed to sink Ukraine's last remaining surface combatant, the *Yuri Olefirenko*, as the latter was conducting coastal bombardments off the Kinburn Spit and Kherson, eventually sinking the vessel in port. A failure to sink a dynamic target in a highly congested battlespace does not bode well for Russian efforts to target vessels such as aircraft carriers at what will likely be engaged at considerably greater distances. Furthermore, the Russian capabilities most relevant to maritime strike such as the Tu-22M3 Backfire bomber are available in relatively limited numbers compared to the Cold War. Russia fields 63 Backfires at the time of writing and would likely have fewer remaining in service during a major conflict. As such, the likely heavy losses taken by the Backfire force in any attack on an allied maritime component would mean that, if unsuccessful, Russia would have squandered an important strategic capability, which also forms a component of its nuclear triad, for limited effect. Other capabilities such as nuclear-powered attack submarines (SSNs) are also available in far more limited numbers than was the case in the Soviet era – meaning the Russians have a more slender margin for error as the loss of these capabilities cannot be countenanced unless targets of commensurate value are destroyed. It is thus vital for the Russians that if strategic capabilities are committed to the attack under conditions where western forces enjoy greater situational awareness, the odds of success are maximised.
Nuclear weapons could play an important role for the Russians as an offset. However, as will be discussed in subsequent sections, their utility at sea should be contextualized. Nonstrategic nuclear weapons and even strategic capabilities cannot easily be used as an area effect tool to destroy stronger fleets. They can, however, influence important aspects of maritime competition.

Nuclear weapons and anti-surface warfare – its importance and the need for caveats

It should thus not be entirely surprising in the context of the above discussion that Russia retains an emphasis on nuclear use at sea within its naval doctrine. It is, at least in theory, conceivable that the use of nuclear weapons at sea could mitigate the impact of an imperfect kill chain. This being said, there are certain limitations to nuclear use at sea which should also be borne in mind.
There are, broadly speaking, three ways in which a nuclear weapon might be used against a vessel. The first is the destruction of either a vessel's hull or its superstructure through the overpressure generated by an airburst of a nuclear armed missile. Secondly, the thermal energy generated by a nuclear detonation can harm crew members – though this will primarily affect individuals above decks, and since the Cold War vessels have been designed to minimise crew exposure in this area. Third, the shockwave from an underwater detonation can, in principle, physically destroy a hull.
To mission kill a vessel such as an *Arleigh Burke* class destroyer, a nuclear detonation would need to achieve an overpressure of around 48 kPa (7 psi). While comparable data does not exist regarding aircraft carriers, it is worth noting that when landing vertically an aircraft such as the F-35B generates around 18,144 kg (40,000 lb) of pressure which would imply that carrier flight decks can sustain considerably more pressure. However, there is no reason to believe other superstructure elements such as the castle should be less resistant to pressure than those on an *Arleigh Burke*.
Based on data gathered from Operation Crossroads, which saw the US Navy Test a 23 kt nuclear weapon against a combination of captured Japanese vessels and obsolete US assets, we can assess that a comparable nuclear weapon could achieve this level of overpressure against a DDG at a distance of around 1.2 km. This would be comparable to the nuclear payload carried on a missile such as the Russian RPK-6/ RPK-7 (SS-N-16 Stallion). On the one hand, this introduces certain advantages – a missile can miss by a margin and still achieve effects. However if, for example, a ballistic missile is within 1.2 km of its target, a manoeuvring re-entry vehicle should be able to guide it to its intended target with a conventional payload. This would also hold for an active seeker equipped cruise missile flying at a high altitude. In other words, if an opponent's reconnaissance and targeting system is refined enough to locate a high-value target with sufficient fidelity to place a missile within roughly a kilometre of its destination, it can complete a kill chain with conventional munitions.
A cruise missile such as the Russian KH-101/102 will carry a considerably larger payload of 250 kt meaning that it would generate comparable levels of overpressure at longer distances of around 2.88 km. However, to get within roughly 3 km of an aircraft carrier, a high-flying missile (which would be necessary in order to cause an airburst) would have had to have evaded all of the defences of a vessel barring its CIWS – added to which, the use of a 250 kt warhead is a rather uneconomical and high-risk means of defeating terminal phase defences. If the means to defeat the other layers

Credit: US Army

Operation Crossroads, Baker nuclear weapons test, on 26 July 1946. Operation Crossroads demonstrated both the strengths and the limits of nuclear weapons as a naval tool.

Credit: Russian MoD

Nuclear-capable cruise missiles such as the Kh-101 are deployed from bombers such as the Tu-95.

of a ship's IAMD can be arrived at, avoiding terminal phase defeat should be possible without the need for nuclear escalation.

An alternative might be bracketing an area with a salvo of nuclear-tipped cruise or ballistic missiles. However, in order to achieve area effects over the roughly 20 km² area within which a ship might be if tracked on the basis of a source such as shore-based OTH radar, a large number of nuclear-tipped warheads would need to be used. This number would grow larger still given that planners would necessarily need to account for the fact that a large part of an incoming salvo would likely be intercepted by shipboard air defences – something evidenced by the air and missile war around Kyiv, for example. Preparing such a salvo would thus require potentially hundreds of low yield warheads to be moved from storage sites to airbases in which strategic aircraft were positioned – raising the prospect that an opponent could not distinguish preparatory activity from preparations for a wider nuclear attack. Moreover, even if an opponent did distinguish the intended targets of an attack and recognised that maritime platforms are the intended vector, this visible preparatory activity would incentivise the suppression of launch platforms with conventional deep strike capabilities.

Undersea detonations – a more viable approach

The detonation of a nuclear warhead underwater might represent a more fruitful method of nuclear use at sea. The shock waves generated can potentially be used as a means of anti-surface warfare (ASuW), a crude means of both countering submarines and disrupting undersea sensor networks such as the US' Integrated Undersea Surveillance System (IUSS). Indeed, this was a use case for both nuclear mines and nuclear-armed torpedoes during the Cold War. The shock wave produced by the detonation of a 100 kt weapon underwater can generate 18,616 kPa (2,700 psi) of pressure at a distance of around 1 km. During the Cold War, tests such as the U.S Navy's 1955 Wigwam underwater nuclear test demonstrated that a 30 kt nuclear weapon could sink a contemporary submarine at a range of 1.6 km (1 mile) – although modern submarines would enjoy greater pressure resistance than their early Cold War counterparts. An even larger payload such as the estimated 2 Mt payload on the Russian Poseidon would, of course, produce comparable levels of overpressure at even greater distances.

However, once more, ASuW is the least-fruitful use case. A large, fast-moving

Credit: US Government

The USS Agerholm tests a nuclear ASROC, on 11 May 1962.

nuclear torpedo should in principle be detected and engaged by anti-submarine warfare (ASW) capabilities at well beyond the distances at which they would be effective at generating an effective shock wave. It should be noted, after all, that ASW capabilities are expected to hold at bay cruise missile equipped submarines using a combination of undersea sensors, maritime patrol aircraft (MPA) and the organic ASW capabilities of a surface force. There is another challenge to using nuclear armed torpedoes as an ASuW capability. When shock waves are generated by an underwater detonation, particularly when close to the surface of the ocean, the upward-travelling waves will rapidly encounter the surface, and thus air, which is a much less rigid medium than water. This contact with a less rigid medium leads to rarefaction – that is, a negative pressure wave being reflected back into the water. The interaction between the initial positive pressure shock wave and the reflected negative pressure wave causes a net reduction in water shock pressure. Consequentially, when objects are near the surface of the water, the effects of a shock wave dissipate more rapidly. Thus, for example, during the Swordfish nuclear tests 10 kt RUR-5A anti-submarine rockets (ASROCs) were launched to distances of about 2.5 km from the destroyer USS Agerholm without the launch vessel facing risks from overpressure. Notably, 2.5 km is well within the range of most modern conventional torpedoes such as the MK 48 ADCAP. As such, it is unclear why, if a submarine has slipped to within 2.5 km of its surface target, it would not use a conventional torpedo. It is for this reason that nuclear weapons were, during the Cold War, largely viewed as a reversionary capability to be used in the event that unexpected flaws in conventional capabilities were discovered in the context of high-intensity combat.

There could be other reasons to use a submerged nuclear capability against a vessel, in principle. For example it might be deemed desirable to 'slime' a vessel – exposing it to enough radioactive fallout that it could not be easily rotated into port for functions such as vertical launch system (VLS) replenishment unless radiological contamination has been controlled for. Moreover, personnel on a vessel would need to conduct their activities in protective gear, potentially slowing the tempo of action. The Agerholm tests would suggest that ships which maintain a roughly 350 m distance from the detonation point can limit their exposure

Credit: Russian MoD

Nuclear torpedoes such as Russia's Poseidon can carry payloads of 2 Mt.

to fallout. Even so, larger-payload weapons detonating at or close to the surface could have the effect of imposing a requirement for vessel decontamination. Even if this did not remove a vessel from a naval order of battle, it would impose requirements on a fleet which would slow its operational tempo. A vessel does not necessarily need to be sunk to be prevented from operating effectively.

ASW represents another area where nuclear use may make more sense. Nuclear detonations at greater depths experience less water shock pressure loss from the effects of rarefaction, potentially making nuclear warheads a useful means of engaging submarines as well as other types of underwater target. Weapons comparable to the RUR-5A could be used to prosecute submarine contacts at long distances, as could even heavier payload systems such as the Poseidon. Currently, only one Russian system carries the Poseidon (the special purpose submarine *Belgorod*) but it could be deployed on other platforms or, indeed, on the seabed. While it would, of course, also be possible to target a submarine using a conventional torpedo or depth charge within ranges of 1-2 km, the use of a nuclear payload would limit a submarine's ability to evade a projectile by trying to outrun a munition, using decoys or diving to greater depths. One of the major challenges with this model was, historically, the fact that the launch platform was itself at risk. This was true for submarines, but also of helicopters, with the Soviets estimating that the likelihood of a helicopter which launched a nuclear depth charge surviving was about 50%. Uncrewed systems could, in principle, obviate this challenge to an extent if they are capable of sufficiently heavy lift.

There are additional functions that nuclear weapons might play in the subsurface environment. For example, they might be used to disable the sensors which comprise networks such as IUSS. Indeed, the use of nuclear weapons in this capacity represented a major component of Soviet planning for a war with NATO. Area effects against fixed arrays of hydrophones are likely to be considerably easier to achieve than the targeting of mobile surface groups and would likely form one part of a layered effort to disrupt Western situational awareness at sea.

This could have crucial knock-on effects for the conduct of surface warfare. Should networks such as IUSS cease to be effective and if area effects can be delivered against at least some Western submarines at reach, then the already stretched Western ASW forces would find it even more difficult to operate at scale. This, in turn, could enable Russia's attack submarines and guided missile attack submarines (SSGNs) to operate with greater freedom – particularly if Allied ASW capabilities are stretched thin by the allocation of US capabilities to the Indo-Pacific, and in the context of a forecast trough in SSN numbers beginning in the late 2020s. The latter is due to the US Navy's relative decrease in SSN procurement levels during the 1990s, and Los Angeles class SSNs being slated for retirement at a faster rate than their replacement *Virginia* class SSNs are entering service.

Deterrence at sea and from the sea

Ultimately, the nuclear threat at sea should be contextualised but not entirely downplayed. It is likely the case that an opponent such as Russia cannot entirely compensate for its targeting weaknesses by using nu-

Credit: US Army

Alternate view of the 26 July 1946 Baker test during Operation Crossroads, which took place at the Bikini Atoll.

clear weapons as an area effect capability. Nonetheless, the use of nuclear capabilities at sea can considerably complicate the employment of naval vessels and could be particularly consequential in the subsurface competition.

This is of considerable concern if, as is often stated, Western nations view their relative advantages in the subsurface competition as a key and enduring advantage. This perceived advantage is already stretched thin by the inherent difficulties in scaling the existing western approach to ASW which will be compounded by geopolitical shifts that will spread US capabilities thin. Adversary nuclear use at sea will exacerbate these challenges and add a new dimension to any conflict with Russia – one in which nuclear weapons have been used against strategic capabilities such as SSNs and hydrophone networks but no civilians have been killed.

While Western policy has historically favoured drawing no distinction between various forms of nuclear use, it is unclear that this is tenable. In practice a degree of flexibility is likely to be needed to deliver response options that are calibrated and proportionate to the provocation at hand. Developing additional low-yield nuclear weapons such as the US' nuclear submarine-launched cruise missile (SLCM) could represent one avenue. However, the use of these capabilities is complicated by two factors. First, they would likely have to be used against an opponent's homeland for a provocation which occurred at sea – effectively generating a strategic level escalation from a theatre level escalation. Second, it is not obvious what a target of commensurate value would be. Targets such as individual airbases would not be so critical to a Russian war effort that a rational Russian leader might accept their loss as the price of a successful maritime campaign which could have strategic ramifications. By contrast, targets such as command centres or the large scale targeting of military facilities with nonstrategic nuclear weapons raise the prospect of strategic escalation.

One avenue might be the forward positioning of nuclear-powered ballistic missile submarines (SSBNs). This approach (which is likely a necessity for British and French SSBNs in any case) would mirror Thomas Schelling's strategy of reducing one's own options in an imagined game of chicken. In this metaphor, one side consciously removes its own options so as to deter an opponent who might calculate that if the other has the option to back down, they will. This can be analogised to cutting one's own brakes in a game of chicken and informing an opponent that this is the case. If allies forward-positioned SSBNs, they would have no choice but to treat any Russian provocation at sea as strategic by definition, irrespective of its scale, and this very fact might deter Russia from presuming that nuclear escalation could be controlled. However, such an approach also means that events cannot be easily controlled – that very fact makes this deterrent credible but also makes it fraught with risk.

An alternative approach might rely on conventional counterforce capabilities. While it is true that nuclear strikes on strategic targets within Russia would likely precipitate uncontrollable escalation, the ability to engage strategic targets with conventional systems in a limited way might not. This was the basis of allied maritime planning in the 1980s, which would have seen SSNs used to strike Soviet SSBNs. In a contemporary context, conventional prompt strike capabilities might be used in a comparable way to demonstrate an ability to engage targets such as command centres or nuclear storage sites with conventional means. That the alliance might be able to do this without risking an all-out nuclear war has been a pervasive Russian fear, which could be used to deter Russian nuclear use at sea. This would require considerable capability investments which are, however, beyond the remit of this article.

In sum then, the impact of nuclear weapons at sea should neither be overstated nor ignored. While they are not transformative across the board, they can change maritime dynamics in important ways which makes deterring their use critical. ■

Autonomous weapon systems: is a practical approach possible?

Manuela Tudosia

While widely debated among politicians and ethically savvy people, the complexities around autonomous weapon systems (AWS) can quickly turn into a headache for engineers and the warfighter. It is well-known that interpretations of the concept vary, depending on culture, social group, political system, and even power politics.

Integrating certain levels of autonomy into weapons systems is accepted today, representing an unavoidable step to cope with overly complex processes and reaction times for a human, for example, when it comes to missile interception. The most contested aspect regarding the high degree of autonomy in a weapon system is when it is able to unleash its lethal effect without 'meaningful human control'. Arguably, we would speak in this case about "Lethal Autonomous Weapon Systems" (LAWS) for which a commonly agreed definition does not exist, as recognised on the website of the United Nations Office for Disarmament Affairs (UNODA).

From the perspective of international humanitarian law (IHL), LAWS are covered by the Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons (CCW). In 2023, the Group of Governmental Experts (GGE) on Emerging Technologies in the Area of LAWS agreed "on the notion that weapons systems based on emerging technologies in the area of LAWS must not be used if they are incapable of being used in compliance with IHL."

Credit: US Navy

Defensive weapon systems that require autonomy for detection and engagement of incoming projectile threats, such as the pictured Phalanx close-in weapon system (CWIS) or 'hard kill' active protection systems seen on land vehicles, are generally accepted and not subject to (L)AWS controversies.

Author

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GA-ASI's Gray Eagle Extended Range (GE-ER) UAV is a further development of the MQ-1C Gray Eagle, and features an automatic take-off and landing system (ATLS) that allows the aircraft to be launched and recovered without any operator interaction.

To remind the reader, the core principles of IHL are:
1) distinction between civilians and combatants;
2) prohibition on attacking those not directly engaged in hostilities;
3) prohibition on inflicting unnecessary suffering;
4) the principle of necessity;
5) the principle of proportionality.

CCW/GGE also published, an informative but non-exhaustive compilation of definitions and characterisations on emerging technologies in the field of LAWS. While the compilation was aimed at facilitating the Group's discussions, it seems to serve in many analyses as a reference for national interpretations of the concept of (L)AWS, and to highlight the differences in perspectives between countries.

Persistent ambiguities regarding a commonly-agreed definition can also imply that the freedom to design certain autonomy functions depends on national understandings, and that the industrial base – whether private or public – will likely follow the requirements derived from their (main) customer, as long as the IHL principles are respected.

Parameters in the characterisation of AWS

The majority of definitions highlight two main parameters: the degree of machine autonomy allowing the system to make decisions and act more or less independently; and the degree of human control, for example to:
- approve the system's decisions before acting;
- reverse the system's decisions to act, possibly even during execution.

Human control over AWS is particularly important when the target involves other human presence, especially civilians, who risk becoming collateral victims. More generally, human control is important because humans – endowed with natural cognitive abilities – are assumed to be better able to discriminate subtleties in changing situations, including receiving new orders. By contrast, machines tend to make decisions based on pre-programmed tasks, rules, and on the processing of available data. As such, an underlying parameter in the characterisation of AWS is the application of artificial intelligence (AI) and machine learning (ML), both key enablers for the performance of the system, including for its degree of ability to discriminate, judge and take action, especially against incoming threats that are too fast-moving for a human to be able to react.

The degree of human control is generally placed in three categories: human *in, on, and out of the loop*. Even the descriptions of these three categories tend to vary depending on which stakeholder describes them. For the purposes of this article, the explanations used by the US Congressional Research Service (CRS) to describe the 'US Policy on Lethal Autonomous Weapon Systems' are used as a reference.

On the other hand, AI and ML could also enable autonomy beyond the possibility of human control and agency, making machine decisions irreversible and/or highly unpredictable. As a result, some regulatory and ethical aspects regarding LAWS become a more specialised extension of the AI/ML frameworks. However, it is worth mentioning that "AI is not a prerequisite for the functioning of autonomous weapons systems, but, when incorporated, AI could further enable such systems. In other words, not all AWS incorporate AI to execute particular tasks", as clarified on the UNODA website.

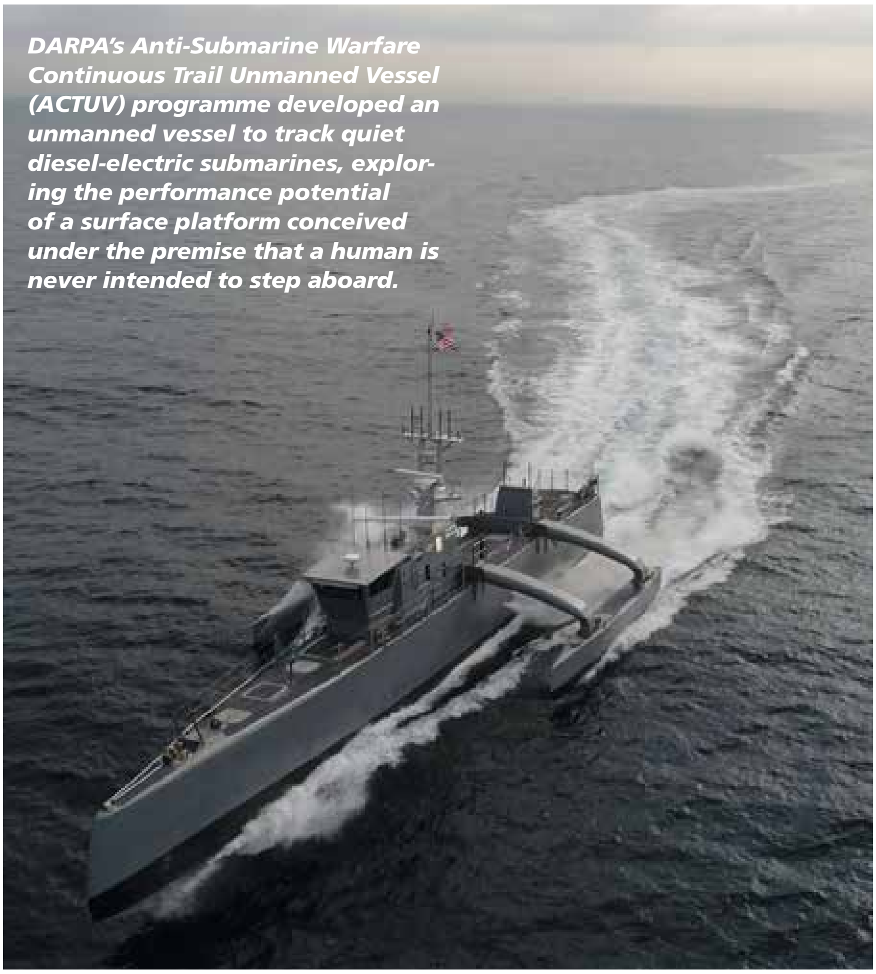
While general agreement seems to prevail on the aforementioned parameters, nuances in scope, as well as in the applicable AI policy and ethical frameworks, may lead to different technological paths for AWS, with consequences beyond the issue of LAWS alone.

Trends of major players

Likely fostered by the competition between them, the US and Chinese definitions (or, rather, 'conceptualisation') of (L)AWS tend to be the most emphasised by the followers of this debate. Both countries admit the possibility of autonomous weapons, including LAWS, therefore a total ban is not envisaged.

Thanks to existing policy, the US approach is relatively clear in the distinctions it makes between 'autonomous' and 'semi-autonomous weapons systems' (SAWS), though it is slightly unclear where the 'lethal' (LAWS) category is applicable.

The US Department of Defense (DoD) Directive 3000.09 on 'Autonomy in Weapons Systems' provides formal definitions serving the purpose of the directive:
- An AWS is "a weapon system that, once activated, can select and engage targets without further intervention



Credit: DARPA

DARPA's Anti-Submarine Warfare Continuous Trail Unmanned Vessel (ACTUV) programme developed an unmanned vessel to track quiet diesel-electric submarines, exploring the performance potential of a surface platform conceived under the premise that a human is never intended to step aboard.

by an operator. This includes, but is not limited to, operator-supervised AWS that are designed to allow operators to override the operation of the weapon system, but can select and engage targets without further operator input after activation."

- A SAWS is "a weapon system that, once activated, is intended to only engage individual targets or specific target groups that have been selected by an operator. This includes: weapon systems that employ autonomy for engagement-related functions (….), provided that operator control is retained over the decision to select individual targets and specific target groups for engagement".

The DoD directive is applicable to both lethal and non-lethal, kinetic and non-kinetic force by AWS and SWAS. The views on LAWS, more specifically, could be derived from the joint position submitted to the UN CCW/GGE (1/2023/WP.4) by Australia, Canada, Japan, the Republic of Korea, the UK, and the US, where lethality appears to be a sub-set of "sophisticated weapons with autonomous functions" (potentially enabled by AI), which include "those weapon systems that, once activated, can identify, select, and engage targets with lethal force without further intervention by an operator".

Describing the US Policy on LAWS, the US CRS characterises them around the idea of a sub-set: a "special class of weapon systems that use sensor suites and computer algorithms to independently identify a target and employ an onboard weapon system to engage and destroy the target without manual human control of the system".

The role of the human operator in target selection and engagement decisions is a particularly important parameter in the US interpretation since it is used to distinguish complete autonomy from other forms of autonomy. According to the US CRS paper, semi-autonomous weapons correspond in the US policy to the category of 'human in the loop', meaning weapon systems that "only engage individual targets or specific target groups that have been selected by a human operator". These can also include "fire and forget" weapons, such as certain types of guided missiles which deliver effects to human-identified targets using autonomous functions.

'Human-supervised' or 'human on the loop' AWS are placed one degree of autonomy higher, meaning that though autonomous, operators still "have the ability to monitor and halt the weapon's target engagement." 'Full autonomy' is represented by 'human out of the loop', meaning a "weapon system[s] that, once activated, can select and engage targets without further intervention by a human operator." Without official confirmation for this, it seems that LAWS are only associated with the category of 'full autonomy'.

Contrary to what some critics suggest, the DoD Directive implicitly admits AI is an important enabler and stresses the importance of compliance with the DoD's 'AI Ethical Principles' and their 'Respon-

Credit: Ziyan UAV

Blowfish A3 is a rotary-wing reconnaissance and attack UAV, part of the Blowfish family developed by the Chinese company Ziyan UAV. Thanks to an optional AI module, Blowfish A3 can automatically identify and track targets, to allow engagement of moving targets.

sible Artificial Intelligence Strategy and Implementation Pathway' in the design and the development of AWS.

Besides being an official source for the US approach on AWS, DoD Directive 3000.09 is primarily a document establishing policy and assigning responsibilities for the development and use of autonomous and semi-autonomous functions in weapon systems. It defines guidelines to minimise the probability and consequences of failures in these systems, as well as rigorous procedures that must be applied for:

i. The design, verification and validation, and testing and evaluation of AWS and SWAS;
ii. the types of approval processes, often very complex, that are necessary for staring design and development of AWS and SWAS;
iii. the approval processes for any modification of an existing system.

The DoD Directive is a functional document that helps engineers and decision-makers to clearly understand what they can/cannot, should/should not do along the entire process of AWS design and development. It is also built upon the US ethical framework, but design and development are not only left to ethical interpretations.

In the context of CCW discussions, China makes a distinction between 'acceptable' and 'unacceptable' AWS. In the first category, the weapons could have a high degree of autonomy, but are always under human control, can be suspended by the human and, therefore, are deemed or expected to comply with basic IHL principles. The unacceptable AWS should include, but not be limited, to a sum of characteristics such as:

1) Lethality conferred by the payload;
2) absence of human intervention and control during the entire process of executing a task;
3) irreversibility of the mission;
4) indiscriminate killing regardless of conditions, scenarios and targets;
5) the possibility for the system to learn autonomously and thus to evolve, through expanding its functions and capabilities in a way exceeding human expectations.

The last characteristic hints to the possibilities offered by AI and ML. In the CCW context, China has given LAWS the same five basic characteristics as the 'unacceptable 'AWS.

The Chinese concept of AWS differs from that of the US in that it is constructed around ethical arguments (acceptable/unacceptable) and does not revolve around measurable parameters such as the degree of human control. Moreover, the concept of LAWS is narrowed down to a sum of basic characteristics, raising the question whether the lack of one would 'disqualify' the system from being a LAWS. As such, the design characteristics/requirements for LAWS are very narrow, and therefore difficult to meet as a sum, but the design characteristics for other (acceptable) AWS are very wide in scope.

The inclusion of the evolution/autonomous learning characteristic, hinting at the opportunities and risks of AI, is an interesting aspect of the Chinese understanding of LAWS. Before the 2017 'New Generation AI Development Plan', aiming to transform China into the AI world leader by 2030, the 2016 'Notification on National S&T Innovation Programs for the 13th Five-Year Plan' introduced the notions of "brain-inspired computing" and "brain-computer intelligence." The China Brain Project adopted in 2016 implements brain-inspired AI research which seeks to (mathematically) describe the brain processes contributing to behaviour, to develop brain mappings and brain-computer interfaces.

In terms of system design, the combination between the various facets of the Chinese AI strategy, and the trends hinted in the '2019 Defense White Paper' – that war is evolving towards "informationised" and "intelligentised" warfare – could lead us to think of a concept of "post-AWS" where, based on sophisticated cognitive processes replicating human brain processes, AWS:

- Are capable of capturing and understanding obvious or subtle changes in the environment, are able to better discriminate between the various types of targets and engage them only under proper conditions, and, if needed, reverse the mission themselves;
- can better team up with the human operators via exponentially improved human-machine interfaces (HMIs), allowing human and machine to take collaborative decisions but leaving ultimate agency to the human.

In such a scenario – which is only imagined by the author – the five basic characteristics of unacceptable AWS (or LAWS) would be even harder to meet as a sum.

It is worth mentioning that, in the CCW context, the Russian Federation characterises LAWS as "a fully autonomous unmanned technical means other than ordnance that is intended for carrying out combat and support missions without any involvement of the operator." It is

Credit: Nickel Nitride, via Wikimedia Commons

ZALA Lancet is an UAV and loitering munition, or kamikaze drone, developed by Russian company ZALA Aero Group. Lancet is estimated to be the primary loitering munition used by Russia in the War in Ukraine and to have inflicted significant damage to the Ukrainian equipment and crews.

noticeable that support missions are also included, and that the targeting function is not specifically addressed. Russia stresses that the "issue [of LAWS] pertains to prospective types of weapons" and their definition should "contain the description of the types of weapons that fall under the category of LAWS" (...) "not be limited to the current understanding of LAWS, but also take into consideration the prospects for their future development", and be "universal in terms of the understanding by the expert community".

At the opposite end of the Chinese narrowed characterisation, the Russian concept is broad, with AWS design possibilities mostly restricted by the designer's imagination.

The EU is known to have one of the strictest regulatory and ethical frameworks, not only regarding LAWS, but autonomy and

AI in general. The 2018 European Parliament resolution on AWS refers to LAWS as "weapon systems without meaningful human control over the critical functions of selecting and attacking individual targets". The resolution called for relevant EU bodies to develop and adopt a common position on LAWS that ensures this meaningful human control, and to work towards the start of international negotiations on a legally binding instrument prohibiting LAWS. The EU Statement made at the 2023 CCW meeting of the High Contracting Parties is also built around the notion of human control. The human must make the decisions regarding the use of lethal force, exert control over the weapons and remain accountable for these decisions. It is also stated that the future GGE mandate "should contain concepts that enjoy widespread support, including [a] so-called 'two-tier' approach to weapons systems in the area of LAWS." The notion of a two-tier approach was introduced in 2023 in the CCW/GGE discussions and suggests that certain AWS will/ should require prohibition and all others regulation. Several countries seem to support this approach, but it remains to be seen if any agreement will be reached on the types of LAWS that should be prohibited.

The EU framework does not prevent variations of interpretation at member state level, especially when defence remains mainly a national competence. Nonetheless, the convergence of views between them was proven by the common position in CCW/GGE in 2022 by Finland, France, Germany, Italy, The Netherlands, Spain and Sweden, as well as Norway, a country that participates in many EU research programmes. This 2022 joint position went in the direction of a two-tier approach.

The European Defence Fund (EDF) excludes the development of what the EU understands as LAWS from its funding actions, but funding for early warning systems and countermeasures for defensive purposes can be envisaged. Anyone acquainted with the EDF process is aware of the complexity of the ethical assessment regarding autonomy and AI functions. At the submission stage, this process was thankfully simplified through a questionnaire and a range of reference documents. Whereas an ethics evaluation is an absolute necessity, it remains a process of elaborate interpretation based on ethics references. For engineers, who are typically used to respond to a set of design functional requirements, and to take structured and controlled steps based on system engineering and quality assurance standards, a document similar to the US DoD Directive 3000.09, but adapted to EU concepts, would probably be even more welcome.

Design considerations

Taking the analysis above into consideration, and despite some differences, there is agreement at the transatlantic level that human control is an important parameter for the classification of autonomy in weapons. On the other hand, LAWS are understood through the filter of two parameters: machine autonomous identification, selection and engagement of human targets, combined with an impossibility for the human to decide on the engagement, or to reverse it. Precisely to avoid a loss of human control and to better understand machine behaviour (including unpredictable deviations) several actions are necessary, and these include:

- Research to define more granular levels, or aspects, of human control, beyond the notions of *in, on and out of the loop*. Such research shall not be only driven by ethics considerations, and even emotions, but it shall be based on technical realities and rigorous testing and configuration of management processes. Based on this, research shall also be performed into modalities of improving human control despite complexity, as well as into developing *trusted* AI, which is able to integrate human inputs in real time.
- The quality assurance standards must be constantly updated to reflect evolution of automation in conjunction with evolution of human control capacity.
- In a context where multi-domain operations are expected to increase in complexity, an elaborate concept of 'modular autonomy' may be needed, whereby certain autonomous systems can be given the possibility to function autonomously in certain situations but be reconnected to the architecture and the human-led command and control chain when required. Such a concept goes in the direction of a 'reverse-Matrix' scenario where the machine is connected or disconnected, rather than the human.

Conclusion

From an IHL perspective, Russia's war of aggression against Ukraine has shown how much indiscriminate damage can be inflicted by armed platforms which dispose of very basic autonomy functions, such as loitering munitions. Principles of IHL do not state that it is preferable to have a human making decisions, compared to a high-performing AWS which, thanks to its sensing superiority, is capable of precise and discriminate targeting. The main difficulty with AWS, especially LAWS, is the issue of agency and responsibility in case of technical, operational or strategic failure. It should be understood that more autonomy does not necessarily mean less human control, and enhanced capacity to interact with the machines does not necessarily mean superhumans. It is just that, at this point in time, we cannot say clearly who should be held responsible.

Credit: SBU

Sea Baby is a multi-purpose unmanned surface vehicle (USV) developed for use by the Security Service of Ukraine (SBU). It is reported to have been used for the first time in the July 2023 attack on the Kerch Strait Bridge connecting Crimea to mainland Russia.

The EU’s space strategy for security and defence

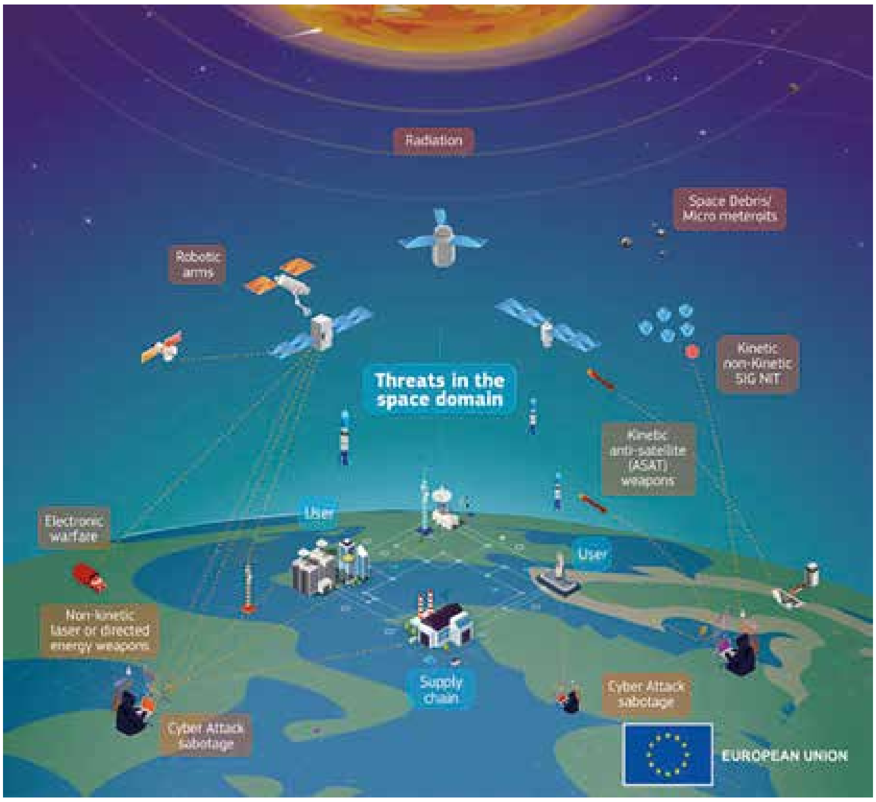
Robert Czulda

In 2022, the EU launched its first ever Space Strategy for Security and Defence. The document confirms that the EU has understood the military significance of space. However, the question remains whether Brussels will be able to achieve its goals.

The space policy constitutes one element of the EU’s broader policy having earlier been included in the 2009 Lisbon Treaty, which introduced a range of new policy areas and expanded a number of them. The treaty unequivocally granted the EU competence in the field of research and technology development. However, most of the documents adopted by the EU primarily refer to a civil dimension, especially to societal and economic matters. For example, the ‘Europe 2020’ strategy proposed in 2010 referred to space activities in the context of globalisation and as a driving force for the innovation of European industry.

It is essential for the EU’s space activities to have dual-use capabilities. Space is now a fully-fledged operational domain and although it has been utilised by various armed forces for decades, its military significance is not always consistently understood and recognised. This is particularly relevant for EU decision-makers, who often have an ideological aversion to military-related activities. Space assets today are crucial in providing critical capabilities to armed forces. The list includes navigation and targeting, communication, as well as observation and analysis of the battlefield – optical, and synthetic aperture radar (SAR) satellites.

The Russian aggression against Ukraine, including its critical phase in early 2022, when Russian preparations for war were assessed based on satellite imagery, vividly illustrates the importance of space systems for both security and foreign policy. Monitoring military movements and their buildup in offensive positions, allows for pre-emptive decision-making, both politically and militarily. Satellite data are also crucial during wartime operations. Real-time detection, identification, and tracking of targets, in order to subsequently destroy them with beyond-visual-range strike systems, such as UAVs or cruise missiles, would not be possible without systems deployed in space.



Credit: European Commission

Key threats in the space domain.

It is important to remember that space assets do not constitute a universal solution and are not a panacea for every situation. Alongside space systems, alternative solutions should also be developed. A diversity of solutions is key to protecting European forces from jamming. For instance, satellite communication can be suppressed, which can impact UAV navigation and communications. The example of Ukraine, whose communications were suppressed during the early portion of the February 2022 Russian invasion, is a perfect illustration. It is also important to note that both China and Russia possess anti-satellite (ASAT) capabilities, with Russia conducting a direct ascent ASAT (DA-ASAT) test in 2021.

Another key aspect is accessibility. Commercial solutions exist on the market, but in a crisis situation, such as during a war, states might not have control over them. These systems can be jammed, disabled, or become politically inaccessible – a good example is Ukraine’s problems with access to the Starlink system, due to interventions by SpaceX CEO Elon Musk. Therefore, it is crucial for states, but also for the EU as an institution, to build effective, modern, and resilient solutions over which they have

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both technical and operational control. If Europe wants to increase its strategic autonomy, then a space programme must be one of its priorities.

The EU's vision for space

Although over the years the EU has published several space-related documents, a strategy launched in March 2023 by the European Commission is the first document that emphasises the significance of hard power. It is a result of the adoption a year earlier of the Strategic Compass for Security and Defence, in which space, along with cyberspace and the sea, was identified as a contentious strategic domain whose security must be ensured. Researchers Raúl González Muñoz and Clara Portela noted that "this marks a shift in policy from a focus on mostly scientific and civilian uses of EU space assets to prioritizing defence-oriented applications".

The EU openly acknowledged the fact that "space is a critical enabler for military missions and operations as well as one of their operational domains along with land, sea, air, and cyber" and reiterated "the need to fully integrate the space dimension into the planning and conduct of Common Security and Defence Policy (CSDP) missions and operations (…) it is necessary to take defence needs into consideration in the creation of dual-use services". The EU strategy proposes two pilot programmes: one to supply initial space domain awareness services by the end of 2024, building on Member States' capacity, and another to introduce a new governmental Earth observation service within the Copernicus Programme. Moreover, the EU plans to respond to space threats, conduct exercises, and detect and identify space objects (space domain awareness).

The EU emphasises the necessity of a shared understanding of threats related to space and a need to build resilience in systems and services. To this end, the European Commission will consider proposing an EU Space Law and establishing an Information Sharing and Analysis Centre (ISAC). There are also plans to ensure the EU's long-term autonomous access to space and increase the EU's technological sovereignty. The EU also acknowledges that space-based services are increasingly crucial for military operations, but simultaneously recognises that those assets are highly vulnerable and need to be protected in close cooperation with partners, such as NATO, which acknowledged space as a new operational domain in 2019 and published its first space policy three years later. The EU also underscores the importance of cooperation with the United States.

EU space capabilities

The announcement of the EU's space strategy in 2023 does not mean that certain capabilities had not already been built up, although these are much more modest – especially in the military dimension – compared to American, Chinese, or Russian solutions. It should also be noted that the EU's space activities do not hold a monopoly in Europe. Several major European economies have their own potential, such as France, Germany, Spain, and Italy; a good recent example of existing capabilities is the Athena-Fidus, a Franco-Italian dual-use satellite providing secure communication to their armed forces and emergency services. As noted by Muñoz and Portela, *"France has long been at the forefront of the development of space capabilities, boasting significant assets in areas such as satellite communications, Earth observation (EO) and military surveillance. Germany has also made substantial strides in the development of space assets, particularly in the domains of EO and communications. Italy has focused on EO and communications capabilities in close collaborations with France, while Spain has also invested in military surveillance and communications."* Regarding the EU's own space capabilities, which are intended to form the backbone of its space strategy for security and defence, the Galileo system was already launched in 2016, effectively initiating the European space policy as established by the Lisbon Treaty. It provides Europe with positioning, navigation, and timing (PNT) capabilities, and according to Muñoz and Portela, "Galileo offers greater accuracy and reliability in higher latitudes than other GNSS [global navigation satellite systems] systems and provides a signal that is more resistant to interference and jamming." It is also worth mentioning the European Geostationary Navigation Overlay Service (EGNOS) system, developed on behalf of the European Commission. EGNOS, a satellite-based augmentation system (SBAS), is used to enhance the performance of GNSS, such as GPS and Galileo. The latest version, developed by Airbus Defence and Space and known as V3, incorporates enhanced security features for civil aviation and offers new services for maritime and land users. Although EGNOS was initially designed for civilian markets, it undoubtedly has military applications as well, as improvements to positioning accuracy benefit navigation and mapping generally.

The EU also operates the Copernicus Earth observation programme, and it already encompasses security-related applications, aiding emergency response, border control, maritime surveillance, and homeland security. Copernicus has established partnerships, including with FRONTEX, and has previously provided maps and intelligence reports to various EU Member States. The security role of Copernicus may further expand in the future. Another example of dual-use potential is the EU Space Surveillance and Tracking (SST) system, a component of the EU's space situational awareness (SSA) initiative. It identifies hazardous objects, such as space debris, which is relevant to detecting hazards caused by DA-ASAT –

Credit: ESA

Galileo's new Telemetry, Tracking and Control (TT&C) facility is a 13.5 m diameter parabolic dish mounted on top of a 10 m structure. Known as TTCF-7, it is based at Kourou, French Guiana, beside the earlier TTCF-2.

Credit: ESA

Ariane 6 (A64 variant) during test removal of mobile gantry at Europe's launch facility in Kourou, French Guiana, on 23 June 2023

for instance, the 2021 Russian DA-ASAT test generated approximately 1,500 pieces of debris. Additionally, there is the GOVSATCOM project, which is to offer satellite communications services, and future Infrastructure for Resilience, Interconnectivity and Security by Satellite (IRIS2).

The EU's space capabilities have numerous limitations, with one of the primary ones being the lack of sufficient independence in launch systems. A significant boost is expected with the launch of the Ariane 6 launch vehicle, which is intended to provide Europe with its own capabilities to lift payloads into orbit. The launch vehicle comes in two variants – Ariane 62 (with two boosters) and the heavier Ariane 64 (with four boosters). The latter weighs close to 900 tonnes and measures 60 m in length, and will be capable of placing payloads up to 20,600 kg into Low Earth Orbit (LEO), or 11,500 kg into geostationary transfer orbit (GTO). The first launch of Ariane 6 is expected to occur between 15 June and 31 July 2024. The next step is the development of a new launch system, which, unlike the Ariane 6, will feature reusable elements. This system, dubbed 'Ariane Next', which is still in a very early stage of development, is expected to be powered by the Precursor Reusable Oxygen Methane cost Effective propulsion System (PROMETHEUS) engine, fuelled by a mixture of liquid methane and liquid oxygen.

Ongoing projects

Thus far, several space-related programmes have been undertaken within the European Defence Fund (EDF) and Permanent Structured Cooperation (PESCO). The latter includes initiatives such as Common Hub for Governmental Imagery (CoHGI) facilitating the exchange of classified governmental imagery at the European level; European Military Space Surveillance Awareness Network (EU-SSA-N), aimed at developing autonomous, sovereign military SSA capabilities to detect and respond to nat-

Credit: ESA

Eine neue Fahrzeuggeneration für den ungeschützten Patiententransport erreicht die Truppe The Artemis I mission, using NASA's Space Launch System (SLS) rocket and the Orion spacecraft with its European Service Module, at Launch Pad 39B at NASA's Kennedy Space Center in Florida, USA, on 12 November 2022.

ural and man-made threats; and EU Radio Navigation Solution (EURAS) focused on developing military PNT capabilities.
Through the Preparatory Action on Defence Research (PADR), a precursor programme of the EDF, the European Commission funded projects such as QUANTAQUEST and OPTIMISE, both aiming to find ways for the EU to prevent disruptions in space. Additionally, the Innovative and iNteroperable Technologies for spacE Global Recognition and Alert (INTEGRAL) project, intended to create a command and control (C2) system assisted by AI and utilising SSA data produced by military space assets, is noteworthy. The EU also funded other interesting projects through the EDF, such as Space-based Persistent ISR for Defence and Europe Reinforcement (SPIDER), a feasibility study on the development of multi-mission affordable intelligence, surveillance, and reconnaissance (ISR) satellite constellations.
There is also Responsive European Architecture for Space (REACTS), which aims to provide "a new disruptive and collaborative defence capability: a resilient and scalable Network of Responsive Space Systems (RSS), fully interoperable, able to launch satellites and commence data delivery within a timeframe of 72 hours". The multinatiOnal Development INitiative for a Space-based missilE earlY-warning architecture II (ODIN'S EYE II) is another project supported by the EDF. It is intended to contribute to the further development of a European space-based missile early warning (SBMEW) architecture initiated under the European Defence Industrial Development Programme (EDIDP). The target system addresses timely warning, technical intelligence, missile defence systems against ballistic, hypersonic, and ASAT threats, as well as proliferation control. Time will tell which of the many funded programmes will succeed and how many of them will become operational.

Credit: ESA

The upper stage for Europe's Ariane 6 launch vehicle in Bremen, Germany.

Closing thoughts

The publication of the EU's Space Strategy for Security and Defence in March 2023 is undoubtedly a positive move. In doing so, the European Union has demonstrated its understanding of the current geopolitical context, including clear tensions that are unlikely to diminish in the coming years. The military significance of space systems has been recognised, but significant issues – including crucial legal restrictions – remain. As Chiara Cellerino rightly pointed out, while the EU space policy falls within the competencies of the EU, "security and defence remains an exclusive competence" of its member states.
Experts also highlight other deficiencies, such as a "common narrative rather than a defence-oriented approach". The EU's space strategy is very general and consists mainly of a collection of declarations. The EU is very active when it comes to expressing its position, expectations, and hopes, but at the same time it is less effective in terms of concrete actions.
Even if the EU overcomes executive impotence, other problems will remain; for instance, how should the EU's space assets be used for military purposes? In the past, not all EU Member States were in favour of using the Galileo system for security-related activities. With the expansion of operational capabilities, problems will accumulate. As noted by Baudouin-Naneix and Liza Raïs, *"the development of a common approach regarding the military use of space technologies meets numerous difficulties. Firstly, the development of such a programme implies the merging of different military systems and doctrines into a single defence doctrine. Secondly, as most of the satellite systems – either communications or even navigation – are related to sensitive and sovereign data or information, a high number of member states are still unwilling to delegate access to the latter at a supranational level"*.

The challenge ahead for Germany's armed forces

Martin Konertz

While Germany has signalled a change of approach toward its armed forces, a number of challenges remain to be overcome before the Bundeswehr reaches a sufficient level of capability and readiness.

Credit: MRV

Germany by international comparison (2021 figures)

Land	Population (millions)	GDP (USD trillion)	Armed forces personnel (thousands)
Germany	83.2	4.28	184.8
UK	67	3.14	156.2
France	67.7	2.96	207.5
Italy	59.1	2.16	171.5
Spain	47.4	1.45	118.7
Poland	37.7	0.68	121.0

Comparison of Germany's population, GDP and armed forces personnel to major European NATO allies. Sources for figures: World Bank, Statista.

As the most populous nation with the greatest economic power and a country in the middle of the continent, our army must become the cornerstone of conventional defence in Europe, the best-equipped armed force in Europe." With these words, the Federal Chancellor described the political and strategic demands on the Bundeswehr in his speech at the Bundeswehr Conference on 16 September 2022, with a clarity that has not been seen in the last 30 years of German security policy. It is anchored in the June 2023 National Security Strategy, introduced as the 'backbone of conventional defence' in the November 2023 Defence Policy Guidelines and thus the basis for the future orientation of the Bundeswehr towards its core mission of defending the nation and her allies.

Ensuring credible conventional defence is a paramount military strategic-operational task. It requires the Bundeswehr to be able to conduct major conventional operations in a NATO context. To this end, it must once again be able to deploy and be ready for action at the same time, with large bodies of troops, no longer relying only on small troop contingents assembled for a specific mission, in a time-consuming manner, and for international crisis management. However, the current structure of the Bundeswehr, which is optimised for operations within this framework, is characterised by centralisation – especially of operational and command support – and by the distribution of responsibilities. This does not allow the Bundeswehr as a whole to respond quickly enough.

In future, the Bundeswehr must have substantial operational and strategic reserves in its structure that do not currently exist. Only this way can the ability to reinforce allies within the framework of collective defence be credibly achieved. The divisions of the Army are currently only operationally capable with the support of other military bodies, and require more organic combat and operational support in when operating as large formations. During the Berlin Security Conference in November 2023, the Inspector of the Army described the drawing up of large formations from the current basic structure as "a nightmare for every troop commander". Neither Germany nor any other European NATO member currently has the necessary support forces for the corps level. Only three of the twelve Bun-

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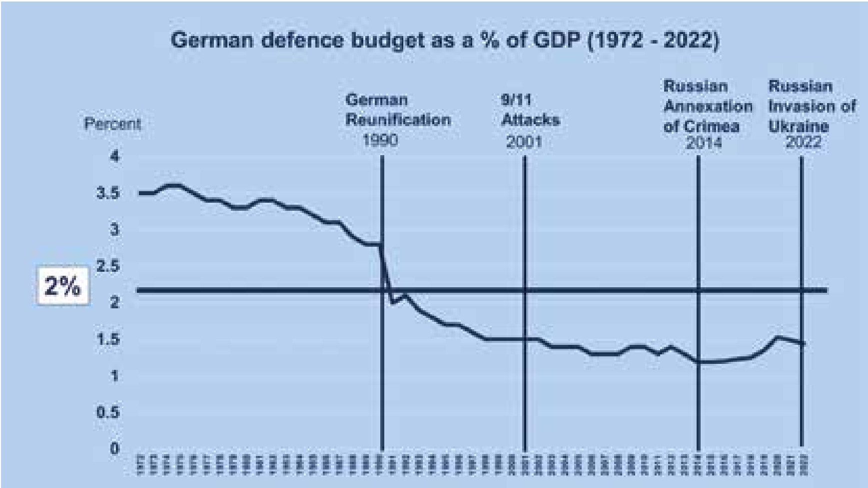
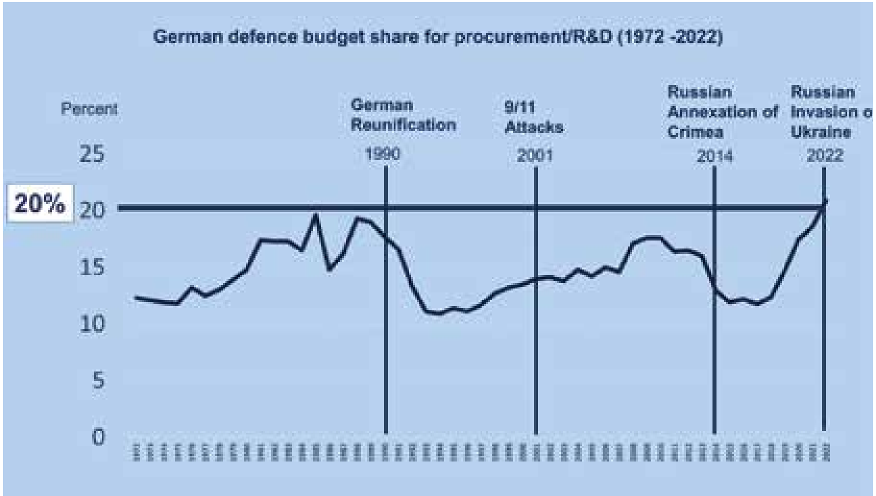
In his last assignment, retired **Brigadier General Martin Konertz** was Director for Capability, Armament & Planning at the European Defence Agency in Brussels.

Credit: MRV



German defence spending as a percentage of GDP from 1972 to 2022, with reference to the NATO target of 2% on defence. Source for figures: NATO.

Credit: MRV



Share German defence budget on procurement and R&D from 1972 to 2022, with reference to the NATO target of 20%. Source for figures: NATO.

deswehr field army divisions remain, though they were considered necessary for credible conventional deterrence and defence until 1990. Moreover, one of these three remaining army divisions is not scheduled to be ready for defence and deployment until 2025, and another until 2027, which shows how unsuitable the current basic structures and procedures of the Bundeswehr are for its new core mission.

In terms of size, structure, equipment and capabilities, the Bundeswehr of the future must clearly stand out in comparison with Germany's European allies to credibly meet the requirements of conventional defence. The Bundeswehr's capability profile must have a broad base; over-specialisation in certain tasks and cumbersome organisational structures are not compatible with force's role as pillar of Europe's conventional defence.

Multinational framework

NATO is the multinational framework for collective defence in Europe. With the Strategic Concept from June 2022, it has refocused on this core task, and decided to increase the deployability of parts of the NATO force structure by 2025 with the New Force Model (NFM) and new regional defence plans. Based on these changes, NATO determines its new minimum overall requirement for military capabilities, forces and resources as part of its quadrennial force planning process. The overall requirement will probably be geared more toward collective defence than for the previous focus on international crisis management. New planning goals will be formulated for each individual NATO nation by spring 2025. They will specify the scope, quality and availability of national armed forces and describe the specific national contributions to NATO's collective defence.

Since 2023, the fulfilment of NATO planning goals has been anchored for the first time in the National Security Strategy and Defence Policy Guidelines as a national political requirement for the Bundeswehr. It must be consistently applied in the National Security Strategy and implemented, along with additional NATO requirements, to build a Bundeswehr capable of credible conventional defence. This was not achieved with the Bundeswehr's previous concept from 2018, even though it already included NATO requirements at the time as an 'essential target' for the Bundeswehr's capability profile. However, implementation was subject to available resources and national decisions. International crisis operations therefore de facto continued to determine the Bundeswehr's capability profile rather than national and collective defence.

Resources

Germany's National Security Strategy and Defence Policy Guidelines enshrine NATO's target of spending 2% gross domestic product (GDP) on defence. This goes hand in hand with the NATO requirement to invest 20% of the defence budget annually in procurement as well as research and development. These NATO guidelines are not unrealistic or arbitrary political guidelines, rather, they are based on years of practical experience in NATO defence planning, outlining the minimum financial outlay for an operationally ready, modern and future-oriented armed force.

Nevertheless, Germany deliberately deviated from these NATO decisions for decades after the end of the Cold War. The result of this deliberate underfunding in defence was a Bundeswehr that is too small, not ready for defence and not capable of war, with a considerable investment backlog.

The NATO 2% target is only being met through the current Bundeswehr special fund, and only for a limited period until 2027, meaning that only a very limited repair of the past is possible. Winning the future will only be possible if 2% on defence is allocated year after year, even after 2027. During the Cold War, Germany demonstrated that this is possible without jeopardising its own prosperity and as a successful welfare state. In view of the threat to the Federal Republic, defence spending was consistently well above 2% of GDP.

A comparison with some European NATO member states shows the considerable differences in population size and economic strength. Germany's obligation to protect by far the largest share of Europe's population is not currently reflected by the size of its armed forces. Germany has the economic capacity to change this and to provide the necessary financial resources. There is simply no substitute for an armed force capable of credible conventional deterrence and defence. ■

European Security & Defence

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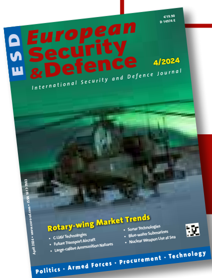

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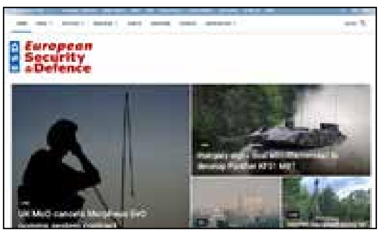

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