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ESTIMATION OF THE WORLD MARKET AND APPLICATION OF NANOMATERIALS IN THE AEROSPACE INDUSTRY

The object of the study is the global aerospace market status, segment analysis, dynamics, competition, and prospects. The methods of searching and analyzing literature data, summarizing, systematizing, and visualizing data with diagrams are used.

The aerospace industry is at the forefront of technological innovation and is constantly searching for new advanced materials to improve productivity, efficiency, and safety. The aerospace market encompassing the design, manufacture, and maintenance of aircrafts, space vehicles, and related systems. It includes the commercial and military sectors, as well as the space exploration field.

The world market of the aerospace industry was studied. Factors affecting the market positively and negatively were identified. According to the global aerospace market segmentation by vehicle types, the leading position in 2023 was occupied by the commercial aircrafts segment with a share of 63.4 %; by the vehicle size – by the narrow-body aircraft segment (72.4 %); by the end consumer – by the private sector segment (65.4 %); by operation – by manually operated aircrafts segment (79.4 %); and by geographic regions – by the North American segment (47.3 %). The main strategic trends and directions of the further aerospace market development are presented.

The world market of aerospace materials was studied. Factors affecting market dynamics are identified, and market challenges are highlighted. According to the world aerospace market segmentation by the materials types, the leading place in 2022 belonged to the composite materials segment with a share of 69 %; by the aircraft type – to the commercial aircrafts segment (51 %); and by geographical regions – to the European segment (35.0 %).

The trends of the sustainable aerospace industry development are summarized: modern aircraft design, use of sustainable aviation fuel, urban air mobility, modern traffic technology, and air transportation management optimization. For each trend, possible actions leading to changes in the aerospace industry are considered.

The question of the nanomaterials use in the space industry is considered. Some characteristics and possibilities of application of nanocomposite materials, nanocoatings, nanofluids, nanosensors, and carbon nanotubes, as well as examples of the nanomaterials application in aircraft components are given. The industry problems are identified, and their possible solutions are given.

Keywords: *aerospace market, aerospace materials market, market segmentation, market trends, market limitations, market development directions, nanomaterials.*

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1. Introduction

The aerospace industry is at the forefront of technological innovation and is constantly searching for new advanced materials to improve productivity, efficiency and safety. Nanomaterials (NM) are considered to be one of the most promising materials in this field [1, 2]. These materials are characterized by unique properties, such as a significantly larger surface area compared to their bulk counterparts, exceptional magnetic characteristics, significant quantum effects, and increased thermal and electrical conductivity. These characteristics, as well as exceptional mechanical properties and strength, antimicrobial, antiviral and antifungal properties make NM indispensable for use in various aerospace components. The use of NM is not limited by their physical characteristics. Catalytic properties and the ability to self-repair minor damage increase their potential applications.

The field of aerospace and defense industry is one of the leaders in the use of nanomaterials and nanotechnologies. The segmentation of the nanotechnology market by industry [3] showed that this industry ranks third in revenue with a share of 15.4 %, second only to healthcare (19.5 %) and electronics (16.6 %). But the largest growth rates during the forecast period (2022–2030) will be observed in the aerospace and defense sectors. A similar situation in terms of revenue shares exists in the nanotechnology market of the leading "player" – the United States of America: health care – 21.2 %, electronics – 18.6 %, aerospace and defense industry – 15.3 %.

The aerospace market is a global industry that encompasses the design, manufacture and maintenance of aircraft, spacecraft and related systems. It includes the commercial and military sectors, as well as the field of space exploration. The key "players" of the market are manufacturers of aerospace products, defense enterprises and space agencies. This market involves the development of advanced technologies, from advanced materials and propulsion systems to satellite communications and space exploration initiatives. Demand is driven, in particular, by the following factors: passenger travel, defense needs, and growing interest in space exploration. It is a highly competitive and dynamic industry where constant innovation and international cooperation play a crucial role in shaping its future.

The review [4] emphasizes that the aerospace industry is one of the strategic ones in many countries of the world. Among the leaders in this field are almost all the G7 countries, except for Italy. The aerospace industry is connected to many other industries of the national economy, which are auxiliary to it or use new technologies obtained as a result of research in this field. The space sector, which includes the production and launch of satellites, is gaining more and more importance, which is currently a sign of a certain economic independence of the country. The statistical data presented in the review correspond to 2016–2017. Given the rapid pace of development of the industry, they need to be updated and clarified.

The aim of research is to identify regularities, track modern trends and innovations in the development of the global aerospace market, and clarify the possibilities of using nanomaterials in the aerospace industry.

To achieve the aim, the following objectives should be performed:

1. Determine the potential demand and volume of the global aerospace market.
2. Summarize information on the state and development trends of the global aerospace market.
3. Carry out a segmental analysis of the world aerospace market and the market of aerospace materials.
4. Monitor the dynamics and competition in the global aerospace market and aerospace materials market.
5. Identify key trends in the global aerospace market and aerospace materials market.

2. Materials and Methods

The object of research is the state, trends and structure of the global aerospace market and the aerospace materials market, directions of application of nanomaterials in the aerospace industry.

The following scientific methods were used in the study:
- method of searching for literary data on the subject under study;
- method of analysis of literary sources;
- comparative analysis of various methodological approaches;
- content analysis of documents;
- method of systematization and classification when conducting research on the achievements of modern science in the aerospace industry.

3. Results and Discussion

3.1. Research of the global aerospace market

3.1.1. General characteristics of the market. The volume of the world aerospace market in 2023 was 308.7 billion USD. Since 2018, it has been growing at a compound annual growth rate (CAGR) of 0.8 %. The market is expected to grow from 308.7 billion USD in 2023 to 461.9 billion USD in 2028, with the CAGR of 8.4 %. The market will grow by 4.8 % on average from 2028 and reach 583.3 billion USD in 2033 [5].

According to research estimates [6], the size of the world aerospace market was estimated at 321.5 billion USD in 2022 and, according to forecasts, will reach approximately 678.2 billion USD by 2032, growing at a CAGR of 7.8 % during the forecast period from 2023 to 2032 (Fig. 1).

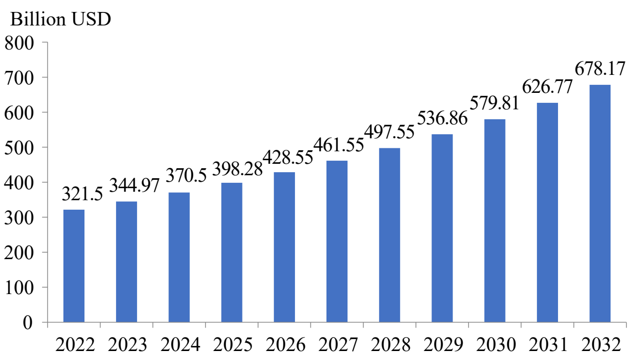

Fig. 1. Volume of the world aerospace market, billion USD (built on the basis of data [6])

Key conclusions regarding the development of the global aerospace market:
- in 2022, North America accounted for more than 46 % of market revenue;
- according to estimates, the Asia-Pacific region will experience the highest SSTs in the period 2023–2032;
- by type of vehicle in 2022, the segment of commercial aircraft occupied the largest market share – 43.5 %;
- by vehicle type, the aerospace support segment is expected to grow at an impressive CAGR of 8.5 % between 2023 and 2032;
- by the size of the vehicle, the segment of narrow-body aircraft received more than 78.2 % of the revenue share in 2022;
- by vehicle size, the wide-body aircraft segment is expected to expand with the fastest CAGR during the forecast period;
- by end consumer in 2022, the private sector segment had the largest market share of 65.4 %;
- by end user, the public sector segment is expected to expand with the fastest growth rate during the forecast period;
- by operation in 2022, the manually operated aircraft segment received more than 68.5 % of the revenue share;
- by operation, the autonomous aircraft segment is expected to expand at the fastest rate during the forecast period.

In 2022, the size of the US aerospace market was estimated at 103.52 billion USD, and by 2032, according to forecasts, it will reach approximately 218.37 billion USD with the CAGR of 7.8 % for the period 2023–2032 (Fig. 2).

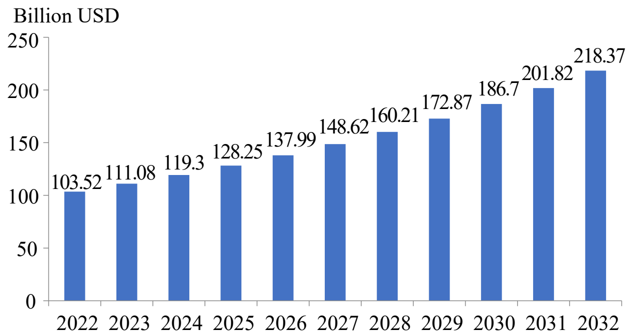

Fig. 2. Volume of the US aerospace market, billion USD (built on the basis of data [6])

The growth factors of the global aerospace market are:
– commercial aviation – the aerospace market continues to grow rapidly due to the growing demand for commercial aircraft. This surge in demand is particularly noticeable in emerging markets, driven by a growing middle-class population and urbanization, leading to increased passenger traffic;
– defense needs – increased global defense spending and continued geopolitical tensions drive the military aerospace sector. Governments around the world are prioritizing increasing their military capabilities, thus fueling demand for advanced aviation and defense technology;
– space exploration – the space exploration segment is in the midst of a renaissance, with growing interest in scientific missions, satellite technologies, and even commercial space ventures. This increased interest and investment is driving innovation and expansion in the aerospace market;
– technological progress – the aerospace industry remains at the forefront of technological innovation, constantly developing materials, power plants and avionics technologies;
– ecological aviation – environmental friendliness is increasingly coming to the forefront of aerospace problems. The industry is experiencing a marked shift towards environmentally friendly and fuel-efficient aircraft; this change is caused by consumer demand for greener travel options and clear environmental regulations;
– digital transformation – big data analytics, the Internet and artificial intelligence are changing maintenance, operation and passenger experience;
– space tourism – the growing space tourism sector offers exciting business opportunities as many companies embark on commercial space travel. As technological advancements and regulatory frameworks evolve, this segment has enormous potential for those willing to invest in its growth;
– basic maintenance services – the need for maintenance, repair and overhaul services remains constant. Companies that offer reliable maintenance and repair services have a steady stream of revenue and can benefit from the increased number of aircraft and spacecraft in operation;
– electric propulsion – companies that invest in this technology are well positioned to meet the increased demand for environmentally friendly and economical air transportation.

The growth of commercial aviation, defense and security needs is one of the important factors affecting the dynamics of the aerospace market. The components of this factor with corresponding tasks are:
– constant expansion of commercial aviation is the main "catalyst" of the aerospace market – modernization and expansion of the air fleet to meet the increased demand;
– implementation of innovations aimed at creating aircraft – creating more economical aircraft, increasing comfort and environmental friendliness;
– steady progress in air traffic control systems – ensuring safe and efficient operation in conditions of an increasing number of people;
– new aircraft production – growing demand for maintenance, repair and overhaul services;
– increased global requirements for defense and security – giving priority by governments to strengthening military potential in a complex and unstable geopolitical landscape;
– innovations in military aviation and technologies – creation of modern aerospace companies.

The growth of the global aerospace market is inevitably associated with certain limitations with the corresponding consequences:
– geopolitical uncertainty and regulatory compliance – Geopolitical instability and tensions can significantly restrain market demand in the aerospace industry. These uncertainties include trade disputes, sanctions and diplomatic conflicts that could disrupt global supply chains, affect international cooperation and alter defense procurement decisions. Geopolitical tensions can reduce the willingness of countries to cooperate in space missions and research projects, which, in turn, can hinder the growth of the aerospace sector;
– compliance with regulatory requirements – strict regulatory requirements can also restrain demand in the aerospace market. The aerospace industry is subject to numerous safeties, environmental and airspace management regulations. Compliance with these regulations often requires significant investment in research and development. The complex and changing nature of these regulations can introduce uncertainty and difficulty into business planning, making it difficult to navigate the market effectively;
– rising cost of raw materials and fuel and construction materials – prices for fuel and construction materials, which are constantly increasing, can also restrain demand in the aerospace market;
– increase in the number of cyber-attacks – the actions of cyber attackers or malicious programs, which are aimed at capturing information data and obtaining full control over resources and disabling aerospace systems, can contribute to the danger of the aerospace market.

Despite its limitations, the aerospace market is currently experiencing a significant boom, driven largely by two ground-breaking developments: the emergence of space tourism and the emergence of urban air mobility. Backed by industry leaders like SpaceX, Blue Origin and Virgin Galactic, space tourism has spawned a whole new market focused on suborbital and orbital travel. This sector not only attracts the attention of wealthy individuals, but also contributes to significant investment aimed at creating safe and affordable commercial space travel. As this industry continues to grow, it promises to create increased demand for spacecraft, advanced powerplants and technology, thereby driving the growth of the entire aerospace industry.

Similarly, urban air mobility, characterized by eVTOL aircraft and autonomous air taxis, is revolutionizing urban transportation. Given the heavy congestion of city streets and the increased emphasis on sustainable mobility solutions, urban air mobility offers an attractive alternative for short-distance travel within the city limits. Its arrival will create demand for innovative aircraft designs, electric propulsion systems, air traffic management solutions and the necessary infrastructure, further stimulating growth in the aerospace sector. Together, space tourism and urban air mobility are key factors in shaping the future of the aerospace industry, pushing the boundaries of technology and redefining the use of air travel.

3.1.2. Segmentation of the global aerospace market

Segmentation of the aerospace market by vehicle type. Segmenting the aerospace market by vehicle type into commercial aircraft, aircraft maintenance, repair and overhaul services, aerospace support and ancillary equipment shows that the commercial aircraft market was the largest segment of the aerospace market with a share of 63.4 % or 195.8 billion USD from total volume in 2023. Going forward, the commercial aircraft segment is expected to be the fastest growing segment in the aerospace market segmented by vehicle type, with a CAGR of 9.5 % by 2028 [6].

Research results [7] also confirm the leading position of the commercial aircraft segment in 2022, but with a slightly smaller share of 43.5 %. Commercial airplanes are airplanes designed for passenger and cargo transportation. In the aerospace market, the commercial aircraft category includes narrow-body, wide-body and regional aircraft. A noteworthy trend in this segment is the evolution of green and fuel-efficient aircraft. Manufacturers use advanced materials and innovative aerodynamics, including composite structures and wings, to improve aircraft performance while addressing environmental concerns. In addition, the widespread adoption of digital technologies, such as advanced avionics systems and data analytics, is critical to improving safety, improving the passenger experience and optimizing operational efficiency.

The aerospace support segment is expected to grow at a CAGR of 8.5 % during the forecast period. Aerospace support covers a wide range of services, including maintenance, repair and overhaul, as well as logistics and technical support of aircraft and related systems. The aerospace support sector is witnessing a shift towards predictive and proactive maintenance through data analytics and technology. These improvements ensure more efficient and cost-effective operations, reduce downtime and keep the aircraft in optimal condition. In addition, the growing use of 3D printing and additive manufacturing in aerospace support offers innovative solutions for component replacement and repair, further expanding the industry's capabilities.

Segmentation of the aerospace market by vehicle size. The segmentation of the aerospace market by vehicle size into wide-body, narrow-body, regional and other aircraft shows that the narrow-body aircraft market was the largest segment of the aerospace market with a share of 72.4 % or 223.9 billion USD from the total volume in 2023. In the future, the segment of narrow-body aircraft is expected to become the segment of the aerospace market with the fastest growth rates with a CAGR of 8.8 % during 2023–2028 [6].

The share of the segment of narrow-body aircraft, determined in the study [7], practically coincides with previous data and amounted to 78.2 % in 2022. Narrow-body and wide-body aircraft are different categories in the aerospace market. Narrow-body aircraft such as the Boeing 737 and Airbus A320 typically have a single aisle, making them suitable for short- and medium-haul routes, seating 100–240 passengers. They are popular due to their efficiency and versatility, which contributes to significant demand, especially in regions with increased air traffic.

On the other hand, the wide format aircraft segment is projected to grow at the fastest rate during the forecast period. Wide-body aircraft such as the Boeing 777 and Airbus A350 have two aisles and a larger passenger capacity (usually over 240 passengers). These aircraft are best suited for long-haul international flights. Recent trends show a shift towards fuel-efficient engines in both aircraft categories, reducing environmental impact and operating costs while increasing passenger comfort.

Segmentation of the aerospace market by end user. The segmentation of the aerospace market by end user into the public and private sectors shows that the private sector market was the largest segment of the aerospace market with a share of 65.4 % or 201.2 billion USD from total volume in 2023. Going forward, the private sector segment is expected to be the fastest growing segment of the aerospace market.

According to research [7], in 2022, the private sector segment had the highest market share of 65.4 % by end consumer (Fig. 3). In the aerospace market, the private sector mostly includes commercial airlines, aerospace manufacturers, space tourism companies, and private space exploration enterprises. This sector is driven by profit motives, innovation and competition. It is seeing significant growth due to the booming demand for air travel and the growing space tourism industry.

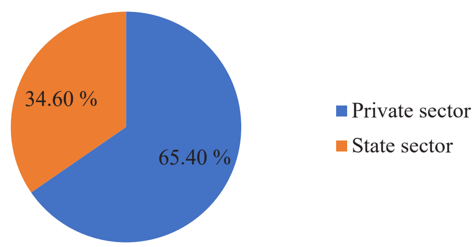

Fig. 3. Segmentation of the aerospace market by end user (2022), % (built on the basis of data [7])

The public sector is expected to grow at the fastest rate during the forecast period. The government sector includes defense and space agencies. It is characterized by government research, development and procurement. According to recent trends, governments around the world are increasing their defense budgets, encouraging innovation in the military aerospace industry, and promoting international cooperation in space exploration, thereby influencing the trajectory of the aerospace market.

Segmentation of the aerospace market by operation. Segmentation of the aerospace market by operation into manned and autonomous aircraft shows that the manned aircraft segment was the largest segment of the aerospace market with a share of 79.4 % or 245.3 billion USD from total volume in 2023. Going forward, the autonomous aircraft segment is expected to be the fastest growing segment in the aerospace market with a CAGR of 10.1 % during 2023–2028 [6].

According to the results of research [7], in 2022, manually controlled aircraft occupied the largest market share – 68.5 %. Manually piloted aircraft are traditional aircraft operated by human pilots who directly control the aircraft's flight, navigation and decision-making processes. While advances in automation have reduced the pilot's workload, manually operated aircraft remain critical to commercial and military aviation. Trends in the manned aircraft aerospace market include the integration of advanced avionics, improved human-machine interfaces, and improved pilot training to improve safety and efficiency.

On the other hand, the autonomous aircraft segment is projected to grow at the fastest rate during the forecast period. Autonomous aerial vehicles, also known as unmanned aerial vehicles (UAVs) or drones, are aircraft capable of operating without human intervention. These devices are used for surveillance, delivery and data collection. Trends in the aerospace market for autonomous aircraft involve the development of advanced artificial intelligence, improved sensors, and regulatory frameworks to support safe and advanced use in various industries such as e-commerce, agriculture, and defense.

Segmentation of the aerospace market by geographic regions. The segmentation of the aerospace market by geographic regions indicates that North America was the largest region in the aerospace market with a share of 47.3 %, or 146 billion USD, in 2023 [6]. The second and third places were occupied by the Asia-Pacific region and Western Europe, respectively. The fastest growing regions in the aerospace market are expected to be the Middle East and South America, with CAGRs of 12.6 % and 12.2 %, respectively. For the regions of North America and Western Europe, 8.4 % and 7.7 % respectively are expected to be the CAGR.

According to research results [7], North America had the largest share of income – 46 % in 2022 (Fig. 4). North America remains the global aerospace region, home to industry giants such as Boeing and Lockheed Martin. The region boasts a developed aerospace market with a strong focus on innovation and advanced technology. Notable trends in North America include a push for sustainable aviation, growing space exploration efforts led by companies like SpaceX, and increased defense spending. In addition, the competitive commercial aviation sector is constantly striving to improve efficiency and the passenger experience, making North America a critical center for aerospace advancement.

According to estimates, the Asia Pacific region will witness the fastest growth rates of the market. The region has seen significant growth in commercial aviation due to increased passenger numbers, particularly in countries such as China and India. In addition, governments are investing in defense aerospace. The region is also becoming a significant participant in space activity as countries such as China make strides in lunar exploration and satellite technology. Trends include increased aircraft production, aerospace innovation and international cooperation in space.

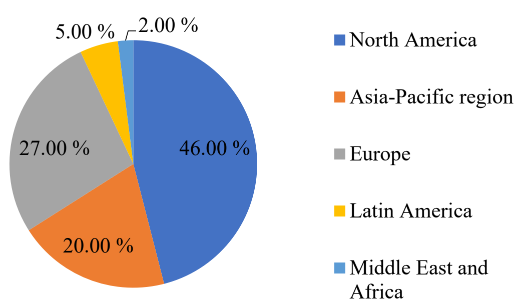

Fig. 4. Segmentation of the global aerospace market by geographic regions, % (built on the basis of data [7])

The European aerospace market is known for its advanced technology and innovation. Such leading "players" of the industry as Airbus and Rolls-Royce are located here. The region shows high demand for commercial and military aircraft, with a strong focus on green aviation practices and strong safety regulations. European space agencies such as ESA promote space exploration. Europe's aerospace sector is distinguished by its commitment to excellence and environmental sustainability.

3.1.3. Features, trends and directions of market development. The peculiarity of the global aerospace market is that several "big players" work on it. The share of the ten largest "players" was up to 63 % of the total market in 2022. The concentration of the market can be explained by the presence of a large number of "players" in different geographical regions. Prominent "players" purchase products and enter into partnerships with other companies to consolidate their market positions around the world, while others distribute products. Airbus SE was the largest competitor with a market share of 17.4 %, followed by The Boeing Company with 11.3 %, Raytheon Technologies Corporation with 8.8 %, General Electric Company with 8.5 %, Safran S. A. with 4.1 %, General Dynamics Corporation with 3.1 %, Honeywell International Inc. with 2.6 %, Rolls-Royce Holdings plc with 2.6 %, Bombardier Inc. with 2.3 % and Northrop Grumman Corporation with 2.2 %.

The largest opportunities in the aerospace market, segmented by vehicle type, will emerge in the commercial aircraft segment. Its global annual sales will reach 112.4 billion USD by 2028. The biggest opportunities in the commercial aircraft market will appear in the passenger aircraft segment, which will reach 59.1 billion USD (52.6 %) of global annual sales by 2028. The largest opportunities in the market for aircraft maintenance, repair and overhaul services segmented by vehicle type will appear in the commercial aircraft maintenance services segment, which will receive 12.5 billion USD global annual sales by 2028. The best opportunities in the aerospace support and support equipment market, segmented by vehicle type, will appear in the satellite segment, which will reach 8.7 billion USD in global sales by 2028. The largest opportunities in the aerospace market, segmented by vehicle size, will appear in the narrow-body aircraft segment, which will reach 117.2 billion USD of global annual sales by 2028. The largest opportunities in the aerospace market, segmented by end user, will appear in the private sector segment, which will receive 105.8 billion USD of global annual sales by 2028. The largest opportunities in the aerospace industry of the market segmented by operations will arise in the manual operations segment, which will receive 114.2 billion USD global annual sales by 2028. The size of the aerospace market will grow the most in the USA by 57.5 billion USD.

The main strategic trends of the aerospace market are:
– use of 3D printing for innovative aerospace applications;
– use of machine learning methods, such as artificial intelligence (AI), to improve aircraft safety and production productivity;
– partnership and cooperation to expand the range of products and geographical presence;
– use of AHMS systems to help companies in the process of maintenance and repair and reduce operational costs;
– search for alternatives to reduce emissions and fuel consumption (more investment in the electric mode of aircraft);
– launch of modern and perfect aircraft for passenger transportation;
– use of cloud platforms to develop the design of their aircraft;
– strengthening operational capabilities by concluding new contracts;

– increasing business opportunities through investments and focusing on strengthening business operations through strategic cooperation and partnerships.

Analyst experts recommend that aerospace companies focus their efforts on:

– development of aerospace capabilities with the help of innovations in 3D printing;
– increasing aerospace efficiency with the help of machine learning;
– transformation of aerospace services with the help of AHMS innovations;
– electric aircraft for economic and environmental advantages;
– cloud cooperation for effective aerospace development;
– expansion of the commercial aircraft market segment for sustainable growth;
– narrow-body and wide-body segments for accelerated growth;
– passenger aircraft and commercial gliders/UAVs for sustainable growth;
– rocket engines and commercial gliders/drone maintenance services for strategic expansion;
– satellite market for strategic business growth;
– emerging markets and continued focus on developed markets;
– diversification of sales channels for the expansion of the aerospace market, provision of competitive price offers;
– strategic pricing for success in the aerospace market, participation in trade exhibitions and events, continued use of advertising promotions;
– integrated promotion strategies, focusing on the growth of the private sector to expand the aerospace industry;
– understanding the needs of end users for strategic growth.

3.2. Research of the world market of aerospace materials

3.2.1. General characteristics of the market. The global aerospace materials (AM) market is expected to grow from 38 billion USD in 2022 to 79.42 billion USD in 2032 and will grow at a compound annual growth rate (CAGR) of 7.7 % from 2023 to 2032 (Fig. 5).

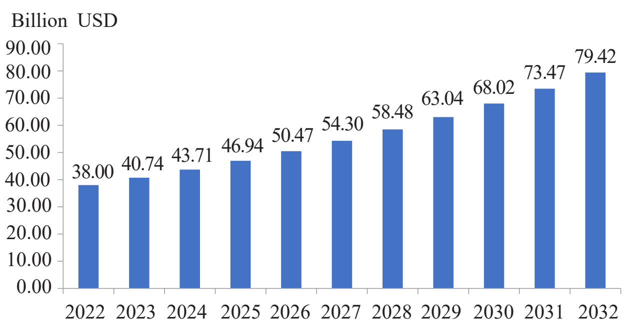

Fig. 5. Volume of the global aerospace market, billion USD (built on the basis of data [7])

The key features of the market are:

– by aircraft type in 2022, the commercial segment had a market share of 51 %;
– in 2022, 83 % of the market belonged to the exterior segment;
– by type, the composite segment received 69 % of the revenue share in 2022;
– in 2022, the European region received 35 % of the total market revenue [7].

AMs used for aerospace applications have improved qualities: high tensile strength, higher transparency, greater temperature resistance, and a hard surface. For aircraft parts, including windows, airframes, interiors, engine parts, mirrors, power plants and ceilings, aircraft manufacturers do not use traditional metals, preferring complex polymers or composites based on glass or carbon fiber. Increasing demand for light and fuel-efficient aircraft is one of the reasons for the expansion of the global aviation equipment market. Due to the lighter weight of the aircraft, the operating costs of the trip are significantly reduced and the aircraft operator benefits from fuel savings.

The growth of air traffic in developing regions such as Asia Pacific is causing an increase in the number of aircraft, increasing the demand for AM. In addition, the aviation components industry is greatly affected by the growing demand for brand new aircraft. However, the expansion of the aviation materials industry is held back by the availability of several options for creating complex structures. On the other hand, as the market for passenger airliners grows, more such aircraft are produced in emerging markets, which opens up huge opportunities.

One of the growth factors of the global AM market is the need for new modern materials. Materials used to make aircraft parts are known as aerospace resources. Most of these substances are alloys of aluminum and other metals, although synthetic polymer composites already occupy a significant part of the industry. Various aircraft components such as cabin interiors, structural frames, power plants, etc. are manufactured using these substances.

High strength, lightness and heat resistance are ideal characteristics of AM. These materials have excellent wear resistance and durability. Historically, titanium and aluminum alloys accounted for about 80 % of all elements used in aircraft construction. Composite materials, such as fiber-reinforced polymers and fiber-metal hybrid composites, are increasingly being used today. In addition, the development of aviation materials will change as a result of the increased use of nanotechnology in industry.

3.2.2. Expectations, dynamics and challenges of the global aerospace materials market. The nearest expectations of the aerospace materials market are:

– growing defense costs and increasing the use of hybrid materials in the production of aircraft;
– growing future market needs due to the increased need for aviation in the Middle East and the Asia-Pacific region;
– market prospects will be determined by the use of nanomaterials and nanotechnologies.

Dynamics of the aerospace materials market are determined by the following factors:

1) increasing demand for aviation from developing countries and budget airlines:

– in a best-case scenario, the aviation and military sectors will experience a surge in demand for aviation components as aircraft companies begin operating at full capacity without travel restrictions or supply chain disruptions. Before the epidemic of COVID-19, the consumer segment of air transport grew in the global aviation industry;
– low-cost operators have emerged as serious competitors in the industry, especially in developing countries in the Asia-Pacific region and South America. The Asia Pacific, Middle East and Africa region has more travelers. The majority of customers flying to Asia Pacific and Europe

are carried by carriers such as Qatar Airways, Emirates and Etihad Airways, which are among the largest operators of commercial aircraft in the Middle East;
2) lower prices, approximately from budget airlines:
– the need for larger aircraft is increasing as more people use air transport. Companies that supply aviation materials and other components needed by the aviation industry will profit from this demand. The main reason for the need to choose materials for aircraft is the aviation sector;
– according to the estimates of the civil aviation organization, air transportation grows by 4.6 % annually; as a result, the need for aviation components and military aircraft is growing rapidly. In the future, a decrease in prices from budget airlines is expected, which will also directly support the expansion of the aerospace materials business;
3) the latest innovations of the aerospace industry:
– a component that contributes to the growth of the market is the extensive research of alternatives to combinations of metals to eliminate individual deficiencies;
– fuel efficiency and durability of aircraft will increase significantly thanks to the use of new materials;
– production of aerospace materials using composites and nanomaterials will revolutionize the sector.

The following challenges of the aerospace market can also be highlighted.

– *Due to regulatory requirements, repair, maintenance and overhaul services are expensive:* concerns and adjustments in the sector are also justified by the increase in the use of composite materials. Repair, maintenance and overhaul of composite aircraft are key issues. International regional and local government regulators continue to develop global standards set by the International Civil Aviation Organization. The maintenance requirements for composite are different from those for metal, and most repair companies lack a lot of knowledge about the care of laminated composites. In their latest versions of aircraft, well-known commercial aviation manufacturers such as Airbus and Boeing have used complex lightweight structures as "breakthrough" materials. Composite materials make up the largest proportion of all materials used in the Airbus A350 XWB and Boeing 787 aircraft.
– *Decrease in commercial aircraft supplies:* the aerospace component market will be directly affected by the decrease in aircraft supplies. Since passenger airliners account for more than 80 % of all material consumption, a reduction in material demand caused by a decrease in aircraft orders will be detrimental to the market. As an example, contracts for such Boeing 737MAXs were canceled following the recent disasters involving the Malaysian and Ethiopian airlines.

The market opportunities of the aerospace market are growing. The need for aviation components is due to the expansion of the UAV market. Drone programs are a valuable resource for militaries around the world. Although there are many untapped opportunities in numerous applications, the commercial and civilian UAV sector is still in its early stages. Military spending on unmanned aerial vehicle technology is projected to increase as a share of total defense funding, providing growth prospects for specialized drone manufacturers and computer programmers.

3.2.3. Segmentation of the world market of aerospace materials

Market segmentation by material type. All modern aircraft manufacturers use aluminum alloys to create wings, fuselage and other aircraft components. Because aluminum and its alloys are characterized by high tensile strength, oxidation resistance, temperature resistance, and light weight, they are preferred in aircraft manufacturing over iron and steel. The largest consumers of aluminum alloys were commercial and industrial aircraft. The epidemic of COVID-19 has disrupted the distribution network, which has led to a decrease in demand for aluminum alloys in the aviation industry. The largest share in the market of aviation materials is occupied by aluminum alloys. In many commercial aircraft, about 80 % of the structural sections are made of aluminum. Aluminum is a popular choice due to its advantages, which include high strength, light weight, corrosion and temperature resistance.

The use of composites – a new class of materials for the manufacture of aircraft – is expanding both in the international market and in the use of new generations of aircraft. Due to their resistance to corrosion and deformation, polymer composites are superior to aluminum, as well as alloy steels. In 2022, the share of composite materials in the total volume of aerospace materials was 69 %, and the share of plastic and metal was 18 % and 13 %, respectively (Fig. 6).

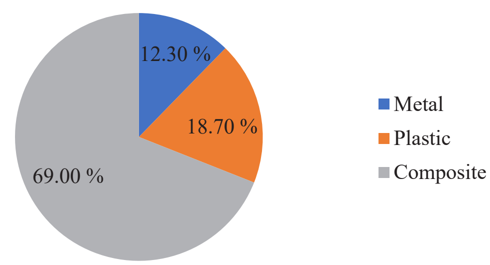

Fig. 6. Segmentation of the aerospace materials market by type of material (2022), % (built on the basis of data [7])

Segmentation by aircraft type. Due to the extensive use of a variety of materials, including aluminum and titanium alloys and structural components in manufacturing, the commercial aircraft sector accounts for the lion's share of the global aviation equipment market. The commercial aircraft sector accounts for more than 75 % of all demand for components in quantitative terms. As the number of passengers in developing countries increases, the demand for airplanes increases. The need for new aircraft will increase as a result of this growth, as will the need for aircraft components.

It appears that the predominant sector of the aircraft market is business. The huge demand is created by the wide application of such aircraft for a variety of functions, including cargo and passenger transport. The need for commercial aircraft is growing due to the increase in the number of air travelers and low-cost air travel. The aerospace company's need for aerospace components has decreased since the COVID-19 epidemic.

In 2022, the share of commercial aircraft accounted for 51 % of the total market volume, the following percentages for the shares of the remaining segments: helicopters – 25 %, military aircraft – 14 %, business support – 8 %, other segments – 2 % (Fig. 7).

Segmentation by geographic regions. The share of aerospace materials market segments by region in 2022 was, %: North America – 28, Asia-Pacific region – 23.1, Europe 35.0, Latin America – 9.2, countries of the Middle East and Africa – 4.7 (Fig. 8).

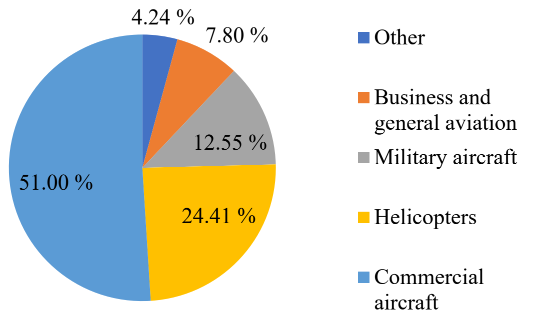

Fig. 7. Segmentation of the aerospace materials market by type of aircraft (2022), % (built on the basis of data [7])

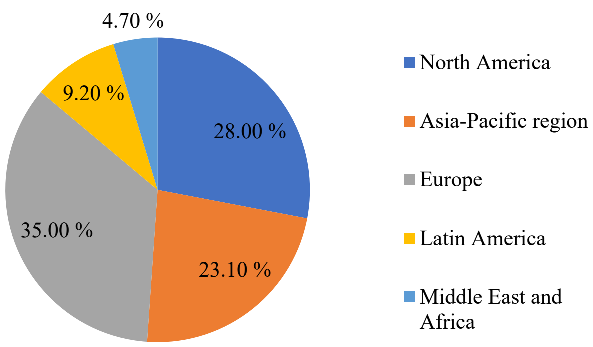

Fig. 8. Segmentation of the global aerospace materials market by geographic regions (2022), % (built on the basis of data [7])

A significant share of the aviation equipment market was in Europe due to the need for commercial and corporate aviation. Germany delivered the largest number of commercial airliners in 2021, followed by the USA and France. The reduction in deliveries of the Boing 437 Max is a result of production cuts in the US, which is home to numerous important aerospace component manufacturers, including TenCate, Solvay, SGL Carbon, VSMPO and AMG NV. The demand for composite materials in Europe is mostly due to the growth of Boeing air transport. In addition, military helicopters are produced in the region. COVID-19 has had a particularly negative impact on the European region, resulting in reduced industrial and commercial activity in each of the continent's major countries, including Italy, Germany, the UK and France.

3.3. Trends of sustainable development of the aerospace industry. Summarizing the data of modern literary sources makes it possible to single out five trends of sustainable development leading to changes in the aerospace industry: modern aircraft design, use of sustainable aviation fuel, urban air mobility, modern traffic technology, optimization of air transportation management. Currently, the aerospace industry is largely dependent on fossil fuels. The aerospace industry must implement several decarbonization measures to address climate change.

Annual emissions of the aerospace industry amount to about 1 billion tons of carbon dioxide, and, according to forecasts, this figure will triple by 2050. Adequate sustainable development measures must be taken to prevent this inevitable growth. Industry is under constant pressure to review its operations and implement innovative technologies to minimize greenhouse gas emissions. Companies in the sector are moving beyond carbon offset trading and placing more emphasis on sustainable operations, with airlines committing to zero carbon emissions by 2050.

The aerospace industry relies heavily on fossil fuels, with airplanes burning several tons per trip. When burned, these fuels release carbon dioxide, nitrogen oxides, sulfate aerosols, and water vapor that deplete the ozone layer, raising global temperatures. Therefore, the aerospace industry must implement decarbonization measures to address climate change.

3.3.1. Modern aircraft design. Aircraft manufacturers mostly optimize aircraft designs to achieve the best fuel efficiency and reduce weight. An economical aircraft has a lower impact on the environment because it burns less fuel and has lower emissions. Manufacturers can increase performance through minor improvements to the aircraft:
- optimization of the engine design to increase the efficiency of fuel use;
- improvement of aerodynamic structures;
- study of the use of light materials for the manufacture of aircraft;
- use of new coatings.

Aircraft manufacturers have access to advanced design software that they can use to model the performance of various aircraft designs and evaluate how different manufacturing materials affect fuel efficiency. They can assess the longevity of a new fleet of aircraft and predict emissions over the lifetime of the aircraft.

Airlines can also use modern design software to renew aging air fleets, control supplies and use sustainable materials while using sustainable supply chains. The advent of progressive manufacturing means that aircraft manufacturers can reproduce complex part designs faster and use less raw materials. The introduction of additive manufacturing technologies, such as 3D printing, enables manufacturers to produce complex shapes with virtually no waste. They can apply modern coatings that make planes lighter and more efficient.

3.3.2. Use of sustainable aviation fuel. The use of sustainable aviation fuel (SAF) is gaining importance as airlines strive to achieve zero emissions. This fuel has similar chemical characteristics to fossil fuel, but has less ability to destroy the ozone layer. It releases carbon that has already been removed from the environment. Emissions from SAF have a shorter "life cycle", which further reduces the level of ozone depletion.

Airlines can use SAF without redesigning engines or designing additional aircraft infrastructure. SAF is produced from a variety of plant and animal materials, algae and food waste. But its production is still in the development stage, which makes SAF more expensive compared to fossil fuels.

However, the aerospace industry is making impressive progress in producing synthetic SAFs using hydrogen. Companies are ramping up hydrogen production from low-carbon sources and processes. The use of SAF can reduce the impact of greenhouse gas emissions by more than 80 %. The aerospace industry faces many challenges in its quest to optimize the production of clean jet fuel. Addressing this issue will bring the industry closer to the goal of net zero emissions.

3.3.3. Urban air mobility. The expansion of urban air mobility is another trend shaping sustainability in the aerospace sector. There are two technologies in this direction: electric vertical take-off and landing (EVL) and drone delivery. Although the development of EVL is at an early stage, it promises to transform air travel into short and medium-haul flights. Companies use UAVs for delivery in cities, and their carrying capacity increases over time.

The majority of EVLs and UAVs have electric power, that is, they do not emit harmful substances. At the same time, the aircraft is charged using energy from renewable sources. They also have fewer rotating parts to reduce noise pollution, a concern in the aerospace industry. Fossil-fueled EVLs are economically designed to minimize fuel consumption and reduce emissions. Urban air mobility uses the shortest travel routes, increasing the availability of low-cost air travel.

3.3.4. Modern movement technology. Today's airplanes and aircraft of the future will not rely solely on fossil fuel engines. The pursuit of sustainable flights requires structural changes in aircraft and spacecraft engines. Improved engine technologies are aimed at increasing efficiency, increasing fuel reserves and better aircraft characteristics. According to experts, some advanced powerplants include electric powerplants; hybrid systems; use of solar energy and fuel cells.

Electric power plants use motors powered by batteries. Hybrid systems combine fossil fuels with advanced powertrains such as electric, hydrogen and fuel cells. Advanced powerplant technologies require significant aircraft modifications to change power transmission.

The development of advanced propulsion systems requires close cooperation between the aerospace industry and other sectors, such as the automotive industry, which has made significant advances in battery technology. With the advent of these propulsion technologies, airlines are achieving better fuel efficiency and can significantly reduce greenhouse gas emissions.

3.3.5. Optimization of air transport management. Some airlines still use legacy air traffic management systems, which reduces the efficiency of route planning and asset management. Airlines can minimize their carbon footprint by digitizing air traffic management and using advanced technology to improve route planning and asset maintenance, as well as improve operational efficiency.

The use of advanced technologies such as artificial intelligence can improve fuel economy by simplifying flight route planning, predicting market dynamics and suggesting routes based on weather conditions. This helps companies optimize the use of their fleet for more economical operation.

Optimized flight route planning means companies can reduce aircraft mileage, resulting in lower emissions and fuel consumption. They can also digitize customer management in passenger terminals to reduce paperwork and other activities associated with greenhouse gas emissions.

Thus, the transition to zero emissions in the aerospace industry requires radical changes in all aspects of activity. Reducing greenhouse gas emissions is not just the preserve of airlines. The entire industry, including manufacturers and other actors in the supply chain, must implement sustainable technologies to reduce waste and pollution. The sector must use advanced technologies to maximize assets and operational efficiency. The ultimate goal of sustainability-driven aerospace innovation is to deliver zero emissions for a safer, cleaner planet.

3.4. Application of nanomaterials in the aerospace industry

3.4.1. Nanocomposite materials. The addition of NMs (carbon nanotubes, graphene, and nanoclays) to traditional aerospace materials (polymers, metals, and ceramics) results in the improvement of many of their characteristics. Summarizing the results of research [2, 8–11], it is possible to determine the following properties with their corresponding application:

– increased strength, stiffness and stability, exceptional strength-to-weight ratio – ensuring demanding aerospace applications, providing aerospace components with lightness without losing their mechanical characteristics, saving fuel, reducing weight and operating costs;
– increased thermal stability and thermal conductivity – possibility of functioning at extreme temperatures;
– improved electrical properties – ability, depending on the type and concentration of NM nanoparticles, to increase electrical conductivity or give the composite insulating properties. These features are useful for electrically conductive aircraft components or for shielding against electromagnetic interference;
– self-healing ability – property of the corresponding nanocomposites to independently eliminate small damages. This function increases the service life and safety of aerospace equipment and structures exposed to harsh conditions;
– ability to change surface properties and reduce resistance – use of nanocomposites in the design of aerospace surfaces leads to improved aerodynamics and stealth capabilities.

3.4.2. Nano coating. Summarizing the results of research [8, 12–14] on the use of nanocoatings (NC) in the aerospace industry makes it possible to determine the properties that they give to materials with appropriate application:

– ensuring resistance to corrosion – protecting aerospace components from destruction due to the influence of moisture, chemicals and aggressive environments. Providing these properties extends the service life of critical parts of aircraft and leads to lower maintenance costs;
– creation of conditions to prevent the formation of ice on the surface of aircraft or facilitate its easy removal – such coatings increase the safety and efficiency of flights in adverse weather conditions;
– increased hardness and wear resistance – protection of aerospace products from damage caused by abrasion and friction, especially in areas of high load, such as chassis and engine components;
– thermal protection properties – protection against extreme heat generated during high-speed flights or entering the Earth's atmosphere. Such coatings insulate and reduce thermal loads on the structures on which they are applied;
– protective properties – protection of aerospace surfaces from UV radiation and harmful effects of solar radiation, protection of spaceships and astronauts from radiation;
– aerodynamic properties – ability to change the flow of air around aerospace surfaces, reducing drag and increasing fuel efficiency. This is especially important for achieving higher speeds and greater fuel economy.

3.4.3. Nanofluids. This class of NM refers to liquids containing nano-sized particles. Summarizing the results of research [1, 15] on the NF use in the aerospace industry makes it possible to determine the properties that they give to materials with the appropriate application:

– improvement of heat transfer compared to traditional liquids – improvement of the efficiency of cooling systems in aerospace vehicles, in aircraft and rocket

engines. NFs are used as heat carriers for dissipating excess heat during operation;
– high thermal conductivity of NF – providing better cooling characteristics and preventing engine overheating;
– thermal insulation properties – NF is used for thermal insulation of spaceships and satellites;
– specific thermal properties – NF use to control the temperature of sensitive electronic components, protecting them from extreme temperature fluctuations;
– antifreeze properties – NFs with unique properties are used to remove ice or protect aircraft surfaces. They prevent the accumulation of ice on wings, engine inlets and other critical parts, increasing flight safety during adverse weather conditions;
– improved heat transfer – in space missions or aerospace research involving cryogenic fluids, NFs provide improved heat transfer capabilities, ensuring stable operation of cryogenic systems and reducing evaporation losses;
– possibility of thermal energy storage – NF use in efficient energy storage systems, which can be useful for managing power and thermal loads in aerospace vehicles;
– reduction of resistance – fuel economy and improvement of aerodynamic characteristics.

3.4.4. Nanosensors. Nanosensors (NS) are built into the structures of aircraft and spacecraft to monitor their condition. Summarizing the results of research [1, 8] on the NS use in the aerospace industry makes it possible to determine the properties that they give to materials with the appropriate application:

– ability to detect changes in voltage, vibration and temperature – providing control of data on the structural integrity of the vehicle in real time. This allows early detection of possible defects or damage, ensuring operation and reducing maintenance costs;
– possibility of detecting traces of gases and chemicals – control of the presence of toxic gases, fuel leakage or pollution. These sensors are vital to the safety of the crew and passengers on board, especially in confined spaces such as the cockpits of aircraft or spacecraft;
– ability to measure changes in temperature and pressure – nanoscale thermometers and pressure sensors to measure changes in temperature and pressure in critical aerospace systems, such as engines, avionics and other power plants; monitoring these parameters helps optimize equipment performance and avoid problems;
– possibility of use outside the aircraft – monitoring of the state of the environment during flight, for example, monitoring humidity, radiation levels and the presence of solid particles. This information is essential for the safety of the vehicle and its occupants, and can assist in weather and atmospheric research;
– ability to determine the composition of aerospace fuel – NS is used to determine the quality of fuel and identify its potential leaks. Timely detection of fuel leaks is crucial to prevent accidents and ensure fuel efficiency;
– ability to detect obstacles – emergency vehicles are used in autonomous aerospace systems to determine the approach and detect obstacles during takeoff, landing or docking. This increases the safety and reliability of unmanned aerial vehicles and spacecraft;
– possibility of application for monitoring people's health – in the context of space missions, NS are used as biosensors for monitoring the health of astronauts by detecting biomarkers or physiological changes, ensuring timely intervention in the event of medical problems.

3.4.5. Application of carbon nanotubes in the aerospace industry. Carbon nanotubes (CNTs) have a number of promising opportunities for use in the aerospace industry. Summarizing the results of research [2, 12, 16, 17] on the use of CNTs in the aerospace industry makes it possible to determine the properties they give to materials with the appropriate application:

– combination of light weight and mechanical strength – CNTs are ideal components for creating advanced composites, they improve the properties of traditional materials such as aluminum and titanium, which increases the structural integrity and safety of aircraft and spacecraft;
– exceptional electrical conductivity allows the creation of conductive coatings and nanowires, ensuring the effectiveness of electrostatic charge management and shielding from electromagnetic interference;
– possibility of energy storage – creation of batteries and supercapacitors based on CNTs is important for the aerospace industry, given the need to reduce weight and increase efficiency;
– high thermal conductivity – CNTs with high thermal conductivity provide effective heat management, dissipating it from critical components;
– ability to detect and adapt to such parameters as deformation, temperature, pressure – creation of sensitive sensors and devices;
– preservation of properties at miniaturized sizes – with applications extending to nanoelectronics, CNTs are the basis of next-generation aerospace systems, including lightweight displays and advanced processors;
– possibility of economic transportation – the promising role of CNT in the construction of space "elevators" – innovative means of cost-effective transportation of cargo.

3.4.6. Application of nanomaterials in aircraft components. Such NMs as CNTs, graphene, and nanofibers are composite structural materials used in aircraft to improve their mechanical properties. These materials provide exceptional strength and stiffness while maintaining a lightweight profile. When integrated into composite matrices, they increase load-bearing capacity and structural integrity, enabling stronger and lighter aircraft components. The improved properties also contribute to better resistance to fatigue, impact and other forms of stress. NMs can contribute to the development of aircraft with greater fuel efficiency, flight duration and range, as reduced weight results in lower fuel consumption.

NCs provide numerous benefits such as corrosion resistance, improved anti-icing properties, aerodynamics and wear protection. They are used to repel water, prevent ice build-up and increase the overall durability of the aircraft. For example, superhydrophobic nanocoatings can prevent water from accumulating on the wings and fuselage, improving fuel efficiency and reducing the risk of icing.

NF is used in airplanes for effective thermal management. These fluids demonstrate better heat transfer properties compared to traditional heat carriers. NF use in cooling systems allows more efficient heat dissipation, preventing overheating, and improves the overall state of system efficiency. Such heat transfer capabilities of NF contribute to increasing the service life of components and reducing maintenance requirements.

NSs play a crucial role in monitoring the structural condition of aircraft components. These sensors are embedded in composite materials to detect changes in strain, temperature, humidity, and other parameters. NSs provide real-time data on the state of aircraft structures, allowing early detection of mechanical damage and fatigue. This service approach increases safety and reduces maintenance costs. NS is also used for non-destructive evaluation during routine inspections, which allows for a more thorough assessment of the condition of the aircraft without the need for large-scale disassembly.

The Boeing 787 Dreamliner is an aircraft that contains many NMs. Composite materials reinforced with carbon fibers are widely used in its design [18]. Such NMs as CNTs are used to improve the mechanical properties of these composites. CNTs increase the overall strength, stiffness and crack resistance of composites, which helps reduce weight and increase fuel efficiency.

NCs are used to protect aircraft surfaces from environmental factors such as corrosion, wear and icing. Also, NC was developed to improve aircraft aerodynamics and fuel efficiency. The advantages provided by NCs are a reduction in drag and an increase in laminar flow over the surface of the aircraft.

3.4.7. Problems and potential solutions

Challenges. NMs in aerospace applications offer enormous opportunities and advantages, but there are challenges that need to be solved:

– production consistency – ensuring uniform distribution of NM in composite matrices is crucial for achieving desired properties, inconsistent dispersion can lead to changes in material behavior and disrupt structural integrity;

– health and environmental concerns – handling of NM raises concerns about the safety of workers and the impact on the environment, it is important to carefully determine the possible potential risks associated with exposure to nanoparticles during production and maintenance;

– regulation and standardization – NM use in the aerospace industry requires compliance with regulatory standards to ensure the reliability and safety of the aircraft, the development of relevant testing and certification protocols is ongoing;

– high cost of NM – they can be expensive to manufacture and integrate into aerospace programs, which can affect the overall cost of aircraft production; balancing benefits and costs is a necessary requirement for manufacturers.

The integration of NM, NC, NS and NF into composite aircraft structures provides a wide range of benefits, ranging from improved mechanical properties and durability to improved temperature management and structural health monitoring. Although challenges exist, continued research and development in this area could reshape the aerospace industry and lead to more efficient, safer, and technologically advanced aircraft.

Decision. There are many problems waiting to be solved. Regarding ensuring the quality of NMs, improvement of their production processes will contribute to their uniform dispersion and controlled inclusion of NMs. Environmental problems related to NM, research and implementation of environmentally friendly materials need to be solved. An effective way of leveling the impact on the environment can be the NC application. In order to solve the problems of regulation of the NM introduction, joint efforts of various branches of production, assistance of scientific and regulatory bodies in the development of standardized testing and certification are required. Wholesale production and large market demand, industry cooperation, and reprocessing of products from NM can help reduce the NM cost. A large volume of supply and demand can significantly reduce the long-term cost. Collaboration using knowledge resources and infrastructure can lead to cost sharing and foster innovation.

Practical significance. The results obtained during the research can be used for a comparative assessment of the state of the Ukrainian aerospace market, determining its advantages and weaknesses. Taking into account factors that positively and negatively affect the world market will provide an opportunity for better integration of the Ukrainian market into the world market. The experience of using nanomaterials and nanotechnologies by other countries can be useful for the development of the aerospace industry.

Limitations of the study. One of the limitations of this study is a certain number of signs of segmentation of the global aerospace market, which can be increased in further research. The implementation of the research results is hindered by the state of war in Ukraine and insufficient attention to the development of the industry by the state and investors. The widespread implementation of research results in the Ukrainian aerospace market is significantly hindered by Russia's war of aggression against Ukraine and insufficient funding of scientific research in the field.

The influence of martial law conditions. In the conditions of martial law, there are significant disruptions in the supply chains of materials and spare parts necessary for the manufacture and maintenance of aircraft.

Prospects for further research. Using the approaches and methods of evaluating the global aerospace market, it is possible to evaluate the Ukrainian aerospace market in the future.

4. Conclusions

The research shows that the aerospace industry is at the forefront of technological innovation and is constantly searching for new advanced materials to improve productivity, efficiency and safety. The global aerospace market was valued at 321.5 billion USD in 2022. It is projected to reach approximately USD 678.2 billion USD by 2032, growing at a CAGR of 7.8 % during the forecast period 2023 to 2032.

In 2022, North America accounted for more than 46 % of market revenue; according to estimates, the Asia-Pacific region will experience the highest average annual growth rates in the period 2023–2032. By vehicle type, in 2022 the commercial aircraft segment held the largest market share – 43.5 %; the aerospace support segment is expected to grow at a CAGR of 8.5 % between 2023 and 2032. In 2022, by vehicle size, the narrow-body aircraft segment accounted for 78.2 % of revenue; the wide-body segment is expected to expand at the fastest CAGR. By end user, the private sector segment had the largest market share of 65.4 %; the public sector segment is expected to expand with the fastest growth. By operations, the manually operated aircraft segment had a share of 68.5 %; the autonomous aircraft segment is expected to grow at the fastest rate.

The main growth factors of the global aerospace market are: commercial aviation, defense needs, space exploration, technological progress, ecological and economical aviation, digital transformation, space tourism, basic maintenance services. The limitations of the global aerospace market are: geopolitical uncertainty and compliance with regulatory requirements; increase in the cost of raw materials, fuel and construction materials; increasing number of cyber-attacks.

According to the segmentation of the global aerospace market by type of vehicle, the leading position in 2023 was occupied by the segment of commercial aircraft with a share of 63.4 %; by the size of the vehicle – the narrow-body aircraft segment (72.4 %); by end consumer – the private sector segment (65.4 %); by operation – segment of manually operated aircraft (79.4 %); by geographic regions – the North American segment (47.3 %). The main strategic trends and directions of further development of the aerospace market are given.

The size of the global market for aerospace materials in 2022 was 38 billion USD. It is expected to grow to 79.42 billion USD in 2032, at a CAGR of 7.7 % from 2023 to 2032. According to the segmentation of the world aerospace market by type of materials, the leading place in 2022 belonged to the segment of composite materials with a share of 69 %; by type of aircraft – segment of commercial aircraft (51 %); by geographical regions – the European segment (35.0 %).

The main trends of sustainable development of the aerospace industry are: improvement of aircraft design, use of sustainable aviation fuel, expansion of urban air mobility, application of modern aircraft movement technology, optimization of air transportation management. They will lead to fundamental changes in the future of the aerospace industry. The ultimate goal of sustainability-driven aerospace innovation is to deliver zero emissions for a safer, cleaner planet.

In the aerospace industry, nanomaterials are widely used, in particular, nanocomposites, nanocoatings, nanofluids, nanosensors, and carbon nanotubes. Their use provides increased strength, rigidity, hardness, wear resistance, thermal stability, thermal conductivity; improvement of electrical properties; ability to self-heal and change surface properties; resistance to corrosion; built into aircraft structures to monitor their condition and ensure the safety of passengers and crew.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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