AIR DOMAIN TECHNOLOGICAL PRIORITIES OUTLOOK

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Aerospace, Security and Defence Industries Association of Europe | Rue du Trône 100 I 1050 Brussels, Belgium I T: +32 2 775 81 10 I
info@asd-europe.org I www.asd-europe.org

Aerospace, Security and Defence Industries Association of Europe | Rue du Trône 100 I 1050 Brussels, Belgium I T: +32 2 775 81 10 I
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EXECUTIVE SUMMARY

Unexpectedly isolated in an unstable geopolitical landscape, Europe is facing a wide spectrum of threats in all domains (air, sea, land, cyber, and space) as well as in the electromagnetic and informational fields. To safeguard its citizens and strategic interests, European nations must carefully ramp up their arsenals and defence capabilities.

Air dominance has consistently proven to be a decisive asset in modern conflict. Europe must make significant investments in its technological sovereignty, military capabilities, arsenal and defence infrastructure.

Europe's military aircraft industry is a globally competitive force, supported by a strong industrial base, institutional frameworks, and a commitment to strategic autonomy. Through cooperative programs led by the European Defence Agency (EDA) and financed through the European Defence Fund (EDF), the continent is not only preserving its existing capabilities but also laying the foundation for future air dominance. Sustained political commitment, funding continuity, and industrial alignment will be critical to consolidating and expanding Europe's role in the global military aviation landscape.

Capability investments must include the development of access denial strategies across all domains, with particular emphasis on integrated surface-to-air defence. Simultaneously, Europe must enhance its Suppression and Destruction of Enemy Air Defences (SEAD/DEAD) capabilities. Intelligence, Surveillance, and Reconnaissance (ISR) solutions also need to be deployed in all domains, while strike weaponry should be long-range, all-weather, sharp, and preferably connected to provide more agility.

Drones will play a pivotal role in SEAD, ISR, Anti-Access/Area Denial (A2AD), and deep strike missions. Therefore, counter-Uncrewed Aerial System (UAS) capabilities must also be addressed. Sensor technologies must become more advanced and collaborative, capable of generating large volumes of data that will have to be processed and secured, especially through the integration of Artificial Intelligence (AI).

Of course, the Air milieu will be more tightly integrated within Multi-Domain Operations (MDO), requiring seamless interoperability between systems, particularly among North Atlantic Treaty Organization (NATO) allies. Procuring equipment and systems made in the European Union (EU) will ensure compatibility with national defence policies and strategic autonomy. By securing the access to national markets within the EU, EU industries will remain self-reliable to innovate, develop, produce equipment and systems as well as taking business risks to ensure security of supply to their EU Member States (EU MS) customers.

This paper identifies eleven technical areas in which the European Defence Technological and Industrial Base (EDTIB) has got the potential to take up their part of those challenges and to propose

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to the EU MS state of the art, competitive and sustainable products and services. The priorities and required developments within each area are outlined below:

1. The analysis of **armament and air defence** highlights the critical importance of advanced weapon systems, air defence systems, collaborative combat integration, and the development of armament technologies. The interconnectivity of these elements underscores the need for a comprehensive approach to military capability development, supported by collaborative efforts among European nations. By addressing the functional requirements, priorities, and transversal issues associated with each subtopic, this analysis provides a roadmap for enhancing military effectiveness and ensuring security in an increasingly complex global landscape.

2. **Electromagnetic Spectrum Operations (EMSO) and Electronic Warfare (EW)** are essential for maintaining strategic and tactical superiority in modern military operations. EMSO encompasses all activities that involve the use of electromagnetic spectrum. The continuous evolution of EMSO and EW technologies is vital to counter emerging threats and maintain technological and operational superiority. With the increasing complexity and sophistication of adversarial tactics, there is a need for advanced EMSO and EW solutions that can adapt to changing battlefield conditions, ensuring the effectiveness of military operations.

3. It is fundamental to pave the way for a truly European Collaborative Air Combat capability, with the Combat Cloud as a key force multiplier. This involves bringing the **interoperability, integration and interaction** of different military assets, systems and platforms to new levels of operation, maximizing the exploitation of their sensors, effectors, and decision-making processes, and amplifying their combined effect. The result is tactical superiority by information and coordination superiority.

4. There is a wide range of development that Europe can tackle to push forward **EU Uncrewed Aerial Vehicles (UAVs) technological capability,** bypassing current constraints and limitation and increase their performance. While more traditional Militar Air domain capabilities rely on heavier industries, the UAV industry, and its value chain scope, can be an opportunity for European industry to strengthening their industrial complex, its resilience and scale, and reinforce Europe position as a military solution provider.

5. The **Next Generation Rotorcraft (NGR)** is a corner system in the air dominance. Future platforms will be required to be connected to the MDO environment, to increase their survivability, to improve their mission efficiency and adaptability to the various types of conflicts, to ensure crew workload reduction, and to remain affordable. New designs should take into account the life cycle requirements. Above all, the future platform will have to comply with a modular open system architecture to allow those specifications to be available.

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6. **New generation of Propulsion Systems for Air Platforms (fixed and rotary wings)** are needed to meet increasing electrical demand, with focus on improved power density and energy generation. The objective is to lay the foundation for new propulsion architectures and technologies, including next-generation turbofan, turboprop, and turboshaft engines, as well as fuel cell systems, noise reduction solutions, predictive maintenance tools, and integrated power systems for weapon platforms. These technologies must be specifically tailored to meet the military operational requirements of various aircraft types, ranging from air combat and military transport aircraft to rotorcraft, helicopters, and UAVs dedicated to reconnaissance and strike missions.

7. **Sensors** are linked to providing the necessary situation awareness and fire control to all types of air platforms. This includes functional and mission sensor suites. The objective is to ensure a European sovereign approach and solution to those capabilities to assure a strategic autonomy, the competitiveness of the EDTIB and the performing of defence assets.

8. To address the growing complexity of future air operations, the next-generation **cockpit technologies** will be essential to enhance situational awareness, reduce cognitive workload, enable faster and more informed decision-making and ensure mission effectiveness across both crewed and uncrewed platforms in increasingly complex MDO.

9. The last war operations showed that the geolocalisation of platforms and soldiers in contested and denied GNSS environment has become crucial to the operational superiority of the armed forces. **Positioning, Navigation and Timing (PNT)** encompasses all aspects linked to providing the necessary navigation system and technologies for any type of MADIG platform being crewed/uncrewed, rotary or fixed wings, including with swarming capacities. Specific efforts should be done to develop a European PNT system that includes state-of-the-art dedicated technologies and is adaptable to any air domain platforms.

10. The range of **systems required for military air platforms** spans from high-performance flight control actuation and electronics for next-generation combat aircraft to innovative hydraulic and electric power solutions for uncrewed aerial systems, tactical and strategic transport vehicles, medical evacuation (MEDEVAC) aircraft, military rotorcraft, drones, and smaller airborne platforms. Each of these requires specialized technical attributes tailored to their unique operational demands.

11. Effective **Modelling & Simulation (M&S)** offering to European armed forces require comprehensive approach, coordinated and cooperative development, and interoperable and secure networking technology solutions from European defence industry. Enablers are sovereign European frameworks and funding mechanisms to European industry for M&S technology development and production, common architecture-based development,

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info@asd-europe.org I www.asd-europe.org

interoperable data-centric technology and networking solutions based on existing and developing international standards. Well-functioning EU-NATO cooperation and supporting executive policy in EU institutions must prevail. It is highly recommended that Europe develop a comprehensive M&S industrial approach, and it is recommended to connect M&S into ongoing European defence capability development activities.

To ensure that Europe remains competitive and technologically on par with global powers in the critical field of military aircraft systems, greater efforts are needed. These efforts must focus on providing fundamental technologies, subsystems, and systems, while ensuring that these developments take place within a stable and resilient European supply chain. The resilience and efficiency of the supply chain will be ensured also by securing elements such as raw materials and electronics (components). The security of supply of those elements are mandatory if the Armed Forces want to also win the war of the digital transformation of the battlefield. AI, cyber and quantum are the next generation weapons of the battlefield. Defence stakeholders need to master them to ensure operational superiority. Finally, but not least, the industrial sector needs to focus its efforts on attracting and retaining well-trained employees. Innovation, development, and management of major defence programmes require specific high-level skills. Therefore, defence needs to remain an attractive sector. European cooperation, strategic alignment, and funding are essential. A holistic approach to the development of future military air platform systems is a key element of all national and European level.

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INTRODUCTION

About ASD and MADIG

ASD is the voice of European Aerospace, Security and Defence Industries. The association actively supports the competitive development of the sector in Europe and worldwide and represents overall more than 4,000 companies across 21 European countries. ASD members collectively employed 1,027,000 people and generated a turnover of €290.4 bn in 2023, accounting for 93% of the people employed, and 98% of the aerospace and defence industry's turnover within the EU Member States (MS).

Within ASD, the Military Air Domain Industrial Group (MADIG) works to enhance Europe's military air domain industry. MADIG focuses on contributing to a favourable policy and regulatory landscape by engaging with key institutions like the European Defence Agency (EDA), European Commission (EC), North Atlantic Treaty Organization (NATO), and national ministries of defence. It develops unified positions on EU policies, monitoring critical developments, and addressing challenges facing the military air sector.

References

The present paper summarizes the outcome of a series of discussions between MADIG and European Union (EU) institutional stakeholders. The EDA's air domain priorities and enablers outlined in the 2023 revision of the Capability Development Plan (CDP) and the Overarching Strategic Research Agenda (OSRA) have also been considered in the drafting process.

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TRENDS AND CHALLENGES

The strategic context is constantly evolving.

The post-Cold War world order is being widely contested, both politically regarding Western leadership and economically. The international situation is therefore highly unstable, and the risks of escalation into hard, violent confrontation are numerous and high.

Facing a wide spectrum of threats in all domains (air, sea, land, cyber and space) and in the electromagnetic and informational fields, Europe and its nations have to carefully ramp up their arsenals and capabilities to protect its citizens and strategic interests.

Lessons drawn from the main ongoing conflicts for the Air domain:

- **The need for combined and joint interoperability.** NATO is the only body with integrated combined command structures capable of planning, programming, and managing high-intensity operations against a major potential adversary. Conventional forces at the Alliance's disposal must be fully interoperable and of a high standard.
- **The development of access denial strategies in all domains.** Freedom of action is being strongly contested in all battlespaces on both the Ukrainian and Russian sides, particularly in the cyber domain, in space, in the electromagnetic spectrum, and in the air with the deployment of A2AD capabilities.
- **The importance of surface-to-air defence in a wider integrated air defence system.** Surface-to-air defences have shown that they are formidable in denying airspace, constraining air control and therefore overall freedom of military action. The extent of the threat to be dealt with in this type of conflict underlines the need for a multi-layered surface-to-air defence system, integrated into an extended air and missile defence system coordinated with fighter aircraft, and with a varied range of effectors, from very high-performance interceptor missiles to low-cost conventional or directed-energy weapons.
- **The importance of having SEAD/DEAD capabilities.** To control the air, you have to control both the enemy's fighters and the enemy's surface-to-air capability. The latter underlines the importance of having SEAD/DEAD capabilities.
- **Battlefied transparency: agility and the predominant role of ISR in an increasingly short decision-making timeline.** Necessity to know, perceive, analyse, decide, and command in a decision-making tempo that is faster than that of the adversary. The role of space or stand-off airborne detection is predominant in a theatre.

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- **The need for all-weather remote precision strike capability.** The Russian aggression in Ukraine shows the need to increase the effectiveness of ammunition for both operational and logistical reasons. The conflict has also shown the importance of long-range to limit the loss of life, preserve troop morale and thus increase their ability to endure.

- **AI and digitalization of the battlespace.** The amount of data produced and exchanged on the battlespace has become enormous and keeps rising exponentially, opening the door to the introduction of AI algorithms in every step of every mission. AI, cognition, data, digital and cyber technologies have the potential to become a cornerstone for any military arsenal to prevail in warfighting in all domains of future warfare.

- **The importance of drones and counter UAV systems, especially in air-to-ground combat on the front line.** The growing importance of small, fairly rudimentary drones or robotic extensions, often derived from the civilian world and adapted at low cost with acceptance of heavy losses, for risky air-to-land surveillance and reconnaissance missions and opportunistic strikes and combat on the front line (aerial contact drones, remotely operated munitions). Facing these threats, new technologies are emerging to detect, track, and mitigate unauthorized or rogue drones, including the use of machine learning algorithms.

- **The eternal dilemma between quality and quantity.** Better to have both, but Western technology has shown its effectiveness with anti-tank missiles, ground-to-air missiles, intelligence provided by the West (space, airborne early warning, other), anti-radar missiles, long-range precision weapons (cruise missiles, High Mobility Artillery Rocket System or HIMARS) and ground-to-air batteries.

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KEY CAPABILITIES

The European defence industry occupies a leading position in the global military aviation sector, underpinned by world-class technological capabilities, a robust industrial ecosystem, and a strong policy framework supporting defence cooperation and innovation. As the EU advances its ambitions for strategic autonomy and operational readiness, the military aircraft domain remains a cornerstone of its defence and security positioning. Key institutional mechanisms, particularly the EDA and the EDF, play a vital role in consolidating capabilities, addressing fragmentation, and enhancing interoperability across MS.

Strategic and industrial strengths

1. European aerospace champions and platforms

Europe's military aviation industry is anchored by major prime contractors, and these companies lead complex programmes including the Eurofighter Typhoon, Rafale, Gripen, and A400M Atlas well as rotary wings platforms from Airbus and Leonardo such as Tigre and NH 90, demonstrating Europe's ability to deliver highly capable, exportable, and interoperable platforms across the spectrum of air operations. The presence of a wide network of highly specialized SMEs and mid-tier suppliers reinforces supply chain resilience and technological depth.

2. Technological superiority and innovation ecosystem

Europe remains at the forefront of aerospace innovation, particularly in critical domains such as digital avionics, radar and EW systems, AI-enabled mission systems, stealth design, connectivity and propulsion. Emerging technological areas, such as autonomous systems, combat cloud integration, and next-generation crewed-uncrewed teaming, are being actively pursued in both national and cooperative programmes. Dual-use R&D and synergies with the civil aviation sector strengthen Europe's long-term competitiveness. To ensure that Europe remains competitive and technologically on par with these global powers in the critical field of military aircraft systems, greater efforts are needed. These efforts must focus on providing fundamental technologies, subsystems, and systems, while ensuring that these developments take place within a stable and resilient European supply chain.

3. Export leadership and international partnerships

European military aircraft are actively deployed by NATO allies and global partners, ensuring wide operational reach and industrial return. European platforms are frequently selected for their performance, lifecycle value, and interoperability, reinforcing the continent's role as a reliable and strategic defence partner.

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4. <u>Operational interoperability and training</u>

Through initiatives such as multinational fleet integration, joint training, and harmonized certification, Europe fosters high degrees of interoperability among its air forces. Programmes like the European Air Transport Command (EATC) and pooled air-to-air refuelling assets improve force projection and resilience in multinational operations.

Capacity and institutional coordination

Europe's defence industrial base benefits from a continent-wide supply chain, advanced testing and certification infrastructure, and state-backed innovation support. However, fragmentation and duplication have historically limited economies of scale and coherence in capability development.

To address this, EU institutions have increasingly promoted collaborative frameworks, pooling of resources, and cross-border cooperation to achieve greater strategic coherence and industrial efficiency.

More matured European Defence Institutions and expansion of Support Mechanisms

European defence institutions, most notably the EDA and Directorate-General for Defence Industry and Space (DG DEFIS), aim at gaining increased capacity and agility to coordinate multinational defence initiatives. In parallel, the EU will introduce a broader and more diverse set of instruments to finance and support defence capability development, such as EDF, the Security Action for Europe (SAFE) and the proposed European Defence Industry Programme (EDIP). Together, these developments mark a strategic shift towards a more cohesive and autonomous EDTIB.

Conclusion

The European defence industry's capabilities in the military aircraft sector are globally competitive and technologically advanced. With strong institutional support through the EDA and EDF, the EU is well-positioned to shape the next generation of air power. Strategic investment, cooperative development, and coherent policy direction are essential to maintaining Europe's leadership in this domain and ensuring the continent's long-term security and defence resilience.

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GLOBAL RISKS TO OUR INDUSTRIAL CAPACITY

The air domain is facing numerous challenges to perform the expected missions. Out of those, ASD considers that some risks require specific urgent actions. That is the case for:

- security of supply of raw materials,
- security of supply of electronics components,
- challenge of the digital transformation of the operational theatres,
- attraction and retention of well-trained employees.

Raw materials

The supply of raw materials has always been a challenge for the defence sector, especially for the air domain. Titanium and Germanium are some examples of raw materials for which the EU defence industry is largely in shortage and rely on almost solely non-EU suppliers.

The Critical Raw Materials (CRM) Act, adopted in 2022, identified all those substances as critical for the EU industry. The solutions that are proposed do not fully satisfy the defence sector: in case of crisis or need for production ramp up, there is no guarantee that the suppliers will continue to sell to the EU defence sector. EU industry needs to find other means to ensure its supply: recycling, managing leftovers, … The support of European commission will be necessary to accompany the EU industry in this change.

Electronic components

For decades now, electronic components have been included in all currently available defence equipment and systems, whose latest design have experienced an increase of such embedded components. Air domain is certainly one of the most concerned domains in this aspect. The supply of electronic components has always been a challenge for the purchasing departments of the EU defence industry.

The COVID-19 pandemic has revealed and increased this issue, due to the cessation of transactions and freight. The shortage of electronic components impacted all sectors, but in the case of the defence sector, it could have spillover effects in the capacity of a MS to defend itself against an aggression.

Further, the defence sector accumulates difficulties linked to its specificities:

- Quantities needed. The overall demand of the defence sector represents a small part of the overall demand of the combined sectors.
- Requirements. The design requested by the defense sector is different from the mainstream request of larger sectors such as the automotive industry.

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The United States (US) has adopted a US Chip Act which support the relocalisation of chips producers on US ground. By adopting the EU Chip Act in 2022, MS have enacted rules in case of crisis, and the supply to the defence industry would become priority. Nevertheless, the EU Chip Act lacks incentives in regards of long-term perspective where EU foundries are needed to secure the supply. Considering that most foundries are found in Taiwan, the current geopolitical situation puts the EU defence sector at risk.

Digital

Following the digitalization of the air domain equipment and the progress of communication technologies, ground and airborne systems generate a very large amount of data, that need to be stored and protected, processed, and distributed. The EU is lagging behind the US, Russia and China in digital technologies that are pivotal to its sovereignty, including AI, cloud and cybersecurity. Data-driven approach to maintenance helps to reduce unplanned downtime, optimize repair schedules, and extend the service life of critical components.

More details can be obtained from the Digital Transformation Commission.

Human resources

Through the project ASSET+, the list of critical expertise for defence engineering is known to the community. The focus of the project was on AI, robotics and autonomous vehicles, cybersecurity domain and the Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance (C4ISTAR) domain. More than 210 job profiles have been identified as relevant to be included in the design of educational training activities. Public authorities and private entities have the possibility to refer to the outcome of this study and its recommendations, thus being in the public domain.

Nevertheless, such in depth work has not been done for the technicians and specialized workers which are essential categories of employees for the industry to be able to innovate, develop, manufacture and repair equipment and systems. European Commission (EC) should, as it was done for engineers, investigate ways to encourage, incentivize and train young adults to work for the defence sector and ensure that the private sector becomes more attractive and able to welcome them in such a way that they will remain in the sector.

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TOPICS' PRIORITIES

The complexity of the air domain and the necessary complementarity with other activities run within ASD obliges to structure the sector according to several topics that were considered as relevant. The topics have been defined in accordance with the EDA 2023 Capability Development Priorities in air combat, air superiority and enablers categories. The objectives are to identify priorities that should be considered by the institutional stakeholders. These include MS, EU institutions such as the EC and EDA, or NATO for either capability priorities definition or funding. Further to areas related to systems, the areas cover either equipment and sub-equipment (propulsion, armament and air defence, sensors, cockpit technologies and military air platform systems and subsystems) or capacities (PNT, simulation, interoperability and EMSO).

Armaments and Air Defence

The field of armament and air defence is undergoing a transformative evolution driven by technological advancements, geopolitical dynamics, and the necessity for enhanced security measures. Armaments and Air Defence consist of advanced weapon systems, air defence systems, collaborative combat integration, and the development of armament and defence technologies. Integration of these elements is essential for maintaining operational superiority in MDO and ensuring effective deterrence against emerging threats.

Capabilities

1. Advanced weapon systems

Advanced weapon systems are crucial for modern military operations, enhancing precision, survivability, and response capabilities. Key developments include Autonomous Launch Enhancement (ALE), Precision-Guided Missiles and Munitions (PG2M), Hypersonic Weapons, Directed Energy Weapons (DEWs), Stealth and Counter-Stealth, and UAV/UCAV armament systems. These technologies are essential for countering emerging threats and maintaining strategic advantages.

To strengthen European defence autonomy, investments should be made in hypersonic and DEW technologies through flagship projects. Collaborative R&D among European nations should be enhanced, focusing on missile and UAV advancements. Identified capability gaps in NATO Industrial Advisory Group (NIAG)'s studies should be addressed, particularly in hypersonic defence and AI-driven missile guidance. Joint procurement initiatives should be leveraged to facilitate technology-sharing and joint development. Procurement of sovereign European systems for medium and long-range air and missile defence should be privileged to reinforce autonomy.

2. Air Defence Systems

The evolving threat landscape, highlighted by the war in Ukraine, has underscored the need for robust air defence systems. The modernization of missile defence, integrated air defence systems (IADS), counter-UAS solutions, and advanced radars is essential for ensuring European security.

Addressing capability gaps in European missile defence requires investment in multi-layered air defence. AI-driven enhancements in radar detection and cooperative engagement systems must be prioritized. Domestic production of missile interceptors should be bolstered to enhance European autonomy

3. Collaborative Combat & MDO

The future of warfare relies on seamless coordination between air, land, sea, cyber, and space domains. MDO enhance real-time situational awareness, interoperability and decision-making, crucial for NATO's collective defence strategy.

AI-enhanced ISR and decision-support systems should be prioritized for multi-domain integration. Secure communications must be reinforced through quantum encryption to protect against cyber threats. Cross-national training initiatives should be established to ensure seamless coordination in joint operations.

4. Armament and Defence Technology Development

Breakthroughs in AI, materials science, propulsion, and autonomous systems are shaping the next generation of military technologies. These innovations are key to improving European military readiness and response capabilities.

AI should be integrated into missile guidance for enhanced precision as well as in Command and Control (C2) for augmented surveillance and control. Investment in composite materials must be prioritized to increase durability. Sustainable propulsion development should focus on hybrid and cryogenic fuel systems. Autonomy in weapon engagement should align with NATO frameworks to ensure interoperability.

Priorities to address

1. Priorities in Armaments and Advanced Weapon Systems

The urgency of modern conflicts, such as in Ukraine, highlights the need for resilient, interoperable air and missile defence systems. Priorities include next-generation PGMs, hypersonic missiles, and DEWs to counter evolving threats, particularly from adversaries like Russia. Clear development timelines are essential for maintaining NATO’s strategic edge.

Advancing European weapon systems and armaments require alignment with strategic frameworks like the Permanent Structured Cooperation (PESCO) framework, the EDF, the CDP, the Key Strategic Activities (KSA), and the CapTechs, fostering joint development and procurement. Integrating AI and machine learning is crucial for enhancing decision-making and operational efficiency. Collaboration through the EDA and NIAG studies ensures efficient capability development.

2. Priorities in Air Defence and Multi-Domain Operations

Key priorities include integrating AI and machine learning to improve decision-making and operational efficiency, alongside advancing radar technologies and systems (i.e. sensors, data link) integration for superior detection and tracking. The development of integrated air and missile defence systems capable of countering emerging threats, particularly from adversaries like Russia, is critical.

Clear development timelines are necessary to ensure NATO's rapid responsiveness to evolving threats. Through multinational cooperation and technological innovation, European defence forces can achieve enhanced combat effectiveness and resilience.

Enhancing air defence within MDO requires interoperability, joint training, and standardized protocols aligned with strategic frameworks like PESCO, CDP, KSA, CapTechs, and NIAG studies. Collaborative procurement and technology sharing among European nations are essential for strengthening collective defence.

Electromagnetic Spectrum Management, EMSO, Countering EW

EMSO and EW are essential for maintaining strategic and tactical superiority in modern military operations. The effective management of the electromagnetic spectrum is crucial for ensuring that military forces can achieve and maintain spectrum superiority and dominance. EMSO encompasses all activities that involve the use of electromagnetic spectrum during pre-mission, post-mission and the execution of the mission to gain and maintain operational effectiveness, freedom of manoeuvre and resilience in complex environments.

The aim is to contribute to various aspects of Electromagnetic Spectrum Management, EMSO and EW related to all kinds of military aerial platforms, both legacy and new. The scope particularly includes multiple technologies and areas.

These items are crucial for ensuring effective performance and operational superiority in increasingly contested and technologically sophisticated environments. The development and integration of these technologies will enable military air forces to maintain tactical advantage, gain and maintain enhanced mission effectiveness, ensure the safety and security of operations across the electromagnetic spectrum.

- Provide a reliable and trustable European portfolio of EMS management, EMSO and EW tools.
- Secure European systems compliance with NATO related standards.
- Integrate benefits from related ongoing European development projects such as EDF.

Capabilities

1. Spectrum Monitoring and Management Tools

By continuously monitoring the spectrum, operators can detect interference, unauthorized usage, potential threats, ensuring mission critical systems remain operational and resilient. Spectrum Management tools, such as frequency allocation software, signal analysis, real time spectrum analyser, play a crucial role in optimizing spectrum usage. These tools enable planners and operators to deconflict frequencies, mitigate interference, enhance situational awareness ensuring seamless coordination and operational superiority in the electromagnetic domain.

2. Signal Intelligence (SIGINT) And Electronic Support Measures (ESM)

SIGINT and ESM activities in air domain must enhance situational awareness, support mission planning and enable effective decision making in contested environments. SIGINT focuses on intercepting, analysing and exploiting enemy communication and radar emission to gather critical intelligence on adversary capabilities, intentions and locations. ESM, as a subset of EMSO, involves detecting, identifying and geolocating electromagnetic signals to provide real time threat warnings and facilitate countermeasure deployment.

3. Electronic Protection (EP) Solutions (Technologies and Methods) Against Adversary's Electronic Attacks

Among many objectives of EP solutions in air domain, safeguarding friendly system from adversary electronic attacks and ensure the integrity and effectiveness of critical mission is a top priority. EP technologies and methods focus on mitigating the effects of jamming, spoofing and other electromagnetic interference. Some of the solution include, frequency hopping, spread spectrum techniques, adaptive filtering, advanced encryption protocols which enhance resilience of avionics system. Additionally, modern EP integrates cognitive electromagnetic warfare system that leverage artificial intelligence to detect and counter evolving electronic threats in real time.

4. Electromagnetic Attack and Countermeasures, including collaborative jamming, stand-off jamming, stand-in jamming, escort jamming and decoys

The objective of electromagnetic attacks in the air domain is to degrade, deny, disrupt or deceive an adversary's use of electromagnetic spectrum, thereby reducing their operational effectiveness and gaining a tactical advantage. Collaborative Jamming leverages multiple platforms working in unison to create a more effective and adaptable interference strategy. Stand Off jamming involves deploying jamming assets at a safe distance from enemy defences, while stand-in jamming uses assets positioned closer to the target, often employing low observable or uncrewed system to penetrate contested areas. Escort jamming accompanies strike or force protection packages protecting them by neutralizing enemy radars and communication systems. Finally, decoys and deceptive techniques aim to confuse or mislead adversary sensors, drawing attention away from high value assets.

5. Cyber-Electromagnetic Activities (CEMA)

CEMA combines and synchronises cyber operations, EW and spectrum management to disrupt, degrade or exploit adversary system while protecting friendly assets. This includes conducting offensive cyber operations to compromise adversary networks, leveraging electromagnetic attacks to deny or manipulate enemy use of the spectrum and employing EP to ensure resilience of friendly system. Additionally, spectrum management ensures efficient allocation and deconfliction of electromagnetic resources across coalition forces.

6. Integrated EW Self-Protection Systems (including sensors and effectors) for Threat Detection, Classification, Discrimination and Identification, and Reaction against those Threats

Integrated EW Self Protection System must ensure the survivability of airborne platforms by detecting, classifying, discriminating, and reacting to threats in real time. These systems incorporate a network of advanced sensors (i.e. RWR, MAWS, LWS) and effectors (i.e. chaff, flares, DIRCM, jammer) to provide comprehensive protection against radar guided, infrared and other type of threats. Once a threat is identified, the system classifies and discriminate the nature and allowing a tailored response. Integrated processing unit, such as EMSO MANAGER, coordinate all these components to enable rapid and automated reactions, ensuring seamless protection in high threat environment.

7. Collaborative EW engagement for ESM and Electronic Countermeasures (ECM)

EW engagement that includes the use of ESM and ECM must be able to enhance operational effectiveness by leveraging the coordinated action of multiple platforms in the electromagnetic spectrum. Collaborative ESM involves distributed sensing and data sharing among platforms to provide a comprehensive picture of EM environment enabling an accurate threat detection, classification, and geolocation. This shared situational awareness allows for precise targeting of adversary systems. Collaborative ECM focus on synchronized jamming and deception techniques utilizing multiple assets to overwhelm or confuse enemy sensors and communications. By employing technique such as Network Jamming, adaptive interference and coordinate decoy deployment, collaborative EW maximize the impact of countermeasures while reducing individual platform exposure.

8. AI and Machine Learning (ML) applied to previous items

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AI and ML enable advanced threat detection, classification, and prediction by analysing vast amount of sensor and environmental data at high speed. In spectrum monitoring and management these technologies optimize frequency allocation and interference mitigation, while SIGINT and ESM improve the accuracy of signal analysis and threat geolocation. For EP, AI algorithm enhances resilience by dynamically countering adversary electronic attacks and adapting to new tactics. In electronic attack operations, AI and ML facilitate smarter collaboration, optimize decoy deployment, and improve synchronization among platforms. Similarly, integrated self-protection system, such as EMSO MANAGER, benefit from AI powered automation to ensure faster and more precise response.

9. <u>EW Ground Support Systems for Programming, Data Management and Data Exploitation during all phases of the mission</u>

Prior to a mission EW ground is used to program on board EW systems, including threats libraries, jammer configurations and countermeasure profiles ensuring they are tailored to the specific operational environment and anticipated threats. During the mission, ground equipment should in the future facilitate real time monitoring and data exchange, enabling mission planner to adjust EW parameters as needed based on changing of threats. Post mission the equipment is used for data exploitation, including analysing recorded electromagnetic spectrum activity, evaluating the effectiveness of EW operation and update database.

Priorities to address

1. <u>EMSO manager</u>

In modern warfare all EW equipment raw data from each single equipment need to be elaborated to generate valuable information that may be used in the cockpit supporting decision making and problem-solving process. This level of understanding must be at EMSO level that is able to recognize how to generate valuable information starting from raw data coming from on board and offboard platform.

2. <u>Advanced AI and ML</u>

AI and ML are the technologies that are able to elaborate a great amount of data compared to the human brain. For this reason, thanks to the capability to share information coming from different platform, AI\ML would be able to generate valuable information that the operator will never be able to understand. The ability to understand connection among raw data would also provide valuable information about adversary’s tactics, techniques and procedures.

3. <u>Capability lab</u>

Technologies and equipment cannot provide the capability alone. A capability lab is the core where all the test and development take place. Because the threat will continue to evolve at higher speed in

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the next future, also the capabilities need to evolve very fast and the only way to match the phase is to plan and develop in advance.

Interoperability, integration and connectivity in an MDO environment

Interoperability, integration and connectivity focus is to contribute to advancing aspects of the air domain's compatibility, communication, and collaboration capabilities. This is crucial for integrating diverse systems and platforms in MDO, covering all kinds of air force assets, including both crewed and uncrewed aerial platforms from fixed or rotary-wing to single and UAV swarms or missiles. Short and long-term operational needs are considered and the full potential of new disruptive solutions, such as Combat Cloud**,** are to be boosted as Collaborative Combat multipliers**.**

Capabilities

1. <u>European Collaborative (AIR) Combat Capability</u>

It is fundamental to pave the way for a truly networked, European Collaborative (AIR) Combat capability, to create a unified defence capability that can multiply the response to emerging threats and ever-growing complexity. The aim is to improve the interoperability, integration and interaction among military assets, systems and platforms (new and legacy, crewed and uncrewed) to new levels of operation and to all domains, achieving MDO. Connectivity between man and uncrewed platforms at the tactical level will be key for success of the missions though not enough. By enabling seamless interoperability, secure data-sharing, and synchronized mission execution, European air forces can boost the exploitation of their sensors, effectors, and decision-making processes and maximize their combined effect. This fosters situational awareness and leads to tactical superiority by information and coordination superiority. Capability will support the "plug and fight" concept for Member State's Armed Forces.

Related initiatives in consideration:

- EU standard for Collaborative Air Combat (considering MDO), establishing architecture common principles, standardized functional interfaces, and data formats, boosting Combat Cloud as a Collaborative Combat multiplier.
- Alignment of the different EU Collaborative Combat Initiatives performed so far in the different domains, establishing common principles to assure interoperability among them.
- Completing running EU initiatives such as EDFs related to Collaborative Air Combat (i.e. EICACS) and Collaborative Services in Cloud environments (i.e. EDOCC).
- Supporting the development of new-gen technologies, including new advanced tactical data links.

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- Incremental interoperability approach that allows for progressive adoption at EU level, including this kind of requirements in EU and national procurement processes.

The scope includes multiple **technologies and different initiatives in consideration to be promoted**:

1. Combat Cloud applied to the defence sector

The definition of a European Basic Reference Architecture for Combat Cloud, taken as reference for all domains (MDO). Evolution of existing standards and development & consolidation of new ones. Alignment of the different Combat Cloud Initiatives at EU level. Collaborative Combat Governance: New International initiative for the definition and maintenance of Collaborative Combat and Clouds federation standards, cross systems interoperability testing and collaborative combat services ecosystem management. Development of European Security, enabling European autonomy in those aspects, including security architecture and protocols, algorithms, keys and all their management. Promotion of a Combat Cloud federation framework to enable effective multi-nation MDO operations, ensuring secure, resilient, and sovereign interoperability among national Combat Cloud based Command, Control, Communication, Computing, Cyber, Combat and Intelligence (C6I) systems.

2. Innovative Defence Architectures and Battle Management Command, Control, Communication, Computing, Cyber, Combat and Intelligence (BMC6I)

As keystone of the information and coordination superiority, there must be a continuous evolution of BMC6I systems to face the evolving threats and needs, and ready to coordinate operations with all types of either independently or in cooperation with NATO. C6I systems play a fundamental role in the decision-making process by providing accurate and timely data to support military leaders to assess situations, plan strategies, and make informed decisions efficiently. It is crucial to drive and encourage the Incremental transition to Combat Cloud, as the new paradigm, multiplying the Collaborative Combat and C6I capabilities amongst force assets during conflict situations at all warfare levels (strategic, operational and tactical). Complementary, development and adoption of Cloud infrastructure and services for EU collaboration at different levels.

3. Next Generation Secured Communications and Data Link

A new paradigm in military tactical communications is emerging, driven by advanced technologies and the increasing demand for more secure, efficient, and resilient systems to face new threats. Legacy communications systems are insufficient for handling future dynamic and contested environments. next-generation communications are required to provide discrete, secure, high-bandwidth, and resilient communications. These features are the backbone to support interoperability over different domains (MDO), enabling real-time information sharing across domains, including space connectivity for air combat.

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- ⇨ Promotion of EU certified and combat-proven standards for tactical communications and radio interoperability, including EU joint procurement initiatives; Advancing towards new air interfaces for Line-of-Sight (LOS) tactical communications (i.e. standardized waveforms) to complement legacy concepts (i.e. radiated Link 16); Integration of artificial intelligence to optimize real-time network management. Advance the application and integration of the fifth and sixth generations of cellular network technologies (5G/6G) in the military domain; Standardization of interfaces between the different networks and communication technologies to enable interoperability; and Complete running EU initiatives such as EDFs like European Protected Waveform are in consideration. Promotion and use of new satellite secure communications constellations as the Infrastructure for Resilience, Interconnectivity and Security by Satellite (IRIS2) conceived for supporting defence operations anywhere providing low latency and high data bandwidth connections for star and mesh network topologies while assuring multidomain interoperability among connected assets.

4. <u>Built-in AI & AI-aided Command, Control, Communications, Computers, Collaboration and Intelligence (C5I) Smart Decision Support Services</u>

AI has the potential to revolutionize defence by providing advanced analysis and decision-making capabilities to foster the overall Observe, Orient, Decide, and Act (OODA) loop at the different warfare levels, from strategic to tactical one. Supporting the application of AI technologies in different EU initiatives and projects, including motivation R&D investments and adoption of AI-solutions, ensuring European autonomy.

- ⇨ AI-integration throughout the different levels of the Combat Cloud stack, development of new generation of C2 Services integrating AI, AI technologies for control execution with autonomous systems and for crewed-uncrewed systems coordination and collaboration, Resilient Battle Command protocols for multi-agent system and associated protocols in modern operations, Distributed agreement and argumentation protocols for Forward Edge Battle systems real time coordination in intense EW conditions.

5. <u>Cybersecurity and Cyberdefence integration</u>

Cyber threats are the top risk in connected, AI-driven, and cloud-enabled military environments. MDO will rely on secure networks, protected data, and resilience against cyber warfare. Cybersecurity is a top priority to protect interconnected systems and key element to ensure mission continuity, protecting sensitive data, and preventing enemy infiltration into C2 systems. Data centric approach and dynamic zero-trust security should be considered for protecting sensitive information and ensuring the integrity of critical operations. Cybersecurity capabilities in the air domain, including combined decision-making management between kinetic (tactic) and non-kinetic (cyber) domains, platforms seamless integration with cyber defence capabilities and built-in data multilevel security.

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6. Computing and networking technologies, edge avionics

Decentralized processing and edge computing are crucial to handling the vast amount of real-time data generated in combat without overloading central networks. Implementing advanced computing for real time, embedded technologies, and networking technologies, including edge avionics are essential for improving processing capacity and real-time connectivity on the battlefield, enabling more efficient and effective battlefield operation.

⇨ Application and use of advanced technologies (Software Defined Radio (SDR) and AI on Field-Programmable Gate Arrays (FPGAs), Graphics Processing Units (GPUs), Neural Processing Units (NPUs), or next-generation processors) for enhancing processing capacity and real-time connectivity on the battlefield. Analysis, design and development of platform-customized edge computing solutions required to operate within the most demanding conditions, including Denied, Disrupted, Intermittent and Limited (D2IL) environments.

Use of UAVs, including Vertical Take-Off and Landing (VTOL)

The use of UAVs constitutes a significant aspect of advancing European air domain capabilities and strengthening the EDTIB, as well as the European sovereignty. Technology now supports the expansion of UAV deployments to multiple combined systems, from a few systems to a predictably large number of heterogeneous UAV units, which can change the state of combat and defence strategy and tactics. Such a level of technology and its democratization in a military combat scenario, as seen in recent times, accelerates the development and innovation, shortens the time from lab to operational engagement and makes UAVs a critical tool for disrupting conventional tactics thus playing a crucial role in the military air and air-to-land domain.

Within MADIG, the focus on UAV falls in the UAV of classes I and II up to 1.5 tons, and provides all necessary sub-systems of Class III systems.

The utilisation of UAVs encompasses a broad spectrum of applications, including but not limited to air combat operations, armed overwatch, persistent surveillance, transportation, decoy, air-to-air refuelling, single or multiple cooperative system or swarms and MUM-T capability. Dual-use UAV capabilities and technologies are also of relevance.

Capabilities

1. Autonomous Collaborative Operation

Developing and refining autonomous capabilities in UAVs or a combination of jointly coordinated aerial platforms (swarms, teaming) to enable efficient and safe operation without constant human intervention, such as obstacle detection and avoidance, navigation in complex environments, automatic flight path planning, and real-time decision-making algorithms for mission execution including Human-in-the-Loop (HITL) rules.

An important and essential part of autonomous operation is the reliable position determination of the UAV for the onboard flight control. AI based aerial recognition based on Electro-Optical and IR sensors or any other fully independent means of position determination shall be evaluated and tested. This goal incorporates also the capabilities of UAVs to operate in concert with other air vehicles, crewed or uncrewed.

2. Communication and Data Connectivity

Enhancing communication systems and data connectivity to ensure reliable and secure transmission of information between UAVs and ground control stations, and between the UAVs of a swarm, addressing challenges such as bandwidth limitations, signal interference, jamming/spoofing and cybersecurity threats. Platform independent standards shall be harmonized and established based on high processing capabilities of future onboard systems.

3. Payload Integration

Addresses multiple purposes. Firstly, facilitating the integration of diverse and multiple payloads onto UAV platforms, including sensors; cameras; radar systems; sense and avoid; identification, friend or foe (IFF); EW, Automatic Identification System (AIS); communication systems, or refuelling capability pods, while optimizing weight distribution, power consumption, and operational effectiveness. Future combinations of multiple payload and sensor configuration shall be studied and evaluated. Particular attention shall be directed to payloads and sensors providing onboard pre-processing capabilities of multiple sensors to extract the necessary information onboard the UAV out of the high data volume.

Secondly, "Resilient navigation" (including PNT but also navigation and other techniques) especially independent of external signals (i.e. GNSS, data link, reference signals) supported on payloads which should be integrated into the drone system; Fusion of onboard platform sensors with payload sensors shall be evaluated for resilient position determination, also based on future AI capabilities.

Lastly, armament integration and its security aspects, should be assessed and particularly on the arming/disarming of the military payload, fire control, precision, man in the loop (when required), etc

4. Airspace Integration and Traffic Management

Developing solutions for the safe and efficient integration of UAVs and swarms into crewed airspace, including collision avoidance systems, air traffic management protocols, and cooperative surveillance technologies to prevent conflicts and ensure airspace deconfliction.

5. Environmental Considerations

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Addressing environmental concerns associated with UAV operations through the adoption of quieter propulsion systems, energy-efficient designs, and environmentally sustainable practices. New methods of radar cross section management as well as thermal cross section management shall be evaluated.

6. Scalability and Interoperability

Designing UAV systems that are scalable and interoperable with existing infrastructure and platforms, enabling seamless integration into broader defence and civilian networks, interoperability with allied forces, and compatibility with diverse mission requirements in an integration shared C2 and payload data environment hosting UAS as well as UAS teaming with multi-domain crewed platforms.

7. Operational resilience

Encompasses the sustainability, reliability and support of the UAVs embedded in the operational capacity, Firstly, to enhance redundancy and reliability in UAV systems to mitigate the risk of single-point failures and ensure mission continuity in challenging environments or adverse conditions. Secondly, to establish robust maintenance and operational support frameworks to ensure the long-term sustainability of the UAV operations. Lastly, to sustain a quicker and safer update or upgrade of the UAS system as a response to a fast-changing technological environment.

8. Verification and Certification

Development of standardized testing and certification procedures for UAVs and swarms should be done to validate performance, safety, and compliance with regulatory requirements, ensuring that UAV systems meet stringent standards for airworthiness and operational readiness. Moreover, develop testing and certification frameworks that support a time reduction of the UAS certification processes and, when relevant, alignment with civilian standards and processes.

9. Commonality and interoperability with topics of interest

In the coming years, UAVs will become the most used air vehicle as the main platform in aviation and will be utilized at every level of airspace. This situation necessitates direct interaction with almost all topics within the scope of the MADIG study.

10. AI

AI will power UAV to deliver new applications or supporting the conception and design of new UAV configuration. Such developments will promote more effective operations, by more efficiently and automated onboard processing of multiple sensor data and extracting intel to be spread through the data link(s). AI can support mission deployment optimization, designing solution that fit the available capacities, as well as assist in other areas, such as maintenance and logistics. On a tactical level, AI

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may be used to support the coordination of multiple combined UAS system and their mission adaptation to the changing condition of the tactical scenario.

In the battlefield, AI could be used to enhance the decision-making process and to automatize its decision chains, maintaining HITL for the kill chain.

Finally, within this capability is included the technology and industry ecosystem and infrastructures required to promote the fast development of AI solution by EU.

11. <u>Survivability</u>

Develop solutions that improve UAV platform's ability to survive, as well as the optimal survivability of swarms in contested or hostile environments. This includes low detectability solutions (small size, low signatures, stealth capabilities), high susceptibility (high manoeuvrability, adaptive flight paths to avoid being hit, countermeasures), reduced vulnerability (resistance to impacts, kinetic forces, electromagnetic interference), and improved recoverability (ability to recover from damage or impacts).

12. <u>Propulsion and Power Generation</u>

Study and evaluation of modernization or new product and technologies introduction regarding more reliable and safer, lighter, powerful, efficient and environmentally friendly aero engines.

13. <u>Counter-UAS</u>

Development of continuous counter measures to tackle the threat posed by UAS systems, it covers the traditional target phases, from detection and alert of UAV to its tracking, classification, identification, to effectors to eliminate, deter, limit impact, avoid or escape UAVs threats. It may cover different technologies from radar to observation and tracking technology as well as a multiple number of responses type such as kinematics effectors, Radio Frequency or navigation interference, spoofing of navigation data, take control over UAV, or UAS sensors interference. The nature and capacity of the counter UAS is linked to the UAS configuration, type and characteristics.

Priorities to address

1. <u>Collaboration</u>

   - Increase UAS cooperation and collaborative models for joint decision-making processes toward higher autonomy.
   - Establish a robust interoperability model or concept to support joint operation of heterogeneous and evolving UAS.
   - Improve AI models to support multiple UAS mission configuration.

- Develop the use of AI solutions combined with a crewed-uncrewed interface to operate multiple UAVs.

2. <u>Resilience</u>

   - Flight navigation in denied information conditions (GPS denied, communications denied, onboard sensor degraded, magnetic interference).
   - Increase survivability and resilience of UAS.

3. <u>Other</u>

   - Support the generation of infrastructures that can support the faster development and testing of UAS.
   - Improve tool kit solution for counter UAS.
   - Develop smaller and high performing propulsion system to increase the smaller UAS speed and versatility.
   - Improve UAS system model and architecture to support a faster pace of technology evolution while supporting integration into a multi-platforms multi domain operational environment.
   - Develop more effective training methods for UAS sensor operator data interpretation and UAS operator proficiency in the design of UAS missions.

New Generation Rotorcraft System

Lessons from the War

The lessons learned from the Ukrainian war have challenged the conventional use of helicopters on the battlefield. The survivability and connectivity of helicopters are the main drivers behind the transformation of their operational use.

- Enhanced Anti-Access/Area Denial (A2/AD) in the aerial domain, particularly at low altitudes, coupled with the presence of medium-altitude attack drones operating in the same environment as helicopters, has made them much more vulnerable within a roughly 20km zone around the front line.
- The second major factor in this transformation is the transparency of the battlefield. Forward operating bases are becoming priority targets, leading to the need for dispersed maintenance and extended operational distances.
- The third factor is the strengthening of multi-domain operations (MDO), which aim to increase effects on the battlefield. Connectivity is a major factor in efficiency, enabling helicopter cooperation with their environment. Beyond offensive capabilities, it also contributes to the aircraft's survivability.

Enduring Helicopter Strengths

Helicopters, however, retain their inherent advantages:

- Multi-mission, even dual-use capabilities (civil and military).
- A specific operational environment: very low-altitude flight, navigating obstacles with the ability to land almost anywhere.
- Rapid action to deliver quick effects on the ground with a high payload capacity.
- Multi-environment capability: both land and maritime.
- Hovering capability.

Expanding Operational Capability in a System of Systems Environment

Evolving battlefields are expanding operational capabilities within a System of Systems environment.

- Helicopters maintain their environmental specificity: low-altitude flight amidst obstacles.
- They are an integral part of MDO, highlighting the importance of hyper-connectivity to be a full component of global system-of-systems concepts like FCAS (Future Combat Air System) and MGCS (Main Ground Combat System).
- However, due to their environmental constraints, they must also be capable of being their own system bubble (communication masking constraints due to obstacles, stealth constraints in deep operations like CSAR or SOF).

European Helicopter Industry Landscape

The European helicopter industry is built upon a NATO operational base and an industrial base with two leading integrators (Airbus Helicopters and Leonardo Helicopters) driving a very significant capabilities ecosystem.

- The Operational Base: Almost all European military helicopter fleets are also part of NATO.
    - NATO serves as the operational compass through its operational procedures and standards, which dictate interoperability.
    - Capability relies on several pillars that define the capability requirement, such as ACT (Allied Command Transformation) or ACO (Allied Command Operations), foresight (NIAG/JCGVL), and standard definition (NIAG).
- The NGRC Program:
    - A high-visibility program aimed at defining the future military multi-mission helicopter in the Medium class (9-15t MTOW).
    - Involves '6' countries (France, Germany, Italy, Netherlands, Canada, UK, and the USA as observer) currently in the concept phase, with launch planned for 2030 and an Entry into Service (EIS) between 2035-2040.

   - High-performance helicopter (+180 knots, 250 NM combat radius).
   - NSPA (NATO Support and Procurement Agency) program team.
   - A market for 1.300 aircraft.
   - A platform + capabilities program.
- Concept Study Phase:
   - 5 studies underway with 3 competing OEMs (LH, Sikorsky, AH).
   - Study concludes September 2025.
   - Phase 2 expected Late 2026 / Early 2027.
- The European Industrial Base is supported by the European Defence Fund (EDF) program, ENGRT, with co-leadership from AH-LH.
   - ENGRT is envisioned by the European Commission as a European solution to NATO's NGRC program.
   - ENGRT1 is currently ongoing, concluding late 2026 – R&T phase.
   - ENGRT2: EDF 2024 Call, Grant phase for a notification in August 2025.
   - Duration: 3 years.
   - Funding: €100M from EDF + €60M co-financing.
   - 13 participating nations, 53 industrial partners.

NGRS is the technological synthesis of NATO's NGRC military program.

- It will enable military helicopters to adapt to a new multi-domain operational environment in collaboration with the development of UAS (Unmanned Aircraft Systems).
- It will allow the European industry to offer NATO compatible standards for European technological solutions.
- It should facilitate the inclusion of the British industry in the ENGRT program through a high-level partnership.
- It should make it possible to identify and strengthen the European Defense Technological and Industrial Base (EDTIB) to serve better interoperability, interchangeability, and the development of innovation and industrial and capability agility, notably with a broad network of SMEs and partner laboratories.

The objective of the study, given the technological challenges required, is to identify the European industrial players who can contribute to this ecosystem, to determine the weaknesses to be addressed by complementary studies, and to coordinate NGRS with other capabilities to maximize the collaborative multi-domain effect.

Propulsion and Power Generation for Air Platforms (fixed and rotary wings)

The propulsion and power generation for air platforms encompasses all aspects linked to providing the necessary energy, both propulsive and non-propulsive, for any type of platforms, being fixed and

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rotary wings, crewed and uncrewed. This includes engines, power transmission systems, electrical generators, fuel systems, and many other essential components.

Improved energy generation (both 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. The ambition is to prepare the ground for new architecture and technologies of future propulsion engines respectively adapted to air combat aircraft, other fixed wings aircraft such as air military transport, rotorcraft, helicopters and UAVs designed for reconnaissance and strike missions.

The primary goal is to foster consensus among European industries on propulsion and power generation related-policies, documents and activities that are pertinent to advancing European capabilities, technologies and industrial foundation. It is indeed key to promote the competitiveness of the European technological and industrial base by attracting new investments and preparing the ground for future collaborative research and development programs. Research & Technology (R&T) plays a pivotal role in meeting these requirements by driving innovation, enhancing safety, reducing environmental impact, and providing key operational benefits. The continued investment in R&T is essential to ensure the advancement and competitiveness of the engine aerospace industry.

Scope of activities to promote propulsion and power generation of all kinds of military aerial platforms:

- Studies of modernization or new product and technologies introduction regarding aero engines, advanced power transmission, accessories gearbox, propulsion system for uncrewed solutions, non-propulsive electrical power generation in aircraft, Hybrid Electric Propulsion System and fuel systems.
- Evaluation and adoption of alternative and sustainable fuels.

Priorities to address

1. <u>Advanced Turbofan, Turboprop and Turboshaft Engines</u>

Innovations in turbine engine technology to enhance fuel efficiency, increase affordability, reduce emissions, and increase reliability. Research into high-temperature materials, optimized aerodynamics, and advanced combustion techniques. Focus on extending range, reducing cost, increasing thrust, and improving fuel consumption. Development of hybrid-electric propulsion systems that provide increased range, enhanced stealth capabilities, and improved fuel efficiency for tactical military aircraft. Emphasis on rapid power delivery for high-performance manoeuvres and silent operations. Power generation systems must be capable of supporting not only propulsion but also the vast array of on-board systems, including avionics and different type of armament or other mission systems. Efficient energy management and distribution are critical to ensuring that power demands are met without compromising system performance.

2. Fuel Cell Technology for Aircraft

Research and implementation of hydrogen fuel cell systems for propulsion and auxiliary power units (APUs).

3. Noise Reduction Technologies

Innovations in propulsion system design and materials to minimize noise and make detection more difficult. Develop propulsion systems with reduced acoustic signatures to enhance stealth capabilities.

4. Predictive Maintenance Technologies

Development of digital twin models for propulsion systems to enable real-time monitoring, data analytics, and predictive maintenance. This includes integrating sensors and AI-driven diagnostics.

5. DEW Power Systems

Create advanced power generation and management systems capable of supporting DEWs such as laser systems and electromagnetic railguns on military aircraft.

Focusing on these specific projects and future products for the military aviation market will address the unique demands of military operations, such as increased performance, stealth, reliability, and operational flexibility. Investment in these areas will drive the development of advanced technologies that enhance the capabilities of military air platforms, ensuring superiority and readiness in various operational scenarios. By prioritizing these projects, European military forces can maintain a technological edge, improve mission effectiveness, and reduce logistical challenges in the ever-evolving landscape of modern warfare.

Sensors for air platforms

The evolution of the warfare scenarios is modifying the traditional boundaries of the sensor suites both for Radar and EO/IR technologies. Multifunctional and multi-mission requirement are the main drivers, but this evolution is possible by the increase in computational capabilities in collecting and integrating data from different sensors and systems (search tracking and targeting, Detect and Avoid, augmented situational awareness, early warning receiver) and platforms.

The aim is to contribute to advancing aspects of the air distributed, multi-sensors and multi-platforms sensors suite enhanced by data fusion increasing capabilities. Interoperability, integration and

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connectivity, empowered by Combat Cloud as key Collaborative Combat multiplier, will enable cooperation between different platforms in order to achieve air superiority in contested environments.

Sensors suite for air platforms encompasses all aspects linked to providing the necessary situation awareness and fire control to all types of platforms, crewed and uncrewed. This includes functional and mission sensor suites. The objective is also to ensure a European sovereign approach and solution to those capabilities.

Capabilities

1. Orchestration sensor collaborations

Orchestrating sensor collaboration in defence applications aims at enhancing detection capabilities, improving tracking accuracy, and ensuring timely responses to threats. The orchestration involves combining data in real-time from multiple sensors and different platforms in coordinated manner to integrate and improve overall situational awareness: improved detection and reliability, enhanced tracking and targeting, reduced false positives, increased situational awareness, and adaptability to dynamic threats.

2. Threat and target detection, localization, classification, identification

Accurate and timely execution of target detection, localization, classification and identification is crucial for effective defence, especially in contested environments where real-time decisions need to be made with limited information. Therefore, advanced sensor networks, automated decision systems, and cross-platform coordination are fundamental to neutralize threats.

- ⇨ Enable the automatic interpretation, Increase data fusion and detected target reporting from multi-modal sensor using, Combine visible-band (EO), thermal-band (IR) and radar sensing, Enable a range of automatic classification driven machine learning techniques, Facilitate the automatic detection of either target type with cross-modal target confirmation, Enable a real-time target detection using information from both multiple sensors and multiple sensor platforms provide environment-enhanced situational awareness, and Improve detection range vs stealth objects.

3. Common Operating Picture construction (COP) and maintenance

The COP provides a shared, real-time visual representation of the battlefield or operational environment. The COP integrates data from various sources, such as sensors, intelligence, and operational reports, to offer commanders and decision-makers a comprehensive and unified view of the current situation. Construction and maintenance of the COP require sophisticated technologies, robust data fusion, and real-time communication to ensure that the picture remains accurate, actionable, and timely throughout the operation.

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- ⇨ Data Integration and Fusion, Data Fusion Algorithms, Geospatial Mapping, multispectral imaging, Real-Time Coordination, User Interface (UI) and Visualization, Collaboration and Communication, and Decision Support Systems (DSS).

Priorities to address (at capability level)

1. Distributed Sensor Suites (Optronics, radar, EW, Communication)

In defence, a distributed sensor suite is vital for enhancing situational awareness, improving decision-making capabilities, and the ability to rapidly respond to emerging threats. These systems are an essential component of modern defence strategies, achieving the information superiority.

- Integrated multi-sensor suites: deployment of equipped with EO/IR sensors, Active Electronically Scanned Array (AESA) radars, and EW capabilities for surveillance, tactical support, and reconnaissance missions.
- Collaborative sensor networks: development of distributed sensor networks across multiple platforms operating in formation. Each platform acts as a node in a network, sharing radar, EO/IR, and EW data.
- High-resolution radar imaging: implementation of high-resolution radars for terrain mapping and detection of low-observable (stealth) objects, even in poor visibility conditions.
- Autonomous detect & engage systems: use of distributed sensors to feed autonomous threat detection and engagement systems, reducing crew workload.

2. Detect & Avoid system:

- Collision avoidance with UAV integration: Deter & Defend (DDA) systems to prevent collisions with UAVs or other helicopters operating in the same airspace, leveraging radar and integrated EO/IR sensor data.
- Dynamic threat avoidance: DAA systems capable of identifying and tracking incoming threats, such as missiles or enemy fire, suggesting alternative routes to evade danger.
- Integration with autonomous piloting: DAA systems integrated with advanced autopilots to enable helicopters to autonomously navigate during long missions or in low-visibility conditions.
- Multi-sensor and multi-platform data fusion management: the management of multi-sensor and multi-platform data fusion focuses on integrating information from diverse sensors to create a common operating picture (COP).

Priorities to address (at technological level)

1. EO/IR sensors

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Electro-optical/infrared (EO/IR) sensors are indispensable in modern warfare, providing military with enhanced situational awareness, targeting capabilities, and survivability. Future advancements in EO/IR technology promise even more sophisticated applications on the battlefield.

- Enhanced situational awareness: improved image resolution and sensitivity, multi-spectral imaging, 360-degree situational awareness, sensor fusion, and neuromorphic processing.
- Advanced targeting capabilities: automatic target recognition and tracking, precision targeting, long-range target engagement, and non-line-of-sight targeting.
- Increased survivability: degraded visual environment (DVE) mitigation, obstacle avoidance, and future applications of EO/IR sensors on military helicopters will focus on enhancing situational awareness, improving targeting capabilities, and increasing survivability.

2. Radar and Integrated Electronic Warfare

- Advanced Detection: millimetre-Wave Radar
- Advancements in Technology: Miniaturization and Integration, and Enhanced Signal Processing
- Operational Enhancements: Multi-Mode Operations, and Integration with Helmet-Mounted Displays
- Enhanced Sensor Fusion: Future radar systems integration with other sensors (like EO/IR, Light Detection and Ranging or LIDAR, and SIGINT) to create a more comprehensive battlefield picture
- Electronic Warfare Resilience: radars capable of operating in contested electromagnetic environments and conducting electronic warfare (jam enemy communications or radar while maintaining operational integrity)

3. Hyper-Spectral sensors

- Surveillance and reconnaissance: Material Identification
- Threat detection: Chemical and Biological Warfare
- Target acquisition: Precision Targeting
- Environmental monitoring: Tracking Environmental Changes
- Counter-Improvised Explosive Device (IED) operations: Mine and IED Detection
- Search and Rescue: Locating Personnel

4. Digital Training for Cognitive Sensors

Digital Training for Cognitive Sensors refers to the digital preparation of advanced sensors equipped with learning, adaptation, and autonomous decision-making capabilities. These sensors leverage AI to => analyse real-time data, identify threats or relevant events, and continuously enhance their

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performance. Digital training involves virtual simulations and test environments where sensors learn to handle complex scenarios before deployment in the field.

- ⇨ Technological Advancements: Advanced virtual simulations, Digital twins, Training with real-world data, On-field continuous learning, Integration with advanced AI platforms, Hybrid Physical-Digital Simulations, Immersive AI Training Ecosystems and Dynamic Scenario Scripting.

5. AI applications for Signal processing, Classification, Identification:

AI applications in signal processing aim to improve the classification and identification of threats.

- ⇨ Technological Advancements: Machine learning for complex signals, Autonomous classification, Continuous learning, Neuromorphic processing, Quantum Signal Processing, and AI-Powered Counter-Deception Systems.

6. Multiband EO (visual+thermal) seekers and RF seekers of increasing band and complexity (AESA antenna)

Multiband seekers combine EO and RF data to enhance targeting and precision in complex environments.

- ⇨ Technological Advancements: Dual-band seekers, Complex AESA antennas, Adaptive sensors, Multi-layered Targeting Systems, and Enhanced Hyperspectral Fusion.

Cockpit technologies

In the future theatre of operations, military pilots will face increasingly complex challenges driven by rapidly evolving threats, multi-domain operations, and the integration of crewed and uncrewed systems. Pilots will need to process vast amounts of real-time data from multiple sources, including sensors, satellites, and other platforms across air, land, sea, and space domains. Identifying actionable intelligence amidst this flood of information will be critical. Operations will require seamless collaboration across domains, necessitating quick decision-making in high-stakes scenarios. The integration of crewed-uncrewed teaming (MUM-T) will demand simultaneous control and coordination of multiple platforms. Additionally, the speed of threat evolution, such as hypersonic weapons, advanced air defences, and electronic warfare systems, will compress decision timelines and increase operational risk. As missions grow more dynamic and longer, mental strain on pilots will intensify, potentially leading to errors.

These challenges require a strategic commitment to cockpit technologies that enhance situational awareness, reduce pilot workload, and ensure mission effectiveness. Europe must anticipate these needs by promoting targeted R&D initiatives and capability development across both legacy and next-

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generation platforms, including both crewed and uncrewed, helicopters, transport aircrafts to ground control stations.

Capabilities

To address the challenges faced by military pilots, several capabilities are prioritized. Enhanced crew situational awareness is crucial for improving the ability of the crew to understand and interpret the operational environment, ensuring optimal performance of the crew during the mission execution. Increasing the safety of the crew during missions is essential, as is providing better explanations for crash events due to human errors. Improving the debriefing process to enhance mission and crew performance and enhancing training programs to better prepare the crew for missions are also key priorities.

Several technologies are essential to support these capabilities and address the challenges, and different initiatives in consideration to be promoted:

1. AI

The AI integration play a significant role. Virtual assistants, or virtual copilots, can assist pilots in decision-making, while AI-driven systems can take over certain tasks. Predictive analytics and AI-assisted decision-making systems analyse data and provide recommendations to support the pilot's decisions.

2. New generation human-machine interactions

They are essential for future cockpit systems, enabling more intuitive and adaptive communication between pilots and platforms. Technologies such as natural language processing, gesture recognition, eye tracking, and brain-computer interfaces can be combined to compose a natural interfacing between human and machine, reducing cognitive load and enhancing decision-making.

3. Adaptive human-system collaboration

Intuitive interfaces enhance interaction between pilots and systems, while cognitive workload management systems help manage and reduce the cognitive load on pilots. Real-time adaptation systems adjust to changing dynamically according to conditions (mission and flight context) and pilot's state and needs based on AI application. Neuroergonomics principles will guide the design of these systems to align with the pilot's cognitive and physiological characteristics, ensuring that technologies adapt seamlessly to human limitations and capabilities.

4. Advanced and adaptive visualization technologies

They contribute to enhanced situational awareness. Augmented and mixed reality (AR, MR), along with helmet technologies, provide advanced visualization. Dynamic information presentation systems improve ergonomics and reliability, and displays designed to improve size, weight, and power (SWAP) further enhance these aspects.

5. Crew monitoring systems

They are vital for maintaining pilot health and performance. Physiological monitoring sensors, embedded into the pilot's helmet, equipment or pilot's clothes, track the pilot's vital signs, while cognitive state monitoring uses AI models to assess metrics like eye movement and brain activity. Alert systems notify pilots of critical conditions and adaptive Health Management Information System (HMIS) can respond to instantaneous visualization needs depending on the context and the pilot's status. Furthermore, such metrics can aid pilots gain proficiency and readiness when used as feedback during training sessions

6. New technologies to enhance cockpit ergonomics and comfort

Technologies such as advanced oxygen systems, allow natural breathing, reducing pilot fatigue and improving operational safety.

7. Defining open standards and certification pathways

To ensure interoperability and reduce development costs.

A proactive stance must be adopted in defining the next generation of cockpit technologies by promoting dual-use innovation between civil and military applications as well as to invest in sovereign capabilities to reduce external dependencies.

Positioning, Navigation and Timing (PNT)

PNT encompasses all aspects linked to providing the necessary navigation system for any type of platform being crewed/uncrewed, rotary or fixed wings, including with swarming capacities. This includes navigation systems in GNSS but also, and mainly, in GNSS-denied and contested environments at user equipment level.

Resilient PNT is achieved with a layered defence:

- Safeguard PNT with improved sensors (position, attitudes, velocity, timing).
- Robustify GNSS acquisition.
- Use of non-GNSS multi-sensor fusion.
- Navigate from alternative RF signals.
- Multiply the single resiliency with collaborative PNT.

- Continuous improvement with Navigation Warfare (NAVWAR) capabilities (offensive jamming/spoofing capabilities, threat monitoring and classification).

The objective is to nurture cutting-edge technologies and develop modules and functions, ready to integrate across multiple host platforms, while also ensuring a European sovereign approach and solution.

Activities

- Inertial sensors: accelerometers, gyros (all technologies, laser vibrating, Microelectromechanical Systems or MEMS and quantum): improved MEMS sensors with better gyro bios characteristics, miniaturized FOG sensors, next-generation optical sensors, Hardened Inertial Measurement Units (IMU), quantum accelerometers and gyroscopes.
- Precise time keeping including miniaturisation and quantum technologies: next-generation atomic clock for airborne, Hardened Quartz oscillators.
- GNSS user equipment (including Galileo Public Regulated Service (PRS) 2G implementation, HAS, SAR): anti-jamming and multi-element antennas PRS Receivers, PRS Smart receiver (all-in-one anti-jamming electronic unit and receiver), anti-jamming and anti-spoofing capabilities/protection (including Identification-Detection-Mitigation (IDM) algorithms), security certification, Standardization of interfaces, integration activities in host equipment and antennas.
- GNSS user reequipments infrastructure: services architectures for test and support facilities, key management, PRS security management and other PRS information management capability.
- Non-GNSS multi-sensor fusion: star tracker positioning aids, Visual Based Navigation (VBN), Visual Inertial Odometry (VIO), correlation of gravity/magnetic anomalies, speed adjustment, quantum non-inertial sensors.
- Alternative RF signals: signals of opportunity (low Earth orbit or LEO, and 5G), PNT by design (IRIS2, eLORAN).
- Collaborative PNT: Type of mutual observation, Minimization of data exchange between the collaborative members, Particularity of swarming use-cases.
- Time transfer and distribution (radio, laser, ethernet, …).
- Guidance.
- Piloting.
- Detect & avoid system: Low swap requirements equipment, vision and acoustic based systems and its certification.

Priorities to address (at capability level)

- Operate in GNSS denied or challenged environments

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- Operate in non-segregated airspace
- Collaborative PNT
- NAVWAR

Priorities to address (at system level or functional chain)

- Adopt a system approach to Positioning, Detect & Avoid system, Guidance, Piloting, Timing

Priorities to address (at technological level)

- Improved MEMS sensors with better gyro bias characteristics
- Hardened IMU
- Next-Gen optical sensors
- Next-Gen atomic clock for airborne
- Quantum sensors
- Galileo PRS 2G user equipment update
- Alternative sensor fusion (in particular vision and mapping)

Priorities to address (at infrastructure level)

- PRS service infrastructure
- PRS security management and other PRS information management capability
- PRS related supply chain more resilient and robust (decrease dependence from non-EU technologies and products, interchangeability between sources of Modules and Receivers, production)

Military Air Platform Systems and Subsystems

The range of systems required for military air platforms spans from high-performance flight control actuation and electronics for next-generation combat aircraft to innovative hydraulic and electric power solutions for uncrewed aerial systems, tactical and strategic transport vehicles, medical evacuation (MedEvac) aircraft, military rotorcraft, drones, and smaller airborne platforms. Each of these requires specialized technical attributes tailored to their unique operational demands.

Capabilities

1. <u>Flight Control Systems (Flight Control Computing and Actuation incl. internal Weapon Bay Actuation Systems)</u>
   - Precision and manoeuvrability: digital fly-by-wire or fly-by-light systems offer enhanced stability and control for critical manoeuvres or evasive lifesaving actions.

- Stealth and flight control: the integration of stealth principles with weapon bays and actuation systems combined with advanced flight controls the effectiveness of stealth is significantly improved and this technology must be promoted within the EU defence industry.
- Automation and safety: innovative flight controls can automate certain functions, reducing pilot workload and minimizing human error. Systems also incorporate redundancy to ensure safe operation even in adverse conditions or incurred battle damage.
- Integration with avionics / modular platforms: modern flight controls must integrate seamlessly with avionics and weapon systems, providing real-time data that enhances situational awareness and target acquisition.

2. <u>Landing Gear Systems</u>

- Operational versatility: modern landing gear systems must be designed to withstand the extreme stresses of high-speed operations, varied terrain conditions, and rapid deployment scenarios. For modular air combat platforms, including uncrewed systems, landing gear designs must accommodate diverse operational profiles, such as VTOL capabilities or carrier-based operations. Retractable, low-profile designs contribute to stealth and aerodynamic efficiency for maintaining air superiority.
- Maintenance and reliability: innovative materials and designs are revolutionizing the durability and reliability of landing gear systems. Advanced materials such as titanium alloys, carbon fibre composites, and high-strength aluminium alloys are increasingly used in landing gear components improving overall aircraft performance and heat-resistant materials. Reliability is further bolstered by the integration of predictive maintenance technologies.

3. <u>Hydraulic and Electric Power Systems</u>

System architectures are evolving toward higher degrees of electrification. Pure electro-mechanical actuation is an obvious solution for control surface actuation, electric systems for avionics and to ensure redundancy and safety. This trend is also accompanied by a rise in onboard voltage levels, enabling the integration of more demanding systems and contributing to improved power efficiency and weight reduction.

4. <u>Environmental Control and Air Management Systems (ECS and AMS)</u>

Future Directions in ECS and AMS: Innovations in ECS and AMS are increasingly driven by demands for higher efficiency, lighter weight, and reduced power consumption. Next-generation systems utilize smart sensors and adaptive control algorithms to optimize environmental conditions and cooling dynamically. Technologies for non-propulsive energy generation and power management are pivotal in enhancing the performance of ECS and AMS in military aircraft. In modular and uncrewed combat platforms, ECS and AMS are being designed to operate autonomously, ensuring seamless functionality without direct crew intervention.

5. <u>Avionics Platforms (Integrated Modular Avionics)</u>

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Avionics platform requirements, mission computing, safety-critical computing, and cockpit interfaces work in unison to create an integrated, responsive, and reliable combat system. The use of open standards, modularity, and scalable architectures means that these avionics systems can be continually upgraded and improved, providing a future-proof solution for the military air domain. By adopting cutting-edge technologies and enabling collaborative air combat capabilities, European aircraft can maintain a competitive edge in the increasingly complex and high-stakes environment of modern warfare.

- Military Avionics Platform Requirements and Generic Architectures
- Mission computing
- Safety critical computing
- Cockpit Interface / Graphics / Video Interface and Processing

6. Fuel management

Fuel management is not only about ensuring the right amount of fuel for a mission but also optimizing the processes surrounding fuel usage and refuelling. By integrating advanced fuel gauging systems, fuel compatibility sensors, stealthy on-aircraft refuelling pods, and automated refuelling systems, European military aircraft can perform at their best, even in the most demanding operational environments. These innovations lead to increased operational flexibility, reduced maintenance time, and enhanced stealth capabilities. The integration of these technologies ensures that aircraft can operate at peak performance while maintaining readiness for combat missions without compromising their survivability or operational effectiveness.

- Gauging System Technology (External Fuel Tanks)
- Fuel Compatibility (The Revolution with Synthetic Fuels)
- Stealth and aerial refuelling capabilities with low radar cross-section (RCS)

Training and Simulation in an MDO environment

Concerning MDO capabilities, complex next-generation defence systems in all strategic domains require extensive M&S capability to support forces training and efficient operations. The importance of M&S in the support of armed forces operations and MDO capability development will increase significantly in the future to counter peer and near-peer threats. Rearming of Europe requires enhanced industrial participation in military training to more efficiently support military capability build-up.

Concurrently Europe aims to reduce the reliance on US originated solutions, and avoid developing a dependence on Chinese originated technologies, and it requires determined and cooperative actions both from European institutions and defence industry and significant investment to reduce the military Science and Technology capability gap with the US. It is highly recommended that Europe develop a

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comprehensive M&S industrial approach that combines the aim of strengthening the European defence industry with the European defence capability development and M&S services availability.

In order to strengthen EU defence industry in a very competitive and rapidly developing M&S environment it is recommended to connect M&S into ongoing European defence capability development activities. Short- and medium-term development of MDO related M&S capability offered by EU defence industry should be connected to funding of European defence ramp-up and to activities in strengthening the EU-NATO partnership.

M&S covers training and education, mission rehearsal, support to operations, capability development, and acquisition and procurement. This covers simulations that can be purely analytical, data-driven processes used in R&D, for test and evaluation and for operational decision making or computer-generated models and environments for immersive, interactive scenarios for a variety of military purposes including mission preparation, concept of operations development, logistics support, training.

ASD MADIG aims to communicate and to foster European defence industry's stronger role in the field of M&S in EU and NATO frameworks, in training and simulation offering, and promote the M&S related technology development. The general objective is to optimize the development of complex systems by European defence industry using the M&S as a Services (MSaaS) paradigm.

The scope is in modelling, simulation and training related to MDO and air domain, including aerial systems and equipment, uncrewed systems and self-protection. These capacities are critical not only to achieve mission readiness, but also to efficiently design, test and evaluate complex systems, simulate and validate mission plans, simulate and train for critical missions, develop new tactics and capabilities, and to achieve "value for money" at a reasonable cost when conducting M&S activities in the most realistic scenarios and environments for MDO capabilities development.

M&S require tools and assets to build and render military scenarios, develop strategies or test equipment. These tools and assets might create isolated simulations but over time are more likely to include the ingestion of real-world data to improve the models using "digital shadows" or be used to influence systems in the real world using "digital twins".

<u>Functional areas</u> according to training audience and activities are (but not limited to):

- Crew training and mission preparation: for this domain, Life Virtual Constructive (LVC) training features mix real actors using real resources (Live) and simulators (Virtual) within simulation environments where the actors are simulated (Constructive). The other key feature is immersing armed forces personnel in relevant and connected tactical situations and providing them with all they need to exercise their skills and enhance their preparedness.

- Maintenance training and support: given the increasing complexity of systems and maintenance procedures and the need for highly qualified technicians, training resources need to be sophisticated and regularly updated in order to prepare them as effectively as possible. Training resources should be easily changed to add new threats and equipment's to be pro-active with new use-cases, paradigms and resulting improvements. Virtual Maintenance Trainers (VMTs) using VR and AI technologies are an important development.
- C2 & military air traffic control training: these solutions answer to training requirements of air operations C2 units and personnel and of civilian and military air traffic controllers and make it possible to test control procedures in the changing air domain environment.

Intuitive real-time interaction: This interaction requires tools, whether hardware or software, and the integration of these tools into platforms to enable intuitive real-time interaction using sensors that determine the user's position, viewpoint and haptic activity and then display the virtual elements, often overlaying the real world, in a realistic manner. For this, specific sensors are needed:

- Accurate localization of the users, including in uncontrolled indoor environment is beyond state of the art but will be a strong enabler for future Extended Reality (XR) applications.
- Accurate real environment capture and digitization is also needed to ensure virtual elements can interact with real ones

It is highly critical that Europe develops home-grown rendering platform capable of rivalling American products (i.e. Unreal Engine) on which a large part of the European M&S industry depends.

When developing MDO capability, it is a necessity to utilize modern M&S capabilities due to complexity and scale of modern operations and environments. Efficient utilization of M&S ensures a coherent approach across the different domains.

Priorities to address (at technological level)

- LVC training & wargaming platforms and next-generation (no code, AI powered) scenario authoring for cost-effective creation of complex MDO simulation scenarios and behaviours
- AI models (for instance for scenario generation and behavioural modelling)
- Immersive technologies, ER
- LVC trainers
- Metaverse and Digital Twins modelling tools and rendering engine.
- Modelling as a Service and Cloud technologies (MSaaS)
- Cybersecurity
- Open architecture-based development

LIST OF ABBREVIATIONS

2G	Second generation of cellular network technology
5G	Fifth generation of cellular network technology
6G	Sixth generation of cellular network technology
A2AD	Anti-Access/Area Denial
AESA	Active Electronically Scanned Array
AEW	Airborne Early Warning
AI	Artificial Intelligence
AIS	Automatic Identification System
ALE	Autonomous Launch Enhancement
AMS	Air Management Systems
APUs	Auxiliary power units
AR	Augmented Reality
AS	Autonomous Systems
ASD	Aerospace, Security and Defence Industries Association of Europe
ASW	Anti-Submarine Warfare
ASuW	Anti-Surface Warfare
BMC6I	Battle Management Command, Control, Communication, Computing, Cyber, Combat and Intelligence
C2	Command and Control
C4ISTAR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
C5I	Command, Control, Communications, Computers, Collaboration and Intelligence
C6I	Command, Control, Communication, Computing, Cyber, Combat and Intelligence
CASEVAC	Casualty evacuation
CBM	Confidence-building measures
CDP	Capability Development Priorities/Capability Development Plan
CEMA	Cyber-Electromagnetic Activities
COP	Common Operating Picture
CRM	Critical Raw Materials
D2IL	Denied, Disrupted, Intermittent and Limited
DDA	Deter & defend
DEAD	Destruction of Enemy Air Defences
DEW	Directed Energy Weapons
DG DEFIS	Directorate-General for Defence Industry and Space
DIRCM	Directional Infrared Counter Measures
DSS	Decision Support Systems
DVE	Degraded visual environment

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EATC	European Air Transport Command
EC	European Commission
ECM	Electronic Countermeasures
ECS	Environmental Control Systems
EDA	European Defence Agency
EDF	European Defence Fund
EDIP	European Defence Industry Programme
EDOCC	European Defence Operational Collaborative Cloud
EDTIB	European Defence Technological and Industrial Base
EICACS	European Initiative for Collaborative Air Combat Standardization
EIS	European Innovation Scoreboard
eLORAN	Enhanced Long-Range Navigation
EMSO	Electromagnetic Spectrum Operations
ENGRT	EU Next Generation Rotorcraft Technologies Project
EO	Electro-Optical
EP	Electronic Protection
ESM	Electronic Support Measures
EU	European Union
EW	Electronic Warfare
FOG	Fiber Optic Gyroscope
FPGA	Field-Programmable Gate Arrays
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPUs	Graphics Processing Units
HAS	High Accuracy Service
HIMARS	High Mobiity Artillery Rocket System
HITL	Human-in-the-Loop
HMIS	Health Management Information System
IADS	Integrated air defense systems
IDM	Identification-Detection-Mitigation
IED	Improvised Explosive Device
IFF	Identification, friend or foe
IMA	Integrated modular avionics
IMU	Inertial Measurement Unit
IR	Infra-Red
IRIS2	Infrastructure for Resilience, Interconnectivity and Security by Satellite
ISR	Intelligence, Surveillance, and Reconnaissance
KSA	Key Strategic Activities
LEO	Low Earth orbit

LIDAR	Light Detection and Ranging
LOS	Line-of-Sight
LVC	Life Virtual Constructive
LWS	Laser warning system
MADIG	Military Air Domain Industrial Group
MAWS	Missile approach warning system
MDO	Multi-domain Operations
MEDEVAC	Medical evacuation
MEMS	Microelectromechanical Systems
ML	Machine Learning
MR	Mixed Reality
M&S	Modelling & Simulation
MS	Member States
MUM-T	Manned-Unmanned Teaming
NATO	North Atlantic Treaty Organization
NAVWAR	Navigation Warfare
NGR	Next Generation Rotorcraft
NGRC	Next Generation Rotorcraft Concept
NIAG	NATO Industrial Advisory Group
NPUs	Neural Processing Units
NSPA	NATO Support and Procurement Agency
OODA	Observe, Orient, Decide, and Act
PESCO	Permanent Structured Cooperation
PG2M	Precision-Guided Missiles and Munitions
PGM	Precision-Guided Missiles
PNT	Positioning, Navigation and Timing
PRS	Public Regulated Service
RCS	Low radar cross-section
RF	Radio Frequency
RWR	Radar warning receiver
SAFE	Security Action for Europe
SAR	Synthetic-aperture radar
SDR	Software Defined Radio
SEAD	Suppression of Enemy Air Defenses
SIGINT	Signal Intelligence
SMEs	Small and Medium Enterprises
SWAP	Size, weight and power
UAS	Uncrewed Aerial Systems

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UAV	Uncrewed Aerial Vehicles
UCAV	Uncrewed Combat Aerial Vehicle
UI	User Interface
US	United States
VBN	Visual Based Navigation
VIO	Visual Inertial Odometry
VMTs	Virtual Maintenance Trainers
VTOL	Vertical Take-Off and Landing
XR	Extended Reality

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