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European Defence Fund

Indicative multiannual perspective 2026-2027

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ANNEX

European Defence Fund, indicative multiannual perspective 2026-2027

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I. INTRODUCTION

This multiannual perspective presents possible call topics that are considered beyond those of the current work programme. It aims to enable EU Member States and European Defence Fund (EDF) associated countries [1] to coordinate long-term planning, in line with the main outcomes expected from EDF support, especially for large capability projects that need to be supported through several work programmes under the EDF.

The outlined call topics, together with ongoing and completed EDF projects, reflect the priorities and areas of interests of the Member States, in line with the EU's Strategic Compass for Security and Defence [2]. The EDF contributes to strengthening the European Defence Technological and Industrial Base and enhancing the EU's preparedness, as stipulated in the European Defence Industrial Strategy [3] and the White Paper for European Defence – Readiness 2030 [4].

Furthermore, to allow industry and Member States to focus on and invest in cooperation in a more structured and transparent way, the following table provides percentage indications of the EDF budget expected to be allocated to some categories of actions throughout the multiannual financial framework (2021-2027).

This indicative multiannual perspective does not constitute or generate any commitment from the Commission. The table below and the content of the multiannual perspective will be revised annually in the light of the discussions as part of the preparation of the successive annual EDF work programmes and subject to the availability of annual appropriations.

Category of actions	Indicative EDF budget contribution during 2021-2027
1. Defence medical support, chemical biological radiological nuclear (CBRN), biotech and human factors	
2. Information superiority	> 10%
3. Advanced passive and active sensors	
4. Cyber	
5. Space	> 10%
6. Digital transformation	
7. Energy resilience and environmental transition	> 5%
8. Materials and components	
9. Air combat	> 10%
10. Air and missile defence	> 5%
11. Ground combat	> 10%
12. Force protection and mobility	
13. Naval combat	> 10%
14. Underwater warfare	
15. Simulation and training	
16. Disruptive technologies	4-8%
17. Open calls for innovative and future-oriented defence solutions	

(1) EU Member States and EDF associated countries (according to Article 5 of EDF Regulation) are referred to as Member States from now on.
(2) Council of the EU 7371/22 of 21 March 2022 on 'A Strategic Compass for Security and Defence'.
(3) JOIN (2024) 10 final of 5 March 2024 on 'A new European Defence Industrial Strategy: Achieving EU readiness through a responsive and resilient European Defence Industry'.
(4) See European Commission – White Paper for European Defence – Readiness 2030.

The EU Defence Innovation Scheme (EUDIS) is a tailored set of innovation support measures focused on small and medium-sized enterprises (SMEs), including start-ups, and other non-traditional defence industry players. EUDIS aims to provide them with more opportunities to access and benefit from the EDF. These measures are integrated into the EDF calls for proposals through various approaches, e.g. in the form of i) technological challenges; ii) calls with financial support to third parties; iii) spin-in calls [5] to tap into the dual-use potential of results generated in civil funded EU R&D programmes; and iv) non-thematic calls for SMEs and research organisations on disruptive technologies. EUDIS also includes several support actions such as SME business coaching and organising annual defence hackathons, and enables access to equity funding for innovative defence SMEs and mid-caps through the European Investment Fund. Further SME innovation support services might be added in the future. This tailored approach towards smaller market players aims to build a stronger EU defence innovation ecosystem throughout the EU and help EU Member States develop their military capabilities. EUDIS measures represent approximately 20% of the budget allocated to the EDF annual work programmes.

To ensure interoperability and interchangeability, the EDF will encourage Member States to take up existing common standards and identify the areas where new standards need to be developed, e.g. by building on the European Defence Standards Reference system managed by the European Defence Agency (EDA). It identifies standardisation gaps and best practice standards to support programmes, organisations and agencies.

Furthermore, the EDF will support the implementation of the objectives of the Strategic Technologies for Europe Platform (STEP) [6], with a minimum budget of EUR 1.5 billion allocated to funding activities that contribute to STEP between 2024 and 2027. As set out in the Commission's proposal of 22 April 2025 [7], defence technologies have been suggested as an additional investment area under STEP, alongside digital technologies and deep-tech innovation, clean and resource-efficient technologies, and biotechnologies.

II. INDICATIVE PLANNING PER CATEGORY OF ACTIONS

1. Defence medical response, Chemical Biological Radiological Nuclear (CBRN), biotech and human factors (MCBRN)

The development of defence medical response and chemical, biological, radiological and nuclear (CBRN) capabilities is characterised by a constant flow of innovation resulting from a high level of R&D in industry and specialised research organisations as well as close cooperation with the end-users, particularly Member States' medical and CBRN command centres, including crisis response centres. The ability to consider and integrate human factors [8], evolving defence capabilities – such as the extensive use of unmanned vehicles – and technical systems is needed to achieve the intended benefits in terms of the safety and security of soldiers and first responders in operational scenarios.

([5]) See European Commission – EUDIS: Spin-in Calls.
([6]) See European Union – Strategic Technologies for Europe Platform (STEP).
([7]) COM (2025) 188 final of 22 April 2025 incentivising defence-related investments in the EU budget to implement the ReArm Europe Plan.
([8]) Human factors refer to environmental and organisational factors, as well as human and individual characteristics, that influence behaviour in operational conditions in ways that can affect health and safety. Considering the human interaction with the technology and systems used, it is important to improve soldiers' effectiveness, readiness (e.g. helmet design including head-up displays, physiological constants monitoring, manual handling of equipment especially in difficult terrain, protective clothing, teamwork and leadership, communication, situational awareness on land, at sea and in the air).

In the context of MCBRN, the European Defence Technological and Industrial Base is used to also integrate civilian solutions into offers made to military customers. The constant emergence of new CBRN threats, asymmetric warfare, the weaponisation of biological agents, the lessons learned from the COVID pandemic (biological threats) and the Russian war of aggression against Ukraine (e.g. use of drones, security of nuclear power plants) are driving forces for R&D in MCBRN defence. Moreover, given the high level of global competition, in particular from the US and Asia, and its impact on Member States' and the EU's defence capability priorities, it is highly relevant to maintain a sustained level of investment at European level in this area.

Within the MCBRN category of actions, particular attention is paid to solutions related to:

- the development of CBRN medical countermeasures, biotech included;
- the continuous and strategic development of capabilities in the field of reconnaissance, surveillance and detection, identification and monitoring of CBRN threats;
- new and innovative decontamination methods and procedures;
- CBRN protection and health-state monitoring solutions.

Medical response is also addressed in the Simulation and training (SIMTRAIN) category for medical emergencies.

A number of other EU defence initiatives address the MCBRN field, including:

- The topics addressed in the EDF within the MCBRN category are in line with the priorities of the **Capability Development Plan** [9] and related key areas, in particular the medical support [10] and CBRN defence [11] priorities.
- Participating Member States are working together on MCBRN-related projects as part of **Permanent Structured Cooperation** [12].
- The results of the last cycle of the **Coordinated Annual Review on Defence** [13] identified the development of CBRN protection as an opportunity for cooperation.
- The **Overarching Strategic Research Agenda** defines a number of Technology Building Blocks focused on CBRN and human factors (HF) [14]. These will be developed within the relevant EDA Capability Technology Group (CapTech) CBRN and HF.
- Biotechnologies have been identified as one of the three target investment areas addressed by the **Strategic Technologies for Europe Platform** (STEP) [15]. Topics addressed under MCBRN can therefore be eligible for the STEP Seal under the EDF.

In addition, as civilian solutions contribute to the overall EU response in the context of CBRN protection and response, there are also a number of EU civil efforts and programmes to address CBRN threats [16] that the military can draw on and adapt to their needs.

([9]) See EDA – The 2023 EU Capability Development Priorities.
([10]) Key Area Remote Medicine and Medical Support, Key Area Robotics and Autonomous Systems for Evacuation.
([11]) Key Area Improved and Innovative Recovery and Decontamination Methods and Equipment, Key Area Enhanced Sensors/Advanced Materials.
([12]) See PESCO – CBRN Defence Training Range (CBRNDTR), CBRN Surveillance as a Service (CBRN SaaS) and Unmanned Air Transport of Injured Soldiers (UNATIS).
([13]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([14]) Technology Building Blocks related to CBRN & HF CaptTech/Working Group (WG): Human Autonomy Teaming, Human Performance Monitoring and Enhancement, Customized Training, Integration of Human's Clothing and Equipment in Platforms, Personal Protective Equipment, Detection, Identification and Monitoring of CBR, CBRN Hazard Management, CBRN Modelling and Simulation, Protection of Critical Infrastructure from CBRN, Protection of Food and Water Supply from CBRN, Assessment, Diagnosis, and Medical Countermeasures of CBRN Hazards and Human Resources and Social Sciences.
([15]) See European Union – Strategic Technologies for Europe Platform (STEP).

As a result, the MCBRN category under EDF supports actions across the following fields:

- **Enhancing medical countermeasures**

Medical countermeasures (MCMs) are products and equipment used to diagnose, prevent, protect against or treat diseases and health effects caused by CBRN agents. The EDF has supported the **European Defence Medical Countermeasures Alliance,** which was launched in 2023 under the framework partnership agreement RESILIENCE [17]. The overall objective of the Alliance is to implement, in close consultation with the Ministries of Defence, a European multi-annual action plan for R&D on MCMs against CBRN threats and strengthen European cooperation in order to address current or future CBRN threats with a critical mass of players [18] in this field.

The specific objectives of the Alliance will be achieved through various specific grant agreements [19] for R&D on diagnostic, prophylactic and therapeutic MCMs against CBRN threats). It will also ensure that R&D is properly translated into concrete MCM solutions available to the Member States' armed forces, e.g. by building on some results from the EDF 2021 COUNTERACT project [20]. This aims to establish a robust and agile network within the EU to develop and deploy MCMs against major CBRN threats.

In addition, the EDF 2022 iMEDCAP project [21] includes a user-driven scenario to autonomously detect a casualty and automatically develop an evacuation and rescue strategy. It also provides for an interoperable patient box equipped with diagnostic and intervention devices that can remotely provide first aid while a patient/casualty is being transported. A call for further research on autonomous triage and evacuation has been published for 2025.

- **Strengthening CBRN detection capabilities and operational response**

Support to detection, identification and monitoring started in 2020 with the European Defence Industrial Development Programme (EDIDP)'s 2020 CBRN-RSS project [22]. This project strengthened EU Member States' reconnaissance, surveillance and incident management capabilities against CBRN agents.

R&D efforts continued with the EDF 2021 projects MoSaiC [23] and TeChBioT [24]. MoSaiC provided low-cost chemical and biological monitoring technologies using unmanned surveillance and sampling systems. TeChBioT provided new highly selective and sensitive detectors that operate at high temperatures, enabling the rapid detection and identification of non-volatile biological and low-volatile chemical agents.

([16]) For example, the Horizon Europe programme and the EU Civil Protection Mechanism.
([17]) European Strategic alliance for research, development and innovation on medical countermeasures against CBRN threats.
([18]) Research and technology organisations, private companies (large industries, mid-caps and SMEs), military medical institutes, universities and hospitals.
([19]) The first specific grant agreement, launched in 2023, is a research action that addresses (i) early and high-throughput in diagnosing acute and late radiation-induced human health effects in preparation for an RN event; (ii) innovative decorporating and human decontaminating agents for dealing with RN threats; (iii) production of phage-based diagnostics and therapeutics for infections caused by CBRN-relevant bacteria; (iv) new generation vaccines, including orthopoxviruses; and (v) next-generation cholinesterase reactivators against nerve agent intoxication. Additional specific grant agreements for defence medical countermeasures are included in the 2026 work programme both for R&D actions.
([20]) European agile network for medical COUNTERmeasures against CBRN threats.
([21]) Development of intelligent military capabilities for monitoring, medical care and evacuation for contagious, injured and contaminated personnel.
([22]) Chemical, Biological, Radiological and Nuclear Reconnaissance and Surveillance System.
([23]) Real-time monitoring and sampling of chemical and biological menaces for improved dynamic mapping of threats, vulnerabilities and response capacities.
([24]) Surveillance and Reconnaissance Techniques for Chemical and Biological Threats.

The EDF 2023 CBRN SoS project [25] will design an overarching information system that can integrate with, or cooperate with different existing CBRN defence information systems and components at national and the European level in a modular and flexible way.

In addition, CBRN decontamination systems and technologies are included in the EDF annual work programme for 2026. This call topic seeks new or improved concepts and technology in all stages of the current military decontamination processes for personnel and equipment.

To overcome the difficulty in identifying the source or origin of dissemination of harmful agents, the CBRN forensics capacity may be considered in the future. Additionally, the networking and automation of CBRN data is likely to become one of the most important developments in strengthening the EU CBRN defence capabilities. As a result, it may also be considered in this category in coming years.

- **Human factors, soldier CBRN protection and health state monitoring**

Beyond detection, identification and monitoring and MCM considerations, this category of actions is expected to address other aspects such as human factors, specific CBRN protection for soldiers and monitoring of the physiological and cognitive state of patients and dismounted soldiers [26].

In this vein, the EDF 2022 WEMOR project [27] is investigating the feasibility of a comprehensive health and wellness management system through a single wearable biomarker monitoring device to maximise soldier effectiveness, readiness, protection and recovery.

In addition, in the field of CBRN protection, the EDF 2021 Nano-SHIELD project [28] aims to develop a solution based on nanofiber membranes – specifically designed for military, law enforcement and public use – to filter out harmful chemical molecules and pathogenic biological entities as well as shield against nuclear radiation. Further activities on innovative and sustainable personal protective equipment with improved filtration and contamination prevention or decontamination, including special protective clothing, may be considered in the future.

The EDF 2023 project CAPSARII [29] aims to transform the monitoring of soldiers' psychophysical conditions by developing an innovative smart textile/wearable device.

Additionally, topics related to human factor considerations such as the development of concepts, methods and technologies for enhancing human performance and optimising human-system integration can be considered within this category of actions.

([25]) Enhancing cross-border CBRN operational readiness and effectiveness through an overarching system of systems approach.
([26]) Soldiers or groups of soldiers operating on foot in the field, as opposed to those operating in armoured vehicles, helicopters or other means of transportation.
([27]) Wearable device for monitoring warfighter health and sustainability.
([28]) Multifunctional nanofiber membranes as CBRN Shield for next generation defence and civil application.
([29]) Cyber-secure weArable, ultra-low-Power networked SensoRs for soldIer health monitoring.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the MCBRN category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototype** of a CBRN system of systems capable of federating existing components (standardised architecture and interfaces) and integrating technologies.
- A set of available defence MCM solutions ready for joint procurement and MedTech products to meet future needs.
- **Prototype** of automated and autonomous battlefield casualty evacuation systems.
- **Proof-of-concept and design** of a (semi-)automated decontamination solution for personnel and equipment.
- Concepts, methods and technologies for enhancing human performance and optimisation of human systems integration.
- **Proof-of-concept** and design of CBRN forensics capacity.

2. Information superiority (C4ISR)

Based on a wide range of technologies and capabilities, information superiority enables suitable, timely and accurate information to be collected, pre-processed, processed and shared swiftly and securely with all relevant parties. This is particularly important given that timelines are becoming shorter and the volume of data to be collected and processed is increasing dramatically. Information superiority is therefore essential for any operation as it enables command and control structures at all levels to make informed decisions.

This category of actions contributes to strengthening the EU's strategic autonomy by enhancing its freedom of action in the areas of command, control, communications and computing (C4), electronic warfare as well as intelligence, surveillance, target acquisition and reconnaissance (ISTAR).

In line with the **Action Plan on synergies between the civil, defence and space industries** [30], possible synergies with other initiatives at EU level should be systematically exploited where relevant. Additionally, to address cross-cutting technologies relevant for information superiority in a timely manner, efforts should be made to ensure synergies and complementarity with other EDF categories of actions, particularly those relating to advanced passive and active sensors, cyber, space, digital transformation, and materials and components.

Information superiority is also addressed in other EU initiatives and actions:

- The activities falling under C4ISR category are addressed within a number of the **Capability Development Plan** [31] priorities, the main ones being the Multi-domain Command and Inform Capabilities and Persistent and Resilient C4ISTAR priority areas.
- The **Coordinated Annual Review on Defence** Report (2024) [32] identified multiple areas relevant for information superiority as part of consolidated collaborative opportunities, such as command and information systems and satellite communication.

([30]) COM (2021) 70 final of 22 February 2021.
([31]) See EDA – The 2023 EU Capability Development Priorities.
([32]) See EDA – Coordinated Annual Review on Defence: Report 2024.

- Projects under the C4ISR category [33] that bring innovativeness and reduce strategic EU dependencies can benefit from the **Strategic Technologies for Europe Platform** [34].
- Several **Permanent Structured Cooperation** (PESCO) projects contribute to information superiority [35].

The EDF covers the following fields of information superiority capabilities and technologies:

➢ **Command and control (C2)**

As part of the Common Security and Defence Policy (CSDP), operation headquarters for specific missions and operations (executive or non-executive) are currently selected from a list of available facilities. Although the EU does not have a permanent military command structure, the Military Planning and Conduct Capability, which was established in 2017 as part of the External Action Service/EU Military Staff, is a step towards establishing a permanent EU operation headquarters.

In line with the objectives of the EUMILCOM PESCO project [36], which aims to improve the command and control (C2) systems of EU missions and operations, the EDIDP 2019 ESC2 project [37] aimed to deliver a design for a suite of modular and scalable C2 capabilities. Additionally, the EDF 2022 EC2 project [38] is developing a reliable prototype of a European C2 platform that integrates a suite of C2 tools designed to support the decision-making, planning and conduct of CSDP missions and operations from the strategic to the operational level. This European C2 suite of tools should be interoperable with NATO under the Federated Mission Networking framework as well as with the Member States' C2 systems and any relevant EU tools that contribute to situational awareness. It will complement and boost the emerging C2 capabilities currently used by the Military Planning and Conduct Capability.

In parallel, both internal and external threats, whether symmetric or asymmetric, require a rapid response and the ability to deploy special operations forces (SOFs) swiftly to areas of interest. As part of CSDP operations, SOF-led small joint operations can provide a flexible range of military options for responding rapidly and effectively to crises in an evolving crisis management landscape. In line with the objective of the related PESCO project [39], this was addressed by the EDF 2022 PROTEAS project [40] , which is developing a dedicated SOF command post and its C2 systems to provide adequate flexibility, interoperability, deployability, scalability, robustness, discretion and redundancy, particularly with regard to communications systems and networks. The project is expected to deliver a fully tested and validated prototype by the end of 2026, with the aim of joint procurement by interested Member States.

Furthermore, achieving Single European Sky (SES) interoperability is likely to present a significant challenge to all Member States in the coming years. Military Air C2 systems will need to be adapted to cross-border and SES interoperability rules, particularly with regard to: (i) civil-

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([33]) For example, EDF calls on the Multifunctional Information Distribution System (MIDS), Future military communications and follow-up on ESSOR /EU MIDS.
([34]) See European Union – Strategic Technologies for Europe Platform.
([35]) See PESCO projects – Strategic C2 System for CSDP Missions and Operations (EUMILCOM), One Deployable Special Operations Forces Tactical Command and Control Command Post for Small Joint Operations (SOCC for SJO), Next Generation Small RPAS, European Medium Altitude Long Endurance Remotely Piloted Aircraft Systems – MALE RPAS (EURODRONE) and European High Atmosphere Airship Platform – Persistent Intelligence, Surveillance and Reconnaissance Capability (EHAAP).
([36]) See PESCO - Strategic C2 System for CSDP Missions and Operations (EUMILCOM).
([37]) European Strategic Command and Control.
([38]) European Command and Control System.
([39]) See PESCO – One Deployable SOF Tactical C2 Command Post (CP) – (SOCC).
([40]) DePloyableSpecial OpeRationsFOrcesMulTiEnvironment CommAnd Post and C2 System.

military/military-military coordination; and (ii) the need for connected, secure, reliable and automated data exchange. Another critical aspect to be considered is confidentiality, including the operational need to 'anonymise' some military flights, and the EDF 2022 SESIOP project [41] is addressing this issue. Additional topics in this area could be considered in the future. In any case, coordination and synergies between various EU-funded activities are required to help achieve the following, while avoiding unnecessary duplication:

- connected secure, reliable and automated systems or interfaces for ATM/ANS data exchanges;
- systems or interfaces that ensure confidentiality and anonymisation of some military flights and related critical information;
- conspicuity of military drones and the sharing of information required for training and dual-use mission approval (e.g. the use of military drones for overwater search and rescue);
- dynamic airspace management and reconfiguration solutions;
- a safe and accessible airspace.

Moreover, in the C2 area the EDF 2024 IRONPLAN project [42] builds on EU-funded civil projects to create the first smart, transparent and verifiable C2 system.

➢ **Communications**

Reliable, advanced and interoperable communication concepts and solutions are critical for joint operations. This is particularly true of radio communications, including waveforms, as well as tactical communications and information systems.

The EDF contributes to the development of solutions for tactical communications and information systems, including standardised architecture and interfaces. This is particularly important for intelligence, surveillance and reconnaissance (ISR) network systems as these must comply with national and NATO standards. This will ensure sustainability in the domestic market, reduce dependency on third parties and bolster EU strategic autonomy.

The EDIDP ESSOR project [43] aimed to develop an interoperable secure defence communications system that complies with the Software Communication Architecture standard. A related call topic is included in the EDF annual work programme for 2025, which aims to develop a European multifunctional information distribution system for major defence platforms, providing tactical interoperability via Link 16. It aims to develop a new generation of scalable and multifunctional cognitive transceivers with AI features for use in manned and unmanned military platforms as well as for C2 entities involved in joint operations in multidomain environments.

Moreover, the EDF 2024 HARPIA-Defence project [44] integrates AI-driven surveillance, secure communications and autonomous systems into a unified defence ecosystem. In addition, the EDF 2024 project AI-WASP [45] aims to develop a pioneering solution consisting of an AI-based multifunctional aperture and transceiver, resulting in a prototype of two different system variants to be integrated into unmanned aerial systems and ground vehicles or stations.

([41]) Single European Sky and InterOPerability.
([42]) Integrated Reconfigurable Operational Planning, Navigation, Communication, and Coordination.
([43]) Interoperable communication activities for waveforms at tactical level compliant with European Secure SOftware defined Radio (ESSOR) and Software Communication Architecture software defined radio platforms.
([44]) Harmonised Approach for Resilient Proactive Intelligence Assessment in DEFENCE.
([45]) Artificial Intelligence Warfare Adaptive Swarm Platform.

Robust, wideband communications systems that are reliable, interoperable and mobile, and capable of withstanding detection, acquisition and jamming, are essential for defence operations and electronic warfare. Against this backdrop, the EDF 2021 HIDRA project [46] aims to develop solutions for better detection of faint signals despite strong interference, while the EDF 2021 5G COMPAD project [47] aims to showcase various interoperable tactical bubbles and end-to-end tactical networking, including the potential integration of military assets. The EDF 2024 5G COMPAD 2.0 follow-up project [48] will provide new advanced capabilities to improve interoperability and integration in a multi-domain operational environment. Meanwhile, the EDF 2023 5G-MILNET project [49] is also addressing the issue of the 5G standard for military applications. Further actions for future military communication systems may be considered in the future..

Furthermore, the EDF 2023 OPTIMAS project [50] is developing an airborne laser communication system that can be integrated into air, naval and land units and is applicable to various satellite constellations, while the EDF 2021 P2P-FSO project [51] dealt with free space laser communications. Additionally, the EDF 2023 SDAM4PRD project [52] will develop a counter communication system for disrupting an adversary's satellite communication.

- **Intelligence, surveillance, target acquisition and reconnaissance**

Unmanned aerial vehicles (UAVs) and remotely piloted aircraft systems (RPAS), including high altitude platform systems (HAPS), complement space capabilities and are essential vectors for communications, intelligence, surveillance, target acquisition and reconnaissance (ISTAR). They are critical to achieving and maintaining battlefield superiority in any operation. It is therefore important for the EDF to support collaborative actions in this area in order to: (i) mitigate the risk of dependency on non-EU country suppliers of such technologies; (ii) sustain the European Defence Technology Industrial Base in the field of aeronautics, including the supply chain; and (iii) incentivise joint procurement at EU level.

Since its launch in 2016, the medium-altitude long-endurance remotely piloted aircraft system (MALE RPAS) programme [53] – conducted as part of the organisation for joint armament cooperation (OCCAR) and financially supported by four Member States – has successfully passed several significant development milestones. In 2021, the programme received financial support from the EDIDP.

The EDF ambition for MALE RPAS is to support ISTAR missions in particular and the development of technologies and systems to be used with the aircraft. This will therefore contribute to EU strategic autonomy while ensuring supply chain openness throughout the EU where possible. Complementary topics for EDF funding could therefore be considered to support various related operational requirements when using such a capability.

In addition, the flexibility provided by such multipurpose/multirole tactical unmanned aerial systems (UAS) enhances tactical commanders' ability to make timely decisions based on intelligence and situational awareness information. In this context, the EDIDP 2019 LOTUS

([46]) High Instantaneous Dynamic Range Direct RF sampling modular chiplet Architecture.
([47]) 5G Communications for Peacekeeping And Defence.
([48]) 5G Communications for Peacekeeping and Defence 2.0.
([49]) A portable, private, high-performance, secure, robust, resilient and rapidly deployed ad-hoc tactical 5G and beyond communications system for military operations.
([50]) OPTIcal MilitAry Secure communications.
([51]) Platform to Platform Free Space Optical link.
([52]) Satellite Detection, Analysis and Measurement system for Proactive and Reactive Defence.
([53]) See OCCAR – MALE RPAS.

project [54] aimed to develop an all-European interoperable tactical RPAS with increased survivability and advanced autonomy. The complementary EDF 2023 ACTUS project [55] addresses mission autonomy, environmental resistance and ability to have some specific payloads on board.

Moreover, in line with the objectives of the PESCO Next Generation Small RPAS project [56], the EDF ambition should be to support the emergence of a European market offer for tactical RPAS with increased capabilities that could be jointly procured by interested Member States. This could be used for land, maritime, air and special force operations as well as by non-military bodies involved in e.g. border control, law enforcement or disaster management. Against this backdrop, the EDF 2024 Small UAS [57] and VANTAGE [58] projects aim to develop small (class I) enhanced European UAS.

While core technologies for situational understanding and collaborative behaviour of unmanned systems operating in swarms are addressed under the digital transformation category, the EDF 2023 STEALTH project [59] develops navigation systems in an uncertain or hostile airspace domain using UAV swarms. In addition, several EDF projects deal with different aspects of UAVs, such as HYBRID [60], ALTISS [61], SEAWINGS [62] and AMLTD [63] from the EDF 2021; EAGLES [64], PASITHEA [65] and TDRIC [66] from the EDF 2022; HSM4COM [67], MPortISTAR [68] and SWARM-C3 [69] from the EDF 2023.

Furthermore, R&D for developing specific payloads for unmanned systems should be addressed in due course to equip the next generation RPAS upon their entry into service. The EDIDP 2020 SIGNAL project [70] aimed to improve resilience in complex and/or saturated electromagnetic environments by providing SIGINT capability. Complementary actions may be considered in the future.

Stratospheric persistent airborne systems are particularly well suited to complementing the means of gathering relevant and critical ISR information in support of military operations. They can be deployed quickly and easily and are characterised by their long range and endurance, low operational constraints, and ability to collaborate and interoperate with multiple different systems. Against this backdrop, the EDF 2021 EuroHAPS project [71] aimed to demonstrate the relevance of ISR stratospheric systems in supporting military operations. A follow-up action may be considered in the future to develop a prototype and pave the way for joint procurement by interested Member States.

As with other manned and unmanned air assets, the integration of all the ISR vectors mentioned above into non-segregated airspace must be both safe and effective, particularly in the context of the

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([54]) Low Observable Tactical Unmanned air System.
([55]) Advanced capabilities & Certification for Tactical UAV Systems.
([56]) See PESCO – Next Generation Small RPAS.
([57]) Small UAS.
([58]) Vertical Autonomous Next-generation Tactical Aerial European drone.
([59]) Swarm Technology for Enhanced Autonomous fLight and Tactical Handling.
([60]) Hydrogen Battlefield Reconnaissance and Intelligence Drone.
([61]) Highly Automated Swarm of Affordable ISR Long Endurance UAVs for force protection.
([62]) Sea/Air Interphasic Wing-in-Ground Effect Autonomous Drones.
([63]) Additive Manufacturing of Lightweight Laser Target Designator.
([64]) Efficient Autonomous multirole drone Guard for critical infrastructures surveillancE missionS.
([65]) A Hybrid Autonomous Unmanned Vehicle system opening new horizons in conducting military operations in the marine environment.
([66]) Tactical Drones in Rain and Icing Conditions.
([67]) European cybersecurity HSM/TPM device for securing micro/nano satellite and UAV communications.
([68]) A Man-Portable vertical take-off ISTAR UAV system.
([69]) Command, Control, and Communications for Multi-X Swarms.
([70]) Photonics-bAsed SIGINT payloaD fOr Class II RPAS.
([71]) High altitude platform systems demonstration.

Single European Sky. To this end, the EDIDP 2019 EUDAAS project [72] and its follow-up, the EDF 2023 project EUDAAS2 [73], aim to develop and validate a European detect-and-avoid solution to enable RPAS to operate alongside other manned and unmanned aircraft. In this field, the EDF should aim to help achieve a level of maturity that enables the envisioned European detect-and-avoid capabilities to be integrated into as many assets as possible within the various Member States' fleets.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the C4ISR category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototype** of a European C2 suite of tools contributing to CSDP missions and operations.
- **Prototype** of a special operations forces multi-environment command post and C2 System (SOFC2), ready for joint procurement.
- EU-certified and combat-proven **standardised architecture and interfaces** for tactical communications and radio interoperability.
- MALE RPAS **prototype**, ready for joint procurement.
- HAPS **prototype**, ready for joint procurement**.**
- Tactical RPAS **prototype**, ready for joint procurement.
- EU interoperable and standardised Air C2 solution used to fully integrate military aircraft into the general airspace in the context of the Single European Sky, contributing to information sharing across the civilian and defence domains.

3. Advanced passive and active sensors (SENS)

The integration of advanced sensors into modern defence systems has revolutionised the ability of military forces to detect, track and respond to threats, playing a critical role in improving situational awareness, surveillance and tactical decision-making on the battlefield.

Both active and passive sensors can contribute to electronic warfare operations. These rely on specialised equipment to exploit the electromagnetic spectrum in order to gather intelligence, disrupt enemy systems and protect friendly systems from interference or jamming.

- **Active sensors** are devices or systems that emit specific signals or energy (e.g. electromagnetic or acoustic waves) into the environment and then analyse the reflected or returned energy signals to gather information. They actively scan the environment to detect and track objects, targets or events. Examples of defence applications include radar, light detection and ranging (LIDAR) and sonar systems that emit radio, optical or acoustic waves to detect, track and even identify targets such as aircraft, missiles or submarines.

- **Passive sensors** detect and analyse signals or energy from their environment without transmitting any signals themselves. They rely on signals in the environment (cooperative or opportunistic) to gather information. Examples in defence applications include passive

[72] European Detect and Avoid System.
[73] European Detect & Avoid System, phase 2.

radar, infrared or acoustic sensors. They are used for tasks such as surveillance, early warning and target identification.

Sensors have been identified as critical technologies in the **Action plan on synergies between civil, defence and space industries** [74] as they are relevant to the defence, space and related civil industries and contribute to the EU's technological sovereignty by reducing the risk of overdependence on others for the most needed missions. Sensing technologies are also among the targeted investment areas under the **Strategic Technologies for Europe Platform (**STEP) [75]. Unfunded but good proposals under the SENS category may therefore be eligible for the STEP Seal under the EDF [76].

In addition, solutions related to advanced active and passive sensors for defence are addressed through complementary initiatives and programmes:

- Activities in this category of actions are linked to a number of **Capability Development Plan** priorities [77].
- As part of **Permanent Structured Cooperation** (PESCO), participating Member States are leveraging sensor-related solutions in several projects [78].
- The latest **Coordinated Annual Review on Defence** Report (2024) [79] mentions the use of sensors in several areas for project collaboration, including future ground combat systems and space technologies.
- Sensor solutions as enabling technologies are addressed in the **Overarching Strategic Research Agenda** Technology Building Blocks [80], developed in CapTechs, mainly the CapTech Radar and CapTech Optronics, supported by the closely related CapTech Components and integrated into CapTechs that cover specific domains such as air, maritime, land and space.

The solutions addressed in this category of actions contribute to achieving several objectives, including **strengthening the supply chains** for advanced sensors and ensuring that Member States' armed forces have access to cutting-edge equipment and can fulfil their missions without having to rely exclusively on the support of forces from allied non-EU countries. European cooperation must also focus on the **interconnection and interoperability of sensors**. Sensors that provide data in standardised formats increase the value of the data by allowing their smooth integration into ISR cycle. They also allow systems to be interconnected. Networking multiple sensor systems can significantly improve the quality of the information provided and enable **greater detection performance and coverage**. It is therefore important that the system design and data output allow for further interconnection and data fusion.

To achieve these objectives, the EDF supports projects covering different aspects that leverage the sensing technologies:

([74]) COM (2021) 70 final, 22 February 2021.
([75]) See European Union – Strategic Technologies for Europe Platform (STEP).
([76]) Within SENS, the following call topics were identified as contributing to STEP: Covert sensing and its follow-on, Multidomain sensors demonstrator and test and its follow-on, AI-based joint communication and sensing heterogeneous multispectral and multisensory systems (TBC) and AI optronic sensors for enhanced detection, recognition identification and tracking (TBC).
([77]) Including CDP priorities: Critical Infrastructure Protection & Energy Security, Integrated Air & Missile Defence, Air Combat, Persistent and resilient C4ISTAR and Maritime Domain Awareness. For details, see EDA – The 2023 EU Capability Development Priorities.
([78]) See PESCO – Essential Elements of European Escort (4E), Timely Warning and Interception with Space-based Theater Surveillance (TWISTER), Counter Battery Sensors (COBAS), Artic Command & Control Effector and Sensor System (ACCESS),Integrated Multi-Layer Air and Missile Defence System (IMLAMD), Common Handheld Optronic Interface (CHOI) and Infantry Navigation w/o GNSS (InfNav w/o GNSS).
([79]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([80]) Technology Building Blocks related to sensors include: Communication and distributed sensor networks, surface and underwater and Scalable Multi-function RF Sensors.

➢ Optronic systems and detectors

Optronics was initially covered by the EDIDP 2020 SIGNAL project [81], which aimed to develop electronic support measures (ESM) and electronic intelligence systems that could be installed on Class II of Remotely Piloted Aircraft Systems (RPAS) [82]. In 2021 and 2023, research topics focused on strengthening the supply chain for various infrared detector technologies [83]. The EDF 2021 HEROIC project [84] aims to enable European IR sensor suppliers to sustainably develop the next generation of EU read-out integrated circuit (ROIC) for IR sensors for defence applications. An action to further develop the technology has been addressed in 2025.

In addition, the EDF 2021 ENLIGHTEN project [85] aims to develop disruptive technologies for the next generation of short-wave infrared electro-optical sensing devices to see scenes hidden behind obstacles. It aims to provide a non-line-of-sight technology that is a game-changing capability with the potential to improve the competitiveness, endurance and survivability in different operational scenarios. The EDF 2021 Mini-BOT project [86] aims to establish the first European supply chain of high-performance optical transceivers.

The EDF 2023 ECOSYSTEM project [87] focuses on substrate and epitaxy supply chain technologies, cryogenic and ROIC bumping to strengthen the European infrared detection system supply chain as a whole. Additionally, the EDF 2024 POINTER [88] project is developing a disruptive LIDAR technology, enabling high-resolution 4D imaging under any lighting or weather conditions.

The EDF 2024 Silfrared project [89] will create low-cost, high-resolution and fast-response detectors for night vision applications.

In the future, the EDF could support efforts to validate various innovative optronic sensor technologies and concepts, possibly through a cross-border defence innovation network. A fully photonic radar is to be considered to complete this cycle, together with the application of AI to optronic sensors for better detection, recognition, identification and tracking by land imaging systems.

➢ Radio frequency systems

The Preparatory Action on Defence Research (PADR) 2019 CROWN project [90] was a forerunner in this field as it was the first step towards a multifunctional radio frequency (RF) [91] system based on active electronically scanned array (AESA). The EDIDP 2020 PADIC project [92] addressed a coastal radar network system using passive sensor acquisition in an open architecture. Following these PADR and EDIDP actions, the EDF 2021 ARTURO project [93] aimed to develop advanced radar technologies in Europe. In parallel with ARTURO, the EDF 2022 TIRESYAS project [94]

([81]) Photonics-bAsed SIGINT payloaD fOr Class II RPAS.
([82]) NATO unmanned aerial systems classification: Tactical RPAS between 150 kg and 600 kg.
([83]) In line with several CDP priorities, including Critical Infrastructure Protection & Energy Security, Integrated Air & Missile Defence, Air Combat and Persistent C4ISTAR.
([84]) High Efficiency Read Out Circuits.
([85]) European Non-Line-of-Sight Optical Imaging.
([86]) Miniaturized Board-mountable Optical Transceiver for high data rate Military Satellite Communications.
([87]) European COmon SupplY chain for Sovereign T2SL and infrared Modules.
([88]) Photonic integrated coherent LIDAR with range and rate adaptability for early detection and precise locking on fast moving objects.
([89]) Silicon-based materials for the short-wave infrared range.
([90]) European active electronically scanned array with Combined Radar, cOmmunications, and electronic Warfare fuNctions for military applications.
([91]) Radar, electronic warfare and communications.
([92]) Passive Acquisition by Digital Convergence.
([93]) Advanced Radar Technology in eUROpe.
([94]) Technology Innovation for Radar European SYstem ApplicationS.

focuses on hypersonic and emerging threats and supports a collaborative approach to new concepts of RF systems to make them more versatile. In addition, the EDF 2023 FESPAN project [95] aims to predict anomalies in the propagation of electromagnetic signals. The EDF 2024 ABBOT project [96] addresses the protection of equipment from disruptive electromagnetic interference threats.

Follow-up activities in the field of RF systems are addressed by the EDF 2024 SCEPTER project [97], which aims to combine radar, electronic warfare and communication functions with adaptive cognitive features, creating modular and interoperable systems. These systems should build on technological advances achieved by the solutions provided by the projects mentioned in the previous paragraph. The development of a demonstrator for testing these multi-domain sensors is included for 2026. In addition, to strengthen the supply chain, the EDF 2024 ARRAYS project [98] addresses the need for European commercially available RF components.

Among other follow-on activities, the development of a multi-band 4D radar system [99] linked to the PESCO 4E project has been included in the EDF work programme for 2025 to provide more robust and capable radar systems primarily for naval platforms and, in the future, for ground or air platforms. Smart management of the frequency spectrum will be used to adapt to different environments, threats and jamming scenarios, including the use of multistatic configurations and multifunctional capabilities such as data links to cooperate with other platforms and effectors, or electronic warfare capabilities to jam or protect the systems. Further development of this concept may be considered in the future. In addition, a new topic on an Enhanced Cognitive EW System with Intelligent Radar ESM and Communications ESM Signal Analysis is included in the EDF work programme for 2026.

- **Multi-sensor systems**

The EDF 2022 CASSATA project [100] aims to covert sensing, i.e. the ability to sense without being detected, by fusing three types of sensors (passive sensors, active sensors with a low probability of interception and their interactions) to improve the accuracy and reliability of target detection, identification and tracking. Further R&D in this field may be considered in the future.

The EDF 2023 OPERANT project [101] leverages sensor cooperation to develop a cost-efficient, enduring and autonomous distributed acoustic sensing network, providing vital information on adversarial terrains.

The EDF 2021 Q-SiNG project [102] will provide a navigation system demonstrator for GNSS-denied areas. In addition, the EDF 2024 projects ORDEAL [103], NAVISENSE-X [104], ORIGAMI [105], SNADE [106] and SWARMER [107], all facing technological challenges, address multi-sensor integration for robust autonomous drone navigation in non-permissive environments. The aim is to improve navigation in GNSS [108] denied, unknown and complex environments as well

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([95]) Forecasting Electromagnetic Signal Propagation Anomalies.
([96]) Disruptive structural radar ABsorBing and EMI shielding cOmposite Technologies.
([97]) European Multifunction System Concept applied to Communications, Electronic Warfare and Radar.
([98]) Advanced European RF Components for Wideband Array-Type Radar, Electronic Warfare and Communication Systems.
([99]) In line with several CDP priorities, including Integrated Air & Missile Defence, Air Combat and Persistent C4ISTAR.
([100]) Covert and Advanced multi-modal Sensor Systems for tArget acquisition and reconnAissance.
([101]) rOcket dePloyed deEp Reconnaissance ANd Transmission system.
([102]) Quantum-based Simultaneous inertial Navigator and vector Gravimeter.
([103]) Operational Resilience of Drones in Experiments and Autonomous fLight.
([104]) Autonomous UAV Navigation in GNSS-Denied Environments through Multi-Sensor Fusion and AI-Driven Algorithms.
([105]) DrOne swaRm navIgation in Gnss-degraded And non-perMissive envIronments.
([106]) Smart Navigation for Autonomous Drones in Extreme Environments.
([107]) Swarming Autonomy in non-peRMissive EnviRonments.
([108]) Global Navigation Satellite Systems.

as increase resilience against adversarial countermeasures. Moreover, the EDF 2024 project SIGMA [109] focuses on technological and operational demonstration in a real-world environment of a system for detecting, locating and characterising sources of disruption to GNSS positioning systems.

To complement the capabilities for endo-atmospheric interception and space-based early warning capabilities supported in other categories of action in 2021 and 2022, the EDF 2023 EISNET project [110], which combines different integrated air and missile defence systems [111] through standardised interfaces and data, will contribute to the development of concepts, architectures and proof-of-concept demonstration for networked sensor capabilities based on different European assets to detect small, fast or highly manoeuvrable targets. In the future, a radar system combining opportunistic passive sensor [112] multifunction networks for air and maritime surveillance based on digital and multichannel AESA platforms could be considered.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the SENS category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Demonstrators** of interoperable RF and optronics sensors, such as radar, LIDAR, and electronic warfare systems, with various configurations.
- **Experimented proof-of-concepts** of supplementary sensors to enable UAVs to navigate through GNSS-denied environments and validate their effectiveness.
- **Demonstrators and prototypes** of cognitive system concepts that leverage RF spectrum-sensing and deception techniques through AI/ML capabilities.
- **Prototypes** of advance multifunction RF AESA systems.
- **Demonstrators** of standardised architectures and interfaces for integrating sensors into a modular, scalable and interoperable network.

4. Cyber

In view of the rapidly evolving cyberthreat landscape and the increasing risks and cyber incidents, the cooperation in military cyber defence R&D is important to meet the EU's ambition of strengthening cyber resilience and capability building and maintaining freedom of operation in cyberspace. This category of actions therefore focuses on projects that address new technologies required to meet this ambition as well as operational requirements, in particular in two areas:

- detection, protection and response to cyberthreats;
- cooperative cyber range platforms for improved interoperability and skills development.

Cyber solutions developed under this category of actions are also highly relevant to other categories that rely on digital technologies, such as DIGIT or C4ISR, and also address cyber considerations for other domains and defence systems, such as next generation military communications and autonomous systems, empowering multi-domain operations.

([109]) Space Integrated system for GNSS Monitoring and Analysis.
([110]) European Interactive Sensor-based dynamic defence NETwork.
([111]) In line with the CDP priority 'Integrated Air & Missile Defence' and "Maritime Domain Awareness'.
([112]) In line with CDP priorities 'Maritime Domain Awareness' & 'Integrated Air & Missile Defence'.

The Cyber category of actions is in line with the priorities set out in the **2022 Second Defence Package,** including the **EU Policy on Cyber Defence** [113], and the priorities identified in the joint communication on the analysis of defence investment gaps [114].

The vulnerabilities identified show that the EU is highly dependent on non-EU countries for cybersecurity and cyber defence technologies. This has clear implications for the EU's strategic autonomy and European sovereignty in the field of critical technologies. For this reason, cybersecurity solutions have been identified as one of the targeted investment areas [115] under the **Strategic Technologies for Europe Platform** (STEP) [116]. Projects submitted following an EDF STEP labelled call for proposals, which are of good quality but not funded due to the limited EDF budget, will be awarded a STEP Seal [117].

In line with the **Action plan on synergies between civil, defence and space industries** [118], synergies with civil EU programmes such as Horizon Europe and Digital Europe will be explored to avoid unnecessary duplication of efforts and enable an efficient take-up of results. In this context, the **roadmap for critical cyber technologies** will continuously monitor the potential synergies and provide input where appropriate. Joint investments in innovative cybersecurity solutions will also be supported by other instruments and actors, such as the European Cybersecurity Competence Centre and its network. Complementary to the EDF, defence-specific cyber solutions are addressed through other initiatives and programmes:

- Activities falling under the Cyber category of actions are in line with the priorities of the **Capability Development Plan** [119]. The implementation of these priorities is guided by corresponding Priority Implementation Roadmaps [120] as agreed by the European Defence Agency Steering Board.
- A number of **Permanent Structured Cooperation** (PESCO) Cyber projects [121] are being implemented by participating Member States.
- One of the key findings of the **Coordinated Annual Review on Defence** Report (2024) [122] was the importance of investing in secure and resilient cyber defence and cyber situational awareness, considered equally critical to other capabilities designed for high-intensity warfare and future conflicts. Increased cooperation is also required in the area of cyber-secure and interoperable communications, where limited progress has been made.
- Priorities related to the main operational cyber challenges have been translated into several Technology Building Blocks [123] in line with the **Overarching Strategic Research**

([113]) JOIN (2022) 49 final of 10 November 2022 on EU Policy on Cyber Defence.
([114]) JOIN (2022) 24 final of 18 May 2022 on Defence Investment Gaps Analysis and Way Forward.
([115]) Under the area of deep and digital technologies.
([116]) See European Union – Strategic Technologies for Europe Platform (STEP).
([117]) Within Cyber, the following call topics were identified as contributing to STEP: Post quantum security networks (Follow-on), Cyber Situational Awareness and Understanding exchange platform (Follow-on), Cyber and Information Toolbox (Follow-on), Risk, Robustness and Resilience for autonomous vehicles in military operations (Follow-on) (TBC).
([118]) COM (2021) 70 final of 22 February 2021 on Action Plan on synergies between civil, defence and space industries.
([119]) Priority Full Spectrum Cyber Defence Operations Capabilities and Priority Cyber Warfare Advantage and Readiness. For details, see EDA – The 2023 EU Capability Development Priorities.
([120]) Priority Implementation Roadmap on Cyber Warfare Advantage and Readiness and Priority Implementation Roadmap on Full Spectrum Cyber Defence Operations Capabilities.
([121]) See PESCO – EU Cyber Academia and Innovation Hub (EU CAIH), Strategic C2 System for CSDP Missions and Operations (EUMILCOM), Cyber and Infor mation Domain Coordination Centre (CIDCC), Cyber Threats and Incident Response Information Sharing Platform (CTISP), Cyber Rapid Response Teams and Mutual Assistance in Cyber Security (CRRT), Cyber Ranges Federation (CRF).
([122]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([123]) Technology Building Blocks related to cyber include: Cyber Defence Situational Awareness, Cognitive Science with cyber implications, Exploring convergence opportunities between Cyberoperations and Electronic Warfare, Cross-cutting cyber defence for land, maritime, air and space, The protection of military communications and information systems, Quantum computing and cryptography with cyber implications, Autonomous cyber response capabilities, Modelling and Simulation for cyber defence.

Agenda. These blocks are addressed within the CapTech Cyber and related CAT-B projects [124].

EDF projects under the Cyber category of actions will complement the landscape described with the specific aim of strengthening cyber defence operation capabilities and improving cyber defence situational awareness and system interoperability across the Members States:

- **Strengthening cyber defence operation capabilities**

Following on from the EDIDP projects CYBER4DE [125], PANDORA [126] and DISCRETION [127], the EDF annual work programmes included calls for proposals to improve capabilities for operations in cyberspace.

Based on the existing near-term cyber defence capability gaps, further development actions for cyber ranges were needed. The EDF 2021 ACTING project [128] develops a network of advanced interconnected (federated) domain-oriented cyber ranges for training and exercises. In addition, the EDF 2022 FACT project [129] aims to provide an advanced cyber-physical test range capability through a pan-European federated approach. The EDF 2024 CITADEL Range project [130] addresses the remaining challenge of designing and developing solutions that represent a significant advance over the current state-of-the-art solutions, taking into account the broader technology landscape.

In addition, the EDF 2021 projects AINCEPTION [131] and EU-GUARDIAN [132] address improved cyber operations capabilities, including advanced incident management, that build on the EDIDP projects CYBER4DE and PANDORA. The EDF 2023 AIDA project [133] aims to further exploit these results by developing a common European framework made of prototyped AI-based cyber defence agents capable of performing autonomous and semi-autonomous actions that cover the entire cyber incident management lifecycle to support operators and decision makers in different scenarios. The information warfare dimension, which is intrinsically linked to multi-domain cyber operations, has been addressed by the EDF 2022 EUCINF [134] and EDF 2023 TRITON [135] projects.

Furthermore, from a hardware perspective, a research call topic on *Risk, robustness and resilience for autonomous vehicles in military operations* is included in the EDF annual work programme for 2025 with a spin-in approach. This would support cyber defence in line with emerging technologies, including AI, and would help achieve the main expected outcomes. A follow-on action may be considered in the future to take this matter from research to development and eventually industrialisation.

([124]) For example, the CAT-B CERERE project, which aims to develop a new solution to measure and test the cyber resilience of a specific complex system in a simulated environment.
([125]) Cyber Rapid Response Toolbox for Defence Use.
([126]) Cyber Defence Platform for Real-time Threat Hunting, Incident Response and Information Sharing.
([127]) Disruptive SDN secure communications for European Defence.
([128]) Advanced European platform and network of cybersecurity training and exercises centres.
([129]) Federated Advanced Cyber physical Test range.
([130]) Cyber Infrastructure for Training in Advanced Defence Exercises and Learning.
([131]) AI Framework for Improving Cyber Defence Operations.
([132]) European Framework and proofs-of-concept for the Intelligent Automation of Cyber Defence Incident Management.
([133]) Artificial Intelligence Deployable Agent.
([134]) European Cyber and INFormation warfare toolbox.
([135]) Generative Automation of Security Penetration Tests.

To detect hardware trojans that could leak information or alter the functioning of defence systems, the EDF 2022 HARTROID [136] project was launched.

The EDF 2023 BATTLEPAD project [137] aims to improve the security and reliability of end-user devices such as mobile phones and tablets, with benefits for defence applications. As verifiable, secure and trustworthy IT components are basic building blocks for safe and secure defence systems and general automated solutions, a call topic on *Improved cyber defence operations capabilities* has been included in the EDF annual work programme for 2025.

The EDF 2023 SEQURED project [138] addresses the quantum threats to defence systems. Additionally, the EDF work programme for 2026 includes call for proposals on *Quantum Secured Tactical Networks*. The aim is to provide EU armed forces with a network architecture framework based on quantum technologies. Other topics could be considered in the future to step up the security and safety of Internet of Military Things components. These would primarily address software solutions, but could also address hardware.

- **Improving cyber defence situational awareness**

Member States have identified the need to enhance proactive detection capabilities and improve cyber situational awareness as a prerequisite for more effective cyber operation capabilities. This could include or be linked to the development of a comprehensive threat hunting model. The EDIDP ECYSAP project [139] laid the groundwork for addressing cyber situational awareness (CSA). This line of work has been complemented by the EDF 2022 NEWSROOM project [140], which aims to overcome the current limitations of CSA by studying all relevant CSA aspects and designing an integrated CSA platform that combines data insights and cyber intelligence. In addition, the EDF 2023 ECYSAP EYE project [141] further matures the development of this pathway, with the aim of enabling the transition from defensive postures to understanding changes in cyberspace and exploiting the opportunities they present. A further follow-on to CSA development may be considered in the future.

Contributing to enhanced situational awareness, the EDF 2023 DAEDALUS [142] project will design miniaturised and cyber hardened airborne radio frequency front ends for Satcom. Additionally, the EDF 2024 VEODDA project [143] aims to develop a prototype-stage demonstrator of a cybersecurity solution to guarantee the veracity of Earth Observation data.

([136]) Hardware Trojans Identification in Large-Scale integrated circuits.
([137]) Single end-user Device for Secure Command, Control and Communication.
([138]) Strengthening Defense Networks for the Quantum Era.
([139]) European Cyber Situational Awareness Platform.
([140]) Adapting Cyber Awareness for Evolving Computing Environments.
([141]) European Cyber Situational Awareness Platform - Enhanced Cyberspace Operations.
([142]) Design of Airborne Efficient and Disruptive Advanced front-end for Long range Unlimited Secure systems.
([143]) Veracity of Earth Observation Data for Defense Applications.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the CYBER category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototype** of common and interoperable systems for cyber defence operations, including advanced incident management in support of cyber rapid reaction teams.
- **Prototype** of common and interoperable systems for information warfare covering the full spectrum of cyberspace.
- **Prototype** of common and interoperable cyber situational awareness systems leading to mission-centric prototypes, contributing to a common cyber operational picture at EU level.
- **Prototype** of federated and collaborative cyber ranges to support the development of cyber warrior skills through training and exercises and the resilience of cyber-physical systems.

5. Space

Military operations rely heavily on space-based data and space-enabled capabilities, including dual-use ones. These capabilities are required to provide secure, robust, reliable and high-performance services in an ever-changing threat landscape. Space capabilities can provide fast, continuous and discreet situational awareness services that are globally available, including in space itself. They also support decision-making processes and the conduct of military operations.

Joint R&D actions under this category of actions will provide access to higher-performance services such as increased bandwidth and area coverage, service continuity, greater responsiveness and resilience, and improved interoperability. These actions will also help strengthen the EU's strategic autonomy by consolidating demand for capabilities.

In complementary ways, several other EU defence initiatives address the space domain:

- The **Capability Development Plan** highlights Space Operations [144] and Space Services [145] as EU defence priorities [146].
- Several Member States are working on space-related projects as part of **Permanent Structured Cooperation** [147].
- The 2024 **Coordinated Annual Review on Defence Report** [148] identified space services, space technologies, satellite communications and satellite-based ground observation as areas of significant potential for collaboration among EU Member States.
- In the EDA framework, the **CapTech Space** addresses challenges in space defence, with five objectives focusing mainly on research and technology (R&T) [149]. Participating

([144]) Key areas: Space situational awareness, Access to space, Protection of space systems.
([145]) Key areas: Space-based Earth Observation capabilities, Positioning, Navigation and timing, Satellite communication (SatCom).
([146]) See EDA – Capability Development Priorities.
([147]) See PESCO – Common Hub for Governmental Imagery (CoHGI), Defence of Space Assets (DoSA), EU Radionavigation Solution (EURAS), European Military Space Surveillance Awareness Network and Timely Warning and Interception with Space-based TheatER surveillance (TWISTER).
([148]) See EDA – Coordinated Annual Review on Defence Report.

Member States run several **CAT-B projects** on space-based situational awareness or low Earth orbit satellites [150].

Furthermore, in line with the Action plan on synergies between civil, defence and space industries [151] and the joint communication on a European Union Space Strategy for Security and Defence [152], possible synergies with other initiatives at EU level, such as the Space Programme and Horizon Europe, should be systematically considered where relevant.

Against this background, the Space category of actions addresses the following fields:

- **Earth observation for ISR applications**

Some Member States are already developing and using their own military-class space capabilities for ISR applications within national and, in some cases, multinational frameworks. However, these high-end capabilities have certain limitations on revisit, responsiveness and spectral diversity. Meanwhile, the private sector is offering an ever-growing range of services to an ever-increasing number of customers, including ministries of defence. These services include very high-resolution, low-revisit satellites and high-revisit constellations of medium- to high-resolution small satellites (not limited to imagery). These commercial offerings are not usually designed primarily for defence purposes and have certain limitations (e.g. security and non-EU dependencies). Finally, the EU's Copernicus programme provides a variety of Earth Observation services to support various EU policies, including security-related ones such as maritime surveillance, border control and support for external actions. These services could be further developed within the next decade.

In this context, the EDF's ambition is to support the development of a prototype European space-based ISR constellation. This constellation would be able to provide reactivity, e.g. tactical tasking of satellites and delivery of space ISR, if needed, via a secure space-based communication infrastructure [153]. It would also offer near real-time monitoring, e.g. high revisit rates on areas of interest, while providing diversity of sources, e.g. night vision/infrared, hyperspectral, radar and passive RF detection. This capability could take the form of a constellation of small satellites, complementing existing high-end national/multinational governmental and commercial capabilities. It will also cover ground segment aspects and a federation layer, including, where possible, those promoted within the PESCO framework. Synergies with the EU Space programme should also be explored (e.g. shared use of the system based on predefined use cases, possible agreed governance and co-financing) in view of a potential future EU Earth Observation governmental service [154].

The EDIDP 2019 OPTISSE [155] and EDIDP 2020 NEMOS [156] projects already addressed the early development stage of technologies and products for small optical satellites for maritime surveillance. Building on this momentum and with the aim of meeting the aforementioned objective while expanding the scope of ISR beyond maritime surveillance alone, the EDF 2022 SPIDER

([149]) Coordinate and strengthen R&T for Space Defence in Europe; Overcome shortfalls and support new capabilities in the space domain as regards defence and security; Foster innovative cooperation among the EDA participating Member States in R&T for space defence; Act as an interface between MoDs and industry for achieving European autonomy; Generate innovative collaborative R&T projects for space defence.

([150]) CAT-B projects: Autonomous Space-based Situational Awareness and Artificial Intelligence (ASSAI), Military Crisis-Response Satellite Constellation (LEO-2-VLEO) and Very Low Earth Orbit Satellite for Defence (VLEO-DEF).

([151]) COM(2021) 70 final of 22 February 2021.

([152]) JOIN(2023)9 of 10 March 2023 on the European Union Space Strategy for Security and Defence.

([153]) For example, the Secure connectivity constellation promoted by the Commission.

([154]) For which the Commission engaged with EDA, who shared with DG DEFIS the Common Staff Requirements and Business Cases established within the project team Space-based Earth observation (PT SBEO), consulted Member States' defence and security communities and launched two 1-year feasibility studies in 2024, which drew their conclusions in Q2-2025.

([155]) Very high resolution OPTIcal payload for Small Satellites for defencE applications.

([156]) Novel Earth and Maritime Observation Satellite.

project [157] initiates the development of a constellation of small satellites for ISR applications. To allow for continuity of efforts towards the expected outcome of EDF 2021-2027 support, the EDF work programme for 2025 includes a call for further development up to prototyping and partial in-orbit testing. Further funding may be required in the future to achieve the expected outcome.

- **Space domain awareness**

Although space is widely recognised as a congested, contested and competitive environment, only a limited number of EU Member States have developed and are using space situational awareness (SSA) capabilities (mainly national demonstrators or secondary missions of assets not designed to perform SSA). From an operational perspective, these Member States cooperate within various multinational frameworks, including the EU Space Surveillance and Tracking (EU-SST) framework, in which they provide space surveillance and tracking services such as collision avoidance, re-entry analysis and fragmentation analysis. Meanwhile, the private sector in Europe is beginning to offer SST/SSA services, including to ministries of defence. However, the EU and its Member States still lack a full spectrum of SSA capabilities to ensure the autonomous, sustainable and secure development of activities in space, while monitoring and protecting their space assets against an increasing range of threats [158]. Such SSA capabilities and EU-SST services will be essential for developing a European approach to space traffic management and for addressing the challenges outlined in the EU Space Strategy for Security and Defence [159].

To detect, identify and characterise the threats to space-based infrastructure and services, the EDF aims to support the full development of a prototype of European SSA capability, in synergy with the EU Space programme where possible. This prototype would provide a comprehensive space picture and deliver services to both defence and civil end-users. This could take the form of a network of national, commercial and multinational/EU assets [160], allowing the sharing and processing of SSA data as well as the delivery of ad hoc services. Such EDF support should lead to the joint procurement of SSA capabilities interfaced with EU-SST.

The EDIDP 2020 SAURON project [161] addressed the early development stages of enhanced sensors, while the EDIDP 2020 INTEGRAL project [162] focused on advanced command and control for SSA. Additionally, the EDF 2021 NAUCRATES [163] and SPRING [164] projects aimed to develop microsatellites for geostationary orbit surveillance and intelligence. Building on this momentum and with a view to meeting the aforementioned objective, the EDF 2023 EMISSARY [165] and BODYGUARD [166] projects addressed the system as a whole (i.e. sensors [167] and C2) for space-based surveillance of threats and protection of space assets. Furthermore, the EDF 2023 STAALION project [168] will further develop technologies for in-situ threat analysis, while the EDF 2024 LUCID project [169] will examine the military specific features of threat

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([157]) Space based Persistent ISR for Defence and Europe Reinforcement.
([158]) Definitions of SSA in the defence domain and in the civilian domain have a different coverage. SSA for defence includes the need to characterise and anticipate potential unfriendly behaviour in space, which is not covered by civilian SSA definitions.
([159]) JOIN(2023)9 of 10 March 2023 on the European Union Space Strategy for Security and Defence.
([160]) Including those that could be hosted by the EU Secure Connectivity infrastructure.
([161]) Sensors for Advanced Usage & Reconnaissance of Outerspace situatioN.
([162]) Innovative and iNteroperable Technologies for spacE Global Recognition and Alert.
([163]) Microsatellite for Geostationary Orbit Surveillance and Intelligence.
([164]) Space Response to Risk & Integration with Ground segment.
([165]) European Military Integrated Space Situational Awareness and Recognition capabilitY.
([166]) Autonomous SSA Bodyguard Onboard Satellite.
([167]) Including new compact spaceborne hyperspectral cameras and miniaturised FMCW-based space radars or more in general miniaturised compact sensors for nanosatellites for space-to-space SSA.
([168]) Space Threats Analysis based on Automated reaL-time In-situ capabilities and Onboard processing decentralized Network.
([169]) Lunar and Cislunar Identification and Detection.

detection in the cis-lunar region from ground and space, and the EDF 2024 SPADER project [170] will address technologies for vaporising space debris. Further funding may be required in the future to achieve the expected outcome of EDF 2021-2027 support.

- **Space-based missile early warning**

While the threat posed by ballistic and hypersonic missiles is growing, e.g. due to developments in missile and/or space programmes and the breakdown of landmark arms control pacts, the EU and its Member States lack operational missile early warning capabilities and are entirely dependent on non-EU partners.

In this context and in line with the Capability Development Plan priority of developing an Integrated Air and Missile Defence capability, the EDF should support the development of a space-based early warning capability that can detect and track missiles early on (e.g. ballistic and hypersonic) prior to handover to ground-based radars. This would directly contribute to the protection of EU territory against missile threats. It could also represent a significant step towards a more comprehensive European anti-missile defence capability [171] that incorporates various stakeholders, technologies and products.

The EDIDP 2020 ODIN'S EYE [172] project addressed the early development stage of such space-based early warning capability. Building on this momentum and with a view to meeting the aforementioned objective, the EDF 2022 ODIN'S EYE II project aims to progress to the design phase.

- **Positioning, navigation and timing, and navigation warfare**

The emergence of new threats such as advanced electronic warfare (e.g. sophisticated jamming and spoofing), cyberattacks at different levels and hybrid threats as well as the possibility of attacks on space and ground infrastructure requires improvements in robustness and resilience. This will ensure an adequate level of positioning, navigation and timing (PNT) performance and dependability for EU forces in any operational situation.

To improve EU strategic autonomy, PNT solutions, in particular Galileo PRS-enabled receivers for various defence equipment and applications, must therefore be developed and progressively integrated into military platforms alongside other PNT sources where appropriate. Such European solutions will help EU defence users to reduce their dependencies on non-EU GNSS providers. At the same time, European navigation warfare (NAVWAR) capabilities must be developed to counter the aforementioned threats and improve the overall resilience of PNT solutions. In this respect, potential synergies with Galileo 2nd generation should also be explored.

In this context, the EDIDP 2019 GEODE project [173] and the EDF 2021 NAVGUARD project [174] are actively contributing to this objective by advancing the development of PRS receivers and space and ground-based NAVWAR surveillance respectively. Additionally, the EDF 2024 SIGMA project [175] will conduct in-orbit experimentation to identify the sources of GNSS signal disruption. The EDF work programme for 2026 includes follow-on developments of Galileo PRS receivers with NAVWAR capabilities for integration into various platforms and testing.

([170]) Space Debris removal system using concentrated solar rays.
([171]) See AIRDEF category of actions.
([172]) multinatiOnal Development INitiative for a Space-based missilE earlY-warning architecturE.
([173]) Galileo for EU Defence.
([174]) Advanced Galileo PRS resilience for EU Defence.
([175]) Space Integrated system for GNSS Monitoring and Analysis.

- **Secure satellite communications**

While a limited number of Member States are developing and using military-class satellite communications (SatCom), others rely on government-secured assets or commercial providers to provide an increasingly wide range of secure communication services. The ability to exchange (classified) data with guaranteed availability in any operational scenario is a key element associated with strategic autonomy. The growing number of SatCom applications (e.g. UAS and broadband) and the increasing sophistication and variety of threats (e.g. cyber, hybrid, ground- and space-based) will require greater SatCom capacity, coverage, robustness and resilience.

Additionally, ensuring interoperable and secure satellite communications for defence would provide effective and adequate services for defence users over time and space, address the proliferation of security risks, allow for new usage and lead to increased EU interoperability, availability and reduced dependency on non-EU SatCom service providers. The EDF 2021 EPW [176] project is contributing to this objective by developing a preliminary European protected waveform (EPW) that aims to create a European standard for secure satellite communications with adaptable security and resilience layers. Additionally, the EDF 2021 RFSHIELD project [177] will address the protection of SatCom services from interferences. Meanwhile, the EU is paving the way for a future secure connectivity space infrastructure (space connectivity constellation/IRIS^2), which could implement this EPW standard in the future to provide government satellite communication services that would benefit both civilian and military end-users (e.g. additional bandwidth for defence applications that require low latency and/or do not require military SatCom, improved geographical coverage, relay for other space- or ground-based capabilities). The EDF 2024 EPW-Phase 2 [178] project will build on this work, while enabling the further analysis of potential future synergies with IRIS^2. Further funding may be required in the future to meet the expected outcome of EDF 2021-2027 support.

In addition, R&D into space cloud infrastructure and services together with space connectivity solutions for air combat have been identified as potential topics of interest that may require support in the future. Furthermore, interfacing with and using IRIS^2 could present new opportunities for future defence systems. In this respect, future R&D activities should focus on developing the necessary IRIS^2 end-user terminals for defence applications.

- **Responsive space**

While the European Space Agency is co-financing the development of a family of space launchers ranging from light to heavy (Vega and Ariane), which are operated from Europe's Spaceport in French Guiana, the EU and its Member States currently lack responsive and mobile launch solutions that can discreetly put microsatellites or agile vehicles for specific defence applications into specific orbit, within 48-72 hours' notice, including on-orbit services and operations.

In this context, the EDF 2022 REACTS [179] project was selected for funding as a first step in this field, and a potential follow-up topic could be considered in the future.

In a complementary manner, the EDF work programme for 2025 includes a call for proposals for a collaborative spin-in development action on technologies and capabilities that enable future on-orbit services and operations for defence applications, while considering potential synergies with ongoing

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([176]) European Protected Waveform.
([177]) RF Interference Removal for Military Services Based on Spaces Link.
([178]) European Protected Waveform (Phase 2).
([179]) Responsive European Architecture for Space.

and upcoming civilian R&D initiatives [180] in this field (dual-use potential). Depending on the achievable ambition, a follow-up topic could be envisaged in the future.

- **Space data processing**

To catch up with the 'data wall', it is of the utmost importance that the Member States and the EU work together in a coordinated and efficient manner to address the issue of space data processing, making the best possible use of AI techniques.

The EDIDP 2019 PEONEER [181] project and the EDF 2021 IntSen2 [182] project already addressed the development of such data processing for ISR applications. As a cross-cutting research topic relevant for 'Earth observation/ISR' and/or for 'Space domain awareness', the EDF work programme for 2024 included technological challenges [183] on multisource satellite image analysis [184] in order to encourage emulation and innovation in the area of processing of space military and/or dual-use data for specific defence applications. This led to the selection of four projects, i.e. MARTINA [185], ARGOS [186], ARGUS [187] and MYRIAD [188]. If Member States are willing and if the technological challenges are successful, these efforts could continue in the future. A dedicated development action could be implemented to integrate the AI modules and techniques identified into operational systems, providing the defence community with augmented processing and exploitation capabilities.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the Space category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototype** of PRS receivers integrated into EU Member States' military systems and tested (autonomy/synergy Space/Defence) and strengthening of NAVWAR capabilities, ready for joint procurement.
- SSA **capabilities** interfaced with EU SST and ready for joint use or procurement.
- **Prototype** of space-based missile early warning system interconnected with other relevant sensors and effectors.
- **Prototype** of space-based multi-sensor ISR constellation, including a user-ground segment federation layer.
- **Prototype** of a secure waveform for satellite communications ready for joint use or procurement (potential synergies with the space connectivity constellation, subject to further analysis).

([180]) See European Commission – In Space Operations and Services – a strategic ability for the future.
([181]) Persistent Earth Observation for actioNable intElligence survEillance and Reconnaissance.
([182]) Proactive automatic imagery intelligence powered by AI exploiting European space assets.
([183]) As promoted by the EU Defence Innovation Scheme.
([184]) This could also support the parallel development of the multi-sensor ISR constellation and contribute to the EU Space Strategy for Security and Defence.
([185]) Multi-source satellite imagery ARTificial INtelligence Analysis challenge.
([186]) AI Reconnaissance for Geo-based Operational Systems.
([187]) Advanced Reconnaissance and Geospatial Unified Surveillance.
([188]) Multi-source information sYstem based on Remote sensing aI Analytics to support the strategic Defence domain.

6. Digital transformation (DIGIT)

Digitalisation [189] and big data have made AI and autonomous systems a reality, although we are only at the beginning of technological progress in these areas. These new technologies are changing the way defence activities are conducted. It is therefore necessary to create and develop core AI technologies for computer-aided decision-making, human-system cooperation, robotics and autonomous systems for defence. This includes the generation of representative data to train and test the systems, and the organisation of objective and comparative evaluation campaigns, e.g. as through technological challenges, to drive progress towards meeting defence needs while leveraging civil research and generating spill-over effects. There is also a need to develop defence big data and cloud services to manage, share and make efficient use of the ever-increasing amounts of data involved in defence activities.

This category of actions focuses on core technologies that address several capabilities in a cross-cutting way. Dedicated AI-related technologies for specific capabilities, such as unmanned systems, situational awareness, ISR, training and mission planning, medical support, maintenance and logistics are covered under other thematic categories.

Several EU initiatives have relevant connections with the topics under the DIGIT category:

- A wide range of **Capability Development Plan** [190] priorities are reflected in this category, such as the priority 'persistent & resilient C4ISTAR' [191] or 'cohesive & well-trained EU militaries' [192]. The EDF's main expected outcome 'safe and trustworthy micro & nano drones and robots, including situational understanding' also contributes to the 'airborne command & inform capabilities' priority.
- **Permanent Structured Cooperation** projects [193] also address digitalisation trends, utilising automated systems or AI.
- The latest **Coordinated Annual Review on Defence** Report (2024) [194] identified AI as one of the main European collaborative opportunities for R&T and promotes the development of trustworthy AI.
- As part of the **Overarching Strategic Research Agenda**, the CapTech Information is developing several Technology Building Blocks relevant for digital transformation [195].

The EDF addresses digital transformation in the following fields:

- **Trustworthy AI**

Technologies should be further developed to improve the performance of AI systems in dealing with challenging data types (e.g. images, video, audio, speech, text) encountered in defence applications. Such systems are needed to process large amounts of data and ensure efficient human-machine interaction.

An important cross-cutting need is to develop technologies for trustworthy autonomous learning, i.e. the ability of a system to adapt and learn from its environment, including from user monitoring, without intervention by expert developers or regression. Such technologies can be highly disruptive

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([189]) Digitalisation involves the integration of digital technologies into various systems, while digitisation refers to the process of converting analogue data into a digital format.
([190]) See EDA – The 2023 EU Capability Development Priorities.
([191]) Key area 'digital transformation'.
([192]) Key area 'boosting digital skills to enable multi-domain operations'.
([193]) See PESCO – Automated Modelling, Identification and Damage Assessment of Urban Terrain (AMIDA-UT).
([194]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([195]) These Technology Building Blocks include: Management and processing Information from Heterogeneous Information Sources; Tactical Cloud Infrastructure for C4ISR System; Internet of Things (IoT) for Defence; Information Process Enhancement by using AI and Big Data.

and impactful for many capabilities, especially where the information to be managed is highly variable or unpredictable and a high degree of adaptability is required. These technologies would also reduce the current need to provide data to system developers to obtain improvements, which is an issue where confidential data is involved. More generally, they would increase technological independence.

In the context of autonomous learning, there is also a need to ensure that AI systems can explain and justify their results to users, a feature referred to as explainable AI. This will become even more important with the emergence of high-performance generative AI and dialogue systems (chatbots). There is also a need to develop dedicated hardware architectures for energy-efficient AI. This is essential for embedded systems, where energy consumption is a bottleneck. It is also important for non-embedded computing systems as the energy consumption and environmental costs of computing centres become increasingly important. Dedicated hardware, and especially analogue hardware, is also harder to hack, which helps improve cybersecurity. It also links the knowledge acquired by the system more closely to the hardware device in which it is embedded, thereby increasing traceability, accountability and trust.

The EDF 2021 ALADAN project [196] develops an AI-based language solution for defence applications. Additionally, the EDF 2024 COP-GPT project [197] will develop an AI-driven, real-time Common Operational Picture for modern military operations.

The issue of trustworthy autonomous learning is addressed by the EDF 2021 FaRADAI [198] and KOIOS [199] projects. It is also addressed by the EDF 2023 projects ARCHER [200], NEMO [201], AtLaS [202] and LINGUARISE-DC [203] as part of the technological challenge on *human language technologies*, and in addition it will be addressed by the EDF 2025 technological challenge on *privacy-preserving learning for human-AI dialogue systems*. It should be further addressed in a cross-cutting way under future AI-related topics.

The issue of energy-efficient AI systems is addressed by the EDF 2023 ARCHYTAS project [204]. This is a long-term effort that should be pursued both through a follow-on topic and in a cross-cutting way through applied AI topics.

Additionally, the EDF 2024 PRECISE project [205] addresses the critical need for sophisticated modelling tools to assess the impact of military actions on civilian infrastructure.

- **Micro- and nano drones and robots**

In robotics, a cross-cutting and particularly challenging area of R&D is autonomous micro- and nano drones and robots, including swarming. In some operational situations, this is likely to become the main if not the only option for protecting our forces and conducting operations. It requires multidisciplinary research to tightly integrate AI, sensors, effectors and energy storage. The challenge is to develop systems that are not only highly capable, but also secure and trustworthy.

([196]) Ai-based LAnguage technology development framework for Defence ApplicatioNs.
([197]) GPT-Powered Common Operational Picture with Autonomous UxV Swarms.
([198]) Frugal and Robust AI for Defence Advanced Intelligence.
([199]) Knowledge Extraction, Machine Learning and other AI approaches for secure, robust, frugal, resilient and explainable solutions in Defence Applications.
([200]) Advancing Robust and Creative Human language technologies through CHallenge Events and Research.
([201]) laNguagE Modules develOpment.
([202]) AI-based Natural Language Processing of Low-Quality and Multilingual Data in Defence Applications with User Adaptation.
([203]) Language Innovations: Nimble, Guided, User-friendly, Agile and Robust Solutions Eliminating Defence Challenges.
([204]) ARCHitectures based on unconventional accelerators for dependable/energY efficienT AI Systems.
([205]) Prediction and Response of Effectors on Critical Infrastructure and Structural Environments.

These issues are addressed by the EDF 2022 projects AIDEDex [206], CONVOY [207], DeterMine [208], HiTDOC [209] and TICHE [210] as part of the technological challenge on *Hidden threat detection*. Another technological challenge in this field is included in the EDF annual work programme for 2026, addressing *AI-based tactical situational awareness using swarms of small robots and drones*. Other challenges on swarm operations and wider threat detection may be considered in the future.

In addition, the EDF 2024 technological challenge on *Robust autonomous drone navigation*, organised under the 'Advanced passive and active sensors' category of action, also addresses these issues with a focus on contested environments. More generally, efforts should be made to produce more integrated, smaller and energy-efficient drones and robots.

- **Defence big data and cloud**

The amount of data generated by defence operational and R&D activities is huge and growing. Most of it is unused, although a significant part would be very useful. This is due to the lack of pooled management of data collection, storage and curation. To support the development of such pooled services, two types of facilities should be considered, depending on whether the information to be managed is classified or not. Secure data cloud facilities serve smaller communities with smaller amounts of very specific data, while data collection and curation centres serve larger communities with larger amounts of more general data. Access to datasets of verified quality and integrity is particularly important as this would help increase the trustworthiness of the systems developed that use this data. The importance of cloud technologies for defence has been highlighted by the EDA CLAUDIA study [211].

In addition to the operational domain-specific collaborative combat systems addressed in other categories of action, the EDF 2021 EDOCC project [212] addresses the issue of military multi-domain operations cloud services, with a follow-on topic planned for 2026. In addition, the EDF 2022 project STORE [213] will produce annotated image databases that will be shared with a large consortium and beyond. The organisers of the ongoing or planned EDF technological challenges will produce databases that will be shared with the participants of each challenge and will remain available for further system development. Building on these efforts, further support for the emergence and strengthening of data production centres that serve the AI system development community for different AI domains may be considered in the future.

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[206] Artificial Intelligence for Detection of Explosive Devices – Extended.
[207] ClOud iNtelligent explosiVe detectiOn sYstem.
[208] Detect and Recognize Mines and IEDs hidden in the environment.
[209] Hidden Threat Detection.
[210] Threats Identification by Collaborative vehicles for Human lifesaving against Explosives.
[211] See EDA – Cloud Intelligence for Decision-Making Support and Analysis.
[212] European Defence Operational Collaborative Cloud.
[213] Shared daTabase for Optronics image Recognition and Evaluation.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the DIGIT category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototypes** of military operational cloud systems.
- **Demonstrators** of energy-efficient, trustworthy and adaptive AI core technologies ready to be integrated into defence systems.
- **Demonstrators** of safe and trustworthy micro- and nano drones and robots, including situational understanding and collaborative behaviour.
- **Demonstrators** of shared databases for training, testing and certification of AI systems, and the associated environment to produce, curate and distribute them.

7. Energy resilience and environmental transition (ENERENV)

The aim of this category of actions is to create and develop energy-efficient solutions and green technologies in the defence sector. Energy security is fundamental to any military activity. Movement, endurance and the ability to conduct any type of operation depend on the availability of energy, and supply chains must be guaranteed and protected. The increasing demand for energy for modern capabilities requires easy access, efficient storage and sustainable use across all military domains. Climate change is driving the search of sustainable energy sources beyond fossil fuels, creating challenges and threats that are changing the way the armed forces operate, driving capability requirements and ultimately influencing defence R&D.

In view of the current planetary crisis (climate change, loss of biodiversity and pollution, all caused by the depletion of natural resources), the overall contribution of this category of actions will help Europe to achieve ambitious environmental objectives. The **European Green Deal** [214], with its strong focus on climate neutrality, has become one of the EU's priorities. This should be reflected in all EU policies and programmes. The environmental transition will reshape geopolitics, including global economic, trade and security interests. It should also be recognised that the global climate and environmental challenges are significant threat multipliers and sources of instability. These challenges can become sources of conflict, food insecurity, population displacement and forced migration. State and non-state actors compete for access to scarce resources (e.g. critical raw materials, but also water and arable land), which can lead to crises and conflicts. Some of these will affect the EU and require a common response.

In March 2020, the EU adopted a Circular Economy Action Plan [215] – one of the main building blocks of the European Green Deal, the EU's agenda for sustainable growth. Circularity would support interoperability, asset availability, operational efficiency and security of supply. Defence must contribute to the reduction of waste through the development of innovative technologies to address e.g. waste management, the safe use of chemicals, component traceability, environmental protection, water management and green military components through eco-design, maintenance, repair, reuse, remanufacturing, refurbishment and recycling.

([214]) COM (2019) 640 final of 11 December 2019 on the European Green Deal.
([215]) COM (2020) 98 final of 11 March 2020 on A new Circular Economy Action Plan.

Water is an increasingly scarce commodity and often places a significant logistical burden on remote operations. Low-cost, high-throughput and robust treatment technologies for water from a variety of sources are important, as are advanced packaging and preservation technologies.

Because military forces consume a lot of energy, security of supply is critical. For forward deployed forces operating in harsh environments, technologies are needed to reduce reliance on large supplies and minimise fuel transportation, thereby limiting logistical footprints and operational vulnerabilities. This translates into a greater level of manoeuvrability and independence. As a result, deployed forces will be more effective. In this context, new developments should focus on high-density/high-power storage systems (e.g. tailored batteries, fuel cells, multi-source energy systems, etc.) and advanced energy conversion technologies. Alternative propulsion (air, land and sea) on existing and future platforms will depend on the ability to downscale energy sources and increase energy efficiency.

Energy and environmental challenges are also addressed through several EU defence initiatives other than the EDF:

- From a **Capability Development Plan** (CDP) [216] perspective, EDF's actions and the main expected outcomes from this category are aligned with the priorities in the areas of land, sea, air and logistics, promoting green defence, modernisation and sustainability to enhance military capabilities, and more specifically with the CDP priority 'Sustainable & Agile Logistics' or with some key areas of the priorities 'Air Combat' and 'Air Transport' [217] when it comes to new generation engines.
- The Energy Operational Function projects [218] under **Permanent Structured Cooperation** also tackle energy and environment-related challenges.
- The CapTech Energy and Environment addresses the issue along three main strategic lines: operational energy, energy efficiency and environmental impact of military activities.

The EDF targets the following areas within this category of actions:

➢ **Future efficient and multi-source energy solutions**

The increase in energy consumption should be achieved through new power sources such as renewable energy, high energy sources, hybrid powertrains or hybrid power generation, batteries, energy storage and fuel cells. However, these new forms of consumption pose challenges in terms of their integration into weapon systems, their technological development and logistical operational management.

In line with the objectives and priorities of the Common Security and Defence Policy (CSDP), energy efficiency in the defence sector should be improved, including for CSDP missions and operations, without compromising operational effectiveness. It will also address the development of common benchmarks and standard architectures for the increased use of renewable energy sources and the resilience of defence-related critical infrastructure.

The EDF will contribute to the development of a prototype for future efficient and multi-source energy solutions for the defence sector operating in harsh environments, paving the way for future joint procurement at EU level.

([216]) See EDA – The 2023 EU Capability Development Priorities.
([217]) The key areas of NG air combat systems & NG multipurpose helicopters respectively.
([218]) See PESCO – Energy Operational Function (EOF) and Substitute for Lead in Infantry Ammunition (SLIA).

The EDF is already contributing to this objective through three complementary projects:

- The EDF 2021 INDY project [219] developed a strategic roadmap to establish future energy-independent and efficient deployable military camps based on a paradigm shift for energy production, conversion, storage, transport, distribution and final usage. It builds on (military and civilian) EU and national projects.
- The EDF 2021 NOMAD project [220] assesses current energy storage systems developed for civil use and that might be used at military level. It develops an application-oriented analysis, including a draft guideline recommendation for novel, safe and usable energy storage technologies for military deployments in forward operation bases and will validate it in a relevant environment. A follow-up action on *High-performance energy systems* is included in the EDF annual work programme for 2026.
- In addition, the EDF 2024 SENTINEL project [221] will prototype and qualify key energy capabilities to enhance the operational efficiency and tactical autonomy of military camps and operations, while reducing the logistical burden and supporting flexible and high-capacity energy supply.

These projects aim to develop a sustainable, deployable, safer and cost-efficient energy storage system that operates in a severe military environment subject to different geographical locations, weather and climate conditions (including extreme environments).

➢ **Efficient engine representative of new architecture and technologies**

Improved power generation technologies (propulsive and non-propulsive) are required to meet increasing power demands, including power density considerations. Furthermore, these constraints are common to high value military equipment for next generation platforms.

In line with the CDP priorities, the EDF actions support the development of prototypes of efficient and environmentally friendly engines, representative of new architectures and technologies adapted to air combat aircraft, fixed wings or rotary wings, ground vehicles, including main battle tanks and naval vessels. This would pave the way for future joint procurement at EU level.

This objective is addressed through the EDF 2021 NEUMANN project [222], which will develop technologies and perform collaborative system studies for novel energy aircraft domains, focusing on: i) propulsion; ii) electrical and thermal systems; and iii) management. The ambition is to: i) give the EU full technological sovereignty over military air platforms; and ii) develop new technology building blocks for next generation integrated propulsion and energy systems to be evaluated on a dedicated European propulsion and energy ground test platform. Two call topics in this area have been included in 2025, dedicated to aircraft and helicopter propulsion systems, followed by a research call on a *new turbofan engine* in 2026. Further development actions on aircraft propulsion may be considered in the future.

In addition, the EDF 2021 HEGAPS [223] project developed a cyber-physical system to test different options and technologies for propulsion systems in an integrated naval energy grid. In addition, the EDF 2023 CALIPSO project [224] addresses military vehicle propulsion (focusing on naval and

[219] Energy Independent and Efficient Deployable Military Camps.
[220] NOvel energy storage technologies usable al MilitAry Deployments in forward operating bases.
[221] Sustainable Energy Capabilities for Enhanced Military Camps and Operations.
[222] Novel Energy and propUlsion systeMs for Air dominance.
[223] Hybrid Energy Grid and Propulsion System.
[224] Innovative propulsion solutions for land and naval defence applications.

land) by integrating sustainable fuel technologies (spin-in from the civil sector), which remains a challenge for European defence autonomy and superiority. A further call on hybrid naval propulsion has been launched in 2025.

Also in this area, the EDA HybriDT II [225] CAT-B project aims to identify the most suitable technology for a modular and scalable hybrid architecture that is best suited for military purposes. This would meet the objectives of significant weight and space savings, reduced thermal radiation and reduced fuel consumption.

In addition, the EDF 2024 INNCH2PROP project [226] will design and develop an innovative, ceramic-based combustion chamber for aerospace engines powered by hydrogen. The EDF 2024 DAMAGER project [227] will address the development of a low-cost, high-performance scalable propulsion system that can be manufactured rapidly in large quantities.

- **Environmental transition**

a) Water reuse

Drinking water is a critical requirement for military operations. Experience in arid regions has shown that water must be reused to enable military operations. The new modular military field camp will therefore use water reuse technologies to reduce the need for fresh water. As the application of this technology for mobile water supply is quite new, experience is very limited. As a result, different concepts and technologies need to be evaluated to ensure safe water reuse throughout the entire water cycle of a camp. Graphene and its oxide form – graphene oxide – are new materials that could potentially be used in this area. The research activities are expected to provide an innovative concept for water supply in a military field camp for regions with scarce water resources, possibly exploring the microbiological properties of graphene materials.

Particular emphasis will be placed on innovation and the use of standards that can help reduce the environmental footprint of armed forces and create opportunities to reuse valuable components and scarce materials. To avoid duplication of effort and funding, synergies with other research programmes should be considered, in particular with the EU Graphene Flagship, which brings together nearly 170 academic and industrial partners from 22 countries, to explore different aspects of graphene and related materials.

In this context, the EDF 2023 S.W.I.F.T. project [228] offers a disruptive approach to water management through technological innovation – including graphene-based treatment technologies and advanced photocatalytic processes – for modular field camps suitable for deployed military units in expeditionary and European defence contexts. Additionally, the EDF 2024 INNOSWAMP [229] project develops an innovative water pre-filtration system tailored to defence applications. The objective of the EDF is to contribute to the development of a prototype technological solution to ensure the safe reuse of water for military and peacekeeping missions, including through further EDF activities in the future.

([225]) Hybrid drive train demonstrator – Phase II.
([226]) Innovative Thrust Chambers for Hydrogen Based Low Emissivity Propellants.
([227]) stuDy of Additive ManufActuring for low-cost, low-observable, hiGhly-deployable, expendablE/attritable tuRbojet engines.
([228]) Sustainable Water Innovations for Fielded Troops.
([229]) Innovative and Streamlined Water Prefiltration System for Military Personnel.

b) Sustainable components for defence applications

The specific challenge is to advance the state of the art in research and innovation of new high performance lead-free piezoelectric materials for military underwater sensor applications to replace titano-zirconate Pb_1-xZr_xTiO_3 (PZT). Future phases of development and industrialisation are envisaged, leading to the prospective establishment of at least one European supply chain in this field. New materials may also provide opportunities for additional benefits, such as increasing the operational frequency bandwidth of sensors or source generators, improving duty cycle limitations or reducing sensor size. These possibilities can improve the performance of the sensors and should therefore be considered in the evaluation of the materials and processes to be investigated.

To be compliant with REACH [230] Regulations and other relevant regulations such as those on restricting hazardous substances or on waste electrical and electronic equipment, lead and its salts must be eliminated from consumer goods and industrial devices.

This issue is being addressed by the EDF 2022 SCUALE project [231]. It is developing disruptive lead-free ceramic processes such as textured ceramics and 3D printing as well as disruptive fibre-optic sensing that improves operational performance in terms of bandwidth, system noise and weight.

c) Recycling in defence

There are no formal statistics available on the amount of waste generated by the defence sector. However, as most of it is incinerated or dumped in landfills, there are opportunities to reduce the environmental impact of military activities using innovative technologies and processes, and the implementation of best practices compatible with military constraints.

It is therefore necessary to analyse, test and validate suitable solutions for the mechanical and 'green' chemical recycling of waste from soldiers' individual or collective equipment (ammunition, uniforms, helmets, boots, rucksacks, plastic elements, harness, etc.) as part of the wider circular economy management of military artefacts. It is essential to find solutions that are cost-effective and ensure good performance of the recycled materials, taking into account the specific requirements of the defence sector. Particular emphasis will be placed on innovation and the use of standards that can help reduce the environmental footprint of armed forces and create opportunities for the reuse of valuable components and scarce materials, including through eco-design.

In line with these objectives, several projects and calls are underway. The EDF 2022 UTILE project [232] is developing several technologies that make it possible to implement circular strategies for the recovery and reuse of various types of soldier personal protective equipment used by the European national armed forces. In addition, the EDF 2023 ZEROWASTE [233] project uses advanced biotechnologies to produce energy and food for military personnel in remote infrastructure or operational areas using military waste as a resource. In addition, the 2026 call for proposals on *Ammunition Waste Collection and Disposal Unmanned Platforms* aims to detect and dispose of ammunition waste and residues from military training areas and battlefields using a semi-autonomous remote management system.

([230]) See EUR-Lex – Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals.
([231]) Sustainable Components for Underwater Acoustics using Lead-free materials in Europe.
([232]) Ensuring Circularity of Soldier Personal Protection Equipment.
([233]) ZERO emissions in a circular military economy: from military individual equipment waste to food and energy.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the ENERENV category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototype** of a future green, efficient, resilient, safe and multi-source energy solution for the defence sector when operating under harsh environmental conditions.
- **Demonstrator** of efficient and green engine representatives of new architecture and technologies, each adapted to each of the following capabilities:
  - next generation air combat aircraft, fixed and rotary wings;
  - next generation ground vehicles, including main battle tanks;
  - next generation naval vessels.
- **Prototype** of a technological solution to ensure the safe reuse of water for military and peacekeeping missions.
- **Prototype** of a green innovative solution for recycling technologies and circularity, particularly for soldier equipment.

8. Materials and components (MATCOMP)

Materials and components are critical enablers of a wide range of solutions that form the core of military capabilities. Both are considered to be emerging and disruptive technologies. This category of actions supports technologies for products and systems that span multiple domains, including land, sea, air, space and cyber. As a result, it is strongly linked with other categories of the EDF work programmes. Some research topics may also be included in other categories of action, provided the intended application is sufficiently specific. Examples include 'Active and passive sensors for optoelectronic detector materials' and 'Energy resilience and environmental transition for innovative techniques, including recycling'.

This category of actions aims to support innovation for high-performance and protective materials and develop electronic components highly relevant for European defence and defence specific to technologies for manufacturing and maintenance. Two main fields are therefore involved:

- **Advanced materials**

Novel materials and manufacturing are two technology areas with identified disruptive potential. Developing materials with unique properties such as strength, heat resistance, weight and durability improves performance in military applications. Advanced manufacturing techniques enable more efficient and flexible production and maintenance processes.

A key enabler for unlocking the disruptive potential of novel materials and manufacturing techniques is to focus on specific areas where this potential could be maximised. This is often not known in advance. This category of actions is therefore particularly well suited to measures that allow for flexibility and innovation.

➢ Critical components and electronics

Critical components and electronics are key enablers of disruptive technologies on the battlefield. They support digitalisation and introduce new capabilities through the miniaturisation of electronics. They have applications that span all military domains.

In this category of actions, synergies with the civil sector need to be emphasised. The aim is to reap the benefits of R&D and synergies with infrastructure and competencies that are being largely dominated by civilian actors, while avoiding unnecessary duplication. This will ensure the efficient uptake of results, while acknowledging the differences in the requirements for materials and components specific for defence applications. The EDF work programmes can address these defence-specific solutions directly, especially when the technology is clearly linked to military performance for European armed forces. This is achieved through the **EU Defence Innovation Scheme** measures in the form of a spin-in calls for proposals, which provide follow-up funding for additional R&D to address the specific requirements of defence applications.

Cross-fertilisation can also be leveraged in the area of sustainability to develop solutions that aim to achieve the zero-pollution principle of the European Green Deal, while also improving performance in areas where the defence sector currently benefits from regulatory exemptions, such as those relating to the REACH Regulations [234].

Solutions related to materials and components for defence are also addressed through complementary initiatives and programmes:

- Most of the activities in this category of actions are indirectly related to the **Capability Development Plan** priorities [235] of cross-domain capabilities that help achieve the EU's level of ambition.
- As part of **Permanent Structured Cooperation**, participating Member States target in particular material and component technologies for which the security of supply and freedom of use may be restricted [236].
- The latest **Coordinated Annual Review on Defence** 2024 Report [237] lists collaborative opportunities for which materials and components are relevant as enablers for a large spectrum of defence solutions [238].
- The **Overarching Strategic Research Agenda** defines several Technology Building Blocks that are focused on materials and components [239] and that are being developed within corresponding EDA CapTechs, namely the CapTech Materials & Structures and the CapTech Technologies for Components and Modules.

([234]) See EUR-Lex – Regulation on the Registration, Evaluation, Authorisation and Restriction of Chemicals.
([235]) Including Priority Future Soldier Systems under Key Area Equipment and Systems for Improved Survivability and Priority Sustainable and Agile Logistics under Key Area Additive Manufacturing Based Enabling Capabilities. See EDA - The 2023 EU Capability Development Priorities.
([236]) See PESCO – Materials and components for technological EU competitiveness (MAC-EU).
([237]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([238]) For example, in capability development of soldier armament equipment.
([239]) Technology Building Blocks related to Components CaptTech/Working Group (WG): RF Photonics, IR imaging detector & sources, Terahertz detectors & sources, Microwave Power, RF Transceiver modules, Enabling Components for Advanced Antennas, ADC & DAC, Signal generation and Time Reference, System-on-Chip, High voltage SiC devices and related energy storage for pulsed power applications, Defence critical supply chain, Advanced Packaging, PCB and Thermal Management Technologies. Technology Building Blocks related to Materials CaptTech/Working Group (WG): Light Weight for High Performance Structures, Materials, structures for Protection Against Military Threats, High temperature materials, Camouflage and signature management technologies, Emerging materials for future platforms, Materials, structures & concepts for platform monitoring, New manufacturing, joining and repair processes, Surface engineering for maximum lifetime and/or hostile environments, Advanced and smart textiles for soldier systems and platforms, Computational design and materials modelling.

- Advanced materials technologies, semiconductors and microelectronics are considered to be of strategic importance to the EU's economic security [240]. Given their importance, projects in this category of actions can benefit from the **Strategic Technologies for Europe Platform** [241].
- **The EU Observatory on Critical Technologies** monitors and identifies critical technologies for space, security, defence and public order, and provides regular analysis and risk assessment.
- There are numerous **other civil EU initiatives** [242], research programmes [243] and Member State initiatives [244] in the field of materials and components that can contribute to progress in security and defence thanks to the dual use of these solutions, as pointed out by the **roadmap on critical technologies for security and defence** (2022).

With all these special features, the MATCOMP category of actions aims to contribute to the following objectives:

➢ **Innovation support for high-performance and protective materials**

First, the aim of this category of actions is to improve soldier performance in the field by leveraging advanced materials for protection, camouflage and other functionalities. Following on from the PADR 2017 ACAMSII project [245], the EDF 2022 ARMETISS project [246] and the EDF 2023 MINEFIELD project [247] are developing a set of smart clothing, textiles and equipment that integrate complementary functions. The EDF work programme for 2026 includes an additional call for proposals for smart and multifunctional textiles.

The PADR 2019 METAMASK [248], the EDF 2022 ACROSS [249], EDF 2023 CATHERINA [250], EDF 2024 METASTEALTH [251] and CAMO V2 [252] projects address adaptive camouflage and stealth solutions, for example through smart textiles with infrared and thermal detection-resistant properties. In terms of novel solutions for protection in hostile environments, the EDF 2021 ECOBALLIFE project [253] investigates eco-designed ballistic systems that provide durable, lightweight protection against current and emerging threats in both platform and personnel applications.

In addition, the EDF 2023 ADMIRABLE [254] and EDF 2023 IMMUNE [255] projects are developing novel, high-performance materials that can either withstand high temperatures or

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([240]) Commission Recommendation (EU) 2023/2113 of 3 October 2023 on critical technology areas for the EU's economic security for further risk assessment with Member States.
([241]) See EU – Strategic Technologies for Europe Platform (STEP).
([242]) For example: the European Chips Act (2023) complemented by the Industrial Alliance on Processors and Semiconductor Technologies; European Alliance for Industrial Data Edge and Cloud as announced in the European industrial strategy (2021).
([243]) Such as the Horizon Europe programme, Digital Europe programme or European Space programme.
([244]) For example, Important Projects of Common European Interest, which bring together private interest groups and other players to overcome challenges in the area of innovation and infrastructure.
([245]) Adaptive Camouflage for the Soldier II.
([246]) smARt Multifunction tExtiles for integrated Soldier Systems.
([247]) Energy autonomous smart clothing to enhance soldier safety and connectivity in the battleground.
([248]) Metasurfaces for time-domain adaptive masking.
([249]) Adaptive Camouflage foR sOldierS and vehicleS.
([250]) CAmouflage THERmal INtelligent and Adaptive.
([251]) METAsurfaces for the next generation of STEALTH platforms.
([252]) Camofoil 2.0 – Advanced material for disruptive approach to signature management.
([253]) Research in ecodesigned ballistic systems for durable lightweight protection against current and new threats in platform and personal applications.
([254]) Additive Manufacturing of composite based fire-resistant materials for stealth, Ballistic Lightweight armoured structures.

significantly reduce weight. These projects were developed in response to a call for proposals specifically designed to spin in innovative solutions from civil applications.

- **Develop electronic components highly relevant for European defence**

An important factor in the production of electronic components specific for defence purposes is the ability to integrate electronic subcomponents from different providers into a single product. One such enabler is packaging technology, as developed by the EDF 2022 EPICURE project [256]. Packaging technology must respond to the specific requirements of defence applications, such as the ability to manage frequency ranges, heat and high power. In that respect, the EDF 2024 ePERFECT [257] project aims to establish a supply chain for RF components for use by the European Defence Technological and Industrial Base in their defence equipment.

Similarly, standardising chiplets would allow components that originate from different manufacturers to be interconnected, thereby creating a more robust and dynamic industrial landscape. The EDF work programme for 2025 includes a call for proposals on chiplets for defence applications, aiming to explore the development and sharing of a common hardware library of chiplets and their military applications.

Research into advanced components for RF applications is crucial for enabling applications in the higher frequency band and lower microwave bands. This is supported through the EDF 2021 AGAMI_EURIGAMI project [258], which covers the entire gallium nitride supply chain and focuses on integrating it into systems for radar and electronic warfare systems. In addition, the EDF 2021 POWERPACK [259] project is developing disruptive technologies for miniaturised RF identity chips for high-frequency and high-power operations, and the POWERFLEX project [260] develops new flexible antennas based on new and advanced materials.

To protect defence systems, the EDF 2021 SMiEQ project [261] will prototype a secure microcontroller with an embedded quantum random number generator.

- **Support of innovative technologies for manufacturing and maintenance**

New manufacturing techniques such as additive manufacturing could have a positive impact on the logistics footprint and maintainability of military equipment. These techniques also allow new designs to be developed. In that respect, the EDF 2021 ROLIAC project [262] is developing additive manufacturing technologies for lightweight military grade parts using novel materials. In addition, the EDF 2022 DISCMAM [263] project is developing a reliable digital method for the repair and manufacture of spare parts using additive manufacturing.

Based on previous results, the EDF 2023 MaJoR project [264] addresses the materials and techniques that need to be adapted and certified for defence maintenance applications. The project resulted

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([255]) Advanced FILAVA-based materials for a new generation of ultralight, more resistant, ecodesigned, morpho- and REACH-compliant personal protection equipment's hard-components for the EU's military.
([256]) European Packaging for highly Integrated Circuits for Reliable Electronics.
([257]) European High-Performance Processor for RF Defence Applications.
([258]) European Innovative GaN Advanced Microwave Integration.
([259]) Novel 3D heterogeneous integration for future miniaturised power RF transceiver front ends.
([260]) Smart, Heterogeneous Technological Platform Extending the Power and Frequency Limits Of Flexible Nanoelectronics.
([261]) Secure Microcontroller with Embedded Quantum Random Number Generator.
([262]) Robust and Light AM components for military systems.
([263]) Digital Supply-Chain for On-Site Maintenance in defence by Additive Manufacturing.
([264]) Maintenance, Joining, and Repair innovation in multidomain defence.

from a call for proposals designed to support a cross-border defence innovation network, which will host the test platform and provide testing and other services to innovative organisations.

A sustainable supply of electronic components requires the creation of a pan-European supply chain. The development of electronic components should therefore also include elements of manufacturing and defence-specific supply chain technology.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the MATCOMP category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototypes** of smart textiles and adaptive masking/camouflage solutions, ready for use and/or procurement.
- **Demonstrator** of technology for stealth and radar camouflage.
- **Demonstrator** of advanced packaging assembly and test services.

9. Air combat (AIR)

This category of actions includes the development and effective integration of air combat systems and technologies into overarching systems that enable data sharing and sensor networking. This integration is essential to operate in increasingly complex air environments. In the future, these capabilities will operate through a combination of manned and unmanned platforms, likely integrated into larger joint operational contexts, with a collaborative combat approach.

This category encompasses a wide range of high-end capabilities, both manned and unmanned, including vectors, effectors, dedicated weapon systems and payloads. In particular, next generation fighter and helicopter systems and technologies, as well as cutting-edge self-protection capabilities, are critical for achieving the desired air superiority and penetration mission requirements. In line with the collaborative warfare concept that will drive operations in the near future, all these air combat systems should be interoperable and networked across a broad spectrum, integrating with different generations of aircraft, satellites, naval and ground assets. They should also comply with NATO, EU and national regulations, standards and architectures where applicable. These capabilities require a long development cycle and significant investment.

Air combat will benefit from the activities carried out in other categories of actions, such as the next generation of propulsion and energy systems for air fighters and helicopters. These are being addressed in the category related to energy resilience and environmental transition, as well as other topics related to advanced passive and active sensors, cyber and space.

The results or outcomes of the work carried out under several EU initiatives are relevant to the topics addressed under this category of actions:

- **Capability Development Plan** [265] priorities, in particular the priority 'Air combat' [266] for topics related to electronic warfare, swarms, new generation missiles, and the priority 'Air transport' [267] as regards next generation helicopters and air-to-air refuelling.

([265]) See EDA – The 2023 EU Capability Development Priorities.
([266]) Key areas: Upgrade of current air combat platforms; Next generation air combat systems; Next generation joint precision strike.
([267]) Key areas: Next generation multipurpose helicopter; Air-to-air refuelling UAS.

- Several **Permanent Structured Cooperation** projects in the areas of 'Air' [268] and 'Strategic enabler and force multipliers' [269].
- The latest **Coordinated Annual Review on Defence** Report (2024) [270] has identified electronic warfare as an opportunity for cooperation between Member States.
- Technology Building Blocks developed within the CapTechs 'Aerial systems' [271] and 'Missiles and munitions' [272] as part of the **Overarching Strategic Research Agenda**.

The EDF supports air combat actions in the following fields:

➢ In the field of **air fighters**

Current fleet inventories indicate that several air combat systems currently in service (e.g. Rafale, Eurofighter, Tornado) may reach the end of their life cycle in the coming years. Member States are planning to invest in the development or acquisition of next generation air fighter systems, which should, as a minimum, have stealth, survivability, enhanced capabilities and improved connectivity. This will enable them to operate in networks of assets, including unmanned ones, and be able to employ a wide range of improved stand-off weapon systems.

In support of the CDP priorities and Coordinated Annual Review on Defence findings, the EDF ambition in this field should be to support the development of key components, technologies and functions, including through a digital twin approach, that could eventually be integrated into the envisaged next generation air fighter systems. In this way, the EDF will support the European value chains and help maintain critical skills in the design, testing, certification and production chains related to the required cutting-edge aeronautical technologies, while ensuring interoperability of future fighter systems.

To achieve this objective, the EDF 2021 EPIIC [273] project aims to improve fighter cockpits, in particular through adaptive human-system collaboration, visualisation, crew monitoring and interaction modalities. A follow-up topic in this area has been included in the EDF annual work programme for 2025. In addition, the development of critical technologies for the next generation of fighter systems, such as avionics, are being addressed by the EDF 2023 NG-MIMA [274] project, for which the follow-up topic on *Smart technologies for next generation fighter* systems is included in the EDF annual work programme for 2026.

Also in this area, the EDF 2024 GARUDA project [275] aims to establish the foundational architecture for unmanned collaborative combat aircraft systems. A follow-up topic may be considered in the future.

On the optimisation of combat jet training platforms, the EDIDP 2019 FITS4TOP [276] project provided a complete ground-based training system offering the option of teaming between a real aircraft and a simulator through a Live, Virtual and Constructive solution.

([268]) See PESCO – Airborne electronic attack (AEA), TIGER Mark III, Future short-range air-to-air missile (FSRM), Next generation medium helicopter (NGMH) and Future (unmanned) Air-to-Air Refuelling Capability.
([269]) See PESCO – EU collaborative warfare (ECOWAR).
([270]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([271]) These Technology Building Blocks include: Autonomous air vehicle operation; Cooperative air vehicle operation; Detect, sense and avoid systems; Human-machine-interface and cognitive ergonomics; Rotorcraft: next generation high performance vertical lift; Fixed wing.
([272]) Technology Building Block, Precision guided munition and missiles.
([273]) Enhanced Pilot Interfaces & Interactions for fighter Cockpit.
([274]) Next Generation Military Integrated Modular Avionics.
([275]) reconfiGurable Autonomous collaboRative UnmanneD Aircraft.
([276]) Future Integrated Training Solution for TOP gun.

- In the field of **helicopters**

With their unique ability to take off and land from almost anywhere, the importance of rotorcrafts in military operations is widely recognised as they are considered as powerful enablers of multi-domain operations. Indeed, military rotorcrafts perform a variety of missions such as armed reconnaissance, Strike, Combat Search and Rescue (SAR), MEDical EVACuation (MEDEVAC), Utility, Air Assault and Close Aerial Support that are critical to the success of military operations. Beyond their purely military role, military helicopters are also key assets for improved civilian security and protection and EU resilience, making a vital contribution to disaster relief, civil search and rescue, and sanitary crises.

The objective of the EDF is to support the development of a prototype for a next generation European rotorcraft system, possibly with high-speed, long-range and high-altitude capabilities. To achieve this objective, the EDF 2021 ENGRT [277] and EDF 2024 ENGRT II [278] projects aim to develop such a system and pave the way for future joint procurement at EU level.

- In the field of **collaborative air combat and aerial situational awareness**

A key challenge is to jointly develop a European perspective that will enable Member States to address medium and long-term collaborative air combat capabilities. This involves combining future air combat systems, both manned and unmanned platforms, legacy platforms and their evolution, including sensors and effectors. With the plausible introduction of unmanned systems into air combat, future interoperability will require much deeper interconnection, which can be provided by cutting-edge technologies, including a new generation of tactical data links.

The objective of the EDF in this field is to support the development of standardised architectures and interfaces for collaborative air combat. This includes the use of fully operational standards for the integration of unmanned platforms in non-segregated airspace, which could be incorporated into various air combat development and upgrade programmes.

To achieve this objective, the EDF 2021 EICACS [279] project related to collaborative air combat will focus on interoperability and AI integration into manned or unmanned platforms, legacy platforms and their evolution, including sensors and effectors, with a follow-up topic included in the EDF annual work programme for 2025. In addition, the EDIDP 2020 MUSHER [280] project is addressing issues of manned-unmanned teaming, and a topic aimed at enhancing aerial situational awareness through advanced passive systems may be considered in the future.

- In the field of **combat, endurance and survivability**

Fixed and rotary wing platforms should be capable of long endurance operations, in particular through air-to-air refuelling. They should be equipped with combat and self-protection systems that would enable them to counter-attack threats that could hamper air missions in contested environments.

As part of the EDF and in line with the CDP priorities, a call topic on enhanced *autonomous air-to-air refuelling* capabilities is included in the EDF annual work programme for 2026.

([277]) EU Next Generation Rotorcraft Technologies Project.
([278]) European Next Generation Rotorcraft Technologies Phase II.
([279]) European Initiative for Collaborative Air Combat Standardisation.
([280]) Development of a generic European Manned unManned Teaming system.

In addition, the EDIDP 2020 CARMENTA [281] project and its follow-up EDF 2023 CARMENTA PF [282] project are developing improved self-protection capabilities, with a further action on *self-protection systems* included in the EDF annual work programme for 2026.

The EDF 2021 Facelift [283] project improves the strategic surveillance capability, survivability and operational resilience of future stealth aircrafts.

Moreover, as European armed forces are increasingly confronted with sophisticated long-range IADS and A2/AD systems, the EDIDP 2019 REACT [284] project and its follow-up EDF 2022 REACT II [285] project aim to develop a state-of-the-art airborne electronic warfare capability that can be jointly procured and possibly deployed on both manned and unmanned platforms.

Air-to-air combat remains a challenging and multidisciplinary area where the requirements for air-to-air missiles continue to grow in number and complexity. The EDF 2024 BEAST project [286] aims to define and consolidate the requirements for a Future Short-Range Missile, in line with the CDP priorities and as supported by the related PESCO project [287]. A follow-up topic may be considered in the future.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the AIR category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- Fully integrated **demonstrators** of critical components and technologies for next generation fighter systems and modular avionics.
- **Standardised architecture and interfaces** for collaborative air combat.
- **Demonstrators** of key technologies and system architectures for next generation rotorcraft.
- **Prototype** of an airborne electronic warfare capability, leading to joint procurement by the Member States.
- **Prototype** of a multiplatform self-protection system.

10. Air and missile defence (AIRDEF)

This category of actions encompasses a wide range of capabilities aimed at protecting EU forces and populations against aerial threats, from counter unmanned air systems (C-UAS) to ballistic missile defence systems.

Several EU defence initiatives contribute to studies and projects in this area:

- The **Capability Development Plan** [288] highlights integrated air and missile defence (IAMD) [289] as an EU priority.

([281]) Future European Self Protection System for Fixed Wing (Transport, Mission) and Rotary Wing (Transport, Combat) airborne platforms.
([282]) CARMENTA PRIMUM FUGA.
([283]) Fluidic Actuators for Control of stEaLth aIrcraFT.
([284]) Responsive Electronic Attack for Cooperative Task.
([285]) Responsive Electronic Attack for Cooperation Tasks II.
([286]) Boosting European Advanced Missile System Technologies.
([287]) See PESCO – Future Short-Range Air to Air Missile (FSRM).
([288]) See EDA – The 2023 EU Capability Development Priorities.
([289]) Key areas: 'Next generation multilayered IAMD systems', 'Upgrade of current air defence systems', 'Counter UAS capabilities'.

- The 2024 **Coordinated Annual Review on Defence** [290] report identifies IAMD among the main collaborative opportunities for EU Member States. In addition, they have signed a Letter of Intent on cooperation in the field of IAMD.
- There are several projects that address this domain as part of **Permanent Structured Cooperation** [291].
- As part of the **Overarching Strategic Research Agenda**, the CapTech Missiles and Munitions, CapTech Space and CapTech Air contribute to studies on ballistic missile defence and hypersonic technologies.

Against this background, this category addresses the following fields:

➢ **Counter UAS**

A wide range of UAS, including off-the-shelf commercial drones and mini/micro-UAS that can fly in swarms, are being increasingly used for offensive or intelligence-gathering purposes. This poses a growing threat to military forces and civilian populations, as has been widely observed on the battlefield in Ukraine.

In line with CDP priorities and Coordinated Annual Review on Defence findings, the EDF ambition in this field is therefore to support the development of active and passive protection against armed and intelligence-gathering UAS, thereby increasing force protection and the resilience of critical infrastructures, while contributing to information superiority.

The EDIDP 2020 JEY-CUAS project [292] is paving the way for the development of a joint European C-UAS capability. The EDF 2023 project E-CUAS [293] builds on this work with the aim of developing a prototype and paving the way for possible future joint procurement at EU level. In addition, other projects are investigating new technologies to enhance C-UAS systems like fluidic thrust vectoring – the EDF 2023 ACTOR project [294] – or electromagnetic pulse – the EDF 2024 SENTINEL project [295].

Further actions that contribute to the development of effective C-UAS capabilities may be considered in the future. Given the wide range of products with different applications and outcomes that have already been developed across the EU, a technological challenge in this area could also be considered to trigger a step forward in helping the Member States and EDF associated countries identify the best solutions.

➢ **Missile defence and protection against hypersonic threats**

The emergence of new threats such as manoeuvring ballistic missiles, hypersonic cruise missiles and hypersonic glide vehicles poses an additional challenge for European and NATO ground-based air defence systems.

The EDF ambition in this field is to support the development of a prototype of a European endo-atmospheric interceptor. To meet this ambition, the EDF 2021 EU HYDEF [296] and EDF 2023 HYDIS^2 [297] projects address the initial phase of development through a dual-sourcing approach

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([290]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([291]) See PESCO – Counter Unmanned Aerial System (C-UAS), Timely Warning and Interception with Space-based TheatER surveillance (TWISTER) and Integrated Multi-Layer Air and Missile Defence System (IMLAMD).
([292]) Joint European sYstem for Countering Unmanned Aerial Systems.
([293]) European Counter Unmanned Aerial Systems.
([294]) Aerodynamically Controlled Thrust ORientation for enhanced manoeuvrability in counter UAS and future advanced defence applications.
([295]) System for Enhanced Threat detection, Interception and soft-kill Neutralisation of Lethal drones.
([296]) European Hypersonic Defence Interceptor.
([297]) Hypersonic Defence Interceptor Study².

involving all the relevant industries throughout the EU. A call for proposals for further development is included in the EDF work programme for 2026.

In the meantime, several projects have been launched on hypersonic technologies. For example, the EDF 2023 DEMETHRA project [298] will investigate novel scramjet technologies for developing a realistic hypersonic vehicle and address the challenges of supersonic combustion jet engines. Furthermore, a topic to collect all information necessary to successfully counter hypersonic glide vehicles was included in the EDF work programme for 2024, with a follow-up topic in 2026. Due to the sensitiveness of the data to be collected, this topic is classified. The test facilities were also considered, with the EDF 2022 SILENT project [299] defining the roadmap for the development of the EU's first quiet hypersonic wind tunnel.

In addition, the development of an integrated multi-layer, fixed or mobile, air and missile defence may be considered in the future.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the AIRDEF category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototypes** of technologies and systems ready to be procured or used for an effective multi-layer air and missile defence, including a **prototype** of an endo-atmospheric interceptor.
- **Prototype** of a counter UAS system, ready for joint procurement.
- **Demonstrator** of a hypersonic glide vehicle for specific data collection.

11. Ground combat (GROUND)

Land platforms and their weapon systems are essential capabilities for all ground combat operations. This category of actions focuses on main land combat systems such as main battle tanks (MBTs), infantry fighting vehicles (IFVs), armoured personnel carriers (APCs), light armoured vehicles (LAVs), all-terrain vehicles (ATVs), unmanned ground systems (UGS) and indirect fire systems, while ensuring a collaborative form of combat for European land forces.

This category of actions aims to increase the coherence of the European capability landscape, which is currently lacking due to the diversity of land systems and the need to modernise and upgrade legacy systems. Member States should collaborate closely with the defence industry to develop and refine generic open architecture standards for land platforms, implement modularity, automation, and shorten supply chains. Modular platforms can easily be upgraded and reconfigured as technology evolves or warfighting requirements change.

The land environment is challenging and highly varied on a global scale. It is also rapidly changing and complex, with natural obstacles that block visibility, communications links and navigation systems. The different levels of complexity, ranging from open to urban terrain and underground areas, present significant challenges for image processing, autonomous navigation and, most critically, enemy detection and engagement.

([298]) DEvelopMent of Enabling technologies for a THust-vectored hypersonic vehicle featuring innovative combustoR and mAterials.
([299]) Studies and pre-desIgn of next-generation quiet hypersonic wind tunneL facilities for EuropeaN strategic auTonomy.

For these reasons, the ground combat capabilities require efficient interaction, communication and coordination with other ground forces, including dismounted troops, as well as with other services in a multi-domain environment. They therefore require extensive connectivity and interaction for enhanced situational awareness and collaborative engagement capability across platforms, integrating (i) various types of sensors and effectors integrated into land capabilities (i.e. manned and unmanned platforms as well as dismounted soldiers); and (ii) sensors and effectors from other domains (air, sea, space and cyber). In order to ensure complementarity and avoid duplication, cross-fertilisation with relevant categories of actions under the EDF (such as C4ISR, SENS, MCBRN, DIGIT and MATCOMP) is facilitated.

In addition to the EDF, several mutually reinforcing EU actions and initiatives are being carried out in the land domain:

- The Member States' ambition to develop main ground combat systems was reiterated in the **Strategic Compass** (2022), with MBT and soldier systems as focus areas.
- EDF topics and EDF main expected outcomes from this category of actions are in line with the priorities of the **Capability Development Plan** [300]. The implementation of these priorities will be guided by the Priority Implementation Roadmaps on *Ground Combat Capabilities, Land Based Precision Engagement* and *Future Soldier Systems.*
- Call topics under this category of actions contribute to the cooperation opportunities identified in the **Coordinated Annual Review on Defence** [301], such as for *Future Ground Combat Systems* or *Long-Range Precision Strike, Artillery.*
- Participating Member States focus on the land domain through **Permanent Structured Cooperation** projects [302].
- Several Technology Building Blocks [303]defined by the **Overarching Strategic Research Agenda** focus on the land domain, and these are addressed within the CapTech groups 'Ground Systems (Land)' and 'Missiles and Munitions'.
- Some of the call topics [304] addressed in this category of actions target investment areas addressed by the **Strategic Technologies for Europe Platform** (STEP) [305] and may therefore be eligible for the STEP Seal under the EDF.

Against this background, the EDF supports ground combat-related R&D along five main lines of effort:

([300]) CDP priorities focused on land forces: Ground Combat Capabilities, Land Based Precision Engagement and Future Soldier Systems. For full details see EDA – The 2023 EU Capability Development Priorities.

([301]) See EDA – Coordinated Annual Review on Defence: Report 2024.

([302]) See PESCO – Integrated Unmanned Ground System (iUGS), Integrated Unmanned Ground System 2 (iGUS2), EU Beyond Line of Sight Battlefield Missile Systems (EU BLOS), EU Collaborative Warfare Capabilities (ECoWAR).

([303]) Technology Building Blocks focused on land domain include Land Systems Architecture & Integration, Power Generation, Storage and Management for Land Systems, Passive and Active Protection for Land Systems, Less-than-lethal Effectors, Manned/Unmanned Teaming, Adaptive Cooperation Between Manned and Unmanned Systems With Different Level of Autonomy, Target/Threat Recognition and Identification, Health and usage Monitoring, Novel User Interfaces for Soldier – Assets Integration/Control, Mobility and Counter-Mobility, Weapon System Integration.

([304]) For example, Multipurpose unmanned ground systems or Affordable mass munitions.

([305]) See European Union – Strategic Technologies for Europe Platform.

➢ Land platforms

Future warfare and operational challenges require the development of the next generation of ground capabilities as well as the modernisation of current legacy platform, such as MBTs, IFVs, UGS, ATVs, LAVs and APCs. These platforms must be strengthened with improved interoperability, agility, survivability, mobility, endurance, versatility and security, including cybersecurity, and be capable of operating in challenging conditions and environments, including electromagnetic contested environments. The platforms must have the ability to be optionally manned and must support forces in a wide range of missions in a digitised and network-centric battlefield environment. This would also facilitate the achievement of scalable effects on other ground platforms such as logistics and engineering support vehicles, while promoting efficient maintainability and support, high levels of operational readiness and optimised life cycle costs.

In this context, the EDIDP 2020 FAMOUS project [306] and its follow-on, the EDF 2021 FAMOUS2 project, aim to develop the next generation of armoured platforms and upgrade existing ones through the development of modularity and multifunctionality. In addition, the EDF 2024 AURIGA project [307] aims to design, develop and prototype key technology bricks, enabled by armoured infantry fighting vehicle system architecture. Further development efforts may be considered in the future. Moreover, the EDIDP 2020 SRB project [308] and its follow-on, the EDF 2023 SRB2 project, are developing a fully rotary hydro-pneumatic suspension system to modernise and develop new heavy armoured vehicles. Additionally, the EDF 2024 SVDC project [309] uses AI algorithms to achieve optimal vehicle performance under changing conditions.

MBT capability remains an essential backbone for high-intensity land operations. The combination of mobility, firepower and protection remains essential in conventional manoeuvre warfare. However, many MBT assets currently held by Member States are ageing or obsolete. In recent years, Member States have presented plans to modernise in-service platforms and replace equipment that is approaching the end of their service life. This provides an opportunity for potential future cooperation to enhance the EU's overall MBT capability, as initiated by the EDF 2023 MARTE [310] and FMBTech [311] projects. To follow up on these projects, the development of a full-scale demonstrator is included in the EDF work programme for 2026.

➢ Collaborative combat

The future land battlefield is characterised by a very harsh and rapidly changing environment in which activities are highly intense. Interaction between the different ground platforms, as well as with other operational domains such as air, sea, space and cyber, is therefore essential for maintaining operational superiority. Against this backdrop, the EDF 2022 LATACC project [312] aims to enhance the collaborative combat capabilities of the armed forces, and a call for further development in this area was published in 2025. In addition, the EDIDP 2019 LYNKEUS project and its follow-on, the EDF 2021 MARSEUS project [313], address the need for a collaborative close combat architecture to engage targets with Beyond Line of Sight (BLOS) capability. Furthermore, the EDF 2024 AktarEUs project [314] proposes to continue the enhancements by developing an

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([306]) European future highly mobile augmented armoured systems.
([307]) ArmoURed Infantry Ground Assault.
([308]) Rotary Suspension for Armoured Vehicles.
([309]) Smart Vehicle Dynamic Controller.
([310]) Main ARmoured Tank of Europe.
([311]) Technologies for existing and Future MBTs.
([312]) LAnd TActical Collaborative Combat.
([313]) Modular ARchitecture Solution for EU States.
([314]) Advanced Knowledge for indirect Trajectory Attack at long Range for EU states.

integrated BLOS system. Improving the navigation solutions for land but also aerial vehicles is addressed by the EDF 2023 BadB project [315].

- **Indirect fire**

As the warfare conditions evolve, land forces must be able to operate in high-intensity combat environments and face adversaries with enhanced protective systems and extended range firepower. In this context, the firepower used to engage adversaries beyond line of sight, i.e. artillery and missiles, needs to be improved in terms of range, precision, efficiency and resistance to electronic warfare. The EDIDP 2020 FIRES project [316] and its follow-on, the EDF 2023 FIRES 2 project, aim to develop a future family of ammunition for European indirect fire systems. Meanwhile, the EDIDP 2020 e-COLORSS project [317] paved the way for the development of a European long-range artillery system and launcher.

To modernise and upgrade the observation for artillery/indirect fire support, the EDF VICTORIOUS project [318] was launched in 2023.

- **Ammunition and weapon systems**

The development of new guns and warheads, including new propulsion technologies based on pulsed power (e.g. electromagnetic guns), is still to be pursued in order to increase the platform's firepower. The increase of ammunition velocity has become an area of increased interest for the armed forces as it raises significant challenges for deploying countermeasures (e.g. hypervelocity). After the PADR 2019 PILUM project [319], which paved the way for electromagnetic railguns and hypervelocity projectiles, the EDF 2022 THEMA project [320] is further developing the technology and critical components in this field. Additionally, the EDF 2023 DEMAROCK project [321] will develop an innovative and disruptive electromagnetic launcher for 70 mm rockets. Meanwhile, the EDF 2021 NEWHEAT project [322] aims to enhance the performance of conventional shaped charges to defeat modern MBTs and destroy reinforced bunkers. In addition, the EDF 2021 SHOLFEA project [323] is developing a family of shoulder-launched missile systems to address the operational needs of future infantry units. Furthermore, the EDF 2024 NINJA2 project [324] will develop an intelligent ammunition system to enhance precision and resilience in all modern weapon systems. To reduce the probability of weapon failure through predictive maintenance, the EDF 2023 RAPTOR [325] project was launched.

- **Unmanned ground systems**

The EU has significant opportunities for cooperation on unmanned systems. The CDP highlights the increasing importance of benefiting from using unmanned systems to minimise risk to personnel manning platforms and enhance the robustness, sustainability and resilience of ground systems.

([315]) GNSS-free navigation and geolocation of objects based on satellite imagery maps and other sensor data.
([316]) Future Indirect fiRes European Solution.
([317]) European COmmon LOng Range indirect fire Support System.
([318]) Innovative Ai-Enhanced, Remotely Powered, Indirect Fire Observation System Utilizing Unmanned Vehicles.
([319]) Projectiles for Increased Long-range effects Using electroMagnetic railgun.
([320]) TecHnology for ElectroMagnetic Artillery.
([321]) Disruptive Electromagnetic 70 mm Rocket System.
([322]) New European Warhead Technologies.
([323]) Shoulder launched family for European armies.
([324]) Non Interferable Non Jammable Accurate Ammunition.
([325]) Remote weapon condition-based monitoring System.

A comprehensive set of unmanned systems should enhance manoeuvrability on land by deploying systems in both land, air and underground domains, thereby gaining an operational advantage over the adversary. The strategic relevance of the manned-unmanned teaming and adaptive cooperation between manned and unmanned systems is also linked to improving the ability of land systems to carry out complex operations by making greater use of unmanned assets. The PADR 2019 INTERACT project [326] paved the way for the full integration of unmanned systems into military operations by addressing critical requirements such as interoperability and standardised architecture and components. The EDIDP 2019 iMUGS project [327] developed a modular and scalable architecture for hybrid manned-unmanned systems. Furthermore, the EDF 2024 iMUGS2 project [328] is addressing the development of unmanned modular and open system architectures. Follow-on action may be considered in the future. Meanwhile, the EDF 2021 COMMANDS project [329] is developing a solution to enable trusted and effective cooperation between manned and unmanned assets.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the GROUND category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototypes** of modular and multi-functional systems of systems and technology integration for platform upgrades, ready for joint procurement.
- Full system **demonstrator** for a future MBT and contribution to next generation IFV, and other armoured vehicles.
- **Prototype** of BLOS capability ready for procurement.
- Long-range indirect fire **demonstrator**.
- **Prototype** of UGS ready for procurement.
- **Prototypes** of new ammunition and weapons systems.
- **Preliminary prototyping and demonstration** of a solution for improved connectivity and interaction between land platforms (manned/unmanned, mounted/dismounted) required for multidomain operations.

12. Force protection and mobility (PROTMOB)

Force protection and mobility ensure that armed forces at all operational levels can effectively carry out their assigned missions in the face of potential enemy action, while ensuring the security of supply for the forces on the battlefield. The availability of advanced force protection and mobility capabilities is therefore an important operational requirement.

This domain covers a wide range of aspects, ranging from the design parameters of major combat platforms to dismounted soldier systems. The current and future technological spectrum of military assets must work together to ensure that forces can move quickly and safely while also protecting personnel and assets from a wide range of threats. The European capability landscape is characterised by different standards and systems. Maintaining an overview of the related needs and

(326) INTERoperability Standards for Unmanned Armed ForCes SysTems.
(327) Integrated Modular Unmanned Ground System.
(328) Integrated Modular Unmanned Ground System 2.
(329) Convoy Operations with Manned-unManneD Systems.

activities, including the state of the art of the technologies that can be used in this context, remains a major challenge throughout the planning periods.

Several EU defence initiatives contribute to studies and projects in this area:

- The **Capability Development Plan** [330] highlights the following priorities: Future soldier systems [331], Air transport [332] and Military mobility [333].
- Participating Member States are implementing a number of connected **Permanent Structured Cooperation** projects [334].
- **The Coordinated Annual Review on Defence** [335] Report (2024) identified the following relevant collaborative opportunities: soldier armament equipment and air transport, including tactical and strategic airlifts.
- As part of the **Overarching Strategic Research Agenda**, the Captech on Ground systems focuses among other things on improving soldier systems and the protection of land forces (including C-IED [336]), and develops the related Technology Building Blocks [337]. The Captech Aerial systems also has a work strand on Tactical and strategic fixed wing transport aircraft.

This EDF category of actions includes soldier systems, future cargo capabilities and the protection and mobility of military forces.

➢ **Soldier systems**

Soldier systems support force protection and enhance the operational effectiveness, reliability and endurance of individual soldiers and formations. They include gender-neutral equipment for military personnel, such as protective clothing, to enable operations with an appropriate level of protection in any operational environment.

The development and integration of cutting-edge technology into soldier systems are key for the armed forces and should provide soldiers with improved situational awareness, decision support, effective engagement and the ability to operate in GNSS [338] denied environments. Simple and effective human-machine interfaces should also be provided to support manned-unmanned teaming.

At EU level, there is an industrial overcapacity in the field of soldier systems. This has led to fragmentation of R&D investment and the development of different, non-interoperable systems.

To overcome this problem, the PADR 2017 GOSSRA project [339] was launched to develop an EU open architecture for soldier systems. This was taken forward by the EDF 2021 ACHILE project [340], which aims to develop highly innovative solutions for the next generation of dismounted soldier systems. Further development activities in this area are planned for 2025. In

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([330]) See EDA – The 2023 EU Capability Development Priorities.
([331]) Key areas: Equipment and systems for improved survivability, Weapons, arms and equipment with increased lethality and accuracy, Enhanced individual systems and integration for full interoperability in a multi domain operational environment.
([332]) Key areas: Tactical cargo unmanned aerial system, New tactical and strategic air transportation platforms.
([333]) Key areas: Enhanced sustainability, resilience and preparedness of lift and logistical capabilities, Accessibility and availability of civilian transport infrastructure for military platforms, Integration of military air capabilities in the EU airspace.
([334]) See PESCO – EU Collaborative Warfare Capabilities (ECoWAR), Future Medium-size Tactical Cargo (FMTC), Strategic Air Transport for Outsized Cargo (SATOC) and Next Generation Dismounted Soldier System (NGDSS).
([335]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([336]) Counter-Improvised Explosive Device.
([337]) These Technology Building Blocks include: novel user interfaces for soldiers; land systems architecture and integration; mobility and counter mobility.
([338]) Global Navigation Satellite System.
([339]) Generic Open Soldier System Reference Architecture.
([340]) Augmented Capability for High End Soldiers.

addition, the EDF 2021 LODESTAR project [341] contributed to the integration of augmented reality and AI into future soldier systems, with a follow-on EDF 2024 project LODESTAR II [342].

Additionally, the EDF 2024 HARVEST project [343] aims to revolutionise military personnel power management by developing a lightweight, wearable energy system with reduced weight and increased operational duration.

- **Future cargo capabilities**

Tactical transport aircraft are the 'workhorses' of the battlefield, performing missions such as airdrop deliveries, parachute drops, logistics, medical evacuations, air-to-air refuelling and special operations in harsh and adverse conditions. Beyond their purely military role, tactical transport aircraft are also key assets for enhanced civil protection/security and EU internal needs, making a vital contribution to disaster relief, search and rescue efforts and health crisis response.

The EDF 2023 FASETT project [344] is carrying out a feasibility study on future mid-size tactical cargo aircraft, as supported by the related PESCO project and identified as a medium to long-term cooperation opportunity during the last Coordinated Annual Review on Defence cycle. The EDF 2024 FASETT2 project [345] aims to mature the technologies identified in FASETT. With the aim of replacing the ageing fleet, further activities in this area may be considered in the future to meet Member States' needs.

In addition, strategic airlift of outsized cargo (SATOC) is also a core capability for rapid long-range military projection and global mission support, as supported by the related PESCO project. All operations conducted to date have relied on this critical capability for deployment and subsequent maintenance. Beyond their military role, SATOC aircraft are also key assets that make a critical and indispensable contribution to immediate logistical support over long distances, disaster relief and rapid response to general crises. There is currently no service provider with the appropriate capability to support the Member States' needs. The EDF 2023 ESOCA project [346] therefore aims to identify, define and assess short- and long-term options for a future European strategic airlift with an outsized cargo capacity. Possible further actions could be considered in the future.

- **Protection and mobility of military forces**

In the field of force protection, the PADR 2017 VESTLIFE project [347] has developed a new lightweight and modular bulletproof integral solution for dismounted soldiers with specific clothing architectures. In addition, the EDF 2023 GENIUS project [348] aims to improve the accuracy of detection of improvised or unexploded explosives. Further developments in this area could be considered in the future.

To facilitate the mobility of armed forces and increase their efficiency, the EDF 2021 SDMMS project [349] is developing a secure, innovative, user-transparent and traceable solution for the exchange of information between countries requesting any military movement in peacetime and

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[341] Live Operational Data Enhancement for Situational awareness Through Augmented Reality.
[342] Live Operational Data Enhancement for Situational Awareness Through Augmented Reality, part II.
[343] Harnessing Adaptive Renewables: Versatile Energy Supply Technology.
[344] Future Air System for European Tactical Transportation.
[345] Future Air System for European Tactical Transportation 2.
[346] European System for Outsized Cargo Airlift.
[347] Ultralight Modular Bullet Proof Integral Solution for Dismounted Soldier Protection.
[348] Next GEneration of IA and combat cloud systems for NeutralIsation of Unexploded threatS.
[349] Secure Digital Military Mobility System.

wartime. This project will lead to the important first step of digitising military mobility permits and the clearance landscape. In addition, due to the radical changes in the strategic security environment, Europe needs further innovations to digitise the military mobility landscape. A follow-on action on *Secure digital military mobility system* is included in the EDF annual work programme for 2026. The aim is to improve the efficiency of the prototype developed under the SDMMS project by adding features such as post-quantum cryptography, wartime resiliency, tracking and monitoring of movements, digitisation of military customs formalities, and secure mobile applications [350].

In the field of mobility of armed forces, the PADR 2019 ARTUS project [351] has also paved the way for a small swarm of intelligent and autonomously operating unmanned ground vehicles to provide logistical support to infantry platoons during their missions. In addition, the development of a future multirole light aircraft is included in the EDF annual work programme for 2026, with the objective to bridge the gap between today's battlefield and modern technology. Experience from the conflict in Ukraine shows the relevance of such a universal platform, which will be able to provide direct air support, ground targeting, intelligence, surveillance and reconnaissance with combat elements, and air strike coordination and reconnaissance with air traffic control support in a forward position in hostile environments.

Additionally, the EDF 2024 SABER project [352] aims to transform aerial delivery and data gathering systems for battlefields on land, sea and air using existing drones and ground rovers as part of a universal multi-agent system that enables scalability and cost-effectiveness. The further development of autonomous precision aerial delivery systems may be considered in the future.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the PROTMOB category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Standardised architecture and interfaces** for European soldier systems and **prototypes** of upgrades for soldier systems (e.g. protection equipment, small arms, ammunition, CIS).
- Full-size **demonstrators** of systems that improve soldiers' situational awareness, decision-making, physical and cognitive capability, effective engagement in non-permissive, multidomain environments, and teaming with unmanned systems.
- **Prototype** of a digital military mobility system that allows secure and timely information processing.
- **Demonstrators** of state-of-the-art and innovative technologies that contribute to the development of future mid-size tactical cargo aircraft.
- **Demonstrators** of state-of-the-art and innovative technologies that contribute to the development of Strategic Air Transportation of Outsized Cargo.

(350) The further digitisation efforts of the military customs formalities are directly aligned with the goal of Action Plan 2.0 to step up EU-NATO cooperation.
(351) Autonomous Rough-terrain Transport UGV Swarm.
(352) Strategic Autonomous vehicles for BattlEfield Reconnaissance and logistics.

13. Naval combat (NAVAL)

Naval power and supremacy at sea is essential for Member States' armed forces to fulfil their missions, protect EU citizens and their territory, and project power into more distant geographical areas. It plays a key role in supporting a credible foreign policy in times of peace as well as in times of crisis. Maritime security is also vital to the European economy, as the EU is surrounded by seas and oceans and has the largest exclusive economic zone in the world [353].

The evolving operational environment and threats require the development of cutting-edge naval systems and platforms. These should be capable of operating in a fully networked and integrated manner in challenging multi-domain threat environments, including, where necessary, extreme climatic and geographical environments (e.g. the Arctic). They should also meet the requirements of the most advanced environmental legislation.

From a technological and industrial perspective, despite the fragmentation of the EU naval internal market, the European naval industry remains globally competitive and should maintain its technological leadership. The capacity of system integrators and equipment suppliers is a strategic asset for the European naval sector, which should be preserved and strengthened. The EDF contributes to this effort by supporting R&D of naval-related technologies, standards, systems, and state-of-the-art naval platforms and ships.

Some naval projects are currently paving the way for future broader actions under other categories, such as the small optical satellites for maritime surveillance funded under the EDIDP 2019 OPTISSE project [354] and the EDIDP 2020 NEMOS project [355]. The Space category of actions has also benefited from the momentum created by extending the scope of ISR beyond maritime surveillance within the EDF 2022 SPIDER project [356]. Similarly, the Naval combat category of actions benefits from R&D activities carried out in other categories. This was the case with the Energy resilience and environmental transition category of actions, where the development of green naval fuel was addressed by the EDF 2023 CALIPSO project [357] as part of innovative propulsion systems for defence applications, and the topic on naval hybrid propulsion and power systems was included in the EDF annual work programme for 2025.

Enhancing maritime capabilities is one of the six strategic objectives of the revised **EU Maritime Security Strategy** (2023), with the EDF being one of the tools to support EU action in the field of maritime security. A number of other mutually reinforcing EU actions and initiatives are carried out in the naval domain:

- EDF topics and the main expected outcomes from this category are in line with the priorities of the **Capability Development Plan** [358]. The implementation of these priorities is guided by the Priority Implementation Roadmap on *Naval Combat and Maritime Interdiction* in coordination with the roadmap on *Maritime Domain Awareness* developed by the EDA.
- Participating Members States develop naval initiatives through **Permanent Structured Cooperation** projects [359].

([353]) When adding all the exclusive economic zones of Member States, including the overseas countries and territories.
([354]) Very high resolution OPTIcal payload for Small Satellites for defencE applications.
([355]) Novel Earth and Maritime Observation Satellite.
([356]) Space based Persistent ISR for Defence and Europe Reinforcement.
([357]) Innovative propulsion solutions for land and naval defence applications.
([358]) Naval combat and maritime interdiction in all the three key areas, namely the upgrade of current naval surface systems, next generation naval surface combat systems, and long-range armed manned and unmanned maritime systems. For details, see EDA – The 2023 EU Capability Development Priorities.
([359]) See PESCO – European Patrol Corvette (EPC), Medium size Semi-Autonomous Surface Vehicle (M-SASV), Essential Elements of European Escort (4E) and EU Collaborative Warfare Capabilities (ECoWAR).

- Most of the topics addressed in this category support the **Coordinated Annual Review on Defence** [360] collaborative opportunity on the *Development of Next Generation of Class of Multipurpose Modular Surface Combatant Vessels*.
- Several Technology Building Blocks [361] defined by the **Overarching Strategic Research Agenda** focus on the maritime domain, including naval combat, and these are addressed within the CapTech on Maritime.

Against this background, the EDF supports naval combat-related R&D along two main lines:

➢ **Developing European state-of-the-art capabilities in naval systems and ships**

A next generation class of combat ships to meet the needs of European navies in the 21st century is being developed under the EDF 2023 EPC2 [362] project, building on the initial design of the corvette class ship under the EDF 2021 EPC [363] project.

The EDF 2022 EUROGUARD [364] project will prototype a first-of-its-kind, versatile, medium-size, semi-autonomous surface naval vessel for coastal operations and will demonstrate the benefits of a common system architecture for future European semi-autonomous and fully autonomous naval ships. To achieve this objective, a final follow-on has been included in the EDF annual work programme for 2026.

Following on from the EDIDP 2020 TRANSFLYTOR [365] project, the EDF 2023 ARROW [366] project aims to develop a prototype of a lightweight hydrofoil boat with advantages for intelligence, surveillance, reconnaissance and special operations missions.

To maintain the manoeuvrability and superiority of European naval forces, the EDF 2022 E-NACSOS [367] project aims to ensure the superiority of EU naval surface vessels at sea, while preserving EU naval surveillance sovereignty, by developing novel protocols, interfaces and target architectures capable of addressing new and asymmetric threats in the area of anti-air warfare and air and missile defence. A follow-on topic on *Naval collaborative surveillance & engagement* may be considered in the future.

Taking into account the diversity of the EU in terms of main naval scenarios, missions and current capabilities of EU navies, these actions reflect the critical importance of the maritime domain for all Member States. The widest possible distribution of supply chains should be sought to ensure maximum inclusiveness.

➢ **Innovative technological solutions for naval projects**

These actions focus on technologies, standards or systems to be incorporated into specific naval projects and are enablers for both the naval industry and EU navies. They are inclusive in nature.

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(360) See EDA – Coordinated Annual Review on Defence: Report 2024.
(361) Technology Building Blocks focused on the maritime domain (not exclusive to naval combat) include Communication and distribution sensors network, surface and underwater, Simulation and training, Platform survivability and operability in challenging conditions, Energy and propulsion, Increased autonomy and robotics, Identifying and countering threats, high-energy weapons integration, Smart industrialisation and predictive maintenance.
(362) European Patrol Corvette, the European class of naval vessel.
(363) European Patrol Corvette.
(364) EUROpean Goal based mUlti mission Autonomous naval Reference platform Development.
(365) Troop Transportation Flying Vector.
(366) Autonomous Rapid Recognition Operation Warship.
(367) EU NAval Collaborative Surveillance Operational Standard.

OCEAN 2020 [368], the EU's largest collaborative defence research project funded under the PADR, paved the way for improved European maritime situational awareness and increased effectiveness and interoperability for joint operations. The EDIDP 2019 SEA-DEFENCE [369] project produced a roadmap of technologies to be included in the next generation of naval platforms.

Digital transformation was addressed by two EDF 2021 projects: EDINAF [370] aimed to develop the foundations of digital ship and ship digital architecture, while d-THOR [371] developed the next generation of ship structural health monitoring for predictive maintenance. The follow-on topic for *Digital Ship and Naval Combat Cloud* has been included in the EDF annual work programme for 2025.

Additionally, the EDF 2024 NEREUS project [372] aims to lay the foundations for a smart system of systems for future European naval platforms. A follow-on topic for *Functional Smart System-of-Systems with integrated survivability for Future Naval Platforms* may be considered in the future.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the NAVAL category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- A **first ship** of a modular, multi-role patrol corvette class, ready for joint procurement.
- A **first ship** of a medium-size, semi-autonomous surface vessel class, including different mission modules, ready for joint procurement and including the development of standardised architecture and interfaces for automation.
- Development of a naval collaborative **surveillance and engagement capability**, ready for joint procurement and integration on different platforms.
- Development of **standardised architecture and interfaces** related to smart ships and digital transformation, including the naval combat cloud.

14. Underwater warfare (UWW)

UWW remains an essential factor in the operational plans of European navies and is an integral part of naval capability development. The **Strategic Compass** (2022) identifies the need to protect critical maritime infrastructure, including the seabed, by developing joint operational, capability and technological solutions.

The ability to counter underwater threats is a fundamental prerequisite for ensuring freedom of operation in the maritime domain. The range of capabilities required extends from underwater effectors to mine countermeasures, including their enablers such as situational awareness. The future of UWW follows the megatrends of digitalisation and convergence. The European Defence Technological and Industrial Base is relatively well positioned globally, but continuous R&D efforts are needed to ensure technological sovereignty and competitiveness in this highly sensitive and export-restricted area.

[368] Open Cooperation for European mAritime awareNess.
[369] Survivability, Electrification, Automation, Detectability, Enabling Foresight of European Naval Capabilities in Extreme conditions.
[370] European DIgital NAval Foundation.
[371] Digital Ship Structural Health Monitoring.
[372] Naval systEm of systems and integRatEd sUrvivability of future EU platformS.

The primary directions in technological advancement in this field involve challenges such as interoperability of various unmanned systems, swarming technologies and multimodality (convergence). Future systems are also expected to share and collaborate on tasks such as intelligence gathering, communication, analysis, positioning, surveillance and engagement. Actions aimed at solving common general underwater challenges, such as the real-time exchange of broadband information, would meet the needs of the wider domain.

It is therefore essential to consider the underwater environment with its interfaces from the air to the seabed, the specific threats it poses and the enabling infrastructure it requires. EDF activities focus on developing technologies for **future effectors**, their **countermeasures** and support functions, including the protection of critical seabed infrastructure.

Enabling or contributing technologies and solutions for UWW may also be addressed through other EDF categories of actions such as material and components and sensors, where relevant. Furthermore, the UWW category of actions is inextricably linked to the naval combat category, as all UWW capabilities always have an interface to naval systems.

A number of other complementary or mutually reinforcing EU actions and initiatives are carried out in the UWW domain:

- Main expected outcomes from the UWW category of actions are in line with the priorities of the **Capability Development Plan** [373]. The implementation of these priorities is guided by the Priority Implementation Roadmap on Maritime Domain Awareness and the roadmap on Underwater and Seabed Warfare.
- UWW and related capabilities are also addressed by the participating Members States in the form of several **Permanent Structured Cooperation** projects [374].
- Additionally, several EDF actions and the main expected outcomes from this category support **Coordinated Annual Review on Defence** [375] collaborative opportunities, such as *Enhancement of UMS performances*.
- The CapTech on Maritime also addresses the underwater dimension of naval platforms and related systems, informing the common European R&T priorities defined in the **Overarching Strategic Research Agenda**. EDA R&T activities in this CapTech also include CAT-B projects [376].

As the UWW category of actions follows megatrends such as digitalisation, convergence and underwater communications, it is in line with target investment areas of the **Strategic Technologies for Europe Platform** (STEP) [377]. Certain topics [378] under UWW may therefore be eligible for the STEP Seal under the EDF.

EDF projects under UWW focus on R&D in three main fields: mine warfare, anti-submarine warfare and seabed warfare, and situational awareness and command and control (C2).

([373]) CDP priority 'Underwater and Seabed Warfare' under the key areas 'Underwater Force protection Systems' and 'Seabed warfare & Deep-Water operational capabilities'; and Priority 'Maritime Domain Awareness' under the key area 'Comprehensive Underwater Surveillance Capabilities'. For details, see EDA – The 2023 EU Capability Development Priorities.

([374]) See PESCO – Maritime (semi-) Autonomous Systems for Mine Countermeasures (MAS-MCM), Maritime Unmanned Anti-Submarine System (MUSAS), Deployable Modular Underwater Intervention Capability Package (DIVEPACK), Critical Seabed Infrastructure Protection (CSIP) and Upgrade of Maritime Surveillance (UMS) and Modular Seabed Vessel (MSV).

([375]) See EDA – Coordinated Annual Review on Defence: Report 2024.

([376]) As an example, the EDA CAT-B SABUVIS II study aims to design and implement a swarm of autonomous underwater vehicles that closely collaborate together, with particular emphasis on the leaders in charge of the navigation function. It addresses communications and distributed sensor networks at both surface level and underwater, increased autonomy as well as energy and propulsion technologies.

([377]) See European Union – Strategic Technologies for Europe Platform (STEP).

([378]) For example, Layered Critical Seabed Infrastructure Protection.

➢ Mine warfare

Next generation modular mine countermeasure (MCM) solutions, underwater threat detection capabilities and agile multipurpose effectors are sought, with a focus on innovation. The aim is to develop remotely operated, highly scalable networked systems with autonomous features that are market ready. Modularity and scalability are critical features for integration into different platforms. Signature management to counter multi-influence underwater sensor threats is also addressed. A related area of interest is technological enablers, such as quantum magnetometers as part of a multi-influence sensing network.

The EDF 2023 EequalMCM project [379], which is a follow-up to the EDIDP 2020 MIRICLE project [380], aims to deliver new MCM capability prototypes ready for industrialisation in the EU. In addition, the EDF 2024 EUROSWEEP project [381] will develop a common European unmanned minesweeping system with autonomous features.

➢ Anti-submarine warfare and seabed warfare

Any type of underwater vehicle or moving threat is considered relevant to **anti-submarine warfare (ASW)**. New stand-off hard-kill solutions are being developed, particularly for counter-torpedo subjects, without limiting targets to torpedoes only. Adaptive solutions using networks of manned and unmanned assets across the kill chain are essential. The platform agnostic approach is preferred for capability enhancement as it provides future procurement opportunities for a wider group of Member States.

The growing importance of **seabed warfare (SBW)** is being taken into account in ASW solutions. The EDF 2023 SEACURE project [382], which is a follow-up to the EDIDP 2020 SEANICE project [383], will develop and demonstrate at sea an integrated system of systems of unmanned platforms for joint anti-submarine and seabed warfare operations to protect critical maritime infrastructure. Additionally, a topic on *Layered Critical Seabed Infrastructure Protection* is included in the EDF annual work programme for 2026.

➢ Situational awareness and C2

Digital infrastructure, network and data centricity for integrated communications above and below the surface and cybersecurity by design for systems of systems should be considered. This will contribute with enablers to other capabilities (such as MCM, ASW and SBW).

Advanced cognitive sensor technologies, which can be used for several UWW capabilities, will enable the future integrated (underwater) operational environment. Modular and non-static sensor and communication node platforms are included. The development of ultra-sensitive acoustic sensors based on quantum technologies could be considered. EU competitors are currently exploring this technology. In addition, for secure communication systems, post-quantum cryptography can provide information-theoretic security for radio and underwater communications.

The EDIDP 2020 CUIIS project [384] has developed a C4I [385] mission system in the form of a portable tablet for underwater situational awareness for military divers. The EDF 2022 SWAT-

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([379]) European Extended Mine Countermeasures.
([380]) Mine Risk Clearance for Europe.
([381]) European Autonomous Heavy Minesweeping System.
([382]) SEabed and Anti-submarine warfare Capability through Unmanned featuRe for Europe.
([383]) antiSubmarine warfare European Autonomous Networked Innovative and Collaborative Environment.
([384]) Comprehensive Underwater Intervention Information System.

SHOAL project [386] aims to develop a system of systems concept for a swarm of unmanned systems operating autonomously and effectively as a team for an underwater mission against a moving subsurface threat. In addition, the EDF 2021 FIBERMARS project [387] is working on distributed acoustic sensing technology, while the EDF 2022 AVALON project [388] is paving the way for the implementation of novel, high-performance underwater optical wireless networks for military applications. Moreover, the EDF 2024 ASTERION project [389] will develop a universal architecture for underwater communication for both intra-node components and network components between the nodes.

For submarine special operations, the EDF 2024 PLEIADES [390] project proposes an innovative solution, allowing submarines to deploy an underwater swarm of hybrid autonomous unmanned vehicles to operate in enemy littoral waters. Additionally, the EDF 2024 AQUILA [391] project aims to develop an innovative, autonomous, easy-to-deploy and cost-effective end-to-end system for launching micro autonomous unmanned vehicles (AUVs).

To improve the design of underwater platforms and the proper integration of sonar, a topic on *Development and validation of models predicting flow-related underwater noise* was included in the EDF annual work programme for 2026.

Development activities to **improve diving operations** in contested environments may be addressed in all areas where relevant. Similarly, the protection of **critical maritime infrastructure** may be addressed in all areas.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the UWW category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototype** of a modular MCM toolbox.
- **Prototype** of unmanned ASW and SBW C4I.
- **Experimentation and demonstration** of a swarming system of underwater drones for shallow water missions.
- Testing of MCM, ASW and SBW platforms and a heavy minesweeping drone.
- **Proof-of-concept** of a stand-off hard-kill solution for dynamic underwater threats, including counter-torpedo solutions.
- **Demonstration** of secure optical and acoustic underwater communications.

15. Simulation and training (SIMTRAIN)

Simulation and training activities are critical for defence, improving the readiness and efficiency of existing systems used by armed forces and enabling significant cost savings compared to live activities. In addition, military simulation allows the development and testing of theories of warfare or tactics outside the context of actual hostilities, thereby reducing the risks for armed forces.

([385]) Command, Control, Communications, Computers and Intelligence.
([386]) SWArm and Teaming operation of manned & unmanned underwater vehicle SHOAL.
([387]) Using fiber optical cables for maritime situational awareness.
([388]) UnderwAter optical wireless communication network architecture empowered by adVanced opticAl materiaLs for sea bOrder protection and deep-sea exploration.
([389]) Adaptive and Secure Technology-Enabling Reliable and Integrated Opto-acoustic underwater Networking.
([390]) Hybrid Autonomous Unmanned Vehicles Swarm For Submarine Special Operations.
([391]) Autonomous QUick Insertion and Launch of AUVs.

Distributed simulation can improve cooperation between EU Member States and EDF associated countries provided it meets common technical standards.

The Simulation and training (SIMTRAIN) category of actions under the EDF addresses the overarching field of **Modelling and Simulation** (M&S) and its concrete military applications in the areas of decision-making from strategic to tactical level, system design and testing, training and education. EDF actions in this category must integrate the latest technological innovations relevant for the domain, such as:

- **Digital twins**
  Digital twins of various forms and degrees of realism enable more accurate testing and analysis of systems and of military strategies and tactics. They allow military planners and strategists to test and refine their theories and approaches in a safe and controlled environment, without the risks and consequences of actual combat. By using digital twins in simulation-based war games, military organisations improve and speed up decision-making, enabling them to respond more effectively to emerging threats and rapidly changing situations.

- **Artificial intelligence (AI)**
  AI-supported war games can speed up the decision-making process. Digital twins as described above are also increasingly incorporating AI. But while AI has been a hot topic among military technologists for years, the training community is still in the early stages of exploring how it can be applied to its high-tech simulators and modelling software.

- **Augmented Reality (AR)**
  AR is a real-time interactive first-person experience that augments the user's real-world environment with computer-generated content using 3D registration (alignment) of virtual content and the real world through pose tracking. The integration of AR technology into military training will create innovative and more efficient training methods, enabling a wide range of scenarios with an extremely realistic combat training environment based on real events or schematics. EDF calls also address other technologies for diverse learning. This enables military personnel to acquire practical skills in a simulated environment, including virtual, mixed and extended reality, as well as the metaverse [(392)].

- **Live, Virtual, Constructive training interoperability**
  For simulation, future expectations include the prioritisation of rapid prototyping and development cycles with upgrades via software packages to reduce the overhead costs of upgrading physical training systems. A trend that is expected to continue is the gradual adoption of live, virtual and constructive blended architectures and strategies, with a strong focus on upgrading and integrating legacy training systems.

The technologies used in M&S (e.g. AI and other critical technologies) are considered of **strategic importance** for the EU's economic security [(393)]. Projects under the SIMTRAIN category as well as other EDF projects contributing to the development of **critical technologies** can therefore benefit

(392) The metaverse is a hypothetical iteration of the internet as a single, universal and immersive virtual world that is facilitated by the use of virtual reality and augmented reality headsets. It can be used for military training, using realistic scenarios in a controlled environment.
(393) Commission Recommendation (EU) 2023/2113 of 3 October 2023 on critical technology areas for the EU's economic security for further risk assessment with Member States.

from the Strategic Technologies for Europe Platform [394]. This helps enhance their visibility and the possibility of cumulative funding.

The EDF as well as the EDF precursor programme EDIDP have so far addressed several aspects of M&S, with soldier training being one of the most widely used applications. Simulation proves to be useful in various EDF categories of actions, regardless of the type of activities of the projects (e.g. studies, design, prototyping and testing). Other EDF categories support the development of technologies mentioned, enabling or enhancing simulation (e.g. AI addressed in DIGIT) and ensuring the interconnectivity and complementarity between the categories addressed under the EDF.

Moreover, M&S applications developed can be leveraged in both civil and military contexts. Under the EDF, even non-traditional defence actors (e.g. research and technology organisations, academia) contribute to the innovativeness and interoperability of these **dual-use solutions**, fostering synergies between civil and defence industries.

Enhancing the simulation and training solutions is one of the **defence capability goals of Member States**, as identified in a number of complementary defence initiatives and programmes:

- Several **Capability Development Plan** priorities [395] are addressed within the SIMTRAIN category, as reflected in the operational objectives described below.
- Participating Member States are currently working together on a number of **Permanent Structured Cooperation** simulation and training-related projects [396].
- The latest **Coordinated Annual Review on Defence** Report (2024) [397] has identified benefits of modelling, simulation and digital twin solutions also for space technologies, specifically for the enhancement of security of space assets, such as collision avoidance and threat prediction. The report also recommends exploring options for joint training facilities to enhance interoperability across European armed forces and promote shared expertise.
- The **Overarching Strategic Research Agenda** defines several Technology Building Blocks that are focused on simulation [398] and that are being developed within corresponding EDA CapTechs, mainly the CapTech on Simulation Technologies.

EDF addressed SIMTRAIN's **operational objectives** across multiple fields, including:

➢ **Decision-making from strategic to tactical level**

The EDF 2022 FEDERATES project [399] addresses the lack of a common European simulation baseline. It aims to connect different simulators across Member States by using the same network

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([394]) In the following sectors: Digital technologies & deep technologies innovation, Clean & resource efficient technologies and Biotechnologies. Within SIMTRAIN, the following call topics were identified as contributing to STEP: Simulation and training for medical emergencies (EDF 2024), Live, Virtual, Constructive training interoperability (EDF 2025), and M&S AI Framework (EDF 2026).

([395]) Including Priority Cohesive & Well-Trained Militaries under Key Area Enhanced Education and Training Enablers, Priority Cohesive & Well-Trained Militaries, Priority Air Combat under Key Area NG Air Combat Systems and Priority Cohesive & Well-Trained Militaries under Key Area Enhanced Education & Training Enablers, and facilities. For details, see EDA – The 2023 EU Capability Development Priorities.

([396]) See PESCO – Integrated European Joint Training and Simulation Centre (EUROSIM) Main Battle Tank Simulation and Testing Center (MBT-SIMTEC) and CBRN Defence Training Range (CBRNDTR).

([397]) See EDA – Coordinated Annual Review on Defence: Report 2024.

([398]) Technology Building Block related to Simulation CaptTech / Working Group (WG): Integrated Live, Virtual and Constructive (I-LVC) for Training, Simulation and Serious Games Solutions, Artificial Intelligence (AI) and Big Data (BD) for Decision-Making Support, Immersive, Virtual and Augmented Reality, Cyber Defence Simulation, Joint Strategic, Operational and Tactical level simulators, Modelling & Simulation as a Service (MSaaS) for synthetic environment and rapid scenario generation, Simulation for Systems of Systems (S3). Technology Building Block on Modelling, Simulation and Training are also addressed in other CapTech/WG, such as on Maritime, Cyber R&T, Optronics and CBRN & HF.

([399]) FEDerated Ecosystem of euRopean simulation Assets for Training and decision Support.

and standards. This project will therefore result in protocol and defined requirements on how to implement European modelling and simulation as a service solution for distributed synthetic training and decision-making. A complementary action to develop concrete software may be considered in the future.

In line with current technological trends, the use of AI to improve decision-making and foster the development of high-end simulators should be further explored. A call topic on *Modelling & Simulation supported AI framework for military decision-making and training* is therefore included in the EDF annual work programme for 2026. Additionally, AI and Reinforcement Learning show huge potential for military planning, decision-making and concepts of operations. To address these developments and bridge the reality gaps in such technologies, the EDF 2024 BATTLEVERSE project [400] addresses and identifies suitable methods and solutions.

- **System design and testing**

Digital twin technology is particularly relevant for system design. A call topic focusing on design and analysis for aerial systems has therefore been included in EDF 2025, with the aim of using digital twins as a method to design, test and validate aerial systems before building physical prototypes. Additionally, and as identified in the Coordinated Annual Review on Defence [401], the security of space assets can also benefit from digital twin solutions.

- **Training and education**

Simulation in this area has been addressed under EDIDP through the projects VERTIgO [402], FIIST [403], FITS4TOP [404] and VireTS [405]. Completed projects such as FIIST and VireTS have provided specific simulation capabilities for pre-deployment and in-theatre training of personnel. More specifically, VireTS delivered a prototype for training military medical personnel. In addition, the EDF 2024 READYMED EUROPE project [406] will incorporate other categories of users, such as military instructors and system administrators, into the developed military medical training platform.

In addition, the EDF 2021 ABITS project [407] built on results from FIIST as it used the same simulator and aims to develop a tactical in-door training solution that integrates performance quantification, physiological state and analysis in the training-simulation loop. For rapid deployment in the field, which is crucial for European defence readiness, the EDF 2022 TRAVISMOS project [408] is developing a mobile, modular, scalable and flexible virtual simulation solution.

Partially building on another EDIDP project, FITS4TOP, the EDF annual work programme for 2025 includes the topic Live, Virtual, Constructive training interoperability. While FITS4TOP carried out studies and design for a European-wide solution for an integrated training system with

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([400]) A Human-Centred MSaaS Ecosystem for Enhanced Mission Planning and Execution via Battlefield Modelling, Adversarial AI, and Multi-domain Simulation Environments.
([401]) See EDA – Coordinated Annual Review on Defence: Report 2024, p. 9.
([402]) Virtual Enhanced Reality for inTeroperable traIning of CBRN military and civilian Operators.
([403]) Future Integrated Indoor Soldier Training.
([404]) Future Integrated Training Solution for TOP gun.
([405]) Development of Virtual Reality Trauma Simulator.
([406]) Technology-Enhanced Military Medical Training for Increased Readiness and Survivability in the Battlefield.
([407]) Advanced Biometrics In Training and Simulation.
([408]) TRAining with VItal Signs MOnitoring in modular Setup.

the focus on Live, Virtual and Constructive technologies, the call topic under EDF 2025 aims to provide a full-scale demonstrator suitable for maritime and ground forces [409].

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the SIMTRAIN category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Prototype** of European M&S as a service solution for distributed synthetic military training, ready for use and/or procurement.
- **Prototype** of systems to monitor soldiers' psychological and physical state in real-time during simulated training, ready to be integrated into different simulators.
- Initial **demonstrator** of a multi-functional digital twin of an aerial system, able to integrate future updates at sub-system level.
- **Demonstrator** of toolsets using AI for decision-making processes, wargaming or combat simulators, including in multidomain operation contexts.
- **Demonstrator** of multinational Live, Virtual and Constructive combat training capabilities in a representative multi-domain operational scenario.

16. Disruptive technologies (DIS)

This category of actions addresses the development of disruptive technologies (DIS) for defence [410], including those based on concepts or ideas originating from non-traditional defence actors [411]. In this context, two main areas of work are considered:

- **Disruptive technologies based on concepts or ideas originating from non-traditional defence state-of-the-art technologies**, such as AI, big data, the internet of things, autonomous systems, biotechnologies and quantum technologies. These techniques are expected to have a significant impact when applied in defence and military environments, helping to address gaps in military capabilities that are covered by other categories of actions within the EDF. The key point is that the research into and/or application of these cross-cutting technologies addresses or enables specific defence capabilities.

- **Emerging technologies that are equally disruptive and contribute to (or complement) the development of innovative defence systems**, such as directed energy weapons, over-the-horizon radar applications, adaptive camouflage, and electromagnetic artillery systems.

Coordination and consistency with other categories of actions (e.g. DIGIT for AI core technologies and SENS for quantum-sensing technologies) is ensured to avoid duplication of effort.

Other EU initiatives and activities also address disruptive technologies for defence:

([409]) For air forces, a solution in this field already exists and can be further expanded upon.

([410]) 'Disruptive technology for defence' means an enhanced or completely new technology that brings about a radical change, including a paradigm shift in the concept and conduct of defence affairs, such as by replacing existing defence technologies or rendering them obsolete.

([411]) Calls in this category of actions encourage the driving role of new players in defence research and innovation, including excellent researchers, ambitious high-tech SMEs and visionary research centres of big companies, universities or research and technology organisations.

- From the perspective of the **Capability Development Plan** (CDP) [412], the activities falling under the DIS category align with priorities for the development of the next generation of combat systems for land, sea and air. In addition, the development of other disruptive technologies, including AI and quantum technologies, is referenced across a plethora of CDP priorities.
- Participating Members States also focus on disruptive technologies through **Permanent Structured Cooperation** projects [413].
- **The 2024 Coordinated Annual Review on Defence** Report [414] mentions the importance of harnessing emerging disruptive technologies for full-spectrum operations, as well as the importance of industry collaboration in innovation to reduce financial risks, secure defence supply chains and ensure technological competitiveness.
- Disruptive technologies are also targeted as part of the **EU Defence Innovation Scheme** instrument. This aims to lower the entry barriers to the defence sector for smaller industry players and innovators by focusing on technological readiness and market maturity.
- Projects focusing on emerging and cutting-edge technologies that target the **Strategic Technologies for Europe Platform** (STEP) [415] priority areas [416] are awarded a STEP Seal [417] to make it easier to find alternative funding.
- Where relevant, complementarity with activities of the **European Defence Agency** is leveraged, for example with regard to ongoing CAT-B projects and within CapTechs.

Against this background, the EDF supports disruptive and emerging actions in the following fields, among others:

➢ **AI**

Future military capabilities will include a significant number of systems that will make extensive use of AI techniques. These techniques can be applied to help develop capabilities within conventional operational domains.

In the naval domain, for example, the continuous increase in the number of sensors and the volume of data related to the detection, classification and identification of surface and underwater contacts makes the implementation of task automation techniques highly desirable. Advanced processing techniques based on AI should therefore be incorporated into vessels' systems to reduce the operator workload and increase the accuracy and speed of the processes.

In the air domain, the EDF 2024 NEUROQUAD project [418] combines AI, quantum computing and neurotechnology to enhance pilot performance through real-time monitoring and prediction of the pilot's cognitive state.

([412]) See EDA – The 2023 EU Capability Development Priorities.
([413]) For example, see PESCO – Quantum Enablers for Strategic Advantage (QUEST) and Directed Energy Systems (DES).
([414]) See EDA – Coordinated Annual Review on Defence: Report 2024.
([415]) See European Union - Strategic Technologies for Europe Platform (STEP).
([416]) For example, the EDF call *New abilities in the Over-the-Horizon sensing* (D) and selected projects under Actions targeting disruptive technologies for defence.
([417]) The STEP Seal will also allow for proposals that score highly but are not selected under the EDF to receive funding from the European Innovation Council with no additional evaluation.
([418]) Disruptive 'NEURO-QUantum-AI technology symbiosis' for Real-Time Cognitive Monitoring and Decision Support to improve Pilot Control and Safety.

➢ Quantum technologies

Possessing and deploying quantum technologies for sensing could be a game changer for many defence applications, so mastering these technologies is essential for mission superiority and competitiveness.

The EDF annual work programme for 2021 already addressed quantum sensors for positioning, navigation and timing (PNT) and target acquisition, including: (i) chip-sized accelerometers and gyroscopes; (ii) quantum vector magnetometers for magnetic navigation/geo-referencing based on magnetic anomaly maps; and (iii) electromagnetic and optronics sensing.

The EDF 2021 ADEQUADE project [419] followed up on the PADR 2019 QuantaQuest project [420], which generated major technological developments in three main areas: (i) fully autonomous positioning and timing for military platforms; (ii) secure communication for C4ISR; and (iii) a quantum network of sensors for synergic connection. The EDF 2024 projects ORQESTRA [421], Q-ARM [422] and SQORPION [423] further build on research in these areas.

The EDF 2024 QANCOMFIN project [424] designs novel and disruptive sets of classical and quantum algorithms for the prediction of crack propagation in materials.

➢ Directed energy weapons

In the face of evolving conventional and unconventional threats that are highly agile and difficult to detect, directed energy weapon (DEW) systems have the potential to transform the course of future conflicts. Laser-based DEW systems are a cost-effective solution to the emerging needs for highly precise, targeted and agile weapon systems. However, under certain conditions (e.g. urban environments, protests and riots, public events), controlling collateral damage and preserving human life is of the utmost importance.

In many of these scenarios, traditional effectors can no longer be used, and radio frequency directed energy weapons (RF DEW) could be a more effective means of carrying out less-than-lethal attacks at a lower cost. One major advantage of such weapons is that they require less accuracy than many conventional weapons such as artillery. The weapon's destructive energy is delivered almost instantaneously, enabling multiple targets to be engaged simultaneously.

However, the main limitation of RF DEW is that, unlike laser-based DEW, it is not possible to produce a narrow, high-powered, focused RF beam. In principle, any equipment that employs modern electronic components is at risk of an RF DEW attack. For example, armoured vehicles and ships could malfunction or become completely inoperative, and aircraft could fall out of the sky. An in-depth understanding of RF DEW lethality could therefore also help identify countermeasures.

Previous EU-funded research projects under the PADR such as TALOS [425] and the ongoing EDF 2023 TALOS-TWO project [426] are paving the way for the design and development of an EU high-power laser effector. Once developed, it aims to be integrated into military systems (air combat,

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([419]) Advanced, Disruptive and Emerging QUAntum technologies for DEfense.
([420]) Quantum Secure Communication and Navigation for European Defence.
([421]) Orchestrating the Operational Deployment of Quantum Resistant Services for Next-Generation Secure Defence Systems and Communications.
([422]) Quantum Agile and Resilient Military Communications.
([423]) Spin-based Quantum Optics for Robust and Precise Inertial Sensing, Orientation and Navigation.
([424]) Quantum Computing with Finite Elements for crack propagation in defence applications.
([425]) Tactical Advanced Laser Optical System.
([426]) Tactical Advanced Laser Optical Systems: Technologies for High Power Laser, Vulnerability study, Vignette development and Operational Study.

naval, land or counter unmanned aircraft systems). A topic that addresses DEW and follows on TALOS-TWO may be considered in the future.

Contributing to the development of advanced lasers, the EDF 2023 LACE [427] project was launched.

Different topics or follow-on topics could be considered based on Member State input and the results of the actions carried out under the 'non-thematic' calls of previous years. For example, to follow up and complement the EDF 2021 iFURTHER project [428] in the field of over-the-horizon systems, the topic *New abilities in the Over-the-Horizon sensing* is included in the EDF annual work programme for 2026.

Main expected outcomes from EDF support in 2021-2027

Without affecting the discussion on other potential R&D topics to be addressed in future annual work programmes, the EDF's aim in the DIS category of actions should be to help achieve the following main expected outcomes (complementary to the outcomes of other categories of actions in the full spectrum of defence domains):

- **Demonstrator** of a medium calibre electromagnetic artillery system (contributing to the development of long-range indirect fire capability).
- **Prototype** of directed energy weapons (contributing to the development of innovative air combat, naval and land systems).
- **Demonstrator** on quantum communication such as key distribution and networked systems.
- **Demonstrator** on accelerometers and gyroscopes for positioning navigation and timing purposes.
- **Demonstrator** of quantum processor usage in defence applications.

([427]) LAser Ceramics.
([428]) High Frequency Over The Horizon Sensors' Cognitive Network.