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European Defence Fund

Indicative multiannual perspective 2025-2027

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ANNEX 2

European Defence Fund indicative multiannual perspective 2025-2027

CONTENTS

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.

Furthermore, to allow industry and Member States to focus on and invest into 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 in the context 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	

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 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

(1) EU Member States and EDF Associated Countries (Norway) are hereinafter referred to as Member States.

form of i) technological challenges; ii) calls with financial support to third parties; iii) spin-in calls [2] 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, and concerning 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 (EDSTAR) managed by the European Defence Agency (EDA), which identifies standardisation gaps and best practice standards to support programmes, organisations, and agencies.

Furthermore, the EDF will help implement the Strategic Technologies for Europe Platform (STEP) objectives with specific calls that aim to support R&D in critical technologies in the areas of digital technologies and deep-tech innovation, clean and resource-efficient technologies, and biotechnologies. A minimum budget of EUR 1.5 billion will be used to support actions contributing to STEP in 2024-2027.

(2) Spin-in Calls (europa.eu)

II. INDICATIVE PLANNING PER CATEGORY OF ACTIONS

For each category of actions addressed in this indicative EDF multiannual perspective, the refined selection of topics for the EDF's 2026 and 2027 work programmes will undergo further assessment and consolidation. Also, the Member States' proposals, including new ones, will need to be justified. The selection of topics will also be determined based on the availability of the results of the projects launched under EDF precursor programmes and the outcome of the EDF calls for proposals.

1. Defence medical response, CBRN, biotech and human factors (MCBRN)

Medical response and CBRN capability development is characterised by a constant flow of innovation, resulting from a high level of R&D within industry and specialised research organisations, as well as close cooperation with the users, particularly Member States' medical and CBRN command/centres. The ability to consider and incorporate human factors, evolving defence capabilities and technical systems is needed to achieve the intended benefits. The European defence industry generally integrates civil solutions into offers to military customers. Considering the high level of competition particularly with companies from the USA and Asia, as well as its reflection in Member States' and European defence capability priorities, a sustained level of investment at European level is highly relevant in this domain. Therefore, special attention is paid to: i) continuous and strategic development of capabilities in the areas of detection; ii) identification and monitoring of CBRN threats; iii) new and innovative decontamination methods and procedures; iv) CBRN-related data networking and automation; and v) the development of medical CBRN countermeasures.

- **Medical countermeasures**

In line with the capability development plan (CDP) priorities [3], the EDF has helped implement the European Defence Medical Countermeasures (MCM) Alliance launched in the context of a framework partnership agreement (FPA)in 2023. Overall, the Alliance aims to implement a European multiannual action plan for research and development on MCMs against CBRN threats and step-up European collaboration to tackle current or future CBRN threats with a critical mass of players in the domain. These players include research and technology organisations, private companies (large industries, mid-caps and SMEs), military medical institutes, universities and hospitals. Furthermore, this action plan will be implemented in consultation with the ministries of defence of Member States. The specific objectives of the Alliance will be achieved through different specific grant agreements (SGAs) in research and development of diagnostic, prophylactic and therapeutic MCMs against CBRN threats, while ensuring that R&D properly translates into concrete medical countermeasures available to Member States' armed forces.

The first SGA, launched in 2023, is a research action that involves addressing: (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 of reactivators of cholinesterases against nerve agent intoxication.

(3) CDP priority 'medical support and the key area 'remote medicine'.

The MCM field was also covered under the EDF's 2021 COUNTERACT project [4], which aims to establish a robust and agile network within the EU to develop and deploy MCM against major CBRN threats.

In addition, the EDF's 2022 iMEDCAP project [5] includes a user-driven scenario for detecting an autonomous casualty, and automatically drawing up an evacuation and rescue strategy, as well as an interoperable patient box equipped with diagnostic and intervention devices that can remotely provide first aid during transport of patient/injured person. There has been a call for further research on autonomous triage and evacuation in 2025, in line with CDP priorities [6].

- In the field of **reacting to CBRN threats**

Involvement in the detection, identification and monitoring (DIM) area started in 2020 with the CBRN-RSS project [7] under the European Defence Industry Development programme (EDIDP). This project strengthened the reconnaissance, surveillance and incident management capabilities of EU Member States against CBRN agents. Efforts have been pursued with the EDF's 2021 MoSaiC [8] and TeChBioT [9] projects. MoSaiC provided low-cost chemical and biological monitoring technologies using unmanned monitoring and sampling systems. TeChBioT provided new highly selective and sensitive detectors that operate at high temperatures, enabling rapid detection and identification of non-volatile biological and low-volatile chemical agents.

In line with CDP priorities [10], the EDF's 2023 CBRN SoS project [11] uses the capabilities developed in previous years to build higher-level architectures for DIM, by designing an overarching information system that can integrate various existing national CBRN defence information systems and components in a modular and flexible way. Furthermore, CBRN decontamination systems and technologies and CBRN attribution capacity could be explored in the future.

The networking and automation of CBRN data, as mentioned above, has not yet been considered in any EDF call topics, although this is likely to be one of the most important developments in strengthening the EU's CBRN defence capabilities.

- **Human factors, CBRN protections and health state monitoring**:

Beyond DIM and MCM considerations, human factors, dedicated soldier CBRN protections, as well as the monitoring of the physiological and cognitive state of patients and dismounted soldiers [12], are also expected to be addressed in this category of actions, in line with CDP priorities [13]. In that vein, the EDF's 2022 WEMOR project [14] investigates the feasibility of a comprehensive health and wellness

(4) European agile network for medical COUNTERmeasures against CBRN threats.
(5) Development of intelligent military capabilities for monitoring, medical care and evacuation for contagious, injured and contaminated personnel.
(6) Priority 'Medical Support' and key area 'Robotics and Autonomous Systems for Evacuation'.
(7) Chemical, Biological, Radiological and Nuclear Reconnaissance and Surveillance System.
(8) Real-time monitoring and sampling of chemical and biological menaces for improved dynamic mapping of threats, vulnerabilities and response capacities.
(9) Surveillance and Reconnaissance Techniques for Chemical and Biological Threats.
(10) CDP priority 'CBRN Defence' and key area 'Improved & Innovative Recovery and Decontamination Methods and Equipment'.
(11) Enhancing cross-border CBRN operational readiness and effectiveness through an overarching system of systems approach.
(12) 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.
(13) CDP priority 'CBRN Defence' and key area 'Enhanced Sensors/Advanced Materials'.
(14) Wearable device for monitoring warfighter health and sustainability.

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's 2021 Nano-SHIELD project [15] aims to develop a solution based on nanofiber membranes specifically designed for military, law enforcement and public filtration of harmful chemical molecules, pathogenic biological entities as well as for shielding against radiation and nuclear radiation. Further activities on innovative and sustainable personal protective equipment with improved filtration and contamination prevention or decontamination, including special protective clothing, could be considered in the future.

Medical response is also addressed in the category 'Simulation and training' regarding *simulation and training for medical emergencies*, including through a follow-on action in 2024. Related activities are also expected in the category 'Materials and components' in the context of defence medical equipment and spare parts.

In terms of findings during the last cycle of the coordinated annual review on defence (CARD), the development of CBRN remote sensor systems was identified as a medium- to long-term collaborative opportunity.

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 (complementing the outcomes of other categories of actions in the full spectrum of defence domains):

- CBRN system of systems EU MSs approach (standardised architecture and interfaces) and technologies integration.
- Set of available defence medical countermeasures jointly procured (EU autonomy) and MedTech products to meet future demands.
- Automated and autonomous systems for the evacuation of casualties on the battlefield.
- Automated decontamination solutions for personnel and equipment.
- Concepts, methods and technologies for human performance enhancement and human systems integration optimisation.

2. Information superiority (C4ISR)

Information superiority is essential for any operation as it concerns the entire cycle of the military decision-making process, with ever shorter timelines and an ever-increasing amount of data to collect and process. It addresses a broad range of technologies and capabilities allowing command entities at all levels to base their decisions on suitable, timely and accurate information and to pass on information swiftly and securely to the relevant actors. As part of the EDF, joint R&D actions regarding information superiority will help boost the EU's freedom of action in the fields of: i) command, control, communications and computing (C4); ii) intelligence, surveillance, target acquisition and reconnaissance (ISTAR); and iii) joint electronic warfare. Therefore, this will

(15) Multifunctional nanofiber membranes as CBRN Shield for next generation defence and civil application.

strengthen the EU's strategic autonomy. The EDF Programme Committee has indicated that the level of ambition in terms of the EDF's budget contribution to information superiority corresponds to more than 10% of the total EDF budget.

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

- **Command and control (C2)**:

As part of the common security and defence policy (CSDP), operation headquarters (OHQ) for specific missions and operations (executive or non-executive) are currently chosen from a list of available facilities. While the EU does not have a permanent military command structure, the Military Planning and Conduct Capability (MPCC), established in 2017 as part of the External Action Service (EEAS)/EU military staff (EUMS), represents the first step towards a permanent EU OHQ.

In the context of the Permanent Structured Cooperation (PESCO), 6 Member States are involved in the project 'Strategic C2 System for CSDP Missions And Operations' (EUMILCOM). It aims to improve the command-and-control systems of EU missions and operations by providing an ambitious strategic-level suite of capabilities, in a modular and scalable approach. In April 2021, the participating Member States adopted the high-level requirements for such a project, developed in close cooperation with the MPCC.

In 2020, the EDIDP project 'European Strategic Command and Control' (ESC2) was launched with the objective to deliver a design for further development by 2023, in line with the objectives of the EUMILCOM PESCO project.

Against this background, and in line with CDP priorities and CARD findings, the EDF's ambition should be to develop, by the end of 2025, a reliable prototype of a European C2 software suite that can allow secure and effective planning and conduct of CSDP missions and operations at strategic and operational levels. This European C2 software suite should be interoperable with NATO and Member States' C2 systems to the greatest extent possible, and also with any relevant EU tools contributing to situational awareness. It is intended to complement and boost emerging C2 capabilities currently used by the MPCC. To meet this objective, the EDF's 2022 EC2 project [16] targeting a software suite model was awarded funding.

In parallel, it appears that symmetric and asymmetric threats inside and outside the EU's territory require a fast response and the ability to rapidly deploy special operations forces (SOFs) to areas of interest, whenever needed. As part of CSDP operations, SOF-led small joint operations (SJOs) can provide a wide range of flexible military options for rapid and effective response across the spectrum and at all stages of the rapidly evolving crisis management landscape. In line with the objective of the related PESCO project 'SOCC [17] for SJO', the development of dedicated SOF command post and C2 systems was addressed by the EDF's 2022 PROTEAS project [18], which should provide adequate

([16]) European Command and Control System.
([17]) One deployable SOF tactical command and control (C2) command post (CP) for SJOs.
([18]) DePloyableSpecial OpeRationsFOrcesMulTiEnvironment CommAnd Post and C2 System.

flexibility, interoperability, deployability, scalability, robustness, discretion and redundancy, particularly concerning communications systems and networks. This project is expected to deliver a fully tested and validated prototype by the end of 2026, with a view to joint procurement by interested Member States.

Furthermore, Single European Sky (SES) interoperability is likely to be a significant challenge in the coming years for all Member States. Military Air-C2 systems will need to be adapted to cross-border and SES interoperability rules, especially regarding: i) civil-military/military-military coordination; and ii) connected, secured, reliable and automated exchanges of data needs. Confidentiality, including the operational need to 'anonymise' some military flights, is another critical aspect to be considered. To tackle this challenge in a timely manner, the EDF's 2022 SESIOP project [19] was awarded funding. Additional topics could be planned for this area. In any case, coordination and synergies between various EU-funded activities are required, while avoiding unnecessary duplications, to help achieve:

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

➢ **Communications**:

Advanced, reliable and interoperable concepts and solutions for communication are critical for joint operations. This is particularly the case for radio communications, including waveforms, as well as tactical communication and information systems.

In line with CDP priorities and CARD findings, the EDF's aim should be to help develop solutions for tactical communications and information systems (CIS) including standardised architecture and interfaces, particularly in the field of intelligence, surveillance and reconnaissance (ISR) network systems, which comply with national and NATO standards. This will enable sustainability in the domestic market, reduce the dependencies on third parties and contribute to the EU strategic autonomy.

As part the EDIDP, in 2021, a project was launched aiming to develop an interoperable secure defence communications system compliant with the 'European secure software defined radio' (ESSOR) programme and software communication architecture (SCA) software defined radio platforms. A related topic is addressed under the 2025 EDF work programme to develop a European MIDS (i.e. multifunctional information distribution system) for fighters. It aims to develop a new generation of a scalable and multifunctional cognitive transceiver family with artificial intelligence features for military use in manned and unmanned platforms and for command entities involved in joint operations in multidomain environment. System design should support secure communication, network data link, positioning, blue force tracking, the identification of a friend or foe, electronic warfare capabilities and AESA [20] control.

In addition, broadband and reliable communications systems for interoperability, mobility and security that are robust against detection, acquisition and jamming are key capabilities for defence operations

([19]) Single European Sky and InterOPerability.

([20]) Active electronically scanned array.

and electronic warfare, in any spectrum of the information environment. This issue has been addressed through the EDF's 2021 5G COMPAD project [21], which aims to demonstrate different interoperable tactical bubbles and end-to-end tactical networking, including the possibility of their integration with military assets. A follow-up topic was addressed in 2024 and further actions are planned for future military communication systems in the future. In 2024, a topic on AI multifunctional aperture systems to manage radio frequency (RF) interferences in highly dynamic communication environments has also been addressed. In addition, the EDF's 2023 OPTIMAS project [22] addresses airborne laser communication system applicable to various satellite constellations for integration into air, naval and land units.

In the future, further topics addressing tactical communications systems could be considered.

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

Complementing space capabilities, unmanned aerial vehicles (UAV) and remotely piloted aircraft systems (RPAS), including high altitude platform systems (HAPS), are essential vectors for intelligence, surveillance, target acquisition and reconnaissance (ISTAR). They are critical to achieving and maintaining battlefield superiority in any operation. Therefore, it is important for the EDF to support collaborative actions in this area to: (i) mitigate or reduce the risk of dependencies on non-EU country suppliers for such technologies; (ii) help sustain the European defence technological and 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 – conducted in the framework of the organisation for joint armament cooperation (OCCAR) and financially supported by four Member States – has successfully passed several significant milestones in terms of development. This development programme received financial support from the EDIDP in 2021. According to the current schedule, the first flight is expected in 2027.

In line with CDP priorities [23] and CARD findings, the EDF ambition regarding MALE RPAS should be, in due course, to help develop technologies and systems to be used with the aircraft, therefore contributing to EU strategic autonomy while ensuring the openness of the supply chain throughout the EU whenever possible. Therefore, a related topic has been addressed in 2024, without excluding further actions in the years to come. Complementary topics could also be envisaged for various related operational requirements when using such a capability.

In addition, the next generation of tactical unmanned aerial systems (UAS) for use in military operational domains, including with dual-use potential, are addressed under the EDF. Therefore, the flexibility that a multipurpose/multirole system provides to tactical commanders will contribute to information collection and the timely delivery of the information obtained for use in the production of intelligence and situational awareness. In this context, the EDIDP's LOTUS project [24] aimed to develop an all-European interoperable tactical RPAS with increased survivability and advanced autonomy. A complementary project awarded in 2023 addresses mission autonomy, environmental

(21) 5G Communications for Peacekeeping And Defence.
(22) OPTIcal MilitAry Secure communications.
(23) CDP priority 'Airborne Command and Inform Capabilities'.
(24) Low Observable Tactical Unmanned air System.

resistance and ability to have some specific payloads on board (i.e. project ACTUS [25]). Moreover, as part of PESCO, 10 Member States are involved in the 'Next Generation Small RPAS' (NGSR) project, which aims to develop the next generation of tactical UAS supported by technologies and standards that allow for an open architecture, autonomy, modularity and interoperability to maximise system effectiveness to enable European countries to reach that capability. 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 ground, maritime, air and special force operations, as well as by non-military agencies involved in, e.g. border control, law enforcement or disaster management. In addition, small (class I) enhanced European UAS has been addressed in 2024. Core technologies for situational understanding and collaborative behaviour in swarms are addressed under the 'digital transformation' category.

R&D for developing specific payloads for unmanned systems should be addressed in due course to equip the next generation RPAS upon their entry onto service. In 2020, a first project was awarded funding under the EDIDP in this area – the SIGNAL project[26] – to improve resilience in complex and/or saturated electromagnetic environments. Complementary actions should be considered in the near future.

Stratospheric persistent airborne systems are particularly suitable for complementing the set of means for ISR to gather relevant and critical information supporting military operations. They are easily and quickly deployable, characterised by very long-range and long-endurance features, with low operational constraints and able to collaborate and interoperate with multiple different systems. Against this background, a project related to high altitude platform systems (HAPS) was awarded in 2021 under the EDF – EuroHAPS project [27]. It aimed to demonstrate the relevance of ISR stratospheric systems to support military operations. A follow-up action is being considered in the future, to develop a prototype, therefore paving the way for a joint procurement by interested Member States.

All the ISR vectors mentioned above, like the other manned and unmanned air assets, are to be integrated safely and effectively into non-segregated airspace, especially in the context of the Single European Sky. In that respect, in 2021, the EDIDP's '*European Detect and Avoid System*' (EUDAAS) project was launched. It aims to develop and validate a European detect and avoid solution so that RPAS can operate along with other manned and unmanned aircrafts. A follow-up project was awarded in 2023 under the EDF (i.e. project EUDAAS2[28]). In this field, the EDF should aim to help reach a level of maturity that allows the envisioned European detect and avoid capabilities to be integrated into the maximum possible assets within the various Member States' fleet.

([25]) Advanced capabilities & Certification for Tactical UAV Systems.
([26]) Photonics-bAsed SIGINT payloaD fOr Class II RPAS.
([27]) High altitude platform systems demonstration.
([28]) European Detect & Avoid System, phase 2.

Main expected outcomes from EDF support in 2021-2027:

Without affecting discussions 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:

- prototype of a European C2 software suite contributing to MPCC/EU OHQ;
- joint procurement of a SOFC2;
- EU-certified and combat-proven standardised architecture and interfaces for tactical communications and radio interoperability;
- MALE RPAS prototype, leading to joint procurement;
- HAPS prototype, leading to joint procurement;
- tactical RPAS prototype, leading to joint procurement;
- capabilities and technologies, including detect and avoid, used to fully integrate defence aircraft into the general air space in context of the Single European Sky (SES).

3. Advanced passive and active sensors (SENS)

Advanced 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 energy signals reflected or returned to gather information. They actively scan the environment to detect and track objects, targets or events. Examples of defence applications include radar, LIDAR and sonar systems, which emit radio, optical or acoustic waves to detect, track and even identify targets such as aircraft, missiles or submarines.

By contrast, passive sensors detect and analyse signals or energy from their environment without transmitting any signals themselves. They rely on signals in the environment (collaborative or incidental) to gather information. Examples in defence applications include passive radar, infrared or acoustic sensors. They are used for tasks such as surveillance, early warning and target identification.

Both active and passive sensors can also be used for electronic warfare applications, which use the electromagnetic spectrum to gather intelligence, attack enemy systems and protect our own systems from disruption or damage.

Since sensors are relevant across the defence, space and related civil industries, contributing to EU's technological sovereignty by reducing risks of overdependency on others for most needed missions, they are categorised as critical technologies in the 2021 action plan on synergies between civil, defence and space industries [(29)].

European cooperation in this field is useful for strengthening the supply chains for advanced sensors to ensure 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. Another focus of European cooperation must lie in the field of interconnection and interoperability of sensors. Sensors providing data in standardised formats improve the value of the data by allowing their smooth integration in the intelligence surveillance and reconnaissance (ISR) cycle but also by enabling systems to be interconnected. The interconnection of multiple sensor systems can significantly improve the quality of the information provided and enable a higher detection performance and

([29]) COM(2021) 70 Final, dated 22 February 2021.

coverage for sensing. Therefore, it is important that even for specific sensor types such as optronic sensors, the system design and data output already enable further interconnection and data fusion.

As an enabling technology, sensors are also usually considered in broader collaborative projects. Technological advances contribute to capacities in the field of information superiority in general and to air, maritime and ground combat capabilities in particular. Application-specific sensor requirements (e.g. underwater and CBRN applications) could be considered in the relevant category of actions.

- **Optronic systems and detectors**:

R&D on optronics has been regularly addressed since the EDIDP-2020-SME call, where the SIGNAL project [30] was selected to develop electronic support measures (ESM) and electronic intelligence systems capable of being installed in Class II RPAS. Research topics included in the 2021 and 2023 EDF work programmes that focused on strengthening the supply chain for various infrared detector technologies [31]. The EDF's 2021 HEROIC project [32] aims to enable European IR sensor suppliers to sustainably design the next generation of EU read-out integrated circuit (ROIC) for IR sensors for defence applications. A development action to push the technology even further is addressed in 2025.

In addition, the EDF's 2021 ENLIGHTEN project [33] aims to develop disruptive technologies for next generation electro-optical sensing devices in the short-wave infrared range to enable vision of scenes hidden behind obstacles. It aims to provide a non-line-of-sight technology which is a game-changing capability with the potential to improve the competitiveness, endurance and survivability in different operational scenarios. Following a complementary call included in the 2023 work programme, the ECOSYSTEM project [34] focuses on substrate and epitaxy supply chain technologies, cryogenic and ROIC bumping to make the European supply chain for infrared detection systems stronger overall.

In the following years, 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 envisaged to close this cycle. In that sense and as well linked to 4E [35], a new topic about an enhanced cognitive electronic warfare system with intelligent radar ESM and communications ESM signal analysis is planned in the future, together with the application of AI to optronic sensors for better detection, recognition, identification and tracking by land imaging systems.

- **Radio-frequency systems**:

The CROWN project [36] under the Preparatory Action on Defence Research (PADR) was a precursor in this field, being the first step for a multifunction RF (radar, EW, and communications) AESA-based system. The EDIDP's 2020 PADIC project [37] addressed a coastal radar network system exploiting acquisition by passive sensors in an open architecture. The EDF 2021 and 2022 work programmes included research topics on advanced radar technologies. The EDF's 2021 ARTURO project [38] aims

([30]) Photonics-bAsed SIGINT payloaD fOr Class II RPAS.
([31]) In line with several CDP priorities including 'Critical Infrastructure Protection & Energy Security', 'Integrated Air & Missile Defence'', 'Air Combat' and 'Persistent C4ISTAR'.
([32]) High Efficiency Read Out Circuits.
([33]) European Non-Line-of-Sight Optical Imaging.
([34]) European COmon SupplY chain for Sovereign T2SL and infrared Modules.
([35]) Essential Elements of European Escort.
([36]) European active electronically scanned array with Combined Radar, cOmmunications, and electronic Warfare fuNctions for military applications.
([37]) Passive Acquisition by Digital Convergence.
([38]) Advanced Radar Technology in eUROpe.

to develop advanced radar technologies in Europe. Concurrently with ARTURO, a complementary project TYRESIAS [39] was funded in 2022. This initiative focuses on hypersonic and emerging threats and supports a collaborative approach to new concepts of radio-frequency systems so they can become more versatile. In addition, the EDF's 2023 FESPAN project [40] will forecast electromagnetic signal propagation anomalies.

Follow-on activities in the field of radio-frequency systems to increase their adaptability and flexibility have been included in 2024, like Advanced Radar Technologies III, which focuses on multifunctional AESA RF systems. These systems should build on technological advances achieved through the solutions provided by the projects mentioned in the previous paragraph. The implementation of a demonstrator to test these multidomain sensors is envisaged in the future.

Among other follow-on activities, the development of a multiband 4D Radar system [41], linked to the PESCO project 4E, is included in 2025 to provide more robust and capable radar systems primarily suitable for naval platforms and for ground or air platforms in future. Smart management of the frequency spectrum will be used to adapt to different environments, threats and jamming scenarios, including using multistatic configurations and multifunctional capabilities as datalinks to cooperate with other platforms and effectors or electronic warfare capabilities to jam or protect the systems. This concept is expected to be further developed in the coming years.

- **Multi-sensor systems**:

The EDF's 2022 CASSATA research project [42] targets covert sensing, i.e. the capability to sense without being detected, fusing three types of sensors (passive sensors, active sensors with low probability of intercept and the interplay of those sensors) to improve accuracy and reliability in detecting, identifying and tracking targets. Further R&D in this field will be considered in the future.

A research topic on multi-sensor integration for robust autonomous drone navigation in non-permissive environments was included in EDF work programme for 2024. Implemented as a technological challenge, this topic targets improved navigation in GNSS [43] denied, unknown and complex environments, as well as increased resilience against adversarial countering efforts. To complement the capabilities for endo-atmospheric interception and space-based early warning supported by other categories of actions in 2021 and 2022, respectively, the EDF's 2023 EISNET project [44] – combining different integrated air and missile defence (IAMD) systems [45] through standardised interfaces and data – will help develop concepts, architectures and a proof-of-concept demonstration for networked sensing capacities based on various European assets to detect small, fast or highly manoeuvrable targets. This is in line with: i) PESCO's TWISTER project [46] that aims to improve the ability to detect, track and counter missile threats; and ii) the EDA's CAT-B project ASSAI [47] that aims to increase space-based situational awareness by integrating ground-based laser tracking sensors with various space-based sensors to be installed on new satellites.

([39]) Technology Innovation for Radar European SYstem ApplicationS.
([40]) Forecasting Electromagnetic Signal Propagation Anomalies.
([41]) In line with several CDP priorities including 'Integrated Air & Missile Defence', 'Air Combat' and 'Persistent C4ISTAR'.
([42]) Covert and Advanced multi-modal Sensor Systems for tArget acquisition and reconnAissance.
([43]) Global Navigation Satellite Systems.
([44]) European Interactive Sensor-based dynamic defence NETwork.
([45]) In line with the CDP priority 'Integrated Air & Missile Defence' and ''Maritime Domain Awareness'.
([46]) Timely Warning and Interception with Space-based TheatER surveillance.
([47]) Autonomous Space-based Situational Awareness & Artificial Intelligence.

In the future, a radar system combining opportunistic passive sensor [48] multifunctionality 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 (complementing the outcomes of other categories of actions in the full spectrum of defence domains):

- maturation of concepts and technologies through developing demonstrators and prototypes of interoperable passive and active RF and optronics sensors for single or multifunction applications with radar-LIDAR, electronic warfare, and communications, bringing in high-power, multiband, stationary/mobile, multistatic and networked configurations;
- improved European supply chain for optronics, radar and jammers;
- a solution involving supplementary sensors to navigate through GNSS denied environments.
- technological leap in cognitive (adaptable) systems, focusing on RF spectrum-sensing techniques and cognitive capabilities supported by artificial intelligence/machine learning;
- maturation of the technologies and concepts underpinning multifunction RF AESA systems;
- development of standardised architecture and interfaces for integrating sensors into an interoperable modular and scalable networked grid.

4. Cyber

Identified vulnerabilities reveal that the EU has a high level of dependency on non-EU countries for cybersecurity and cyber defence technologies. This clearly affects the EU's strategic autonomy. Incentivising cooperation in R&D cyber defence that leads to the development of cyber defence technologies and systems is in line with the EU's ambition to strengthen cyber resilience and capability building. This helps achieve the objective of ensuring full-spectrum cyber defence capabilities and is consistent with priorities set in the 2022 Defence Package and in the EU Strategic Compass ([49]) as well as the priorities identified in the joint communication on the analysis of defence investment gaps. The EDF cyber category priorities and topics included in 20212023 EDF work programmes and beyond address identified capability gaps and are consistent with CDP priorities (*'Enabling Capabilities for Cyber Responsive Operations').* Actions are in line with the action plan on synergies and the EU policy on cyber defence, which highlights the need for a full-spectrum cyber defence, including active cyber defence capabilities.

To increase cyber defence capabilities and in line with CDP priorities [50], R&D for improved cyber situational awareness, strengthening cyber operational capabilities is needed, including on i) detection, protection and response; and ii) cooperative cyber range platforms for better interoperability. The

([48]) In line with CDP Priorities 'Maritime Domain Awareness' & 'Integrated Air & Missile Defence'.
([49]) A Strategic Compass for a stronger EU security and defence in the next decade - Consilium
([50]) CDP priorities 'Full Spectrum Cyber Defence Operations' and 'Cyber Warfare Advantage and Readiness', also addressing cyber considerations for next generation autonomous systems for air, sea and land.

focus is on actions and projects addressing new technologies developed against new and evolving cyber threats.

- **Cyber defence operations**:

Given the rapidly evolving landscape of threats and to counter increased risks and cyber-attacks, several topics addressed in the EDF work programme from 2021 until 2024 have aimed to improve cyberspace operation capabilities, following the EDIDP's CYBER4DEF [51] and PANDORA [52] projects.

Based on the existing short-term cyber defence capability gaps, further development actions for cyber ranges are needed. The EDF's 2021 ACTING project [53] develops a network of advanced interconnected (federated) domain-oriented cyber ranges for training and exercises. Furthermore, the EDF's 2022 FACT project [54] aims to deliver an advanced cyber-physical test range capability through a European wide federated approach. The EDF's 2024 call topic on *Next-Generation Cooperative Cyber Range* (NGCR) aims to address the remaining challenge in designing and developing solutions that deliver noticeable progress vis-à-vis the current state-of-the-art, taking into account the wider technology landscape.

The EDF 2021 AINCEPTION [55] and EU-GUARDIAN [56] projects address improved cyber operations capabilities in response and incident management. Both projects build on earlier EDIDP projects, such as CYBER4DEF. The EDF's 2023 AIDA project [57] aims to further use these results in developing a common European framework made of prototype AI-based cyber defence agents to carry out autonomous and semi-autonomous actions covering the whole cyber incident management life cycle, to support operators and decision-makers within various scenarios. A complementary topic on further developing these efforts to produce a suite of tools to be used in an operational cyber command structure is planned in a follow-on 2025 call. The information warfare dimension, intrinsically related to cyber operations development, was addressed through the EDF 2022 EUCINF project [58].

Furthermore, from a hardware perspective, a research call topic on *Risk, robustness and resilience for autonomous vehicles in military operations* is addressed in 2025 with a spin-in approach. This would support cyber defence in line with emerging technologies and would help achieve the main expected outcomes. A follow-on action is suggested in later years to take this item further from research towards development and eventually industrialisation. The EDF's 2023 TRITON project [59] will lay the foundation for this work.

As verifiable, secure and trusted IT components are basic building blocks for safe and secure defence systems as well as general automated solutions, a call topic on *Improved cyber defence operations capabilities* is addressed in 2025. Further topics could be considered after 2025 to step up the security and safety of IT components. These would foremost address software solutions but could also address hardware.

([51]) Cyber Rapid Response Toolbox for Defence Use.
([52]) Cyber Defence Platform for Real-time Threat Hunting, Incident Response and Information Sharing.
([53]) Advanced European platform and network of cybersecurity training and exercises centres.
([54]) Federated Advanced Cyber physical Test range.
([55]) AI Framework for Improving Cyber Defence Operations.
([56]) European Framework and proofs-of-concept for the Intelligent Automation of Cyber Defence Incident Management.
([57]) Artificial Intelligence Deployable Agent.
([58]) European Cyber and INFormation warfare toolbox.
([59]) Generative Automation of Security Penetration Tests.

Cyber operation capabilities require a continuous improvement process. To address a new concept of operation for cyber defence, it is proposed that a research topic, such as a follow-up action on the EDF's 2022 EUCINF project, could be considered.

- **Cyber defence situational awareness**:

Member States have identified the need to enable proactive detection capabilities to be stepped up and improve cyber situational awareness as a prerequisite for more effective cyber operations capabilities. This could include or be connected to the development of a comprehensive threat hunting model. The EDIDP's ECYSAP project [(60)] already addressed cyber situational awareness. This line of effort was complemented by the EDF's 2022 NEWSROOM project [(61)] which aims to overcome the current limitations of cyber situational awareness (CSA) by studying all relevant CSA aspects and designing an integrated CSA platform combining data insights. In addition, the EDF's 2023 ECYSAP EYE project [(62)] further matures the development of this path. Developing information sharing tools could be planned based on national requirements, including incident coordination systems with functionalities for EU-wide opportunities. In this field, the EDA CAT-B project CERERE [(63)] aims to develop a new solution to measure and test the cyber resilience of a specific complex system in a simulated environment.

Synergies with other EU programmes, particularly Horizon Europe and Digital Europe, will be considered to avoid unnecessary duplication of efforts and to enable an efficient uptake of results. The cyber technology roadmap by the Commission, assisted by the EDA and in consultation with the industry and Member States, will continuously monitor the potential synergies and provide inspiration where relevant, without affecting the decisions taken by the EDF programme committee.

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 (complementing the outcomes of other categories of actions in the full spectrum of defence domains):

- development of European common and/or interoperable tools for:
  - cyber operations and incident management
  - information warfare defensive operations and preventive measures;
- cyber situational awareness mission-centric prototype;
- resilience for cyber-physical systems.

5. Space

Military operations rely heavily on space-based data or space-enabled capabilities, including those with dual-use potential. Space capabilities can provide fast, globally available (including in space itself), continuous and discrete services for situational awareness. Having these capabilities helps decision-making and the conduct of military operations, and in assessing the results of these specific activities. Military applications and use cases require space capabilities to provide secure, robust,

(60) European Cyber Situational Awareness Platform.
(61) Adapting Cyber Awareness for Evolving Computing Environments.
(62) European Cyber Situational Awareness Platform - Enhanced Cyberspace Operations.
(63) Cyber Electromagnetic Resilience Evaluation on Replicated Environment.

reliable and highly effective services in an evolving threat environment. In the context of the EDF, joint R&D actions in the space domain will target consolidation of the demand of capabilities, access to more effective services (e.g. broader bandwidth, increased area-access, continuity of services, higher reactivity, and resilience) and improved interoperability while helping increase the EU's strategic autonomy. Identified axes of effort described below are in line or significantly contribute to the priorities for developing capabilities. The EDF Programme Committee has currently indicated that the level of ambition in terms of the EDF's contribution to space corresponds to more than 10% of the Fund's total budget.

In line with the action plan on synergies between civil, defence and space industries [(64)] and the joint communication on a EU Space strategy for security and defence [(65)], possible synergies with other initiatives at EU level (Space programme, Horizon Europe…) should be systematically taken into account where relevant.

- **Earth observation for ISR applications**

Some Member States are already developing and using, in a national and sometimes multinational setting, their own military-class space capabilities for ISR applications. However, these high-end capabilities have some limitations (e.g. revisit, reactivity, spectral diversity). In parallel, the private sector is offering an increasing range of services (very high-resolution low revisit satellites and high revisit constellations of medium- to high-resolution small satellites, not limited to imagery) to a widening range of customers, including ministries of defence. This commercial offer is not usually designed to meet defence needs as a priority and has some limitations (e.g. security, non-EU dependences). Furthermore, the EU's Copernicus programme offers a wide range of Earth observation services to support various EU policies, including security (maritime surveillance, border control and support to external actions) which may be further developed within the next decade.

As part of PESCO, eight Member States are involved in the 'Common hub for governmental imagery' (CoHGI) project, which aims to enable classified governmental imagery to be exchanged at European level between Member States as well as with EU entities. In addition, from a CARD perspective, the development of space-based Earth observation and early warning capabilities has been identified as a medium- to long-term enabler that could be pursued in a collaborative manner.

In this context, the EDF's aim should be to help develop by 2030 the prototype of a European space-based ISR constellation able to: i) provide reactivity e.g. tactical tasking of satellites; ii) deliver space ISR, if needed via a secure space-based communication infrastructure[(66)] and near real-time monitoring (e.g. high revisit on areas of interest); and at the same time iii) offer diversity of sources (e.g. night vision/infrared, hyperspectral, radar, passive RF detection). Such a capability might take the form of a constellation of small satellites and complement 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

(64) COM(2021) 70 Final, dated 22 February 2021. https://ec.europa.eu/info/sites/info/files/action_plan_on_synergies_en.pdf

(65) JOIN(2023)9 - Joint communication to the European Parliament and the Council - European Union Space Strategy for Security and Defence, dated 10 March 2023 JOIN(2023)9, dated 10 March 2023 https://defence-industry-space.ec.europa.eu/eu-space-policy/eu-space-strategy-security-and-defence_en.

(66) For example, that could be the secure connectivity constellation promoted by the Commission.

cases, possible agreed governance and co-financing), because of a potential future EU Earth observation governmental service [67].

The EDIDP already addressed the early development stage of technologies and products for small optical satellites for maritime surveillance – the EDIDP's OPTISSE [68] and NEMOS [69]) projects. Building on this momentum and in order to meet the above-mentioned objective while expanding the ISR's scope beyond just maritime surveillance, the EDF's 2022 SPIDER project [70] starts the development (studies, design) of a constellation of small satellites for ISR applications (not specifically focused on maritime surveillance). A follow-up action involving development (up to prototyping and partial in-orbit testing) is the subject of a call in 2025 to allow for efforts to continue towards the outcome expected from support provided under the 2021-2027 EDF. A further follow-up action might be needed to fully reach the expected outcome.

These projects complement and may build upon the activities carried out by the EDA [71].

- **Space domain awareness (SDA)**

While space is widely recognised as a congested, contested and competitive environment, only a limited number of EU Member States are so far developing and using space situational awareness (SSA) capabilities (which are mainly national demonstrators or secondary missions of assets not designed to perform SSA). From the operational perspective, these Member States are cooperating within various multinational frameworks, including the EU Space Surveillance and Tracking (EU-SST) framework where they provide space surveillance and tracking services (e.g. collision avoidance, re-entry analysis, fragmentation analysis). In parallel, the private sector in Europe is starting 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 an autonomous, sustainable and secure development of activities in space while monitoring and protecting their space assets against an increasing range of threats [72]. Such SSA capabilities and EU-SST services will be key for developing a European approach of space traffic management (STM) and for meeting the challenges identified in the new EU space strategy for security and defence.

As part of PESCO, five Member States are involved in the 'European military Space surveillance awareness network'. This aims to develop an autonomous and sovereign EU military SSA capability that is interoperable, integrated and harmonised with the EU-SST framework initiative. In addition, from a CARD perspective, developing a space situational awareness architecture and systems has been identified as a medium- to long-term enabler that could be pursued in a collaborative manner.

([67]) For which the Commission: i) engaged with the EDA, who shared with DG DEFIS the common staff requirements and business cases established within the project team Space-based Earth observation (PT SBEO); ii) consulted Member States defence and security communities; and iii) launched an invitation to tender for a study on 19 June 2023.

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

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

([70]) Space based Persistent ISR for Defence and Europe Reinforcement.

([71]) CAT-B project Military Crisis-Response Satellite Constellation (LEO-2-VLEO), that will demonstrate a new type of space platform to serve the needs of high-performances services with improved Earth observation performance from very low Earth orbit (VLEO) compared to LEO. The satellites will be able to manoeuvre from LEO to VLEO in response to crisis and military operations. Another CAT-B project, Very Low Earth Orbit Satellite for Defence (VLEO-DEF), will develop a new VLEO satellite tailored for defence needs, that will include optimised high-performance computer on-board data handling (HPC OBDH), telemetry and communication systems and innovative propulsion means. The satellite will be able to provide improved performance for ISR from space.

([72]) Definitions of SSA in the defence and civilian domains cover different items. SSA for defence includes the need to characterise and anticipate potential unfriendly behaviour in space which is not covered under the 'civilian' SSA definition.

To detect, identify and characterise the threats to space-based infrastructure and services, the EDF should aim, in synergy with the EU Space programme where possible, to help fully develop the prototype for a European SSA capability, able to 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 and multinational/EU assets [73], allowing the sharing and processing of SSA data and delivery of ad hoc services. Such EDF support should lead by 2030 to the joint procurement of SSA capabilities interfaced with EU-SST. The planned activities are in line with the CDP priorities and their implementation roadmaps.

The EDIDP already addressed the early development stages of improved sensors (i.e. the EDIDP's SAURON project [74]) and advanced command and control (i.e. the EDIDP's INTEGRAL project [75]) for SSA. In addition, the EDF's 2021 NAUCRATES [76] and SPRING [77] projects aimed to develop microsatellites for GEO orbit surveillance and intelligence. Building on this momentum and in order to meet the above-mentioned objective, a follow-up topic addressing the system as a whole (*i.e.* sensors [78] and C2) and a research topic on space-based surveillance of threats and protection of space assets have been addressed in the EDF's 2023 work programme, resulting in the EMISSARY [79] and BODYGUARD [80] projects. In addition, the EDF's 2023 STAALION project [81] will further develop technologies for in-situ threat analysis. Depending on the achievable ambition for this topic, a complementary project might be needed to reach the outcome expected from EDF support in 2021-2027.

These projects complement and may build upon the activities carried out in the context of the EDA [82].

- **Space-based missile early warning**

Whereas the (ballistic and hypersonic) missile threat is growing (e.g. development of missile and/or space programmes, rupture of landmark arms control pacts), the EU and its Member States lack operational missile early warning capability and fully rely on non-EU partners.

As part of PESCO, six Member States are involved in the project 'Timely warning and interception with space-based theatre surveillance' (TWISTER). This aims to strengthen the Member States' ability to better detect, track and counter missile threats through a combination of increased capabilities for space-based early warning and endo-atmospheric interceptors.

In this context and in line with the CDP priority aiming to develop an integrated air missile defence (IAMD), the EDF should aim to help develop a space-based early warning capability to detect the departure of missiles (e.g. ballistic, hypersonic) and track them before handing over to ground-based radars, therefore directly helping protect the EU's territory against missile threats. Such a development could also be a major milestone towards developing a more ambitious European anti-missile defence

(73) Including those that could be hosted by the EU's secure connectivity infrastructure.
(74) Sensors for Advanced Usage & Reconnaissance of Outerspace situation.
(75) Innovative and iNteroperable Technologies for spacE Global Recognition and Alert.
(76) Microsatellite for geostationary orbit surveillance and intelligence.
(77) Space response to risk & integration with ground segment.
(78) Including new compact spaceborne hyperspectral cameras and miniaturised frequency-modulated continuous wave-based space radars or more general miniaturised compact sensors for nanosatellites for space-to-space SSA.
(79) European Military Integrated Space Situational Awareness and Recognition capabilitY.
(80) Autonomous SSA Bodyguard Onboard Satellite.
(81) Space Threats Analysis based on Automated reaL-time In-situ capabilities and Onboard processing decentralized Network.
(82) CAT-B projects Autonomous Space-based Situational Awareness and Artificial Intelligence (ASSAI) and LEO-2-VLEO and VLEO-DEF (previously mentioned) also help improve space-based situational awareness.

capability (see 'Air defence'), able to accommodate various actors, technologies and products. The prototype for such a space-based capability for early warning against missiles should be developed by 2030.

The EDIDP already addressed the early development stage of the space-based early warning capability (i.e. the EDIDP's ODIN'S EYE project [83]). Building on this momentum and in order to meet the above-mentioned objective, the EDF's 2022 ODIN'S EYE II project aims to reach a design phase. A follow-up action is identified for the next years to enable efforts to continue and to reach the outcome expected from EDF support in 2021-2027.

These projects complement and may build upon the activities carried out by the EDA [84].

- **Positioning, navigation and timing and navigation warfare (PNT and NAVWAR)**

The emergence of new threats like advanced electronic warfare (e.g. sophisticated jamming, spoofing, cyber-attacks at different levels, hybrid threats) and even possible attacks on space and ground infrastructure, calls for improvements in the robustness and resilience of EU forces to ensure their PNT performances and level of dependability are adequate in any operational situation. Besides, EU defence users and equipment currently rely on non-EU GNSS providers.

To improve the EU strategic autonomy, PNT solutions – particularly Galileo PRS-enabled receivers for various defence equipment and applications in conjunction, where appropriate, with other PNT sources – need to be developed and progressively integrated into military platforms to address such emerging challenges and set up effective capabilities. At the same time, European NAVWAR capabilities against the threats mentioned above need to be developed to increase the overall resilience of the PNT solutions. In this respect, potential synergies with Galileo second generation could also be explored.

As part of PESCO, eight Member States are involved in the 'EU radio navigation solution' (EURAS) project. This aims to promote the development of EU military PNT capabilities and future cooperation so as to take advantage of Galileo and the public regulated service.

In this context, the EDIDP and the EDF are already actively helping achieve this objective with the advanced development of PRS receivers (i.e. EDIDP's GEODE project [85]) and with a space and ground based NAVWAR surveillance capability (i.e. the EDF's 2021 NAVGUARD project [86]). Follow-on developments around Galileo PRS receivers and/or NAVWAR capabilities (e.g. integration into various equipment and platforms contributing to the NAVWAR surveillance and resilience) are planned for the coming years to reach the outcome expected from EDF support in 2021-2027.

- **Secure satellite communications**:

A limited number of Member States are developing and using military-class satellite communications, while others rely on other governmental secured assets or commercial providers, which are offering an increasing range of secure communication services. Being able to exchange (classified) data with guaranteed availability in any operational scenario is a key factor associated with strategic autonomy. The increasing number of SatCom applications (e.g. UAS, broadband), and the multiplication and sophistication of threats (e.g. cyber, hybrid, ground- and space-based) will require increasing SatCom capacity and coverage, as well as increased robustness and resilience. Interoperable and secured

(83) multinatiOnal Development INitiative for a Space-based missilE earlY-warning architecturE.
(84) Use cases discussed in the study of 'Mission driven LEO to VLEO satellites for defence operations' within HEDI Proof-of-concept.
(85) Galileo for EU Defence.
(86) Advanced Galileo PRS resilience for EU Defence.

satellite communications for defence would need to be ensured, for effective and adequate services over time and space for defence users. This would address the proliferation of security risks, allowing new usage of such communications systems, while leading to increased EU interoperability, availability and reduced dependency on non-EU SatCom service providers. The development of space-based military communications systems has also been identified as a CARD collaborative opportunity.

The EDF is already helping achieve this objective with the preliminary development of a European protected waveform (i.e. the EDFs 2021 EPW project [87]) aiming to create a standardised architecture and interfaces for secure satellite communications with adaptable security and resilience layers. In parallel, the EU is paving the way to a future secure connectivity space infrastructure (space connectivity constellation/IRIS^2) that could implement EPW standardised architecture and interfaces to offer governmental satellite communication services benefiting 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-based or ground-based capabilities). With a follow-up EPW topic included in the EDF's 2024 work programme, it is possible that efforts can continue while further analysing potential synergies with IRIS^2. Depending on the achievable ambition, a follow-up action could be envisaged in the coming years to reach the outcome expected from the EDFs support in 2021-2027.

In addition, research and development on space cloud infrastructure and services as well as on space connectivity solutions for air combat have been identified as potential topics of interest that may require support beyond 2027.

- **Responsive space**:

While the European Space Agency is co-financing the development of a light to heavy space launcher family (Vega and Ariane) operated from the European spaceport in French Guiana, the EU and its Member States are currently lacking responsive and mobile launching solutions able to, within 48-72 hours, discreetly place microsatellites or agile vehicles for specific defence applications, including on-orbit services and operations, into specific orbit.

As part of PESCO, eight Member States are involved in the 'Defence of Space assets' (DOSA) project. This aims to increase the EU's operational efficiency in the space domain by making best use of current and future space assets through cross-cutting space functions of reactive access to space and in-space manoeuvrability, space resilience and training for space military operations.

In this context, the EDF's aim should be to support research and future development of such responsive space systems. The EDF's 2022 REACTS project [88] was selected for funding as the first research project in this field. This should have been completed with a follow-up topic in 2024 to enable efforts to continue, but, in the absence of coordinated support from at least three Member States, such a potential follow-up topic is identified in the future. In a complementary manner and in line with the CDP, the EDF's 2025 work programme is starting a collaborative spin-in development action on technologies and capabilities enabling future on-orbit services and operations for defence applications, while considering potential synergies with ongoing and upcoming civilian R&D [89] in this field (dual-use potential).

Depending on the achievable ambition, a follow-up topic could be envisaged in the coming years.

([87]) European Protected Waveform.
([88]) Responsive European Architecture for Space.
([89]) Horizon Europe Cluster 4.

The activities planned for on-orbit operations and services and the responsive space system are in line with the CDP priorities and their implementation roadmaps.

- **Space data processing**:

To catch up with the 'data wall', it is very important that the Member States and the EU tackle in a concerted and efficient manner the question of space data processing, making best possible use of AI techniques.

The EDIDP and the EDF already addressed the development of such data processing for ISR applications (i.e. the EDIDP's PEONEER project [90] and the EDF's 2021 IntSen2 project [91]). As a cross-cutting research topic relevant for 'Earth observation/ISR' and/or for 'Space domain awareness', the EDF should further support processing of space military and/or dual-use data for specific defence applications. This could be done, e.g. in the form of a 'technological challenge' [92]to foster emulation and innovation. This led to a topic on multisource satellite image analysis [93] being included in the EDF's 2024 work programme. Subject to the willingness of Member States and EDF associated countries, these efforts could be continued in the future with a dedicated development action aiming to integrate identified AI modules and techniques into operational systems to provide augmented processing and exploitation capabilities for the defence community.

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:

- joint procurement for integrating PRS receivers into EU Member State military systems (autonomy/synergy space/defence) and strengthening NAVWAR capabilities;
- joint procurement of SSA capabilities interfaced with EU SST;
- space-based missile early warning prototype interconnected with other relevant sensors and effectors;
- space-based ISR constellation prototype;
- joint procurement of a secure waveform for satellite communications (potential synergies with the space connectivity constellation, subject to further analysis).

6. Digital transformation (DIGIT)

Digitalisation and big data have made AI and autonomous systems a reality, even though we are only at the beginning of technological progress in these domains. These new technologies transform how defence activities are conducted. Therefore, there is a need to create and develop core AI technologies for computer-aided decision-making, human-system cooperation, robotics and autonomous systems for defence. This involves creating representative data to train and test the systems, and organising

(90) Persistent Earth Observation for actioNable intElligence survEillance and Reconnaissance.
(91) Proactive automatic imagery intelligence powered by AI exploiting European space assets.
(92) As promoted by the EU defence innovation scheme (https://eudis.europa.eu/index_en).
(93) This could also support the parallel development of the multi-sensor ISR constellation and contribute to the EU Space strategy for security and defence.

objective and comparative evaluation campaigns, or 'technological challenges', to drive progress towards meeting defence needs while leveraging civil research and generating spillover 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 'digital transformation' thematic category focuses on core technologies addressing several capabilities in a cross-cutting way. Dedicated AI-related technologies for specific capabilities, such as unmanned systems, situational awareness, ISR, training & mission planning, medical support, maintenance and logistics are covered under other thematic categories.

The category addresses a wide range of CDP priorities. The digital transformation is a key area for the priority area of 'persistent & resilient C4ISTAR'. Training and education for digital transformation directly addresses the priority area of 'cohesive & well-trained EU militaries' for the key area 'boosting digital skills to enable multi-domain operations'. The EDF's main expected outcome 'safe and trustworthy micro & nano drones and robots, including situational understanding' helps address the priority area of 'airborne command & inform capabilities'.

- **Trustworthy artificial intelligence**

Technologies should be further developed to boost AI system performances in dealing with challenging types of data (images, video, audio, speech, text…) encountered in defence applications. Such systems are needed to process large amounts of data and ensure efficient human-machine interactions.

An important cross-cutting need is to create technologies for trustworthy autonomous learning, i.e. a system's ability to adapt and learn from its environment, including from user supervision, without intervention from expert developers nor regression. Such technologies can be highly disruptive and have high impacts for many capabilities, especially when the information to manage is highly variable or unpredictable and a high level of adaptability is needed. These technologies would also alleviate the current need to provide data to the system developers to get improvements, which is an issue when confidential data are involved. They would more generally increase technological independence.

Related to autonomous learning, there is also a need to ensure that AI systems can explain and justify their results to the users, a feature referred to as explainable AI. This becomes 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. This is also important for non-embedded computing systems, as the energy consumption and environmental cost of computing centres becomes increasingly significant. Dedicated hardware, and especially analogue hardware, is also more difficult to hack, therefore helping to step up cybersecurity. It also links the knowledge acquired by the system more tightly to the hardware device embedding it, therefore increasing traceability, accountability, and trust.

The issue of trustworthy autonomous learning is addressed by the EDF's 2021 FaRADAI [(94)] and KOIOS [(95)] projects, its 2023 technological challenge on human language technologies (HLT), and its 2025 technological challenge on privacy-preserving learning for human-AI dialogue systems (HAID). It should be further addressed in a cross-cutting way under future AI topics.

([94]) Frugal and Robust AI for Defence Advanced Intelligence.

([95]) Knowledge Extraction, Machine Learning and other AI approaches for secure, robust, frugal, resilient and explainable solutions in Defence Applications.

The issue of energy-efficient AI systems is addressed by the EDF's 2023 ARCHYTAS project [96]. This is a long-term effort which should be pursued both through a follow-on topic and in a cross-cutting way through applied AI topics.

- **Micro and nano drones and robots**

In the field of 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 to protect our forces and conduct operations. It requires multidisciplinary research to tightly integrate AI, sensors, effectors, and energy storage. The challenge is not only to develop high-performing systems, but also those that are safe and trustworthy.

These issues are addressed by the EDF's 2022 technological challenge on *Hidden threat detection* (HTD). There needs to be a follow-on to this challenge in the future, addressing a broader range of threats. The EDF's 2024 technological challenge on *Robust autonomous drone navigation* (RADN), organised under the 'Advanced passive and active sensors' category, also addresses these issues while focusing on contested environments. Furthermore, there needs to be a follow-on of this challenge towards robust systems. More generally, efforts should be pursued toward producing more integrated, smaller, and energy-efficient drones and robots.

- **Defence big data and cloud**

The amount of data produced by defence operational and R&D activities is huge and ever increasing. 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. Therefore, there is a need to support the development of such pooled services. Two types of facilities should be considered, depending on whether the information to manage is classified or not. Secure data cloud facilities serve smaller communities with lower amounts of very specific data, while data collection and curation centres serve larger communities with larger amounts of more general data. Access to data sets 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 was highlighted by the EDA study CLAUDIA [97].

The EDF's 2021 EDOCC project [98] addresses the issue of multidomain cloud services, and a follow-on topic is envisaged in the future. The EDF 2022 project STORE [99] will produce annotated image databases that will be shared with a large consortium and beyond, and the organisers of the ongoing or planned EDF technological challenges will produce databases that will be shared with the participants of each challenge and that will remain available for further system development. Building on these efforts, the emergence and strengthening of data production centres at the service of the AI system developer community for various domains of AI should be further supported.

([96]) ARCHitectures based on unconventional accelerators for dependable/energY efficienT AI Systems.
([97]) Cloud Intelligence for Decision Making Support and Analysis.
([98]) European Defence Operational Collaborative Cloud.
([99]) 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 (complementing the outcomes of other categories of actions in the full spectrum of defence domains):

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

7. Energy resilience and environmental transition (ENERENV)

The aim of this category of action is to create and develop energy-efficient solutions and green technologies in the defence sector. Given the current planetary crisis (climate change, biodiversity loss and pollution, all driven by natural resources depletion), this category's overall contribution will help Europe achieve ambitious environmental objectives. The European Green Deal with its strong focus on climate neutrality has become one of the EU's new priorities that should be reflected in all EU policies and programmes. The ecological transition will reshape geopolitics, including global economic, trade and security interests. In addition, it should 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 the access to scarce resources (e.g. critical raw materials but also water and arable land), which can lead to crises and conflicts. Some of them will affect the EU and require a common response.

In March 2020, the EU adopted a new circular economy action plan (CEAP) – one of the main blocks of the European Green Deal, The EU's new agenda for sustainable growth. The CEAP states '*Circularity is an essential part of a wider transformation of industry towards climate-neutrality and long-term competitiveness*. *It can deliver substantial material savings throughout value chains and production processes, generate extra value and unlock economic opportunities. Despite efforts at EU and national level, the amount of waste generated is not going down*'. Circularity would support interoperability, availability of assets, operational efficiency, and security of supply. The defence activities need to help reduce waste by developing innovative technologies to address e.g. waste management, safe use of chemicals, component tracing, environmental protection, water management and green military components, through ecodesign, maintenance, repair, reuse, remanufacturing, refurbishing and recycling.

Water is an increasingly scarce commodity and often imposes a substantial logistic burden on remote operations. Cheaper, high-throughput and ruggedised treatment technologies for water from various sources are important, but also advanced packaging and preservation technologies.

In parallel, energy security is fundamental for any military activity. Movement, endurance and ability to carry out any kind of operation depends on the availability of energy supply. Increasing demand for energy for modern capabilities requires easy access, efficient storage, and sustainable usage across all military domains. Climate change prompts a move towards sustainable power sources beyond fossil

fuels, generating challenges and threats alternating the way our forces operate, driving the capability requirement and ultimately influencing defence research and development.

Because military forces consume a lot of energy, security of supply is critical. For forward forces deployed to operations and missions in harsh environmental conditions, technologies that reduce the dependency on large supplies and minimise fuel transportation, therefore limiting logistic footprints and operational vulnerabilities, will be needed. This translates into a higher level of manoeuvrability and independence. Therefore, the deployed forces will be more effective. With this in mind, new developments should focus on high density/high power storage systems (e.g. customised batteries, fuel cells, multi-sources energy systems, etc.), as well as modern energy conversion technologies. Alternative propulsion (air, ground, and sea) on existing and future platforms will hinge on the ability to downscale energy sources and increase energy efficiency.

From a CDP perspective, the EDF's actions and the main expected outcomes from this category are aligned with priorities across land, sea, air and logistics, driving green defence, modernisation and sustainability to boost military capabilities.

The EDF Programme Committee has agreed that the EDF budget contribution to energy resilience and environmental transition should be more than 5% of the total EDF budget.

- **Future efficient and multi-sources energy solutions**

The increase in energy consumption should be achieved by means of new power supply such as renewable energies, high energy sources, hybrid powertrains or hybrid energy production, batteries, energy storage and fuel cells. However, these new forms of consumption pose a challenge for their integration into weapon systems, for their technological development and for their logistics operational management.

As part of PESCO, six Member states are involved in the 'Energy Operational Function' project. This has a dual objective of: i) developing new systems of energy supply for camps deployed as part of joint operations and for soldier connected devices and equipment; and ii) ensuring that the energy issue is taken into account from the design of combat systems to the implementation of the support in operations, as well as in operational planning.

In line with the objectives/priorities set out in the common security and defence policy (CSDP) and the Strategic Compass, the energy efficiency in the defence sector should be improved, including for CSDP missions and operations, and without reducing operational effectiveness. Furthermore, the development of common benchmarks and standard architectures for the increased use of renewable energy sources and the resilience of defence-related critical infrastructure will be addressed.

The EDF's aim should be to help develop a prototype for future efficient and multi-source energy solutions for the defence sector operating under harsh environmental conditions, therefore paving the way for future joint procurement at EU level.

The EDF is already helping achieve this objective through two complementary call topics from 2021: *Energy independent and efficient systems for military camps* and *Next generation electrical energy storage for military forward operation bases*.

Two 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).

One is the EDF's 2021 INDY project [100]. It develops a strategic roadmap to establishing 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. A further development call in this area has been included in 2024.

The other, in line with CDP priorities [101], is the EDF's 2021 NOMAD project [102]. This 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 could be considered in the future.

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

Improved energy generation (propulsive and non-propulsive) technologies are needed to meet increasing electrical demand, including power density considerations. Moreover, these constraints are common for high-value military equipment for next generation platforms.

In line with CDP priorities [103], the EDF's aim should be to help develop a prototype for efficient and green engine representatives of new architecture and technologies adapted to the following areas: air combat aircraft, fixed wings or rotary wings, ground vehicles, including main battle tank (MBT), and naval vessels. This would pave the way for a future joint procurement at EU level.

This is addressed through the EDF's 2021 NEUMANN project [104]. This will develop technologies and conduct collaborative system studies for novel energy aircraft domains, focusing on: i) propulsion; ii) electrical and thermal systems; and iii) management. The ambition is: i) for the EU to have full technological sovereignty over military air platforms; and ii) to develop new technology building blocks of next generation propulsion and energy integrated systems, which will be evaluated on a dedicated European propulsion and energy ground test platform. A further development call in this area is included in 2025, with possible follow-on actions in the future.

Moreover, the EDF's 2021 HEGAPS [105] project develops a cyber-physical system to test different options and technologies for propulsion systems in an integrated naval energy grid. In addition, the EDF's 2023 CALIPSO project [106] addresses military vehicle propulsion (focusing on naval and land) by integrating sustainable fuel technologies (spin-in from civil sector), which remains a challenge for European defence autonomy and superiority. Further development actions in this area could be considered in the future.

Also in this field, the EDA's CAT-B project HybriDT II [107] aims to identify the best suitable technology for a modular and scalable hybrid architecture that is best fitting for military purpose. This would fulfil the targets for significant weight saving and space claim, reducing thermal radiation and reducing fuel consumption.

([100]) Energy Independent and Efficient Deployable Military Camps.
([101]) CDP priority 'Sustainable & Agile Logistics' to improve military engagement capabilities.
([102]) NOvel energy storage technologies usable al MilitAry Deployments in forward operating bases.
([103]) CDP priorities 'Air Combat' and 'Air Transport' addressing the key areas of NG air combat systems & NG multipurpose helicopter.
([104]) Novel Energy and propUlsion systeMs for Air dominance.
([105]) Hybrid Energy Grid and Propulsion System.
([106]) Innovative propulsion solutions for land and naval defence applications.
([107]) Hybrid drive train demonstrator – Phase II.

- **Environmental transition**

a) Water reuse

Drinking water is a crucial need for military operations. The experiences in arid regions showed that water needs to be reused to enable military operations. The new modular military field camp will use technologies for water reuse to reduce the demand for fresh water. Since the application of this technology is quite new for mobile water supply, experiences are very limited. Assessing different concepts and the corresponding technology is needed to ensure safe water reuse throughout the entire water cycle of a camp. Graphene and its oxide form – graphene oxide (GO) – are new materials which could potentially be applied in this area. The research activities should create an innovative concept for water supply in a military field camp for regions with scarce water resources, possibly elaborating on the microbiological properties of graphene materials.

Special emphasis will be placed on innovation and use of standards that can help reduce the environmental footprint of armed forces and create possibilities to reuse valuable components and scarce materials. To avoid duplication of efforts and funding, synergies with other research programmes should be considered, particularly with the EU's graphene flagship project, which brings together nearly 170 academic and industrial partners from 22 countries, to explore different aspects of graphene and related materials.

This is addressed through the EDF's 2023 SWIFT project [108]. This offers a disruptive approach to water management through technological innovations – including graphene-based treatment technologies and advanced photocatalytic processes – for modular field camps suitable for deployed military units within expeditionary and European defence contexts. The EDFs aim should be to help develop a prototype of a technological solution to ensure safe reuse of water for military and peacekeeping missions, including through future actions.

b) Sustainable components for defence applications

The specific challenge is to advance the state-of-the-art in the research of, and innovation in, new high-performance lead-free piezoelectric materials for military underwater sensor applications to replace titano-zirconate Pb_1-xZr_xTiO_3 (PZT). The intention is to have future phases of development and industrialisation, leading to the prospective establishment of at least one European supply chain in this domain. New materials can also provide the opportunity to generate additional benefits, for example, enlarging the operational frequency bandwidth of sensors or source generators, improving duty cycle limitations, or reducing the sensor size. These opportunities can upgrade the performance of the sensors and therefore should be considered in the evaluation of materials and processes to be studied.

To be compliant with REACH regulations and other relevant regulations, such as on restricting hazardous substances (RoHS) or on waste electrical and electronic equipment (WEEE), lead and its salts need to be eliminated from consumer goods and industrial devices.

This is addressed through the EDF's 2022 SCUALE project [109]. This develops disruptive lead-free ceramic processes such as textured ceramics and 3D printing as well as disruptive fibre-optic sensing, which improves operational performance in terms of bandwidth, system noise and weight.

[108] Sustainable Water Innovations for Fielded Troops.
[109] Sustainable Components for Underwater Acoustics using Lead-free materials in Europe.

c) Recycling in defence

No formal statistics are available on the amount of waste produced by the defence sector. Most of it is burned or put into landfills – neither being in line with responsible environmental behaviour nor with the goal of reducing the ecological footprint. Therefore, the aim to analyse, test and validate suitable solutions for mechanical and 'green' chemical recycling of waste of soldier individual equipment (uniforms, helmets, boots, rucksacks, plastic elements, harness, etc.) as part of a wider circular management of military artefacts. The EDF's 2022 UTILE product [110] develops several technologies that allow circular strategies to be implemented to recover and reuse different soldier personal protection equipment (SPE) used by the different European national armies.

Furthermore, there is a need to explore the feasibility of innovative technologies, create appropriate processes and validate the technology to pilot (prototype) a solution that significantly changes today's (not sustainable) practices in waste management. It is essential to find solutions that are cost-effective and ensure recycled materials perform well considering the specific requirements for defence. A special emphasis will be put on innovation and use of standards that can help reduce the environmental footprint of armed forces and create possibilities to reuse valuable components and scarce materials, including via ecodesign.

The EDF's aim should be to help develop a prototype of an innovative solution for recycling soldier equipment.

The research will provide the basis for further developments of technology that could have a major impact on recycling. The outcome of this action could be usable and adjustable across the armed forces of EU Member States.

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:

- 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, respectively adapted to each of the following capabilities:
  - next generation air combat aircraft, fixed and rotary wings;
  - next generation ground vehicles, including MBT;
  - next generation naval vessels;
- prototype of technological solution to ensure save reuse of water for military and peacekeeping missions.
- prototype of green innovative solution for recycling technologies and circularity, particularly for soldier equipment.

8. Materials and components (MATCOMP)

Materials and components are enablers for a wide range of solutions at the core of the development of military capabilities. This category supports technologies for a wide range of products and systems strongly linked with other categories in the EDF work programme. Certain material research might be

[110] Ensuring Circularity of Soldier Personal Protection Equipment.

included in other categories if the targeted application is specific enough, e.g. in SENS for optoelectronic detector material. Topics to be addressed are also linked to progress made in joint projects funded under the PADR, EDIDP and the EDA Cat-B programme.

Most of the activities in this category of action are related to the Capability Development Priorities of cross-domain capabilities contributing to achieve EU's level of ambition. On the intergovernmental side, five EU Member States have joined the PESCO project 'Materials and components for technological EU competitiveness' (MAC-EU) that specifically targets materials and components technologies for which the security of supply and the freedom of use may be restricted.

Access to critical materials and components is a challenge common to space, defence and security sectors, as pointed out in the action plan on synergies between civil, defence and space industries. Advanced material technologies and semiconductors, and microelectronics are identified as critical technologies relevant across industries. Strategic dependencies must be better identified, and mitigation measures analysed. In this respect, it is important to assess the risk of the operational use of the technology being compromised or denied. The Observatory on Critical Technologies will provide monitoring and analysis of such technologies, with a first pilot focusing on a selection of semiconductor components.

The Commission has been focusing on the sustainability of strategic supply chains in the fields of materials and components even before the EDF was established, and the risks for defence supply chains has been highlighted by several reports [111]. New materials have also been identified the Strategic Compass as one of the technologies reshaping defence markets.

Materials used must enable and boost the performance of defence capabilities while also complying with the zero-pollution principle of the European Green Deal. Taking into account aspects of sustainability in materials research presents many advantages from an ecological, logistics and security of supply point of view. Therefore, materials developed should comply as much as possible with the zero-pollution principle [112]. Even though defence applications can be exempted from regulations such as REACH, efforts to comply with safety and sustainability requirements can lead to better spin-off opportunities, thereby strengthening the EU's defence technological and industrial base. Regarding electronic components, the features that are small and lightweight and involve low-power consumption (SWaP) are critical to most defence applications due to the challenging operating conditions in this sector. Defence R&D could both take advantage of the civil efforts to improve energy efficiency and contribute to new solutions that might be taken up by civil applications. Call topics issued in this category will therefore involve requests to take ecodesign, circularity and sustainability into account where possible, while call topics that focus on replacing material or production techniques (including recycling) are addressed under the ENERENV category.

The uptake of R&D efforts originating from civil research should in particular be promoted in this category of action. This is achieved using EUDIS measures in the form of a spin-in calls that provide follow-up funding for add-on R&D that addressed the specific requirements for defence applications. This cross-fertilisation could also prove particularly effective in the area of materials, which has broadly been addressed by civil R&D programmes in the past.

Regarding this category, the two main fields on which future defence systems and technologies rely are the use of advanced materials and critical components and electronics.

([111]) 'Materials dependencies for dual-use technologies relevant for Europe's defence sector', Joint Research Centre, 2019. 'European Commission, Critical materials for strategic technologies and sectors in the EU - a foresight study, 2020', Joint Research Centre, 2020.

([112]) COM/2019/640 final.

EDF actions and main expected outcomes from this category directly address innovation for high performance and protective materials across land, sea, air and logistics, as outlined in the relevant CDP priorities.

- **Advanced materials**:

The performance of defence ballistic systems needs to be improved to address the safety and higher survival rate of military personnel. At the same time, novel threats in different military applications require solutions that could ensure the necessary protection. Furthermore, soldier equipment needs to allow for activities that are often physically demanding, while ensuring protection and situational awareness as well as preserving capacity to act, endurance and mobility. Research activities on existing materials or new materials or concepts of protection considering the specific details are therefore needed for fulfilling safety criteria but also flexibility of equipment.

This is addressed through the EDF's 2021 ECOBALLIFE project [113] that will investigate ecodesigned ballistic systems for durable lightweight protections against current and new threats in platform and personal applications. In addition, after the PADR's ACAMSII project [114], the EDF's 2022 ARMETISS project [115] and its 2023 MINEFIELD project [116] aim to develop a set of smart clothes, textile and equipment integrating complementary functions to boost soldiers' capacity to perform their demanding tasks while increasing their safety and well-being during military operations. Moreover, to further protect forces on the battlefield, after the PADR METAMASK project [117], the EDF projects from 2023, CATHERINA [118] and ACROSS [119], address adaptive camouflage, e.g. with smart textile with infrared and thermal detection-resistant properties.

Two other EDF projects, also from 2023, ADMIRABLE [120] and IMMUNE [121] address novel high-performance materials that could fulfil particular requirements for defence applications, i.e. to withstand high temperatures or yield significant weight reduction. These projects resulted from a call specifically designed to support the spin-in of innovative solutions from civil applications.

In addition, the EDF's 2023 MaJoR project [122] addresses the materials and techniques that need to be adapted and certified for defence applications in the domain of repair, joining and maintenance. Based on previous results obtained for civil or defence applications, the goal is to propel such technologies across the 'valley of death' [123]. This project resulted from a call designed to support a cross-border defence innovation network that will host the test platform and will provide tests and other services to innovative players.

The way materials perform can be significantly changed by using innovative assembly techniques. For example, architected materials that follow a top-down design process could outperform materials

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([113]) Research in ecodesigned ballistic systems for durable lightweight protections against current and new threats in platform and personal applications.
([114]) Adaptive Camouflage for the Soldier II.
([115]) smARt Multifunction tExtiles for integrated Soldier Systems.
([116]) Energy autonomous smart clothing to enhance soldier safety and connectivity in the battleground.
([117]) Metasurfaces for time-domain adaptive masking.
([118]) CAmouflage THERmal INtelligent and Adaptive.
([119]) Adaptive Camouflage foR sOldierS and vehicleS.
([120]) Additive Manufacturing of composite based fire-resistant materials for stealth, Ballistic Lightweight armoured structures.
([121]) 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.
([122]) Maintenance, Joining, and Repair innovation in multidomain defence.
([123]) The phenomenon of promising techniques failing to move beyond the research phase into development and eventually procurement.

developed through bottom-up improvements. Such novel design processes for materials could be addressed in the future, in line with CDP priorities [124]. This topic could also have a link to metamaterials, where assembly techniques targeting geometrical properties can lead to radically different properties than their bulk counterpart, and which are potentially covered by the category on disruptive technologies for defence.

New manufacturing techniques such as additive manufacturing could have a beneficial impact on the logistics footprint and availability of some technical equipment. The EDF's 2021 ROLIAC project [125] develops additive manufacturing technologies for lightweight military grade parts using novel materials, and, in the future, another call topic could address additive manufacturing techniques applied to defence equipment and spare parts, as well as bio printing in a defence setting.

- **Critical components and electronics**:

EU programmes in the civil sector play an important role in the field of critical components and electronics. Advanced materials as well as micro/nano-electronics and photonics are two of the six key enabling technologies, which receive prioritised support to research and innovation. Semiconductors were also highlighted by the updated industrial strategy. Another initiative that the Commission is currently preparing is the European Chips Act that aims to mobilise additional public and private investments into the semiconductor supply chain, to complement existing Horizon Europe and Digital Europe measures.

Initiatives such as the European Alliance for Industrial Data, Edge and Cloud and the Industrial Alliance on Processors and Semiconductor Technologies have been created to engage a wide range of partners in joint action. Member states have begun implementing Important Projects of Common European Interest, which bring together private actors and other players to overcome challenges in the area of innovation and infrastructure. Although those initiatives have a focus on civil applications, industries active in the security and defence environment can participate.

These initiatives could also help to make progress in the fields of security and defence, as pointed out by the roadmap on critical technologies for security and defence issued in the 2022 defence package. Synergies with other research programmes, particularly the Space programme and Horizon Europe's funding for electronic components, will need to be considered to avoid unnecessary duplication of efforts and to ensure the efficient uptake of results. However, requirements for electronics and other components can radically differ for defence applications and industrial production faces economic viability challenges due to small production volumes. Therefore, specific support and strategies for defence applications must be put in place to close technological gaps and strengthen technological autonomy.

An important factor in creating a more robust supply chain is the capacity to integrate electronic components from different providers into one product. One of those enabler capacities are packaging technologies, as addressed by the EDF's 2022 EPICURE project [126]. Packaging technologies need to respond to specific requirements for defence applications. They need to protect the electronic components from tough environmental conditions while being able to manage the frequencies and temperature management needs of high power or high frequency applications. Advances in this field are again enablers for different applications in different domains. Dedicated support is needed as the volume necessary for defence applications is too limited to attract R&D investments.

([124]) Compliant with the development of next generation platforms for land, sea and air covered in the priorities, and also priorities related to military engagement capabilities in agile and responsive logistics capabilities.

([125]) Robust and Light AM components for military systems.

([126]) European Packaging for highly Integrated Circuits for Reliable Electronics.

In the same vein, standardising chiplets can allow components originating from different manufacturers to be interconnected thereby creating a more robust and dynamic industrial landscape. Supporting standardised chiplets for defence-specific components could complement efforts from the civil sectors in the coming years.

In 2024, the EDF addressed a development topic to support the supply chain for electronic components relevant for defence applications, e.g. system-on-a-chip or system-in-package including components such as analogue-digital converters, field programmable gate arrays and RF CMOS components. The topic focused on the design and validation of a European high-performance, trustable (re)configurable system-on-a-chip / system-in-package suitable for multiple defence applications.

Research on advanced components for radio-frequency application – as supported through the EDF's 2021 AGAMI_EURIGAMI project [127] that will focus on Gallium Nitride (GaN) integration into systems for radar and electronic warfare – is an important enabler for applications in the higher frequency band and lower microwave bands. Depending on the outcome of this call, a follow-on call on advanced components for radio-frequency application could be envisaged in the future.

Main expected outcomes from EDF 2021-2027 support:

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 enable technologies and capabilities for various defence applications, thereby supporting all other categories of actions, in particular by contributing to:

- support for supply chains for electronic components;
- support for innovation for high-performance and protective materials;
- certification of technologies for manufacturing and maintenance.

9. Air combat (AIR)

This category covers the development of air combat systems and technologies and their effective integration into overarching systems that allow for data exchange and sensor networking. This enables air combat systems and technologies to operate in increasingly complex air environments. All these capabilities will likely be operated in the future through a combination of manned and unmanned platforms, possibly integrated into larger joint operational settings, with a collaborative combat approach. It includes a broad range of high-end capabilities, manned or unmanned, from vectors to effectors, including dedicated weapon systems and payloads. In particular, next generation fighters and helicopter systems and technologies, including cutting-edge self-protection capabilities, are critical to achieving the desired air supremacy and penetration mission requirements. According to the collaborative warfare concept that will drive operations in the near future, all these air combat systems should be interoperable and interconnected in a large perimeter with different generations of various aircraft, satellites, naval and ground assets. They should also comply with NATO, EU and national regulations, standards and architectures when appropriate. These capabilities require long development cycle and heavy investments.

The EDF Programme Committee has indicated that the level of ambition in terms of the EDF's budget contribution to air combat corresponds to more than 10% of the total EDF budget.

- **Air fighters**:

[127] European Innovative GaN Advanced Microwave Integration.

Current fleet inventories indicate that several of the air combat systems that are currently operational (e.g. Rafale, Eurofighter, Tornado) might reach their end-of-lifecycle in the upcoming years. Member States are planning to invest in developing or acquiring next generation air fighters that should at least have effective stealth, greater survivability, increased capabilities and improved connectivity enabling them to operate in networks of assets, including unmanned air assets. These fighters should also be able to use wide options of improved stand-off weapon systems.

Supporting the CDP priorities [128] and CARD findings, the EDF aim in this field should be to help develop key components, technologies, and functions, including through a digital twin approach, which could eventually be integrated into the envisioned next generation air fighter systems. By doing so, the EDF will sustain the European value chains and help maintain critical skills in design, testing, certification, and production chains related to the required cutting-edge aeronautic technologies, while ensuring interoperability of future fighter systems.

To meet this ambition, an EDF call for proposals related to improved pilot environment for air combat was launched in 2021 to improve fighter cockpits through, in particular, adaptive human system collaboration, visualisation, crew monitoring and interaction methods (i.e. project EPIIC [129]). A follow-up call topic in this area is included in 2025.

Combat jet training platforms were addressed under the EDIDP in 2019 (under its FITS4TOP project [130]), but overall critical technologies for the next generation of fighter systems themselves, such as avionics, were addressed in 2023 (through the NG-MIMA project [131]) for which follow-up action could be considered in the future.

In addition, in 2024, the EDF addressed a call topic aiming to explore the other cutting-edge technologies and components that would be required for combat UAV. There would possibly be used in cooperation with next generation of fighter systems. There may be a related follow-up action as in the future.

- **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 powerful enablers in multidomain operations. Military rotorcrafts are fulfilling various missions like armed reconnaissance, strike, combat search and rescue (SAR), medical evacuation, utility, air assault and close aerial support, which are critical for the success of military operations. Furthermore, beyond their pure military role, military helicopters are also key assets for better civilian defence (security & protection) and the EU's internal resilience. They make a critical contribution to disaster relief, civilian search and rescue efforts, and responses to health crises.

The EDF's aim should be to help develop a prototype for a European next generation rotary wings system, possibly with high-speed, long-range and high-altitude features. This would help pave the way for a future joint procurement at EU level.

To meet this ambition, a project related to studies for next generation rotorcraft systems (ENGRT [132]) was selected for funding following the EDF calls for proposals in 2021. A follow-up topic was addressed in 2024.

([128]) CDP priority 'Air Combat' key area 'NG Air Combat Systems'.
([129]) Enhanced Pilot Interfaces & Interactions for fighter Cockpit.
([130]) Future Integrated Training Solution for TOP gun.
([131]) Next Generation Military Integrated Modular Avionics.
([132]) EU Next Generation Rotorcraft Technologies Project.

- **Collaborative air combat and aerial situational awareness**:

A critical challenge is to jointly build a European perspective that enables Member States to address middle and long-term collaborative air combat capabilities that combine: i) future air combat systems; ii) manned or unmanned platforms; iii) legacy platforms and their evolution, including sensors and effectors. With the plausible introduction of unmanned systems into air combat, future interoperability requires a far deeper interconnection that can be provided through cutting-edge technologies, including new generation of tactical data links.

The EDF's aim in this field should be to help develop standardised architecture and interfaces for collaborative air combat – in combination with fully operational standards for inserting unmanned platforms into non-segregated airspace – that could be integrated into various development and upgrading programmes related to air combat.

To meet this ambition, a project related to collaborative air combat (EICACS [133]) was selected for funding following the EDF calls for proposals in 2021, with a follow-up topic to be addressed in 2025. Manned-unmanned teaming was also tackled under the EDIDP in 2020 (i.e. MUSHER project [134]).

In addition, a topic aiming to increase the aerial situational awareness through advanced passive systems may be considered in the future.

- **Combat, endurance and survivability**:

Fixed and rotary wings platforms should be able to operate with a long endurance span, in particular through air-to-air refuelling. Furthermore, they should be equipped with combat and self-protection systems that would allow them to counter threats of attack that can hamper the air mission in contested environments.

As part of the EDF and in line with CDP priorities [135], R&D on future air-to-air refuelling capabilities could be of value in the future.

Regarding self-protection capabilities, a call topic (CARMENTA project [136]) was introduced under the EDIDP and a follow-up (CARMENTA PF project [137]) was addressed under the EDF in 2023. Further actions in this field are also planned in the future.

In addition, as European forces increasingly face sophisticated long range IADS and A2/AD systems, airborne electronic warfare capabilities become increasingly critical. Following the project conducted under the EDIDP in 2019 (the REACT project [138]), a follow-up project (i.e. REACT II [139]) was selected for funding following the EDF calls for proposals in 2022. This project's objective is to develop a state-of-the-art airborne electronic warfare capability, which can be jointly procured and possibly be used on manned and unmanned platforms.

Moreover, as air-to-air combat remains an interdisciplinary and challenging field where requirements for air-to-air missiles are constantly increasing in number and complexity, a call topic is included in 2024. This call topic aims to define and consolidate the requirements for a future short-range missile,

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([133]) European Initiative for Collaborative Air Combat Standardisation.
([134]) Development of a generic European Manned unManned Teaming system.
([135]) CDP priority 'Air Transport' key area 'AAR UAS.
([136]) Future European Self Protection System for Fixed Wing (Transport, Mission) and Rotary Wing (Transport, Combat) airborne platforms.
([137]) CARMENTA PRIMUM FUGA.
([138]) Responsive Electronic Attack for Cooperative Task.
([139]) Responsive Electronic Attack for Cooperation Tasks II.

in line with the CDP priorities [140] and as supported by the related PESCO project involving six Member States. It has been proposed that follow-up topic be considered in the future.

Actions carried out under this category should take advantage of those carried out under other categories as, for example, the next generation of propulsion and energy systems for air fighters and helicopters addressed under the energy resilience and environmental transition category, and other topics related to advanced passive and active sensors, cyber and space.

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:

- critical components and technologies for next generation fighter systems;
- standardised architecture and interfaces for collaborative air combat;
- prototype of next generation rotorcraft, leading to joint procurement;
- joint procurement of an airborne electronic warfare capability.

10. Air and missile defence (AIRDEF)

In line with the CDP priorities [141], the 'Air and missile defence' category embraces a wide range of capabilities, from counter-UAS to ballistic missile defence, that help protect EU forces and populations against aerial threats.

The EDF Programme Committee has agreed that the level of ambition in terms of the EDF's budget contribution to air and missile defence corresponds to more than 5% of the total EDF budget.

- **Counter UAS:**

A wide range of UAS, including off-the-shelf commercial drones and mini/micro-UAS possibly flying in swarms, are increasingly being used for offensive or intelligence gathering purposes, posing a growing threat to forces and populations.

In line with CDP priorities and CARD findings, the EDF's aim in this field should be to help develop active and passive protections against armed and intelligence gathering UAS that will increase force protection and the resilience of critical infrastructures, as well as help boost information superiority.

An ongoing PESCO project is aimed to develop a system that can counter the threat posed by mini and micro UAS and be employed for homeland defence, security and dual-use tasks.

Under the EDIDP, the JEY-CUAS project [142], launched in 2021, is paving the way for the development of a joint European counter unmanned air systems capability. A follow-up project was selected for funding (the EDF's 2023 E-CUAS project [143]) to develop a prototype, leading to possible future joint procurement at EU level. Taking into consideration various solutions for C-UAS already developed throughout the EU, with different applications and outcomes, it is proposed to launch a technological challenge in this area in the future in order to trigger a step forward towards enabling Member States identify the best solutions.

([140]) CDP priority 'Air Combat' – key area 'NG Joint Precision Strike'.
([141]) CDP priority 'Integrated Air & Missile Defence'.
([142]) Joint European sYstem for Countering Unmanned Aerial Systems.
([143]) European Counter Unmanned Aerial Systems.

- **Missile defence and protection against hypersonic threats**:

The emergence of new threats such as manoeuvring ballistic missiles, hypersonic cruise missiles or hypersonic glide vehicles is a further challenge for European and NATO ground and naval-based air defence systems. CARD identifies the development of integrated air missile defence systems as a short- to long-term collaborative opportunity (development and procurement).

The EDF's aim in this field should be to help develop a prototype for a European endo-atmospheric interceptor. To meet this ambition, the initial phase of development was addressed in 2021 (the EU HYDEF project [144]) and in 2023 (the HYDIS^2 project [145]) through a dual-sourcing approach involving all the relevant industries throughout the EU. It is proposed to include a follow-up call topic in the future. In the meantime, a topic aiming to counter hypersonic glide vehicle has been included in 2024, with a possible follow-up topic in the future.

In addition, it has been proposed that the development of an integrated multilayer air and missile defence be explored 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:

- technologies and capabilities ready to be procured or used for an effective multilayer air and missile defence, including a prototype of endo-atmospheric interceptor;
- prototype of counter UAS, leading to joint procurement.

11. Ground combat (GROUND)

Land platforms and their weapons systems are crucial capabilities for all land operations. This category focuses on major land combat systems (e.g. MBT [146], ATV [147] and APC [148]), unmanned ground systems (UGS) and indirect fire while ensuring a collaborative form of combat for European land forces.

There is a lack of coherence in the European capability landscape due to the many different types of land combat systems, including different types of logistic systems, and their modernisation and upgrade status. This is exacerbated by diverging approaches of Member States to prepare for the future as regards land platforms: digitalisation and systems of systems approach vs increase in numbers of combat systems. Reducing the different types of land platforms and converging the approaches to prepare the future will be the major challenge across all planning periods. Against this background, Member States should cooperate on developing and refining generic open architecture standards in collaboration with the defence industry, while also developing modular and open platforms that can be easily upgraded and reconfigured in the light of technological evolutions.

The EDF Programme Committee has agreed that the level of ambition in terms of the EDF's budget contribution to ground combat corresponds to more than 10% of the total EDF budget.

- **Land platforms**

([144]) European Hypersonic Defence Interceptor.
([145]) Hypersonic Defense Interceptor Study².
([146]) Main battle tank.
([147]) All-terrain vehicle.
([148]) Armoured personnel carrier.

Future capability and operational challenges require next generation to be developed and current platforms to be modernised (e.g. ATV, LAV [149], IFV [150], APC). These need to be strengthened with improved interoperability, agility, survivability, mobility, durability, versatility, and security including cyber, and be able to operate in adverse conditions (facing challenging threats in various environments), helping forces in a wide range of missions, in digitised battlefield and network centric environments. This would also help in obtaining scalable effects and other ground platforms such as logistic support vehicles and engineering vehicles, while ensuring efficient maintainability and support, high-level operational readiness and optimised life cycle cost. In that context, the EDIDP's FAMOUS project [151] and its follow-on, the EDF's 2021 FAMOUS2 project develop next generation armoured platforms and upgrade existing platforms. Moreover, further development of modular multifunctional land platforms will be addressed in 2025. Furthermore, the development of *Next generation armoured infantry fighting vehicles* has been addressed in 2024 and further development efforts could be envisaged in the future. In addition, the EDIDP's SRB project [152] and its follow-on, the EDF's 2023 SRB2 project develop a fully rotary hydro-pneumatic suspension system for heavy armoured vehicles.

The increase in the platform's firepower through the development of new guns and warheads, including those based on pulsed-power principle (e.g. electromagnetic guns and hypervelocity projectiles), still needs to be pursued. Against this background, after the PADR's PILUM project [153] paved the way for electromagnetic railgun and hypervelocity projectiles, the EDF's 2022 THEMA project [154] matures technology and critical components in this field. In addition, the EDF's 2023 DEMAROCK project [155] will design an innovative and disruptive electromagnetic launcher for 70mm rockets, while the EDF's 2021 NEWHEAT project [156] aims to improve the performance of conventional shaped charge. Moreover, a call on *Intelligent weaponry and ammunition systems* was launched in 2024.

MBT capability is an essential backbone for high intensity land-based operations. The combination of mobility, firepower and protection has proven its relevance in conventional warfare. Many MBT assets currently held by Member States are ageing or obsolete. In recent years, Member States have unveiled plans to modernise in-service platforms as well as to replace capabilities close to the end of operational life. This presents an opportunity for potential future collaboration to improve the EU's overall MBT capability, as aimed for by the EDF's 2023 MARTE [157] and FMBTech [158] projects, with possible follow-on development actions in the future.

- **Collaborative combat**:

The future battlefield is characterised by a very harsh environment with high intensity activities, including in the land domain. Indeed, the land environment is recognised as hostile, very diverse on the planetary scale, fast changing (so that existing maps no longer apply within a short space of time) and complex (with terrain compartments that may block vision as well as communication links). This presents various levels of structuration (from open to urban terrain, representing a real challenge for

([149]) Light armoured vehicle.
([150]) Infantry fighting vehicle.
([151]) European future highly mobile augmented armoured systems.
([152]) Rotary Suspension for Armoured Vehicles.
([153]) Projectiles for Increased Long-range effects Using electroMagnetic railgun.
([154]) TecHnology for ElectroMagnetic Artillery.
([155]) Disruptive Electromagnetic 70 mm Rocket System.
([156]) New European Warhead Technologies.
([157]) Main ARmoured Tank of Europe.
([158]) Technologies for existing and Future MBTs.

image processing or for autonomous vehicles and robotics). It fully includes the interactions with airspace and therefore the requirement for: i) wide connectivity and interaction (expanded situational awareness and cross-platform collaborative engagement) with: a) different sensors and effectors in the land domain (i.e. manned platforms, UxV and dismounted soldiers) and b) sensors and effectors from other domains (air, space and cyber), as well as ii) underground infrastructure in urban areas. The EDF's 2022 LATACC project [159] aims to improve the collaborative capabilities of armed land forces. Furthermore, a call for further development in this area will be addressed in 2025. In addition, the EDIDP's LYNKEUS project and its follow-on, the EDF's 2021 MARSEUS project [160] address collaborative close combat architecture with beyond-the-line-of-sight capability, with a call for further development in 2024.

- **Indirect fire**:

Given the evolution of the defence environment in Europe, land forces need the ability to operate in a high-intensity threat environment, potentially facing technically advanced adversaries. In this context, the range, precision and efficiency of associated firepower to protect forces such as artillery capabilities, including ammunition, need improving. The EDIDP's FIRES project [161] and its follow-on, i.e. the EDF's 2023 FIRES 2 project, aim to develop a future ammunition family for the European indirect fire systems, while the EDIDP's e-COLORSS project [162] paved the way for the development of a European long-range artillery system and launcher.

- **Unmanned ground systems**:

There are significant opportunities in the EU for cooperation on unmanned systems, which could be based on a shared operational concept and the resulting harmonisation of requirements. Moreover, the CDP underlines the need to deploy unmanned systems to reduce the danger to human personnel and manned platforms, as well as to increase robustness, sustainability, and resilience of ground systems. As part of PESCO, nine Member states are involved in the 'Integrated Unmanned Ground Systems 2 (IUGS2)' project. This aims to develop an unmanned ground system capable of manned-unmanned and unmanned-unmanned teaming with other robotic unmanned platforms and manned infantry fighting vehicles/main battle tanks to provide them full support on the battlefield (both logistical and direct support by fire). Likewise, a new EDA's Cat-B project on 'unmanned ground system (CUGS)' is about to be launched. This project intends to choose and adapt three different kinds of platforms, and to define, design, and develop a set of functional modules which eventually will be articulated into a definitive solution for highly autonomous combat unmanned ground systems.

The PADR's INTERACT project [163] paved the way for unmanned systems to be fully integrated into military operations, as it addressed critical requirements such as interoperability and standardisation. The EDIDP's iMUGS project [164] developed a modular and scalable architecture for hybrid manned-unmanned systems. In addition, further development on unmanned modular ground system of systems has been called in 2024, with a possible follow-on action in the future. In the meantime, the EDF's

([159]) LAnd TActical Collaborative Combat.
([160]) Modular ARchitecture Solution for EU States.
([161]) Future Indirect fiRes European Solution.
([162]) European COmmon LOng Range indirect fire Support System.
([163]) INTERoperability Standards for Unmanned Armed ForCes SysTems.
([164]) Integrated Modular Unmanned Ground System.

2021 COMMANDS project [165] develops a solution to provide trustable and effective cooperation between manned and unmanned assets.

A comprehensive set of unmanned systems should contribute to the capability of land manoeuvre in a joint operational environment to gain positional advantage over the adversary. The strategic relevance of the manned/unmanned teaming and adaptive cooperation between manned and unmanned systems is also linked to the improvement of land systems' capability to conduct complex operations through the increasing use of 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 aim in the GROUND category of actions should be to help achieve of the following main expected outcomes:

- joint development and procurement of modular and multifunctional systems of systems and integration of technologies for platform upgrades;
- full system demonstrator for a future main battle tank and contribution to next generation IFV, and other armoured vehicles;
- BLOS capability ready for procurement;
- development of a long-range indirect fire demonstrator;
- UGS ready for procurement;
- contribution to better connectivity and interaction among land platforms (manned/unmanned, mounted/dismounted) required for conduction of multidomain operations.

12. Force protection and mobility (PROTMOB)

Force protection and mobility at all operational levels minimises losses due to hostile action while ensuring security of supply for the forces on the battlefield. The availability of capabilities to ensure advanced protection of forces and mobility is an important operational requirement.

Force protection and mobility has a broad range of aspects, which vary from design parameters of major combat platforms to individual soldier systems. The European capability landscape is characterised by various standards and systems.

Preserving the overview on force protection and mobility needs and activities, including the cutting edge of technologies usable in this context remains a major challenge across all planning periods.

- **Soldier systems**:

Soldier systems support force protection, and increase operational effectiveness, reliability and endurance of individual soldiers and formations. They comprise the gender-neutral equipment of military personnel, e.g. protective clothing, so they can operate with a sufficient level of protection in any operational environment. Soldier systems are a primary force multiplier and likely have close connections to the PESCO project – EU Collaborative Warfare Capabilities (ECoWAR). This project aims to promote effective and efficient collaboration between current and future platforms and soldiers. Developing and integrating cutting-edge technology in soldier systems is key for forces and

[165] Convoy Operations with Manned-unManneD Systems.

should provide soldiers with improved situational awareness, decision-making aids, effective engagement, ability to operate in GNSS denied environments, and provide simple and effective human-machine interfaces to support soldiers' manned-unmanned teaming. There is an industrial overcapacity in the soldier systems field at EU level. This has led to fragmentation in R&D investments and has also resulted in various non-interoperable systems being developed. In line with CDP priorities [166], an EU open architecture in soldier systems had already begun to be developed with the PADR's GOSSRA project [167]. This has been further pursued under the EDF's 2021 ACHILE project [168]. This aims to develop highly innovative solutions taking into account the next generation dismounted soldier system. Further development has been called for in this area in 2025. To complement this, the EDF's 2021 LODESTAR project [169] help integrate augmented reality and artificial intelligence into future soldier systems.

- **Future cargo capabilities**

Tactical transport aircrafts are the 'workhorses' of battlefields, fulfilling missions such as airdrop deliveries, parachute drops, logistics, medical evacuation, air-to-air refuelling, and special missions under harsh and adverse conditions. These are critical for the success of military operations. Beyond their pure military role, tactical transport aircrafts are also key assets for better civil defence/protection and EU internal needs, making a critical contribution to disaster relief, search and rescue efforts and health crises response.

Future mid-size tactical cargo aircraft (FMTC) address this need within the EU's military transport portfolio, as supported by five Member States through the related PESCO project and identified as a medium- to long-term collaborative opportunity during the last CARD cycle. In line with CDP priorities [170], the EDF's 2023 FASETT project [171] conducts a feasibility study for replacing transport aircraft, meeting the Member States' needs by 2030-2040. Further R&D actions in this field are planned in the future.

Strategic air transportation of outsized cargo (SATOC) is also a core capability for rapid military projection over long distances and mission support worldwide. This is supported by four Member States under the related PESCO project. All operations carried out so far have always had to fall back on this important capability for deployment and later maintenance. Beyond their military role, SATOC aircraft are also key assets that make a critical and essential contribution to immediate logistical support over large distances, disaster relief and fast response to general crises. Currently, there is no service provider who has the appropriate capability to support the Member States' needs. Therefore, the EDF's 2023 ESOCA project [172] aims to identify, define and evaluate short and long-term options for future European strategic airlift capability, in line with CDP priorities [173]. Possible further actions could be considered in the future.

- **Protection and mobility of military forces**

([166]) Priority Future Soldier Systems
([167]) Generic Open Soldier System Reference Architecture.
([168]) Augmented Capability for High End Soldiers.
([169]) Live operational data enhancement for situational awareness through augmented reality.
([170]) Priority 'Air Transport' under the key area 'development of new Tactical & Strategic Air Platforms'.
([171]) Future Air System for European Tactical Transportation.
([172]) European System for Outsized Cargo Airlift.
([173]) Priority 'Air Transport' under the key area 'development of new Tactical & Strategic Air Platforms.

Regarding force protection, the PADR's VESTLIFE projects [174] developed a new lightweight and modular bulletproof integral solution for dismounted soldiers with dedicated clothing architectures. In addition, the EDF's 2023 GENIUS project [175] intends to increase accuracy in detecting improvised or unexploded explosives. Further developments in this area could be considered in the future.

To facilitate the mobility of the forces and increase their efficiency on the ground, the EDF's 2021 SDMMS project [176] develops a secure solution for exchanging information between countries requesting any military movement, while the PADR's ARTUS project [177] paved the way for a small swarm of intelligent and autonomously operating unmanned ground vehicles to support logistically infantry platoons during their missions. The result of the SDMMS project will lead to the important first step of digitising military mobility permits and the clearances landscape being taken.

Stemming from the radical change in the strategic security environment, Europe needs further innovation to deploy SDMMS as an operational solution for digitising the military mobility landscape. The SDMMS#2 is really expected to address the identified needs based on the development phase. It will improve the efficiency of the prototype advanced under SDMMS, by adding features like post-quantum cryptography, wartime resiliency, tracking and monitoring of movement, digitising military customs formalities, and secure mobile applications [178]. In addition, research related to a future light multirole aircraft FMLA [179] that can bridge the gap between today's battlefield and modern technology could be considered in the future. Furthermore, developing autonomous precision aerial delivery systems could 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:

- standardised architecture and interfaces for European soldier systems and joint procurement of upgrades for soldier systems (e.g. protection equipment, small arms, ammunition, CIS);
- Contribution to improving soldiers' situational awareness, decision-making, physical and cognitive capability, effective engagement in non-permissive, multidomain environments, and teaming with UxS;
- Contribution to developing FMTC;
- Contribution to developing SATOC;

13. Naval combat (NAVAL)

The EU is surrounded by oceans and seas, which are essential for the European economy. The EU maritime security strategy identifies a vast spectrum of challenges, threats and risks that could condition an open, safe and secure global maritime domain. Naval power and supremacy at sea are essential for EU countries' armed forces to fulfil their missions and protect EU citizens and territory,

(174) Ultralight Modular Bullet Proof Integral Solution for Dismounted Soldier Protection.
(175) Next GEneration of IA and combat cloud systems for NeutralIsation of Unexploded threatS.
(176) Secure Digital Military Mobility System.
(177) Autonomous Rough-terrain Transport UGV Swarm.
(178) The further digitisation efforts of the military customs formalities are directly aligned with the goal of Action Plan 2.0 goal to step up EU-NATO cooperation.
(179) Future Multirole Light Aircraft.

and to project power into more remote geographical areas. It has also a key role in times of peace and crisis in supporting a credible foreign policy.

Evolving operational environment and threats require cutting-edge naval systems and platforms to be developed. These should be able to operate in a fully interconnected and integrated way, under challenging conditions where multidomain threats exist (land, aerial, surface, subsurface and cyber), including, where needed, in extreme climates and geographical environments (e.g. the Arctic). They should also comply with the requirements of the most advanced environmental legislation.

From a technological and industrial perspective, despite the fragmentation of the EU's internal naval market, the European naval industry remains competitive at global level and should maintain its technological leadership. The capacities of system integrators and equipment suppliers are a strategic asset for the European naval sector, which should be preserved and strengthened.

Having the above in mind, the EDF Programme Committee has currently indicated that the level of ambition in terms of EDF's contribution to naval combat, together with underwater warfare, corresponds to more than 10% of the full EDF budget.

EDF topics and the main expected outcomes from this category are highly aligned with CDP priorities [(180)]. Most of the topics addressed in this category can in particular support the CARD collaborative opportunity – 'Development of Next Generation of Class of Multipurpose Modular Surface Combatant Vessels'. Furthermore, these actions are usually developed as part of PESCO projects, such as the European Patrol Corvette or the Medium Size Semi-Autonomous Surface Vehicle.

Two main lines of work are considered for the 2021-2027 EDF.

1) Support to development actions aiming to provide Member States with effective **state-of-the-art capabilities.** These actions refer to either **new naval vessels and systems** or **the upgrade or current assets**.

   Considering the EU's diversity as regards main naval scenarios, missions and current capabilities of the EU navies, these actions might not interest many Member States, nor involve all the EU naval actors. Therefore, in these cases, inclusivity should be sought through the widest possible supply chains.

   The EDF should strongly support actions in this area with a significant budget and consider subsequent actions to support follow-up development phases once the initial action has sufficiently progressed.

   In this category we can include:

   - the topic 'modular and multirole patrol corvette' addressed by EDF in 2021 and 2023 (i.e. the EPC [(181)] and EPC2 projects);
   - the topic medium-size semi-autonomous surface vessel addressed by EDF in 2022 (i.e. the EUROGUARD project [(182)]), that could be considered again in the future;
   - the topic 'naval collaborative surveillance' that the EDF addressed in 2022 (i.e. the E-NACSOS project [(183)]), which could be scaled up through naval collaborative engagement could be considered again in the future;

(180) 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.
(181) European Patrol Corvette.
(182) EUROpean Goal based mUlti mission Autonomous naval Reference platform Development.
(183) EU NAval Collaborative Surveillance Operational Standard.

- development projects selected under the SME calls in the 2020 EDIDP (i.e. TRANSFLYTOR [184]) and its follow-on under the 2023 EDF (i.e. ARROW [185]).

2) **Support to research and development actions** whose results can benefit most of, if not all, the EU's naval actors. These actions would focus on **technologies, standards, or systems to be integrated**, in one way or another, into **specific naval projects**. They should be considered real enablers for both the naval industry and EU Member State navies. By their nature, these actions are inclusive.

   Two examples of these naval actions that attracted broad interest and involvement were the research project OCEAN 2020 [186] funded under the PADR, and the development project SEA DEFENCE [187] funded under the EDIDP.

   As regards the 2021 EDF, the topics *Digital ship and ship digital architecture* (i.e. project EDINAF [188]) and *Ship structural health monitoring* (i.e. project d-THOR [189]) are clear examples of actions whose results, related to digital transformation in the naval sector, can be easily capitalised upon in the future by other specific projects.

   This is also the case for the topic *Functional Smart System-of-Systems under an integral survivability approach for Future Naval Platforms* addressed in 2024.

Some naval projects are currently paving the way for future wider actions under other categories like, for example, the small optical satellites for maritime surveillance funded under the EDIDP (OPTISSE [190] and NEMOS [191]). The Space category has taken advantage of the momentum created by expanding the scope of ISR beyond maritime surveillance with a topic in 2022 on *Innovative multi-sensor space-based Earth observation capabilities*.

In the same way, the naval combat category of actions should benefit from those actions carried out under other categories, for example, the design of naval green fuel under innovative propulsion systems for defence applications, addressed in 2023 as part of the energy resilience and environmental transition category, and other potential topics in the categories for information superiority, advanced passive and active sensors, and cyber and disruptive technologies (e.g. laser-based weapon systems).

([184]) Troop Transportation Flying Vector.
([185]) Autonomous Rapid Recognition Operation Warship.
([186]) Open Cooperation for European mAritime awareNess.
([187]) Survivability, Electrification, Automation, Detectability, Enabling Foresight of European Naval Capabilities in Extreme conditions.
([188]) European DIgital NAval Foundation.
([189]) Digital Ship Structural Health Monitoring.
([190]) Very high resolution OPTIcal paylod for Small Satellites for defencE applications.
([191]) Novel Earth and Maritime Observation Satellite.

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:

- joint procurement of a modular and multirole patrol corvette class;
- first ship of a medium-size semi-autonomous surface vessel class, including different mission modules, leading to joint procurement of the class and including the development of standardised architecture and interfaces on automation;
- joint procurement and integration into different platforms of a naval collaborative surveillance capability;
- development activities leading to a naval collaborative engagement capability;
- development of standardised architecture and interfaces related to smart ships and digital transformation, including naval cloud combat.

14. Underwater warfare (UWW)

Underwater warfare remains an essential factor of operational plans of European navies and is an integral part of naval capability development. Underwater warfare is also be seen in the context of the EDF to encompass seabed warfare activities including protection of critical infrastructure. The Strategic Compass echoes these requirements, reiterating the need to protect critical maritime infrastructure including the seabed by developing joint operational, capability and technological solutions.

The capability to counter underwater threats is a fundamental enabler of securing freedom of action. The range of capabilities needed span from underwater effectors to mine countermeasures, including their enablers such as situational awareness. The future of underwater warfare is subject to the general megatrends of digitalisation and convergence. The EU's Defence Technological and Industrial Base has a relatively adequate global position, but continuous R&D efforts are required to safeguard technological sovereignty in this highly sensitive and export restricted area.

The dominant lines of technological development concern issues such as swarm technologies with autonomous features operating in several environments where the same system can perform multiple tasks. Future systems are expected to perform intelligence gathering, communication, analysis, positioning, surveillance, and engagement tasks in a joint and networked fashion. Actions addressing solutions to the general underwater challenges, namely the exchange of broadband information in real time, would meet the needs of the broader domain. It is therefore essential to consider the underwater environment together with its interfaces from air to the seabed, but also its specific threats and enabling infrastructure. Actions under the EDF target enabling technologies for **future effectors**, their **countermeasures** and their support functions, including protection of critical seabed infrastructure.

Several EDF actions and the main expected outcomes from this category can be connected to some CARD collaborative opportunities, such as 'Enhancement of UMS performances' and 'Development of a Ship for Underwater Surveillance and Operations'.

- **Mine warfare**:

In this area, next generation modular mine countermeasures (MCM) solutions, capabilities for detecting underwater threats and agile multipurpose effectors – with a focus on innovation – are sought. The aim is to develop remotely operated highly scalable networked systems with autonomous

features that are ready for market uptake. Modularity and scalability are critical characteristics for integration with and updates of legacy systems. Signature management countering multi-influence underwater sensor threats is a potential item to be addressed in future topics. A related strand of interest lies in technological enablers, such as quantum magnetometers as part of a multi-influence sensing network. The EDF's 2023 EequalMCM project [192], which is a follow-on to the EDIDP's MIRICLE project [193], aims to deliver new MCM capabilities prototypes ready for industrialisation in the EU. In addition, the development call topic in the 2024 EDF on *Autonomous heavy minesweeping system* addresses the specific field of minesweeping, complementing the mitigation of capability gaps in this area.

- **Anti-submarine warfare**

Any type of underwater vehicle or moving threat is considered relevant for anti-submarine warfare (ASW). New stand-off hard-kill solutions need to be researched and developed, particularly for counter-torpedo subjects without limiting targets to be affected to torpedoes only. Adaptive solutions using networks of manned and unmanned resources for the complete kill-chain are essential.

The platform agnostic approach is preferred when improving capabilities, as it would provide future procurement opportunities for a larger group of capability owners. The ever-increasing importance of seabed warfare (SBW) is taken into account in ASW solutions. In line with the CDP priorities [194], the EDF's 2023 SEACURE project [195], which is a follow-on to the EDIDP project SEANICE [196], develops and demonstrates at sea an integrated system of systems of unmanned platforms to perform joint anti-submarine and seabed warfare operations to protect critical maritime infrastructure.

- **Situational awareness and C2**

Digital infrastructure, net and data-centricity for integrated communications above and below surface and cyber security-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 with dual- or multifunction capabilities will enable the future integrated (underwater) operational environment. Modular and non-static sensor and communication node platforms are included in the scope. Development of ultra-sensitive acoustic sensors based on quantum technologies could be considered. EU competitors are currently exploring this technology. Furthermore, for safe and secure communication systems, post-quantum cryptography can provide information-theoretic security for radio and underwater communications.

In line with the CDP priorities [197], following the EDIDP's CUIIS project [198], which addressed a C4I mission system for underwater situational awareness, the EDF's 2022 SWAT-SHOAL project [199] develops a concept of a system of systems, based on swarming technologies, to integrate manned and unmanned naval assets, so they collaborate effectively as a team to achieve greater performance and efficiency in a broad spectrum of underwater missions against moving subsurface threats. In addition,

([192]) European Extended Mine Countermeasures.
([193]) Mine Risk Clearance for Europe.
([194]) CDP priority Underwater and Seabed Warfare under the key area Underwater Force protection Systems.
([195]) SEabed and Anti-submarine warfare Capability through Unmanned featuRe for Europe.
([196]) antiSubmarine warfare European Autonomous Networked Innovative and Collaborative Environment.
([197]) CDP priority Underwater and Seabed Warfare under the key area Underwater Force protection Systems and Seabed warfare & Deep-Water operational capabilities, as well as the CDP priority Maritime Domain Awareness under the key area Comprehensive Underwater Surveillance Capabilities.
([198]) Comprehensive Underwater Intervention Information System.
([199]) SWArm and Teaming operation of manned & unmanned underwater vehicle SHOAL.

the EDF's 2021 FIBERMARS project [200] addresses the distributed acoustic sensing technology, while its 2022 AVALON project [201] is paving the way for implementing novel highly capable underwater optical wireless networks for military applications.

Relevant in this field is the EDA CAT-B project SABUVIS II [202]. This aims to design and implement a swarm of autonomous underwater vehicles that closely collaborate, 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.

For all fields, where relevant, development actions that **improve diver operations** in contested environments, can be addressed. Equally, **critical maritime infrastructure** may be addressed under any field of approach. Critical component and material enablers for underwater warfare are addressed under the category of actions for material and components. Certain sensor related technological research may also be addressed in the category of actions for sensors. Some of the more disruptive components, in particular those related to quantum technology, can be addressed in the category of actions for disruptive technologies.

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 suite;
- prototype of unmanned ASW and SBW solutions;
- development of an advanced underwater observation system, including C3 enablers;
- development of manned-unmanned teaming systems for multiple mission types;
- testing of MCM, ASW and SBW platforms;
- development of a stand-off hard-kill solution for dynamic underwater threats, including counter-torpedo solutions.

15. Simulation and training (SIMTRAIN)

The category of action aims to create and develop simulation and training solutions. This is in line with the EU Strategic Compass, which recalls the importance of training to increase readiness and interoperability and mentions that high-end training systems are developed through the EDF. Providing simulation and training solutions is also a Member State goal in defence capabilities as expressed within the scope of EDA's Capability Technology (CapTech) Group on Simulation Technologies.

The use of simulations and simulators to provide training procedures improves individual and collective capabilities. Military forces train with a wide range of simulated weapons, ships, aircraft and other vehicles in conjunction with live training on actual equipment. Within the military and in other professions, modelling & simulation (M&S) helps provide a safer and less resource-intensive rehearsal capability for a wide variety of training activities.

[200] Using fiber optical cables for maritime situational awareness.
[201] UnderwAter optical wireless communication network architecture empowered by adVanced opticAl materiaLs for sea bOrder protection and deep-sea exploration.
[202] Swarm of Biomimetic Vehicles II.

Military simulations are models that enable theories of warfare to be tested and advanced in a controlled environment, without the need for actual hostilities. These simulations can be conducted through various means, including tabletop exercises and computer simulations, known as simulation-based war games. Within these war games, virtual replicas of objects, systems, or processes, called digital twins, are used to simulate their behaviour, performance, and dynamics, creating a more realistic and immersive environment. Digital twins allow for more accurate testing and analysis of military strategies and tactics, enabling 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 making full use of digital twins in simulation-based war games, military organisations can support better and faster decision-making, enabling them to respond more effectively to emerging threats and rapidly changing situations.

Digital twins exist in different forms with various degrees of realism. They increasingly involve AI. Despite AI being a hot topic among military technologists for years, the training community is only beginning to explore how to apply it to their high-tech simulators and modelling software.

Training is one of the most used M&S applications, but there are many other ways that M&S enables defence functions. In particular, M&S is used to analyse new capabilities and inform ministries of defence that are acquiring such capabilities, helping them adopt new tactics, process intelligence and test systems before they are put into the hands of our fighting forces.

M&S helps to reduce costs, increase the quality of products and systems, and document and archive lessons learned. Because the results of a simulation are only as good as the underlying model(s), engineers, operators and analysts must pay particular attention to its construction. To ensure that the simulation results can be applied to the real world, the user must understand the assumptions, conceptualisations and constraints of its implementation. Future expectations include prioritising rapid prototyping and development cycles with upgrades through 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.

- **Modelling and simulation**:

M&S is a broad field that encompasses various subfields, including digital twins, augmented reality and AI.

As part of PESCO, six Member states are involved in the integrated European joint training and simulation centre (EUROSIM) project, while four Member states are involved in the main battle tank simulation and testing centre (MBT-SIMTEC) project.

Simulation has been addressed in two ways: i) under separate EDIDP projects like VireTS [(203)] – for which there have been calls for follow-on activities in the 2024 EDF – VERTIgO [(204)] and FIIST [(205)]; and ii) inside other projects as part of a prototype and testing activity as a means to get initial results.

In addition, the EDF addresses several aspects of M&S,

- **Decision-making and training**: modelling and simulation is contributing to decision-making and training, including the integration of various simulating systems already in service. It

([203]) Development of Virtual Reality Trauma Simulator.
([204]) Virtual Enhanced Reality for inTeroperable traIning of CBRN military and civilian Operators.
([205]) Future Integrated Indoor Soldier Training.

addresses various levels of decision-making from strategic to tactical or decision-making in the field of training. In line with CDP priorities [206], the EDF's 2022 FEDERATES project [207] targets a EU-wide modelling and simulation as a service solution for distributed synthetic training and decision-making, with a complementary action considered in the future.

- **Simulation and training**: the EDF's 2021 ABITS project [208] is developing an in-door tactical training solution that integrates quantification of performance, well-being and analytics into the training-simulation loop, while its 2022 TRAVISMOS project [209] is developing a mobile, modular, scalable and flexible virtual simulation solution for rapid field deployment.
- **Live, virtual, constructive training interoperability:** Member States have identified the need for a project on live, virtual, constructive training interoperability – joint operations and service-specific solutions, partially building on the EDIDP's FITS4TOP project [210]. The EDF's 2025 topic entitled *Live, virtual, constructive training interoperability* addresses this need, in line with CDP priorities [211].
- **Digital twins:** In line with CDP priorities [212], the 2025 EDF includes the following research call topic, *'Multi-disciplinary design and analysis framework for Aerial Systems (System of Systems Digital Twin)'*, which aims to focus on using digital twins as a method to design, test and validate aerial systems before building physical prototypes.

➢ **Augmented reality**:

Augmented reality 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 the virtual content and the real world through pose tracking. Applying augmented reality technology in military exercise training helps to innovate exercise training methods and increase the degree of actual combat. Applying the military training system based on augmented reality technology can build an extremely realistic combat training environment based on real events or schematics. Methods for bridging reality gaps have been addressed under the 2024 EDF.

➢ **AI** (AI) for simulation and training

War games supported by AI can speed up the decision-making process. In line with the CDP priorities [213], the use of AI in simulation could be considered in the future.

([206]) Priority Cohesive & Well-Trained Militaries under the key area Enhanced Education and Training Enablers
([207]) FEDerated Ecosystem of euRopean simulation Assets for Training and decision Support.
([208]) Advanced Biometrics In Training and Simulation.
([209]) TRAining with VItal Signs MOnitoring in modular Setup.
([210]) Future Integrated Training Solution for TOP gun.
([211]) Priority Cohesive & Well-Trained Militaries under the key area Enhanced Education & Training Enablers, and facilities.
([212]) Priority Air Combat under the key area NG Air Combat Systems.
([213]) Priority Cohesive & Well-Trained Militaries.

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):

- creation of an EU ecosystem in M&S for defence and minimisation of existing industrial gaps through increased cooperation;
- technical and innovative M&S solutions provided, including war gaming and scenarios evaluation, suitable for joint procurement or use.

16. Disruptive technologies (DIS)

The EDF Regulation states that the Fund should support actions that are conducive to developing 'disruptive technologies for defence' [214]. Nevertheless, the Regulation also mentions that as disruptive technologies can be based on concepts or ideas originating from 'non-traditional' defence actors, the Fund should allow for sufficient flexibility as regards consulting stakeholders and carrying out such actions.

Based on these assumptions, two main lines of work are considered for the 2021-2027 EDF.

1) **Disruptive technologies based on concepts or ideas originating from 'non-traditional defence's state-of-art'** [215]**,** such as AI, big data, the internet of things, autonomous systems, biotechnologies and quantum technologies.

   When applied in the defence domains, these techniques could have a very large impact. When applied in a military operational environment, they could also help deal with gaps in military capabilities in the fields to be covered as set out in the EDF Regulation.

   The key point is the 'orientation' of the research on and/or the application of these 'cross-board' technologies to topics addressing or enabling concrete defence capabilities.

   - **AI**

   Future military capabilities will include a significant number of systems that will make massive use of AI techniques. AI core technologies are in principle covered under the 'Digital transformation' category, and AI for specific capabilities corresponding to other categories is covered under such categories. Other uses of AI can be covered under the 'Disruptive technologies' category. Coordination and consistency with other categories will be ensured to avoid duplications.

   AI techniques can be applied to help develop capabilities under the conventional operational domains. For example, in the naval domain, the continuous increase in the number of sensors and volume of data related to detecting, classifying and identifying surface and underwater contacts makes it highly recommendable to implement techniques that let us automate these tasks. Based on this, it is recommended to incorporate advancing processing techniques based on AI into vessels'

([214]) Broadly speaking, 'disruptive technology for defence' means an improved 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.

([215]) See NATO - Topic: Emerging and disruptive technologies

systems in order to lower the operator workload and increase the accuracy and speed of the processes.

- **Quantum technologies**

Possessing and deploying quantum technologies for sensing is potentially a game changer in many defence applications, which means that maturing and mastering these technologies is needed for mission superiority as well as competitiveness.

The EDF's 2021 work programme 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 topic addressed in the 2021 EDF, ADEQUADE [216], was also considered as a follow-up to the PADR's QuantaQuest project [217], 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) quantum network of sensors for synergic connection. This field has been further addressed in 2024 as a follow-up topic aiming to elaborate on the results achieved by the project was selected for funding following the EDF calls for 2021.

In the field of quantum communications, an EDA CAT-B project – ANQUOR [218] – is ongoing. It is expected to be completed in 2027. The project will demonstrate the military relevance of quantum communications technology in bringing benefits from civil R&D results and identifying specific military conditions and needs for the use of such technology.

2) **Emerging technologies that are equally disruptive**, **contributing to** (or complementing) **the development of innovative defence systems**, such as laser-based or RF-directed energy weapons, over-the-horizon radars applications, adaptive camouflage, or electromagnetic artillery systems.

- **Directed energy weapons**

Directed energy weapon (DEW) systems have the potential to change the course of future conflicts – particularly when facing evolving conventional and unconventional threats, which are extremely agile and not easily detectable – where there is an emerging need for highly precise, targeted and agile weapon systems.

Laser-based DEW (LDEW) systems provide a cost-effective answer to all these capability needs. Nevertheless, in particular conditions (e.g. urban environments, protests and riots, public events), a surgical control of the collateral damages and preservation of human lives is of utmost importance.

In many of these scenarios traditional effectors are no longer employable while it could be more effective to make use of radio frequency directed energy weapons (RF DEW) to carry out attacks that are less-than-lethal and cheaper. One of the major advantages offered by such weapons is the reduced requirement for accuracy compared to many conventional weapons, such as artillery. The destructive energy of the weapon is delivered almost instantaneously, and many targets can be engaged at the same time.

However, the main limitation of RF DEW is that, unlike LASER, 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 from RF DEW attack, for example, armoured vehicles and ships

([216]) Advanced, Disruptive and Emerging QUAntum technologies for DEfense.
([217]) Quantum Secure Communication and Navigation for European Defence.
([218]) Advanced Networking with Quantum communications with Operational Relevance.

operating erratically or becoming completely inoperative, and aircraft falling out of the sky. Therefore, a deep knowledge on RF DEW lethality could also help identify the methods available to counter them.

Previous EU-funded research projects under the PADR, such as TALOS [219], and the ongoing EDF 2023 project, TALOS-TWO [220]. are paving the way towards designing and building an EU high-power laser effector. Once mature, it will to be integrated into military systems (air combat, naval, land or C-UAS). In parallel, the EDF's 2024 work programme is also implementing RF DEW research actions under the 'Air defence' category of action, as enabling technology for C-UAS effectors.

From this perspective, a topic addressing DEW is planned in the future, either focused on laser-based DEW (as per the 2023 follow-up) or RF techniques.

With the same approach, aimed, on one hand, to ensure adequate funds for promising techniques that enable innovative defence systems to be developed and, on the other, to provide consistency with the previous EU-funded research, the topic Over-the-horizon radars applications (2021 action's follow-up) could be considered in the future [221].

When using novel computational methods (AI), e.g.to design innovative materials for the above-mentioned topics/fields, consistency with other categories of actions will be ensured to avoid duplications.

In light of the above and in accordance with rules set out under the EDF Regulation stating that between 4-8% of the EDF budget must be dedicated to disruptive technologies, it is intended that the following be addressed every year:

- at least one thematic disruptive topic;
- one non-thematic call addressing disruptive technologies in any area of interest for defence (indicative lists of area of interest could be annually provided to guide the proposals towards development of concrete defence capabilities).

From a CDP point of view, main expected outcomes are aligned with the priorities for development of next generation combat systems for land, sea and air. In addition, development of other disruptive technologies including AI and quantum are referenced across a plethora of priorities.

(219) Tactical Advanced Laser Optical System.

(220) Tactical Advanced Laser Optical Systems: Technologies for High Power Laser, Vulnerability study, Vignette development and Operational Study.

(221) Further or different topics could be taken into account based on Member State inputs and/or the results of the actions carried out under the 'non-thematic' calls of the previous years.

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 (helping develop long range indirect fire capability);
- Prototype of directed energy weapons (helping develop innovative air combat, naval and land systems);
- Other disruptive technologies, including quantum, metamaterials and AI techniques for defence applications.