Mech. Adv. Technol. Vol. 5, No. 3, 2021, pp. 275–281

DOI: 10.20535/2521-1943.2021.5.3. 244795

UDC 658.012

The methodology of aggregative evaluation of aircraft cooperative production project efficiency

S.G. Kryvova[1] • A.M. Rudko[2] • O.E. Zubanyov[2] • S.I. Trubachev[1]

Received: 29 September 2021 / Accepted: 24 November 2021

Background. *Evaluation of effectiveness of cooperative aircraft production project is part of the earliest stages of the project life cycle – its "initiation", when the business need is determined and comparative analysis of future costs and expected benefits is carried out. In sectoral practice a variety of methods for assessing the costs of individual stages of the aircraft creation process are widely used. The comprehensive assessment of costs of cooperative production, taking into account the various indices of its localization among part- ners, is absent. At the same time, for the domestic aircraft industry this is an actual task.*

Objective. *To develop a methodology for assessing the basic indices of a cooperative aircraft production project.*

Methods. *The object of the study was the selected model of cooperative production of a light transport aircraft. An integrated assessment of the key indices of the project was carried out, taking into account the different degrees of its localization among cooperants. Based on the results of analytical review, carried out by the authors using multidimensional mathematical and statistical methods for data analysis, an updated parametric method for complex cost estimation has been developed.*

Results. *It is shown that the general trend in the development of the world aviation industry is the cooperation. Its main directions are considered. On the example of the "Project for the establishment of cooperative production of a light transport aircraft" the various options for participation of cooperant and approximate volume of his work in the total cost of the aircraft is simulated. The nature of the influence of the volume of work performed by cooperant on the values of the aircraft cost, fixed costs and project risks is determined.*

Conclusions. *The most general and actual for domestic aircraft production method of large-scale assessment of efficiency of the cooperative aircraft production project is proposed, including the model of cooperative production scheme choosing, which allows to determine such its dependencies at the earliest stage of the project, which permits to present more reasonably future expenses and possible benefits of cooperation project participants.*

Keywords: *cooperative production; evaluation of aircraft cooperative production project efficiency.*

Introduction

Projects in science-intensive industries branches, to which the aircraft construction is concern, require significant amounts of funding due to long-term costly research and development works, and are characterized by a high level of risk. An effective approach to the costs reducing, risk sharing, as well as the possibility of additional market coverage, is the evaluation of usage of various options for cooperative production of aircraft.

✉ *S. G. Kryvova*
skrivova@ukr.net

✉ *A.E. Zubanyov*
zubanevsashka@gmail.com

[1] *Igor Sikorsky Kyiv Polytechnic Institute, Kyiv, Ukraine*

[2] *"Ukrainian Research Institute of Aviation Technology" JSC, Kyiv, Ukraine*

Problem statement

In order to determine the optimal conditions for cooperative production, the cooperants must decide the following fundamental questions: "who should carry out the final assembly of the aircraft?", "who should design the aircraft components?", "who should produce the aircraft components?" and decide regarding the option of distribution cooperative work scope (in other words, with equity participation in the cooperation) between the cooperants. To develop these issues, the authors analyzed the dependences of key parameters of the project (aircraft cost, investment, risks, terms of total investment) on the scope of cooperation works.

Traditional forms of international cooperation in aviation industry

The expansion of international cooperation in the aviation industry is stipulated by the proper trends in the world aviation industry development, namely [1–2]:

1. By globalization of production. The amount of outsourcing in the aviation industry may be about 80 % and above. An illustrative example is the project of a modern wide-body passenger aircraft Boeing-787 Dreamliner building, in which more than 90 % of total production work was outsourced.

2. By globalization of development, which involve the design processes displacement closer to production and potential trade areas and which has a positive effect on reducing the time of entry of the final product into the market.

3. By transferring of base of aircraft after-sales service (maintenance, current repairs, overhaul) from original equipment manufacturers ("Airbus", "Boeing", "Rolls-Royce", etc.) to the suppliers.

4. By using of offset operations in the purchase of imported products, which provides the submission of counter-requirements regarding the investment of a definite amount from the contract amount into the economy of the buyer's country. Common forms of offset operations in the aviation branch: organization of joint production in the buyer's country, licensed production on the buyer's country territory, organization of production of component parts on the buyer's country territory without rights and full technical documentation transfer, organization of scientific-research and development activity on the territory of the buyer's country, the organization of training of personnel of the buyer's country, the purchase of the final product of the buyer's country production. One example of such offset agreement is the military-technical contract for cooperation between the USA and India, under which the USA supplied India with 10 units of Boeing C-17 Globemaster III strategic military-transport aircraft worth US$4.1 billion in 2013–2015 and at that 30 % of the contract value was invested by the United States in the Indian aviation industry.

In general, it may be distinguished the following forms of international cooperation in the aviation industry [3]:

1. Partnership with risk sharing based on the creation of joint (cooperative) production of aircraft, as well as on integration of scientific-research, technological, material and financial resources of partner companies. The production of component parts of the final product of enterprise is distributed in accordance with the technical specialization. A modern example of such a cooperation scheme is the 4 ++ generation KAI-KF-X multipurpose fighter program, led by South Korea and Indonesia. At that, the program is funded by public funds of South Korea (60 %), public funds of Indonesia (20 %) and funds of investor partners (20 %).

2. Cooperation on the basis of contractual cooperation with enterprises-suppliers of component parts. At that, it is accepted to allocate the various levels of suppliers: suppliers of original equipment – they are carrying out the delivery of large components of aircraft, provide the final assembly of a product and delivery of a product to the consumer; first level suppliers – provide supply/assembly of the main sections of aircraft (including engines, avionics, chassis); second level suppliers – supply complex production products; suppliers of the third level – supply special components, raw materials, materials [2]. For example, the program of construction of the above-mentioned Boeing-787 Dreamliner provided for the involvement of more than 15 companies-suppliers of original equipment and suppliers of the first level ("Boeing", "GE", "Fuji", "Mitsubishi", "Kawasaki", "Rolls-Royce", "Saab", etc.).

3. Participation in joint research and innovation programs in the aviation industry, which involves the cooperation of enterprises and research institutions of different countries to conduct research based on the relevant specialization. An example is the "CleanSky" international program (part of the "HORIZON" framework program with a funding of about 80 billion Euros), the main purpose of which is to promote innovation and technology to reduce emissions and noise in civil aviation. Effective example of participation of Ukrainian representatives in the "CleanSky–2" program (2014–2020) may be the experience of scientists of M. Zhukovsky Kharkiv National Aerospace University, (KHAI), whose project to develop a technology for radical reduction of nitrogen oxides in aircraft gas turbine engines in 2019 received a grant for further experimental research [4].

Another example of cooperation expanding is the Brazilian company Embraer, which in the production of passenger aircraft series Embraer 170/190 (produced since 2003) cooperates with 16 partners and 22 suppliers [5–7]. For comparison, (see Table 1), in the production of ERJ 145 series aircraft it is involved 4 partners and 350 suppliers [7]. This scheme of cooperation, combined with other factors, permits to reduce the production cycle of the first aircraft from 8 months (for ERJ 145) to 6.5 months (for Embraer 170/190). The share of aircraft production work, performed by risk-sharing partners, is 36% and includes the following:

– 60 % of equipment (engines, avionics, air conditioning systems);

– 34 % of metal structures (wing and tail);

– 4 % of electrical components (cables, wires and systems) and mechanical systems (brakes, chassis);

– 2 % of materials (aluminium, titanium, cellar, carbon fibers).

Risk-sharing partners include Kawasaki Heavy Industries (Japan), C&D Interiors (USA), Sonaca (Belgium), Pilkington Optronics (England), General Electric (USA), Honeywell (USA), Gamesa (Spain), Hamilton Sundstrand (USA), Latecoere (France), Liebher (Germany) [7].

It should also be noted that one of the trends is that "today" the general contractor (lead developer) reduces the number of suppliers with which it interacts directly (usually

Table 1. Comparative table of ERJ 145 and Embraer 170/190 production projects [5–7]

	ERJ 145 	**Embraer 170/190** 
Passenger capacity (seats)	50	70/118
Year of manufacture beginning	1996	2003
Built units (aircraft)	123	1,596
Number of risk-sharing partners	**4**	**16**
Number of suppliers interacting with the general contractor	**350**	**22**
Development terms (months)	60	38
Production cycle of the first aircraft (months)	8	6.5

suppliers of 2–4 levels), by transferring this function to risk-sharing partners (usually suppliers of 1 level).

Summarizing the abovementioned, it should be noted that the choice of cooperation schemes (Fig. 1) and determining of value of the main indices of cooperative production is an urgent task, including for the aviation industry of Ukraine, as it has accumulated significant experience in cooperative production and development. For example, the production of An-140 aircraft in cooperation with HESA (Iran), An-148/158 aircraft in cooperation with Russia, etc.

On the example of a light cargo aircraft, typical in its parameters for the aircraft industry of Ukraine, the assessment of key parameters (indices) of aircraft cooperative production under different volumes of equity participation of K_2 cooperant in joint production is carried out.

Analysis of dependencies of main indices of the Project for the creation of joint (cooperative) production of aircraft

Creation of joint (cooperative) production of the aircraft is relevant in the following cases:

– firstly, when the Developer and Manufacturer of the aircraft want to diversify the cost of aircraft creation and reduce the cycle of its production;

– secondly, when the Developer and Manufacturer of the aircraft is approached by a potential investor-stakeholder who is interested in acceptable conditions for him to participate in the production (and designing in the future) of a particular model of aircraft.

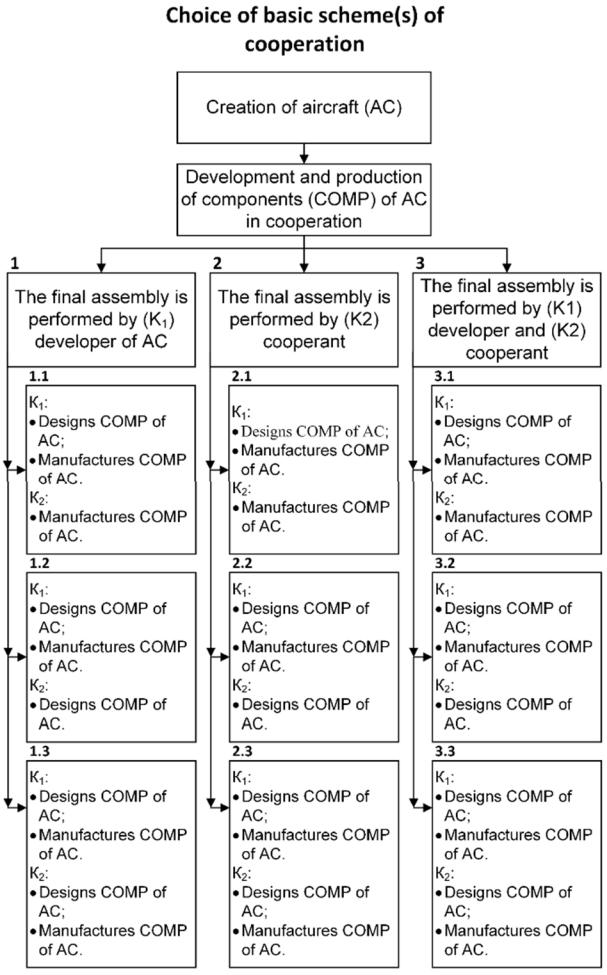

Fig. 1. Variants of schemes of cooperation production (CP) arrangement

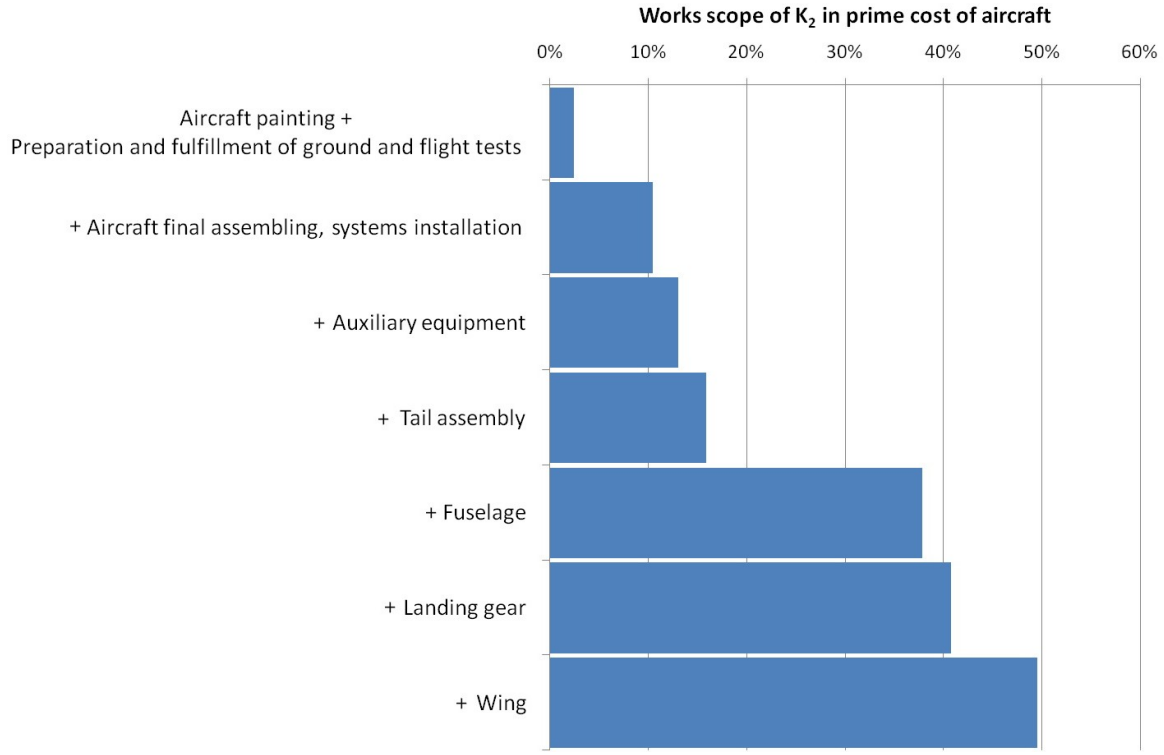

Fig. 2. Options for possible equity participation of K_2 in cooperative production

On the example of the "Project for the creation of joint (cooperative) production of light cargo aircraft" let us consider the second case, as it generally absorbs the first, and analyze the key technical and economic indices of the project.

As the output parameters of the project we accept the following:

– object of cooperation – a light cargo aircraft with an empty weight of 17 tons, payload of 9 tons, engines – two turboprop;

– planned production program – 50 aircraft in 10 years;

– the aircraft is designed and manufactured by K_1 cooperant;

– cooperant K_2 has no aircraft production capacities, but it has a runway.

Let us to model several variants of cooperative works scopes for the K_2 cooperant (see Fig. 2):

– option "1" – execution of final works (application

– of paint and varnish on the aircraft, preparation and fulfillment of ground and flight tests);

– option "2" – implementation of the full cycle of work on the aircraft manufacture.

Values mentioned below are for guidance only and are used to demonstrate the nature of dependencies, because more accurate values require the consideration of more quantity of parameters and features of specific project.

The organization of work under option "1" requires an investment of ≈31 million USD, and the prime cost of the aircraft from K2 cooperant will increase by ≈2% compared to K1 cooperant (see Fig. 3). Under condition of production profitability at the level of 5…10 %, the payback of the project can be achieved by 11…21 aircraft (see Fig. 4).

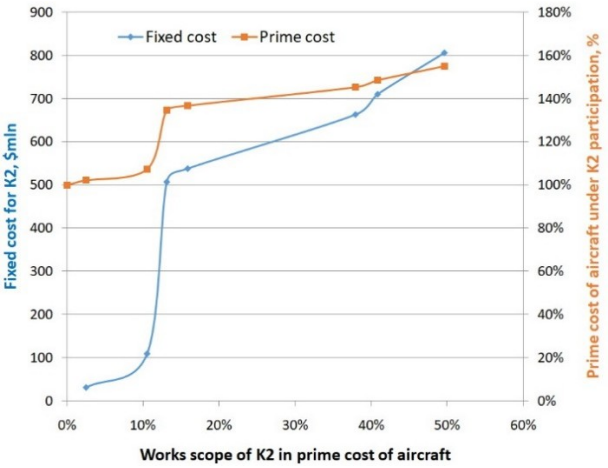

Fig. 3. The nature of the dependence of fixed costs value and prime cost of aircraft manufactured by K_2 cooperant

The work organization under option "2" requires an investment of ≈800 million US dollars, and the prime cost of the aircraft from K_2 cooperant will increase more than 1.5 times compared to K_1 cooperant (see Fig. 3). Under condition of production profitability at the level of 5…10 %,

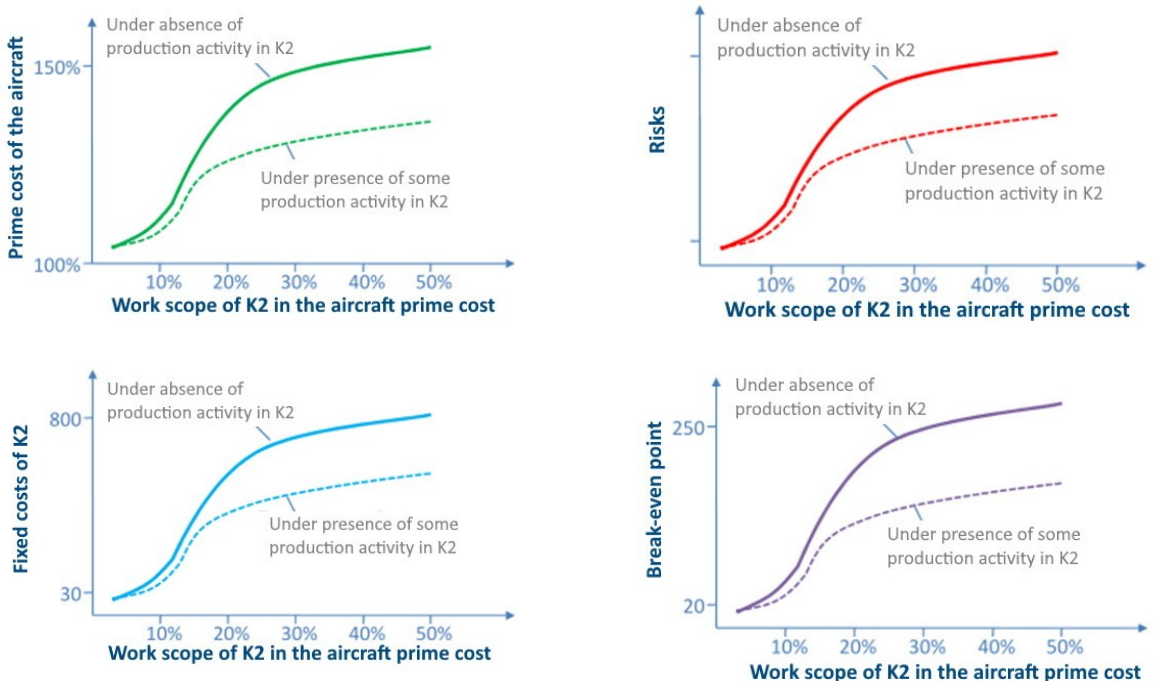

Fig. 4. The nature of impact of scope of work performed by the K_2 cooperant on the value of prime cost of aircraft, fixed costs, risks, break-even point

the payback of the project can be achieved not earlier than after 250 aircraft (see Fig. 4).

Thus, it is possible to state that under increase of scope of localized works the following take place for the K_2 cooperant:

– the prime cost of the aircraft manufactured by K_2 cooperant (see Fig. 3, 4) increases in comparison with K_1 cooperant (see Fig. 3, 4);

– the amount of investment (fixed costs) increases, but not in proportion to the program of aircraft production from K_2 cooperant (see Fig. 3, 4);

– risks increase in proportion to the volume of investments (see Fig. 4);

– the payback of the project decreases (break-even point increases, shifts to the right) due to increased investment (fixed costs), but increases with increasing program of aircraft production in K_2 (see Fig. 4).

It should be noted separately the impact of aircraft production program on fixed costs (aircraft development and production preparation costs) and prime cost of aircraft. So, doubling the production program (from 50 to 100 aircraft) will increase fixed costs by ≈10% and reduce prime cost by ≈10% (see Fig. 3). Subsequent doubling of the production program (up to 200 aircraft) will increase fixed costs by ≈20% and reduce prime cost of aircraft by ≈20%. Further doubling of the production program (up to 400 aircraft) will no longer have such effect on prime cost reduction (reduction by ≈25%) due to significant increase in fixed costs (by ≈35%). Figure 5 illustrates that the first "turning point" with the maximum economic effect of the aircraft production project in K_2 cooperant can be achieved with the production of at least 200 aircraft. This, for example, is confirmed by open source publications regarding minimum cost-effective program for the production of 190… 210 of A400M - aircraft. The described result is the economies of scale.

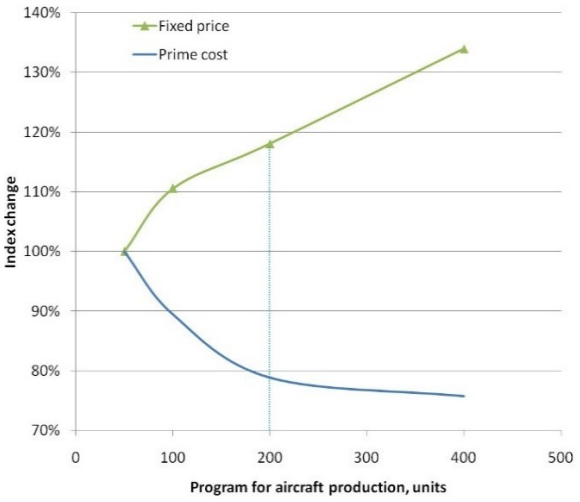

Fig. 5. The nature of impact of aircraft production program on the value of prime cost of aircraft and fixed costs

Conclusions

The method of estimation of basic technical and economic indices, which has been tested on an example of a separate task - the cooperative production of the light cargo aircraft, is offered.

The example of a light cargo aircraft illustrates the increase in the total cost of aircraft under condition of K_2 cooperant involvement. In this case, the payback period also increases (break-even point become estranged).

Thus, the involvement of a subcontractor K_2 cooperant is appropriate in the case when it is combined with the "additional" market for aircraft. Or it is ready to enter into a cooperation project with its investments knowing in advance that the payback of the project may be unattainable or far removed, and the main goal is to acquire competencies in this area of production. Combinations of these conditions are also possible – deferral of profit obtaining due to the acquisition of relevant competencies.

References

[1] D. Mocenco, "Supply Chain Features of the Aerospace Industry Particular Case Airbus and Boeing," *Scientific Bulletin - Economic Sciences*, University of Pitesti, vol. 14(2), pp. 17–25, 2015.

[2] A.C. Rosello, H.-J. Steenhuis, "Offset agreements in Aerospace", in *Proc. of the IAMOT*, 2018, Aston University, Birmingham, UK.

[3] A.I. Pogorletskiy *et al.*, *International business. Theory and practice: Textbook for bachelors*. A.I. Pogorletskiy and S.F. Sutyrin Ed., Moscow: Publishing house Yurayt, 2017.

[4] S.G. Krivova and V.M. Shulepov, "Regarding the optimization of procedures for participation in international research programs in field of aircraft production", *Technological systems*, No. 88/3, pp. 85–91, 2019. DOI: https://doi.org/10.29010/88.12

[5] J.E. Cassiolato, R. Bernardes and H. Lasteres, *Innovation Systems in the South: a case study of Embraer in Brazil. Paper prepared for UNCTAD-DITE investment policy and capacity-building branch*. New York and Geneva, United Nations, 2002.

[6] Paulo S. Figueiredo, S. Gutenberg, R. Sbragia, "Risk Sharing Partnerships with Suppliers: The Case of EMBRAER Risk Sharing Partnerships with Suppliers: The Case of EMBRAER Parcerias de Risco com Fornecedores: O Caso da EMBRAER", *Journal of Technology Management and Innovation*, Vol. 3, Issue 1, pp. 27–37, 2008.

Укрупненная методика оценки эффективности проекта кооперационного производства самолетов

С.Г. Кривова, А.Н. Рудько, А.Е. Зубанев, С.И. Трубачев

Проблематика. *Вопросы оценки эффективности проекта кооперационного производства самолетов входят в состав самых ранних стадий жизненного цикла проекта – его "инициации", когда определяется бизнес – потребность и выполняется сравнительный анализ будущих затрат и ожидаемых выгод. В отраслевой практике широко используются разнообразные методики оценки затрат отдельных стадий процесса создания самолета. Комплексная оценка затрат кооперационного производства, с учетом различных показателей его локализации у партнеров – отсутствует. В тоже время для отечественного авиастроения, это является актуальной задачей.*

Цель. *Разработать методику оценки базовых показателей проекта кооперационного производства самолета.*

Методика реализации. *Объектом исследования являлась выбранная модель кооперационного производства легкого транспортного самолета. Была выполнена укрупненная оценка ключевых показателей проекта. По результатам аналитического обзора, выполненного авторами, с использованием многомерных математико-статистических методов анализа данных разработан актуализированный параметрический метод комплексной оценки затрат.*

Результаты. *Показано, что общей тенденцией развития мировой авиационной промышленности является кооперация. Рассмотрены ее основные направления. На примере "Проекта создания кооперационного производства легкого транспортного самолета" смоделированы различные варианты участия кооперанта и ориентировочные объемы его работ в общей себестоимости самолета. Определен характер влияния объемов работ, выполняемых кооперантом, на величины себестоимости самолета, постоянных затрат, рисков проекта.*

Выводы. *Предложена наиболее общая актуальная для отечественного авиастроения методика укрупненной оценки эффективности проекта кооперационного производства самолета, включающая: модель выбора схемы кооперационного производства, позволяющая на самой ранней стадии проекта определить его зависимости, позволяющие более обоснованно представлять будущие затраты и возможные выгоды участников кооперационного проекта.*

Ключевые слова: *кооперационное производство; оценка эффективности кооперационного производства самолета.*

Укрупнена методика оцінки ефективності проекту кооперaційного виробництва літаків

С.Г. Кривова, А.М. Рудько, О.Є. Зубаньов, С.І. Трубачев

Проблематика. *Питання оцінки ефективності проекту кооперaційного виробництва літаків входять до складу ранніх стадій життєвого циклу проекту – його "ініціації", коли визначається бізнес – потреба та виконується загальний аналіз майбутніх витрат та очікуваних вигід. У галузевій практиці широко використовуються різноманітні методики оцінки витрат окремих стадій процесу створення літака. Комплексна оцінка витрат кооперaційного виробництва з урахуванням різних показників його локалізації у партнерів – відсутня. В той же час для вітчизняного авіабудування це є актуальним завданням.*
Мета. *Розробити методику оцінки базових показників проекту кооперaційного виробництва літака.*
Методика реалізації. *Об'єктом дослідження обрана модель кооперaційного виробництва легкого транспортного літака. Була виконана оцінка ключових показників проекту. За результатами аналітичного огляду, виконаного авторами, з використанням багатомірних математико-статистичних методів аналізу даних розроблено актуалізований параметричний метод комплексної оцінки витрат.*
Результати. *Показано, що загальною тенденцією розвитку світової авіаційної промисловості є кооперація. Розглянуті її основні напрямки. На прикладі "Проекту створення кооперaційного виробництва легкого транспортного літака" змодельовані різні варіанти участі кооперанта та орієнтовні обсяги його робіт в загальній собівартості літака. Визначений характер впливу обсягів робіт, виконуваних кооперантом, на величину собівартості літака, постійних витрат, ризиків проекту.*
Висновки. *Представлена найбільш загальна актуальна для вітчизняного авіабудування методика оцінки ефективності проекту кооперaційного виробництва літака, що включає: модель вибору схем кооперaційного виробництва, що дозволяє на самій ранній стадії визначити його залежності, дозволяючи більш обґрунтовано представляти майбутні витрати і можливі вигоди учасників кооперaційного проекту.*

Ключові слова: *кооперaційне виробництво; оцінка ефективності кооперaційного виробництва літака.*