ТРАНСПОРТНЫЕ СИСТЕМЫ
2.9.1 – Транспортные и транспортно-технологические системы страны, ее регионов и городов, организация производства на транспорте;
2.9.4. – Управление процессами перевозок;
2.9.6 – Аэронавигация и эксплуатация авиационной техники;
2.9.8 – Интеллектуальные транспортные системы

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Aviation industry technological sovereignty optimization problem formulation

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Abstract: The aviation industry faces the difficult task of maintaining and further increasing the population air mobility at the present stage of domestic air transport and country economy development. It is fixed in the Comprehensive Program for Russian Federation Aviation Industry Development until 2030 (as amended by Decree of Russian Federation Government No. 1102-r dated May 4, 2024). There is an urgent need to develop and introduce domestic production components into aircraft type design in the context of the cessation of interaction between Russian aviation enterprises and foreign suppliers of goods and services. These actions make it possible to ensure industrial technological sovereignty and further operation of aviation equipment with the required levels of reliability and safety. The article presents a flowchart of this process developed by the authors. The flowchart considers possible types of import substitution of components. The authors performed a comparative analysis of the forecast of fleet retirement and commissioning of newly developed aviation equipment based on the available statistical data on the operation of short-haul aircraft. The need for the development of sectoral corrective measures is shown based on its results. This fact confirms the relevance of the chosen research area. The process of integration of Russian-made components into the aircraft structure is considered from the point of view of program management in the publication. The authors describe the basic principles and methods of prioritizing projects using the example of 10 components. This considers the total budget of the program, as well as its resource intensity. The optimization task is formulated in the publication based on the results of the work performed. This publication is the main one for the further development of an algorithm that will allow solving priority tasks of continued airworthiness of both the fleet in operation and newly developed aircraft.

Key words: aircraft operation, aviation, component, project, program, planning, prioritization.

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Формулировка задачи оптимизации в рамках реализации технологического суверенитета авиационной отрасли

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Аннотация: На современном этапе развития отечественного воздушного транспорта и экономики страны в целом перед авиационной отраслью стоит непростая задача поддержания и дальнейшего роста авиамобильности населения. Это зафиксировано в Комплексной программе развития авиационной отрасли Российской Федерации до 2030 года (в редакции распоряжения Правительства Российской Федерации от 4 мая 2024 года № 1102-р). В условиях прекращения взаимодействия российских авиационных предприятий с иностранными компаниями – поставщиками товаров и услуг существует острая необходимость разработки и внедрения в типовую конструкцию воздушных судов комплектующих изделий отечественного производства. Данные мероприятия позволяют обеспечить отраслевой технологический суверенитет и дальнейшую эксплуатацию авиационной техники с требуемыми уровнями надежности и безопасности. В публикации представлена разработанная авторами блок-схема данного процесса с учетом возможных типов импортозамещения комплектующих изделий. На основании доступных статистических данных эксплуатации ближнемагистральных воздушных судов авторами выполнен сравнительный анализ прогноза выбытия флота и ввода в эксплуатацию вновь разрабатываемой авиационной техники. По его результатам показана необходимость разработки отраслевых корректирующих мероприятий. Данный факт подтверждает актуальность области выбранного исследования. Процесс внедрения комплектующих изделий российского производства в типовую конструкцию эксплуатируемого воздушного судна рассматривается в публикации с точки зрения программного управления. Авторы приводят описание основных принципов и методик приоритизации проектов на примере 10 комплектующих изделий. При этом учитывается суммарный бюджет программы, а также ее ресурсоемкость. По результатам выполненных работ в публикации формулируется задача оптимизации. Данная публикация является основой для дальнейшей разработки алгоритма, который позволит решать приоритетные задачи поддержания летной годности как находящегося в эксплуатации флота, так и вновь разрабатываемой авиационной техники.

Ключевые слова: эксплуатация воздушных судов, авиация, комплектующее изделие, проект, программа, планирование, приоритизация.

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Introduction

Transport connexity of the country is the primary objective of its aircraft field. Sanctions imposed by foreign companies in February 2022 have drastically changed its development environment and priorities. Interaction in terms of aircraft components supply and maintenance was ceased.

Immediate governmental support measures have allowed to preserve the aircraft fleet and infrastructure. Comprehensive Program for Russian Federation Aviation Industry Development until 2030 objective is to ensure the air transport connexity of the regions, mobility of the citizens and the necessary flight safety level, along with technological sovereignty within the air transportation industry. The number of aircraft necessary for fleet update and replenishment, the optimal classification, supply scopes and periods are chosen, periods of domestic production components production are scheduled, full range of domestic aircraft maintenance is formed and sanctions negative effects are reduced, including foreign made aircraft supply, maintenance and leasing in order to preserve air service competitive market.

Figure 1 shows the forecast data on domestic production aircraft supply according to Appendix 2 for Comprehensive Program for Russian Federation Aviation Industry Development (as amended by Decree of Russian Federation Government No. 1102-r dated May 4, 2024).

Russian manufacturers are currently facing the urgent challenge of developing the mechanisms providing the ongoing aircraft operation by the domestic airlines and maintaining high flight safety level [1, 2]. Measures on foreign aircraft maintenance on the territory of the Russian Federation along with their certain type design modification and substitute domestic domestically produced components implication, which are going or have already gone through testing for new domestic production aircraft under development, were initiated [3].

Research methods and methodology

Making a list of priority components [4, 5] is a primary objective in corrective actions projects. Trade-off fleet retirement analysis is conducted for aircraft in operation on condition of taking or not taking the above mentioned measures. Accuracy and basing on real statistics, not on forecasts or assumptions [6] are principal benefits of this technique.

"ПРИЛОЖЕНИЕ № 2
к комплексной программе развития
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Российской Федерации до 2030 года
(в редакции распоряжения
Правительства Российской Федерации
от 4 мая 2024 г. № 1102-р)

ПРОГНОЗНЫЕ ПОКАЗАТЕЛИ

поставок авиационной техники отечественного производства по годам

Тип воздушного судна	Вместимость, человек	2022 год	2023 год	2024 год	2025 год	2026 год	2027 год	2028 год	2029 год	2030 год	Всего, единиц
Самолеты:											
SSJ-NEW	98 - 103	-	-	-	-	30	28	28	28	28	142
МС-21-310	181 - 211	-	-	-	9	31	36	50	72	72	270
Ил-114-300	64 - 68	-	-	-	-	3	12	12	12	12	51
Ту-214	150 - 215	1	1	1	4	7	17	28	28	28	115
Ил-96-300	237 - 300	1	1	-	2	1	2	2	3	2	14
ТВРС-44 "Ладога"	44	-	-	-	-	-	-	35	35	35	105
"Освей" (ЛМС-192)	15 - 19	-	-	-	-	-	20	46	46	46	158
"Байкал" (ЛМС-901)	9	-	-	-	5	25	25	25	25	34	139
Итого		2	2	1	20	97	140	226	249	257	994

Fig. 1. Supply forecast of domestic aircraft
(headlines downwards: Appendix 2 for Comprehensive Program for Russian Federation Aviation Industry Development (as amended by Decree of Russian Federation Government No. 1102-r dated May 4, 2024). Supply forecast of domestic production aircraft arranged by the years.
Table header, left to right: aircraft type, seat capacity (by number of people), 2022-2030, a total of units. Aircraft, downwards: SSJ-NEW, Yakovlev MC-21-310, Ilyushin Il-114-300, Tupolev Tu-214, Ilyushin-96-300, TVRS-44 Ladoga, UZGA LMS-901 Baikal Total

There is a number of aircraft in operation by years provided not taking any measures in terms of component technological sovereignty shown in continuous line in Figure 2. At the same time the dashed diagram area shows the aircraft number in case of domestic production components application. Graph in Figure 3 shows that these measures are mostly efficient up to 2029, as the retirement due to lifetime is the reason of further decrease in number of aircraft in operation.

The monthly schedule of putting new Russian-made aircraft into operation is unknown. We assume that they are transferred to airlines annually in December. Thus, the schedules for the retirement of the aircraft fleet and the ones newly developed and put into operation appear like shown in Figure 4.

Trade-off analysis shows that even if new aircraft are put into operation, their retirement is so quick that the total number of aircraft in operation is significantly reduced. Under these circumstances, transition to cannibalism is natural one or more units of equipment are selected in order to ensure spare parts for its remaining units [7].

When performing the analysis in this study, the possibility of cannibalization, as well as repair or maintenance of foreign components at a Russian industry enterprise, is not taken into account. Each component is considered independently, assuming that components do not influence each other.

All of the above proves the need to build a global mathematical model and then form a mathematical optimization problem based on it. At the same time, it is quite difficult to give an exhaustive representation of it taking into account all existing internal connections of objects, as well as the impact of external factors. Based on [8], in such a case, it is usually necessary to

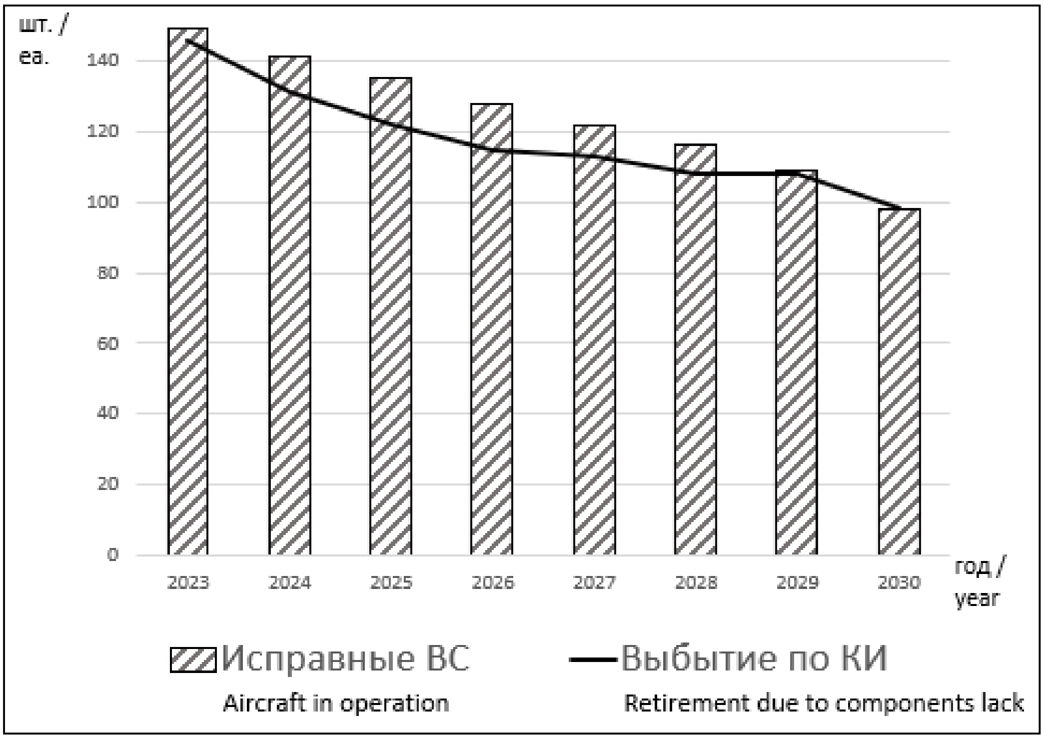

Fig. 2. Aircraft fleet retirement schedule considering the retirement due to components lack

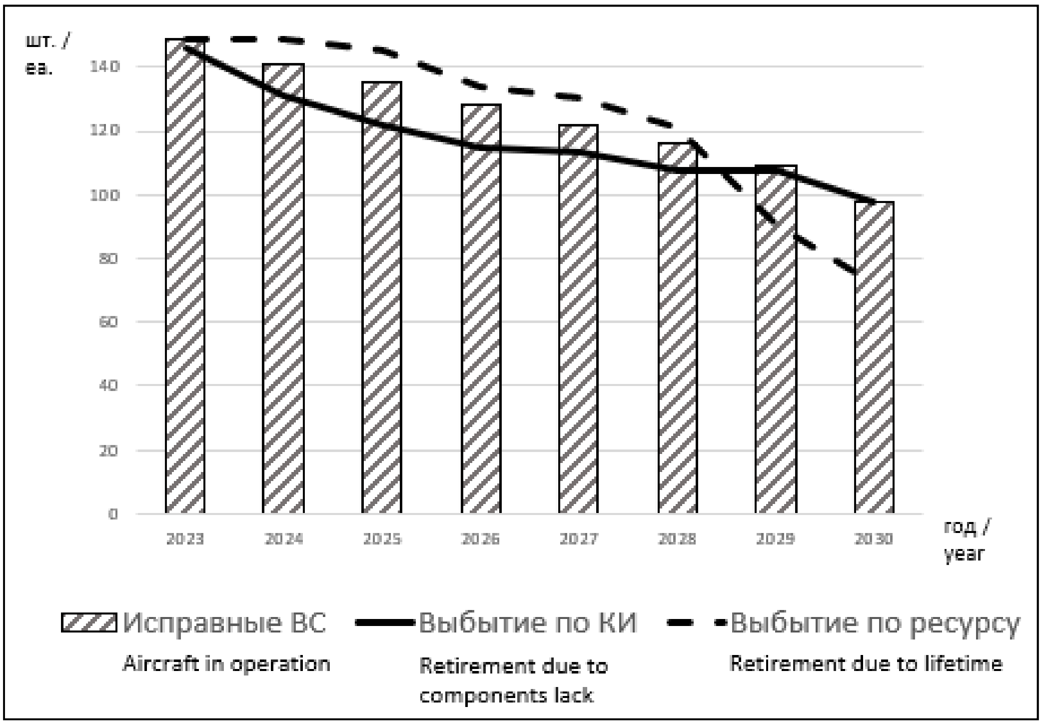

Fig. 3. Aircraft fleet retirement schedule considering the retirement due to lifetime

identify and take into account only the most important aspects of the object under study in order to make its mathematical description possible, as well as the subsequent solution of the problem, while unaccounted factors should not significantly affect the final result of optimization.

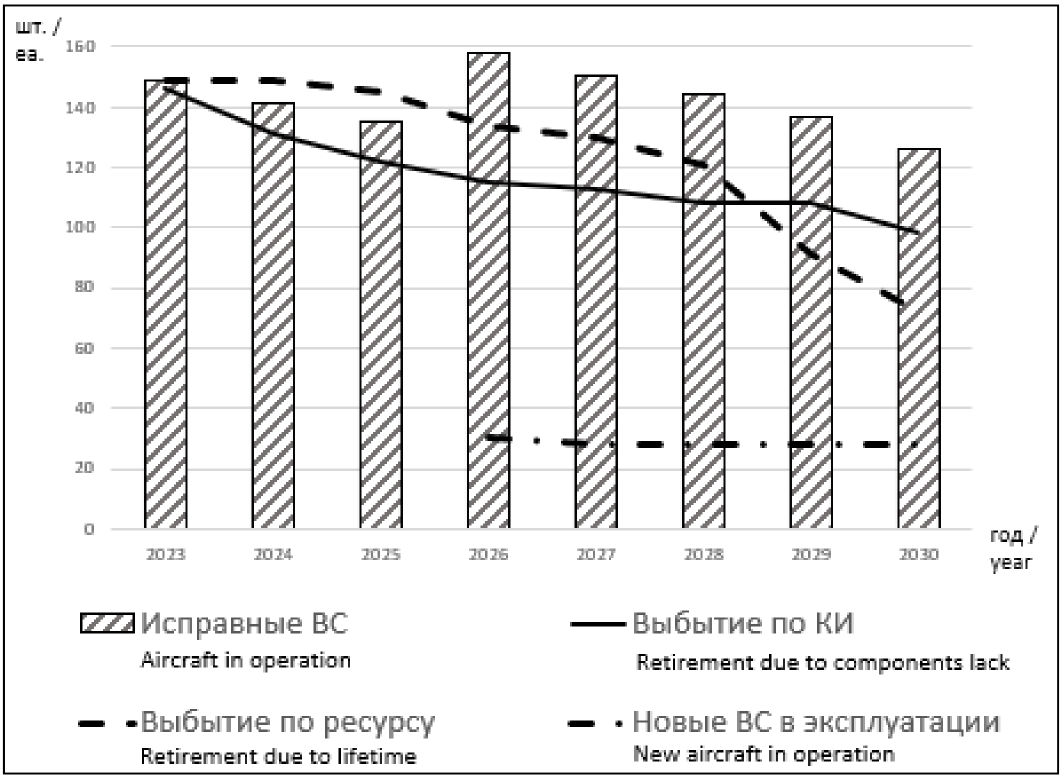

Fig. 4. Aircraft in operation number changes schedule

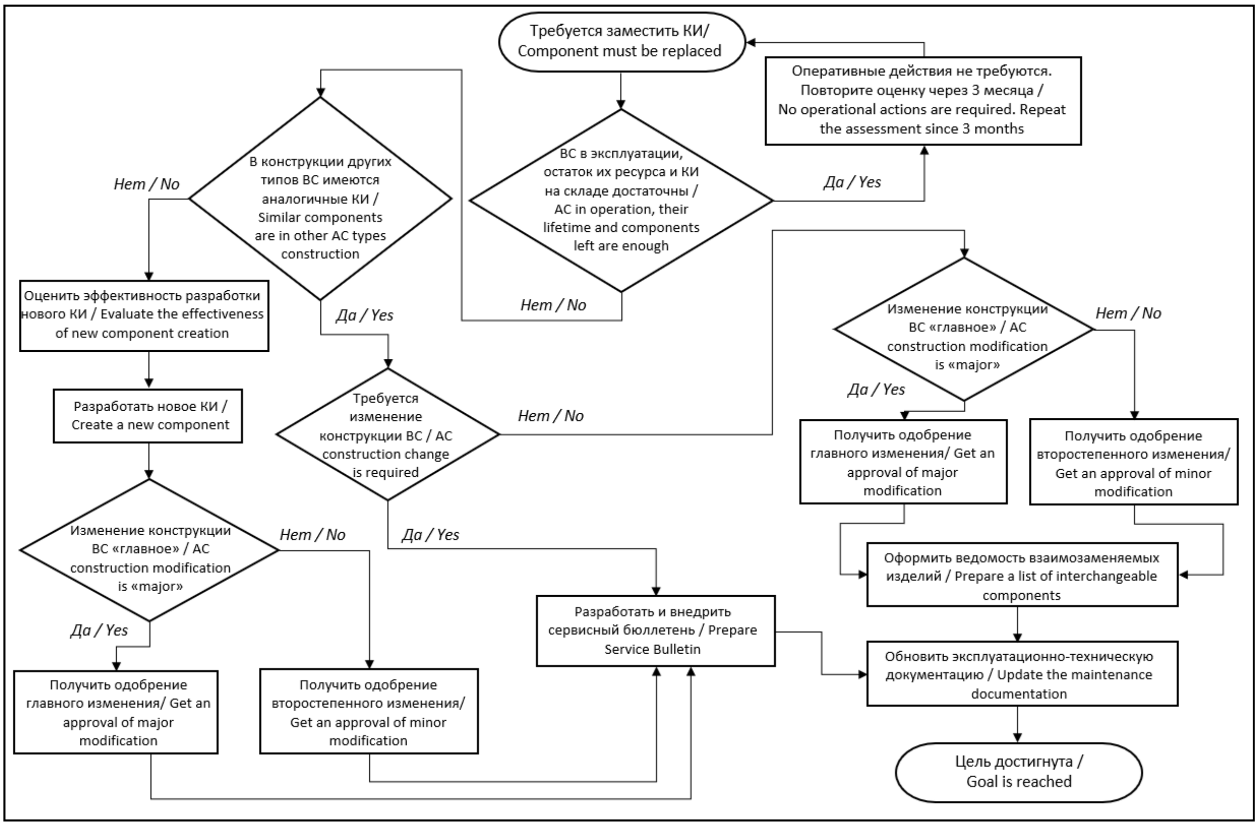

Fig. 5. Process of technological sovereignty ensuring flowchart

This study presents a flowchart developed by the authors for the process of ensuring technological sovereignty, where the input is the emerging need for import substitution of components on the aircraft in operation. This diagram is used to detail the process and also displays the sequence of operations required to be performed.

Figure 5 shows that in order to introduce an alternative domestic product into a standard aircraft design, it is necessary to perform a sequence of actions typical for the process approach [9].

Thus, it is advisable to consider the activities to ensure the technological sovereignty of the aircraft fleet in operation as a set of projects. In this case, each of the changes introduced into the standard aircraft design can be taken as a separate project [10]. At the same time, they all compete for both financial and organizational resources of the aircraft developer, industry production enterprises and certification centers. Consequently, the introduction of domestic production components into the standard aircraft design is a program, the management of which allows for the maximum effect of the import phase-out process [11].

To ensure the most efficient operation of aircraft, it is necessary that their number in the fleet were as large as possible [12]. This paper does not consider the process of putting new aircraft into operation, as it does not depend on ensuring the technological sovereignty of the industry. It is believed that it does not have a significant impact on the disposal of aircraft currently in operation.

Achieving the maximum possible number of aircraft in the fleet is possible in the event of the implementation of the projects of the highest priority [13]. This problem is solved in within the framework of program management [14].

It is known that the highest priority is given to those projects that have a greater effect and lower costs [15]. At the same time, to ensure technological sovereignty, it is necessary to implement projects in parallel [16].

In this study, the absence of synergy is assumed: the influence of the effect of previously completed projects of the program on subsequent projects. At the same time, the effect of completed projects does not increase the budget of the program as a whole [17].

Taking V_i as the priority of the *i*-th project, the total priority of a program that includes n projects can be written as

$$SUM = V_1P_1 + V_2P_2 + ... + V_nP_n; \quad (1)$$

where the variables P_i take the value 1 if the project is implemented, and the value 0 if the project is postponed.

For further formulation of the optimization problem, *SUM* is taken as the objective function. Thus, the optimization problem in implementing technological sovereignty of the aviation industry can be formulated as follows.

$$SUM \rightarrow max. \quad (2)$$

The constraints in this case are:

– the total budget of the implemented projects for the introduction of domestic production components into the type design of aircraft in operation, in this program:

$$C_1P_1 + C_2P_2 + ... + C_nP_n \leq C; \quad (3)$$

– program resource intensity:

$$L_1P_1 + L_2P_2 + ... + L_nP_n \leq L. \quad (4)$$

The program for ensuring technological sovereignty of the aviation industry assumes a phased implementation [18]. In this case, the launch of at least one project in terms of introducing Russian made components into a standard aircraft design, subject to sufficient budget and resources, partially restored after the completion of a previously launched project, is the next stage of the program. In this case, the restrictions on C_i and L_i, given above, change at each subsequent stage.

For the subsequent formation of a list of priority components, it is necessary to take into account data in the form of the number of foreign-made components remaining in warehouses, as well as data on their reliability and assessment of their failures in operation. At the same time, the process of import substitution of components should ensure the safe operation of aviation equipment with a given level of flight regularity.

The required parameter V_i, which allows to form and sort the list of the most critical components, is calculated as follows:

$$V_i = \left(T_i - \frac{S_i}{U_i}\right). \quad (5)$$

Here T_i is the period of time during which it is necessary to ensure the operation of the aircraft due to the components stock available in the warehouse. As shown above in Figure 3, these measures will be effective within the next 72 months. Therefore, within the framework of this study, we take the value of T_i equal to 72 months. Also here is S_i the remainder of serviceable components in warehouses, U_i is the current components consumption in operation per unit of time.

The parameter U_i is determined based on the number of components of one type installed on the aircraft, the planned fleet of aircraft and its planned flight time, as well as the statistics of failures and reliability indicators of components (MTBUR):

$$U_i = \frac{n_i \cdot P_i \cdot F_i}{MTBUR_i}. \quad (6)$$

Here n_i is the number of certain type components installed on one aircraft, P_i is the planned number of aircraft in the operating fleet (according to the 2023 data presented in Figure 2, this parameter takes the value of 149), F_i is the flight hours per aircraft, $MTBUR_i$ is the Mean Time Between Unscheduled Removals.

Research results

The list of 987 components, mostly influencing further aircraft fleet operation was formed and prioritized according to the trade-off analysis conducted. The necessary solutions on each component were classified in accordance with the process block scheme in Figure 5 in the following way:

- foreign-made components replacement for the equivalent certified domestic production one without any extra development necessity;
- foreign-made components replacement for the equivalent certified domestic production one with the necessity of aircraft structure development;
- a brand-new Russian-made component development with its implementation into the aircraft structure.

987 projects by the number of selected and prioritized components were considered within the program of aviation technological sovereignty. The results of the research are presented below in ten entries.

Table 1 shows that sensor with the parameter V = 71 months is the most crucial in terms of technological sovereignty ensuring. In other words, in given period of 72 months stocking with current aircraft fleet flight experience will be enough for 1 month.

Project resource intensity, duration and cost directly depends on technical solution according to block-scheme of technological sovereignty ensuring process. Table 2 data are received for the 10 components considered.

The following optimization restrictions are adopted in this research:

- the project summary budget C is 1000000 rub.;
- program resource intensity L is 100%.

First-stage restrictions according to project priority:

$$87\,823 \cdot 1 + 0 + 0 + 0 + 0 + 131\,594 \cdot 1 + 0 + 0 + 766\,373 \cdot 1 + 0 \leq 1000000; \quad (7)$$
$$15\% \cdot 1 + 0 + 0 + 0 + 0 + 20\% \cdot 1 + 0 + 0 + 60\% \cdot 1 + 0 \leq 100\%. \quad (8)$$

Project delivery stages may be presented by Gant diagram [19].

Project delivery in 12 months is shown in Figure 6. It is shown that resource release takes

Table 1

Components prioritized list

№	**Name**	**S, stock balance, ea (each)**	**MTBUR**	**Quantity per aircraft, ea (each)**	**Component consumption, ea (each)/month**	**V, month**
1	Sensor	2	11 077	1	2.06	71.0
2	Valve	4	12 378	2	3.68	70.9
3	Pump	5	49 071	3	1.39	68.4
4	Gate	9	32 714	2	1.39	65.5
5	Board	7	22 900	1	0.99	65.0
6	Antenna	76	11 644	3	5.87	59.0
7	Alarm system	21	127 221	5	0.90	48.5
8	Fan	8	149 902	2	0.30	45.7
9	Module	26	26 378	1	0.86	41.9
10	Computer	13	57 249	1	0.40	39.3

Table 2

Technical solutions

№	**Name**	**Technical solution type**	**Duration, month**	**Resource intensity, %**	**Price, rub.**	**Price per 1 month, rub.**
1	Sensor	Without any extra development	2	15	175 645	87 823
2	Valve	Without any extra development	2	15	202 587	101 294
3	Pump	Extra development	6	20	675 999	112667
4	Gate	Extra development	6	20	543 897	90 650
5	Board	Extra development	6	20	890 654	148 442
6	Antenna	Extra development	6	20	789 566	131 594
7	Alarm system	Extra development	6	20	1 065 066	177 511
8	Fan	Extra development	6	20	589 678	98 280
9	Module	Development of a brand-new component	36	60	27 589 432	766 373
10	Computer	Development of a brand-new component	36	60	31 654 389	879 289

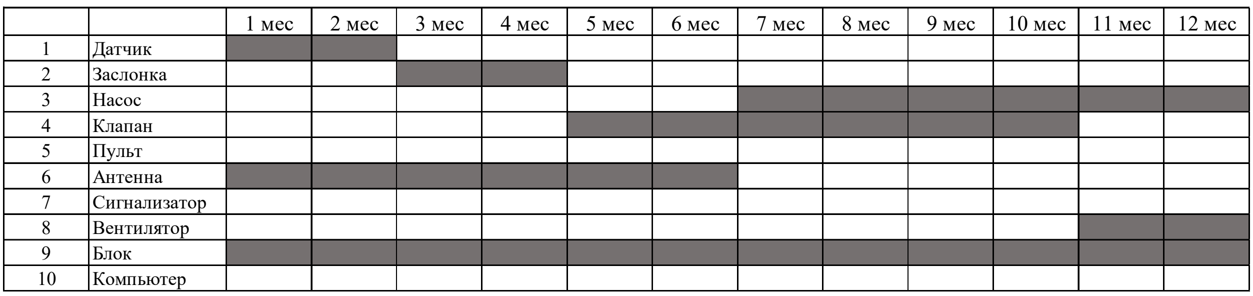

Fig. 6. Implementation stage within program framework (downwards: sensor, valve, pump, gate, board, antenna, alarm system, fan, module, computer; Table header, left to right: months from 1 to 12)

place after each project maturation. At the same time the budget for the period is saved for the next stage [20]. This allows to start the further project delivery in accordance with their priority on the second stage of the program [21].

Results discussion and conclusion

Research showed that aviation industry technological sovereignty ensuring in terms of components is relevant nowadays. It is necessary to reduce aircraft retirement due to lack of components, by using their maximum number in operation.

To achieve this goal, the authors proposed to use the basic principles of software control. With their help, the optimization problem was formulated in the work. Calculations performed on the example of 10 components showed a satisfactory result. In further research, to solve the problem with modern software, it is proposed to build an algorithm.

The results of this work can be used by both design bureau employees and maintenance and repair organizations to create an effective strategy for continued airworthiness of the fleet. They allow you to form plans for the development of components, their purchases and deliveries, taking into account the needs of operating organizations.

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