DEVISING A CONCEPT OF INTEGRATED DESIGN AND MODELING OF AIRCRAFT

The analysis of aircraft design methods reported here has revealed that building a competitive aircraft necessitates devising a scientifically based concept of integrated aircraft design employing CAD/CAM/CAE/PLM software suites.

A generalized concept of integrated design and three-dimensional computer modeling of aircraft involving the CAD/CAM/CAE/PLM systems has been developed. Based on the proposed concept, the principles of integrated design of aircraft were devised. The features of designing the training and training-combat aircraft, transport-category aircraft, light civilian aircraft have been described.

A method for determining the take-off weight, design parameters, and formation of the general appearance of aircraft has been improved. The method is intended to form the appearance of the aircraft at the stages of preliminary design, the purpose of which is reduced to determining the permissible version of the aircraft project. The project must meet the predefined requirements and restrictions in the selected aircraft scheme and the assigned set of parameters that characterize its airframe and power plant.

A method of parametric modeling of aircraft has been improved, which includes the stages of creating a master geometry of the aircraft and a model of space distribution. Parametric models of master geometry and models of space distribution, training and training-combat aircraft, transport-category aircraft, light civilian aircraft have been constructed.

Methods of integrated design of aircraft main units have been devised and theoretically substantiated. Parametric models of master geometry of the wing for a training aircraft, the wings, appendage, and fuselage of a light civilian aircraft were built, taking into consideration the design features of aircraft units of various categories

Keywords: integrated aircraft design, master geometry, concept, three-dimensional parametric modeling, takeoff mass

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1. Introduction

The process of aircraft design includes the preparation of technical documentation that ensures the possibility of industrial production of a new competitive aircraft and its modifications, which meets the specified requirements and allows its reliable operation under the predefined conditions.

Design methods evolved from copying methods and statistical methods to optimal and system design methods. As the experience of solving various problems of optimization of individual elements of the aircraft is accumulated, given the wider use of computers to solve such problems, the number of parameters involved in the process of simultaneous optimization gradually increased. At the same time, the general theory of designing large systems has developed, based on which the theory and practice of designing aircraft gradually acquire logical completion. This provided a truly scientific approach to predicting the parameters and characteristics of a would-be aircraft [1, 2]. Significant results have been achieved in solving such a complex problem as auto-

mation of project and design work. In the second half of the twentieth century, computer-aided design (CAD) systems were created, developed, and widely implemented in research institutes and design bureaus. Their advent became possible due to the development of theoretical foundations of design, success in the field of computational mathematics, programming, and computing equipment [3, 4].

However, the development of these methods did not fully apply modern research-intensive computer integrated systems CAD/CAM/CAE. Introducing them into the design practice required devising a new methodology for design, modeling, engineering analysis, and preparation of the production of prefabricated thin-walled aircraft structures. Lack of experience in achieving the specified performance characteristics of aircraft structures with the help of CAD/CAM/CAE systems inhibits the integration of estimation, experimental design methods with computer modeling methods. It does not allow for high-quality integrated design of prefabricated aircraft structures, which ensures their life cycle.

It is quite relevant to devise the concept of integrated design and computer modeling of aircraft structures. The practical application of constructed methods for achieving the characteristics of the aircraft design while minimizing the mass at the early stages of design would reduce the cost of designing and ensure regulated characteristics of the resource and reliability.

2. Literature review and problem statement

According to data published in [5, 6], the use of CAD allowed, at the end of the twentieth century, to two to three times reduce the design and adjustment time of aircraft, three to five times – the time of preparation of their production. At the same time, development costs are reduced by 50–80 %. However, in this case, as in the application of analytical design methods, the result of the general design included drawings of the general appearance of the aircraft, theoretical drawings of aircraft units, a diagram of technological joints, etc., made by the drawing geometry methods.

However, at the same time, the design of aircraft using CAD was based on two-dimensional models and did not take into consideration some design features. Those features included new types of connections, fasteners, new technologies for their installation, assembly methods, the effect of preloading on the characteristics of the local stressed-strained state (SSS) and fatigue resistance. That did not make it possible to design prefabricated structures and their connections, providing an optimal ratio of mass, resource, aerodynamic, and aesthetic characteristics of aircraft structures. Aviation technical documentation was compiled by drawing geometry methods and was submitted for the production of aircraft on paper. The structure was adjusted on design plazas, which did not always make it possible to identify errors caused by the imperfection of the design method and embedded in the design documentation [7].

Modern AC of any purpose is a complex technical system, which consists of a series of subsystems to ensure its operation. Designing each subsystem requires large expenditures of intellectual, financial, material, labor, and other resources. However, even in the case of high costs, there is no guarantee that the submitted project would fully meet the requirements of tactical-technical characteristics (TTCs) and could meet tactical-technical requirements (TTRs) [8, 9].

The considerable duration of the creation of modern and promising AC predetermines the need to predict the flight-technical, economic, and operational characteristics of AC and their systems. Research in the field of forecasting the level of technical excellence of AC makes it possible to avoid mistakes in determining the concepts of their development. Given the extremely high cost of scientific and technical programs, the duration of the cycle of development, and the value of aviation equipment (AE), such errors can lead to irreversible consequences [10]. Analysis of the aircraft creation process shows that in the initial stages of designing, costs are only 5–10 % of the total costs. At the same time, at this stage, up to 70–80 % of decisions are made that ensure the further effective operation of the designed aircraft. It is this stage of the project life cycle that is most important for research.

Papers [11, 12] report the processes of conceptual design of aircraft. Methods of optimal design and choice of optimal parameters of aircraft using automated design systems are described. However, the issues of ensuring the resource and survivability of the design and the peculiarities of the use of computer integrated systems in the design process are not considered.

Article [13] reports a method for designing, parametric modeling, and optimizing the structure of a wing using the integrated use of CAD\CAE systems. However, only the regular wing zone is investigated without taking into consideration the peculiarities of designing irregular zones and fatigue resistance.

Study [14] presents the design and selection of parameters of the aircraft and its assembly units but does not cover the use of computer integrated systems in the design of aircraft.

The introduction of computer-aided integrated systems into the practice of designing and manufacturing aircraft requires the development and improvement of the methodology for designing aircraft. Leading aviation firms have developed and implemented their methodology for integrated design but this information is not disclosed. Maintaining competitiveness in the market of modern aviation equipment requires reducing the design time and launching new aircraft in mass production, reducing the cost of their development and operation. To this end, it is necessary to devise new and improve the existing principles and methods of designing aviation equipment using computer integrated systems, which are part of the concept of integrated aircraft design [15, 16].

The review of aircraft design methods has shown that in order to create Ukrainian aircraft, it is necessary to devise an authentic scientifically-based concept, principles, and methods of integrated aircraft design (Fig. 1) [15, 16] using the CAD\CAM\CAE\PLM computer systems.

The methods of integrated design should be based on the development of three-dimensional analytical standards of the aircraft surface, its assembly units, prefabricated components and systems [7, 16, 17].

One of the first steps in tackling this issue is the construction of methods for the integrated design and three-dimensional parametric modeling of an aircraft with the help of modern information technologies. To ensure competitiveness, the proposed concept of integrated design should provide the specified characteristics of the projected article at the predefined time spent on design. The design concept should include methods for ensuring the minimal mass of a structure, methods for analyzing and ensuring the resource and survivability of the structure, improved methods of three-dimensional parametric modeling of aircraft design and full integration of these models into the design process.

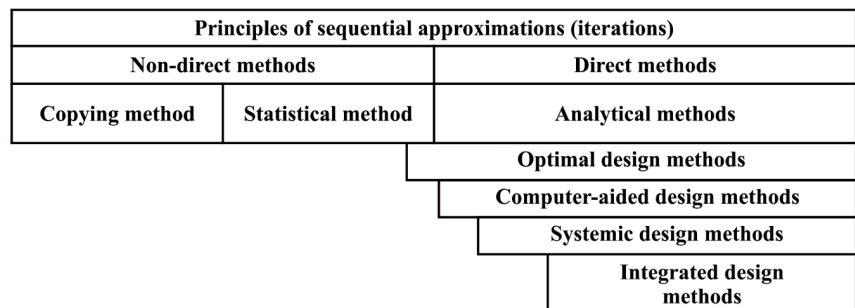| Principles of sequential approximations (iterations)			
Non-direct methods		Direct methods	
Copying method	Statistical method	Analytical methods	
		Optimal design methods	
		Computer-aided design methods	
		Systemic design methods	
			Integrated design methods

Fig. 1. Evolution of aircraft design methods

3. The aim and objectives of the study

The purpose of this work is to devise the concept of integrated design and modeling of aircraft using computer systems, which could shorten the time and reduce the cost of design.

To accomplish the aim, the following tasks have been set:
– to devise the principles of integrated design of aircraft of different categories with the help of CAD\CAM\CAE systems, taking into consideration the resource and the presence of irregular structural zones at the early stages of design;
– to improve the method of forming the general appearance of the aircraft and calculating the take-off weight of aircraft;
– to improve the methods for constructing the master geometry, models of space distribution, and design standards of aircraft of different categories using the CAD/CAM/CAE Siemens NX, Catia, ANSYS systems;
– to determine the components of integrated aircraft design.

4. The study materials and methods

The object of our research is the design of aircraft with gas turbine engines.

The main hypothesis of the study is to reduce the cost and time of designing aircraft with the fuller implementation of integrated design systems using advanced methods for forming the overall appearance of the aircraft and building three-dimensional models.

To form the general appearance of the aircraft project, we applied statistical and analytical methods for determining the take-off mass and geometric parameters, mass-centering, aerodynamic, and energy characteristics of the aircraft. To determine the geometrical characteristics of power elements in assembled units and build their three-dimensional models, the methods of three-dimensional parametric modeling and design of aircraft assembled units and systems were used employing the CAD/CAM/CAE/PLM Siemens NX, Catia suites.

5. Devising a concept of the integrated design and parametric modeling of aircraft

5. 1. Principles of integrated aircraft design

To devise the concept of integrated aircraft formation, the principles of integrated aircraft design have been compiled:

1. The principle of building analytical standards for prefabricated aircraft structures.

Three-dimensional computer models of master geometry, space distribution, analytical references of elements of prefabricated aircraft structures are constructed by methods of analytic geometry using the integrated systems CAD/CAM/CAE/PLM Siemens NX, CATIA in a single information environment to maintain the life cycle of aircraft.

2. The principle of constructing the master geometry of an aircraft.

The parameters for the appearance of the new aircraft of minimum mass and regulated durability should meet the specified promising technical requirements, aviation rules, the concept of designing a new aircraft and be determined from the ratio of the design parameters of the aircraft to its take-off weight.

3. The principle of designing regular zones of prefabricated aircraft structures.

The structural parameters and fabrication technology of regular zones of aircraft structures should ensure the percep-

tion of estimated destructive loads, regulated durability at loads equivalent to loads of typical flight in the operational environment. In addition, it is necessary to ensure the predefined coefficient of fatigue quality, the specified quality of the outer surface, the degree of air tightness.

4. The principle of designing irregular zones of prefabricated aircraft structures.

The structural parameters and fabrication technology of irregular zones should ensure the perception of estimated efforts at static load, regulated durability, quality of the outer surface, and air tightness at the level of characteristics of the regular zone or exceed them.

5. The principles of aircraft systems design:

1) development of automated multi-channel aircraft control systems that provide the required level of reliability and flight safety with a low degree of static stability;

2) development and creation of multi-channel and reliable systems of power supply, hydraulics, mechanization control, air conditioning and supercharging of cabins and other systems;

3) development of on-board equipment complexes that meet the specified requirements for pilot, navigation characteristics.

6. The principle of maintaining and achieving the survivability of prefabricated aircraft structures with fatigue cracks.

The structural parameters of the aircraft design, which meets the requirements for safe destruction, should provide for the ability to control critical sites, identify fatigue cracks, and to use progressive ways to delay their growth, to restore bearing capacity and air tightness of the damaged structure.

5. 2. Method to form the general appearance of an aircraft

At the stage of development of the master geometry of the aircraft, the parameters of the aircraft, its weight and geometrical characteristics need to be defined. Therefore, existing methods have been improved to use in the process of integrated design. The method of choosing the optimal parameters, calculating the take-off weight, and determining the geometric characteristics in order to form the general appearance on the example of a training aircraft (TAC) at the stage of preliminary design is illustrated in Fig. 2. The method involves the formation of initial data, determining the take-off mass and geometric parameters in zero approximation. Then there are the stages of determining the impact of project parameters on the takeoff weight of the aircraft in the first and second approximation, the choice of optimal parameters, the calculation of the takeoff mass in the third approximation. After determining the take-off mass, one checks if the specified TTRs are met, the layout and centering of the aircraft, the determination of geometric parameters, the development of a drawing of general appearance, and master geometry.

To select the optimal parameters for a training aircraft, functional dependences are established between the selected optimization criterion, tactical-technical requirements, and TAC parameters. When using the take-off mass as a criterion for optimization, the following dependence is established:

$$m_0 = f\left(p, t_0, \eta, \lambda, \lambda_{fus}, c_x, c_y, TTR...\right) \rightarrow \min.$$

Project parameters are also subject to restrictions. For example, the specific load on the wing is limited by overload when flying in a turbulent atmosphere and in landing speed.
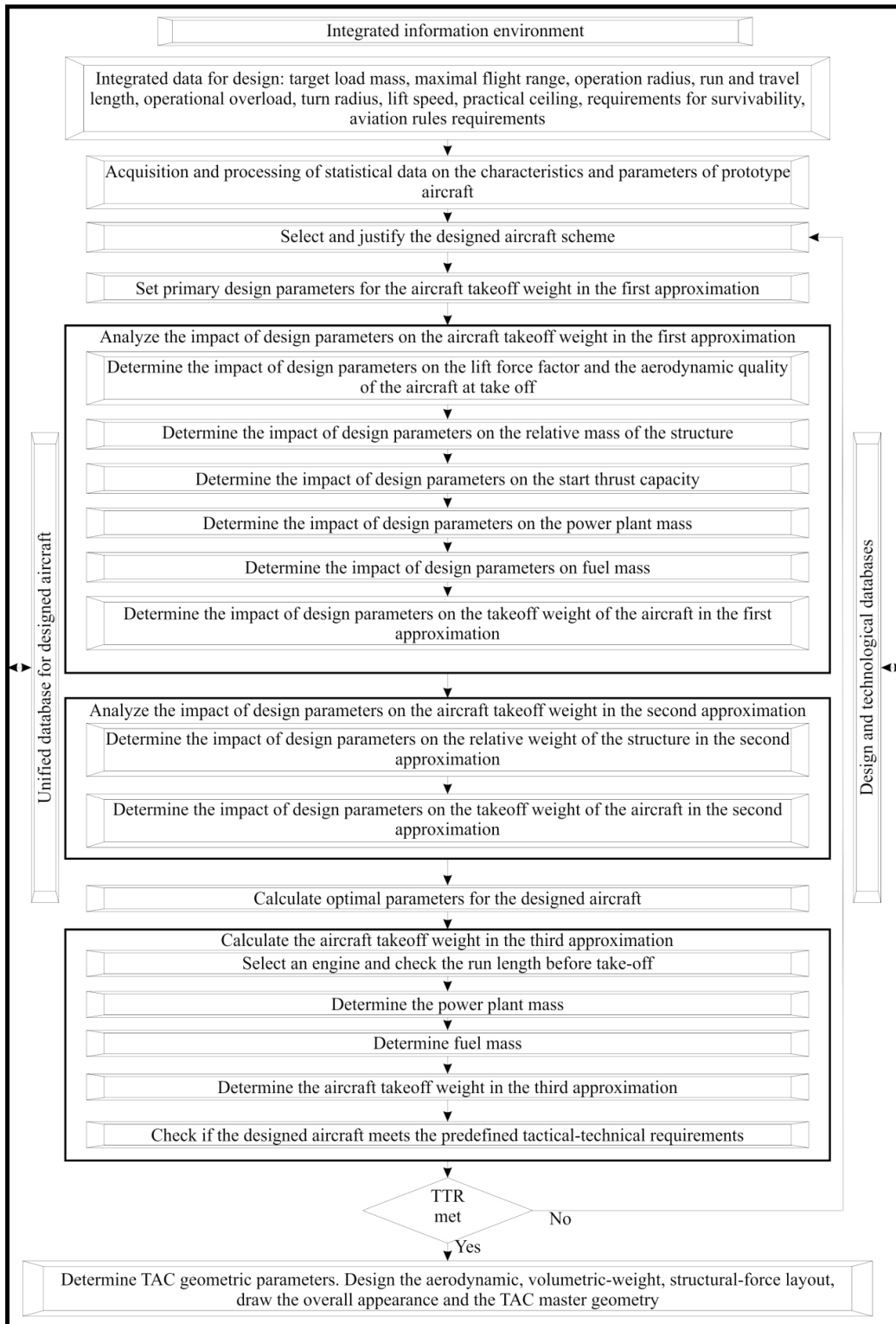
Fig. 2. Method for selecting the parameters of a training aircraft

The takeoff weight of the aircraft is calculated in three approximations. In zero approximation, the relative components of the takeoff mass are determined by statistical data, and the takeoff mass is determined from the following formula:

$$m_0^0 = \frac{m_{payload} + m_{service\,load}}{1 - \left(\bar{m}_{structure} + \bar{m}_{PP} + \bar{m}_{fuel} + \bar{m}_{equipment} \right)}.$$

When determining the takeoff mass in the first approximation, the influence of design parameters on the relative mass of the structure, the relative mass of fuel, the required thrust, and the relative mass of the power plant and the takeoff mass in general are examined:

$$m_0^I = \frac{m_{payload} + m_{service\,load}}{1 - \left(\bar{m}_{structure}\left(p, \lambda, \chi, \ldots\right) + \bar{m}_{PP}\left(p, c_x, t_0, \ldots\right) + \bar{m}_{fuel}\left(p, c_x, c_y, L, \ldots\right) + \bar{m}_{equipment} \right)}.$$

In the second approximation, the mass of the structure is refined by the components: wing, fuselage, appendage, chassis.

The takeoff weight of an aircraft in the second approximation:

$$m_0^{II} = \frac{m_{payload} + m_{service\,load} + m_{equipment} + m_{wing} + m_{fus} + m_{append} + m_{chassis}}{1 - \left(\bar{m}_{PP}(p, C_x, t_0, \ldots) + \bar{m}_{fuel}(p, C_x, C_y, L, \ldots)\right)}.$$

Here, the wing masses m_{wing}, m_{append}, $\bar{m}_{PP}$ and $\bar{m}_{fuel}$ are the functions of specific load on the wing and design parameters λ, χ, $\bar{c}$, ..., therefore the takeoff weight of the aircraft in the second approximation is the function $B_0^{II} = f(p, \lambda, \bar{c} \ldots)$.

Solving the problem $m_0^{II}(\chi^\circ, \eta, \lambda, p) \to \min$, they find the optimal values for the wing parameters of the projected aircraft, the takeoff mass in the second approximation.

In the third approximation, they specify the masses of fuel, they check whether the selected engine satisfies the specified TTRs, specify the mass of the power plant, and determine the takeoff mass:

$$m_0^{III} = m_{payload} + m_{serice\,load} + m_{equipment} + m_{wing} +$$
$$+ m_{fus} + m_{append} + m_{chassis} + m_{PP} + m_{fuel}.$$

After calculating the take-off weight of the aircraft in the third approximation, they find its geometric parameters, conduct aerodynamic, volumetric-weight and structural-force layout, create drawings of general appearance and master geometry.

To verify the method, we determined the design parameters for a TAC aircraft being designed and for the training-combat aircraft Yak-130. Optimization was carried out simultaneously according to four parameters: specific load on the wing, wing elongation, narrowing of the wing, and the angles of the arrow-shaped wings. The basic flight and technical data for Yak-130 and the calculation results are given in Table 1.

5. 3. Methods for constructing the master geometry, models of space distribution, and aircraft design standards

The model of the geometry of a part in a computer form (hereinafter, the analytical standard of a part) is the basic, primary element of the structure in the computer design of the new machine. It contains the reference coordinates of all points of the surface of the part in the predefined coordinate system and is the basis of a computer project of aircraft geometry.

The computer project means the system of design, estimation, and technological models, as well as data for certification, quality management, maintenance in operation, disposal, that is, the management of the life cycle of the aircraft [13].

The aircraft's computer project includes the following models:

– model No. 1. Master geometry of the aircraft (or a model of the surface of the aircraft, which determines the geometry of the surface of the aircraft);

– model No. 2. Model of space allocation of the aircraft;

– model No. 3. Models of joints, connections, and structural and technological connectors;

– model No. 4. Geometry model of the whole product (analytical standards of all parts, components, assembled units, and aircraft in general), that is, a model of complete computer definition of the aircraft.

Below we consider the process of building each of the listed models of the aircraft.

Model No. 1. Master geometry of the aircraft.

The process of constructing model No. 1 can be divided into the following stages:

1) build a mathematical model of the aircraft;

2) devise the theoretical drawings of units;

3) construct models of the surface of assembled units, combining them into the model of the aircraft surface;

4) build the frame (applying traces of the basic surfaces of the structural-force set (SFS) in the volume of theoretical drawing (TD) and the structural-force diagram (SFD)).

Table 1

Results of determining the design parameters for the projected aircraft and the Yak-130 aircraft

Specifications and design parameters	Project. Initial data	Project. Calculation results	Yak-130	Yak-130. Calculation results	Error, %
Payload, kg	2,500	2,500	3,000	3,000	–
Takeoff weight, kg	–	8,447	9,000	9,180	2
Maximal speed, km/h	1,020	1,020	1,050	1,050	–
Flight range, km	875	875	540	750	–
Run length, m	600	450	380	380	–
Lift near the ground, m/s	120	120	100	100	–
Maximal overload	+8, –4g	+8, –4g	+8, –4g	+8, –4g	–
Start thrust capacity	–	0.6	0.56	0.556	0.7
Wing spread, m	–	9.2	9.72	9.96	2.5
Specific load on a wing, daN/m²	–	397.6	380	368	3.2
Wing elongation	–	3.9	4.017	3.97	1.2
Wing narrowing	–	5.6	3.99	4.06	1.75
Wing sweep, degrees	–	22	32	31	3.22

We implemented the devised methods for building the master geometry (surface models) of aircraft when designing a training-combat aircraft (Fig. 3), a training aircraft (Fig. 4), the transport category aircraft [18] (Fig. 5–7), a light civilian aircraft (Fig. 8). The models of the surfaces of the aircraft being projected were built using the Siemens NX system.

Fig. 3. Training-combat aircraft master geometry model

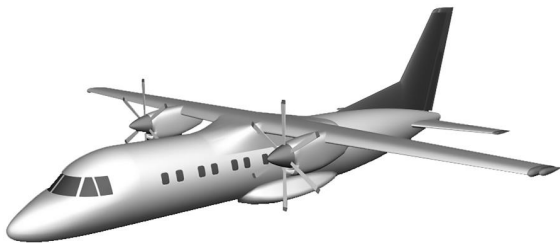Fig. 4. Training aircraft master geometry model

Fig. 5. An-140 master geometry model

Fig. 6. An-74TK300 master geometry model

Fig. 7. An-148 master geometry model

Fig. 8. Civilian light aircraft master geometry model

Model No. 2. Model of aircraft space allocation.

The process of building model No. 2 can be divided into the following stages:

1) design structural-technological joints;
2) draw panels;
3) form a structural-force set;
4) construct structural elements;
5) arrange equipment, devices, purchased articles, etc.;
6) prepare the layout of systems;
7) prepare a crew cabin layout;
8) prepare the layout of a passenger cabin (cargo cabin);
9) join the units and systems;
10) devise an aircraft project tree.

In the process of building a model of space allocation, the layout of the aircraft is prepared – mutual spatial arrangement of aircraft parts, their external shapes, and the structural-force scheme with the placement of crew, armament, cargo, equipment, fuel, and engines. At this stage, the project based on the selected scheme, the selected parameters of the aircraft, and the determined weight characteristics takes the completed form. Completed is the external design, the layout of the main cargoes and volumes inside the aircraft, the structural-force scheme of all parts of the aircraft.

Given this, the layout arrangement combines three interrelated processes that proceed simultaneously and in parallel: aerodynamic layout, volume-weight layout, and structural-force layout. Fig. 9, 10 show fragments of the models of aircraft space allocation, developed using the CAD\CAM\CAE Siemens NX system.
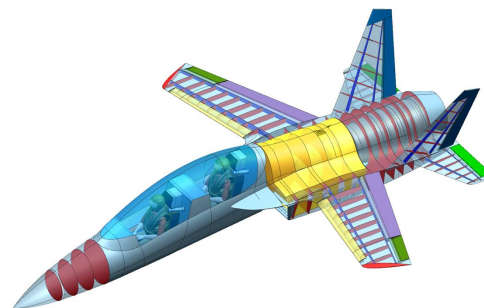

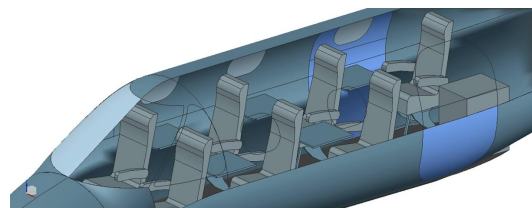Fig. 9. Fragment of the model of space allocation in a training aircraft

Fig. 10. Fragment of the fuselage space allocation model in a light civilian aircraft

Model No. 3. Models of assembled units, their joints.

Building model No. 3 includes the following stages:

1) Determine the complete design of units, joints, and connections.

2) Set the interrelated system of tolerances for the elements of the joint.

Fig. 11 shows an element of the docking unit of the transport category aircraft; Fig. 12–14 – fragments of the analytical standards of elements of the design of a light civilian aircraft frame; Fig. 15 – wing models with two and three longerons of a training aircraft with a wing of reverse sweep.
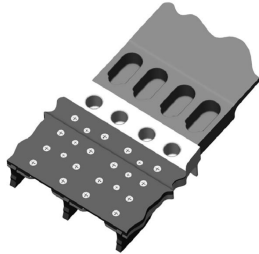

Fig. 11. Element of the docking unit in a transport category aircraft
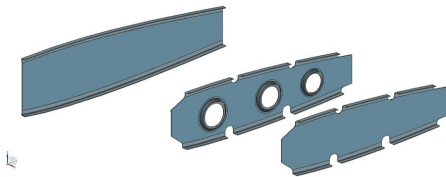

Fig. 12. Fragments of analytical standards of wing ribs in a light civilian aircraft
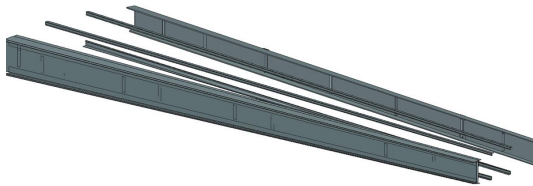

Fig. 13. Fragments of analytical standards of the elements in a wing's longerons of a light civilian aircraft
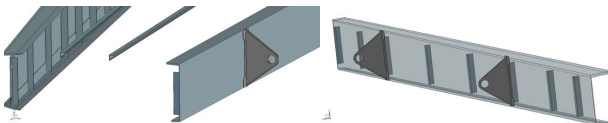

Fig. 14. Fragments of analytical standards of risers and brackets of nodes of hanging the steering rod of height
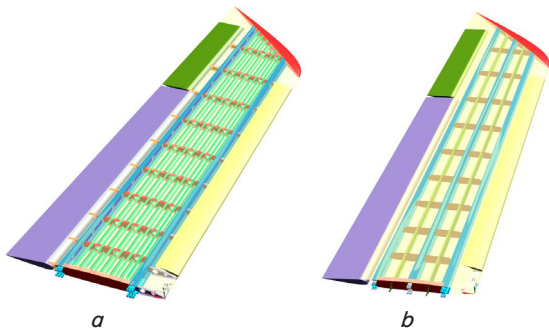

a *b*

Fig. 15. Fragments of analytical standards of design elements of the wing in a training aircraft: *a* — two-longeron; *b* — three-longeron

Model No. 4. Model of the entire article geometry.

Building model No. 4 includes the following stages:

1) zone modeling:

– exact components of the structure with all joints and connections;

– systems with structural fastening elements;

– outlines of units and devices with precise binding of fasteners, as well as checking structural elements in order to detect interpenetration and gaps, assembly;

2) sectional modeling:

– analytical standards of all structural elements;

– drawing databases;

– filling with attribute information;

3) assembled unit modeling:

– systems passing through units without technological dismembering;

– collecting and controlling all information about the project.

5. 4. Determining components in the integrated aircraft design

Integrated aircraft design includes the following components:

1. Integrated information environment, the set of technical and software tools for building an aircraft project.

2. Devising a concept for constructing a new aircraft and the tactical-technical requirements for the design object. The concept of designing a new aircraft is a defining idea on which the requirements for the aircraft are based: in terms of aerodynamics, weight perfection, strength, power plant, etc.

3. Selection of aircraft scheme, determining mass and geometric parameters, the aerodynamic, volume-weight, and structural-force layout. Development of master geometry for the aircraft using the CAD\CAM\CAE\PLM systems.

4. Determining estimated loads acting on aircraft units, permissible stresses in regular and irregular zones to ensure strength and regulated durability. Development of a model for the allocation of aircraft space.

5 Integrated design and construction of aircraft units.

6. Formation of analytical standards for aircraft frame design elements.

7. Compiling design, technological, and operational documentation.

Based on the devised principles and improved methods, we have built a flowchart to form the concept of integrated aircraft design (Fig. 16).

6. Discussion of results of constructing a method for the integrated design and parametric modeling of a training aircraft

The devised principles of integrated design could make it possible to ensure more complete use of the CAD\CAM\CAE systems in the process of aircraft design. Implementing the devised principles in the design process would make it possible to take into consideration the issues of designing irregular zones, ensuring the resource and survivability of aircraft design at earlier stages of design.

The improved method to form the general appearance and calculate the take-off weight of the aircraft, in contrast to the methods reported in [2, 15], allows the optimization to be performed simultaneously according to several parameters of the designed aircraft. Our algorithm for calculating the take-off weight and determining geometric parameters could be used for aircraft of different categories and could be automated, which would make it possible to consider more project options at the pre-design stage.

Integrated information environment, set of technical and software tools to build an aircraft project, industrial and experimental equipment, a team of professionals certified in the field of aircraft engineering and information support for the aircraft life cycle

Devise a concept for designing a new aircraft and its modifications using the integrated computer systems CAD/CAM/CAE/PLM
at the scientific-technical level of perfection and efficiency in terms of aerodynamic characteristics, stability, manageability, weight response, materials, the structure's weight, power plant, strength and resource, control, avionics, manufacturability, reliability, flight safety, which exceed the current world level for a given type of aircraft and ensures its competitiveness in the market of aviation services

Design an aircraft master geometry
Choose an aircraft scheme, the type of PP, determine the weight and geometric parameters of an aircraft that meet the predefined TTR, AP, the concept of aircraft design, the ISO 9000 requirements, optimization criteria. Arrange and center. Determine the aerodynamic and take-off-landing characteristics. Design and construct the master geometry of an aircraft using the integrated computer systems

Determine the estimated loads acting on assembled units, as well as loads in a regular flight, permissible stresses to ensure the strength and rated durability
Determine the geometric characteristics of the force elements in assembled units based on the conditions of static strength, rated durability, survivability at their mass minimization. Design new structural-technological solutions to reach the rated durability of bolted and riveted joints of assembled structures, as well as techniques to inhibit the evolution of fatigue cracks. Build a model of aircraft space allocation and the scheme of its technological splitting.

Build the analytical standards for an aircraft structure
Design and approve the analytical standards for an aircraft surface, its assembled units, systems, component units, joints and connections, structural parts that make up a complete computer model of an aircraft

Compile the design, technological, operational documentation for an aircraft and its systems

Design and technological databases

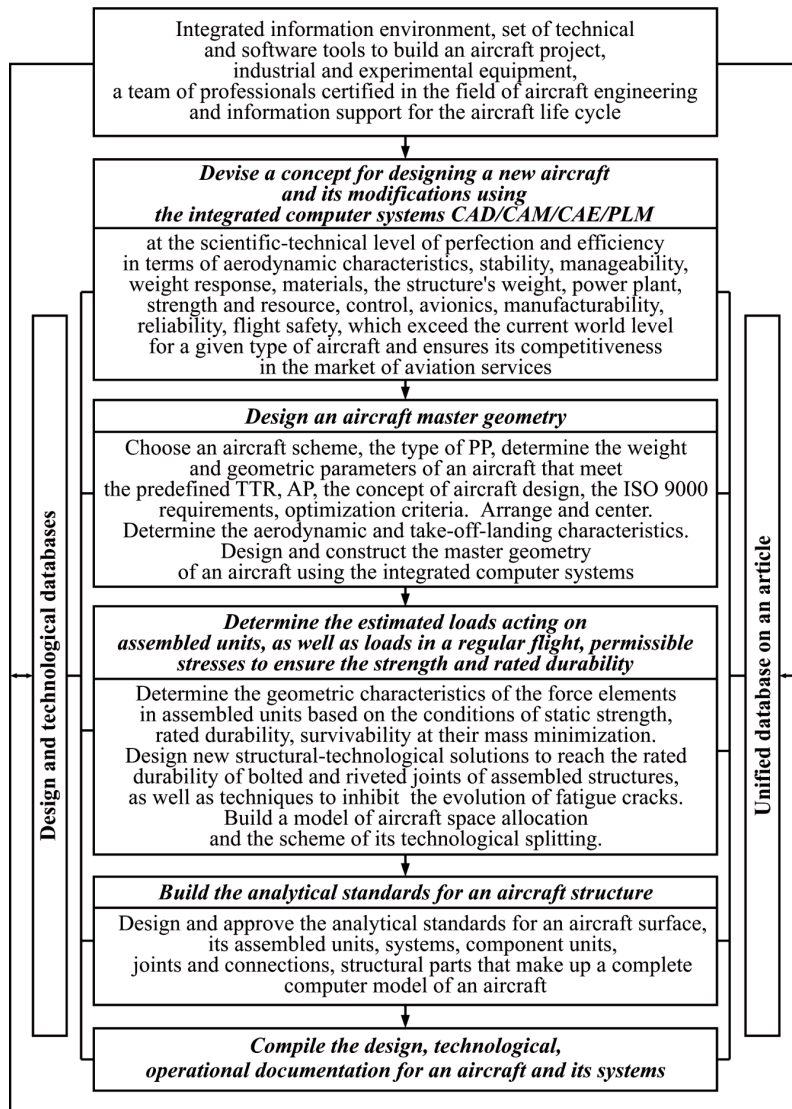*Unified database on an article*

Fig. 16. Flowchart illustrating the concept of integrated aircraft design

We have improved aircraft modeling techniques with the CAD/CAM/CAE Siemens NX systems. According to the devised concept, an aircraft project should be built in a computer form and contain three-dimensional design models to be used at all stages of design and production. The main ones among these models are the master geometry of an aircraft (Fig. 3–8); a model of space allocation in an aircraft (Fig. 9, 10); the models of joints, connections, and structural-technological connectors (Fig. 11); a model of the geometry of the entire article (Fig. 12–15). The advanced modeling methods allow for a more complete parameterization of models, which makes it possible to make adjustments in a shorter time, reduce labor costs when designing aircraft modification.

The geometry of the obtained elements is the primary source of information for the Siemens NX CAM module. This module is used to write programs for CNC machines and design other technological processes. The module makes it possible to organize the design in automatic mode of the processes of stamping, cutting, casting, etc.

In addition, the resulting models are used to form technological equipment and compile design and technological documentation. Such a process in computer systems is much simplified. When compiling drawing documentation, construction errors are practically excluded, since all schemes are executed using one primary source (a model of the part, node, etc.). To compile operational and repair documentation, it is necessary to carry out the process of «disassembling» the received units into components. The process will be significantly simplified due to the fact that simultaneously with the formation of models, the process of devising specifications and the necessary design documentation is also underway.

Thus, using the CAD/CAM/CAE systems makes it possible to design aircraft airframe units with significantly greater efficiency due to the following advantages:

– the built models are the primary source of information for other modules and systems or external software products used;

– all structures produced can be used in the future to compile design, technological, operational, and repair documentation;

– the processes of work on the design and technology of the unit can be carried out almost in parallel;

– using information management simplifies work with the whole nomenclature of documentation;

– there is a significantly higher accuracy of the indicators of the projected nodes;

– technological problems are detected in the early stages of the design of the unit, and not in the production process, and are promptly eliminated;

– it is possible to design equally strong structures with continuous change of geometrical parameters;

– there is a significant reduction in the time intensity of the design and manufacture of parts and assemblies of the unit.

The concept of integrated design and modeling was devised and tested during the construction of projects for the training, training-combat aircraft, transport category aircraft, light civilian aircraft. The applicability of the concept to other categories of aircraft was not investigated.

Each specific project of an aircraft, when using the devised concept, requires the application of a specific efficiency criterion. In this study, the takeoff mass was used as a criterion for optimization.

Further development of the reported concept of integrated aircraft design implies covering more categories of aircraft as each of these categories has specific characteristics in constructing three-dimensional models, specific efficiency criteria to be used in the design.

7. Conclusions

1. The devised principles of integrated design are the basis of the proposed concept the observance of which ensures more complete use of computer integrated systems at all stages of the design process. The principles of taking into consideration the presence of irregular design zones, ensuring

the resource and survivability of aircraft in the early stages of design are ensured using methods to ensure regulated durability in the design of the structure.

2. We have improved the methods for calculating the take-off mass and determining the geometrical parameters of aircraft of different categories at the stage of preliminary design. This allowed us, at the stage of determining the geometrical characteristics and take-off weight of aircraft, to perform optimization for several parameters according to the predefined efficiency criterion. The methods were implemented in software packages that make it possible, at the pre-design stage, to conduct a parametric analysis of more project options in a short time and develop the general appearance of the aircraft.

3. We have improved the methods of master geometry, a space allocation model, as well as parametric analytical standards of aircraft structures. The method has been tested and implemented in computer modeling of structures for the training, combat-training, light civilian aircraft. The models of master geometry and the allocation of aircraft space make it possible to carry out volumetric-weight and structural-force

arrangement; they could be used for calculating the aerodynamic characteristics and strength using a finite element method. The use of computer integrated systems during the aerodynamic, volume-weight, and structural-power layout process makes it possible to reduce costs and consider more structural options.

4. The concept of integrated aircraft design has been devised, the principles of whose application imply a widespread use of the CAD\CAM\CAE systems, methods for ensuring regulated durability in the design of a structure in the early stages of design. The concept involves the development of a preliminary project with the help of the reported method to form the general appearance, the result of which should be a model of master geometry of the aircraft, on the basis of which further development of the design and systems of the aircraft is carried out, the design, technological, and operational documentation is compiled. Implementing the concept in the processes of design and production of aircraft could reduce the design and launch period of new aircraft for industrial production, reduce the cost of their development and operation.

References

1. Ren, H., Chen, X., Chen, Y. (2017). Reliability Based Aircraft Maintenance Optimization and Applications. Academic Press, 260. Available at: https://www.elsevier.com/books/reliability-based-aircraft-maintenance-optimization-and-applications/ren/978-0-12-812668-4

2. Eger, S. M., Mishin, V. F., Liseytsev, N. K. et. al.; Egera, S. M. (Ed.) (1983). Proektirovanie samoletov. Moscow: Mashinostroenie, 616.

3. Vyshinsky, L. L., Flerov, Yu. A., Shirokov, N. I. (2018). Computer-aided system of aircraft weight design. Informatics and Applications, 12 (1), 18–30. doi: https://doi.org/10.14357/19922264180103

4. Bratuhin, A. G. (Ed.) (2000). Aviastroenie: Letatel'nye apparaty, dvigateli, sistemy, tekhnologii. Moscow: Mashinostroenie, 536.

5. Kumar, K. C. N., Gupta, G., Lakhera, S., Shaikh, A. (2015). Structural Optimization of Composite Stiffened Panel of a Transport Aircraft Wing using CAE Tools. Materials Today: Proceedings, 2 (4-5), 2588–2594. doi: https://doi.org/10.1016/j.matpr.2015.07.213

6. Manca, A. G., Pappalardo, C. M. (2020). Topology Optimization Procedure of Aircraft Mechanical Components Based on Computer-Aided Design, Multibody Dynamics, and Finite Element Analysis. Lecture Notes in Mechanical Engineering, 159–168. doi: https://doi.org/10.1007/978-3-030-50491-5_16

7. Vieira, D. R., Vieira, R. K., Chain, M. C., Vieira, A. K. (2019). Features of integration management tools in the aviation industry. International Journal of Product Lifecycle Management, 12 (1), 20. doi: https://doi.org/10.1504/ijplm.2019.104355

8. Global Market Forecast 2019-2038. Airbus. Available at: https://www.airbus.com/aircraft/market/global-market-forecast.html

9. Loginov, V. V., Elanskiy, A. V., Kravchenko, I. F. (2016). Metodologicheskie osnovy formirovaniya parametricheskogo oblika silovoy ustanovki perspektivnogo uchebno-boevogo samoleta. Kharkiv: HUVS im. Ivana Kozheduba, 294.

10. FAA Aerospace Forecasts Fiscal Years 2020-2040. Federal Aviation Administration. Available at: https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2020-40_faa_aerospace_forecast.pdf

11. Torenbeek, E. (2013). Advanced Aircraft Design: Conceptual Design, Analysis and Optimization of Subsonic Civil Airplanes. John Wiley and Sons. doi: https://doi.org/10.1002/9781118568101

12. Sforza, P. (2014). Commercial Airplane Design Principles. Butterworth-Heinemann, 598.

13. Benaouali, A., Kachel, S. (2017). An automated CAD/CAE integration system for the parametric design of aircraft wing structures. Journal of Theoretical and Applied Mechanics, 55 (2), 447–459. doi: https://doi.org/10.15632/jtam-pl.55.2.447

14. Gudmundsson, S. (2014). General Aviation Aircraft Design. Applied Methods and Procedures. Butterworth-Heinemann. doi: https://doi.org/10.1016/C2011-0-06824-2

15. Balabuev, P. V., Bychkov, S. A., Grebenikov, A. G., Zheldochenko, V. N., Kobylyanskiy, A. A., Myalitsa, A. K. et. al. (2003). Osnovy obschego proektirovaniya samoletov s gazoturbinnymi dvigatelyami. Ch. 2. Kharkiv: Nats. aerokosm. un-t «KhAI», 390.

16. Grebenikov, A. G. (2006). Metodologiya integrirovannogo proektirovaniya i modelirovaniya sbornyh samoletnyh konstruktsiy. Kharkiv: Nats. aerokosm. un-t «KhAI», 532.

17. Gumenniy, A. M., Nikolaenko, V. N., Grebenikov, V. A., Petrov, A. N. (2005). Metod integrirovannogo proektirovaniya i komp'yuternogo modelirovaniya kryla passazhirskogo samoleta s pomosch'yu integrirovannyh sistem CAD/CAM/CAE/PLM. Otkrytye informatsionnye i komp'yuternye integrirovannye tekhnologii, 27, 8–30.

18. Donets, O. D., Dveirin, O. Z., Vasylevskyi, Ye. T., Fil, S. A., Hrebenikov, O. H., Humennyi, A. M. (2019). Design features of the regional passenger aircraft airframe. Open Information and Computer Integrated Technologies, 83, 4–27. doi: https://doi.org/10.32620/oikit.2019.83.01