

Подано методику застосування структурно-параметричного геометричного моделювання для комп'ютерного динамічного формоутворення технічних об'єктів на прикладі крила літака. Запропонований підхід та розроблені нові прийоми автоматизованого проектування забезпечують можливість комплексного опрацювання різноманітних технологічних процесів, що використовуються під час виготовлення промислової продукції

Ключові слова: комп'ютерне варіантне динамічне формоутворення, крило літака, структурно-параметричне геометричне моделювання

Подана методика применения структурно-параметрического геометрического моделирования для компьютерного динамического формообразования технических объектов на примере крыла самолета. Предложенный подход и новые приемы автоматизированного проектирования обеспечивают возможность комплексной проработки различных технологических процессов, используемых при изготовлении промышленной продукции

Ключевые слова: компьютерное вариантное динамическое формообразование, крыло самолета, структурно-параметрическое геометрическое моделирование

COMPUTER VARIANT DYNAMIC FORMING OF TECHNICAL OBJECTS ON THE EXAMPLE OF THE AIRCRAFT WING

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1. Introduction

The issues of improving technical facilities are always important. Progressive in this regard are computer information technologies. Complex automation of production shortens the time of creating new products, significantly increases the quality, and reduces the cost. An important task is to combine automated design and manufacturing of products on the basis of geometric modeling. Technological processes of mechanical engineering, particularly in the aviation industry, are characterized by a large number of assembly operations, cutting, pressure cutting, etc., with a large number of possible options. Taking into account the existing requirements for increasing the accuracy, flexibility, productivity, and shortening the time of production preparation, it is necessary to apply new approaches in the field of computer information technologies, which determines the relevance of the outlined scientific issues.

2. Literature review and problem statement

An important direction for the introduction of computer information technology is the use of a parametric approach to geometric modeling during automated design. Study [1], by the example of the variant three-dimensional design of the pin parts, outlines the general procedure to form a typical geometric model with the necessary dimensional parameters and the required interconnections between them.

The main focus is the integration of Pro/Engineer systems and Microsoft Excel spreadsheets, and the study justifies the possibility of increasing the productivity of automated construction at the expense of this approach. The universality and flexibility of parametric methods of geometric modeling is confirmed by article [2], where the corresponding computer constructs of such widespread engineering products as screw cylindrical wire springs are presented. Work [3] shows the effectiveness of information technology data for automated reproduction of assembly units of machine building on an example of a mechanism with two kinematic pairs. The study extends the methods of parametric geometric modeling to the assembly of the unit. However, the general disadvantage of the above-mentioned works is that they do not analyze the integration of the design of technical objects, for example, with calculations of durability, processes of manufacturing, operation, etc.

Study [4] highlights the kinematic optimization of mechanical systems on the basis of dynamic computer simulation. Article [5] shows the effectiveness of using parametric geometric means for combining automated solid-state shape forming with calculations of durability and development of design documentation. Thus, we see that the progressive modern trend is to expand the scope of the practical application of parametric geometric modeling during the creation of various technical objects.

A certain improvement of the analyzed approach to computer geometric modeling is parametric structural shape formation, the main provisions of which are given in article

[6]. In the study, one parametric structural geometric model summarizes several parametric ones, which greatly increases the universality and performance of automated design. Work [7] describes some issues of the use of parametric structural shaping for the development of an aircraft, but the focus is on the stage of sketch design. In article [8], the emphasis is placed on efficient computer modeling of a large nomenclature of unified group of parts, but integration problems with the technology of their production, calculations of durability, etc. are not considered. In article [9], it is shown that further development of parametric structural geometric modeling is a computer variant dynamic formation.

Thus, the analysis of the published data shows that the development of new approaches, methods, techniques and algorithms of the integrated computer variant dynamic formation of technical objects and mechanical engineering processes on the basis of structural and parametric geometric modeling can be regarded as promising in both theoretical and practical terms.

3. The aim and objectives of the study

The aim of the study is to develop, on the basis of structural and parametric geometric modeling, a method of computer variant dynamic formation of technical objects with illustration guidance on the example of an aircraft wing.

To achieve the aim, the following tasks should be solved:

- to offer a mathematical apparatus of the dynamic formation of technical objects;
- to perform an automated variant construction of the surface of the aircraft wing;
- to carry out dynamic computer structural and parametric geometric modeling of the longeron of the central part (centripetal) of the aircraft wing.

4. The mathematical apparatus of dynamic shaping of technical objects

For the computer variant dynamic formation of technical objects, geometrical figures will be used according to their classification by the dimension

$$F = (F_i)_0^3, \tag{1}$$

where F_0 is points, F_1 is lines, F_2 is surfaces, and F_3 is bodies.

The geometric parameters will be presented as a tuple

$$P = (P_i)_1^3, \tag{2}$$

where P_1 , P_2 , and P_3 are position, size and shape parameters.

According to expression (2), possible dynamic geometric modifications are described by the set

$$M = (M_i)_1^3, \tag{3}$$

where M_1 is the modification of the position (movement), M_2 is the modification of dimensions (similarity), and M_3 is the modification of the form (deformation).

On the basis of relations (1)–(3), the investigated types of dynamic modifications of figures are determined by the tuple

$$MF = (MF_i)_0^9, \tag{4}$$

where

$$MF_0 = F_0 \times M, (MF_i)_1^3 = F_1 \times M, (MF_i)_4^6 = F_2 \times M, (MF_i)_7^9 = F_3 \times M.$$

The object under consideration is a certain combinatorial configuration of the elements of set (1), and its modifications are obtained from the elements of tuple (3). It is necessary to take into account the further details of these components, for example in the form

$$F_1 = (F_{i_1})_1^3 = (L_i)_1^3, \tag{5}$$

where F_{1_1} =(first-order lines)=(L_1), F_{1_2} =(second-order lines)=(L_2), F_{1_3} =(other lines)=(L_3);

$$F_2 = (F_{2_1})_1^3 = (S_i)_1^3, \tag{6}$$

where F_{2_1} =(transfer surfaces)=(S_1), F_{2_2} =(rotation surfaces)=(S_2), and F_{2_3} =(other surfaces)=(S_3);

$$F_3 = (F_{3_1})_1^3 = (B_i)_1^3, \tag{7}$$

where F_{3_1} =(multifaceted bodies)=(B_1), F_{3_2} =(rotation bodies)=(B_2), and F_{3_3} =(other bodies)=(B_3);

$$M_1 = (M_{1_1})_1^3 = (m_i)_1^3, \tag{8}$$

where M_{1_1} =(parallel transfer)= m_1 , M_{1_2} =(rotation)= m_2 , and M_{1_3} =(symmetry)= m_3 ;

$$M_2 = m_4, \quad M_3 = m_5, \tag{9}$$

where m_4 =(proportional scaling), and m_5 =(disproportionate scaling).

On the basis of parametric structural shaping, an arbitrary simulated geometric object O is represented by an ordered set of elements:

$$O = (o_i)_1^{N_o}. \tag{10}$$

The possible types of o_i are reproduced by tuples of variants

$$o_i = (o_{ij})_1^{N_{o_i}} \tag{11}$$

and vectors of parameters

$$P_{ij} = (p_{ijk})_1^{Np_{ij}}, \tag{12}$$

where Np_{ij} is the number of parameters of a j -th variant of an i -th element.

The structural correlation between the varieties of the n -th and the m -th components of the object O is determined by the adjacency matrices (Fig. 1, a).

$$C_{nm} = \|c_n, c_m\|; \quad n \in N; \quad m \in N; \quad n \neq m; \tag{13}$$

$$r \in \{1, \dots, N_n\}; \quad s \in \{1, \dots, N_m\},$$

where $c_n, c_m \neq 0$ under any possible interaction of the options o_{nr} and o_{ms} ; otherwise, $c_n, c_m = 0$.

As a result of using dependencies (10)–(13), the model object O is provided by a set of design options

$$O = (O_k)_1^{N_O}. \tag{14}$$

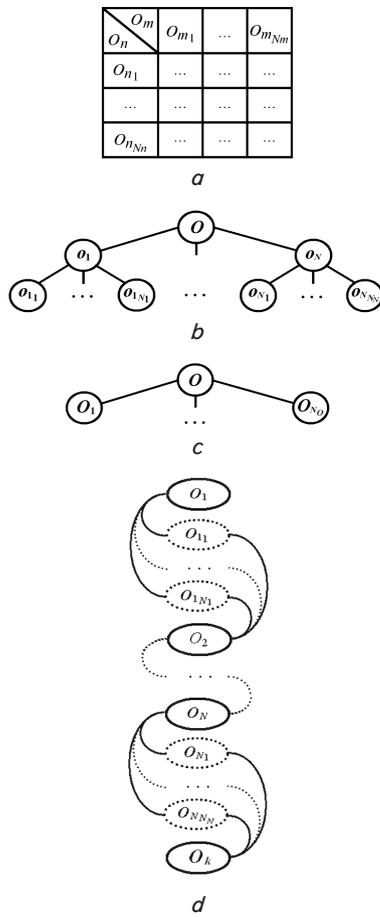


Fig. 1. Components of the parametric structural model of the object O : a shows the matrix of adjacency of the element varieties o_n and o_m ; b is the structure graph; c is the options graph; d is an example of the graph of synthesizing the object O

Formula (14) corresponds to Fig. 1, b . Fig. 1, d shows one of the possible procedures for synthesizing the object O under consideration. The vertices of the given non-oriented graph are the elements of the processed figure under expression (10), and the edges are geometric models (11) that implement these elements with certain values of the parameters used in (12). Each type of O_k of the object under study is a simple elementary chain with a beginning at the vertex O_1 and an end at the vertex O_N ; the total number of N_O is determined by the elements of matrices (13). The values of the parameters in (12) and their various combinations in the form of the necessary target analytic functions are placed in accordance with the length of the proper edges. Then the search for the optimal parametric structural variant of the technical object O is reduced to determining the extremal chain shown in Fig. 1, d of the graph. There are various algorithms for solving such problems – in particular, indexing of vertices, branches and boundaries, etc.

Based on the fact that geometric objects that are variable in time can reproduce certain technological processes of machine building, the developed method suggests that the parametric structural model components should combine the geometric shapes given by formulae (1)–(9), their parameters and dynamic modifications, with the above relations (10)–(14).

For a variant dynamic reproduction of technical objects and processes for their manufacturing, the specific composition of sets (1)–(14) is determined by the existing design conditions, which are illustrated later by specific examples of structural and parametric geometric modeling of the aircraft wing.

5. The results of variant dynamical geometric modeling of the aircraft wing

The following is a variant modeling of the wing surface, which largely determines such characteristics of the aircraft as aerodynamic, strength, weight, technological, etc., as well as computer dynamic structural and parametric shaping of the centreplane longeron.

The indicated information is important in the applied scientific plan because using modern computer information technologies provides an opportunity to increase the efficiency of conducting complex (multicriteria) optimization of the aircraft. This assertion is based on the fact that the tasks of aerodynamics, strength, layout, construction, technology of production and operation, etc. are not only closely related, but they also significantly affect one another. For example, tolerances in terms of the strength of the limit on the variation of the height of the longeron ends is determined by the shape and dimensions of the cross-sectional wings, selected in accordance with the required aerodynamic characteristics, and the latter, in turn, depend to a large extent on the stiffness of the structure of the bearing surface. Also, the complication of the shape of the wing leads to the improvement of its aerodynamics but worsens the manufacturing process. These and other features determine the iterative variant nature of the design of a modern aircraft. Among many other models (aerodynamics, strength, layout, weights, technological, operational, etc.), geometric models have a special place, which is related to the role of the model of the shape and size of the simulated technical object. As a result, the main requirements for computer geometric models ensure not only high accuracy of shaping but also flexible and productive construction of various design variants of products with a dynamic reflection of the included processes of their manufacture and operation, that is, for the entire life cycle.

The following specific examples confirm the validity of the above general methodology of the computer variant dynamic formation of technical objects on the basis of structural and parametric geometric modeling.

5.1. The variant construction of the surface of the aircraft wing

Let the surface as the output have an aerodynamic profile, represented in a rectangular coordinate system Oxy by a set of points

$$\mathbf{r} = (x_i, y_u, y_l)_1^n, \tag{15}$$

where x_i is the abscissa of the points, y_u and y_l are, respectively, the ordinates of the upper and lower parts of the profile, and n is the number of points in each part.

Usually, the abscissas x_i as well as the ordinates y_u and y_l are expressed as a percentage of the length of the chord b , that is, the segment of the line that combines the two most distant profile points and divides it into the upper and lower parts.

According to expression (3), the possible modifications of profile (15) are the position change as well as the proportional and disproportionate types of scaling. The latter is presented later on the example of the dynamic variation of the profile thickness and concavity.

The profile height and the average line are calculated as

$$h_i = y_{u_i} - y_{l_i}, \quad y_{av_i} = 0.5(y_{u_i} + y_{l_i}). \quad (16)$$

The longest segment h_i is called the thickness c of the profile, and the maximum distance from the points y_{av_i} to the chord is the concavity f of the profile f (Fig. 2).

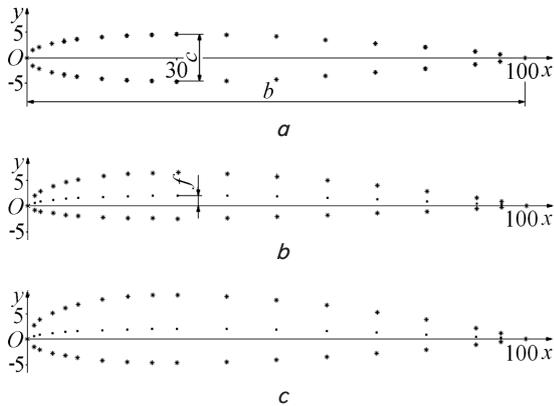


Fig. 2. Modifications of the shape of the discrete aerodynamic profile: *a* shows the output profile NACA-0009 ($f=0\%$ and $c=9\%$); *b* means $f=2\%$ and $c=9\%$; *c* shows $f=2\%$ and $c=13.5\%$

To modify the profile with the coefficient of concavity k_f and the thickness factor k_c ,

$$k_f = f' / f, \quad k_c = c' / c, \quad (17)$$

where f' and c' are a new concavity and a new thickness; the starting points of (15) are transformed as follows:

$$y'_{u_i} = y_{av_i} k_f + 0.5 h_i k_c = 0.5 (y_{u_i} (k_f + k_c) + y_{l_i} (k_f - k_c)),$$

$$y'_{l_i} = y_{av_i} k_f - 0.5 h_i k_c = 0.5 (y_{u_i} (k_f - k_c) + y_{l_i} (k_f + k_c)), \quad (18)$$

where y'_{u_i} and y'_{l_i} are the modified ordinates of the points of the upper and lower parts of the aerodynamic profile.

Under the conditions of using the initial symmetric profile, the required initial concavity f is obtained by multiplying the ordinates of the points of the upper and lower parts, respectively, by the coefficients

$$k_u = (f + 0.5c) / y_{u_{max}}, \quad k_l = (f - 0.5c) / y_{l_{min}} \quad (19)$$

where $y_{u_{max}}$ and $y_{l_{min}}$ are the maximum and minimum ordinates of the initial profile.

The picture of Fig. 2 illustrates the practical application of formulae (15)–(19).

In the case of processing the lines, for example, of the F_{12} shape in accordance with expression (5), the possible dynamic transformations are shown in Fig. 3, where the studied aerodynamic profile is presented as a composite line of arcs of the curves of the second order in the vector parametric form

$$\mathbf{r}_{ij}(u) = \frac{(1-u)^2 \mathbf{r}_{0ij} + w_{ij} 2u(1-u) \mathbf{r}_{1ij} + u^2 \mathbf{r}_{2ij}}{(1-u)^2 + w_{ij} 2u(1-u) + u^2}, \quad (20)$$

where $i \in \{t, b\}; j \in \{1, 2\}$;

$$\mathbf{r}_{0ij} = (x_{0ij}, y_{0ij}), \quad \mathbf{r}_{1ij} = (x_{1ij}, y_{1ij}), \quad \mathbf{r}_{2ij} = (x_{2ij}, y_{2ij})$$

are the radius vectors of the vertices of characteristic triangles in the rectangular coordinate system Oxy ; $w_{ij} \geq 0$ means the weights of vertices \mathbf{r}_{ij} and $u \in [0, 1]$ is the parameter.

In expression (20), t and b denote the top and bottom parts of the profile, and the index j means the ordinal numbers of their arcs connected at the point with the maximal thickness abscissa. Fig. 3 shows variants of modifications, where we use weight ratios of 0.5 and 1, respectively, for the nose and tail sections of the profile.

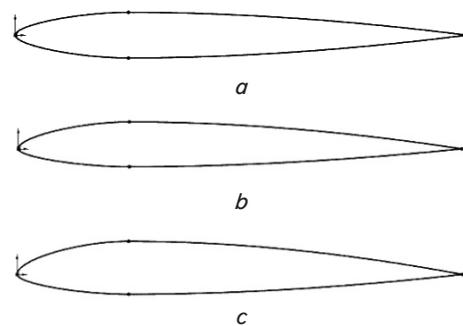


Fig. 3. Modifications of the aerodynamic profile of curves of the second order: *a* is the output profile ($f=0\%$ and $c=10\%$); *b* means $f=1\%$ and $c=10\%$; *c* means $f=1.5\%$ and $c=12\%$ ($k_f=1.5; k_c=1.2$)

After defining the shape of the aerodynamic profile, its proportional scaling to the desired size and setting in the proper position is carried out. Fig. 4 illustrates the linear surface of an arrowhead defined in a rectangular coordinate system $Oxyz$; the basic geometric parameters are the root b_0 and final b_k chords, as well as the L width and the arrow-shaped angle χ . The derivative characteristics are represented by the area $S = b_{cp} L$, where $b_{cp} = 0.5(b_0 + b_k)$ is the average chord, the elongation $\lambda = L / b_{cp} = L^2 / S$, and the narrowing $\eta = b_0 / b_k$.

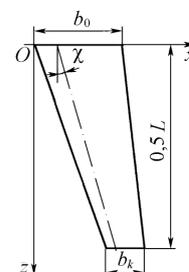


Fig. 4. The plan view of the aircraft wing

The parametric equation of the wing surface is the following:

$$\mathbf{r}_{ij}(u, v) = (1-v) \mathbf{r}_{ij}^0(u) + v \mathbf{r}_{ij}^k(u), \quad (21)$$

where $i \in \{t, b\}; j \in \{1, 2\}; u \in [0, 1]$ and $v \in [0, 1]$ are the parameters.

The use of the indices i and j in formula (21) is similar to expression (20), and the upper indices θ and k are the root and final aerodynamic profiles.

5. 2. The dynamic computer structural and parametric geometric modeling of the centerplane longeron of the aircraft wing

The parametric structural model of the longeron presented in [10] makes it possible to obtain the necessary design variants, but it does not allow reproducing in time technological operations of installing parts, drilling holes, riveting, etc. Let us consider some techniques for improving this model.

The composition of the projected longitudinal LN is represented by the set

$$LN = (LN_i)_1^4, \tag{22}$$

where $LN_1 = \{W\}$ is the wall; $LN_2 = \{B_1, B_2\}$ means the upper and lower belts; $LN_3 = (St_j)_{1}^{N_{LN_3}}$ denotes stilts (St); and $LN_4 = (Rv_j)_{1}^{N_{LN_4}}$ denotes rivets (Rv).

Let the manufacturing of node (22) determine the tuple of technological operations

$$T = (T_i)_1^5, \tag{23}$$

where $T_1 = \{\text{Install } W, B_1, B_2\}$; $T_2 = \{\text{Drill, rivet } B_1, B_2\}$; $T_3 = \{\text{Install } St_j, j = 1 \dots N_{LN_3}\}$; $T_4 = \{\text{Drill, rivet } St_j, j = 1 \dots N_{LN_3}\}$; $T_5 = \{\text{Control the assembled LN}\}$.

According to the general approach described, the figures of (22) are the bodies, and the technological operations of (23) are geometrically reduced to the change in the parameters of the position and the shape of these objects.

Fig. 5 (using the front and left views) shows the result of the T_1 operation.

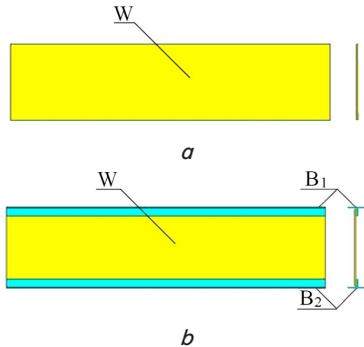


Fig. 5. Installation of the wall and the belts of the centreplane longeron: a shows the wall; b show the upper and lower belts

The parameters of the wall W as a rectangular parallelepiped are length, height, and thickness. For the T-shaped belts B_1 and B_2 , the parameters are the dimensions of the cross sections and the length. The operation of installing these parts consists in moving them to the necessary position of the proper base, which for the bodies can be carried out by the conjugation of face surfaces, edges, vertices, etc.

The operation T_2 is illustrated in Fig. 6, where the belts are attached to the wall of the longeron through drilling of the required holes and subsequent riveting.

For a dynamic simulation of the drilling of cylindrical holes, it is recommended to use a computer solid-state drill

model and its geometric model presented in the Cartesian coordinate system $Oxyz$ as a combination of a cone

$$r(x, y, z) = r \left(\left((1-w) \frac{D}{2} \right) v \cos(2\pi u), \left((1-w) \frac{D}{2} \right) v \sin(2\pi u), wH \right) \tag{24}$$

and a straight circular cylinder

$$\mathbf{r}(x, y, z) = \mathbf{r} \left(\frac{D}{2} v \cos(2\pi u), \frac{D}{2} v \sin(2\pi u), wH \right), \tag{25}$$

where D is the base diameter; H is the height; $u \in [0, 1]$, $v \in [0, 1]$, and $w \in [0, 1]$ are the parameters.

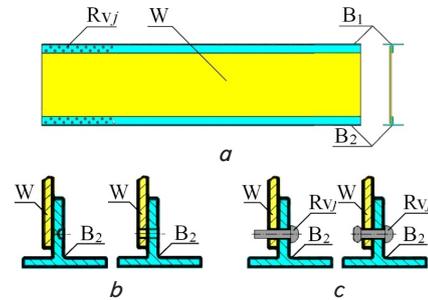


Fig. 6. The technological operation T_2 of drilling and riveting the belts B_1 and B_2 : a is the general view; b is the beginning and completion of drilling a hole; c is the beginning and completion of riveting

Expressions (24), (25) determine the part of the space occupied by the drill at its rotation. During the working process, the drill moves and cuts into the part. From a geometric point of view, this means a Boolean operation of subtracting the proper rolling volume of the drill from the part.

For the computer dynamic constructions of closing heads of rivets, we will use a geometric model of settling a direct circular cylinder, which is shown in Fig. 7.

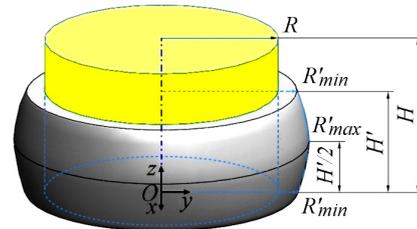


Fig. 7. A model of settling a cylinder

The output cylinder has the base radius R and the height H . For the settled body, the relative compression is

$$\varepsilon = (H - H') / H, \tag{26}$$

where H' is the reduced height, and R'_{min} and R'_{max} are the increased radii of the bases in the contact planes and the median horizontal plane of symmetry.

The lower and upper parts of the lateral surface of the settled body, which are symmetrical in relation to the median horizontal plane, are formed in the rectangular coordinate system $Oxyz$ by rotating around the axis z of the arcs of the second order curves:

$$\mathbf{r}_i(u) = \frac{(1-u)^2 \mathbf{r}_{0i} + w_1 2u(1-u) \mathbf{r}_{1i} + u^2 \mathbf{r}_{2i}}{(1-u)^2 + w_1 2u(1-u) + u^2}, \quad (27)$$

where $i \in \{b, t\}$ are the indices of the bottom and top parts;

$$\mathbf{r}_{0b} = (0, R'_{\min}, 0), \quad \mathbf{r}_{1b} = (0, R'_{\max}, 0), \quad \mathbf{r}_{2b} = (0, R'_{\max}, H'/2),$$

$$\mathbf{r}_{0t} = (0, R'_{\max}, H'/2), \quad \mathbf{r}_{1t} = (0, R'_{\max}, H'), \quad \mathbf{r}_{2t} = (0, R'_{\min}, H')$$

are the radius vectors of the vertices of the characteristic triangles; $w_i \geq 0$ is the weight ratio of the peaks \mathbf{r}_i ; and $u \in [0, 1]$ is the parameter.

During plastic deformation of the body, its volume is considered to be constant and is calculated as

$$V = 2 \cdot \pi \int_0^{H'/2} y(z)^2 dz = 2 \cdot \pi \int_0^1 y(u)^2 z(u) du = 2 \cdot \pi \int_0^1 \frac{\left((1-u)^2 R'_{\min} + ((1-2w_1)u^2 + 2w_1u) R'_{\max} \right)^2 u(1-u+w_1u) H'}{\left((1-u)^2 + 2w_1(1-u)u + u^2 \right)^4} du. \quad (28)$$

For the available data on the relative compression ϵ and the corresponding values of the radii R'_{\min} and R'_{\max} , the required volume V of the deformed body is provided by the values of the weight coefficients w_1 , which are calculated by minimizing the function

$$F(w_1) = |\pi R^2 H - V(w_1)|, \quad (29)$$

the extreme value of which is zero.

Consequently, expressions (26)–(29) constitute the mathematical basis of the computer dynamic constructions of the closing heads of the rivets.

From formula (23), it is evident that the operations are the installation, drilling and riveting of stilts (Fig. 8). These actions are largely similar to those analyzed above for the belts.

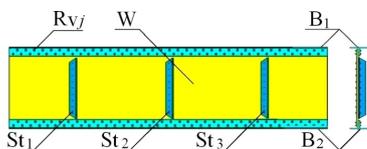


Fig. 8. Operations T_3 and T_4 of installation, drilling, and riveting of stilts

The finishing stage is the control T_5 of manufacturing the longeron, which may consist in checking the composition of the resulting node, the correctness of the values of the parameters of the shape, size and position of its elements, etc.

6. Discussion of the results of the proposed method of computer variant dynamic formation of technical objects on the example of the aircraft wing

The mathematical apparatus of dynamic formation of technical objects has been devised with the aim to improve and develop computerized structural and parametric geometric models by appropriate integration with their available

mathematical support. This is the main scientific theoretical novelty of the results.

The automated variant construction of the aircraft wing surface and the dynamic solid-state modeling of the centerplane longeron are of practical importance. The results have confirmed the reliability of the proposed method of computer-based variant dynamic formation of technical objects on the basis of the parametric structural approach. This applies to the classification of applied geometric figures and their modifications, a combination of stages of sketch, technical and working designs, and the reproduction of certain technological processes of mechanical engineering.

Due to the controversial requirements of aerodynamics, strength, production and operation of the variation of the shape, size and position of the aerodynamic profiles of the projected wing, it is implemented by flexible means. The presented techniques of computer construction are aimed at ensuring the successful implementation of the appropriate multicriteria optimization. Thus, the presence of the possibility of parallel transfer of the final

profile \mathbf{r}^k in the model (Fig. 4) along the z axis determines the required L width of the wing; along the x axis, the angle χ is sagittal, and along the y -axis, the angle V is transverse. The profile rotation around the parallel z axis of the straight line provides a bearing for the aerofoil. It is also important to emphasize the variant nature of the created model of the wing longeron. Each element has its own geometric parameters of shape, size, and position. For example, the cross-section of the stilts can be not only angular (Fig. 8) but also T-shaped, and the stilts have certain dimensions and necessary quantity to be located properly.

Consequently, the fundamentally new features of the proposed dynamic parametric structural geometric models are the presence of their parameters related to the displacement and deformation of the constituent elements.

It is known that the development of complex technical objects, in particular in the aviation industry, has an iterative variant nature. Thus, during the technical task, the main characteristics of the product are determined, the possibility and expediency of its manufacturing are substantiated. The technical proposal contains the specified technical and economic characteristics, the draft design (the fundamental engineering solutions that give a general idea of the structure and operation of the product), and the technical design (the final technical solutions that give a complete picture of the product). In the aviation industry, at the stages of the sketch and technical projecting, various layouts of the technical object and its components are created, which is now often performed in a computerized form, and manufactured. In the course of the working design, the documentation for producing prototypes is first drawn up, and then, after proper correction on the basis of tests, mass production is launched.

In all of the above-mentioned stages of creating technical objects, geometric models are used, which are gradually complicated and refined in accordance with the stages of the lifecycle of mechanically engineered products.

The techniques and algorithms of parametric structural geometric modeling have been implemented at the Antonov Aviation Scientific and Technical Complex during the design of the AN-148 aircraft, the production of the trolley

bus K12 at the State Enterprise Kyiv Aviation Plant Aviant, while performing design and development works for manufacturing technological equipment at the Kharkiv Aviation Manufacturing Enterprise, as well as while developing a system for automation of processes for the formation of a three-dimensional model of a vessel's hull at the Open Joint Stock Company "Research Institute of Automated Systems and Computer Science in Shipbuilding", and at other leading enterprises of Ukraine.

A promising direction of the modern development of parametric structural geometric modeling in the scientific and practical aspects consists in its further improvement by devising new methods, techniques and algorithms of dynamic shaping, which will significantly increase the accuracy and realism of the computer models. Some of the aforementioned issues have been elaborated in this paper by the proposed method of computer-based variant dynamic shape-forming of technical objects, which is illustrated by the example of the wing of an aircraft.

7. Conclusions

1. The scientific theoretical novelty of the obtained results consists in the development of a mathematical apparatus for the dynamic formation of technical objects, which is aimed at improving and further developing of computerized structural and parametric geometric models by appropriate integration with their available mathematical support.

2. The practical value of the obtained results consists in creating a method for the use of parametric structural geometric modeling for computer variant dynamic formation, which allows a flexible combination of the processes of designing and manufacturing technical objects.

3. The obtained practical results have confirmed that the proposed techniques of automated construction provide integrated processing of technological processes used in the manufacture of aircraft products.

4. The presented materials can be applied to various products of mechanical engineering and other industries.

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