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Raw materials in the European defence industry

Claudiu C. Pavel
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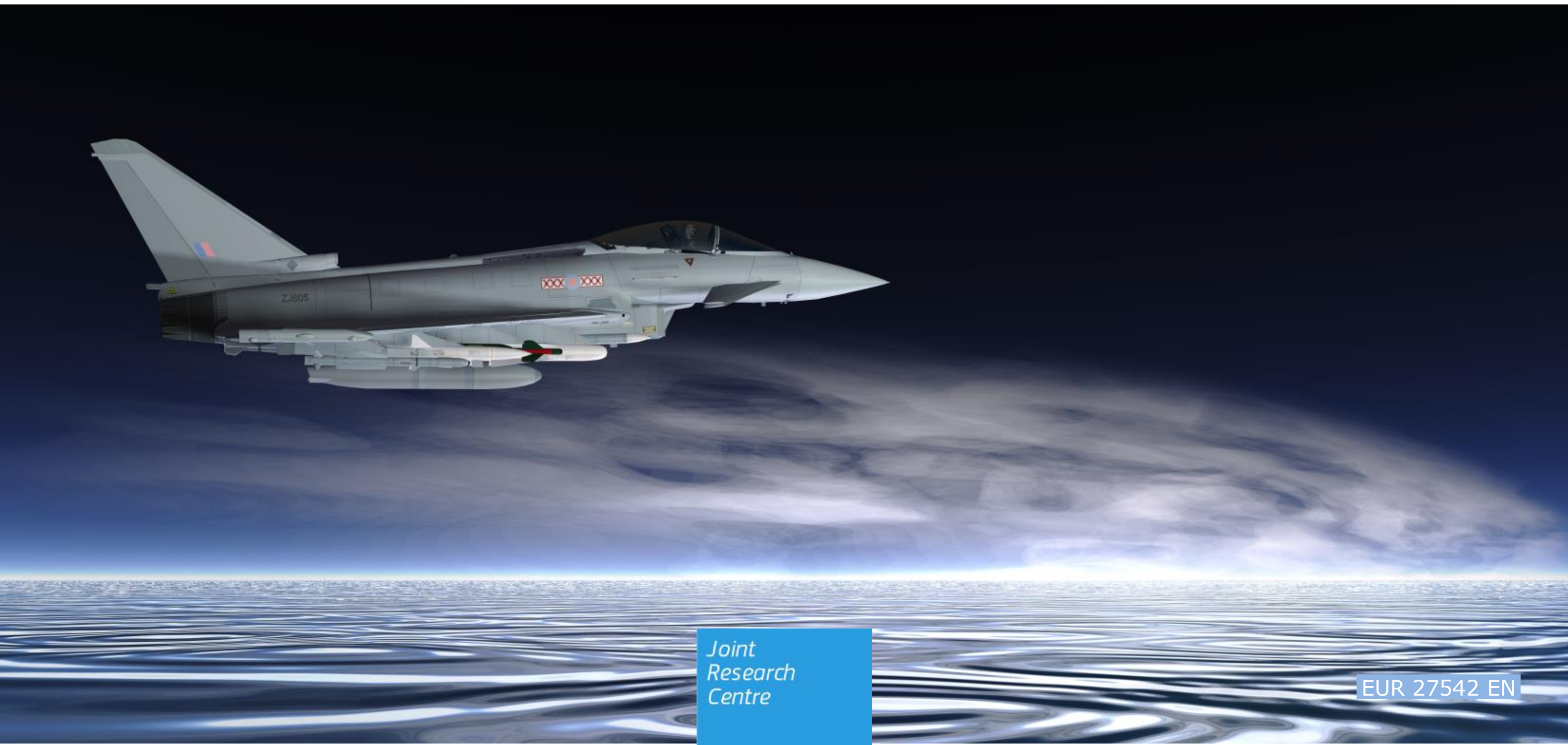

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Raw materials in the European defence industry

Abstract:

Access to raw materials is of growing concern for the European economy. In the context of the EU raw materials strategy, this study identifies the raw materials that are important for the European defence industry and evaluates the potential risks associated to their supply in terms of import dependency. The European defence industrial base requires specialised high-performance processed materials for the production of its defence applications: 39 raw materials are necessary to manufacture such advanced materials. For about half of them, the defence industry relies 100% on imports from countries outside the EU. The demand for raw materials for the production of defence applications is relatively low. Moreover, the lead system integrators and top-tier contractors in the defence industry usually do not purchase raw materials as such, but rather semi-finished and finished products made of high-performance materials. The study identified 47 different alloys, compounds and composites materials important to the European defence industry. Given the very high level of performance and special properties of these materials, that cannot be matched by readily available substitutes – their potential supply risk is much higher compared to the supply risk of the constituent raw materials. The European industry needs to secure the supply of a number of raw materials from international sources, maintain its global leadership in the manufacture of high-performance alloys and special steel, and further develop capabilities for the production of speciality composite materials to tackle the supply risks associated with raw and processed materials used in the defence sector.

Raw materials in the European defence industry

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Directorate for Energy, Transport & Climate
Knowledge for Energy Union Unit

- 2016 –

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Kerrill Grealy	Meggitt Avionics
Roland Lang	Airbus Defence and Space
Neil Watt	Thales

Executive summary

Policy context

Access to raw materials is of growing concern for the European economy. Prepared in the context of the EU raw materials strategy and in support of the European Defence Action Plan (EDAP), this study identifies the raw materials that are important to the European defence industry.

The screening of raw materials used in the European defence industry represents an action within the implementation roadmap, put forward by the European Commission, for promoting a more competitive and efficient defence and security sector[1]. The study was carried out by the Joint Research Centre (JRC) at the request of DG GROW through an Administrative Arrangement (AA). This assessment was built on the JRC's experience on the analysis of the role of raw materials in the transition of the European energy system to a low-carbon economy.

Methods and approach

The study was conducted in close collaboration with DG GROW and has taken stock of a previous analysis subcontracted by the JRC to a consortium of the European Company for Strategic Intelligence (CEIS) and the BIO Intelligence Service. These specialised consultants identified the most important applications from the main defence sectors of the European industry, i.e. aeronautics, naval, land, space, electronic and missile, and further disaggregated these applications into subsystems, components and materials.

The study has also benefited from input collected by the JRC from specialised reports, industrial experts and associations (e.g. Community of European Shipyards Associations). Finally, the report has been reviewed by industrial stakeholders (i.e. Rolls-Royce Plc, Meggitt Avionics, Airbus Defence and Space and Thales) and Member States in coordination with DG GROW.

Main findings

An assessment of the most representative applications of the European defence industry revealed that 47 different processed and semi-finished materials (i.e. alloys, composites, compounds) are important for the manufacture of defence application systems. In the context of this report, the term 'important' is used to denote materials with unique properties, necessary to fulfil the stringent requirements of defence applications. A further assessment of the composition of these 47 important processed and semi-finished materials revealed that 39 raw materials are necessary for their production (Figure I).

An analysis of import dependency showed that the EU is almost 100 % import dependent on 19 of these 39 raw materials (beryllium, boron, dysprosium, germanium, gold, indium, magnesium, molybdenum, neodymium, niobium, praseodymium and other REEs, samarium, tantalum, thorium, titanium, vanadium, zirconium and yttrium) and is more than 50 % reliant on imports for over three-quarters of them. China is the major producer for one-third of the raw materials identified in defence applications.

[1] COM(2014) 387 final: Implementation Roadmap for Communications COM(2013) 542; Towards a more competitive and efficient defence and security sector

Figure I: Raw materials in the European defence industry

The defence sector's materials supply chain is a complex multi-level network of material suppliers, manufacturers, distributors and retailers/wholesalers (Figure II). An efficient supply chain ensures the timely delivery at competitive prices of all intermediate and final products to the original equipment manufacturers (OEMs). The supply chain involves various stages, such as the supply of raw materials, metal refining and processing (e.g. alloying or composite production) and conversion into semi-finished and finished products. A strong and sustainable materials supply chain is essential for the overall growth and competitiveness of the European defence industry.

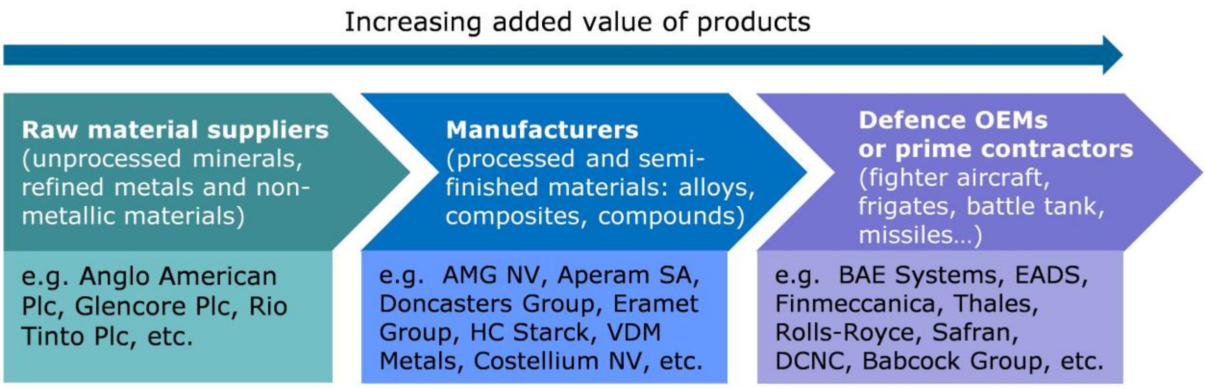

Figure II: A simplified materials supply chain and the main European suppliers

Main conclusions

- The European defence industry requires very specialised high-performance processed and semi-finished materials (e.g. special alloys, composites, etc.) for the production of its defence applications: 39 raw materials are necessary to produce these advanced materials. For about half of them, the defence industry relies 100 % on imports from countries outside the EU.
- Sixteen of the 39 raw materials used in defence applications are included in the EU's critical raw materials list 2014. As regards those defence sectors that mainly use these 16 raw materials, it can be inferred that the defence industry's aeronautics and electronics sectors are the most vulnerable to potential interruptions in the supply of materials.

- The demand for raw materials in the manufacture of defence applications is relatively low. Moreover, the lead system integrators and top-tier contractors in the defence industry do not usually purchase raw materials as such, but rather semi-finished and finished products made of high-performance materials such as special alloys, composite materials, etc. The study identified 47 different alloys, compounds and composite materials that are important to the European defence industry.
- Given the very high level of performance and special properties of these materials which cannot be matched by readily available substitutes, their potential supply risk is much higher compared to that of the constituent raw materials (e.g. minerals and metals).
- The EU is a large manufacturer of alloys and special steels, but should improve its production capacities for speciality composite materials and their precursors, since high-quality composites are finding an increasing number of applications in military components.

The report suggests a number of actions for developing specific future initiatives directed at better understanding and improving the security of supply of raw and processed/semi-finished materials used in the European defence industry:

- This analysis was hampered by the limited information on the types of materials and their use in defence applications which, in general, are bound by confidentiality; therefore it is important that the knowledge base for the materials used in the European defence sector is improved. This can be achieved by promoting information sharing between all relevant stakeholders, the European Defence Agency and the European Commission.
- Undertake additional studies to evaluate each stage of the complex materials supply chain within the European defence industry. These studies should also assess the materials supply risk at application level or within a specific value stream.
- Better exploit the dual-use potential of materials by SMEs and large companies. Promote R&D programmes for the development of high-tech and advanced materials that can address the need of both defence and civil communities.
- The European defence industry needs to strength the downstream segment of its materials supply chain and, in particular, materials processing know-how and materials transformation capabilities.

1. Introduction

1.1 Background

The European Union (EU) is highly dependent on imports of several raw materials that are crucial for a strong European industrial base, an essential building block for the EU's growth and competiveness. The increasing global demand for unprocessed and processed minerals, metals and other semi-finished materials, the volatility in the prices of some of them, as well as the market distortions imposed by some producing countries have highlighted the importance of raw materials to the EU economy and society. Specific industrial sectors of strategic importance to the EU, such as defence and energy, strongly depend on the effectiveness and efficiency of undistorted and uninterrupted material supply chains.

1.1.1 EU Raw Materials Initiative and critical raw materials

The challenges associated with the undistorted access and cost-effective supply of certain raw materials is of growing concern within the EU and across the globe. For example, the supply of several raw materials, which are important to the European defence industry, relies on a limited number of producer countries: beryllium is mainly mined in the USA, niobium in Brazil, platinum in South Africa and rare earths elements, antimony, magnesium, tungsten and other essential compounds, almost exclusively in China. The Raw Materials Initiative (RMI) is the EU-level response which aims to ensure that European industry has secure and sustainable access to raw materials (EC, 2008). In this context, the term 'raw material' refers to metallic, industrial and construction minerals, wood and natural rubber which is used in various industrial sectors, and excludes agriculture and energy materials, i.e. fossil fuels (EC, 2011).

Every three years at least, the European Commission is maintaining and updating a list of raw materials deemed critical for the EU. The term 'critical raw materials' means raw materials of high importance to the EU economy as a whole and the supply of which is associated with a high risk. The latest report on the critical raw materials list includes 20 raw materials, see Box 1.1 (EC, 2014a).

Box 1.1: Twenty raw materials critical for the EU economy, 2014

Antimony	Beryllium	Borates	Chromium	Cobalt	Coking coal	Fluorspar
Gallium	Germanium	Indium	Magnesite	Magnesium	Natural graphite	Niobium
PGMs#	Phosphate rock	REEs* (heavy)	REEs* (light)	Silicon metal	Tungsten	

Platinum group metals
* Rare earth elements

Moreover, the European Commission, through implementation of the Innovation Union, a Europe 2020 flagship initiative, aims to secure Europe's global competitiveness. In addition, it is supporting EU research and innovation activities through the Horizon 2020 financial instrument and European Innovation Partnerships (EIPs), with two main goals:

- Improving conditions and access to finance for research and innovation in Europe;
- Ensuring that innovative ideas are turned into products and services.

The EIPs in particular facilitate collaboration in the Horizon 2020 Framework Programme and assist in the coordination of research in other EU policies and programmes.

With the overall target of reducing Europe's import dependency on raw materials, including critical raw materials, the EIP on raw materials promotes both technological and non-technological innovation along their entire value chain (i.e. raw materials knowledge base, exploration, licensing, extraction, processing, refining, reuse, recycling, substitution) involving stakeholders from relevant upstream and downstream industrial sectors.

The European defence industry relies on the use of a wide range of materials with unique properties that make them essential for the manufacture of high-performance components for military applications. Annex D of the latest European Commission report on critical raw materials for the EU presented an initial, non-exhaustive list of raw materials for defence supply chains (EC, 2014b), based on an analysis carried out by the EDA. The analysis, which focused in particular on ammunitions, electronic components and, in part, on the defence aeronautics sector, identified several raw materials that are important for the defence industry: copper, tungsten, molybdenum, rare earth elements (REEs), gallium, titanium, niobium, beryllium, tantalum, cobalt, platinum group metals (PGM), germanium, magnesium, rhenium, vanadium and chromium.

While access to raw materials supply is important for all European industries, an uninterrupted access to materials is of particular importance to the European defence industry, in view of its pivotal role in Europe's security and operational autonomy.

1.1.2 Tackling the raw materials supply risks in Europe's defence industry

With the central objective of strengthening the defence industry by mobilising all relevant EU policies, in June 2013, the European Commission renewed its vision regarding European defence industrial cooperation, and proposed the Communication 'Towards a more competitive and efficient defence and security sector' (EC, 2013a). Through this Communication, the Commission stressed the importance of raw materials for defence applications and raised concerns about their supply, which could hamper the competitiveness of the defence sector. For example, REEs are indispensable in many defence applications, such as remotely piloted aircraft systems (RPAS), precision guide munitions, targeting lasers and satellite communications. REEs are produced almost exclusively in China, which raises major concerns over potential supply disruptions. The proposed action plan, put forward by this Communication, calls for, among others, the promotion of a more competitive defence industry. Among the actions proposed is the screening of raw materials that are important for the defence sector within the context of the EU's overall raw materials strategy and, if necessary, the preparation of targeted policy actions.

Following the conclusions of the European Council meeting in December 2013 that endorsed the Communication, the Commission developed a roadmap (EC, 2014c) which foresees a study on the screening of raw materials used in the defence industry.

1.2 Overview of international efforts to identify the raw materials used in the defence industry

The global landscape of raw materials production and its associated supply chains is continuously evolving, driven by the rapid economic growth of the industrialised and developing countries that has led to an increase in demand for raw materials used by both defence and civilian industries. For example, the USA, the EU and other major industrialised countries are being confronted by serious global competition for several materials, which often leads to significantly higher commodity prices than in the past.

Information about the defence industry's dependence on raw materials is scarce, being bound by confidentiality. However, limited information is available on some countries, mainly related to strategic industrial stockpiles. The most relevant is the USA National Defence Stockpile (NDS) programme which is operated by the Defense Logistics Agency Strategic Materials (DLA SM, 2015). The main purpose of the NDS is to overcome the issues related to the volatility of the minerals market and to decrease the risk of dependence on foreign and single providers of supply chains of strategic and critical materials used in defence, and essential civilian and industrial applications (DoD, 2015).

According to the United States Geological Survey (USGS), the USA's dependency on raw materials is growing. Between 1999 and 2014, the number of raw materials the USA depends on for more than 50 % of imports increased from 27 to 43 in a list of 100 materials (USGS, 2015). In this respect, the US Department of Defense (DoD) regularly assesses the potential issues related to access to 'strategic and critical' materials (excluding fuel) (see Box 1.2), publishes reports on stockpile requirements, and gives recommendations on material-specific mitigation strategies. Based on a modelling process that estimates the supply and demand for materials under certain 'base case' assumptions, the DoD determines the materials that carry supply risks for the defence, essential civilian and industrial applications. Table 1.1 lists these materials as they were presented in reports published by DoD in 2013 and 2015 on the Strategic and Critical Materials and Stockpile Requirements (DoD, 2013 and DoD, 2015).

It is important to highlight that apart from metals and minerals, the DoD also identified processed and semi-finished materials, such as carbon/silicon carbide fibres and alloys that are important to the strategic defence interests of the USA and which present high supply risk.

Table 1.1: Overview of the strategic and critical materials identified by US DoD

2013		**2015**	
Aluminium oxide, fused crude	Germanium	Aluminium oxide, fused crude	Lanthanum
Antimony	Manganese metal, electrolytic	Antimony	Magnesium
Beryllium metal	Scandium	Beryllium metal	Manganese metal, electrolytic
Bismuth	Silicon carbide	Boron carbide	Silicon carbide fibre, multifilament
Carbon fibre	Specialty rare earth oxide	Carbon fibre	Tungsten ores and concentrates
Chromium metal	Tantalum	Chlorosulfonated polyethylene (CSM)	Tungsten-rhenium (W-Re) alloy
Dysprosium	Terbium	Europium	Yttrium oxide, high purity
Erbium	Thulium	Germanium	
Fluorspar acid grade	Tin		
Gallium	Tungsten		
	Yttrium		

Box 1.2: Defining 'critical and/or strategic materials' for the defence sector

Different definitions of the term 'critical' (and 'strategic') materials, which could be metals, minerals or semi-finished materials, are used in both the USA and the EU.

According to the US Strategic and Critical Materials Report (2015), the USA Stock Piling Act defines strategic and critical materials as those which:

- Would be needed to supply the military, essential civilian and industrial needs, during a national emergency, and
- Are not found or produced in the country (USA) in sufficient quantities to meet such a need.

In the EU, the term 'critical' refers to those raw materials of high importance to the economy in the Union as a whole and whose supply is associated with a high risk.

This study aims to identify materials that are used in defence applications. Assessment of their criticality, according to the EU definition above, is beyond the scope of this work.

Another study conducted in the USA addressed the current issue of REEs and their use in various weapon system components (Grasso, 2013). This study highlighted the options that USA policy-makers may consider, in both the short and long term, for securing access to REEs, such as: establishing material stockpiles for defence purposes, developing a new critical minerals programme, identifying effective alternatives to REEs, establishing partnerships with other countries, and providing financial assistance for their production within the USA.

Although the results of the USA studies and reports are not directly applicable to the EU defence sector due to a different industrial structure and raw materials import dependency, they stress the importance that European competitors place on the issue of raw materials for their defence industry.

Similar work has not been carried out yet at EU level, although some confidential studies on the subject were produced in different European countries such as the UK and France. As mentioned in the previous section, the only overview of the use and role of raw materials in the EU defence sector, albeit broad and incomplete, was given in the annex to the Commission report on critical raw materials for the EU (EC, 2014b) (see Table 1.2).

Table 1.2: Overview of the raw materials and their importance for the European defence industry, according to the reference EC, 2014b. The materials underlined in the first column are also included in the EU's critical raw materials list, published by the European Commission in 2014

Raw material	Main defence applications	Related equipment	Cause of dependency	Type of risk
Tungsten **Copper** **Molybdenum**	Ammunitions, material for ballast, fragment generators and shape charges, nozzle throats and jet vanes (jet engine components)	Thermal vapour compression systems, long-duration motors, anti-armour warheads, aircraft interception warhead and kinetic penetrator	European suppliers need to import most ores and concentrates from outside of Europe in spite of domestic production in Austria, France and Finland	Dependence of the supply on high-quality and high-performance products
Rare earths (those most used in defence applications are: dysprosium, erbium, europium, gadolinium, neodymium, yttrium and praseodymium)	Ammunitions, aeronautics, military surveillance systems, catalytic converters for military motors, permanent magnets, battery cells, nuclear batteries, lasers and X-ray tubes	Motors, actuators, displays and electronic components	European producers are fully dependent on China for these raw materials	Dependence of the supply on a single country
Gallium	Electronic components, integrated circuits, printed circuit boards (PCB), high-power switching	Semiconductor components (in combination with arsenic and nitrogen) for high-power electronics in radars, electronic warfare and communication (phased array) antennae, power conversion for increase of power integration density and efficiency (transversal use for defence systems and platforms), LEDs	Production predominantly outside Europe; demand most likely increasing	Limited availability, increase in demand and price
Titanium	Aeronautics applications for fixed-wing aircraft and helicopters, missile systems, naval vessels	Used in frames to reduce weight and increase durability in extreme conditions	Despite the number of suppliers, Russia and China are dominant with over 40 % of global production	Currently no substitute for titanium in most military applications, risk of increase in demand and price
Other raw materials	**Use in defence applications**			
Beryllium **Cobalt** **Niobium** **Tantalum**	Jet engine components and missile parts			
Platinum Group Metals (PGM)	Electronic devices			
Germanium	Infra-red detectors, thermal imaging cameras, optical fibres			

1.3 An overview of the importance of raw, processed and semi-finished materials in the defence industry

Many raw materials, processed and semi-finished materials are indispensable for the production of defence components and systems because of the high performance requirements which, most of the time, cannot be ensured by the use of conventional substitutes. These materials have unique mechanical, physical, electronic, magnetic/electromagnetic and chemical properties, or superior resistance to corrosion, that make them essential for certain defence applications. High-performance alloys containing niobium, vanadium or molybdenum are used for instance in military aircraft fuselages. Beryllium is used in lightweight alloys in fighter jets, helicopters and satellites because it is six times lighter and stronger than steel, thereby reducing weight and enabling high speed and manoeuvrability. Beryllium is also employed in applications in missile gyroscopes, gimbals and for inner stage joining of elements in missile systems. Titanium-based alloys have high specific strength and excellent corrosion resistance, at just half the weight of steel and nickel-based superalloys – properties that make them indispensable in aeronautics applications. Carbon fibres represent a key constituent of military aircraft, strategic missiles (e.g. Trident II D5) and satellites, thanks to their superior dimensional stability, low thermal expansion coefficient, high strength, high stiffness, low density and high abrasion resistance. However, only a few companies in Europe produce carbon fibres and their precursors.

Box 1.3: Other examples of materials used in defence applications:

- Alloys that contain molybdenum and beryllium are able to maintain their strength and physical properties when exposed to high mechanical stress. They are used for aircraft landing gears;
- Manganese, nickel, molybdenum, chromium and vanadium are present in abrasion- and heat-resistant alloys used for gun barrels in order to extend service time and boost performance;
- A wide array of raw materials, such as antimony, is used in electronic and optical systems, and in particular in semiconductors for making infra-red detectors and diodes for multiple defence applications.

In general, the quantities of raw materials used in defence applications are very small compared with civil applications. This highlights the fact that a potential issue with raw materials in the defence industry is not necessarily the availability of material in large quantities but is more the required quality in terms of material purity or even microstructure.

Box 1.4: Examples of materials of high purity or special structure used in defence applications:

- Purities of level N5+ (equivalent of over 99.999 %) are required for gallium arsenide used in computer chips for defence applications. Only a few producers are capable of producing compounds able to meet this quality requirement, for which there are currently no effective substitutes;
- The production of neodymium-doped yttrium aluminium garnet (Nd:YAG) lasers is highly dependent on imports from outside the EU of some raw materials such as yttrium and neodymium, which are used in very small quantities as dopants to ensure specific physical properties;
- High-purity germanium is required for night-vision systems; special grades of gallium or germanium are needed for radar systems; selenium and tellurium are used in avionics, etc.;
- Superalloys with a single crystal microstructure, coated with a very thin layer of zirconium oxide doped with zirconium (deposited using specific processes) are the only materials used for the production of blades in any high-performance jet engine.

Future developments in defence technologies will increase the demand for many raw materials, such as lithium for batteries, scandium for titanium- and aluminium-based alloys (currently under development), or rare earths, namely neodymium and praseodymium, for the production of NdFeB permanent magnets used in electric engines, for example in remotely piloted aircraft systems (RPAS). Moreover, defence applications under development, e.g. smart coatings, nano-sensors in lightweight uniforms, barcodes for tagging and tracking materials, or sensors to detect life signs, use metal nanoparticles such as gold, titanium, silver, etc. For example, a self-healing artificial material (able to repair/recover itself in case of wear and tear) based on nickel nanoparticles and plastic, which is currently being tested, is expected to have exceptional advantages for defence equipment in the future. Another example is the ceramic alloy called BAM, made from boron, aluminium and magnesium ($AlMgB_{14}$) with titanium boride (TiB_2). This alloy is one of the hardest materials known with potential applications in the production of rifle barrels, armour, blades, jet nozzles and munitions.

Box 1.5: Other examples of complex alloys used in defence applications:

- TA6V alloy (containing circa 90 % titanium, 6 % aluminium and 4 % vanadium) and other high-strength/high-temperature titanium alloys are used in airframes and motors;
- PER718 superalloy (53.9 % nickel, 18.5 % iron, 18 % chromium, 5.2 % niobium, 3 % molybdenum, 0.9 % titanium and 0.5 % aluminium) is used in compressor discs (aircraft propulsion) and high-strength bolts.

Based on the examples mentioned above, it is evident that the defence industry rarely uses raw materials in their elemental state, i.e. as chemical elements or minerals – rather, it utilises high-grade alloys and composites.

1.4 Scope of the study and approach

As highlighted above, a complete list of the raw materials used in the European defence industry and an assessment of their supply risk is currently not available. In this context, the European Commission tasked its Joint Research Centre (DG JRC) to carry out an analysis of the type of raw materials used in the European defence industry. Throughout this analysis, the European Commission regularly exchanged information on progress made with the EDA, which is also working in the area of raw materials and defence. Moreover, the Commission engaged relevant industrial stakeholders for the collection and validation of data used in the analysis. This assessment has built on the JRC's experience in developing the critical raw materials list and previous analyses that assessed the role of raw materials in transforming the European energy system (JRC, 2011 and JRC, 2013).

The aim of this study is to identify the raw materials used in the European defence industry in the context of the EU's raw materials strategy and to assess their import dependency.

The study followed a methodology whereby the most important defence applications were identified and subsequently split into subsystems and components, which ultimately enabled the identification of processed, semi-finished and raw materials used in their manufacture (Figure 1.1). Due to the highly strategic and sensitive nature of the military nuclear sector, those weapon systems (nuclear ballistic and tactical missiles, nuclear submarines) have not been considered within the context of this study.

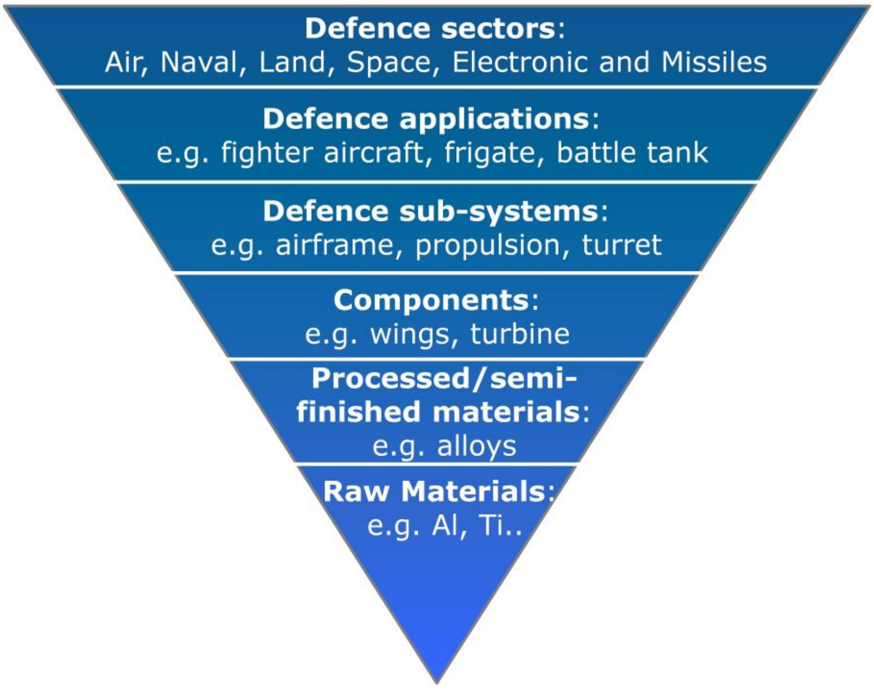

Figure 1.1: Top-down approach followed in this study

More specifically, in a first step, a number of representative defence applications were selected from the land, air, naval, space, electronic and missile sectors. These sectors mirror the wide range of defence applications produced by European companies. In a second step, the selected applications were disaggregated into subsystems and components. In a third step, the processed materials and finally the raw materials used in the production process of those subsystems and components were identified. Where possible, the demand for the materials identified was quantified.

Nevertheless, an increasing number of subsystems, notably from the air, naval, space and electronic sectors, find dual use in both defence and civil applications; hence, the criteria for deciding whether a material is used for defence or civil purposes are becoming increasingly indistinct. Therefore, while the aim of this study is to address the use of materials in defence applications, it should be noted that, to a large extent, the results of the study are also applicable to dual-use applications maximising economic spillovers.

The study is not limited to raw materials, such as minerals or refined metals, since the defence industry usually only uses them once they have been processed, rather than in their raw state. Thus, the study also identified the processed and semi-finished materials, for instance, composites, alloys and compounds that are important in the defence sector. In this report, the term 'important' refers to the capacity of these materials to fulfil the stringent requirements of defence applications.

The EU's import dependency on the raw materials identified was assessed based on the data for EU import/export trade in ores and minerals and primary production. The study also identifies the main countries supplying raw materials to the European defence industry as well as the global and major EU producers of processed and semi-finished materials.

The study used inputs from: (i) industrial stakeholders, including Airbus, Meggitt Avionics, Rolls-Royce and Thales; and (ii) specialised consultants, notably CEIS and BIO Intelligence Services. The consultants gathered inputs from Airbus Group, Astrium, BAE Systems, CSM Italy, Safran, Snecma, Thales and the French Ministry of Defence.

2. Overview of the EU defence industry

2.1 General considerations

The European defence industry comprises a large number of stakeholders, including system integrators and platform producers, system builders, equipment suppliers and an entire network of suppliers involved in the value chain. According to the European Commission, the sector comprises at least 1400 companies in Europe, with over 400 000 employees and generating sales revenue of EUR 96 billion (EC, 2013a). In addition to the aforementioned figures that reflect the economic and social importance of the defence industry, its political and strategic implications are also crucial. Indeed, many of the technologies used in our everyday lives have their roots in the defence industry (e.g. microwave technology, satellite navigation, internet, etc.).

The defence sector is a major industrial player in Europe, with the aeronautics, land and naval sectors accounting for over 95 % of Europe's defence industry turnover (Table 2.1).

Table 2.1: Overview of the main European defence sectors (source: EC, 2013b)

Defence sector	Turnover, 2010 (EUR bn)	Employees, 2010	Examples of key military capabilities	Major system integrators
Aeronautics	46.7	≈ 200 000	Combat aircraft and helicopters: Rafale (France), Gripen (Sweden) and Eurofighter (Germany, Italy, Spain and UK)	EADS[2], BAE, Finmeccanica, and SAAB
Land	≈ 30	128 700	Battle tanks and armoured fighting vehicles, e.g. the Leopard tank (Germany)	BAE Systems, Rheinmetall, Krauss-Maffei Wegmann (KMW), Nexter, and Patria
Naval	17	83 200	Warships	BAE, DCNS, Babcock/VT, TKMS, Navantia, Fincantieri, and Thales

In addition to these three main sectors, other areas of European defence activity include electronics (a key enabler of the major sectors, which also plays a crucial role in modern weapon systems), space and missiles.

The defence industry is organised hierarchically with a top-tier structure (Figure 2.1).

[2] EADS - European Aeronautic Defence & Space Co. – has been rebranded as Airbus Group SE

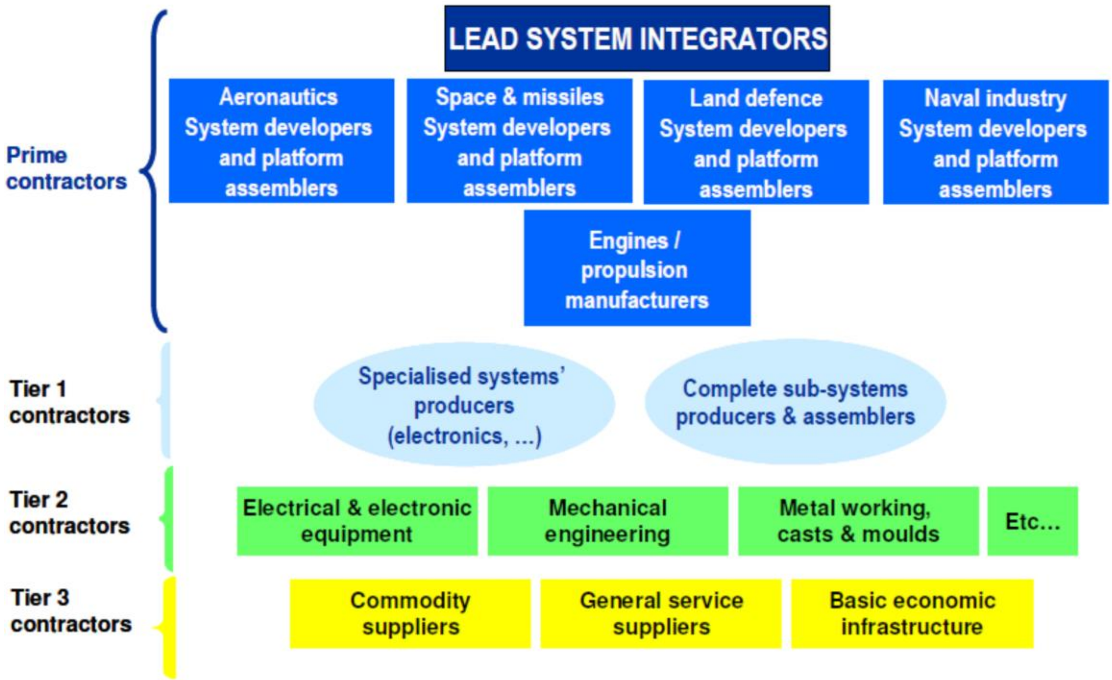

Figure 2.1: Structure of the defence value chain industries (source: EDTIB, 2013)

There are relatively few large companies able to assemble complex weapon systems, known as original equipment manufacturers (OEMs), lead system integrators or prime contractors. For the production of their defence products, the OEMs are supported by companies and subcontractors lower down the production chain that supply the OEMs with specific components, subsystems and products. European defence industrial production is concentrated in six countries: UK, France, Italy, Germany, Sweden and Spain, together accounting for 87 % of overall European defence production (EC, 2013b). Details of the estimated number of defence-related applications produced by European industry as well as the manufacturers are presented in Appendix 1. The 20 largest European defence companies which are ranked highest in the top 100 defence companies in the world are also located in these six European countries (Table 2.2).

Although the global decline in arms sales which began in 2011 is continuing, fears of a deep decline in sales among European companies have yet to materialise. Overall, sales of European defence products in 2013 were mixed across Europe, with some companies showing growth while others were in decline. These contrasting trends indicate diverse national policies with regard to government budget priorities as well as different success rates among individual OEMs in export markets. Exports of European defence equipment to markets such as the Middle East, Asia and South America represent an important factor in compensating for the reduction in EU Member State' demand, as it has been estimated that these markets will grow at a faster rate than the European market (Figure 2.2). For instance, in 2011, over half of sales made by the top 15 European industry suppliers were completed with non-European countries (EC, 2013b).

Table 2.2: Highest-ranked European defence companies in Stockholm international peace research institute (SIPRI) Top 100 (source: EC, 2013b and SIPRI, 2014). Note: 'S' in the first column denotes a subsidiary company

World ranking 2013	Company	Country	Arms sales (USD million)			Arms sales share (% of total sales), 2013	Employment, 2013
			2011	2012	2013		
3	BAE Systems	UK	29 150	26 770	26 820	94	84 600
7	EADS (now Airbus Group SE)	Trans-European	16 390	15 400	15 740	20	144 060
9	Finmeccanica	Italy	14 560	12 530	10 560	50	63 840
10	Thales	France	9480	8880	10 370	55	65 190
S	EADS Cassidian (EADS)	Trans-European	-	6420	6750	85	28 800
14	Rolls-Royce	UK	4670	4990	5550	23	55 200
16	Safran	France	5240	5300	5420	28	66 230
19	DCNS	France	3610	3580	4460	100	13 650
S	Eurocopter Group (EADS)	France/ Germany	3540	3700	3760	45	22 400
S	MBDA (BAE Systems, UK/EADS, trans-European /Finmeccanica Italy)	Trans-European	4170	3860	3720	100	10 000
26	Babcock International Group	UK	2850	3180	3270	59	10 260
S	AgustaWestland (Finmeccanica)	Italy	3440	2940	3180	59	13 230
31	Saab	Sweden	3080	2900	2950	81	14 140
32	Rheinmetall	Germany	2980	3000	2860	14	21 080
39	Serco	UK	2230	2200	2560	32	120 540
S	EADS Astrium (EADS)	France/ Germany/ UK	2350	2540	2530	33	17 000
45	CEA	France	2300	2190	2270	40	15 870
S	Selex ES SpA (Finmeccanica)	Italy	-	880	1930	73	10 600
52	Dassault Aviation (Dassault Aviation Groupe)	France	1240	1410	1840	35	8080
55	Cobham	UK	2160	1880	1820	65	10 090

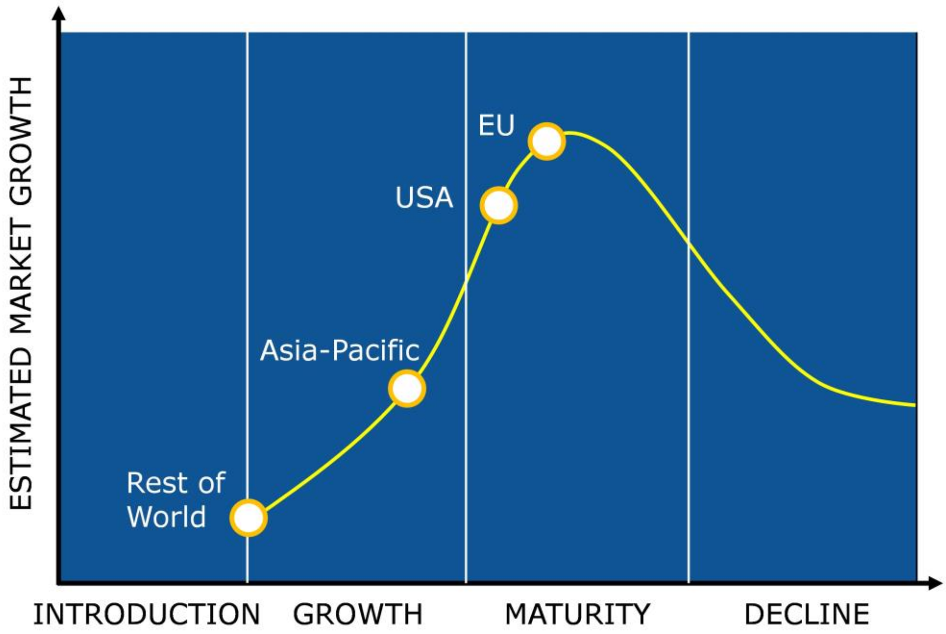

Figure 2.2: Broad view of the global market for defence applications: Asia-Pacific includes China, South Korea, Japan and India; Rest of World: e.g. Brazil

There are efforts at the European level to consolidate the defence industry which is still highly fragmented and often leads to overcapacities and duplications. In 2007, the EU Member States agreed on establishing the European Defence Technological and Industrial Base (EDTIB), which aims to create a genuine internal market and industrial base, and a competent and globally competitive and innovative European defence sector (EDTIB, 2013). The gradual implementation of this strategy at the European rather than national level should also address self-sufficiency for the security of supply, including raw materials.

2.2 Identification of key defence systems and applications

The European defence industry produces a large number of systems, subsystems and applications and involves a significant number of OEMs and subcontracting companies. In the context of this study, the identification and estimation of the demand for materials required for the production of such equipment and defence products was based on the most important representative defence applications selected based on the following criteria:

- Criterion 1: Applications that require large quantities of materials to be built (e.g. warships) and those that are produced in high numbers (e.g. main battle tanks);
- Criterion 2: Applications that are strategic assets (e.g. fighter aircraft) and are thus essential for the military capacity of the Member States;
- Criterion 3: Applications that are high-tech systems (e.g. satellites) that represent a force multiplier on the battlefield, and require specific materials, for instance of high purity.

Based on this set of criteria, a list of defence applications has been compiled that are representative of the European defence industry. These applications are grouped into six sectors: air, naval, land, space, electronic and missile (Tables 2.3 to 2.8).

Table 2.3: Representative defence applications and system integrators for the air sector

Air applications (8)	Example	System integrator	Criteria
Fighter aircraft	Rafale Eurofighter Gripen F-35	Dassault Aviation Airbus D&S, Finmeccanica (Alenia Aermacchi), BAE Systems Saab Finmeccanica, BAE Systems	2, 3
Combat helicopter	Tiger A129 Mangusta	Airbus Helicopters AgustaWestland	2, 3
Transport aircraft (heavy)	A400M	Airbus D&S	1, 2
Transport aircraft (tactic)	CN-235	Airbus D&S	2
Maritime patrol aircraft	Falcon 50M	Dassault Aviation	2, 3
Multi-role helicopter	NH90 AW101	Airbus Helicopters AgustaWestland	2, 3 2, 3
Unmanned aerial vehicle	S100 Camcopter	Schneibel	2, 3
Unmanned fighter aerial vehicle	nEUROn	Dassault Aviation	2, 3

Table 2.4: Representative defence applications and system integrators for the naval sector

Naval applications (7)	Example	System integrator	Criteria
Aircraft carrier	Elizabeth-class	BAE Systems	1, 2, 3
Amphibious assault ship and helicopter carrier	Mistral-class Juan Carlos-Class	DCNS Navantia	1, 2, 3
Destroyer and frigate	FREMM Type 124	DCNS and Fincantieri TKMS	1, 2, 3
Corvette	Holland-class	Damen	1, 2, 3
Offshore patrol vessel	Gowind-class	DCNS	1, 2, 3
Submarine	Type-212 Scorpene-class	TKMS DCNS	1, 2, 3
Torpedo	Spearfish Black Shark	BAE Systems Whitehead Sistemi Subacquei	2, 3

Table 2.5: Representative defence applications and system integrators for the land sector

Land applications (7)	Example	System integrator	Criteria
Main battle tank	Leopard-2	Krauss-Maffei Wegmann	1, 2
Infantry fighter vehicle	VBCI Puma IFV Boxer	Nexter KMW and Rheinmetall Rheinmetall	1, 2
Armoured personnel carrier	Patria AMV	Patria	1, 2
Self-propelled artillery	CAESAR Panzerhaubitze 2000	Nexter Krauss-Maffei Wegmann and Rheinmetall	1, 2
Towed artillery	105 LG	Nexter	1, 2
Ammunitions	M982 Excalibur (155 mm) BONUS (155 mm) DM53 (120 mm)	BAE Systems Bofors Nexter and BAE Systems Bofors Rheinmetall	2
Assault rifle	G36	Heckler & Koch	2

Table 2.6: Representative defence applications and system integrators for the space sector

Space applications (7)	Example	System integrator	Criteria
Infrared satellite	Spirale	Thales (TAS)	2, 3
Radar satellite	SAR Lupe	OHB System	2, 3
ELINT satellite	CERES	Airbus D&S	2, 3
Communication satellite	Syracuse	Thales (TAS)	2, 3
Optical satellite	Helios	Airbus D&S, Thales Alenia Space	2, 3
Navigation satellite	Galileo	Airbus D&S, Thales Alenia Space	2, 3
Launch systems	Ariane-V Vega	Airbus D&S ESA and Italian Space Agency	1, 2

Table 2.7: Representative defence applications and system integrators for the defence electronics sector

Electronic applications (2)	Example	System integrator	Criteria
Radar	Giraffe	Saab	2, 3
Communication systems	FIST	Thales UK	2, 3

Table 2.8: Representative defence applications and system integrators for the missile sector

Missile applications (5)	Example	System integrator	Criteria
Air-air missile	MICA IR	MBDA	2, 3
Surface-air missile	Aster 30	MBDA	2, 3
Anti-tank missile	MILAN	MBDA	2, 3
Anti-ship missile	Exocet	MBDA	2, 3
Cruise missile	SCALP/Storm shadow	MBDA	2, 3

More information about each defence application (i.e. application, producer, country of origin and country in service) is presented in Appendix 2.

In order to identify the materials needed by the defence industry, each defence application was split into subsystems and components. The composition of those components in terms of materials used in the production process has been identified and quantified whenever this information was available, and is presented in the following chapter.

3. Inventory of materials used in defence applications at system and component level

This chapter identifies the subsystems and components used in assembling defence applications and the materials needed for their production. This information was collected, following the approach described in section 1.4, from available literature, through the contracted companies (CEIS and BIO Intelligence Service), and from industrial stakeholders.

The inventory reveals valuable information about both the disaggregation of defence applications in subsystems, components and constituent materials, and the perception of the issue of raw materials within the European defence industry. While information about the composition of the components and subsystems was readily obtained in some sectors (e.g. air, naval and land), in certain cases (e.g. the space and electronic sectors) this information was not found, for two main reasons:

- The information was not shared due to issues of confidentiality, from either commercial or security perspectives;
- The lead system integrators or even the subcontractors downstream in the supply chain are not fully aware of the materials used in their systems. Industrial stakeholders admit that the management of material flows a couple of tiers down in the supply chain becomes very opaque.

The analysis showed that similar subsystems between applications, for example, the 'airframe' in transport, fighter and unmanned aircraft, comprise the same components (e.g. 'body', 'wings', 'tail', 'nose' and 'axis'). The components for these similar sub-systems are made mostly from the same types of material, although in different quantities. To avoid repeating similar information, the inventory of materials for each component, produced in this study, is built upon the aggregation of subsystems in similar 'generic' applications, for example, 'aircraft', 'submarine' or 'missile'.

The list of materials used for components in the subsystems of 'generic' applications in all sectors is presented in Tables 3.1 to 3.6. Information not available is denoted by N.A.

Table 3.1: Decomposition of the air-sector-related generic defence applications into subsystems, components and materials

Defence application	Subsystem	Component	Materials used
Aircraft (fighter, transport, maritime patrol and unmanned)	Airframe	Body	Carbon-epoxy composite (fibre T800)
			Aluminium alloy 7000 series (7010, 7040, 7050, 7075) and 2000 series (e.g. 2024)
			Other alloys containing: beryllium, cadmium, chromium, germanium, gold, lead, nickel, tantalum, tin, tungsten and molybdenum
		Wings	Carbon-epoxy composite (fibre T800)
			Aluminium alloys 2000 series (e.g. 2024) and 7000 series (e.g. for upper skin)
			Titanium alloy, mainly TA6V
		Tail	Carbon-epoxy composite (fibre T800)
			Aluminium alloy 2000 series (e.g. 2024)
			Titanium alloy, mainly TA6V
		Nose	Kevlar, glass-fibre-epoxy

Defence application	Subsystem	Component	Materials used
Aircraft (fighter, transport, maritime patrol and unmanned) (continued)	Airframe (continued)	Axis	Special steel alloy, e.g. MARVAL X12
	Propulsion	Fan & compressors	Mainly titanium-based alloys (e.g. TA6V) Carbon-fibre composites
		Combustor	Nickel superalloy (e.g. N-18) Aluminium-magnesium alloy in the carter Superalloys (e.g. HS25, HS31, HS188)
		Turbine (high pressure and lower pressure)	Nickel single-crystal alloy (e.g. AM1) Nickel-aluminium-platinum or yttrium-stabilised zirconia in the thin coating of turbine blades (thermal barrier coating) Nickel alloy (e.g. Inco 718)
		Nozzle	Carbon-carbon composite
		Post combustion	Carbon-carbon composite
		Drive shaft and propellers (for maritime patrol and transport aircraft)	Kevlar composite
	Landing gear	Landing gear body	Aluminium alloys Copper-beryllium alloys Titanium and titanium alloys Special steels, e.g. MLX19
		Wheels	Rubber
		Brakes	Composites
	Electronic systems	Sensors & avionics	Gallium arsenide Mercury-cadmium-telluride crystals Germanium and compounds with germanium Kevlar Aluminium alloys Titanium alloys Other compounds, substrates and alloys containing: rare earths, nickel, boron, indium and cobalt
		Communication / identification systems	Gallium arsenide 99.999+ % Gallium nitride 99.999+ % Beryllium alloys (copper-beryllium, aluminium-beryllium) Other compounds containing silver
		Energy storage	Barium titanate Lithium compounds

Defence application	Subsystem	Component	Materials used
Aircraft (fighter, transport, maritime patrol and unmanned) (continued)	Electronic systems (continued)	Electro-optical systems	Mercury cadmium telluride crystals
			Neodymium-doped yttrium aluminium garnet
			Kevlar
			Copper-beryllium alloys and beryllium oxides
			Carbon-carbon composites
			Rare earths (all except scandium, promethium, terbium, lutetium)
			Gallium arsenide
			Other compounds with indium, selenium, germanium or boron
			Zinc sulphide
			Zinc selenite
			Thorium fluoride
			Tantalum peroxide
			Hafnium dioxide
			Titanium dioxide
	Weapon systems	Canon, missile and bomb (for fighter aircraft)	N.A.
		Chaff (counter measure)	N.A.
		Flares	N.A.
	Connectors	All integrated wire network	Aluminium-beryllium alloys
			Copper
	Canopy	Canopy	Special glass
			Germanium compounds
Helicopter (combat and multi-role)	Airframe	Body	Aluminium alloy
			Titanium alloy
		Wings	Carbon reinforced polymer fibres and Kevlar
			Aluminium and aluminium alloys
		Tail	Copper-bronze alloy
	Propulsion	Compressors	Cast aluminium light alloy
			Inconel nickel alloy
			Steel
			Titanium
		Combustor	Aluminium-magnesium alloy
			Yttrium in alloys
			Superalloys (e.g. HS25, HS31, HS188)
		Turbine	Single-crystal materials (e.g. CMSX4 alloy) including rhenium

Defence application	Subsystem	Component	Materials used
Helicopter (combat and multi-role) **(continued)**	Propulsion (continued)	Nozzle	N.A.
		Drive shaft	Fibre elastomer Titanium Composite
	Dynamic parts	Main gearbox	N.A.
		Drive shaft	Kevlar Carbon laminate
		Rotors	Glass fibre reinforced plastics Fibre-composite
	Landing gears	Landing gear body	Copper-beryllium alloys
		Wheels	N.A.
		Brakes	N.A.
	Electronic systems	Sensors	Mercury cadmium telluride crystals Laser crystals as neodymium-doped yttrium aluminium garnet (Nd-YAG) Compounds containing indium Carbon and carbon composites Beryllium oxides and beryllium-copper alloy
		Avionics	N.A.
		Communication / identification systems	Gallium arsenide 99.999+ % Gallium nitride 99.999+ % Beryllium alloys (with copper or aluminium) Silver compounds
		Energy storage	Barium titanate and compounds with lithium
		Electro-optical systems	Mercury cadmium telluride crystals Laser crystals as Nd-YAG Indium compounds Beryllium oxides and beryllium-copper alloys Carbon and carbon composites
	Weapon systems	Canon, missile and bomb (for combat helicopter)	N.A.
		Machine gun	N.A.
		Flares	N.A.
	Connectors	All integrated wire network	Copper Aluminium-beryllium alloys
	Canopy	Canopy	Nomex honeycomb material with carbon and Kevlar skins

The distribution of materials in the various parts of a fighter aircraft (Rafale) and a transport aircraft (A400M) is shown in Figures 3.1 and 3.2. It is noted that these pictures show the distribution of raw materials and not the alloys used in the application, i.e. titanium, aluminium and vanadium instead of TA6V.

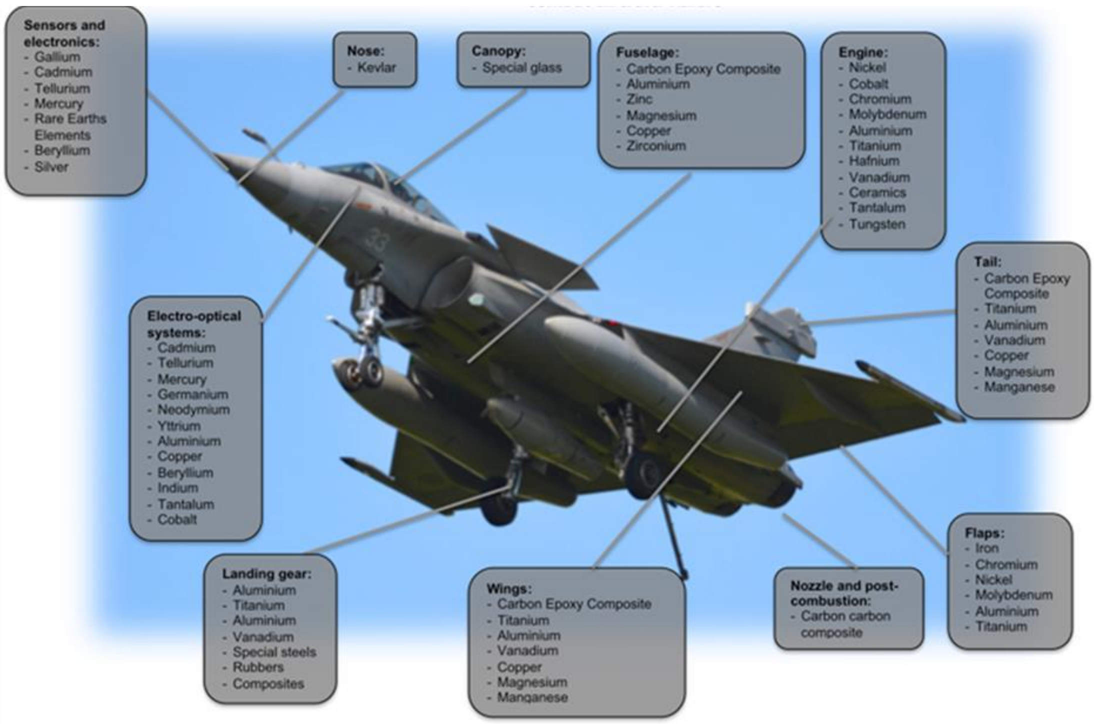

Figure 3.1: Components and raw materials used in different parts of the combat aircraft Rafale produced by Dassault Aviation (France) (source: CEIS)

Figure 3.2: Components and raw materials used in different parts of the transport aircraft A400M produced by Airbus D&S (source: CEIS)

Table 3.2: Decomposition of the naval sector-related generic defence applications into subsystems, components and materials

Defence application	Sub-system	Component	Materials used
Aircraft and helicopter carrier, amphibious assault ship	Hull	Belt	Special steel Titanium
		Upper belt	Special steel Titanium
		Bulkheads	N.A.
		Turrets	N.A.
		Barbettes	N.A.
		Conning tower	N.A.
		Conning tower tube	N.A.
		Submerged torpedo tubes	N.A.
	Propulsion	Integrated full electric propulsion (IFEP)	Compounds and alloys containing lithium, cobalt, samarium, lead, etc. Barium titanate
		Gas turbine	Titanium alloys Nickel-based alloys
		Diesel turbine	Composites Nickel-copper-aluminium alloy
		Advanced induction motors	N.A.
		Azimuth thrusters (e.g. for Mistral class)	Bronze Copper
		Five-bladed propellers (e.g. for Mistral class)	Composites Nickel-copper-aluminium alloy
		POD (propulsion with outboard electric motor, e.g. for Juan Carlos class)	Samarium-cobalt alloy Barium titanate
	Super-structure	Deck	Aluminium alloys Composites Special steel
		Flight deck	Special steels MARVALX12, MLX17 and MY19
		Hangar	Special steels NYB66 Inconel 625 and PYRAD53NW superalloys
	On-board electronics	Long-range radar	Gold
		3D medium-range radar	Gold
		Electro-optical system	N.A.
		Glide-path camera	N.A.

Defence application	Sub-system	Component	Materials used
Aircraft and helicopter carrier, amphibious assault ship (continued)	On-board electronics (continued)	Navigation radar	Aluminium Steel Graphite-epoxy Titanium Gold
		Air/surface sentry radar	N.A.
		Optronic fire-control systems	N.A.
	Armament	Naval guns	Aluminium alloys Composites CLARM HB7 steel
		Anti-aircraft guns	N.A.
		Torpedo	N.A.
		Sinbad missile defence systems	N.A.
		Browning machine guns	Alloys containing copper, silver, nickel, tin, zinc or lead
Corvettes, offshore patrol vessels and frigates	Hull	Hull	Special steel Titanium Light alloys Composites
	Propulsion CODLOG/ CODLAG (combined diesel-electric and/or gas)	Gas turbine	N.A.
		Electric motors	Lithium compounds Samarium-cobalt alloy Lead and lead compounds Barium titanate
		Diesel engines and generators	N.A.
		Gearboxes (for diesel engines, gas turbine and cross connection)	N.A.
		Motor	N.A.
		Shafts, driving controllable pitch propellers	Composites Nickel-copper-aluminium alloy
		Bow thruster	N.A.
	Super-structure	Decks	Aluminium 5000 and 6000 series alloys Composites and glass-reinforced plastics Special steels NYB66 Inconel 625 and PYRAD53NW superalloys
	On-board electronics	Multi-purpose passive electronically scanned array radar and active electronically scanned array radar	N.A.

Defence application	Sub-system	Component	Materials used
Corvettes, offshore patrol vessels and frigates **(continued)**	On-board electronics (continued)	Long-range air and surface surveillance radar (D band)	Gold Special steel APX4
		Air and surface detection, tracking and guidance radar (I band)	Gold Special steel APX4
		Long-range infra-red surveillance and tracking system	N.A.
		Multi-function I/J band ARPA radars	N.A.
		Electro-optical fire control and 360° surveillance system	N.A.
		Bow sonar	Carbon composites Piezoelectric ceramics
		Combat Management System	N.A.
	Armament	Anti-air and anti-ship missiles	N.A.
		VLS (vertical launching system) for anti-air missiles	N.A.
		Guns	N.A.
		Naval guns	Aluminium alloys Composites CLARM HB7 steel
		Small guns	N.A.
		Remote weapon systems	N.A.
		Land-attack cruise missiles	N.A.
		VLS for land-attack cruise missiles	N.A.
		Anti-submarine warfare	N.A.
		Launcher for torpedoes	N.A.
		Torpedoes	N.A.
		CIWS (Close-in weapon system)	N.A.
		Gas-operated cannon	N.A.
		CIWS (Close-in weapon system)	N.A.
		RAM launchers	N.A.
Submarine	Hull	Hull	Ultra-high-strength low alloy steel (HSLA) Special steel Titanium
	Propulsion	Diesel engine	MARVAL18 steel Barium titanate
		PEM fuel cells	Platinum
		Electric motor	Samarium-cobalt alloy
		Seven-bladed skewback propeller	Carbon composite

Defence application	Sub-system	Component	Materials used
Submarine (continued)	Propulsion (continued)	AIP (Air Independent Propulsion)	N.A.
		Batteries	Lead and lead compounds Lithium compounds Silver compounds
	Super-structure	Decks	Carbon composites
		Habitations	N.A.
	On-board electronics	Sonar	Carbon composites Piezoelectric ceramics
		Periscope	Carbon composites APX4 steel
		ESM system	N.A.
		Combat Management System	N.A.
		Electronic warfare systems	N.A.
		Navigation radar	N.A.
	Armament	Torpedo tubes	
		Torpedoes	Silver-oxide aluminium (AgO-Al) Compounds containing lead, lithium or silver Aluminium alloys
		IDAS missiles	N.A.
		External naval mines	N.A.
		Anti-ship missiles	N.A.
		Cruise missiles	N.A.
		Mines	N.A.
Torpedoes	Propulsion	Sundstrand gas turbine with pump jet	Compounds containing lead, lithium or silver Aluminium alloys
		Contra-rotating direct-drive brushless motor	Aluminium alloys Lead and lead compounds
		Battery	Silver-oxide aluminium (AgO-Al) Compounds containing lead, lithium or silver

Figures 3.3 and 3.4 show the location of materials in the principal parts of a naval surface vessel and a submarine, respectively:

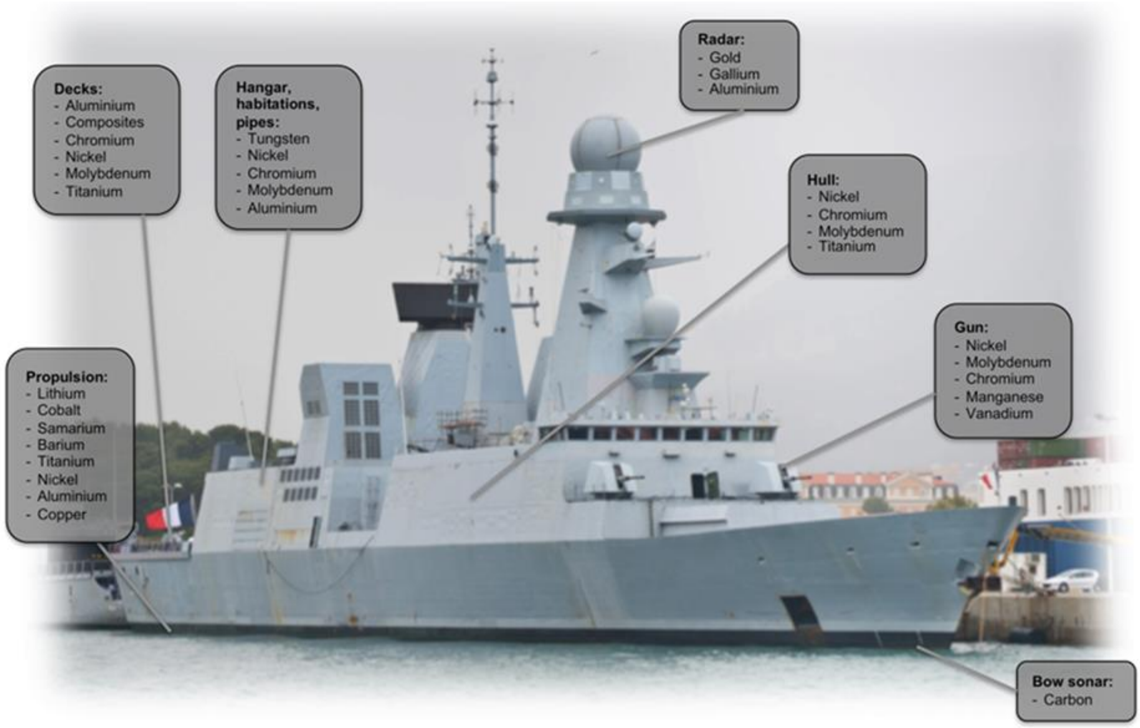

Figure 3.3: Components and raw materials used in a naval surface vessel (source: CEIS)

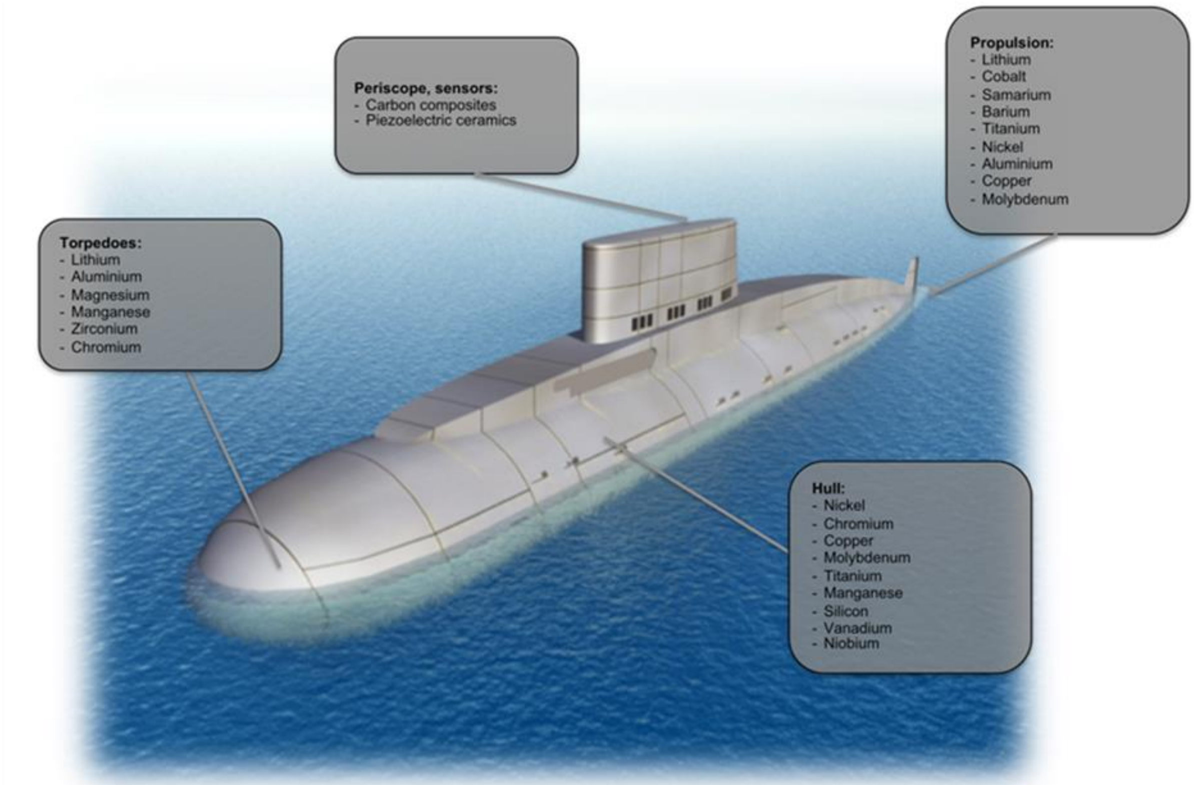

Figure 3.4: Components and raw materials used in a submarine (source: CEIS)

Table 3.3: Decomposition of the land sector-related generic defence applications into subsystems, components and materials

Defence application	Sub-system	Component	Materials used
Main battle tank	Armour	Hull, turret, tank floor	Composites, tungsten alloys, titanium, beryllium alloys, light aluminium alloys, very high hardness steel
	Propulsion	Turbo-diesel engine	N.A.
	Running gear	Dual rubber-tyred road wheels	N.A.
		Return rollers	N.A.
	On-board electronics	NBC over pressurisation system	N.A.
		Fire-control system	N.A.
		Telescope and periscope	N.A.
		Binoculars	Mercury cadmium telluride crystals Compounds containing germanium, copper or tantalum Quartz ceramics
	Armament	Smoothbore tank gun	Carbon Manganese alloys
		Machine gun	Alloys containing nickel, molybdenum, chromium, vanadium, etc.
		Shells	N.A.
		Smoke mortars	N.A.
Infantry fighter vehicle, armoured personnel carrier and self-propelled artillery	Armour	Hull API Turret	Welded light aluminium alloy Very high hardness steel Composites Titanium Beryllium alloys
	Propulsion	Turbo diesel	N.A.
	Running gear	Wheels	N.A.
	On-board electronics	*Leurre infrarouge* (LIRE)	N.A.
		SIT communication equipment	Gallium arsenide 99.999+ % Gallium nitride 99.999+ % Be alloys (e.g. beryllium copper or beryllium aluminium) Silver
		Fire control (laser telemeter + thermal camera)	N.A.
		Combat identification equipment/IR	Germanium 99.999+ Quartz ceramics Glass Copper

Defence application	Sub-system	Component	Materials used
Infantry fighter vehicle, armoured personnel carrier and self-propelled artillery (continued)	On-board electronics (continued)	Combat identification equipment/IR (continued)	Compounds/alloys containing tantalum or indium Mercury cadmium telluride crystals Laser crystals as neodymium-doped yttrium aluminium garnet Carbon and carbon composites Beryllium oxides Beryllium copper alloy
		NBC detection and protection equipment	N.A.
		Sensors	N.A.
		Periscope	N.A.
		Inertial navigation system	Germanium 99.999+ Quartz ceramics Glass Copper Compounds/alloys containing tantalum or indium Mercury cadmium telluride crystals Laser crystals as neodymium-doped yttrium aluminium garnet Carbon and carbon composites Beryllium oxides Beryllium copper alloy
		Phased array radar	Ceramics Mercury cadmium telluride crystals Neodymium-doped yttrium aluminium garnet Kevlar Beryllium copper alloys Carbon-carbon Rare earths (all except scandium, promethium, terbium, lutetium) Gallium arsenide Compounds of indium or selenium Germanium and germanium compounds Zinc sulphide Zinc selenite Thorium fluoride Tantalum peroxide Boron compounds Hafnium dioxide Titanium dioxide
	Armament	Cannon	Special performance steels (CLARM HBR, CLARM HB3, CLARL HB7, GKH and GK4W)
		Shells	N.A.

Defence application	Sub-system	Component	Materials used
Infantry fighter vehicle, armoured personnel carrier and self-propelled artillery (continued)	Armament (continued)	Coaxial machine gun, Howitzer	Alloys containing carbon, manganese, nickel, molybdenum, chromium, vanadium
		Galix grenade-launching system	N.A.
		Mortar carrier	N.A.
Towed artillery	Running gear	Split trail	Steel alloys
	On-board electronics	Inertial navigation	Germanium 99.999+ Quartz ceramics Glass Copper Compounds containing tantalum or indium Mercury cadmium telluride crystals Laser crystals as neodymium-doped yttrium aluminium garnet Carbon and carbon composites Beryllium oxides Beryllium copper alloy
	Armament	Howitzer	Alloys containing carbon, manganese, nickel, molybdenum, chromium, vanadium
Ammunition	Shell	Body	Titanium and titanium alloys
		Base	N.A.
		Ballistics	N.A.
		Payload	N.A.
	On-board electronics	GPS/SAL guidance system	Germanium 99.999+ Quartz ceramics Glass Copper Compounds containing tantalum or indium Mercury cadmium telluride crystals Laser crystals as neodymium-doped yttrium aluminium garnet Carbon and carbon composites Beryllium oxides Beryllium copper alloy
Assault rifle	Structure	Body	Special steels (e.g. NCAV, FDMA, 819B, MY18,FDMA, FADH, 819AW, GHK, FND)
		Telescopic sight	N.A.
		Barrel	Special steels (GKH, GH4W, F65) Special stainless steels (MLX12 and MLX12H)

Examples of the location of different components and raw materials in a main battle tank and assault gun are represented in Figures 3.5 and 3.6, respectively.

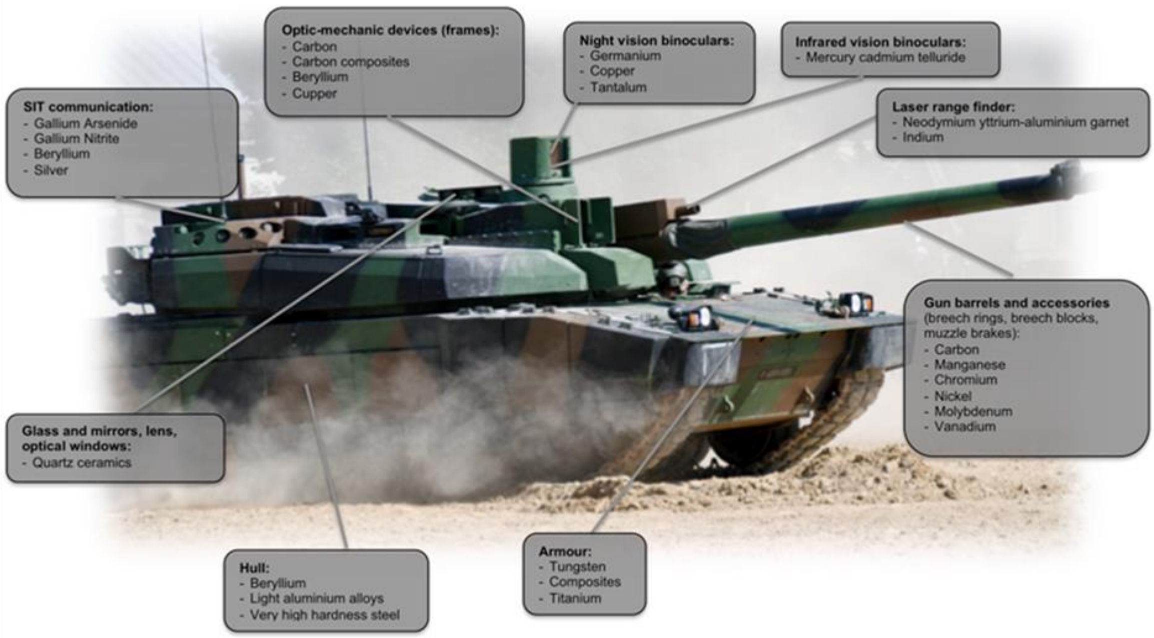

Figure 3.5: Components and raw materials used in a main battle tank (e.g. Leclerc), but also representative of infantry-fighting and armoured-fighting vehicles (source: CEIS)

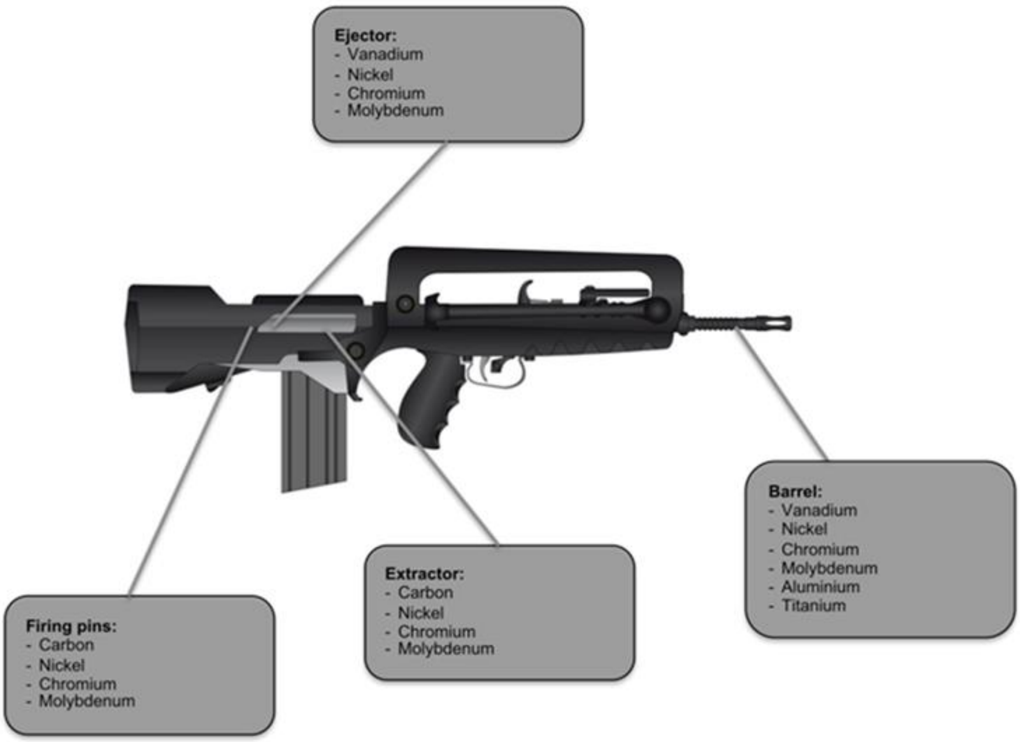

Figure 3.6: Components and raw materials in assault gun (e.g. Famas) (source: CEIS)

Table 3.4: Decomposition of the space-sector-related generic defence applications into subsystems, components and materials

Defence application	Subsystem	Component	Materials used
Satellites	Frame	Frame	N.A.
	Propulsion	Main and secondary motors	N.A.
		Solar panel	N.A.
	Electronic systems	Sensor	N.A.
		Positioning	N.A.
		Communication/identification systems	N.A.
		Energy storage	N.A.
		Electro-optical systems	N.A.
	Connectors	All integrated wire network	N.A.
Launch systems	Frame	Body	N.A.
		Nose	N.A.
	Propulsion	Propellants Fan and compressors Combustor Turbine Nozzle	N.A. N.A. N.A. N.A. N.A.
	Electronic systems	Positioning	N.A.
		Communication systems	N.A.
		Energy storage	N.A.
	Connectors	All integrated wire network	N.A.
OTHER SYSTEMS RELATED TO THE SPACE SECTOR			
Platform or bus	Structure	Panels Stiffeners Tubes	Carbon-fibre-reinforced plastic, Titanium and metallic alloys
	Thermal control	Heat pipes Radiators Optical solar reflectors (OSR) Thermal blanket	N.A. N.A. N.A. N.A.
	Power supply	Batteries	Lithium compounds
		Solar arrays	Gallium arsenide cells, carbon-fibre-reinforced plastic
		Power control and distribution unit	N.A.
	Data handling	Processor Flight software Payload interface unit GNSS receiver	N.A. N.A. N.A. N.A.
	Altitude-control system	Star tracker Momentum wheel	N.A. N.A.

Defence application	Subsystem	Component	Materials used
Platform or Bus **(continued)**	Propulsion	Tanks Thrusters Engine Pipes	Titanium alloys N.A. N.A. N.A.
	Telemetry	Antenna Wave guides Low-noise amplifier	N.A. N.A. N.A.
Optical observation payload	Telescope	Mirrors	N.A.
		Lenses	N.A.
		Structure	N.A.
	Focal plane	Detectors	N.A.
		Focal plane base plate	N.A.
		Video electronics unit	N.A.
	Image chain	Compression unit	N.A.
		Mass memory unit	N.A.
		Cyphering unit	N.A.
Payload	Repeater	Travelling wave tubes (TWT)	N.A.
		Electronic power supply (EPC)	N.A.
		Wave guides	N.A.
	Antenna	Reflectors	Carbon-fibre-reinforced plastic
		Structural support	N.A.

Table 3.5: Decomposition of the electronic-sector-related generic defence applications into subsystems, components and materials

Defence application	Subsystem	Component	Materials used
Radar	Transmitter	Transmitter	N.A.
	Waveguide	Waveguide	N.A.
	Antenna	Antenna	N.A.
	Receptor	Receptor	N.A.
	Exploitation system	Exploitation system	N.A.
	Connectors	All integrated wire network	N.A.
Communication systems	Transmitter	Transmitter	Gallium arsenide Gallium nitride Beryllium oxide Silver compounds
	Antenna	Antenna	N.A.
	Receptor	Receptor	N.A.
	Exploitation system	Exploitation system	N.A.
	Connectors	All integrated wire network	N.A.

Table 3.6: Decomposition of the missiles-sector-related generic defence applications into subsystems, components and materials

Defence application	Subsystem	Component	Materials used
Missiles	Radome	Sensors/seeker	Fused silica ceramics High-temperature co-fired ceramics Low-temperature co-fired ceramics Composites Silicon rubber Nickel alloys
	Guidance section	Guidance package	Niobium alloys Epoxy Copper Lithium niobate
	Warhead section	Inertial sensor electronics	N.A.
		Fuse	Copper-molybdenum-tantalum alloy
		Safety and arming device	N.A.
		Warhead	Special steels (e.g. 819B)
	Propulsion system	Propulsion arming and firing unit	Lithium compounds Lead salts Special steels containing aluminium (e.g. APX4) Special steels (e.g. MARVAL X12H, MARAGING 250 & 300, APX4) Samarium-cobalt alloys Neodymium-iron-boron alloys Copper-molybdenum-tantalum alloys
		Propellant	N.A.
		Heat shield	N.A.
	Control actuator section	Motor pump actuator	Samarium-cobalt alloys Neodymium-iron-boron alloys
		Link antennae	N.A.
	Connectors	All integrated wire network	N.A.
	Frame	Body frame	Special steels (e.g. 17.4Ph, 15.5Ph, MARVALX12, MARAGING 250) Tungsten or molybdenum alloys Copper-molybdenum-tantalum alloys Aluminium alloys (2025, 5083, 5086, 6061, 6082, 7010, 7040, 7050, 7175) Titanium and titanium alloys Carbon composites Glass fibres Polyamide resin Ceramic-carbon fibres
		Rudder	N.A.

The main components and raw materials used in a missile are shown in Figure 3.7.

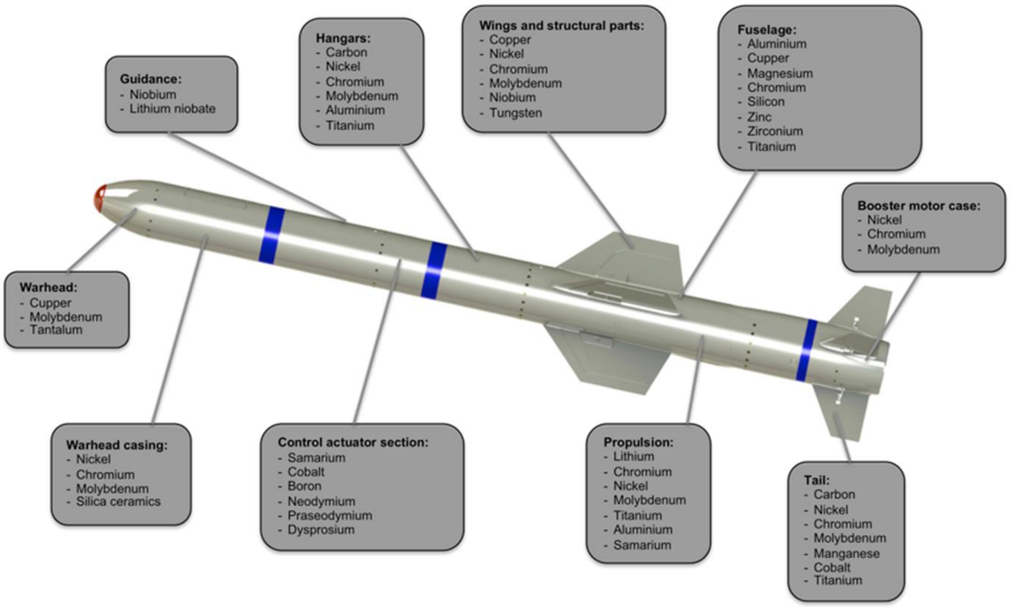

Figure 3.7: Components and raw materials used in a missile (source: CEIS)

An attempt to compile an inventory of raw materials coupled with quantitative data on their usage met with a series of challenges:

- Most industrial actors in the defence industry, particularly the large OEMs, produce dual-use applications, thus their civilian activities coexist with military activities. In many cases, the civilian activities represent a larger part of the company’s turnover (e.g. EADS: 80 %, Safran: 72 %, Finmeccanica: 50 %, see Table 2.2). The same materials are often used in military and civilian applications. As a result, materials are purchased without any distinction being made regarding their use in civilian or military products;
- In general, the consumption of materials for military applications is relatively low compared to that for civilian applications. However, the European naval sector makes an exception of this. According to the Community of European Shipyards Associations (CESA), the share of European naval defence orderbook is about half of the total number of orderbook vessels, mainly driven by the Patrol vessels for the export market. Without taking into account the production timeframe, the value, dimensions, weight and workload of each specific vessel, it can be estimated that the annual consumption of raw materials for the production of naval vessels in Europe is similar if not less to one requested for the civil vessels. There is no indication of any risk in the supply chain of these materials. Key players in the European naval defence industry consider that over 95% of the materials, components and systems are sourced from Europe;
- None of the stakeholders consulted expressed any major concerns and/or awareness about the volume of raw materials they consume. Thus, it can be concluded that the issue of quantity of raw materials used is not perceived as a high priority for the defence industry. On the other hand, the quality of materials is of paramount concern: military application materials have to comply with quality properties (composition, microstructure, physical-chemical or mechanical properties), which are far more stringent than those required for most civilian applications;

- For defence companies, the demand for materials is met with contracts. Hence, many companies perceive the issue of quantities of raw materials as irrelevant since it is linked to signed deals. Thus, the supply of materials is considered solely as a logistic, supply-chain issue. Predicting future demand for materials is challenging for the defence industry in view of the long duration of contract negotiations and programme cycles.

Box 3.1: Development programme for the Tiger fighter helicopter

The Tiger fighter helicopter programme, initiated in 1984, originally involved partners from France and Germany, with Spanish partners joining later. The programme comprises 356 procurement contracts and 441 R&D contracts in Germany alone. Initially, the German military placed an order for 212 helicopters; Australia also placed an order. The first Tiger helicopter from the serial production was delivered in 2010, six years later than projected in 1984. By 2014, only 35 Tiger helicopters had been delivered to the German armed forces. In the meantime, the initial order for 212 units was reduced to 68.

Given the strategic importance of the defence sector for European security, competitive access to all types of material needed by the defence industry is essential to guarantee uninterrupted production and the sustained full operation of all European defence capabilities. As highlighted throughout this report, all these materials are indispensable for the defence industry, irrespective of the quantities involved, since they have essential unique properties and characteristics that ensure the performance of the defence applications in which they are used.

The next chapter focuses on the various types of processed and raw materials used by the European defence industry.

4. Inventory of materials in the European defence industry

4.1 List of processed materials used in defence applications

As explained in the previous chapter, defence equipment is mainly made from processed and semi-finished materials, i.e. alloys, composites and other compounds rather than raw materials as such. For example, gallium is not used in its elemental metallic form but as gallium arsenide, gallium nitride or gallium antimonide in many defence applications such as communications, night vision, radar and satellites. Another example is nickel, which is widely used as a matrix component in superalloys with a single crystal microstructure for blades in the turbines of jet engines. It is also important to recognise that most OEMs do not buy raw materials in their elemental form to produce components, but rather acquire the actual components or semi-finished alloys and other compounds. Table 4.1 summarises and classifies into three categories (i.e. alloys, composites and compounds) the identified semi-finished materials which are used in the defence industry either by last-tier contractors or directly by OEMs.

Table 4.1: List of processed materials used in defence applications

Processed materials	Typical component/ subsystem	Example of defence applications
Alloys (20)		
Aluminium alloy 2000 and 7000 series (2024, 7010, 7040, 7050, etc.)	Internal structural parts of aircraft fuselage and panelling	Fighter aircraft Transport aircraft (tactic and heavy) Maritime patrol aircraft
Aluminium-beryllium alloys	Electronic systems for communication and identification	Fighter aircraft Transport aircraft (tactic and heavy) Maritime patrol aircraft
AM1 Nickel mono-crystalline alloy	Jet turbines in propulsion systems	Fighter aircraft Transport aircraft (tactic and heavy)
Bronze	Bushes, bearings, airframe tail and propulsion systems in azimuth thrusters	Fighter aircraft Combat helicopter Multi-role helicopter
Cadmium mercury telluride	Electro-optical systems for sensors and infra-red detectors	Fighter aircraft Combat and multi-role helicopter Transport aircraft (tactic and heavy) Maritime patrol aircraft Main battle tank
Copper-beryllium alloys	Landing gear body and on-board electronics for phased array radar	Fighter aircraft Transport aircraft (tactic and heavy)
HS25, HS31, HS188 cobalt alloys	Combustor components used in propulsion	Fighter aircraft Combat helicopter Transport aircraft (tactic and heavy) Maritime patrol aircraft

Processed materials	Typical component/ subsystem	Example of defence applications
Inconel and other nickel alloys (e.g. Waspaloy, Nimonic, Udimet, etc.)	Refractory alloy used in aircraft turbojet engines for discs, blades and casing; hangar and desks' super-structure of aircraft and frigates, and for high-strength bolts	Fighter aircraft Combat helicopter Transport aircraft (tactic and heavy) Multi-role helicopter
Light aluminium alloys (other than 2000 and 7000 series), e.g. 5059, 6061 and others (e.g. aluminium-copper-lithium alloys)	Engineering structures and components of lightweight defence vehicles (including marine); armour structures, rocket, missile casing, pipe systems such as fuel, frames and structural parts	Fighter aircraft, Transport aircraft Main battle tank Infantry fighter vehicle
Light alloys – others	Lightweight armour vehicles, rockets, missiles, marine and aircraft structures	Destroyers and frigates
N-18 Nickel superalloy	Turbines, fan and compressors in aircraft engines	Fighter aircraft
Single crystal materials (e.g. CMSX4 alloy)	Major component of turbine engines for aeronautics applications (e.g. helicopters)	Combat helicopter Multi-role helicopter
Special stainless steels (e.g. MLX12 and MLX12H)	Barrel structure of assault rifle	Assault rifle
Special steel alloy MARVAL X12	Axis of ailerons and propulsion arming and firing	Fighter aircraft Transport aircraft (tactic and heavy) Missiles (all)
Special steels MLX19	Landing gears in aircraft and helicopter applications	Fighter aircraft Transport aircraft (tactic and heavy)
Special steels (e.g. NCAV, FDMA, 819B, MY18, FADH, 819AW, GHK, FND, GH4W, F65)	Structure of assault rifle body	Assault rifle Missiles (all)
Special steels MARVAL X12H, MARAGING 250 & 300, APX4, ALUMINUM, 17.4Ph, 15.5Ph	Cruise and propulsion motor of missiles	Missiles (all)
Steel and corrosion resistant steel (CRES steels)	Armour plate for tanks, field artillery pieces; components used in aircraft carriers and submarines; fasteners, bolts	Fighter aircraft Transport aircraft Combat helicopter Multi-role helicopter
Titanium alloy: TA6V (Ti-6Al-4V), Ti3Al2.5V	Tail and wings of airframes, landing gears and propulsion combustor; high-loaded and fatigue-critical parts; hydraulic pipes	Fighter aircraft Transport aircraft (tactic and heavy) Maritime patrol aircraft
Very high hardness steel	Armour components, armour plate, armour piercing projectiles	Main battle tank Infantry fighter vehicle

Processed materials	Typical component/ subsystem	Example of defence applications
Composites (13)		
Carbon laminate	Drive shaft (frames and beams)	Combat helicopter Multi-role helicopter
Carbon composite	On-board electronic for bow sonar and periscope; seven-bladed skewback propeller; super-structure of desks and body frame	Destroyers and frigates Submarines Missiles (all)
Carbon-carbon composite	Post-combustion parts of propulsion systems; nozzles	Fighter aircraft Combat helicopter Transport aircraft (tactic and heavy) Maritime patrol aircraft Multi-role helicopter Infantry fighting vehicle
Carbon-epoxy composite	Aeronautics structural parts such as airframe, wings or fuselage	Fighter aircraft Transport aircraft (tactic and heavy) Maritime patrol aircraft
Ceramic-carbon fibres	Structural parts of missile (e.g. nose cap); heat-shield material for emergency systems/flight recorders on fighter aircraft (black box)	Missiles (all) Fighter aircraft
Co-fired ceramics (low and high temperature)	Optoelectronic module and sensor packaging	Missiles (all)
Composite materials (carbon reinforced polymer fibres and Kevlar)	Rotor blades, fuselage, drive shafts, flight controls and transmission; solar arrays for power supply and antenna of satellites	Combat helicopter Multi-role helicopter
Composites - other	Components of aircraft (e.g. rotor blades, fuselage, drive shafts, flight controls and transmission), tank armour and liners, fighter vehicles (e.g. body, frame, drive shafts, suspension), missiles (e.g. launcher, rocket motor), superstructures, turrets, propeller and parts of modern submarines	Fighter aircraft Multi-role helicopter Aircraft carrier Destroyers and frigates Corvettes Submarines Main battle tank Infantry fighter vehicle Missiles (all)
Fibre-composite	Rotors for dynamic parts of helicopter	Combat helicopter Multi-role helicopter
Fibre elastomer	Drive shaft for propulsion	Combat helicopter Multi-role helicopter
Glass fibre	Components of assault rifle and guided missile motor casings	Missiles (all)
Glass-fibre-reinforced plastics	Rotors for dynamic parts of helicopter	Combat helicopter Multi-role helicopter
Nomex honeycomb with carbon and Kevlar	Canopy and satellite structures	Combat helicopter Multi-role helicopter

Processed materials	Typical component/ subsystem	Example of defence applications
Compounds (14)		
Ceramics	Armour components and combustion chambers of propulsion systems	Fighter aircraft
Epoxy resin	Guidance package of missile's radome	Missiles (all)
Fused silica ceramics	Sensors/seeker of missile's radome	Missiles (all)
Gallium arsenide	Fibre-optic data communications, wireless network, modern night-vision technology, phased array radar, sensor and avionics, other electro-optical systems and satellite (highly efficient solar cells)	Fighter aircraft Transport aircraft (tactic and heavy) Maritime patrol aircraft Communication systems
Gallium nitrite	Semiconductor for electronic devices (radar, transmitter, base stations)	Communication systems
Glass	Optical devices; as sapphire glass in armour	Infantry fighter vehicle
Kevlar	Structural part of airframe (e.g. nose, wings and body), drive shaft, canopy, body armour and flak jackets	Fighter aircraft Combat helicopter Transport aircraft (tactic and heavy) Maritime patrol aircraft Multi-role helicopter
Neodymium Yttrium-Aluminium garnet (Nd-YAG)	Lasers (long-range finders and target designators), phased array radar	Combat helicopter Transport aircraft (tactic and heavy) Multi-role helicopter Maritime patrol aircraft Infantry fighter vehicle
Piezoelectric ceramics	Active element for sonar	Destroyers and frigates Submarines
Polyamide resin	Body frame of missile	Missiles (all)
Quartz ceramics	GPS/SAL guidance system, inertial navigation, combat identification equipment/IR	Main battle tank Infantry fighter vehicle
Rubber	Tyred road wheels for running gears, general wheels	Fighter aircraft
Silicon rubber	Sensors/seeker of missile's radome	Missiles (all)
Special glass	Canopy	Fighter aircraft

Defence applications are mainly made from metallic alloys and composite materials. For example, aluminium alloys (2000 and 7000 series), carbon-epoxy composites as well as titanium alloy TA6V (90% Ti, 6% Al, 4% V) are used in the airframe of the Rafale fighter aircraft. The propulsion system of this aircraft, a gas turbine, is mainly made from two nickel-based alloys (N-18, using cobalt, chromium, molybdenum, aluminium, titanium and hafnium; and AM1, using cobalt, chromium, molybdenum, aluminium, titanium, tantalum and tungsten), as well as from aluminium, titanium and steel alloys that can maintain their high strength properties in a corrosive high-temperature environment (Figure 4.1). The propulsion system in fighter helicopters is also based on a nickel alloy (Inconel).

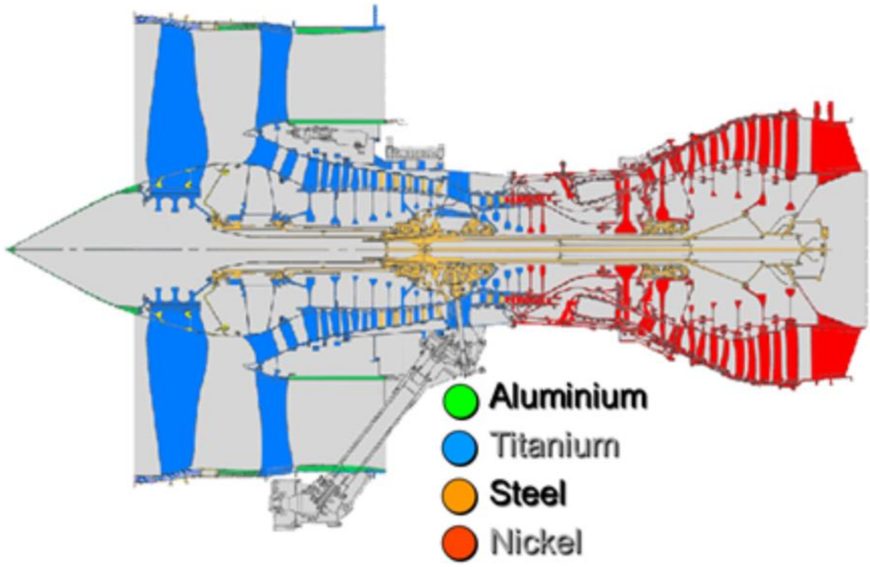

Figure 4.1: Base alloys used in a gas turbine (source: Rolls Royce [Clifton, 2013])

Landing gears in aircraft and helicopters are made of special aluminium alloys and steels, such as MLX19 (with iron, chromium, nickel, molybdenum, aluminium and titanium). In naval applications, the hull of submarines is made of ultra-high-strength low alloy steel (HSLA) containing nickel, chromium, molybdenum, manganese and vanadium. Cannon barrel and missile bodies are also made of special steels (for example, MARVAL X12) and nickel alloys. Aluminium alloys are used to manufacture torpedoes.

4.2 List of raw materials used in defence applications

The aggregated list of raw materials (e.g. metals and non-metals) that constitute the alloys and compounds presented in the previous table, and examples of their roles in the defence sector are listed in Table 4.2. Based on their structure and properties, these raw materials are grouped into four categories: metals, precious metals, rare earth elements and non-metals.

To summarise, 39 raw materials have been identified as necessary for the production of defence-related subsystems and components. The analysis shows that 16 of them are included in the EU's critical raw materials list published by the European Commission in 2014 (EC, 2014b). These are: beryllium, chromium, cobalt, gallium, germanium, indium, magnesium, niobium, tungsten, platinum and six REEs (dysprosium, neodymium, praseodymium, samarium, yttrium and a group of other REEs).

Table 4.2: List of raw materials used in defence applications

Raw materials	Role in defence industry	Examples of defence applications
Metals (28)		
Aluminium	Major component for various alloys and compounds used in aeronautics, in the composition of electro-optical systems (e.g. laser crystal as neodymium-doped yttrium aluminium garnet), navigation radars; also used as light metal in airframe wings	Fighter aircraft Combat helicopter Transport aircraft Maritime patrol aircraft Multi-role helicopter Aircraft carrier Destroyers and frigates Corvettes Submarines Torpedoes Assault rifle Missiles (all)
Barium	In combination with titanium in electric and diesel motors for propulsion, and for energy storage in electronic systems	Fighter aircraft Combat helicopter Transport aircraft Maritime patrol aircraft Multi-role helicopter Main battle tank Infantry fighter vehicle
Beryllium	As an oxide and in various alloys with copper or aluminium to produce different components, for instance in fighter airframes, landing gears, connectors, electronic/optical systems for communication and targeting	Transport aircraft Multi-role helicopter Maritime patrol aircraft Aircraft carrier Destroyers and frigates Submarines
Cadmium	As mercury cadmium telluride in semiconductor for IR imaging systems or in complex alloys used in aircraft's airframe; as alloying element in solders, for corrosion-protection coatings and lubrication; in nickel/cadmium batteries and for coating electrical connectors	Fighter aircraft Transport aircraft Maritime patrol aircraft
Chromium	Component of super- and special alloys used in jet turbines, compressors, bodies, wings and axis for fighter and transport aircraft, construction of submarine hulls, armaments (machine guns and howitzer), electronic systems, and for functional plating, e.g. hard chrome	Fighter aircraft Combat helicopter Transport aircraft Maritime patrol aircraft Multi-role helicopter Destroyers and frigates Corvettes Offshore patrol vessels Submarines Torpedoes Main battle tank Infantry fighter vehicle Assault rifle Missiles (all)

Raw materials	Role in defence industry	Examples of defence applications
Cobalt	Mainly in nickel-based superalloys for turbine, compressors and fans in fighter aircraft propulsion, and in electric motors (magnets) and batteries in combination with samarium and other elements (e.g. nickel or lithium)	Fighter aircraft Combat and multi-role helicopter Maritime patrol aircraft Aircraft carrier Destroyers and frigates Submarines Missiles (all)
Copper	On-board electronics for inertial navigation, binoculars, IR equipment, phased array radars, guidance systems and also as component of alloys used in airframes, landing gear and gas/diesel turbines; propulsion (azimuth thruster five-bladed propellers, diesel engines, propeller shafts) and armament (Browning and machine gun); also used for lightning-strike protection of composite structures	Fighter aircraft Combat and multi-role helicopter Transport aircraft Maritime patrol aircraft Aircraft carrier Destroyers and frigates Corvettes Offshore patrol vessels Submarines Torpedoes Main battle tank Infantry fighter vehicle Missiles (all) Communication systems
Gallium	Communication (e.g. transmitter) and electro-optical systems and on-board electronics as gallium arsenide and gallium nitrite; missile guidance	Combat helicopter Multi-role helicopter Infantry fighter vehicle
Germanium	On-board electronics for inertial and combat navigation, IR tracking systems, binoculars (including night vision), GPS/SAL guidance system; canopy; as substrate in solar cells powering military satellites	Fighter aircraft Transport aircraft Maritime patrol aircraft Main battle tank Infantry fighter vehicle
Hafnium	As hafnium dioxide in electro-optical systems for radar and in a small percentage of superalloys for aircraft propulsion	Fighter aircraft
Indium	Laser targeting, sensors, identification equipment for IR imaging systems and inertial navigation as well as in on-board electronics for phased array radar	Fighter aircraft Combat and multi-role helicopter Transport aircraft Maritime patrol aircraft Infantry fighter vehicle
Iron	Main component of principal special steel alloys and in low percentages in aluminium and nickel-based alloys for construction of different components (e.g. axis of aircraft airframe, body)	Fighter and carrier aircraft Transport aircraft Maritime patrol aircraft Destroyers and frigates Corvettes Offshore patrol vessels Submarines Torpedoes and missiles Assault rifle

Raw materials	Role in defence industry	Examples of defence applications
Lead	Torpedoes, armament (machine guns), for batteries, electric motors and electric propulsion; used for soldering applications (e.g. in aircraft)	Fighter aircraft Transport aircraft Maritime patrol aircraft Aircraft carrier Destroyers and frigates Submarines Torpedoes Missiles (all)
Lithium	Lithium-ion batteries for energy storage, electric propulsion, electronics and in torpedoes; also used as alloying element for high-strength aluminium-based alloys	Fighter aircraft Transport aircraft Multi-role helicopter Maritime patrol aircraft Aircraft carrier Destroyers and frigates Submarines Torpedoes Missiles (all)
Magnesium	As alloy component used in aircraft airframe and missiles; communication equipment, radar and torpedoes; castings for aircraft and helicopters (e.g. gear boxes) and structural parts; frequently used as an alloying element of aluminium-based alloys	Fighter aircraft Combat helicopter Maritime patrol aircraft Destroyers and frigates Corvettes Offshore patrol vessels Torpedoes Missiles (all) Communication systems
Manganese	In aluminium alloys for aeronautics applications and in composition with other steels used for armaments (howitzer and machine/tank gun)	Fighter and carrier aircraft Transport aircraft Maritime patrol aircraft Destroyers and frigates Corvettes Offshore patrol vessels Submarines Torpedoes Main battle tank Infantry fighter vehicle
Molybdenum	Constituent of nickel-based superalloy used in turbine, fan and compressors for propulsion, of other special steel alloys for building the airframe, and ultra-high-strength low alloy steel for submarine hulls; in missile warhead section and propulsion system	Fighter aircraft Transport aircraft Maritime patrol aircraft Destroyers Frigates Corvettes Offshore patrol vessels Submarines Main battle tank Infantry fighter vehicle Assault rifle Missiles (all)

Raw materials	Role in defence industry	Examples of defence applications
Nickel	Principal component of superalloys used in jet turbine, for propulsion, combustor and in other alloys for propeller shafts, controllable pitch propellers and diesel engines; electronic systems, sensors/ seeker in missile; in ultra-high-strength low alloy steel for submarine hulls; used in coatings, e.g. in wear protection (chemical nickel) and for intermediate galvanic layers in coating systems	Fighter aircraft Combat helicopter Transport aircraft Multi-role helicopter Maritime patrol aircraft Aircraft carrier Destroyers and frigates Corvettes Offshore patrol vessels Submarines Main battle tank Infantry fighter vehicle Assault rifle Missiles (all)
Niobium	Guidance section of missiles and in small quantities in composition of nickel super-alloys for high-temperature section of jet turbines	Fighter aircraft Transport aircraft Maritime patrol aircraft Submarines Missiles (all)
Rhenium	Additive in superalloys for turbine engine and aeronautics applications	Combat helicopter Multi-role helicopter
Tantalum	Capacitors for on-board applications: binoculars, identification equipment/IR, inertial navigation, radars; in superalloys used in jet turbines and other propulsion systems; as a liner in shaped charges and explosively shaped penetrators	Fighter aircraft Combat helicopter Multi-role helicopter Main battle tank Infantry fighter vehicle Missiles (all)
Thorium	As thorium fluoride in on-board electronics for phased array radar	Fighter aircraft
Tin	As alloy in airframes and in machine guns; used as a solder element	Fighter aircraft Transport aircraft Maritime patrol aircraft
Titanium	As metal in many military vehicles and weapon systems; in alloys for armour, body shell of ammunition and fighter emergency systems/flight recorders (black box); main component of titanium alloys used in airframe; in other alloys used in turbines, landing gear; as metal in drive shaft, compressors hull or titanium dioxide in electro-optical systems; in composition of air search and navigation radar and missile frames; in the structure of platform and propulsion for satellites	Fighter aircraft Combat helicopter Transport aircraft Maritime patrol aircraft Multi-role helicopter Aircraft carrier Destroyers and frigates Corvettes Offshore patrol vessels Submarines Torpedoes Main battle tank Infantry fighter vehicle Assault rifle Missiles (all)

Raw materials	Role in defence industry	Examples of defence applications
Tungsten	Alloy element for ballast, warheads, shaped charges, throats, soldering, electrics, armour piercing and tank ammunition; also used in alloys in aeronautics for shells (arrowhead), fuselages, wings and turbine engines; tungsten carbide is essential for cutting machines	Fighter aircraft Combat and multi-role helicopter Transport aircraft Maritime patrol aircraft Aircraft carrier Destroyers and frigates Submarines Main battle tank Missiles (all)
Vanadium	Additive to improve the resistance to wear and deformation of steel; vanadium-containing alloys are used for the hull of submarines, in structural parts, engines and landing gear, but also in gun alloy elements, armour, fuselages and wings	Fighter aircraft Transport aircraft Maritime patrol aircraft Aircraft carrier Destroyers and frigates Corvettes Offshore patrol vessels Submarines Main battle tank Infantry fighter vehicle Assault rifle
Zinc	Substrate (zinc sulphide and zinc selenite) in electronics for radar and infra-red detectors; galvanization and in composition of alloys for increasing mechanical properties and resistance to corrosion	Fighter aircraft Transport aircraft Maritime patrol aircraft Submarines Missiles (all)
Zirconium	Additive in alloys for corrosion protection of aircraft fuselage; component in titanium-based alloys used, for instance, in armaments; as an element in many aluminium alloys	Fighter aircraft Maritime patrol aircraft Torpedoes and missiles (all)
Precious metals (3)		
Gold	Electronics for radars (e.g. 3D medium range, guidance, navigation, air search, long-range air and tracking) and in surface detection; as minor component in alloys for fuselage and wings; coatings in high-performance electronics	Fighter and carrier aircraft Transport aircraft Maritime patrol aircraft Destroyers and frigates Corvettes Offshore patrol vessels Submarines
Platinum (Platinum Group Metal)	Thin coating of turbine blades (to increase thermal barrier) in combination with nickel and aluminium	Fighter aircraft Transport aircraft
Silver	Electronics for transmitter, communication and identification systems; in composition in alloys for Browning machine guns and torpedoes (in pump-jet coupled to gas turbine engine); also used for batteries (silver oxide-aluminium battery) and as tribological coating for some applications	Combat helicopter Multi-role helicopter Transport aircraft Maritime patrol aircraft Torpedoes Communication systems

Raw materials	Role in defence industry	Examples of defence applications
Rare earth elements (REEs) (6)		
Dysprosium	As a minor additive in high-powered neodymium-iron-boron (NdFeB) permanent magnets for electric motors, guidance, control systems, actuators and amplifications (e.g. voice coil motors and audio speakers, satellite communication)	Missiles (all) Fighter aircraft (and probably many others)
Neodymium	Component of high-powered neodymium-iron-boron permanent magnets for a variety of applications: electric motors, guidance, control systems, actuators and amplifications (e.g. voice coil motors and audio speakers, satellite communication, etc.); in lasers as neodymium: yttrium-aluminium-garnet crystals	Fighter aircraft Transport aircraft Multi-role helicopter Maritime patrol aircraft Missiles (all)
Praseodymium	In neodymium-iron-boron permanent magnets (usually in mixture with neodymium in a ratio Nd:Pr=4:1) with the same applications as above	Missiles (all) Fighter aircraft (and probably many others)
Samarium	With cobalt in samarium-cobalt permanent magnets used in electric motors and diesel electric for propulsion, and electronic applications	Fighter and carrier aircraft Destroyers and frigates Submarines Missiles (all)
Yttrium	Laser crystals for targeting weapons, finding and sight communication, electrolyte for fuel cells, phosphors for display screens, vision and lighting; in composition in equipment for signal generation, detection and surveillance, in thermal barrier coatings, and as alloying element for special steel grades	Fighter aircraft Combat helicopter Transport aircraft Maritime patrol aircraft
Other rare earths: cerium, erbium, europium, gadolinium, holmium, lanthanum, lutetium, scandium, terbium, thulium, ytterbium	Rather limited and specialised application in defence, such as magnets, radar (signal generation, surveillance and missile launch detection), lasers, sensors, other electronic components, phosphor (avionic display), heat-resistant superalloys and steel alloys	Fighter aircraft
Non-metals (2)		
Boron	Phased array radar, sensors and other electro-optical systems; as boron-carbide ceramics used in body armour; surface treatment and cleaning processes in aircraft manufacturing	Fighter aircraft Missiles (all)
Selenium	Used in specialised electronics (e.g. phased array radar) and in batteries	Fighter aircraft

5. Industrial dependency on raw materials used in European defence applications

5.1 Assessment of import dependency

According to the report 'The development of a European Defence Technological and Industrial Base (EDTIB)' (EDTIB, 2013), the term 'industrial dependency' refers to the reliance of European defence manufacturers on raw materials, components and technologies coming from outside the EU, which are often also used for civilian applications. For instance, major concerns were expressed by the entire global industrial base after China introduced export restrictions to rare earth elements in 2010, given the fact that China accounted for about 97 % of global production at that time. European producers of satellites, unmanned aerial vehicles (UAV) and unmanned combat aerial vehicles (UCAV) depend on specialised technologies which are not produced in the EU. A similar example is the production of carbon-fibre materials used in the aeronautics and satellite sectors, which are manufactured from a polyacrylonitrile (PAN) precursor produced mainly in Japan. The security of materials supply is of growing concern to the European defence industry, driven by the increasing demand from other civilian applications and the growing level of imports.

In this study, the defence industry's dependency on raw materials is estimated in terms of import dependence, a parameter that was calculated at the EU level based on annual data on primary production and net imports:

$$Import\ dependence = \frac{Net\ imports}{Net\ imports + EU\ production}$$

Information about EU production was obtained from several data providers, such as the World Mining Data (WMD, 2015), USGS (USGS, 2015) and British Geological Survey (BGS, 2015). The net imports, defined as the difference between the EU's imports and exports of ores and concentrates, were estimated on data extracted from the UN's Comtrade database (UN-Comtrade, 2015) and world mineral statistics data (BGS, 2015). All data refer to 2013. The results of this analysis in terms of percentage of import dependence are presented in Figure 5.1.

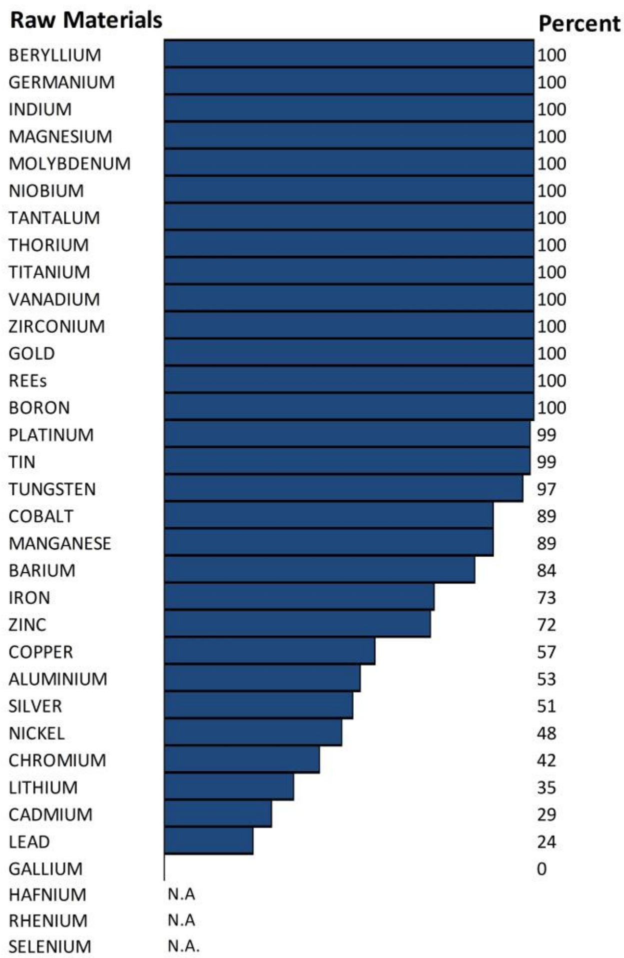

Figure 5.1: EU import reliance on raw materials used in defence industries in 2013

In 2013, the EU was totally dependent on imports for 19 of the 39 raw materials identified in this report (i.e. beryllium, boron, germanium, gold, indium, magnesium, molybdenum, niobium, six REEs, tantalum, thorium, titanium, vanadium and zirconium). For almost three-quarters of those raw materials, the share of imports exceeds 50 %. It should be noted that in Figure 5.1 the rare earth elements are presented as a single group. Gallium can be considered to be totally independent of imports since it is obtained as a by-product of aluminium refining taking place in Europe, although the EU is highly dependent on bauxite imports (Polinares, 2012). The import dependency for hafnium, rhenium and selenium could not be estimated due to the lack of available information on imports and exports. However, these three raw materials do not pose a significant risk to the security of their supply since the EU is a significant producer. Information about EU production and reserves, and the main global supplier countries of the raw materials identified in the defence industry are presented in Table 5.1.

It should also be emphasised that the situation regarding industrial dependency may differ when alloys, composites and other materials and semi-finished products are assessed. Several of these materials are produced by a limited number of manufacturers (a topic analysed in more detail in the next chapter), which may pose a potential risk to their supply, although the constituent raw materials themselves may not be considered critical or at risk. Conversely, the issue of indirect dependency may emerge when even though imported materials are readily available to the European defence industry, foreign suppliers may become exposed to risks associated with the supply of the necessary raw materials.

Table 5.1: Reserves, production and main supplier countries of raw materials used in the EU defence industry – all data refer to 2013

Raw material	Global reserves[3] (thousand tonnes)	EU reserves[4] (thousand tonnes)	EU production (tonnes) and % of global production[5]	Main supplier countries[5]
Aluminium	28 000 000 (as bauxite)	4744 (as bauxite) (600 000 bauxite are also estimated to occur in Greece[3])	2 009 313 (4.2 %)	China 46.13 % Russia 6.85 % Canada 6.21 % USA 4.07 % United Arab Emirates 3.90 %
Barium (as baryte)	350 000	1470	95 446 (1.1 %)	China 42.15 % India 11.98 % Morocco 9.70 % Turkey 7.76 % USA 7.38 %
Boron	210 000	N.A.	Zero; global production is 4 461 780	Turkey 39.67 % USA 23.13 % Chile 13.05 % Argentina 11.21 % Peru 5.03 %
Beryllium	N.A.	N.A.	~Zero (5t of beryl is estimated to take place in Portugal); global production is 260 tonnes[6]	USA 90.22 % China 7.63 % Madagascar 1.15 % Mozambique 0.80 % Portugal 0.08 %[(6)]
Cadmium	660[7]	N.A.	1380 (6.3 %)	China 32.13 % South Korea 17.92 % Japan 8.36 % Mexico 6.66 % Kazakhstan 6.13 %
Chromium	>480 000 (shipping-grade chromite)	8912	296 909 (3.26 %)	South Africa 45.16 % Kazakhstan 15.11 % Turkey 14.04 % India 9.87 % Finland 3.26 %
Cobalt	7200	21 (200 estimated to occur in New Caledonia[3])	5141 (including New Caledonia with 3080 tonnes) (4.68 %)	D.R. Congo 53.55 % China 7.29 % Canada 6.30 % Australia 5.83 % Zambia 5.15 %

[3] Data from USGS, unless otherwise stated: United States Geological Survey, Mineral Commodity Summaries 2015 (available at: http://minerals.usgs.gov/minerals/pubs/mcs/2015/mcs2015.pdf)
[4] Data from European Minerals Yearbook, unless otherwise stated (available at: http://minerals4eu.brgm-rec.fr/m4eu-yearbook/theme_selection.html)
[5] Data from World-Mining-Data, 2015, unless otherwise stated (available at: http://www.wmc.org.pl/sites/default/files/WMD2015.pdf)
[6] Data from USGS: United States Geological Survey, Mineral Statistics and Information (Excel spreadsheets available at: http://minerals.usgs.gov/minerals/pubs/commodity/aluminum/index.html#mcs)
[7] Achzet et al. (2011), Materials critical to the energy industry. An introduction, University of Augsburg (available at: http://www.physik.uni-augsburg.de/lehrstuehle/rst/downloads/Materials_Handbook_Rev_2012.pdf)

Raw material	Global reserves[3] (thousand tonnes)	EU reserves[4] (thousand tonnes)	EU production (tonnes) and % of global production[5]	Main supplier countries[5]
Copper	700 000	45 558	854 942 (4.73 %)	Chile 31.96 % China 8.85 % Peru 7.61 % USA 6.92 % Australia 5.52 %
Gallium	N.A.	N.A.	4 (5.6 %)	China 63.29 % Ukraine 13.92 % Japan 10.13 % Russia 7.59 % Hungary 5.06 %
Germanium	N.A.	N.A.	17 (14.53 %)	China 76.07 % Finland 14.53 % Russia 4.27 % USA 2.56 % Japan 1.71 % Ukraine 0.85 %
Gold	55	5.5	30.74 (including French Guyana with 2 tonnes) (1.08 %)	China 15.04 % Australia 9.42 % USA 8.08 % Russia 6.99 % South Africa 5.61 %
Hafnium	N.A.	N.A.	30 (46.9 %)[8]	France 46.88 % USA 46.88 % Ukraine 3.13 % Russia 3.13 %[(8)]
Indium	N.A.	N.A.	55 (refinery) (7.62 %)[9]	China 56.79 % Korea (Rep. of) 13.85 % Japan 9.70 % Canada 9.00 % Belgium 4.16 %[(9)]
Iron	87 000 000	240 002	18 249 273 (1.2 %)	China 30.51 % Australia 25.35 % Brazil 14.72 % India 6.71 % Russia 3.06 %
Lead	87 000	6438	215 793 (3.85 %)	China 53.48 % Australia 12.68 % USA 6.06 % Peru 4.75 % Mexico 4.52 %
Lithium	13 500	604	110 (0.37 %)	Chile 37.46 % Australia 32.60 % China 13.35% Argentina 8.32% USA 4.66%

[8] MMTA - Minor Metals Trade Association (available at: http://www.mmta.co.uk/hafnium)
[9] British Geological Survey, European Mineral Statistics, 2015 (available at: https://www.bgs.ac.uk/mineralsuk/statistics/wms.cfc?method=searchWMS)

Raw material	Global reserves[3] (thousand tonnes)	EU reserves[4] (thousand tonnes)	EU production (tonnes) and % of global production[5]	Main supplier countries[5]
Magnesium	2 400 000 (as magnesite)	339 602 (as magnesite)	Zero; global production is 953 799 tonnes[9]	China 80.65 % Oman 5.14 % USA 4.19 % Russia 3.15 % Israel 2.87 %[(9)]
Manganese	570 000 000	18 000	44 310 (0.22 %)	South Africa 24.07 % China 20.67 % Australia 17.85 % Gabon 10.50 % Brazil 5.89 %
Molybdenum	11 000	18	Zero. Global production is 260,773 tonnes	China 38.73 % USA 23.28 % Chile 14.85 % Peru 6.96 % Mexico 4.82 %
Nickel	81 000	453 (12 000 estimated to occur in New Caledonia[3])	213 310 (including New Caledonia with 164 406) (8.4 %)	Indonesia 32.73 % Philippines 12.38 % Australia 9.19 % Canada 8.55 % New Caledonia 6.45 %
Niobium	>4300	N.A.	Zero; global production is estimated at 57 695 tonnes	Brazil 92.38 % Canada 6.16 % Other countries 1.46 %
Platinum	66 (all PGM)	0.035 (0.06 - all PGM)	0.99 (0.55 %)	South Africa 71.86 % Russia 12.95 % Zimbabwe 7.17 % Canada 4.39 %
Rare Earths	130 000 (rare earth oxide [REO] equivalent)	N.A.	Zero; global production is 102 872 (REO content)	China 91.18 % USA 5.35 % Russia 1.40 % Australia 1.23 % Brazil 0.58 % Malaysia 0.25 %
Rhenium	2.5	N.A.	5.21 (12.71 %)	Chile 41.67 % USA 17.04 % Uzbekistan 13.20 % Poland 12.50 % Kazakhstan 6.00 %
Selenium	120	3[(3)]	1152 (51.11 %)	Germany 31.06 % Japan 9.76 % Belgium 8.87 % Russia 6.65 % Canada 6.12 %
Silver	530	76.7	1683.75 (6.5 %)	Mexico 22.39 % Peru 14.12 % China 14.11 % Australia 7.07 % Bolivia 4.95 %

Raw material	Global reserves[3] (thousand tonnes)	EU reserves[4] (thousand tonnes)	EU production (tonnes) and % of global production[5]	Main supplier countries[5]
Tantalum	> 100	N.A.	Zero; global production is 1007 tonnes	Rwanda 46.14 % D.R. Congo 19.85 % Brazil 15.05 % Nigeria 6.35 % Canada 3.25 %
Thorium	N.A.	N.A.	Zero; global production as monazite concentrate in 2012 is 6620 tonnes[3]	India 81.57 % Malaysia 9.06 % Vietnam 5.57 % Brazil 3.78 % (monazite concentrate, 2012)[3]
Tin	4800	9.93	84 (0.02 %)	China 43.64 % Indonesia 27.82 % Peru 6.93 % Bolivia 5.65 % Brazil 4.93 %
Titanium	Ilmenite: 720 000, and rutile: 47 000	204	Zero; global production is 4 182 022 tonnes	Australia 15.87 % South Africa 14.88 % China 14.62 % Canada 11.92 % Vietnam 7.74 %
Tungsten	3300	72 (14.2 estimated to occur in Austria and Portugal[3])	2098 (2.43 %)	China 82.78 % Russia 3.60 % Canada 3.50 % Vietnam 1.92 % Rwanda 1.53 %
Vanadium	15 000	N.A.	Zero; global production is 43 916 tonnes	China 52.30 % South Africa 26.79 % Russia 18.37 % Kazakhstan 1.28 %
Zinc	230 000	8034	738 185 (5.46 %)	China 37.72 % Australia 11.27 % Peru 9.99 % India 5.84 % USA 5.80 %
Zirconium	78 000 (ZrO_2 equivalent)	N.A.	Zero; global production is 1 384 456 tonnes	Australia 46.95 % South Africa 15.53 % China 10.83 % Indonesia 7.95 % USA 5.63 %

While the data provided in Table 5.1 give an overall view of the potential of EU mineral raw materials in terms of resources and EU mining production, the following chart (Figure 5.2) shows the distribution of main supplier countries upon which the EU relies to meet its growing demand for these raw materials. This analysis shows that, in 2013, China supplied over one-third of the identified raw materials to the European market.

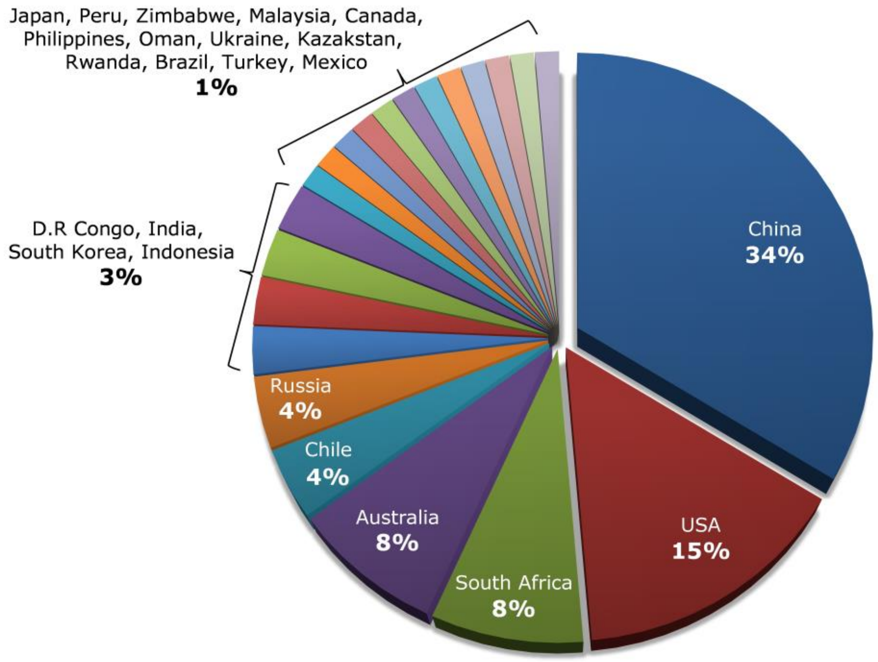

Figure 5.2: Major supplier countries of raw materials in the European defence sector[10]

5.2 Opportunities for increasing EU production

The further development of primary production from indigenous EU sources and the recycling and reuse of materials can help the EU meet domestic demand for raw materials for all industries while decreasing import dependence. Although EU reserves are relatively low compared to world reserves, ongoing exploration projects in the EU and support initiatives in the Member States can prove beneficial in increasing EU primary production in both the medium and longer term. Due to the limited availability of data, it is difficult to get a complete view of exploration projects in EU countries for each raw material. In general, it is considered that, if successful, an exploration activity is likely to start new production within 10 to 15 years.

Exploration investments are strongly linked to material market prices (Figure 5.3). A substantial increase in the mining industry's total budget for global non-ferrous metal exploration was evident during the period 2002-2012, although it has shown a net decrease over the last two years.

In terms of exploration investments, concrete positive results were achieved in the EU. For instance, SNL Metals & Mining estimates that Sweden and Finland each attracted over EUR 62 million for exploration activities in 2013 (SNL, 2014). This asset is in accordance with the 2015 investment attractiveness analyses published by the Fraser Institute (Fraser, 2014), which append high scores to these countries (Table 5.2).

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[10] The graph was created around the following assumptions:

- The first two supplier countries, as shown in Table 5.1, were considered;
- Raw materials for which the EU is a net supplier, i.e. hafnium – France, germanium – Finland, and selenium – Germany, were excluded from this analysis as the focus here is on dependence on foreign sources;
- In the case of rare earth elements, China and USA (the second top supplier) were considered for each individual metal (i.e. dysprosium, neodymium, praseodymium, samarium and yttrium) and for the group of other rare earths.

Figure 5.3: Estimated global nonferrous exploration budget between 1993 and 2014 (source: SNL, 2014)

Table 5.2: Fraser Institute Indexes for several EU countries: the investment attractiveness index combines influences from individual measures of geological attractiveness (Best Practices Mineral Potential Index) and the effects of government policy on attitudes toward exploration investment (Policy Perception Index)

Country	Investment Attractiveness Index		Policy Perception Index, 2014	Best Practices Mineral Potential Index, 2014
	2013	2014		
Bulgaria	52.3	30.2	25.93	0.33
Finland	80.2	83.8	94.67	0.77
France	59.2	55.1	63.59	0.5
Greece	77.3	32.2	35.45	0.3
Hungary	-	20.5	21.35	0.2
Ireland	73.9	78.3	95.99	0.67
Poland	52.2	44.4	40.56	0.47
Portugal	53.2	60.2	63.54	0.58
Romania	37.6	32	19.37	0.41
Spain	58.6	40	33.13	0.45
Sweden	79.5	78.1	92.51	0.69

According to the Fraser Institute, the availability of precompetitive geo-data and demonstration of the potential of minerals are key drivers for investment decisions (60 % of decisions are driven by these factors). In turn, 40 % of exploration and mining investment decisions are influenced by policy factors (Fraser, 2014; Osterholt, 2015). Overall, these perceptions are in line with the EU analyses and were prioritised in recent initiatives, such as the Strategic Implementation Plan of the European Innovation Partnership on Raw Materials.

Examples of good practice in the policy and legal framework, information framework, and land-use planning and permission are provided by many EU countries, such as Finland, Portugal, UK, Germany, Ireland, Austria, France and Denmark. The new Polish Geological and Mining Law, which came into effect in 2012, and the new Mining Act in Finland, in force since 2011, are just two current examples.

In terms of the production of raw materials from EU sources, the USGS estimates a robust increase in nickel mine capacity in Finland and an expansion of existing cobalt refineries scheduled for completion by 2017 (USGS, 2013). The possible market introduction of two new lithium producers in the EU is predicted for 2017 by Roskill (Roskill, 2013). According to the Technology Metals Research (TMR) Advanced Rare-Earth Projects Index, three advanced-stage rare-earth projects are under development in Germany and Sweden. Norra Kärr (Sweden) holds major reserves of 188 000 tonnes of total rare-earth oxides (TREO), hence potentially alleviating, to some extent, current concerns over the security of supply of rare earth elements (TMR, 2015).

In order to further assess the possibilities of increasing the primary production of materials from EU sources, new alternatives, such as deep-sea mining, should also be considered. Deep-sea mining is potentially a significant source of copper, cobalt, gold, zinc, silver and rare earths (including yttrium). As regards mining production from offshore sources, an optimistic scenario suggests that, by 2020, 5 % of the world's minerals, including cobalt, copper and zinc, could derive from ocean floors, a figure which could rise to 10 % by 2030 (EC, 2012).

The risks associated with access to raw materials on time and at a reasonable market price, and the potential negative impact on Europe's overall industrial and economic importance is currently under intense debate in Europe. Through its Raw Materials Initiative (RMI) and the European Innovation Partnership (EIP) on Raw Materials, the European Commission, together with EU Member States, the Knowledge and Innovation Community (KIC) on Raw Materials and industrial stakeholders, has already initiated the development of joint strategies to reduce Europe's dependency and to ensure uninterrupted access to raw materials for European industry, including the defence sector.

It should be reiterated here that representatives of the European defence industry as well as public authorities have highlighted the fact that while raw materials are important, their demand does not currently represent a potential bottleneck to the defence industry. Lead system integrators and top-tier contractors do not usually import raw materials. However, they do purchase, and thus need to secure access to, semi-finished products and high-performance materials such as special alloys, composite materials, etc. In essence, the real challenge for the European defence industry related to materials supply is associated with the strength of the downstream supply chain and the manufacturing capabilities in materials processing and transformation within Europe.

The next chapter provides insights into production capacity at global and European level of some specific alloys and compounds used in both military and civilian applications, with a special focus on the aeronautics sector.

6. Assessment of global and EU production capability for materials used in the defence industry: the case of high-performance alloys and aerospace materials

6.1 High-performance alloys

The high-performance alloys (HPA), also called superalloys or high-alloy materials, represent a complex metallurgical blend of three or more elements that originate from transition metals in group VIIIB, such as nickel (Ni), iron-nickel (Fe-Ni) and cobalt (Co) as well as smaller amounts of tungsten, molybdenum, tantalum, niobium, titanium and aluminium.

Table 6.1: Types, properties and applications of the principal high-performance alloys (source: Global Industry Analysts, Inc., USA [GIA, 2014])

High-performance alloy	Alloy examples	Alloy properties	Example of end-uses
Nickel-based superalloys	- Monel 400 - Incoloy 800H, 825, 903, MA754, MA956 - Inconel 600, 617, 625, 686, 725, 783, 718PF, 803 - Nickel-iron-chromium (alloy 600, 800) - Nickel-chromium (e.g. cast alloys 713C, IN-100, IN-738, MAR-M200, Inconel X-750, Waspaloy, Rene 41, Udimet 700, etc.) - Hastelloy alloys	High strength and corrosion resistant at high temperatures; strong, tough and ductile in a wide temperature range (the properties are modified/improved by addition of other elements in alloy composition)	Gas turbines for marine propulsion, aeronautics, power generation, military and commercial aircraft, chemical-processing vessels, military electric motors, nuclear reactors, submarines, space vehicles, oil and gas exploration
Cobalt-based superalloys	Cobalt alloy 188, L605	Very high thermal shock and hot corrosion resistance; operate in temperature range of 650-1000 °C	Gas turbines and land-based turbines, combustors, flame holders
Iron-based superalloys	Developed from stainless steel, e.g. AISI 600 series, A-286	High temperature strength; high resistance to creep, oxidation, corrosion and wear	Aeronautics, aircraft, automotive, medical, food service, etc.
Titanium-based superalloys	Ti-6AI-4V (TA6V), Ti-5AI-2.5Sn (TA5E_ELI)	Lightweight, high strength, ductility, high corrosion and oxidation resistance	Military and aeronautics, medicine, external fan blades for gas turbines, other domestic purposes

High-performance alloys are characterised by unique properties that enable them to operate better than conventional alloys, in particular at elevated temperatures and pressures and in harsh conditions where high surface stability and mechanical strength are required, such as in jet engines. Nickel-based superalloys are the largest type of superalloy produced, the others being cobalt-based, titanium-based and iron-based alloys. For instance, the nickel-chromium alloys mixed with carbides, intermetallic precipitates and small quantities of tungsten, molybdenum, tantalum, niobium, titanium and aluminium are widely used, based on their enhanced strength and higher operating temperatures. The main high-performance alloys and applications are given in Table 6.1, while the composition of the main alloys used in the defence industry is presented in Appendix 3.

Based on their high surface stability, superior mechanical strength, as well as the ability to withstand deformation at high temperatures, high-performance alloys are used in a broad range of end-use industries, such as aeronautics, power, chemical processing, electronic and electrical, oil and gas, and automotive. In the aeronautics industry, the superalloys are used as lightweight and high-strength materials for the construction of large engines and airplanes.

In defence applications, high-performance alloys can meet the extreme operating conditions that military equipment need to operate in, owing to their superior mechanical strength, surface stability, oxidation, and corrosion-resistance capabilities. These applications include, for example, armour plating with aluminium alloys, missile and rocket constructions using titanium and aluminium alloys, and fighter jet engines using a higher grade of alloys.

According to Global Industry Analysts, Inc. (GIA, 2014), a global leading market research publisher, the global market for high-performance alloys was estimated at 457 700 tonnes in 2013, and the projections indicate a compounded annual growth rate (CAGR) of 4.4 %, reaching 619 636 tonnes by 2020. Europe represents the largest market place with an estimated consumption share of 27.1 % in 2014, followed closely by the USA with 25.9 % (Figure 6.1).

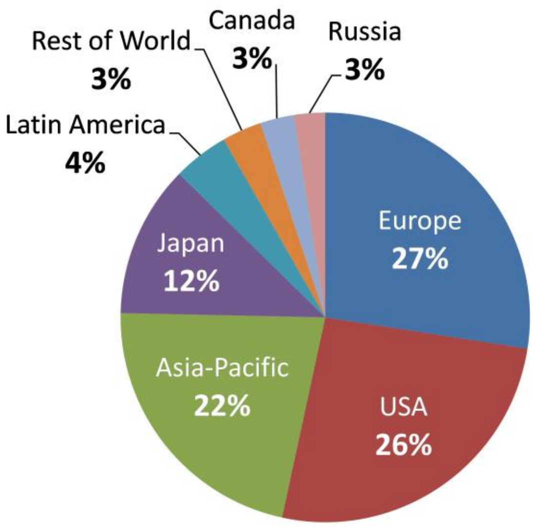
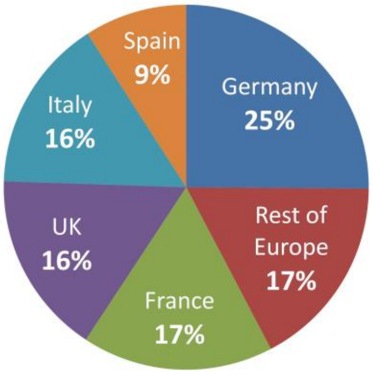


Figure 6.1: Global market share for high-performance alloys by geographic regions[11] and countries in 2014 (source: Global Industry Analysts, Inc., USA [GIA, 2014])

The European market for high-performance alloys is estimated to grow from 125 600 tonnes to 163 022 tonnes during the period 2013-2020. In 2013, Germany accounted

[11] Countries analysed under Europe: Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, the Netherlands, Norway, Poland, Slovakia, Spain, Switzerland, Turkey and the UK. Countries analysed under Asia-Pacific: Australia, China, Hong Kong, India, Indonesia, Korea, Malaysia, New Zealand, Philippines, Singapore, Taiwan and Thailand. Countries analysed under Latin America: Argentina, Brazil, Chile, Colombia, Ecuador, Mexico, Peru and Venezuela. Rest of World included: Middle Eastern countries (Iran, Iraq, Israel, Kuwait, Saudi Arabia, Syria and the UAE) and African countries.

for the largest consumption share in Europe (25 %) while the nickel-based alloys represent the largest product segment in Europe with an estimated share of circa 64 % (Figure 6.2).



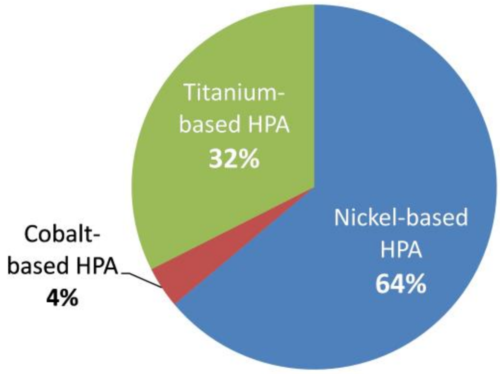


Figure 6.2: European consumption share for high-performance alloys by country (left) and product segment (right) in 2014 (source: Global Industry Analysts, Inc., USA [GIA, 2014])

The dominant end-user sector for high-performance alloys is the aeronautics industry which includes both military and commercial applications. The estimated share of the European aeronautics industry for high-performance alloys was estimated at 48 % in 2014 (Figure 6.3) which corresponds to about 62 850 tonnes.

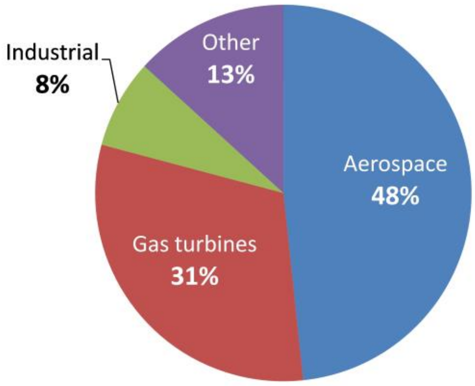


Figure 6.3: European consumption share for high-performance alloys by end-use sector[12] in 2014 (source: Global Industry Analysts, Inc., USA [GIA, 2014])

The aeronautics sector not only has the largest market share for high-performance alloys, but their value is several times higher than those used in industrial applications, for instance, because of the high degree of engineering required for small and sophisticated components.

Currently, the defence industry is using high-performance alloys such as Inconel, Monel, Hastelloy and aircraft-grade aluminium, titanium etc., which demonstrate superior heat and corrosion resistance and specific expansion characteristics. Investments made by

[12] The aeronautics sector includes military and commercial among others. The gas turbines refer to industrial power generation turbines (electrical and mechanical equipment). Other sectors include automotive, oil and gas, and medical, among others.

the defence industry for the development of new defence applications are expected to drive up the demand for high-performance alloys. For instance, the next-generation fighter aircraft, submarine, missile, unmanned aerial/ground vehicle, unmanned combat aerial vehicle and aircraft carrier projects will require cutting-edge technology, including high-performance alloys.

6.2 Materials for aeronautical applications

The defence industry's aeronautics sector is facing the biggest challenges as it requires a large number of very specialised, innovative and complex materials, such as composites and alloys, along with titanium, graphite, fibreglass, etc. This section presents an analysis of the defence and civil aeronautics segments and the materials used by them. The following materials are addressed here, and further denoted as 'aerospace materials':

- aluminium alloys
- steel alloys
- titanium alloys
- superalloys
- composite materials
- others (e.g. ceramics, GLARE - glass laminate aluminium reinforced epoxy, magnesium and special alloys, plastics, etc.).

Traditionally, metals and metal-based alloys have been used for aircraft manufacturing due to their high strength, and heat and corrosion resistance. With the evolution of the aeronautics industry, these materials are constantly being replaced by new lightweight materials such as titanium alloys, composite materials and high-temperature-resistant plastics. For example, the new generation of aircraft uses up to 50 % composites. These materials offer greater strength characteristics compared with traditional materials, providing greater resistance and less weight. In the defence industry, this translates into higher manoeuvrability and long-distance independency (low fuel consumption) of jet fighters.

Box 6.1: Characteristics of the materials used in fighter aircraft

Fighter aircraft are among the most sophisticated defence applications on the market. They are made from numerous special alloys and materials with specific characteristics in order to satisfy two main requirements: *lightweight and stability*. A light airframe is desirable because the aeroplane's manoeuvrability, operational range and payload are determined by its weight. However, the low weight must not impact on its stability, which is under particular stress during manoeuvring in combat situations. An additional requirement for the propulsion system is resistance to heat generated by its jet engines, as combustion produces large amounts of energy, and high temperatures increase engine performance.

Aluminium alloys

Aluminium alloys are used where composites cannot satisfy the requirements in terms of properties and characteristics. In fighter aircraft, this is mainly in internal structural parts of the fuselage but also in the panelling. Numerous aluminium alloys are used, but two are most prominent: the 2000 and 7000 series alloys.

- Aluminium 2000 series contain copper which improves the mechanical properties of the aluminium but lowers resistance to corrosion. 2000 series alloys are mainly used in the panelling of the aircraft body, which requires a high resistance to structural fatigue, low crack propagation properties and a strong tolerance to physical damage.
- Aluminium 7000 series contain elements such as zinc, magnesium and copper which make the alloys suitable for use in parts of the aircraft body that are particularly exposed to high static loading, fatigue, wear and corrosion. It should be noted that, in general, the wear and corrosion characteristics of aluminium alloys are not very strong, although these properties are improved by the application of specific coatings. Those parts include the main frames, the

ribs and longerons of the fuselage and internal parts. The addition of zinc enhances the alloy's mechanical properties, as does magnesium, while the addition of a small amount of zirconium increases resistance to corrosion.

Steel alloys

Special steels are used in parts that require a high level of strength and high resistance to concentrated impacts, but no exposure to medium-high temperatures. These parts include the axis of the ailerons, fastenings, and the landing gear. Steel is also used to manufacture the shafts in aeronautics gas turbines because of their ability to handle high torsional loads.

- MARVAL X12 is used in the axis of the ailerons and comprises elements such as chromium and aluminium to increase resistance to corrosion, nickel to improve resistance to shocks and corrosion, and molybdenum and titanium to increase resistance to wear and heat.

Titanium alloys

Titanium alloys are used because of their lightweight, high strength and excellent fatigue properties and resistance to high temperatures. Hence, titanium alloys are mainly employed in structural parts and other aircraft parts that are exposed to high temperatures, such as the leading edges of wings or ailerons. Titanium alloys could also be used in wear-resistant parts, but in this case surface coating is mandatory. However, titanium is expensive and difficult to produce.

- TA6V is the alloy most used in aircraft because of its properties: good resistance to fatigue, fissures and corrosion. The TA6V alloy contains vanadium which increases resistance to wear and deformation, as well as aluminium which improves resistance to corrosion and reduces the alloy's overall weight.

Superalloys

The materials used in the construction of the propulsion system have to be extremely stable and able to withstand very high temperatures: nickel-based superalloys have such properties. Another property that makes them particularly suitable is refractoriness which is necessary for parts that are exposed to varying levels of high temperature or even thermal shocks.

- N-18 is based on nickel and includes the addition of cobalt and titanium (to increase heat resistance), chromium (to increase resistance against wear and corrosion), molybdenum (to increase resistance to wear and heat), aluminium and hafnium (to increase resistance to corrosion).
- AM-1 mono-crystalline alloy based on nickel is used for turbines. This alloy contains chromium (to increase resistance to wear and corrosion), tantalum (to increase resistance to corrosion and enhance thermal conductivity), cobalt and titanium (to increase resistance to high temperatures), aluminium (to increase resistance to corrosion) and molybdenum (to increase resistance to wear and heat).

Composite materials

- Carbon-epoxy composites have progressively replaced parts that were previously made from aluminium alloys. This is because the carbon-epoxy is extremely strong but, at the same time, lighter than aluminium alloys. These composites also exhibit other important properties:

  - superior strength-to-weight ratio
  - superior rigidity
  - excellent mechanical qualities
  - excellent resistance to fatigue
  - excellent resistance to corrosion

  Nevertheless, they have a number of drawbacks, such as limited resistance to shock, reduced electrical conductivity, limited resistance to high temperatures, and increased sensitivity to ageing in high-humidity environments. A further constraint is the fact that carbon-epoxy composites can only be produced on surfaces, either flat or over a mould, which limits their use to parts of the airframe, wings or fuselage.

Other materials

- Ceramic materials are used in those parts of the propulsion system that are exposed to extreme temperatures, such as the combustion chamber.

According to MarketsandMarkets (M&M, 2015), a global market research and consulting company, the overall market size for materials used in aeronautics applications was estimated at EUR 10 741 million by value and 680 400 tonnes by volume in 2014. Global market is projected to reach EUR 15 343 million or 807 400 tonnes by 2019. The USA and EU currently dominate this market, together accounting for almost 60 % of global sales (Figure 6.4), but Asia-Pacific and the Middle East are expected to be the primary drivers of the aeronautics industry in the coming years.

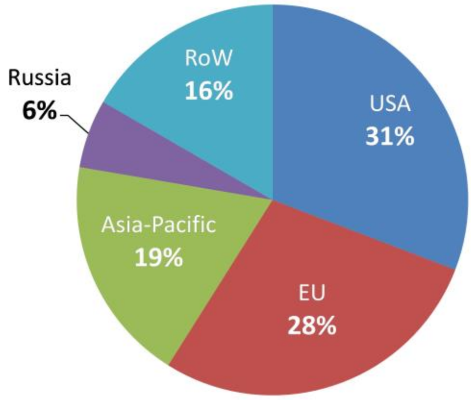


Figure 6.4: Geographical distribution[13] of the global market by volume for aerospace materials in 2014 (source: MarketsandMarkets [M&M, 2015])

Aerospace materials are used for the production of many types of aircraft for both the defence and civilian sectors, which can be grouped into the following categories:

- commercial aircraft
- military aircraft (including fixed-wing and rotary-wing aircraft)
- business and general aviation (BGA)
- civil helicopters

Figure 6.5 shows the global market share (by value) for aerospace materials in different applications.

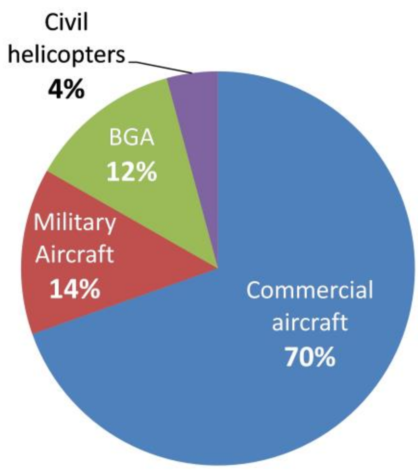


Figure 6.5: Global market share for aerospace materials by end-use applications (BGA: business and general aviation) in 2014 (source: MarketsandMarkets [M&M, 2015])

[13] Asia-Pacific region comprises: China, South Korea, Japan and India. Rest of World (RoW) comprises: Canada, Mexico and Brazil.

The global market for aerospace materials is dominated by the commercial aircraft segment. In 2014, it accounted for about 70 % of the market share by value (72 % by volume), and is projected to fall slightly to 68 % by 2019. The next largest share is attributed to military aircraft with approximately 14 % by value (11 % by volume), BGA – 12 %, and civil helicopters – 4 %. It is estimated that the compound annual growth rate (CAGR) for military aircraft will reach 7 % by value (or 4.2 % by volume) by 2019 compared to 5.9 % by value (or 2.9 % by volume) for commercial aircraft over the same period.

The military aircraft segment, which includes fighter jet aircraft and other military-related aircraft, is the second-largest contributor to the global market size with EUR 1 523 million in 2014, estimated to increase to EUR 2 140 million by 2019. In terms of demand for aerospace materials, the global military aircraft sector used 74 800 tonnes in 2014 which is estimated to increase to 92 000 tonnes by 2019. However, it is expected that the global demand for military aircraft applications will remain sluggish during the next decade due to a cut in defence expenditure in major countries (e.g. USA and EU countries). However, the increase in defence spending by Middle Eastern countries, as well as India, Russia and Brazil, will create new market opportunities for the major aircraft manufacturers.

Aluminium alloys are the materials most used in military aircraft, which accounts for about 37 % of the total demand (Figure 6.6). In terms of value, titanium alloys lead with 31 % (Figure 6.6).

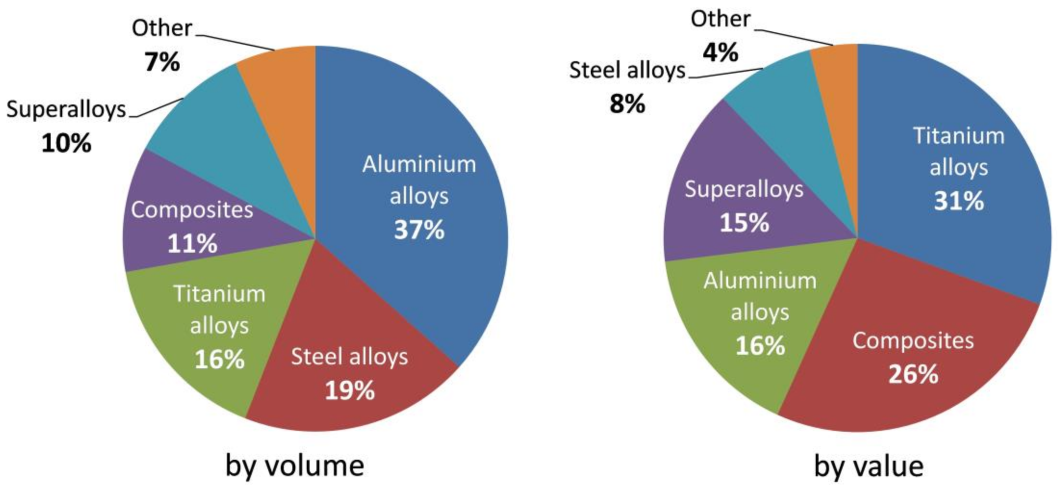


Figure 6.6: Global share for aerospace materials used in military aircraft by volume (left) and by value (right) in 2014 (source: MarketsandMarkets [M&M, 2015])

Driven by significant light weight and other performance advantages, for example, high stiffness and high strength, composite materials such as carbon and aramid-fibre composites are expected to be the fastest growing segment for military aeronautics applications in the coming years. Based on these properties, advanced composites can meet the high-performance standards requested by aeronautics applications, making them progressively essential for a large number of military aircraft. Figure 6.7 shows the percentage of composite used in jet fighters, as estimated by MarketsandMarkets (M&M, 2015). It is not possible for JRC to validate this information; however, based on stakeholder feedback, the use of composite materials in the Eurofighter Typhoon aircraft might be lower than 50 % as illustrated in Figure 6.7 (e.g. while 70 % of the outer surface of Eurofighter Typhoon is made from composites, the total structural weight of composite is about 30 %).

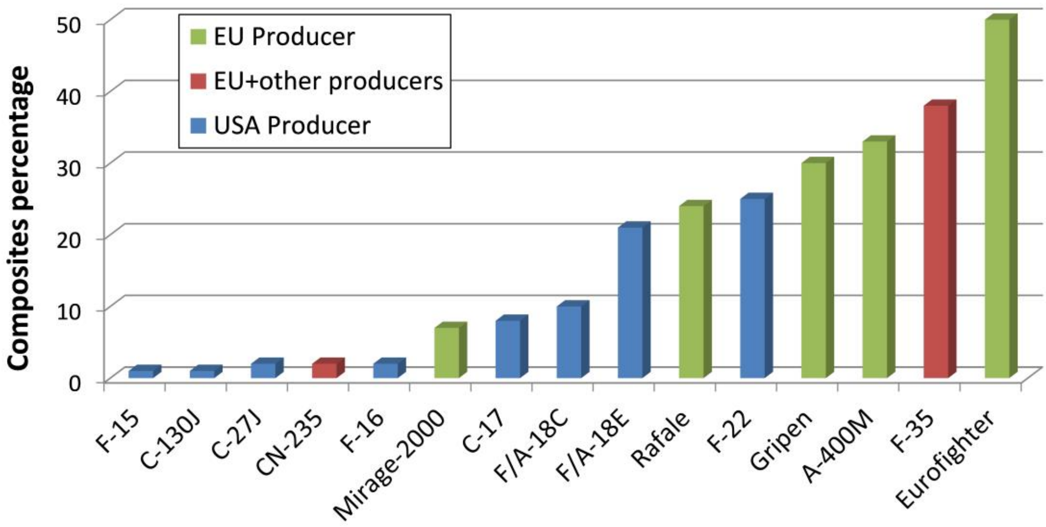


Figure 6.7: Percentage of composite materials (by weight) in various defence aeronautics applications (source: MarketsandMarkets [M&M, 2015])

Overall EU demand for aerospace materials was estimated at 191 700 tonnes in 2014 (with a value of EUR 3 099 million) which represents 28.2 % of global demand (Figure 6.4). Despite the economic slowdown which is still affecting many industries, it is estimated that the European demand for aerospace materials will increase slowly in the coming years, reaching 224 700 tonnes by 2019 (with a value of EUR 4 230 million). The Western European countries are the largest consumers of the aerospace materials as a result of the presence in this region of the leading global producer (Figure 6.8).

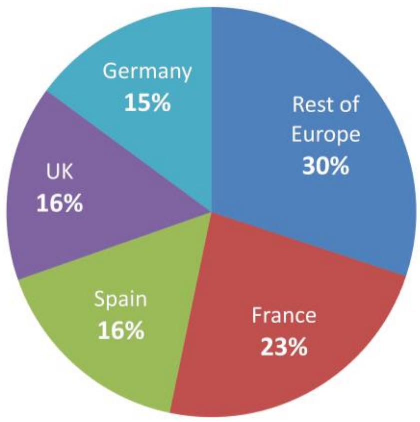


Figure 6.8: Geographical distribution[14] of the EU market by volume for aerospace materials in 2014 (source: MarketsandMarkets [M&M, 2015])

France has the highest consumption of aerospace materials, capturing 23 % of the EU market as a whole, followed by Spain, UK and Germany, each with a similar market share of approximately 16 %.

The aerospace material most used in the EU is the family of aluminium alloys that accounted for 46 % share of the overall EU aerospace materials market in 2014 (Figure

[14] Rest of Europe includes: the Netherlands, Italy, Belgium, etc.

6.9). However, in terms of value, titanium alloys dominate the EU aerospace materials market with 26 %, due to their high prices compared to aluminium-based alloys.

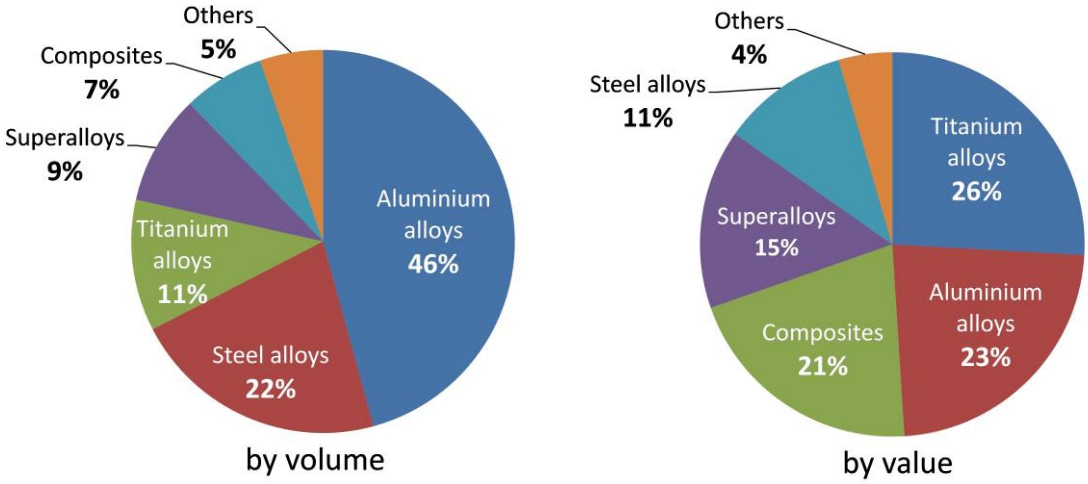


Figure 6.9: The EU market share by material type based on their market volume (left) and value (right) in 2014 (source: MarketsandMarkets [M&M, 2015])

It is estimated that France will show the fastest growing demand for aerospace materials in the EU, which will be driven by the growing demand for commercial aircraft globally; e.g. the CAGR is expected to increase by 3.7 % by volume (or 6.9 % by value) between 2014-2019, reaching a demand of 53 300 tonnes (or EUR 1 029 million) by 2019 (Figure 6.10). Among the aerospace materials, composites are projected to be the fastest growing material type with a CAGR of 6.6 % by volume or 9.6 % by value during the period 2014-2019 (Figure 6.10).

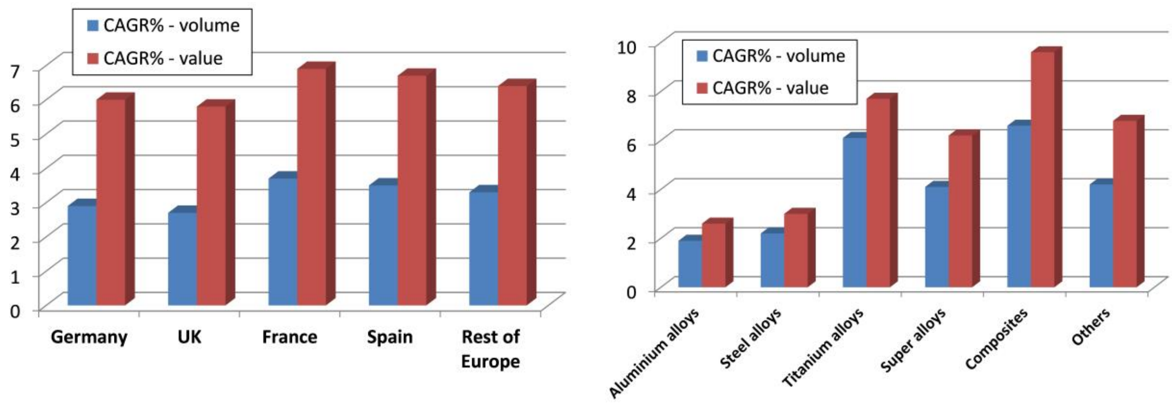


Figure 6.10: Projected compound annual growth rate (CAGR) by EU country (left) and material type (right), 2014-2019 (source: MarketsandMarkets [M&M, 2015])

At the EU level, information about the use of aerospace materials disaggregated by end-use applications, including military aircraft, is not readily available. Based on information provided by industrial stakeholders, an illustrative set of data on the demand for alloys and composites in European aeronautics defence applications, such as fighter aircraft, helicopters (combat and multi-role), transport aircraft (heavy) and maritime patrol aircraft has been estimated by the CEIS. These data are summarised in Table 6.2.

Table 6.2: Estimation of the demand for aerospace materials in the manufacture of several defence applications and their annual EU demand (source: CEIS). Note: these values represent an indication of the materials required for generic aeronautics applications and are not the absolute quantities for each specific application.

Defence application (air sector)	Aerospace materials	Estimated quantities per aircraft or helicopter (tonnes)	Annual EU demand (tonnes)
Fighter aircraft	**Aluminium alloys**		
	7000 series	0.67	46.23
	2000 series	1.22	84.23
	Steel alloys		
	MARVAL X12	0.175	12.09
	Titanium alloys		
	TA6V (mainly)	0.34	23.17
	Superalloys		
	N18-nickel superalloy	0.45	31.08
	AM1 nickel mono-crystalline alloy	0.45	31.08
	Composites		
	Carbon-epoxy composite	0.95	65.62
	Other composite types	0.15	10.36
	Others		
	Rubber	0.35	24.17
Combat helicopter	**Composites**		
	Carbon reinforced with polymer fibres and Kevlar	2.45	26.44
Transport aircraft (heavy)	**Steel alloys**		
	MARVAL X12	1.47	42.42
	Composites		
	Carbon-epoxy composite	24	690.4
	Others		
	Kevlar	2.95	87.79
Multi-role helicopter	**Composites**		
	Carbon reinforced with polymer fibres and Kevlar	5.12	220.64
Maritime patrol aircraft	**Steel alloys**		
	Special steel alloy MARVAL X12	0.46	0.11
	Others		
	Kevlar	0.92	0.21

Based on the data above and the set of European aeronautics defence applications considered in this analysis, it has been estimated that the annual demand for carbon-epoxy composite materials for the production of fighter and transport (heavy) defence aircraft is about 6 % of the overall European demand for composites in the aeronautics sector. Moreover, other high grades of carbon fibres and different resins are also required for military fighter applications, for which there is a niche production.

According to the CEIS, the EU is a major importer of aerospace materials for military aircraft. Considering that all the Union's internal production of aerospace materials is used within the EU, the import dependency for these materials is estimated by the CEIS to range from 20-43 %.

6.3 Global and EU production capability of high-performance alloys and aerospace materials

The production of high-performance alloys is associated with high investments in infrastructure, such as vacuum furnaces, melting and casting equipment. The largest producers provide integrated services ranging from smelting to the supply of semi-finished or finished products. Other players in the industry purchase alloys as billets to process chosen alloys and manufacture castings or milled products. The European alloy industry comprises numerous manufacturers and processors covering a wide range of products and operations.

Europe's alloy industry is represented by companies along the entire value chain of materials, from primary suppliers and traders of processed ores as commodities, to metallurgical companies, milled product manufacturers, stock keepers and distributors of semi-finished and finished products, such as milled bars, sheet and wire. The European companies engaged in the production, processing and supply of specialised high-performance alloys cover a wide area of end-users, including the defence industry sector. As regards the demand for these alloys, the international market is mainly located in Europe, USA and Japan, together accounting for two-thirds of the total market (Figure 6.1). The major suppliers are also based in these regions/countries. Considering the high cost of advanced alloys (which are much higher than shipment costs) and the overall positive political and economic relationships between the EU, USA and Japan, an international market has been created driven by competition for such products. For instance, it is quite common that USA companies are present in the European market and vice versa. To an extent, this also includes end-users from the defence industry.

There are two leading players which supply a complete range of high-performance alloys: Allegheny Technologies Incorporated (USA) and VDM Metals (former Outokumpu VDM) (Germany). Other major companies in the alloy production and supply market include: Precision Castparts Corporation (USA), Carpenter (USA), Aperam (Luxembourg) and Haynes International (USA).

Producers of aerospace materials are mainly located in the USA and Japan. Key players include Alcoa Inc. (USA), Aleris (USA), Cytec Industries Incorporated (USA), Du Pont (USA) and Kobe Steel Ltd (Japan), among others. EU production of metallic aerospace materials that are commonly used in both defence and civilian aeronautics applications is led by two companies with their headquarters in the Netherlands: AMG Advanced Metallurgical Group N.V. and Constellium NV. They are the main suppliers of steel, superalloys, titanium alloys and aluminium alloys.

Information about the largest manufacturers of high-performance alloys and aerospace materials and the suppliers' key products is presented in Table 6.3.

Table 6.3: Global and European suppliers of high-performance alloys and aerospace materials (sources: Global Industry Analysts, Inc., USA [GIA, 2014] and MarketsandMarkets [M&M, 2015])

Supplier	Key product categories	End-use sectors
Major non-EU suppliers		
Alcoa Howmet Casting (USA), former Howmet International, a subsidiary of Alcoa Inc.	Titanium lightweight superalloy; other superalloys (e.g. ingot), titanium and aluminium alloys-based investment casting	Aeronautics (turbine-engine components for jet aircraft), industrial gas power-generation equipment
Alcoa Inc. (USA)	Lightweight metals engineering and manufacturing; various aerospace alloys globally and casting products of aluminium, titanium, superalloys along with fastening systems and landing gears	Aeronautics, defence, transportation, building and construction, oil and energy
Aleris (USA)	Rolled and extruded aluminium products (plate, sheet and coil, extrusions, billets, coated products, tread, foil)	Aeronautics, automotive, construction, defence, etc.
Allegheny Technologies Incorporated (USA)	Speciality materials and high-value products including nickel- and cobalt-based alloys, superalloys, titanium and titanium alloys, speciality steels, super stainless steel and also commodity specialty materials (e.g. zirconium, niobium, hafnium, vanadium, tungsten, etc.)	Aeronautics, defence, automotive, oil and gas, electrical energy, mining, construction, medical, etc.
AMG Aluminium (USA), subsidiary of Advanced Metallurgical Group N.V.	Master alloys and derivative products: grain refiners, hardeners, strontium modifiers for hypo-eutectic/eutectic aluminium silicon alloys, speciality and mechanical alloys	Aluminium industry
Baoji Lixing Titanium Group Co., Ltd (China)	Processed metal products and alloys made from titanium, nickel and molybdenum	Aeronautics, chemical industry
Carpenter Technology Corporation (USA)	Controlled expansion and magnetic alloys, high-strength alloy steels, high-temperature cobalt-, iron- and nickel-based alloys, and cast and wrought stainless steels	Aeronautics (jet engines, landing gears, airframe components), medical, energy, gas turbines, nuclear power plants
Cytec Industries (USA)	Advanced composites and adhesive materials for special environments, high-performance, lightweight materials and process materials	Aeronautics, automotive and industrial coatings, inks, mining and plastics
Du Pont (USA)	Aramid intermediates and Kevlar fibres	Many industries
Haynes International Inc. (USA)	High-performance nickel- and cobalt-based alloys used in corrosion and high-temperature applications (e.g. Hastelloy series, 6B(33), 6BH, etc.)	Various applications from chemical industry, in nuclear reactors, etc.
Hexcel Corporation (USA)	Carbon fibre, composite materials and structural parts	Aeronautics, defence, wind energy, automotive, marine
Huntsman Corporation (USA)	Chemical products and advanced materials such as composites, synthetic and formulated polymer systems	Aeronautics, automotive, coatings, wind energy, construction, electronics, medical, marine

Supplier	Key product categories	End-use sectors
JSC VSMPO-AVISMA Corp. (Russia)	World-leading producer of titanium and major producer of ferro-titanium, aluminium and magnesium alloys	Aeronautics, power engineering, oil and gas, construction, medicine
Kobe Steel Ltd (Japan)	Titanium, and titanium alloys, stainless steel, aluminium and aluminium alloys, forgings and castings	Aeronautics, electrical transportation, construction and mining, and communication
Nippon Yakin Kogyo Co., Ltd (Japan)	Stainless steels, non-slip patterned flooring and large portfolio of high-performance alloys (e.g. corrosion and heat-resistant alloys, high-strength stainless steel, controlled expansion alloys, soft magnetic alloys, neutron-adsorbing stainless steel, etc.)	Fuel cells, solar cells, semiconductors, atomic power generation, desalination systems, astronomical telescopes, flat panel displays, etc.
Olin Brass Corporation (USA)	Standard and high-performance copper alloys	Electronic and communications devices, ammunition, etc.
Precisions Castparts Corp. (USA)	Metal components and products, nickel-based superalloys, titanium, stainless steel and other alloy steels	Aeronautics, energy, casting and forging, industrial gas turbines
QuesTek Innovations, LLC (USA)	Novel high-performance alloys with different compositions, mainly based on aluminium (e.g. Alurium series and SCC alloys)	Aeronautics, oil and gas, high-performance racing, medical, etc.
RTI International Metals (USA)	Titanium milled products and fabricated metal components	Aeronautics, chemicals, propulsion, defence, etc.
Special Metals Corporation (USA), subsidiary of Precision Castparts Corp.	High-performance nickel-based alloys (e.g. Inconel, Incoloy, Monel, Nilo, Nimonic, Nickel/Duranickel, Brightray, Udimet)	Aeronautics, power generation, chemical processing, oil exploration
Teijin Limited (Japan)	Carbon fibre and composite materials, e.g. TENAX (prepreg, woven fabric, filament, metal-coated fibres, oxidised PAN fibre)	Transportation, electronics, energy, healthcare, trading and retail and others
Titanium Metals Corporation (TIMET) (USA)	High-quality titanium metal products and titanium-based downstream products	Aeronautics, comprising defence and commercial aircraft
Toray Industries (Japan)	Carbon-fibre materials (TORAYCA™: PAN-based carbon fibre); synthetic fibre, carbon-fibre-reinforced plastic, and carbon-fibre composite materials (PAN-based carbon-fibre composites)	Aeronautics, polymer, textiles, chemical industries, etc.
Major European suppliers		
AMG Advanced Metallurgical Group NV (the Netherlands)	Master alloys, ferro-titanium, ferro-niobium, titanium aluminide, titanium-boron-aluminium, strontium-aluminium alloys and specialty metals (antimony, graphite, niobium and tantalum); titanium alloys and coatings (e.g. Fortron), super alloys	Aeronautics, energy, electronics, optics, chemical, construction
Aperam SA (Luxembourg)	Stainless steel (estimated production capacity of 2.5 million tonnes) and speciality products (e.g. nickel alloys and electrical steel)	Industrial equipment, renewable energy, chemical processing, oil and gas, aeronautics and automotive

Supplier	Key product categories	End-use sectors
Costellium N.V. (the Netherlands)	Broad range of innovative specialty rolled and extruded aluminium products	Aeronautics, packaging and automotive
Doncaster Group Ltd (UK)	Iron, cobalt and nickel-based high-performance alloys, among other components	Aero-engine components, turbine blades and vanes, hot-end turbocharger wheels, etc.
Eramet Group (France)	High-performance special steels, nickel and cobalt super alloys, pre-machined components of various metals (e.g. aluminium, titanium etc.); high-speed steel, superalloys and tool steels	Aeronautics, energy, automotive, defence, medical and precision engineering
Glencore Plc. (Switzerland), former Xstrata	Various metal commodities: copper, zinc, lead, nickel, alumina and aluminium and iron ore; vanadium and molybdenum products; ferroalloys (e.g. ferrochrome, ferromanganese, silicon manganese, etc.)	Industrial, automotive, construction, steel, power generation, oil and food processing
H.C. Starck GmbH (Germany)	Refractory metals powders and their compounds, advanced ceramic powders, non-ferrous metals (e.g. nickel and nickel salts and boron-based compounds), molybdenum alloys and other semi-finished and finished tungsten, tantalum, niobium, titanium, zirconium, and nickel products and alloys	Aeronautics, aviation, defence, automotive, electronics, optics, energy, medical technologies, etc.
Plansee Holding AG (Austria)	Powder-metallurgical manufactured materials; metal powders and components made from refractory metals: molybdenum and tungsten	Mechanical engineering, automotive, consumer electronics, power engineering, aeronautics, construction, etc.
Tital GmbH (Germany), subsidiary of Alcoa Inc.	Casting products made from titanium and aluminium alloys	Aeronautics, electronics, optics, industrial and medical systems, motor sports
VDM Metals (Germany), former Outokumpu VDM, subsidiary of ThyssenKrupp AG	High-performance nickel alloys, cobalt-based alloys, titanium and titanium alloys, zirconium and special stainless steels	Electrical, electronic, automotive, aeronautics, oil and gas, energy and chemical processing

Although significant composite production has been established in Europe (e.g. at the Hexcel Corp. production plant) driven by the Airbus A350 passenger aircraft, the EU lacks major manufacturers of aerospace-grade carbon fibres and their precursors, e.g. polyacrylonitrile (PAN), which are needed for composite materials and are currently mainly produced in Japan. In spite of the limited production within the EU of all materials used in defence applications, it should be emphasised that at the present time there is a potential low to moderate supply chain bottleneck for aerospace materials and other semi-finished materials used by European defence industries. The European OEMs and lower-tier contractors mainly sign long-term contracts with material suppliers, and they also enter into agreements to develop new technologies (which would include components and advanced materials) for the overall growth of the aeronautics and defence sectors.

6.4 R&D initiatives related to materials development for the defence sector

Companies in the defence sector estimate that most of the current materials used in the production of defence applications will remain in use for the foreseeable future. This is because they have a very high level of performance that is unlikely to be matched in a short period by substitutes. However, the evolution in materials cannot be predicted. Recent developments in material science and engineering, metallurgy, polymer science, chemistry, glass and ceramic technologies, are continuously generating new structural and functional materials offering possibilities in a wide area of applications, including the defence sector. A specific example, optimisation of the composition of a nickel-based alloy used in turbine blades, over time, is shown in Figure 6.11.

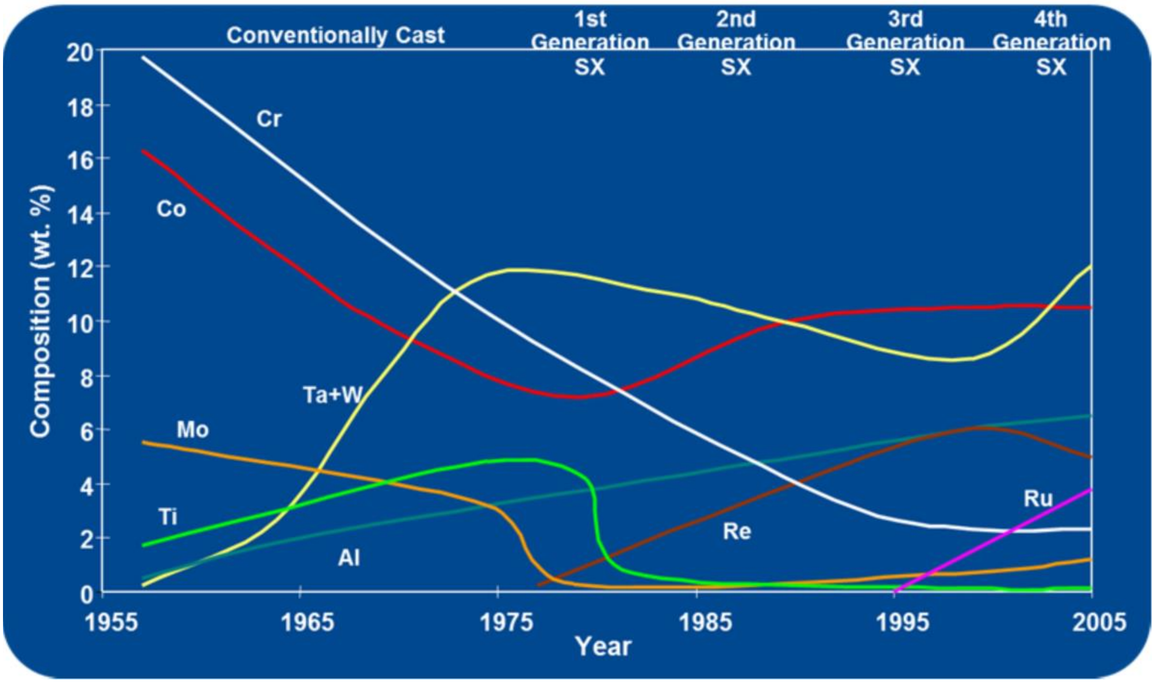


Figure 6.11: Changes in elemental composition of nickel-based superalloys over time (source: Rolls-Royce [Clifton, 2013])

The alloy's performance has been improved over time by replacing the traditional alloying elements, such as chromium (Cr), cobalt (Co) and molybdenum (Mo), with more exotic elements, like rhenium (Re), ruthenium (Ru), tantalum (Ta) and tungsten (W). These changes in alloy composition have enabled gas turbine engines to operate more efficiently and for a longer time.

Innovative applications are continuously being found for materials in the defence industry. For instance, flax fibres which exhibit good mechanical, structure and tensile properties are evaluated as a constituent for making lightweight seats, walls, ceiling and floors in military aircraft.

Although the European defence sector is facing a constant reduction in total R&D spending, it is recognised that research and innovation are key factors in the development of the current and future military capabilities that Europe needs. R&D priorities for materials include the greater efficiency of advanced batteries and high-temperature turbine engines, development of sophisticated electronics, etc., as well as the development of new defence products. Although EU R&D initiatives in the defence sector have not been addressed in this study, a limited number of examples of ongoing research have been identified and are presented in Table 6.5.

Table 6.5: R&D initiatives and associated materials for defence applications

Materials	R&D activity	Usage
Barium titanate	R&D programmes on use in supercapacitors	
Carbon-siliceous fibre composites	Material in test phase	Propulsion system in missiles
Gadolinium	Companies in the aeronautics sector are researching potential uses of gadolinium	Aeronautics thermal barriers
Germanium	R&D programmes to replace gallium arsenide chips with silicon-germanium chips	
Graphene	Multiple research programmes on eventual uses, particularly in the aero-spatial sector	
Lithium	R&D programmes on aluminium-lithium alloys with a small amount of lithium (about 1 %)	Fuselage in aeronautics
Molybdenum	Companies in the aeronautics sector are researching alternative uses of molybdenum	Treatment of surfaces
Nanomaterial	R&D programmes on eventual use	Missiles
Niobium	The shipbuilding industry is considering using niobium once its superconductivity at high temperatures has been researched	Confidential
Sapphire (Al_2O_3)	Multiple research programmes on eventual usage	Infra-red detectors
Spinel ceramics ($Mg_2Al_3O_4$)	Material in test phase	Transparent armouring
Yttrium	The shipbuilding industry is considering using yttrium once its superconductivity at high temperatures has been researched	Confidential

7. Conclusions

This study has compiled an inventory of raw materials that are important to the European defence industry. This has been achieved by identifying the role and type of material used in representative defence applications. The term 'important' is used with reference to the capacity of these materials to fulfil the stringent requirements of defence applications. The analysis carried out in this report has led to the identification of 39 raw materials that are the constituents of advanced materials used for the production of a large variety of defence-related subsystems and components. The list of these raw materials and the associated defence sectors are presented in Table 7.1.

Table 7.1: Important raw materials used in the European defence industry and their application by defence sector; the table also identifies those materials that are included in the EU's critical raw materials list (EC, 2014b)

Raw materials	Presence in the EU critical raw materials list	Major end-use defence sectors
Aluminium	-	Aeronautics, naval, land, missiles
Barium	-	Aeronautics, land, electronics
Beryllium	Yes	Aeronautics, naval, electronics
Boron	-	Aeronautics, electronics
Cadmium	-	Aeronautics, electronics
Chromium	Yes	Aeronautics, naval, land
Cobalt	Yes	Aeronautics, naval
Copper	-	Aeronautics, naval, land, electronics
Dysprosium	Yes	Missiles
Gallium	Yes	Electronics
Germanium	Yes	Electronics
Gold	-	Electronics
Hafnium	-	Aeronautics, electronics
Indium	Yes	Electronics
Iron	-	Aeronautics, naval, land, missiles
Lead	-	Aeronautics, naval
Lithium	-	Aeronautics, naval, electronics
Magnesium	Yes	Aeronautics, electronics, missiles
Manganese	-	Aeronautics, naval
Molybdenum	-	Aeronautics, naval, missiles
Neodymium	Yes	Aeronautics, space, electronics
Nickel		Aeronautics, naval, land
Niobium	Yes	Aeronautics, missiles
Platinum	Yes	Aeronautics
Praseodymium	Yes	Missiles
REEs (other)	Yes	Aeronautics, electronics
Rhenium	-	Aeronautics
Samarium	Yes	Aeronautics, naval, electronics
Selenium	-	Electronics
Silver	-	Electronics
Tantalum	-	Aeronautics, electronics
Thorium	-	Electronics
Tin	-	Aeronautics
Titanium	-	Aeronautics, naval, land
Tungsten	Yes	Aeronautics, land
Vanadium	-	Aeronautics, naval
Zinc	-	Electronics
Zirconium	-	Aeronautics
Yttrium	Yes	Electronics

Of these 39 raw materials, 16 are considered critical for the EU economy by the Raw Materials Initiative (RMI), and are included in the EU's 2014 critical raw materials list. They are: beryllium, chromium, cobalt, dysprosium, gallium, germanium, indium, magnesium, neodymium, niobium, platinum, praseodymium, REEs (other), samarium, tungsten and yttrium. A closer look into the use of these 16 critical raw materials in defence applications indicates that the aeronautics and electronics defence sectors are the most vulnerable to potential supply constraints, based on the high criticality rating assigned to them by the RMI.

An assessment of the raw materials inventory used by the European defence industry based on import dependency criteria revealed that the EU is fully dependent on imports of 19 raw materials (i.e. beryllium, boron, dysprosium, germanium, gold, indium, magnesium, molybdenum, neodymium, niobium, praseodymium, a group of other REEs, samarium, tantalum, thorium, titanium, vanadium, zirconium and yttrium), 11 of which are critical, and it is more than 50 % reliant on imports for over three-quarters of those. However, three raw materials – hafnium, rhenium and selenium – have not been analysed due to lack of available information. China is the major producer of one-third of the raw materials identified in defence applications. The supply risk of raw materials produced in this country is considered high, which means the supply may be interrupted (e.g. by imposing restrictions on exports).

In view of the strategic importance of the defence sector for Europe's security, it is imperative that the related industrial production operates under uninterrupted conditions. Therefore, it must be able to rely on a secure supply chain of raw materials, which must not be conditional on the quantities required.

Current concern in the European defence industry lies in the security of supply of processed and semi-finished materials rather than in raw materials. Most defence applications integrate a large number of semi-finished materials and finished products made from various alloys, composites, etc. – and almost none of them are made from a single raw material. The fact is that the main actors in the European defence industry procure mainly alloys and transformed or pre-transformed composites rather than simple metals.

This study identified 47 different types of alloy, compound and composite materials that are important for the European defence industry. These materials have essential unique properties and characteristics that ensure the performance of the defence applications in which they are used, and therefore are considered indispensable. For instance, aeronautics applications are made essentially from several families of materials, as shown in Figure 7.1.

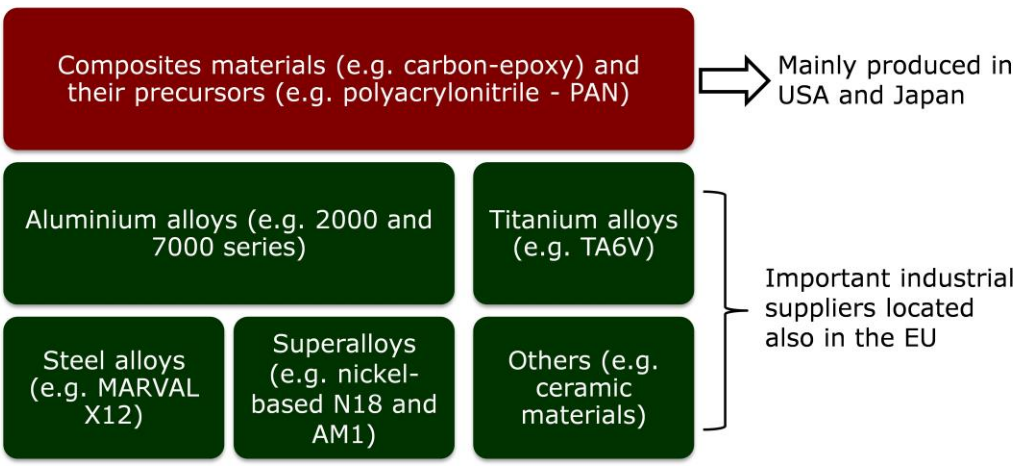


Figure 7.1: Types of materials used in aeronautics defence applications

A competitive, efficient and uninterrupted supply chain of materials is vital for the profitability and competitiveness of the European defence industry. Overall, EU industry is actively engaged in the production, processing and supply of specialised high-performance alloys that are important for a wide area of end-use applications, including those in the defence sector. However, the EU lacks major manufacturers of aerospace-grade carbon fibres and their precursors which are produced mainly in the USA and Japan.

This analysis was hampered by the limited information on the types of materials and their use in defence applications. Open literature is scarce and, in general, industrial stakeholders are reluctant to share information bound by confidentiality. However, it is important that the knowledge base on the raw materials used in the European defence sector is improved. This can be achieved by promoting information sharing between all relevant stakeholders, such as Member States, industrial players and their associations, EDA and the European Commission. This allows potential material supply risks that may threaten the European defence industry to be addressed more efficiently and in a timely way. This study addresses this issue, in response to an action put forward by the European Commission in its Communication 'Towards a more competitive and efficient defence and security sector'.

The materials supply chain that supports the EU defence industry comprises a complex network of material suppliers, manufacturers, distributors and wholesalers/retailers. It is thus the recommendation of this report that further studies assessing in greater detail the supply risk to the raw and processed materials identified in the present study would provide valuable additional information. Such studies should bring more insight on the value chains, spanning from the OEMs, subsystem and component producers, metallurgical transformation and processing process owners to the mining of the constituent raw materials.

A specific assessment of the impact of potential material supply disruptions on the business continuity of the European defence industry needs to be developed. Such an assessment should reflect in depth the issues related to the security of materials supply in the European defence sector, the causes of any previous disruptions, and evolution of the factors that can affect materials supply and demand. Moreover, the analysis and discussions with stakeholders have shown that it is very difficult, and in many cases not useful from the industry's point of view, to conduct assessments at industry sector level. In the case of the defence sector, it may be more appropriate to conduct such assessments at the application level, through the evaluation of materials in the context of specific defence products, followed by an aggregation of the results so that sound conclusions can be drawn for the defence sector. The current EU methodology that screens critical raw materials takes into account the supply risk associated with the upstream stage of the production process combined with its economic importance to the EU. This methodology could be extended to address downstream stages that involve the processing of raw materials towards specialised, high-performance and advanced materials. Furthermore, the impact that any potential disruption of the supply of such processed and semi-finished materials might have on the production of defence applications needs to be assessed.

In essence, a set of actions is recommended for the development of future initiatives intended to improve the security of supply of materials used in the European defence industry:

- Integration of specialised processed materials (i.e. special alloys, composites, etc.) into the multifaceted dimension of the strategy for the security of materials supply. Currently, the industrial security of supply mainly concerns the supply of raw materials, technologies or parts of components to top-tier contractors. Strengthening the production of such specialised materials within Europe's borders would generate a significant shift towards independency from non-European manufacturers, and thus lead to the sustained development of the

European defence industry. This would also offer new opportunities to the European materials industry, creating growth and jobs.

- Identification of potential civil-military research synergies and promotion of those R&D and innovation projects that focus on developing new and high-performance materials with dual-use applications in the defence and civilian sectors.

The findings of this report and the recommended set of actions may be particularly relevant in view of the Commission’s work to develop a roadmap for a comprehensive EU-wide security of supply regime (EC, 2014c).

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List of abbreviations and definitions

bn	Billion (1 000 million)
CAGR	Compound Annual Growth Rate
CRM	Critical Raw Materials
DLA	Defence Logistics Agency of the USA
DoD	Department of Defense
EADS	European Aeronautic Defence & Space Co.
EDA	European Defence Agency
EDTIB	European Defence Technological and Industrial Base
EIP	European Innovation Partnership
EU	European Union
HPA	High-performance alloys
JRC	Joint Research Centre, a Directorate-General of the European Commission
NDS	National Defence Stockpile, a USA programme
OEM	Original equipment manufacturer
REEs	Rare earth elements
RMI	Raw Materials Initiative
SIPRI	Stockholm International Peace Research Institute
TREO	Total rare-earth oxides
USD/EUR	Currency conversion at 1 January 2015 (USD/EUR = 0.82623)
USGS	United States Geological Survey

Appendix 1: Overview of the production of defence-related applications by the European defence sector

The information presented in this appendix has been provided by the CEIS. The approach comprised a preliminary open literature search of the number of land, naval, air, space and missile applications that were selected previously and referred to in Chapter 2. The year at both the start and end of operations has been identified in order to estimate the number of applications produced per year:

$$\frac{Total\ number\ of\ applications\ (land/naval/air/space/missile)}{Total\ number\ of\ years\ from\ first\ to\ last\ year\ of\ operations}$$

Where the last year was not specified, for the purpose of this study an end year of 2014 was assumed. This methodology is purely theoretical and is not entirely representative of the actual number produced every year. Indeed, military applications are often produced based on specific requirements or demands that vary from year to year.

AIR SYSTEMS

The information source for all air systems was the World Air Forces directory 2014 - Flight Global International, unless otherwise stated.

Fighter aircraft

System name	Manufacturer	Number produced	Average annual production
Rafale[15]	Dassault	133 (2001-2014)	9
Eurofighter	Airbus/BAE Sys/Finmecc	Circa 400 (2003-2014)	36
Gripen	Saab	Circa 250 (1997-2014)	15
Average European production (1997-2014)		783	46

Combat helicopter

System name	Manufacturer	Number produced	Average annual production
Tiger	Airbus Group	108 (2004-2014)	10.5
A129 Mangusta	AgustaWestland	No longer in production	N.A.
Average European production (2004-2014)		108	10.5

[15] http://www.senat.fr/rap/a08-548/a08-548_mono.html

Transport aircraft (heavy)

System name	Manufacturer	Number produced	Average annual production
A400M	Airbus Group	11 (2007-2015) About 174 ordered	26.5[16]
A330MRTT	Airbus Group	22 delivered (2005-2014) About 35 ordered	2.5 (2005-2014)
Average European production		33	29

Transport aircraft (tactic)

System name	Manufacturer	Number produced	Average annual production
C-27J	Alenia	About 60 (1999-2015)	About 3.4
CN-235	CASA (+IPTN)/Airbus Group	279[17] (1982-2015)	8.5
C-295	CASA/Airbus Group	117 (1996-2015)	6.2
Average European production		456	18.1

Multi-role helicopter

System name	Manufacturer	Number produced	Average annual production
NH90	NHIndustries	+200 (1995-2014)	22.2
AW101	AgustaWestland (Finmeccanica)	About 140 (1995-2020)	5.6
EC725	Airbus Group	About 110 (+40 produced in Brazil) (1999-2017)	6
AW139	AgustaWestland (Finmeccanica)	18 (2000-2014)[18]	1.3
AW149	AgustaWestland (Finmeccanica)	Not ordered yet	N.A.
AS565	Airbus Group	At least 123 (1983-2014)	4
W-3	PZL-Swidnik	97[19] (1985-2005)	5
Average European production		+678	44.1

[16] http://www.defense-aeronautics.com/article-view/feature/144962/airbus-aims-at-huge-a400m-export-market.html
[17] http://militaryaircraft-airbusds.com/Portals/0/Images/Aircraft/OrdersAndDeliveries/AMOrdersDeliveries.pdf
[18] Many more AW139 were produced, but for civilian or governmental roles (coastguard, police, etc.). The figure refers strictly to military roles
[19] W-3 for military roles only

Unmanned aerial vehicle

System name	Manufacturer	Number produced	Average annual production
Sperwer	Sagem	130 (2000-2014)	9
S100 Camcopter	Schneibel	About 300 (2005-2015)	30
Tracker	Airbus	About 270 (2005-2015)	27
Tanan	Airbus	Under development	N.A.
Skeldar	Saab	Prototype	N.A.
Falco	Selex	About 50 (2002-2014)	4.2
Luna	EMT Penzberg	About 40 (2000-2009)	4.5
Average European production		790	74.7

Unmanned fighter aerial vehicle

System name	Manufacturer	Number produced	Average annual production
Neuron	Dassault Aviation	Under development	N.A.
Taranis	BAE Systems	Under development	N.A.
Average European production		N.A	N.A.

NAVAL SYSTEMS

The information source for all naval systems is Flottes de Combat 2012 - Bernard Prézelin, Editions Maritimes, unless otherwise stated.

Aircraft carrier

System name	Manufacturer	Number produced	Average annual production
Queen Elizabeth	BAE Systems	2 (2010-2020)	0.2
Cavour	Fincantieri	1 (2001-2009)	0.1
Average European production (2001-2020)		3	0.3

Amphibious assault ship and helicopter carrier

System name	Manufacturer	Number produced	Average annual production
Mistral	DCNS	4 completed (2003-2014)	0.4
Juan Carlos	Navantia	3 (2005-2015)	0.3
Average European production (2003-2014)		7	0.7

Destroyer and frigate

System name	Manufacturer	Number produced	Average annual production
Horizon	DCNS	2 (2004-2011)	0.3
FREMM	DCNS	8 (2007-2019)	0.7
Type 125 MEKO	TKMS	4 (2011-2019)	0.9
Type FPS	Odense Vaerft	3 (2008-2013)	0.6
Type F100	Navantia	5 (1999-2012)	0.4
Type 45	BAE Systems	6 (2003-2013)	0.6
Orizzonte	Fincantieri	2 (2008-2017)	0.2
FREMM	Fincantieri	6 (2008-2017)	0.7
Average European production (1999-2019)		36	4.4

Corvette (NB: Corvettes are rarely used in European navies, which prefer frigates or heavy patrol vessels.)

System name	Manufacturer	Number produced	Average annual production
Gowind	DCNS	1 (2010-2012)	0.5
K130	TKMS	5 (2004-2007)	1.7
Meko 100	TKMS	6 (2001-2010)	0.7
Meko 100	Gdynia (TKMS design)	1 (2001-2009)	0.1
Visby	Kockums	5 (1996-2008)	0.4
Super Vita	Elefsis	7 (2002-2013)	0.6
Comandante Cigala Fulgosi	Fincantieri	4 (1999-2002)	1
Sirio	Fincantieri	2 (2009-2011)	0.7
NPO 2000	Estaleiros Navais	4 (2005-2015)	0,4
Holland	Damen	4 (2008-2012)	1
Sigma	Damen	7+ (2005-2012)	1
Average European production (1996-2015)		46+	8

Offshore patrol vessel (NB: The OPV market is highly competitive. Only a few platforms are built in European shipyards, and most of them are built locally with European technical assistance. These figures strictly represent the OPV built in European shipyards.)

System name	Manufacturer	Number produced	Average annual production
Amazonas	BAE Systems/VT	3 (2008-2010)	1
Knud Rasmussen	Karstensens	2 (2005-2009)	0.5
Turva	STX Finland	1 (2013-2014)	0.5
BAM	Navantia	5 (2009-2015)	0.8
Arnomendi	Vigo	2 (2000-2004)	0.5
Fulmar	Gondan	1 (2005-2006)	0.5
Rio Segura	Gondan	1 (2010-2011)	0.5
Rauma 2000	Aker Finnyards	4 (1998-2006)	0.5
River	Vosper	4 (2001-2007)	0.6
Jura	Ferguson and Remontowa	2 (2005-2008)	0.6
Saettia MK4	Fincantieri	4 (2008-2010)	2
PV90	Babcock	2 (2012-2015)	0.6
Bigliani	Intermarine	9 (2003-2007)	2.3
P130 Jasiri	Gondan	1 (2005-2012)	0.1
OPV70	STX and Raidco	1 (2009-2011)	0.5
LFC 2005	Estaleiros Navais	5 (2012-2015)	1.6
Average European production (1998-2015)		47	13

Submarines (conventional)

Among the European military shipbuilders, only DCNS, TKMS, Kockums, Navantia and Fincantieri (with TKMS) build conventional submarines. Some are built mainly outside Europe, like the Scorpene.

System name	Manufacturer	Number produced	Average annual production
Dolphin	TKMS	3 (2012-2017)	0.6
Type 209/1400	TKMS	3 (2001-2008)	0.4
Type 212	TKMS	6 (1998-2014)	0.4
Type 212	Fincantieri	4 (2001-2017)	0.3
Type 214	TKMS	1 (2001-2004)	0.3
Type 214	Hellenic Shipyards	1 (2003-2015)	0.1
Type 214	TKMS	2 (2005-2011)	0.3
Type 218SG	TKMS	2 (2014-2020)	0.3
Scorpene	DCNS	1 (2000-2005)	0.2
Scorpene	DCNS	1 (2004-2009)	0.2
Scorpene	Navantia	1 (2005-2009)	0.3
S80	Navantia	4 (2007-2021)	0.3
Average European production (1998-2021)		29	3.5

Torpedo (NB: The production figures are very scarce in public sources – numbers are only available for a few systems.)

System name	Manufacturer	Number produced	Average annual production
F-21	DCNS	93 (2016-N.A.)	-
F-17	DCNS	-	-
DM-2A4	Atlas Emektronik	-	-
Spearfish	BAE Systems	-	-
Black Shark	Wass (Fincantieri)	At least 250 (2004-2014)	25
TP62	Saab	-	-
MU90 Impact	Eurotorp	At least 1000 300 in France 300 in Germany 300 in Italy	- 25 in France
A244	Eurotorp	At least 1000	-
Average European production		N.A.	N.A.

SPACE SYSTEMS

The information source for space, electronic and missile systems was Deagel Guide to Military Equipment and Civil Aviation (available at: http://www.deagel.com/) unless otherwise stated.

Infra-red satellite

System name	Manufacturer	Number produced	Average annual production
Spirale	Thales	2 (2008-2014)	0.3

Radar satellite

System name	Manufacturer	Number produced	Average annual production
SAR Lupe	OHB System	5 (2006-2014)	0.6

ELINT satellite

System name	Manufacturer	Number produced	Average annual production
CERES	Airbus D&S	3 (2015-2020)	0.6

Communication satellite

System name	Manufacturer	Number produced	Average annual production
Syracuse	Thales	10 (1980-2010)	0.3

Launch systems

System name	Manufacturer	Number produced	Average annual production
Ariane-V	Airbus D&S	(Until 2014)=117 (Total until 2020)=200	8.33

ELECTRONIC SYSTEMS

Radar

System name	Manufacturer	Number produced	Average annual production
Giraffe	Saab	450 (1977-2007)	15

Communication systems

System name	Manufacturer	Number produced	Average annual production
FIST	Thales UK	29 000 (2015-2020)	5800

MISSILE SYSTEMS

Air-air missile

System name	Manufacturer	Number produced	Average annual production
MICA IR	MBDA	1000 (2000-2014)	66.7

Surface-air missile

System name	Manufacturer	Number produced	Average annual production
Aster 30	MBDA	Total Aster: 1000 (2007-2014)	125

Anti-tank missile

System name	Manufacturer	Number produced	Average annual production
MILAN	MBDA	330 000 missiles, 10 000 launchers (1972-2014)	7857 missiles 238.1 launchers

Anti-ship missile

System name	Manufacturer	Number produced	Average annual production
Exocet	MBDA	4045 (1975-2014)	101.1

Cruise missile

System name	Manufacturer	Number produced 2004-2014	Average annual production
SCALP/Storm Shadow	MBDA	2250 (2003-2014)	187.5

Appendix 2: Description of the European defence applications

The purpose of this appendix is to put into context each defence application produced by the European defence industry. This appendix is based on information provided by the CEIS.

AIR SYSTEMS

Fighter aircraft

A multi-role fighter aircraft is a military aircraft – i.e. a stand-alone system with components (including not stand-alone subsystems) integrated to produce a single-system capability – intended to perform different roles in fighter.

The term had originally been reserved for aircraft designed for both major roles:

- a primary air-to-air fighter role;
- a secondary role such as air-to-surface attack.

More roles can be added, such as aerial reconnaissance, forward air control, and electronic-warfare aircraft. Attack missions include the air interdiction, suppression of enemy air defence (SEAD), and close air support (CAS) sub-types.

Rafale
Country of origin: France
Countries in service: France, Egypt
Manufacturer: Dassault Aviation
Empty weight: 10 000 kg

Description
The Rafale is a fourth-generation 'omni-role' fighter aircraft capable of carrying out a wide range of missions. It is produced in three variants: M, B and C; the single-seat M version is for the navy; Rafale B is a two-seat version for the air force; and the C variant is a single-seat fighter for the air force. The first flight of a production Rafale, an M variant, was in July 1999, when it landed on the new French aircraft carrier Charles de Gaulle.

Eurofighter
Country of origin: UK, Germany, Italy and Spain
Countries in service: Germany, Italy, Spain, United Kingdom, Austria and the Kingdom of Saudi Arabia
Manufacturer: BAE Systems, Alenia Aermacchi, Airbus Defence & Space
Empty weight: 11 150 kg

Description
The Eurofighter Typhoon is a highly agile, twin-engine, multi-role fighter aircraft which features the canard-delta wing. It can perform super-cruise ability, features voice command control, and is able to take on air-to-ground attack missions. The Typhoon is a remarkably agile jet fighter at both supersonic and low speeds, achieved despite having a deliberately relaxed stability design. It features a quadruplex digital fly-by-wire control system providing artificial stability; manual operation alone could not compensate for the inherent instability.

Gripen

Country of origin: Sweden

Countries in service: Czech Republic, Hungary, South Africa, Sweden, Thailand, United Kingdom

Manufacturer: Saab AB

Empty weight: 6800 kg

Description

The Saab JAS 39 Gripen is a multi-role and single-engine lightweight fighter which features a fly-by-wire control flight system, relaxed stability design, delta wing and canards. The aircraft was developed to replace the previous Swedish Air Force fighters: the Saab 35 Draken and 37 Viggen.

The development started in 1979 and guided by the need for a new versatile fighter at the height of the Cold War – Sweden thought it needed to prepare its own defence in case the Soviet Union invaded the country.

Since many parts of the airframe need either low-cost or no maintenance at all, and taking into account the physical structure of the aircraft, the anticipated lifespan of the Gripen would be approximately 50 years.

F-35

Country of origin: USA

Countries in service: In initial production and testing, used for training by the USA and UK

Manufacturer: Lockheed Martin Aeronautics

Empty weight: 13 170 kg (F-35A)

Description

JSF is a joint, multinational acquisition programme for the air force, navy, marine corps, and eight cooperative international partners. Predicted to be the largest military aircraft procurement ever, the stealth, supersonic F-35 Joint Strike Fighter (F-35) will replace a wide range of ageing fighter and strike aircraft for the USA and allied defence forces worldwide.

Lockheed is developing the F-35 for the marines, air force and navy and the eight countries that have helped fund its development: Britain, Canada, Australia, Norway, Italy, Turkey, Denmark and the Netherlands. Israel and Japan have also ordered the jet.

The F-35 programme, which began in 2001, is already 70 % over initial cost estimates, and years behind schedule.

Combat helicopter

Tiger
Country of origin: France and Germany
Countries in service: France, Germany, Australia, Spain
Manufacturer: Airbus Helicopters
Empty weight: 3060 kg

Description

The Tiger is Airbus Helicopter's multi-role attack helicopter. It is designed to perform armed reconnaissance, air or ground escort, air-to-air fighter, ground firing support, destruction and anti-tank warfare, day or night and in adverse conditions.

The Tiger attack helicopter has proven its capabilities during operational deployments in Afghanistan, the Central African Republic, Somalia, Libya and Mali. The enhanced Tiger HAD variant provides air-to-ground missile capability, improved target acquisition and ballistic protection, 14 % more power, an evolved electronic warfare suite, and the latest interrogation systems.

The initial production contract was signed on 20 June 1997. The first production machine, a German UHT variant, was rolled out in March 2002. The first production French HAP escort variant performed its initial flight on 26 March 2003. Initial service deliveries of the UHT and HAP began in the spring of 2005.

A 129
Country of origin: Italy
Countries in service: Italy and Turkey
Manufacturer: AgustaWestland
Empty weight: 2530 kg

Description

The AW129 multi-role fighter helicopter is the latest variant of the A129 Mangusta (Mongoose) helicopter in service with the Italian Army. The AW129 is a multi-role helicopter for armed reconnaissance and surveillance, high-value ground-target engagement, escort, fire support and air-threat suppression. It is armed with powerful air-to-ground and air-to-air missiles, an off-axis cannon and an increased weapon payload.

The Mangusta was successfully deployed during UN operations in Somalia, Angola and Kosovo. Italian Army A129 helicopters have been deployed in Iraq as part of Operation Iraqi Freedom and were deployed to Afghanistan in summer 2007 as part of the NATO International Security Force.

Transport aircraft (strategic)

Military transport aircraft or military cargo aircraft are typically fixed-wing and rotary-wing cargo aircraft which are used to deliver troops, weapons and other military equipment using a variety of methods to any area of military operations around the globe. Originally derived from bombers, military transport aircraft were used to deliver airborne forces during the Second World War and for towing military gliders. Some military transport aircraft are tasked with performing multi-role duties, such as aerial refuelling, and tactical, operational and strategic airlifts either on to unprepared runways or those constructed by engineers.

A 400M

Country of origin: EU

Countries in service: Germany, France, Spain, United Kingdom, Luxembourg, Malaysia, Belgium and Turkey (ordered by 10 countries)

Manufacturer: Airbus Group

Empty weight: 70 000 kg

Description

The Airbus A400M Atlas is an international project. This medium-range aircraft made its first flight in 2009, and the first production aircraft were delivered in 2013. The A400M will replace a variety of aircraft, including the Lockheed Martin C-130 Hercules and TRANSALL C-160.

The advanced design of the Airbus A400M incorporates extensive use of composite materials. It is fitted with turboprop engines which were selected because they offer a number of advantages, such as cruise fuel efficiency and lower operating costs.

The A400M has a maximum payload capacity of 37 tonnes and can carry two 8x8 armoured vehicles. This military transport can take off and land on soft semi-prepared airfields and requires relatively short runways. It was also designed to operate with limited or no ground facilities.

Transport aircraft (tactical)

CN-235

Country of origin: Spain and Indonesia

Countries in service: Spain, Turkey, Indonesia, Malaysia, Botswana, Brunei, Burkina Faso, Cameroon, Chile, Colombia, Ecuador, France, Gabon, Ireland, Jordan, Mexico, Morocco, Pakistan, Papua New Guinea, Republic of Korea, Saudi Arabia, Senegal, Thailand, UAE, USA, Yemen

Manufacturer: Airbus Group (Formerly CASA/IPTN)

Empty weight: 10 100 kg

Description

The CASA/IPTN CN-235 is a medium-range twin-engine transport plane jointly developed by CASA of Spain and Indonesian manufacturer IPTN as a regional airliner and military transport. Its primary military roles include maritime patrol, surveillance, and air transport. In addition, and thanks to its versatility and multi-mission capabilities, it is also widely used for maritime surveillance and homeland security applications.

The CN235's reliability and dependability has also been widely demonstrated. In service with some 40 operators worldwide, the aircraft has accumulated over 1 million flight hours. And with more than 270 sold, the CN235 is the best-selling airlifter in the light/medium segment. Its largest user is Turkey, which has 50 aircraft.

Maritime patrol aircraft

Falcon 50M

Country of origin: France

Countries in service: Iran, Italy, Morocco, Portugal, South Africa, Switzerland, Venezuela, Australia, Bolivia, Ukraine

Manufacturer: Dassault Aviation

Empty weight: 9150 kg

Description

The Falcon 50M provides cost-efficient maritime reconnaissance and patrol aircraft (MRA and MPA).

The main missions for these aircraft involve search and rescue at sea, surveillance of fishing zones and combatting trafficking and smuggling.

A project to transform the aircraft for maritime surveillance work involves installing observation windows and a mission control system (provided by Thales) that includes a radar device installed in the nose cone, retractable infra-red optronics and an operator's console in the cabin.

Multi-role helicopter

NH90

Country of origin: EU

Countries in service: Italy, Finland, Belgium, Germany, Greece, the Netherlands, New Zealand, Norway, Spain, Oman, Sweden, Portugal, Australia

Manufacturer: NH Industries (62.5 % EADS Eurocopter, 32.5 % AgustaWestland, and 5 % Stork Fokker)

Empty weight: 6400 kg

Description

The NHIndustries NH90 is a medium-sized, twin-engine, multi-role military helicopter. It was developed in response to NATO requirements for a battlefield helicopter which would also be capable of being operated in naval environments.

The NATO frigate helicopter was originally developed to fit between light naval helicopters like AW's Lynx or Eurocopter's Panther, and medium-heavy naval helicopters like the European EH101. The NH90 has the distinction of being the first production helicopter to feature entirely fly-by-wire flight controls. There are two main variants, the tactical transport helicopter (TTH) for army use and the navalised NATO frigate helicopter (NFH).

In early service, the NH90 suffered several teething issues which, in turn, delayed its active deployment by some operators.

AW101

Country of origin: UK and Italy

Countries in service: UK, Denmark, Portugal, Canada, Italy, Algeria, Japan, Nigeria, Norway, Saudi Arabia, Turkmenistan

Manufacturer: AgustaWestland (Joint Venture)

Empty weight: 10 500 kg

Description

The AgustaWestland AW101 is a medium-lift and multi-role helicopter used in both military and civil applications. It was developed in response to national requirements for a modern naval utility helicopter.

The AW101 can support a myriad of military and civilian-minded requirements to include general passenger transport, maritime defence, anti-submarine warfare, airborne early warning, search and rescue, amphibious support, disaster relief and medical evacuations.

The AW101 first flew in 1987 and entered into service in 1999.

Unmanned aerial vehicle

S-100 Camcopter

Country of origin: Austria

Countries in service: UAE, Germany, China, Russia, Jordan, Libya, USA, Italy, Egypt

Manufacturer: Schiebel

Empty weight: 110 kg

Description

The S-100 UAV System has been developed to carry various sensors for both military and civilian security applications: route surveillance, signal intelligence (SIGINT) and communication intelligence (COMINT), border control, counter measures – improvised explosive device (IED), minefield mapping, convoy protection, PSYOPs (psychological operations).

The UAV can be launched automatically as it performs vertical take-off and landing (VTOL), eliminating the need for special equipment and preparations at the launch and recovery sites. The helicopter navigates by following pre-programmed GPS waypoints; the pilot can also operate it manually. The fuselage is constructed from carbon-fibre monocoque providing maximum capacity for a wide range of payload/endurance combinations.

Unmanned fighter aerial vehicle

nEUROn

Country of origin: France

Countries in service: None (demonstrator)

Manufacturer: Dassault Aviation (Leader), Saab, HAI, RUAG, Airbus (CASA) and Alenia

Empty weight: 6000 kg

Description

The nEUROn programme is a partnership of six European countries jointly developing a European UCAV demonstrator. As a technology demonstrator, nEUROn is designed to be a platform for the evaluation of future cutting-edge technology. The aim of the nEUROn demonstrator is to provide European design offices with a project enabling them to develop know-how and to maintain their technological capabilities in the coming years.

To be fully effective, a single point of decision-making, the French Defence Procurement Agency (DGA – Direction générale de l'Armement), and a single point of implementation, (Dassault Aviation company as the prime contractor) were appointed to manage the nEUROn programme.

The programme was launched in 2003. The main contract was notified to the prime contractor in 2006, and the industrial partnership contracts were signed concurrently. The first flight of the technological demonstrator was completed in December 2012.

NAVAL SYSTEMS

Aircraft carrier

An aircraft carrier is a warship with a full-length flight deck and facilities for carrying, arming, deploying and recovering aircraft which serves as a seagoing airbase. An aircraft carrier is normally the capital ship in a fleet because it enables a naval force to project air power worldwide without having to depend on local bases for staging aircraft operations.

Elizabeth Class

Country of origin: United Kingdom

Countries in service: United Kingdom

Manufacturer: BAE Systems Surface Ships, Thales Group, Babcock Marine

(Combat) weight: 70 600 tonnes

Description

The Queen Elizabeth class is a class of the two aircraft carriers currently under construction for the UK's Royal Navy. The vessels currently have a displacement of approximately 70 600 tonnes (69 500 long tons), but the design anticipates growth over the lifetime of the ships. The ships will be 280 metres (920 feet) long and have a tailored air group of up to 40 aircraft (although they are capable of carrying up to 50 at full load). They will be the largest warships ever constructed for the Royal Navy. The carriers offer the following features:

- Ability to operate offensive aircraft abroad when foreign basing may be denied;
- All required space and infrastructure; where foreign bases are available they are not always accessible early in a conflict, and infrastructure is often lacking;
- A coercive and deterrent effect when deployed to a trouble spot.

Amphibious assault and helicopter carrier

An amphibious assault ship (also referred to as a commando carrier or an amphibious assault carrier) is a type of amphibious warfare ship employed to land and support ground forces on enemy territory by means of an amphibious assault. The design evolved from aircraft carriers converted for use as helicopter carriers, but includes support for amphibious landing craft, with most models including a well deck. Coming full circle, some amphibious assault ships now have a secondary role as aircraft carriers.

Mistral Class

Country of origin: France

Countries in service: France

Manufacturer: STX Europe, DCNS, Admiralty Shipyard

(Combat) weight: 16 500 tonnes (empty)

Description

The Mistral class is a class of three amphibious assault ships, also known as a helicopter carrier, in the French Navy. Referred to as 'projection and command ships', a Mistral-class ship is capable of transporting and deploying 16 NH90 or Tiger helicopters, four landing barges, up to 70 vehicles, including 13 AMX-56 Leclerc tanks, or a 40-strong Leclerc tank battalion, and 450 soldiers. The ships are equipped with a 69-bed hospital, and are capable of serving as part of a NATO Response Force, or with United Nations or European Union peace-keeping forces.

Juan Carlos Class
Country of origin: Spain
Countries in service: Australia, Spain
Manufacturer: Navantia
(Combat) weight: 26 000 tonnes

Description

Juan Carlos I is a multi-purpose amphibious assault ship in the Spanish Navy (Armada Española). Similar in role to many aircraft carriers, the ship has a ski jump for STOVL operations and is equipped with the AV-8B Harrier II attack aircraft. The vessel is named in honour of Juan Carlos I, the former King of Spain. The vessel plays an important role in the fleet as a platform that not only replaces the Newport-class LSTs Hernán Cortés and Pizarro for supporting the mobility of the marines and the strategic transport of ground forces, but also acts as a platform for carrier-based aviation, replacing the withdrawn aircraft carrier Príncipe de Asturias.

Destroyer and frigate

A destroyer is a fast manoeuvrable long-endurance warship intended to escort larger vessels in a fleet, convoy or battle group and defend them against smaller powerful short-range attackers. Modern destroyers, also known as guided missile destroyers, are equivalent in tonnage but vastly superior in firepower to cruisers of the World War II era, capable of carrying nuclear-tipped cruise missiles.

A frigate is any of several types of warship, the term having been used for ships of various sizes and roles over the last few centuries. In modern navies, frigates are used to protect other warships and merchant-marine ships, especially anti-submarine warfare (ASW) for amphibious expeditionary forces, under-way replenishment groups, and merchant convoys. Ship classes dubbed 'frigates' have also resembled more closely corvettes, destroyers, cruisers and even battleships. The rank 'frigate captain' derives from the name of this type of ship.

FREMM Class
Country of origin: France and Italy
Countries in service: France, Italy, Morocco
Manufacturer: DCNS/Armaris, Fincantieri
(Combat) weight: 6000 tonnes (France), 6900 tonnes (Italy)

Description

The FREMM (European multi-purpose frigate) (French Frégate européenne multi-mission or Italian Fregata europea multi-missione) is a class of frigate designed by DCNS/Armaris and Fincantieri for the French and Italian navies. At Euronaval 2012, DCNS demonstrated a new concept called FREMM-ER for the FREDA requirement, again based on the FREMM, but specifically mentioning the ballistic missile defence mission as well as the anti-air feature. FREMM-ER has a modified superstructure replacing Héraklès with the new Thales Sea Fire 500 radar, whose four fixed plates resemble those of the USA Navy's AN/SPY-1.

Type 125 Class
Country of origin: German
Countries in service: German
Manufacturer: Thyssen-Krupp/Lürssen
(Combat) weight: 7200 tonnes

Description
F125 is the project name for the Type 125 Baden-Württemberg class of frigates, currently under development for the German Navy by ARGE F125, a joint venture of Thyssen-Krupp and Lürssen. The F125 class is officially classified as frigates although size-wise they are comparable to destroyers since, with a displacement of more than 7200 tonnes, they will be the biggest class of frigate worldwide. They will replace the Bremen class. In contrast to the Bremen class, which were built with Cold War-era scenarios in mind, the F125 will have much enhanced land-attack capabilities, better suiting them to possible future peace-keeping and peace-making missions. For this reason, the F125 will also mount non-lethal weapons.

Corvettes

A corvette is a small warship. It is traditionally the smallest class of vessel considered to be a proper (or 'rated') warship. The warship class above is that of frigate, and the class below is historically sloop-of-war. The modern types of ship below a corvette are coastal patrol craft and fast-attack craft. In modern terms, a corvette is typically between 500 tonnes and 2000 tonnes although recent designs may approach 3000 tonnes, which might instead be considered a small frigate.

Holland Class
Country of origin: The Netherlands
Countries in service: The Netherlands
Manufacturer: Damen
(Combat) weight: 3750 tonnes

Description
The Holland-class offshore patrol vessels are new oceanic patrol vessels for the Royal Netherlands Navy. They are designed to fulfil patrol and intervention tasks against lightly armed opponents, such as pirates and smugglers, but also have much higher level electronic and radar surveillance roles with great capabilities for military stabilisation and security roles, short of outright war. With no sonar or long-range weapons, they use the surveillance capabilities of the plug-in modular Thales integrated mast which integrates communication systems and two 4-faced phased arrays for air and surface search, and are as advanced as those in the fighter systems in many US Navy (USN) applications.

Offshore patrol vessel

The offshore patrol vessel is a highly versatile ship, designed to perform economic exclusion zone management roles, including the provision of maritime security to coastal areas, and effective disaster relief.

Gowind Class
Country of origin: France
Countries in service: Egypt, Malaysia
Manufacturer: DCNS
(Combat) weight: 2500 tonnes

Description
The Gowind design is a family of steel monohull corvettes developed since 2006 by DCNS to conduct missions in littoral zones, such as anti-submarine warfare (ASW). The Gowind family includes vessels with lengths from 85 to 102 metres and displacement from 1000 to 2500 tonnes. The Gowind design can deploy unmanned aerial vehicles (UAVs), unmanned surface vehicles (USVs) and underwater unmanned vehicles (UUVs). The platform's weapon system consists of a multifunctional radar and surface-to-air MICA (Missile d'interception, de combat et d'autodéfense). It is armed with Exocet anti-ship missiles. The propulsion system is based on combined diesel and diesel (CODAD) and includes water jets for improved manoeuvrability in shallow waters and high-speed performance. There are no funnels on these ships. The radar and other sensors are mounted on a single central mast allowing for a 360-degree view. DCNS offers two variants of the design: Gowind 1000 and Gowind 2500.

Submarine

A submarine is a water craft capable of independent operation underwater. It differs from a submersible, which has more limited underwater capability. The term most commonly refers to a large, crewed, autonomous vessel. It is also sometimes used historically or colloquially to refer to remotely operated vehicles and robots, as well as medium-sized or smaller vessels, such as the midget submarine and the wet sub. Used as an adjective in phrases such as submarine cable, 'submarine' means 'under the sea'. The noun submarine evolved as a shortened form of submarine boat (and is often further shortened to sub). For reasons of naval tradition, submarines are usually referred to as 'boats' rather than 'ships', regardless of their size.

Type 212 Class
Country of origin: German
Countries in service: Germany and Italy
Manufacturer: TKMS
(Combat) weight: 1450 tonnes (surfaced), 1830 tonnes (submerged)

Description
The German Type 212 class, also Italian Todaro class, is a highly advanced non-nuclear submarine design developed by Howaldtswerke-Deutsche Werft AG (HDW) for the German and Italian Navy. It features diesel propulsion and an additional air-independent propulsion (AIP) system using Siemens polymer electrolyte membrane (PEM) hydrogen fuel cells. The submarine can either operate at high speeds on diesel power or switch to the AIP system for silent slow cruising, staying submerged for up to three weeks without surfacing and with no exhaust heat. The system is also said to be vibration-free, extremely quiet and virtually undetectable. Type 212 is the first fuel-cell propulsion-system-equipped submarine series.

Scorpene Class
Country of origin: France
Countries in service: Chile, Malaysia, Brazil, India
Manufacturer: DCNS, Navantia , Mazagon Dock Limited
(Combat) weight: 1565 - 2000 tonnes

Description
The Scorpene-class submarines are diesel-electric attack submarines jointly developed by the French DCN and the Spanish company Navantia and now by DCNS. It features diesel propulsion and additional air-independent propulsion (AIP). The Chilean Navy ordered two Scorpene class, which replaced two Oberon-class submarines which it had retired from service. In 2005, the Indian Navy ordered six Scorpene-class submarines: all the Indian boats will be built in India, at Mazagon Dock and elsewhere, and the last two will be fitted with an Indian AIP module. For the follow-on request for six submarines, DCNS plans to offer a larger version of the submarine to the Indian Navy. In 2008, the Brazilian Navy ordered four Scorpenes. The Chilean Scorpene-class O'Higgins and Carrera were completed in 2005 and 2006, respectively. In 2009, the Royal Malaysian Navy commissioned Tunku Abdul Rahman and Tun Abdul Razak.

Torpedo

The modern torpedo is a self-propelled weapon with an explosive warhead, launched above or below the water surface, propelled underwater towards a target, and designed to detonate either on contact with its target or in proximity to it. While the battleship evolved primarily around engagements between armoured ships with large-calibre guns, the torpedo enabled torpedo boats and other lighter surface ships, submersibles, even ordinary fishing boats or frogmen, and later, aircraft, to destroy large armoured ships without the need for large guns, although sometimes at the risk of being hit by longer-range shellfire.

Spearfish
Country of origin: United Kingdom
Countries in service: N/A
Manufacturer: BAE Systems
(Combat) weight: 1850 kg

Description
The Spearfish torpedo (formally Naval Staff Target 7525) is the heavy torpedo used by Royal Navy submarines. It can be guided either by wire or by autonomous active or passive sonar, and provides both anti-submarine warfare (ASW) and anti-surface ship warfare (ASuW) capability. The torpedo is driven by a pump-jet coupled to a Hamilton Sundstrand 21TP04 gas turbine engine using Otto fuel II and hydroxyl ammonium perchlorate as an oxidiser. The addition of an oxidiser improves the specific energy of the fuel by reducing the richness of the Otto fuel.

Black Shark

Country of origin: Italy

Countries in service: Chile, Ecuador, Italy, Malaysian, Portugal, Singapore

Manufacturer: WASS

(Combat) weight: Classified

Description

The Black Shark is a heavyweight torpedo developed by WASS of Italy. It is most closely associated with the Scorpene diesel-electric submarines produced by France for the export market, but is also found on some Type 209 submarines. The Black Shark torpedo provides fibre-optic wire for increased bandwidth and signal-processing ability compared to copper-wire-guided torpedo types. The sonar capability includes non-Doppler shifted target discrimination and multi-frequency capability that features advanced spatial and angular analysis abilities.

LAND SYSTEMS

Main battle tank

A main battle tank (MBT), also known as a battle or universal tank, fills the heavy-direct-fire role in many modern armies. It was originally conceived to replace the light, medium, heavy and super-heavy tanks. Development was stimulated during the Cold War with the development of lightweight composite armour.

Leopard 2

Country of origin: Germany

Countries in service: Austria, Canada, Chile, Denmark, Finland, Germany, Greece, Indonesia, the Netherlands, Norway, Poland, Portugal, Qatar (planned), Saudi Arabia (planned), Singapore, Sweden, Switzerland

Manufacturer: Krauss-Maffei Wegmann

(Combat) weight: 62 000 kg (A6 version)

Description

The Leopard 2 has been developed as a replacement for the M48 tanks used by the German Army. Developed during the 1970s, this main battle tank is still being used in many armies worldwide. With the reduced size of Western armies, many Leopard 2 tanks have come on to the market. The most common version used today is still the Leopard 2A4, which was introduced in 1985. Nearly 3300 units were produced, but manufacturing lines are now closed. Nearly all the latest developments are focusing on additional armour and ammunition.

Infantry Combat Vehicle

The Treaty on Conventional Armed Forces in Europe defines "infantry fighting vehicle" (IFV) as "an armoured fighter vehicle which is designed and equipped primarily to transport a fighter infantry squad, which is armed with an integral or organic cannon of at least 20 millimetres calibre and sometimes an anti-tank missile launcher".

VBCI

Country of origin: France

Countries in service: France

Manufacturer: Nexter

(Combat) weight: 26 000 kg

Description

The VBCI (Véhicule blindé de combat d'infanterie) was designed as an infantry fighting vehicle to accompany main battle tanks under the most extreme conditions. Nexter is developing a range of vehicle on the same platform and the French Army is planning further specialist variants. They entered service with the French Army in 2008 and have been deployed in Afghanistan, Lebanon and Mali.

The VBCI features modular steel and titanium armour fitted to an aluminium hull. Its 8x8 configuration is designed for high mobility, giving a top speed of 100 km/h via a 410 kW diesel engine. Weapon options include a 25 mm cannon or 7.62 mm machine-gun. Two crews are carried in addition to nine troops.

PUMA IFV
Country of origin: Germany
Countries in service: Germany
Manufacturer: Krauss-Maffei Wegmann and Rheinmetall
(Combat) weight: 43 000 kg

Description

The Puma is one of the best infantry fighting vehicles in the world, offering high mobility, maximum protection and optimum firepower. It offers class-leading protection for a nine-man crew against medium-calibre weapons, hand-held anti-tank weapons, shaped charges, kinetic energy (KE) ammunition, heavy blast/EFP mines, and nuclear, biological and chemical (NBC) weapons.

KMW develops and manufactures the PUMA infantry fighting vehicle together with Rheinmetall Land Systems in a joint venture called the Projekt System & Management GmbH (PSM), based in Kassel, Germany.

Boxer
Country of origin: Germany and the Netherlands
Countries in service: Germany and the Netherlands
Manufacturer: Rheinmetall and Krauss-Maffei Wegmann
(Combat) weight: 33 000 kg

Description

The APC variant of Boxer is a ship for soldiers with multiple functions for the infantry and interfaces for network-enabled warfare. The integral growth potential allows for its adaptation to future emerging military roles, or changing requirements without degrading the mobility performances. The APC can transport up to eight dismounts, besides driver, commander and gunner. After a protracted development, which saw Britain withdraw, deliveries of 272 vehicles to Germany started in 2009; the Netherlands has 200 on order.

Armoured personnel carrier (APC)

An armoured personnel carrier (APC) is a type of armoured fighting vehicle (AFV) designed to transport infantry to the battlefield. APCs are colloquially referred to as ‘battle taxis’ or ‘battle buses’, among other things. Armoured personnel carriers are distinguished from infantry fighting vehicles by the weaponry they carry.

Patria AMV

Country of origin: Finland

Countries in service: South Africa, Poland, Finland, Sweden, Croatia, Slovenia, UAE (planned)

Manufacturer: Patria

(Combat) weight: 26 000 kg

Description

The AMV (advanced modular vehicle) armoured personnel carrier was developed by Patria in association with the Finnish Defence Force. The main goal was to design a platform offering better protection, and greater mobility, payload and internal volume than current XA-203 6x6 APCs. The first prototype of the AMV was built in 2001, the first vehicles were delivered in 2003, and production began in 2004.

The Patria AMV 6x6 is a lighter version of the standard 8x8 vehicle.

Self-propelled artillery

Self-propelled artillery (also called mobile or locomotive artillery) is artillery equipped with its own propulsion system to move towards its target. The term covers self-propelled guns (or howitzers) and rocket artillery. They are high-mobility vehicles, usually based on a caterpillar track carrying either a large howitzer, or another field gun, or alternatively a mortar or some form of rocket or missile launcher. They are usually used for long-range indirect bombardment support on the battlefield.

CAESAR

Country of origin: France

Countries in service: Saudi Arabia, Indonesia, Thailand, France

Manufacturer: Nexter

(Combat) weight: 17 700 kg

Description

The CAESAR (camion équipé d'un système d'artillerie – a truck equipped with an artillery system) is a 155 mm/52-calibre gun-howitzer installed on a 6X6 truck chassis. Caesar was developed in the 1990s. In 1998, a pre-production model underwent trials with the French Army, which received the first five units in 2003. The French Army deployed this system in Southern Lebanon as part as the United Nations Interim Force peace-keeping in Lebanon and during Operation Serval in Mali.

Panzerhaubitze 2000 (PzH 2000)

Country of origin: Germany

Countries in service: Germany, the Netherlands, Croatia, Italy, Qatar and Greece

Manufacturer: Krauss-Maffei Wegmann (KMW) and Rheinmetall

(Combat) weight: 55 000 kg

Description

The Panzerhaubitze 2000 is a 155 mm self-propelled howitzer developed by Krauss-Maffei Wegmann (KMW) and Rheinmetall for the German Army. The PzH 2000 is one of the most powerful conventional artillery systems currently being deployed. It is noted in particular for its very high firing rate: it can fire three rounds in nine seconds, ten rounds in 56 seconds, and between 10 and 13 rounds per minute continuously; two operators can load 60 shells and propelling charges in less than 12 minutes.

Towed artillery

Towed artillery is a highly mobile component of ground unit firepower. It is mounted on carriages and is designed to be towed behind other vehicles to achieve the combination of mobility, readiness, range and rate of fire needed by the commander. Towed artillery ranges from small, lightweight guns to very heavy calibres. It is generally 100-105 mm in calibre and increasingly benefits from technologies such as the Global Positioning System (GPS).

Nexter 105 LG

Country of origin: France

Countries in service: France, Canada, Thailand, Singapore, Belgium, Indonesia, Colombia

Manufacturer: Nexter

(Combat) weight: 1650 kg

Description

Designed especially for rapid deployment units, the Nexter NATO 105 mm light towed gun has been developed by Nexter Systems (previously Giat Industries), as a private venture, specifically for the export market.

The main advantage of the 105 LG is its weight – 1520 kg – making it the lightest gun in its category by far. The gun can be heli-transported, airlifted, parachuted, air-dropped or towed by a wide range of light four-wheel drive vehicles. Operated by a five-man gun crew (which can be reduced to three), the rapidity with which it can be put into and brought out of battery and its firing rate complete the qualities of this artillery piece.

Ammunitions

M982 Excalibur (155 mm)
Country of origin: Sweden
Countries in service: Sweden, USA and Canada
Manufacturer: BAE Bofors and Raytheon Missile Systems
(Combat) weight: 48 kg

Description

The M982 Excalibur (previously XM982) is a 155 mm extended-range guided artillery shell from the Excalibur family of precision-guided, extended-range modular projectiles.

M982 Excalibur is intended to provide armies with the capability to attack all three key target sets, soft and armoured vehicles, and reinforced bunkers, to ranges exceeding the current 155 mm family of artillery munitions. With its accuracy and increased effectiveness, the Excalibur was designed to reduce the logistical burden for deployed ground forces. It also offers lower risks of collateral damage through its concentrated fragmentation pattern, increased precision and near-vertical descent.

Excalibur was fielded in Iraq with its first use in combat operations in 2007.

BONUS
Country of origin: France and Sweden
Countries in service: Sweden, France, Finland, one country in the Middle East
Manufacturer: BAE Bofors and Nexter
Weight: 44.6 kg (total)

Description

The BONUS (BOfors NUtating Shell) programme started in 1993, and is managed within the framework of cooperation between Nexter Munitions and BAE Systems for the Swedish and French Armies. The objective was to develop a smart anti-tank missile.

It is a cargo shell which carries two sub-munitions which are ejected at an altitude of about 200 meters above the target area, and which scan the ground as they fall to earth. Their explosively-formed penetrator warheads attack any armoured vehicles they detect.

DM63 (120 mm)

Country of origin: Germany

Countries in service: Germany, Switzerland, the Netherlands, Denmark, Finland, Turkey

Manufacturer: Rheinmetall

Weight: 21.4 kg (total)

Description

The DM63 is a tungsten-based armour-piercing tank ammunition designed for the Leopard 2 main battle tank in the German Army. This ammunition was developed specifically to fill a capabilities gap in missions out-of-area carried out by the German Armed Forces. DM63 is a further development of DM53 rounds designed to maximise the performance of KE projectiles fired from 120 mm smooth-bore guns.

The new propellant powders, known as surface-coated double-base (SCDB) propellants, enable the DM63 to be used in many climates, with consistent results. The new ammunition has been accepted into service with notably the Dutch, Swiss and German armies.

Assault rifle

The term 'assault rifle', despite its widespread use, is controversial, mainly because there is no single agreed definition for it. It first became well known during and shortly after WW2. The US Department of Defense has long defined assault rifles as fully automatic rifles used for military purposes. It is also commonly defined as a military firearm that is chambered for ammunition of reduced size or propellant charge and that has the capacity to switch between semi-automatic and fully automatic fire (Encyclopaedia Britannica).

H&K G36

Country of origin: Germany

Countries in service: Germany, Spain, Saudi Arabia, Egypt, Australia, Belgium, Brazil, France, UK and others

Manufacturer: Heckler & Koch

Weight: 3.63 kg (empty)

Description

Created for the requirements of the German armed forces, the G36 continues to set the standard in the field of assault rifles. Used as an infantry weapon in a large number of countries, special forces and security forces also rely on its constant reliability.

Essential components of the G36 are made of glass-fibre-reinforced plastic. This gives the user a lightweight weapon with high-performance and low-maintenance requirements.

The G36 is ideally suited for dismounted infantry operations. For optimal handling, weight, and rate of fire in close-quarters battle, and for rapid, accurate and penetrating single fire in long-range combat.

SPACE SYSTEMS

Radar satellites

SAR-LUPE
Country of origin: Germany
Countries in service: Germany
Manufacturer: OHB-System AG
Weight: 770 kg

Description

SAR-Lupe is Germany's first satellite-based reconnaissance system. It consists of five identical small satellites and a ground segment. OHB-System AG developed the overall system as the principal contractor for the German government, leading a consortium of well-known European space companies.

Its mission is to generate high-resolution SAR (synthetic aperture radar) images for military reconnaissance purposes.

A replacement of SAR-LUPE, called SARah, will be put into service during 2017-2019. It will comprise three radar satellites and one optical satellite. SARah's satellites will be bigger and more capable than those of SAR-Lupe.

ELINT satellites

CERES
Country of origin: France
Countries in service: Due to enter in service in 2020 (France)
Manufacturer: Airbus D&S
Weight: N.A.

Description

CERES, the first operational interception system for the French Defence Agency, draws on the experience acquired from the ESSAIM and ELISA demonstrators. It will provide France with its first operational SIGINT capability.

The CERES (Capacité de Renseignement Electromagnétique Spatiale or Space Signal Intelligence Capacity) system comprises three closely positioned satellites that are designed to detect and locate ground signals, along with ground control and user ground segments. It is due to enter into service in 2020.

Airbus and Thales are the joint prime contractors for the entire system. Airbus will handle the space satellite segment of the project while Thales is responsible for the payload and the user ground segment. In addition, Thales Alenia Space acts as a subcontractor to Airbus Defence and Space, supplying the platform.

Communication satellites

SYRACUSE
Country of origin: France
Countries in service: France
Manufacturer: Thales (TAS)
Weight: N.A.

Description

Syracuse (Système de Radiocommunication utilisant un satellite, satellite-based radio-communication system) is a series of French military communication satellites.

Syracuse is intended to ensure the French military can communicate between mainland France and military units deployed around the world. The satellite participates in command, reassignment and logistic aspects of operations. The system is nominally under the command of the French Navy, equipping a total of 54 ships (2009) and is complemented by the Telcomarsat commercial system of communications.

The Syracuse-3 series of spacecraft are the third-generation military communication satellites for the Direction générale pour l'Armement (French Ministry of Defence's procurement agency).

Optical satellites

HELIOS
Country of origin: France
Countries in service: France, EUSC
Manufacturer: Airbus D&S, Thales Alenia Space
Weight: N.A.

Description

Hélios is a family of satellites which provides France with a high-resolution military surveillance system. The Hélios programme was Europe's military optical reconnaissance system comprising both a space and a ground segment, which came into service in 1995, jointly funded by the French, Italian and Spanish governments.

The Hélios I optical observation satellites, launched in July 1995 and December 1999 respectively, were able to acquire high-resolution images of any point on the globe, with daily revisit capability. The new Hélios II system has been designed to process data from both the Hélios I and Hélios II satellites, while remaining open to future space-based intelligence systems.

DGA, the French Ministry of Defence procurement agency ran the programme, retained direct control over management of the ground segment, and delegated responsibility for the space segment to the French space agency CNES.

Navigation satellites

GALILEO

Country of origin: Europe
Countries in service: European Union
Manufacturer: Airbus D&S, Thales Alenia Space
Weight: 675 kg (satellite mass)

Description

Galileo is the European satellite navigation system comprising a global satellite-based network for precise positioning and timing information. It will offer services to users in various domains (commercial, safety and security, science, leisure), including guaranteed and certified services for safety-critical applications (civil aviation, emergency services, security). It will be available with full precision to both civil and military users.

Comprising 30 spacecraft in medium Earth orbit and associated ground infrastructure, the system will be built up gradually in the coming years. Galileo is intended to provide horizontal and vertical position measurements within 1-metre precision, plus better positioning services at high latitudes than other positioning systems.

It will start providing its first services from 2015. Completion of the 30-satellite Galileo system (24 operational and six active spares) is expected by 2020.

Launch systems

ARIANE 5

Country of origin: European Union
Countries in service: N.A.
Manufacturer: Airbus D&S
Weight: 750 tonnes (lift-off mass)

Description

Ariane 5 is a European heavy lift-launch vehicle that is a part of the Ariane rocket family, an expendable launch system used to deliver payloads into geostationary transfer orbit (GTO) or low Earth orbit (LEO). Ariane 5 rockets are manufactured under the authority of the European Space Agency (ESA) and the Centre National d'Etudes Spatiales (CNES). Airbus Defence and Space is the prime contractor for the vehicles, leading a consortium of subcontractors. Ariane 5 is operated and marketed by Arianespace as part of the Ariane programme. Astrium builds the rockets in Europe and Arianespace launches them from the Guiana Space Centre in French Guiana.

Three successive generic versions – Ariane 5G, Ariane 5G+ and Ariane 5GS, have now been retired from service, leaving two operational configurations: Ariane 5ECA and Ariane 5ES.

The Ariane launch log to December 2014 stands at 16 Ariane 5G, 3 Ariane 5G+, 6 Ariane 5GS, 47 Ariane 5ECA and 5 Ariane 5ES, giving a total of 77 launches. Ariane 5 is launched six to seven times a year, of which only one or two are for institutional customers.

VEGA
Country of origin: Italy
Countries in service: N.A.
Manufacturer: ESA and Italian Space Agency
Weight: 137 tonnes (lift-off mass)

Description

Vega is a single-body launcher with three solid-propellant stages and a liquid-propellant upper module for attitude and orbit control, and satellite release. Unlike most small launchers, Vega is able to place multiple payloads into orbit. It is designed to launch small payloads — 300 to 2500 kg satellites for scientific and Earth observation missions to polar and low Earth orbits.

Development of the launcher started in 1998. The first Vega lifted off on 13 February 2012 on a flawless qualification flight from Europe's Spaceport in French Guiana, where the Ariane 1 launch facilities have been adapted for its use. Arianespace has ordered launchers covering the period until at least the end of 2018.

ELECTRONIC SYSTEMS

Radar

GIRAFFE

Country of origin: Sweden

Countries in service: Algeria, Australia, Brazil, Canada, Croatia, Estonia, Finland, France, Indonesia, Ireland, Latvia, Lithuania, Greece, Malaysia, Norway, Pakistan, Poland, Serbia, Singapore, Swede, Thailand, UAE, UK, USA, Venezuela

Manufacturer: SAAB

(Combat) weight: N.A.

Description

Giraffe is a family of G/H (formerly C-band) frequency agile, low-to-medium altitude pulse Doppler air search radars and fighter control centres which can be used in mobile or static short-to-medium-range air defence applications. Giraffe is designed to detect low-altitude, low cross-section aircraft targets in conditions of severe clutter and electronic countermeasures. When equipped as an air defence command centre, Giraffe provides an air picture to each firing battery using manpack radio communication.

Giraffe uses agile multi-beam (AMB), which includes an integrated command, control and communication (C3) system, which enables it to act as the command and control centre in an air defence system; it can also be integrated into a sensor net for greater coverage. It is normally housed in a single 6m-long shelter mounted on an all-terrain vehicle for high mobility. In addition, the shelter can be augmented with nuclear, biological and chemical protection and light layers of armour to protect against small arms and fragmentation threats. There are several variants: Giraffe 40, Giraffe 50AT, Giraffe 75, Giraffe S, ArtE 740, Giraffe AMB.

Communication systems

FIST (Future Integrated Soldier Technology)

Country of origin: UK

Countries in service: First deliveries planned between 2015 and 2020

Manufacturer: Thales UK

(Combat) weight: N.A.

Description

FIST is a British Army project which aims to enhance the infantry's fighter effectiveness in the 21st century as part of the Future Soldier project. The contract was awarded to Thales in March 2003.

The goal is to integrate a modular system for all equipment, weapons and their sighting systems, and the radios an individual soldier carries or uses in order to enhance his/her overall effectiveness on the battlefield. The five main areas of FIST capability are C4I, lethality, mobility, survivability and sustainability.

A major complement for the FIST project is the Bowman communications system which gives secure communications to the troops on the ground, allowing for simultaneous transmission of voice and data and with built-in GPS equipment; it can also send visual information direct from personal cameras.

MISSILE SYSTEMS

Air-air missile

MICA IR

Country of origin: France

Countries in service: France, Greece, India, Morocco, Qatar, Egypt, Republic of China (Taiwan), UAE

Manufacturer: MBDA

Weight: 112 kg

Description

MICA is the reference multi-mission air-to-air missile system for the Rafale and the latest versions of the Mirage 2000 fighter aircraft. Developed by MBDA, MICA (Missile d'interception, de combat et d'autodéfense – interception, combat and self-defence missile) provides a high level of tactical flexibility. This single missile system has been designed to cover all facets of the air-to-air battle – BVR (beyond visual range) interception, dogfight and self-defence. There are two versions of the MICA system: MICA (EM) RF with an active radio-frequency seeker, and MICA IR with a passive dual waveband imaging infra-red seeker. Both missiles are fully qualified and in mass production, being flown by numerous air forces worldwide.

MICA is already in operation around the world, integrated into the air-launched variant, on Rafale in particular, and in the vertical-launched variant on various naval platforms or ground-based air defence systems. Besides the French Air Force and Navy, MICA already counts six export countries as reference customers.

Surface-air missile

ASTER 30

Country of origin: France and Italy

Countries in service: France, Italy, UK, Singapore

Manufacturer: MBDA

Weight: 450 kg

Description

The Aster 30 is a medium-range surface-to-air missile. It offers high-level tactical and strategic mobility and, thanks to its high rate of fire, is capable of countering saturating threats. Moreover, it features a high level of manoeuvrability and agility in order to achieve a direct hit on the target ('hit-to-kill').

The Aster modular family of vertically launched missiles is being developed under the leadership of MBDA within the Franco-Italian FSAF (Future Surface-to-Air Family) programme. Under this programme, France and Italy have agreed to develop and produce a family of naval-platform and ground-based air defence systems for the armed forces in both countries. The following systems use the Aster 30:

- SAMP/T: a land-based medium-range area defence system;
- PAAMS (Principal Anti-Air Missile System): a 360° omni-directional system providing multi-layer air defence to armed fleets or groups of unarmed support and merchant ships.

Anti-tank missile

MILAN

Country of origin: France and Germany

Countries in service: Afghanistan, Armenia, Brazil, Belgium, Chad, Cyprus, Estonia, Egypt, France, Germany, Greece, India, Iraq, Italy, Kenya, Lebanon, Libya, the former Yugoslav Republic of Macedonia, Mauritania, Mexico, Morocco, Pakistan, Portugal, South Africa, Spain, Syria, Tunisia, Turkey, Uruguay, Yemen

Manufacturer: MBDA

Weight: 13 kg (missile + tube)

Description

MILAN (missile d´infanterie léger antichar – light anti-tank infantry missile) is a European anti-tank guided missile which provides an infantry weapon for tactical fire support and precision close fighter operations. Design of the MILAN started in 1962, it was ready for trials in 1971, and was accepted for service in 1972. It is a wire-guided SACLOS (semi-automatic command to line of sight) missile, which means the sight of the launch unit must be aimed at the target to guide the missile.

MILAN ER is the latest development of the fighter-proven MILAN weapon system that has already been selected by over 40 customers around the world. This latest generation high-firepower weapon system has been specifically designed for land fighter forces involved in sustained and demanding close fighter operations.

Anti-ship missile

EXOCET

Country of origin: France

Countries in service: Argentina, Brunei, Bulgaria, Brazil, Cameroon, Chile, Colombia, Ecuador, Egypt, France, Germany, Greece, Indonesia, India, Kuwait, Libya, Malaysia, Morocco, Oman, Pakistan, Peru, Qatar, South Africa, South Korea, Thailand, Tunisia, Turkey, Vietnam, UAE, Uruguay

Manufacturer: MBDA

Weight: 650 kg (SM39)

Description

EXOCET is a complete family of all-weather heavy anti-ship missiles suitable for all types of carriers. It is available in several versions (more recent versions):

- Surface-to-surface (MM) for ships and coastal batteries: EXOCET MM40 Block 3;
- Air-to-sea (AM) for aircraft and helicopters: EXOCET AM39;
- Submarine-surface (SM) for submerged submarines: EXOCET SM39.

MBDA's family of EXOCET missiles comprises a range of easy-to-use, stand-off 'fire and forget' stealth missiles with skimming flight for engaging high-value naval targets; it has the flexibility to be fired from all maritime platforms – surface ships, submarines, fixed-wing aircraft, helicopters and coastal batteries. EXOCET, in production since 1972, was the West's first long-range anti-ship missile with fire and forget and skimming flight capabilities.

Cruise missile

SCALP/Storm Shadow
Country of origin: UK and France
Countries in service: France, UK, Saudi Arabia, Greece, Italy, UAE
Manufacturer: MBDA
Weight: 1300 kg

Description

Storm Shadow/SCALP is a conventionally armed, stealth, long-range standoff precision weapon designed to neutralise high-value targets. This precision, day or night, all-weather missile system is optimised for pre-planned attacks on static targets whose positions are accurately known before the mission. These would typically be well-defended, infrastructure targets such as port facilities, control centres, bunkers, missile sites, airfields and bridges that would otherwise require several aircraft and missions during the opening days of a conflict at a time when air superiority might not yet have been achieved.

Qualified for use on the Tornado GR4, Mirage 2000 and the Rafale, Storm Shadow/SCALP is currently in service with air forces of six nations. Storm Shadow was successfully deployed on Tornado GR4 fighter aircraft by the Royal Air Force during Operation Telic in 2003. The first operational use of SCALP by France in a conflict occurred on 24 March 2011: several SCALPs were fired at a military airbase manned by Gaddafi's loyalist forces in Libya. During the same operations in Libya, the Royal Air Force and the Italian Air Force also fired a substantial number of Storm Shadows at high-value military targets from their Tornado aircraft.

Appendix 3: Composition of main alloys used in the defence industry

This appendix shows the composition of the main alloys used in the European defence sector. The aim is to illustrate the diversity of the alloy compositions and large area of applications. Note that numbers are given as percentages.

ALUMINIUM ALLOYS

Series 2000 (aeronautics structures)

2024

Aluminium	Copper	Magnesium	Manganese
93.5	4.4	1.5	0.6

Series 5000 (naval structures)

5083

Aluminium	Magnesium	Manganese	Chromium
94.75	4.4	0.7	0.15

5086

Aluminium	Magnesium	Iron	Manganese	Silicon	Zinc	Chromium	Titanium	Copper
93.9	4	0.5	0.5	0.4	0.25	0.2	0.15	0.1

5059

Aluminium	Magnesium	Manganese	Iron	Silicon	Zinc	Chromium	Copper	Titanium
89.8-94	5-6	0.6-1.2	<0.5	<0.45	0.4-09	<0.25	<0.25	<0.2

Series 6000 (naval structures)

6061

Aluminium	Magnesium	Silicon	Copper	Chromium
97.9	1	0.6	0.3	0.2

6082

Aluminium	Magnesium	Iron	Manganese	Silicon	Zinc	Chromium	Titanium	Copper
95.35	1.2	0.5	1	1.3	0.2	0.25	0.1	0.1

Series 7000 (aeronautics structures)

7010

Aluminium	Zinc	Magnesium	Copper	Zirconium
89.72	6.2	2.3	1.75	0.13

7040

Aluminium	Zinc	Magnesium	Copper	Zirconium
89.7	6.2	2.1	1.9	0.1

7050

Aluminium	Zinc	Copper	Magnesium	Zirconium
89.08	6.2	2.3	2.3	0.12

7075/7175

Aluminium	Zinc	Magnesium	Copper	Chromium
87.1	5.1	2.1	1.2	0.18

COBALT ALLOYS (mainly used in aircraft engines)

HS-25

Cobalt	Chromium	Tungsten	Nickel	Iron	Manganese	Silicon	Carbon
49	20	15	10	3	1.5	0.4	0.33

HS-31

Cobalt	Chromium	Nickel	Tungsten	Other elements (iron, silicon, manganese)
50-59	24.5-26.5	9.5-11.5	7-8	< 9.5

HS-188

Cobalt	Chromium	Nickel	Tungsten	Iron	Manganese	Silicon	Carbon	Lanthanum
39	22	22	14	3	1.25	0.35	0.1	0.03

NICKEL ALLOYS (mainly used in aircraft engines)

CMSX-4

Nickel	Cobalt	Chromium	Tantalum	Tungsten	Aluminium	Rhenium
	9.6	6.5	6.5	6.4	5.6	3
Titanium	Molybdenum	Hafnium				
1	0.6	0.1				

PER 3

Nickel	Chromium	Cobalt	Molybdenum	Titanium	Aluminium
59.2	19	13.5	4	3	1.3

N-18

Nickel	Cobalt	Chromium	Molybdenum	Aluminium	Titanium	Hafnium
57.1	15.7	11.5	6.5	4.35	4.35	+0.5

INCONEL 718

Nickel	Iron	Chromium	Niobium	Molybdenum	Titanium	Aluminium
53.9	18.5	18	5.2	3	0.9	0.5

INCONEL 625

Nickel	Chromium	Molybdenum	Iron	Niobium	Manganese	Silicon	Aluminium	Titanium
58	23	10	5	4.15	0.5	0.5	0.4	0.4

AM1

Nickel	Chromium	Tantalum	Cobalt	Tungsten	Aluminium	Molybdenum	Titanium
63.5	8	8	6,6	5.6	5	2	1.3

TITANIUM ALLOYS (in aeronautics, naval and land components)

TA6V

Titanium	Aluminium	Vanadium
90	6	4

Ti3Al2.5V

Titanium	Aluminium	Vanadium
94.5	3	2.5

Ti-6242

Titanium	Aluminium	Tin	Zirconium	Molybdenum
86	6	2	4	2

Ti-6246

Titanium	Aluminium	Tin	Zirconium	Molybdenum
82	6	2	4	6

Ti-17

Titanium	Aluminium	Chromium	Molybdenum	Tin	Zirconium
83	5	4	4	2	2

TA6E4Zr

Titanium	Aluminium	Tin	Zirconium	Niobium	Molybdenum
85.5	5.8	4	3.5	0.7	0.5

SPECIAL STEELS

NYB66 (naval conducts and piston)

Iron	Chromium	Nickel	Molybdenum	Tungsten	Nitrogen	Carbon
46	24	22	5.5	2	0.5	- 0.03

APX4 (submarine periscope mast)

Iron	Chromium	Nickel	Molybdenum	Carbon
79	16	4	1	0.06

MARVALX12 (naval and aeronautics components and structure parts)

Iron	Chromium	Nickel	Molybdenum	Aluminium	Titanium	Carbon
76	12	9	2	0.7	0.3	-0.02

MLX19 (landing gears)

Iron	Chromium	Nickel	Molybdenum	Aluminium	Titanium	Carbon
72.4	11	12	2	1,45	1,15	-0.02

100 HLES (HY-100) ultra-high strength steel alloys (submarine hulls)

Iron	Nickel	Chromium	Copper	Molybdenum	Silicon	Manganese	Vanadium
93-96	2.25-3.5	1-1.8	0.25	0.2-0.6	0.12-0.2	0.1-0.4	0.03

HY-80 steel such as 1.3964 ultra-high strength steel alloys (submarine hulls)

Iron	Chromium	Nickel	Manganese	Molybdenum	Nitrogen	Niobium	Silicon
55.3	20.5	15.5	4.6	3.2	0.3	0.13	0.4

CLARM HBR (land cannon)

Iron	Nickel	Chromium	Molybdenum	Carbon	Manganese	Vanadium
93.92	3.5	1.5	0.4	0.3	0.2	0.18

CLARM HB3 (land cannon)

Iron	Nickel	Chromium	Molybdenum	Carbon	Manganese	Vanadium
94.17	3.5	1.4	0.5	0.33	0.2	0.2

CLARM HB7 (land cannon)

Iron	Nickel	Chromium	Molybdenum	Carbon	Manganese	Vanadium
93	3.7	1.6	0.9	0.4	0.1	0.3

GKH (land cannon)

Iron	Chromium	Molybdenum	Carbon	Vanadium
95.5	3	1	0.3	0.2

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