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The Specifics Of The Development Of Additive Manufacturing Technologies In Russia In The Context Of Globalization: Economic And Technological Aspects

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Abstract

The article examines the number of issues concerning the application of additive manufacturing technologies in modern Russia and its adaptation to modern market conditions. Russia, by launching a special military operation in Ukraine, forced itself to develop under global economic sanctions. The economics of additive manufacturing have been insufficiently studied in Russia. We would say that its study is still in the initial stage, despite the fact that some Western researchers have announced a whole new industrial revolution, which would be the additive manufacturing. (Kuhn, 2011; Schiffler, 2015; D'Aveni, 2015) This is due both to the fact that these technologies are not yet so widespread in Russia and that this problem still attracts the attention of a narrow circle of experts who are mainly technicians. Therefore, the analysis of the effectiveness of additive technologies is carried out using production management techniques instead of modern microeconomics. Hence, we do not have a full understanding of why the spread of additive manufacturing in Russia is not on such a large scale as, e.g. in China or Germany. This study identifies the effectiveness of the implementing additive manufacturing technologies into Russian industrial production on the example of the aircraft industry with the use of a linear market model (microeconomic method). The developments of Russian and foreign experts, as well as the situation in the Russian aircraft industry we have modeled, are taken as the basis for this research. The article mainly uses normative analysis. Authors emphasize that the spread of additive manufacturing technologies within the framework of Russian industrial production is difficult due to the low elasticity of supply and demand. The low elastic supply appears to be the key reason for the difficulties in the innovative development of additive manufacturing in Russia.

Keywords: Additive manufacturing; Aircraft industry of Russia; Industrial product markets; Industry microeconomic analysis; Innovations; Innovative technologies; Marketing

Introduction

Additive manufacturing technologies as a nanotechnological breakthrough

By 2020, the global market of additive manufacturing (AM) amounted to about 12 billion US dollars, while Russia, at the turn of 2019–2020, was on the 11th place in the world in the production and these technologies adoption in the economy. In 2016–2018, AM was remaining for Russia a new direction within the framework of the innovative economy, although the growth of their production and distribution in the Russian national economy was then 25%. This shows that in recent years some segments of the Russian economy AM remained in high demand. But, as is often the case with Russia, innovations, in this case AM, did not go beyond the limits of individual "incubator enterprises".

From 2010 to 2020, the Russian AM market grew 10 times, but, again, this happened because of the significant successful development of individual enterprises. The transition to the spread of AM throughout the economy did not happen during that decade, despite the fact the government understood that the country could not reach the sixth technological paradigm without AM.

The AM market comprises the following segments:

■ 3D printing equipment, or serial manufacturing of machine tools and components;

■ 3D printing materials, or universal powders, including those for critical products;

■ 3D printing software, or a single digital platform for development and production;

■ 3D printing services, i.e. a comprehensive offer of outsourcing products.

The largest leaders in the AM development today are 9 following companies: 3D Systems (USA), EOS GmbH (Germany), SLM Solutions (Germany), Stratasys (USA), Objet Geometries (USA-Israel), EnvisionTEC (USA-Germany (DLP)), ExOne (USA), Voxeljet (Germany), Arcam AB (Sweden). The leading manufacturers of 3D printers are Carbon, Desktop Metal, Formlabs. 87% of all additive manufacturing occurs in both North America and the EU. That is largely due to the registration of manufacturing companies and patents in these regions. The most widely used 3D printing technologies are remaining fused deposition modeling (FDM), selective laser sintering (SLS), stereolithography (SLA).

The Russian 3D printing market has been pursuing the import substitution policy since 2014. As a result, by 2020, home-produced equipment in the AM segment accounted for 42% of the total volume of production facilities used in this segment of the Russian innovative economy. In 2018, materials, equipment and services for the AM segment $69 million, or 4.5 billion rubles worth of materials, equipment and services for the AT segment were bought in 2018 whereas the total volume of innovative products, works and services amounted to 3693061.6 million rubles, or almost $53 billion. This is approximately 9% of all procurement in the innovative segment of the Russian economy, which is a lot, but very little compared to the fact that all innovative goods, works and services were reduced in 2018 to 6% of all goods in transit, works and services. In 2014, this indicator was 8.2%. This shows both the knock-on effect of sanctions on the Russian innovation market and the drop in overall demand for innovative products and services.

30% of AM production belongs to the aerospace industry, i.e. an industry working mainly on government orders (the share of the aerospace industry in the global AT market is 12%). (Morgunov, Saushkin, 2016) Another important feature of the Russian AM segment is that all 3D printers developed by Russian companies cannot be used to print critical parts and assemblies. This makes the AM market in Russia highly dependent on imports. However, after 2018, Russian companies carried out a series of developments aimed at creating industrial 3D printers. As for SLM printing for metal powders, it is worth highlighting such developers as JSK Laser Systems, Moscow Center of Laser Technologies LLC (Moscow State Technical University), 3DSLA.RU, TSNIITMASH (JSC Atomenergomash); as for laser surfacing (DMD), The Institute of Laser and Welding Technologies STU and Moscow Center of Laser Technologies LLC. Other Russian companies are also working on AM technologies.

Among the industrial plastics/composites printing units, the leading printers are polymer sand printers created by Total Z LLC and 3D printers for the construction industry developed by the Delovoy Profil LLC. A great achievement by 2020 was the creation in Russia of a 3D printer for the construction industry ("Spetsavia", Apis Cor). However, desktop printers occupy the largest part of the AT market in Russia, in which over 30 companies operate.

At the end of 2019, there were 9 model AM centers in Russia, which all were classed as an industrial grade. According to experts, Russia will need to create 188 AM centers by 2030, 140 of them must be of industrial grade. But by December 2020 the less than a quarter of this has been done. Thus, additive manufacturing in Russia is in its infancy period.

AM is the process of joining materials in order to make objects from 3D model data, in particular, using a 3D printer. AM technologies make it possible to quickly design and reproduce objects which, produced with conventional production methods, are highly labor-intensive. The fundamental difference between additive systems and standard manufacturing methods is that in AM, the material that constitutes the part is deposited layer by layer. In the additive process, a product is created by laying down the successive layers of material along the contour of an object, while the outdated manufacturing methods imply the removal of an extra part of the workpiece. Therefore, additive systems do not require any drawings or pre-developed standard technologies that are impossible or very difficult to change, no patter equipment and casting are also required.

An important advantage of AM is the reduction of production costs, but so far there is no set opinion among researchers about how much AM reduces it. Practice shows that the percentage varies depending on a particular enterprise. One of the reasons for this is that the production of casting molds and stamping dies using outdated production modes is not the same for all types of manufacturing. It is believed that AM can reduce production expenses by up to 90%. According to the calculations of Rosatom experts, AM will reduce the cost of standard parts by up to 85%, but this is only a predicted value. To date, the experts from Rosatom have defined the following parameters for reducing the cost of producing standard parts.

Table 1- Comparison of standard parts of a nuclear fuel assembly using traditional technologies and AM technologies. Based on: “Additive Technologies in the aircraft industry” by Rusatom–Additive Technology LLC, an industry integrator of the Rosatom State Corporation.

Product	The cost of the product produced with traditional processes, rub.	The cost of the product produced with AM, rub.	The cost impact of the AM use determined by the amount of the items, rub.
Top nozzle grid	30,000	28,000	1,200,000
Support grid	25,000	22,000	1,800,000
Anti-debris filter (ADF)	90,000	45,000	48,600,000
Anti-debris filter (ADF)	30,000	15,000	13,200,000

For more complex solutions, Rosatom experts achieved greater cost benefits of incorporating additive manufacturing. For example, the optimization of the WWER-1000 core baffle (a typical unit of a nuclear reactor) through the use of AM resulted in the cost reduction of this unit from 160 million rubles to 80 million. This happened mainly due to a decrease in the workpiece mass from 75 tons to 35.1 tons. Also, the time for the production of the WWER-1000 was reduced by 70%[1]. In addition, the reactor cooling system has also been improved[2].

What is more innovative—the proposal to solve issues in the construction industry with the inclusion of AM tools. However, the scale of cost savings with the introduction of AM depends on the specific project, since "the cost of printing one cubic meter of a finished building structure will vary depending on numerous factors, such as the configuration and thickness of the wall, the brand and composition of the mortar mix used. So the calculation of the exact value is only based on a specific construction project". (Bronova, Nemova, 2021) A significant factor in reducing construction costs when using AM is the total phase-out of permanent formworks. (Bronova, Nemova, 2021) The printed structure also facilitates the installation of utility systems, reducing labor costs in construction. (Bronova, Nemova, 2021) In general, due to the reduction in the duration of construction when using AM technologies, labor savings are as high as 45-55%, material savings reach 25-30%, and overhead costs reduce up to 20-25%. (Bronova, Nemova, 2021) Thus, the cost savings from implementing AM in the construction field, as we can see, is slightly less than those of core baffle for the VVER-1000 nuclear reactor. Nevertheless, the economic benefits in both cases are quite high. In addition, AM technologies are better than traditional ones in terms of solving problems in the construction field, such as issues of occupational safety and dependency on weather. Additionally, the AM technologies reduce the likelihood of errors in the building design. Nevertheless, in Russia, the use of AM technologies in construction is still in the experimental stage, whereas in the West the transition from experimental designs to standardized construction is already happening.

Additive technology is cost-effective for those industries where the production costs per kg are high, so AM systems are widely used primarily in high-tech industries. 3D printing is worthwhile for small batch production in the automotive industry. AM is also widely used in the aerospace industry to create parts of complex design that require a lot of time for testing and manufacturing.

In medicine, additive technologies are now often implemented into the manufacturing of complex geometry parts. Often there is no alternative to the latter. The manufacturing of complex geometry parts from special materials, which is not possible when using conventional processes, and can be achieved only with the inclusion of AM.

Based on the data from a survey of 114 stakeholders responsible for decisions regarding 3D printing for production parts conducted in 2019 by Dimensional Research, sponsored by Essentium, among the main problems of the industry were high cost of technologies and materials, lack of scalability of current technology and printed parts being unreliable. Even in Western experts note that the adoption of AT is associated with high technology costs. And according to the result of the survey conducted by Dimensional Research, 42% of respondents identified this problem as the main one on the path of investment in AM[3].

Another difficulty arising from the adoption of AM is the limited run production.

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[1] Additive Technologies in the Aircraft Industry. M.: "Rusatom – Additive Technology" LLC, is an industry integrator of the Rosatom State Corporation. Retrieved from: https://helirussia.ru/wp-content/uploads/2020/09/1.Prezentatsiya-Helirussia-2020-Rosatom (accessed: 04/29/2022)

[2] Additive Technologies in the Aircraft Industry. M.: "Rusatom – Additive Technology" LLC, is an industry integrator of the Rosatom State Corporation. Retrieved from: https://helirussia.ru/wp-content/uploads/2020/09/1.Prezentatsiya-Helirussia-2020-Rosatom (accessed: 04/29/2022)

[3] Essentium's latest survey: what is the future of industrial 3D printing? Retrieved from: https://www.3dnatives.com/en/essentium-190320195 (accessed: 04/29/2022)

AM technologies are not suitable for traditional conveyor production in general. In Russia, cost reduction strategies of organizations which implemented AM, from the point of view of logistics, were developed relatively recently, by the beginning of 2020. (Khaimovich et al., 2020) For companies adopting AM, it is important to ensure regular capacity utilization to reduce machine and personnel idle time.

It is also necessary to consider an important feature of the AM adoption, which is mentioned in the article written by Y.A. Morgunov: "According to available data, only about 19% of additive manufacturing products companies use as the final product". (Morgunov, Saushkin, 2016) This is because there is the need to exclude residual porosity. (Morgunov, Saushkin, 2016)

A great risk to the Russian AM market is that the production of metal powders for additive manufacturing is not yet so developed in our country, because metal powders have been imported massively for long time. The first powder production was recently established at The NRC "Kurchatov Institute" - VIAM in Moscow. But the risk is associated with the fact that the production base for metal powder AM turned out to be narrow.

To sustain production through the use of AM at the level of 2017–2018 Russia needs about 5.5-6 tons of metal powders[4]. Russia has already achieved such production volumes of metal powders, but the issue of increasing demand outstripping supply in the future remains open.

Speaking about the production potential of AM in Russia, it is also worth mentioning that there have not been optimal starting conditions for Russian companies in recent times, and this affects the current situation. For example, by 2018 Russia had around 2,000 units of industrial 3D systems, which accounted for approximately 2% of the global fleet of such equipment[5].

It is also necessary to consider the national specifics of the need for AM technologies in a particular economy. In the EU countries, special factors caused the need for complex devices created by AM machines. For example, because of the strict aircraft CO2 emissions standards, the EU aircraft manufacturers have faced the need to reduce the maximum aircraft weight[6].

Evaluation of the effectiveness of additive manufacturing: basic methods

Modern assessments of the effectiveness of AM are mainly based on production management techniques. The latter are based partly on expert observations. Common algorithms for determining the effectiveness of AM are: As the criteria for the technology effectiveness for the aircraft production technologies, researchers use the ratio $\Delta\mu/\Delta W$ (1) and the preference rule − ratio → max − at $R \geq [R0]$ and $W \leq [W0]$, where $\Delta\mu =$ ◌(γ ,v, ◌̧) expresses the utility function; q is payload; v is the cruising speed; R is the operating life; ΔW is life-cycle cost and [R0], [W0] is the life-cycle constraints and life-cycle cost, respectively. (Sirotkin, 2015)

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[4] The main trends of the Russian metal powders market for additive technologies. Additive technologies. 2022. №1. Retrieved from: https://additiv-tech.ru/publications/osnovnye-tendencii-rossiyskogo-rynka-metallicheskih-poroshkov-dlya-additivnyh (accessed: 04/29/2022)

[5] Kubanova A.N. Materials of JSC POLEMA for industrial applications in additive manufacturing. Retrieved from: https://aviatp.ru/files/aviaevents-2019/MAKS/Polema.pdf (accessed: 04/29/2022)

[6] Printing the future: Airbus expands its applications of the revolutionary additive layer manufacturing process. Retrieved from: http://www.aviationworldnews.com/news/printing-the-future-airbus-expands-its-applications-of-the-revolutionary-additive-layer-manufacturing-process-37604; https://www.airbus.com/en/newsroom/news/2016-06-airbus-tests-high-tech-concepts-with-an-innovative-3d-printed-mini-aircraft (accessed: 04/29/2022)

The above algorithm is too industry-specific and simplified. In this regard, it is worth referring to the conceptual ideas of Professor Y. A. Morgunov: "the choice of the best option is made according to two criteria: comparative economic efficiency estimated ratio R_e or the estimated payback period of the $P_{e.}$ The preference rule is expressed by inequalities $R_e > R_n$, $P_e < P_n$, where the index "n" corresponds to the normative value of the corresponding criterion. When finding these criteria, it is necessary to calculate the difference between total shop costs in the transition from the first option to the second:

$(\Delta C = C_1 - C_2)$: $\Delta C = \Delta C_m + \Delta C_s + \Delta C_d + \Delta C_e + \Delta C_t + \Delta C_b + \Delta C_{am} + \Delta C_t + \Delta C_{pm} + \Delta C_{ap}$,

where ΔC_m the –difference in the cost of raw materials for the compared options; ΔC_s is the difference in the amount of salaries of production workers with accruals; ΔC_d is the difference in the cost of depreciation and repair of equipment; ΔC_e is the difference in the cost of equipment with regrinding; ΔC_t is the difference in the cost of machine tools and instrumentation; ΔC_b is the difference in the cost of operation and depreciation of buildings; ΔC_{am} is the difference in the cost of auxiliary materials; ΔC_t is the difference in the cost of technological energy; ΔC_{pm} is the difference in the cost of production processes management; ΔC_{ap} is the cost of assembling the components of the product through the use of AM technology (as one part). (Morgunov, Saushkin, 2016)

According to the calculations of Y.A. Morgunov, the creating of a sleeve part through the use of AM requires one hour of working time. Instead, through the use of traditional technologies, it takes approximately 20-40 hours. (Morgunov, Saushkin, 2016) In addition, Y.A. Morgunov also takes into account the saving of materials by reducing the volume of waste. But at the same time, Y.A. Morgunov admits that the machining time is individual for each product. (Morgunov, Saushkin, 2016) However, the data from Rosatom's research and announcements from Russian construction still speak in favor of reducing production costs by 40-50% through the use of AM, but without depreciation.

According to Y.A. Morgunov, it is the high depreciation costs that are a brake upon the development of AM: "The main disadvantage of the layered synthesis of products of spatially complex shape is the relatively large amount of machine processing time. This leads to a high share of depreciation costs in the costing of equipment. Taking into account equipment's high cost (according to different estimates from 0.3 up to 1 million euros, depending on the manufacturer, sizes, options, delivery conditions, etc.), this budget item sometimes becomes a decisive factor. So, according to the data, the share of depreciation costs of a machine tool the machine in some cases can reach 70% of the product cost. But, again, Y.A. Morgunov gives 70% of the product cost as a separate example, but the general tendency of the depreciation impact, albeit hypothetically, on the formation of cost in large segments of industry which have already implemented AM or are going to implement it, is not elaborated.

Hypothetical understanding of the economic benefits of the AM implementation (on the industry level)

The Russian economy has entered a period of forced import substitution. Particularly, this applies to the heavy engineering sector. One of the most complex industries in Russia is aviation, as in 2019 Russia suffered another decline in aircraft production, which was directly related to rising imports of aviation equipment to Russia. Russia exported many aircraft and helicopters before the crisis associated with the coronavirus pandemic. Today, this means that Russia will reorient most of its aviation exports to the home market. At the same time, Russian airlines are also losing access to many imported aircraft.

We are building our logical model on the basis of microeconomics methods with respect to the above-mentioned process of Russian aviation market restructuring, in order to understand how AM technologies can affect the aviation equipment market, in terms reducing prices and, accordingly, sales volumes. We are making an important assumption—aviation products will be sold on the home market at the Russian import prices, because Russia cannot produce high-level equipment at prices lower than imports today. Another important assumption is that we take the 2019 years as a basis of this research. 2019 is the year preceding the coronavirus pandemic. Thus, we assume that in terms of consumption of aviation equipment after the pandemic recession, Russian air carriers will slightly exceed the level of 2019 in 2023 and following years. But there are reasons to expect that consumption will significantly surpass the production rate of 2019.

Determining the average equilibrium price presents considerable difficulty. In our case, we are limiting ourselves to building a model with the cost of an Airbus aircraft, since the samples of this company's models remained dominant on the Russian air carrier market for many years. The problem is that the prices for new and overhauled aircraft are quite different in the Russian market. In addition, in Russia and other countries airplanes are not mass-produced goods, such as motorcycles, and they are purchased individually under separately concluded contracts or in small batches. Again, the Russian market was saturated with imported aircraft that had a long operating life and underwent major repairs, which also influenced the formation of prices in the market. And those prices changed frequently depending not on demand, but on the characteristics of the aircraft available at that time. But it is possible to determine the price, which, one way or another, can be considered as a kind of basic cost for the Russian market of commercial airliners.

We take as a basis the cost of the most popular in Russia and in the world commercial aircraft, Airbus A320, which costed approximately 101 million US dollars during the coronavirus crisis and shortly before it. However, this is the price of a completely new aircraft. Russia's commercial aviation fleet urgently needs renewal, thus there is a tendency of purchasing new aircraft. However, had there been no global economic sanctions, Russian air carriers could slow down the pace of updating the aircraft fleet, continuing to prefer models with a considerable flight hours rate. Nevertheless, it is difficult to buy the Airbus A320 of old modifications today, due to the physical wear of these aircraft models, as well as changes in their fuel economy for the worse, compared with the models that appeared after 2016. It is likely that, in the absence of sanctions, Russian airlines would prefer to buy the Airbus A320neo built in 2017 at a price of 48.15 million US dollars[7]. That is the cost of this airliner before the beginning of the coronavirus crisis. This is a small price for a fairly popular aircraft in the world, compared to the Irkut MC-21 developed by the Yakovlev Design Bureau, the catalog price of which is 96.4 million US dollars. It is planned that this aircraft will enter the market at a price of approximately 48.2 million US dollars[8]. In terms of its technical characteristics, the MC-21 is similar to the A320neo. From here, we can take 48.2 million US dollars as the cost of a commercial airliner in a time of sanctions pressure during spring of 2022 in Russia. Of course, older models of aircraft cost less, but keep in mind that if demand for aircraft in Russia reaches the level of at least 2019, prices will rise to the level of the new MC-21 or A320neo as they are almost identical even if the

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[7] Current prices for civil aircraft. Retrieved from: https://aeronautica.online/prices/current-aircraft-prices-mba-2017 (accessed: 04/29/2022)

[8] Barsky R.How much does a new passenger airplane cost? Science and Technology https://naukatehnika.com/skolko-stoit-novyj-passazhirskij-samolet.htmlnaukatehnika.com (accessed: 04/29/2022)

sanctions pressure will continue. There is no other way considering that the resources expenditure for launching a series of new MC-21 models will impact the production of older models. We cannot expect a radical capacity expansion of the Russian civil aircraft industry in the foreseeable future.

The Russian aviation production reached its peak in 2019—Russia manufactured 150 aircraft and helicopters. That was largely the result of foreign demand. Meanwhile, the production of commercial airliners in 2019 amounted to 30 units. Thus, we can take the 2019 production rate as an indicator of the maximum capability of the Russian civil aviation industry, referring also the fact that the state support measures for aviation companies developed in 2019 stated the goal to produce 154 aircraft and helicopters in 2024.[9] Nevertheless, the production of equipment for commercial use remains auxiliary in the Russian aviation industry. The aviation companies mainly fulfill defense orders, so the Russian aviation manufacturers' offer elasticity is less than 1, and no longer depends on the market price, instead it depends on the supply of components and the speed of mastering their production technology directly in Russia. Let's assume that in a time of sanctions pressure on the Russian economy, the supply elasticity of Russian aircraft manufacturing companies should be approximately 0.1. We will accept this indicator as an important assumption of the model for the convenience of calculations.

In 2019, the supply of all aviation equipment in the Russian Federation in real terms was 631 units. It is difficult to predict the volume of imports of aviation equipment to Russia because of global sanctions and restructuring of the entire Russian economy. In 2019, Russia imported 106 airliners. Due to the shortage of foreign-made spare parts, Russia is actively mastering the production technology of the Tu-214. By 2030, it is planned to produce 70 aircraft of this model, that is, on average, 9 aircraft produced per year. However, in 2022, it is expected to make four MC-21. However, we assume that four MC-21 is the maximum annual production of this model in times of sanctions pressure. Let's focus on the figure of nine Tu-214 aircraft and four MC-21 per year as relatively realistic. Thus, the increase in the production of airliners will not be so significant to radically affect the production structure and the distribution of production capacity between types of aircraft and the cost of these products in Russia.

Recall that 154 aircraft is as much as the Russian aviation industry, according to plans, may produce in the most favorable conditions. Until 2022, a significant part of Russian-made aviation equipment was exported. In 2019, the average export price per unit of Russian-made aviation equipment was 31,964.7 US dollars[10]. We suppose that under severe sanctions against the Russian Federation, the export price during 2019 will be as close as possible to the prices on the home market in the 2020s. This gives us a reason to take the export price of $31,964.7 US dollars per aviation product unit as a base cost for our model. For convenience, we will round up our base cost to $32,000. The same cost per unit of Russian export products as the base cost in our model is relevant for calculating the price elasticity of demand for the Russian market, and this is fair, given that the Russian aviation industry has been firmly embedded within the global market pricing system since the 2000s.

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9 Analysis of the Russian aircraft industry in 2015-2019, forecast for 2020-2024. Retrieved from: https://businesstat.ru/images/demo/aircraft_industry_russia_demo_businesstat (accessed: 04/29/2022)

[10] Analysis of the Russian aircraft industry in 2015-2019, forecast for 2020-2024. // https://businesstat.ru/images/demo/aircraft_industry_russia_demo_businesstat (accessed: 04/29/2022)

One of the reasons for which was the import of a large number of components, replacement of which with home production should cost the same or higher (note that the catalog price of the MC-21 slightly differs from the cost of the A320neo on the Russian market). One of the factors why domestic prices for aviation products in the Russian Federation turned out to be close or even almost identical to prices on the global market is that in the 2010s various resources of Russian aircraft manufacturers were directed to the production of helicopters and aircraft models that were in high demand abroad, and all this happened amid the shortage of capacity and personnel in the aviation industry itself.

To determine the price elasticity of demand for our model, we take as a basis the changes in the export price and the volume of supply (or consumption) of Russian aviation products before the coronavirus crisis.

Table 2 - Dynamics of the main indicators of the aviation market in Russia. Based on: Analysis of the aircraft industry in Russia in 2015-2019, forecast for 2020-2024

The volume of aviation equipment for sale in Russia, calculated as the sum of the stocks of aviation equipment at the beginning of the year, as well as aviation equipment that was home-produced and imported into the country during the year	2016	2017	2018	2019
Export price, thousand dollars per unit	12363.3	13579.8	77084.3	31964.7
Percentage of export dynamics compared to the previous year	-4.0	9.8	467.6	-58.5
Supply (consumption) in Russia, number of items	376	462	695	631
Supply (consumption) in Russia, %	21.3	22.9	50.4	-9.2
Price elasticity of demand (E_d), rounded value, calculated using an online calculator: https://www.calculatoratoz.com/ru/price-elasticruy-of-demand-calculator/Calc-109 ?FormulaId=109	-5.33	2.34	0.18	0.158

The low elasticity of demand for aviation products in Russia before sanctions against Russia tightened after the escalation of the Ukrainian political crisis is associated with the increase in the shortage of aircraft in Russia after 2010, while the demand for air transportation grew steadily after 2000. In 2019, the price elasticity of demand for goods in the aviation equipment market was still much higher than in 2016 and slightly higher than the supply elasticity of commercial aircraft products.

Recall that the maximum estimated volume of aircraft production is 154 units[11]. So we multiply it by 31,964.7 US dollars (recall,

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[11] Analysis of the Russian aircraft industry in 2015-2019, forecast for 2020-2024. // https://businesstat.ru/images/demo/aircraft_industry_russia_demo_businesstat (accessed: 04/29/2022)

this is the export price in 2019). Since the aircraft cannot be produced entirely through the use of AM technologies, our maximum estimated contribution of AM to the production of all aircraft products is 20% of the annual output, which must be expected in a period of forced import substitution. We base our estimate on the data given in the previous section.

Considering that implementing AM technologies can reduce the cost of large parts, modules and assemblies of aircraft by half (see estimates of reducing the production cost with the use of AM technologies above), then reduction in the cost of aircraft and helicopter should reach 10% (based on the data that 20% of all used aircraft components manufactured through the use of AM). Further, we assume that the reduction in the market price of airplanes and helicopters will be proportional to the reduction in cost price, which is possible when there is a trend of increased state regulation of the commercial aviation.

The coefficients of absolute elasticity for supply and demand are constant values with linear dependence. Accordingly, we proceed from the well-known microeconomic formula using elasticity coefficients to construct a linear equation of the market:

$$E_d = -b\frac{P^*}{Q^*}; \qquad E_s = d\frac{P^*}{Q^*}$$

The linear demand function [12]takes the final form:

$$-0{,}158 = -b\frac{32000}{631} = -50{,}72b\ ;\ b = \frac{0.158}{50.72} = 0{,}03;$$

$$631 = a - 0{,}003 * 32\,000 = 631 + 96 = 727;$$

$$Q_s = 727 + 0{,}003P;$$

For clarity, we have focused on the price of $.32,000 thousand per unit, not $32 million. According to the supply function, our calculation algorithm has the following pattern and result:

$$631 = c + 0{,}002 * 32\,000 = c + 64\ ;\ c631 - 64 = 567;$$

$$Q_s = 567 + 0{,}002P;$$

Now let's move on to the climax of our research: how can a change in the supply price caused by the AM implementation benefit the Russian aviation industry? The optimistic scenario is a 10% reduction in cost price. We also assume that Russia may reach the manufacturing of over 600 aircraft and helicopters in a short time. If we include in this figure the increasing number of overhauls of home and foreign-made equipment in this indicator, this is a completely feasible task. Accordingly, we assume that the market value will decrease proportionally to the cost price. Hence, it turns out that the new price of a unit should be $28,800.

We proceed from the basic provision of economic theory that $Q_d = Q_s$. In our model, $Q_s = 567 + 0.002P$, where, with an optimistic prediction for the application of AM, P = 28,800 thousand dollars, hence in this case $Q_s = 624.6$, we round up to 625 items. By analogy, $Q_d = 727 – 0.003P = 640.6$, rounded up to 641 items. Most likely, with state support (especially subsidies), the Russian aviation industry will produce 641 aircraft given the reduction in prices through the use of AM. We should note here that we mentioned a hypothetical and optimistic forecast. Without AM, Russian air carriers will receive, based on the indicators of 2019, 631 items of aviation equipment. Thus, the use of AM at this level of development of AM technologies in Russia can provide an increase in the production of aircraft and helicopters by 10 units. Recall that we

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[12] The standard form of the linear demand equations is Qd = a – b × P , the standard from of the linear supply equation is Qs = a + bP.

considered the overhauls of aviation equipment, which also requires the manufacture of new complex parts, modules and assemblies.

Conclusion

The development and application of AM in Russia is still in its initial state, but, according to our analysis, the adoption of AM can have little impact on the Russian aviation equipment market in the country, manufacturing rates and the level of demand. The reason for this lies not in the AM itself, but in the production base of the aviation industry and the demand for airplanes and helicopters in our country. Supply and demand are slightly elastic, but this situation developed even before the coronavirus crisis.

On the one hand, we are handling a shortage of new and overhauled old aircraft. On the other hand, we see an insufficiently developed production base for commercial aviation. This causes limited economic benefits from the application of innovations in heavy engineering. And we are sure that this situation has developed not only in the Russian aviation industry but also in other fields. Of course, we must consider that the spread of any technology in any industry is limited, and AM technologies will never completely displace traditional technologies.

It is easy to notice in the course of our analysis the following detail—the prices of the Russian new aircraft are still lower than the market prices of aircraft produced by Western aviation companies, because prices of home-produced aircraft strongly depended on the average cost of used imported aircraft, as well as on the prices of Russian helicopters supplied to the markets of third world countries. This is another significant factor that deter Russian companies from implementing AM technologies, as well as other innovations in their production processes. Obviously, as follows from our analysis, the long-term economic benefits of the AM introduction in the aviation industry are still insignificant.

An important conclusion from this work is that the manufacturing for the market with low elasticity of both demand and supply contains high risks for implementing innovations. As for the Russian aviation industry, a relatively weak level of development of production capacities causes this. Potential reserves here can be both the release of additional capacities due to the refusal of individual foreign consumers to purchase Russian equipment in times of economic sanctions and the refusal to produce outdated models of both commercial and military aircraft. However, even in this case, the economic and financial effect of AM implementation into the Russian aircraft industry will still be limited.

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