# Methods of the automated aircraft configuration

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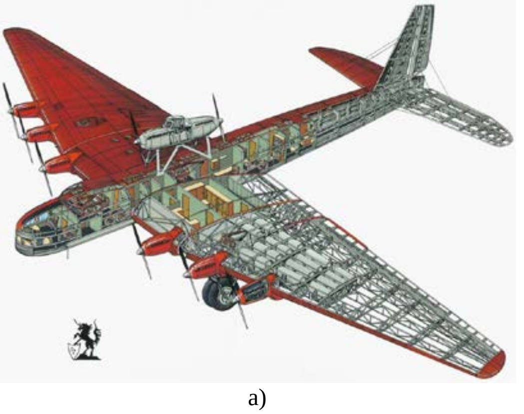
***Abstract:*** *Aircraft are great and comprehensive technical systems, which are characterised by the great configuration density. This article presents formation of the geometrical conceptual design of the aircraft on the basis of the formal heuristic procedures within the framework of the infrastructural constraints. In addition, this article includes description of influence of the aerodynamic configuration and the volume-weight configuration upon formation of the geometrical conceptual design of the aircraft, as well as description of other mass/inertia characteristics of the aggregates, which are to be installed within the specific aircraft. This article also states that in the case of the "very strict" infrastructural constraints, it is necessary to solve "the inverse" problem of configuration, that is the problem, where initial data for formation of the geometrical conceptual design of the aircraft are determined by the necessary configuration space, which is determined by the infrastructural constraints. The article presents the project problem (in aggregate) of finding rational values for parameters of the geometrical conceptual design of the aircraft as the problem of the multiple criteria discrete optimisation. This article states that it is possible to formulate this problem as the search of the vector of structural parameters (that is, search of the multitude of the admissible alternatives of the drawing and designing solutions).*

***Key Words:*** *infrastructure, automated configuration, dense configuration, geometrical models, conditions of mutual absence of intersection*

## 1. INTRODUCTION

Aircraft has the well-developed hierarchical structure and it is considered as great and comprehensive technical system, which is characterised by the great configuration density [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15]. Accomplishment of the constructional design of many products within the aerospace complex is determined by quality of their configuration, that is, by quality of location of the necessary equipment and the useful load. The method, which makes it possible to achieve such success, is connected with utilisation of the state-of-the-art information technologies [1], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25]. As concerns products with high configuration density (first of all, the state-of-the-art aerospace facilities), it is necessary to ensure development of the mathematical support and relevant software for the systems of the automated configuration. Such mathematical support and software are to be developed on the basis of the geometrical models, which are used for description of the form and process of location of the objects that are to be assembled together. Due to development of the state-of-the-art equipment (first of all, transport vehicles and, particularly, development of the aerospace facilities), growth of requirements to such equipment and facilities, as well as due to increase in the density of configuration, designers must permanently improve methods of automation of the construction design [4; 16; 26-27]. In order to ensure visual demonstration of this situation, we have included which presents two aircraft, which belong to various historical periods and which have approximately equal take-off weights (up to 30 tons). You can see “Maxim Gorky” aircraft (USSR, the thirties of the last century (Figure 1 *a*) and the state-of-the-art aircraft Su-24 (Figure 1 *b*). Let’s compare these two aircrafts and take into account the fact that the state-of-the-art aircraft includes much more various airborne equipment units.



a)

b)

Fig. 1 – Two aircraft, which belong to various historical periods and which have approximately equal take-off weights (up to 30 tons). *a* – “Maxim Gorky” aircraft (the thirties of the last century); *b* – our days (Su-30)

First of all, the problem of configuration quality is topical for the long-range aircraft, where increase in overall dimensions causes additional environmental resistance in the course of movement of the transportation vehicle. This problem is very topical for the supersonic aircraft, which are characterised by the comprehensive geometrical forms and high configuration density.

## 2. METHODOLOGY

In principle, “configuration” term is understood as the ensemble of the geometrical objects, three-dimensional position of which is fixed with respect to the general coordinate system (provided that this position complies with the prescribed requirements). Tasks of configuration are to be solved in the course of the constructional design of any technical objects, but this task is very comprehensive if it is necessary to find solutions in respect of configuration of the flying vehicles (FV). Therefore, we would like to state from the very beginning that we will analyse all geometrical models of configuration under investigation in respect of configuration of the FV, because of flying vehicles have the most comprehensive configuration both from the technical point of view, and from the geometrical point of view. However, this fact does not decrease value of these methods for other objects of the constructional design in any matter.

In the course of formation of the general aircraft concept, problem of configuration is reduced to performance of the positioning procedures within the feasible/admissible space of the main aggregates and systems, which form general composition of the aircraft. Formal characterisation of the configuration procedures depends on the intended functional use, on the geometrical, mass, and inertial characteristics, as well as on many other characteristics of these aggregates and system. As concerns certain aircraft types, influence of the strict configurational restrictions and infrastructural constraints is the problem of the conceptional nature: supersonic manoeuvrable aircraft, regional mixed cargo vertical-takeoff-and-landing aircraft (VTOL), as well as long-range aircraft of great and super great passenger-carrying capacity (LRS GPCC).

At the stage of the configuration work, it is necessary to find solution of the triunique problem *of the aerodynamic configuration, volume-weight configuration, and structural-force design*. Within the process of aerodynamic configuration, it is necessary to find more exact values of those parameters, which were obtained in the course of selection of the general aircraft scheme, as well as to reveal more exact values of those characteristics, which represent the aircraft exterior. At the stage of the volume-weight configuration, it is necessary to ensure proper location of the functional components within the prescribed airplane configuration, as well as to calculate mass/inertia characteristics. The stage of synthesis of the design scheme is aimed at resolving the contradictions between requirements of inner design and formation of the external contours of the aircraft. In order to minimise quantity of iterations and ensure convergence of the design, it is necessary to identify the critical factor of this process and to build the design procedures into the uniform algorithm in respect of this factor. The infrastructural constraints (height of the air stairs/ height of the aircraft ramps of the passenger-carrying aircraft; dimensions of the freight elevator on the deck of the aircraft-carrying cruiser, etc.) exert the major influence upon formation of the admissible configuration/ design and upon procedures of positioning aggregates and systems of the aircraft within this space [15]. Figure 2 presents the enlarged flowchart, which makes it possible to take into consideration all these factors.

As a rule, "stringency" of the infrastructural constraints stipulates the configuration space in a unique manner. This fact results in the rationality of solution of the "inverse" problem of configuration, where conceptual design of the aircraft is stipulated by the limited configuration space and is formed on the basis of such limited configuration space. *In this case, implementation of the "inverse" problem of configuration is stipulated by the following two conditions: it is necessary to find and determine the configuration space and then it is necessary to decompose this space in accordance with relevant characteristic attributes.* There are two groups of such attributes: attributes, which are determined by the infrastructural requirements (overall dimensions of the aircraft) in a unique manner and more multiple-meaning attributes (centre-of-gravity location, moments of inertia, and specific density).

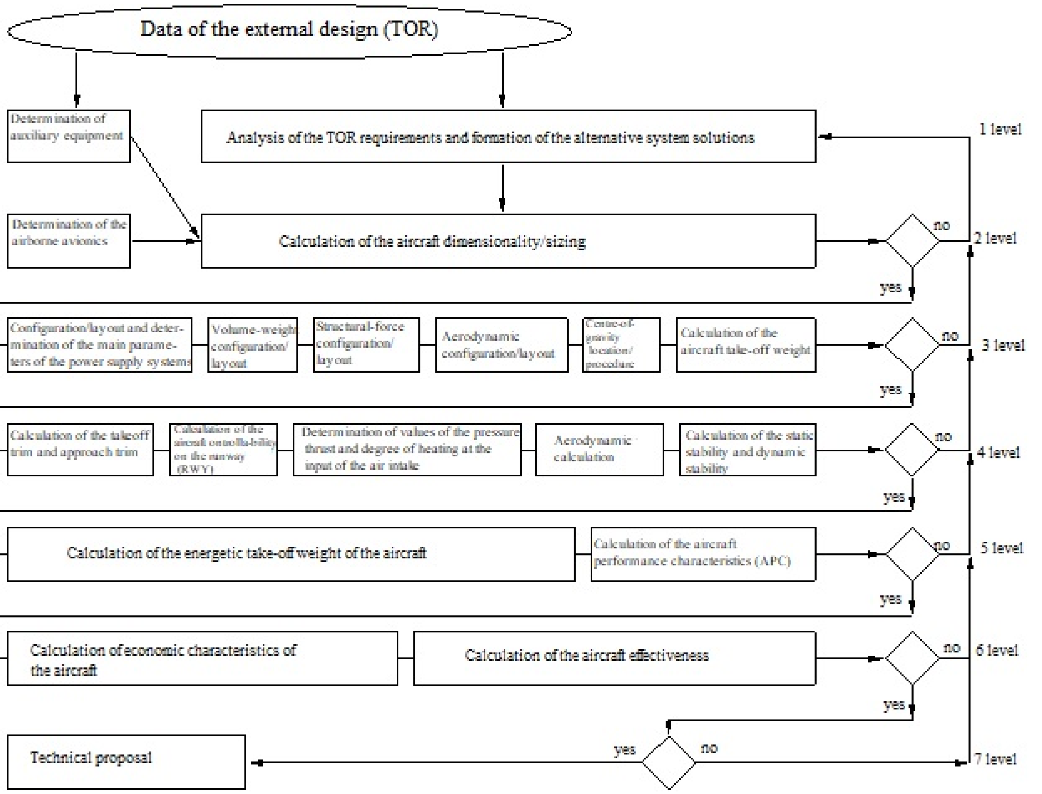



Fig. 2 – Flowchart of formation of the aircraft concept

In the aggregate, the project problem of searching rational values of parameters of the aircraft concept is presented as the problem of the multiple criteria discrete optimization. In principle, it is possible to formulate this project problem as follows: it is necessary to search the vector of structural parameters $X^* \in X_{add}$, where $X_{add}$ is the multitude of the admissible alternatives of the drawing and designing solutions. This vector of structural parameters $X^*$ consists of the components, which are in compliance with the minimum value of the objective function $F(x,u)$, which ensures inclusion of parameters and characteristics of the project to the multitude of constraints $U$:

$$X^* = Arg\,min \underset{\substack{x \in X \\ u \in U}}{F} (x,u), \tag{1}$$

where $X=X(x_i)$ is vector of the project parameters, $U=U(u_i)$ is vector of constraints.

## 3. RESULTS AND DISCUSSIONS

In accordance with the results of analysis of the initial data, which were obtained at the stage at the external constructional design, relevant multitude of requirements and constraints $U=U(u_i)$ is formed. Dimensionality of the vector *"I"* is determined by the TOR of the project. At this stage, it is necessary to replace the requirements, which are the requirements of verbal nature, with the mathematical equivalents of these requirements. These dependencies determine each drawing and designing solution $x_{ij}$, which was entered earlier to the matrix of drawing and designing solutions $[X_{ij}]$ in the verbal form. Quantity of such matrices and their particular composition is determined by the designer for each specific situation on the individual basis.

Search of a new solution is the deepen analysis of advantages and disadvantages of old solutions (first of all) along with subsequent synthesis of the new solution, which would be the result of solving the prescribed problem at the higher technical level.

Search of new solutions is performed within the system of constraints. which are determined by the already established infrastructure [28]. Figure 3 presents three alternative aerodynamic trimming schemes of the long-range aircraft: flying wing, normal scheme, and triplane schemewithin the sphere of constraints of the infrastructural terminal layouts. The aircraft, which were designed in accordance with the normal aerodynamic scheme, do not fit in the quadrate (80 x 80 metres) neither in width nor in length. Triplane scheme is fit in length only, while flying wing scheme is fit in width only. It can be seen from Figure 3 that the aircraft begins to be "more thick" in the case of increase of general dimensions. It is possible to observe increase of the fineness ratio in respect of the aircraft of average dimensions. As concerns the Super Jumbo jet (A-380) it is possible to observe beginning of increase of the fuselage mid section of the aircraft.

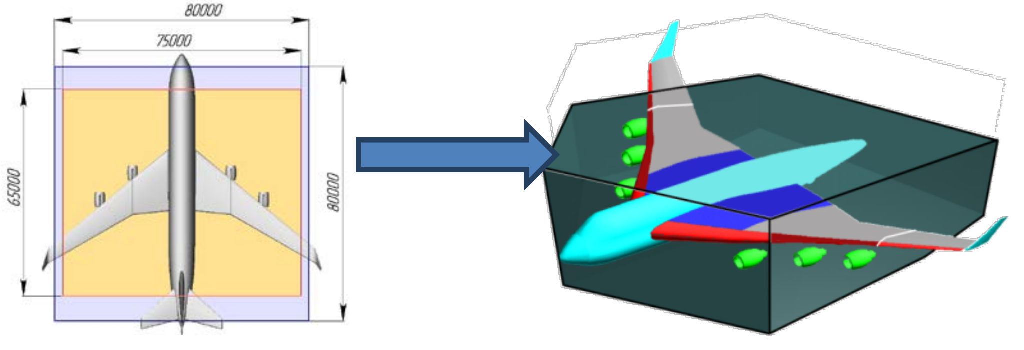



Fig. 3 – Long-range aircraft within the sphere of the infrastructural terminal constraints

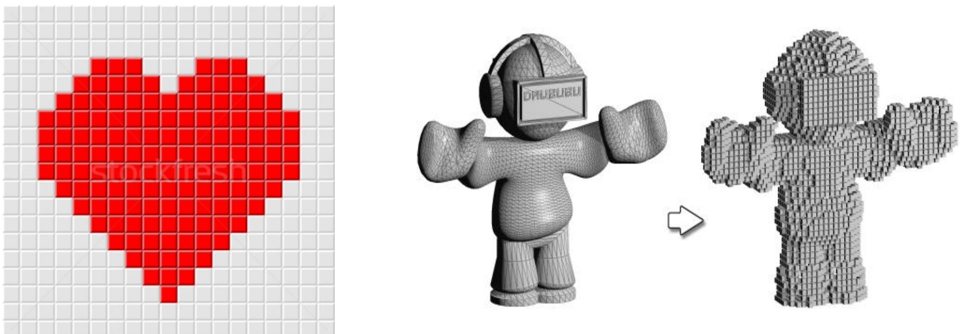
At this stage, it is necessary to form the design scheme solutions in respect of the conceptual design of the aircraft. Then it is necessary to form the design scheme of the aircraft on the basis of the accepted design scheme solutions depending on the prescribed weight of the take-off payload, weight of equipment, and accessories. This design scheme is based on the mutual spatial coordination of the main combined components of the aircraft with the relevant moments of inertia of the aircraft:

If it is necessary to consider the problem on the whole, then it is possible to state the following: from the point of view of the volume-weight configuration, the optimal configuration will be ensured for the aircraft, external contour of which will be determined as the result of positioning of all aggregates provided that all conditions of the inner configuration will be complied with. This condition states that process of configuration must be critical not only in respect of three coordinate axes in three flat surfaces, but also in respect of any arbitrary radius-vector of the junction point of aggregates and systems of the aircraft, provided that this radius-vector begins from the centre of mass of the aircraft.

$$\vec{R} = Min\{|\vec{R}_i(\vec{x}, \vec{y}, \vec{z})|\}, \tag{2}$$

The state-of-the-art computer-generated graphics has made it possible to solve the problem of description, problem of engineering analysis, and problem of visualisation of geometrical objects, that is, problems of practically any complexity. However, it is not possible yet to solve the problem of such geometrical description of objects, which would have the property of *"composability"*, that is, which would solve the problem of their rational location in the space in accordance with the prescribed criteria and which would determine the most important parameter of the configuration quality: *condition of mutual absence of intersection* (CMN).

Therefore, we believe that there exists the extremely interesting and topical task as follows: it is necessary to develop ideas and methods, which would make it possible to minimise the "stupid" enumeration of various alternatives of location (at the very least) or even to avoid such senseless enumeration completely. If an additional requirement of composability (provided that geometrical model must comply with this requirement) would be added to such problems, then these problems must be provided with new properties, which would make it possible to ensure these requirements. It is necessary to be ready to the fact that additions of these new properties would result in over complication of the model or would cause deterioration of other characteristics of this model, which are less important characteristics for us in the relevant cases.



a) b)

Fig. 4 – Receptor model of the 2D object (a) and of the 3D object (b)

We are convinced that application of the non-traditional (as concerns the engineering drawing and computer graphics) *receptor method and method of normal equations* are only attempts of solving this problem. Essence of the receptor method (which was proposed by Professor D. M. Zozulevich [11], [12] in the middle sixties of the last century) is as follows: it is necessary to ensure discretisation of the space of location and discretisation of the objects, which are to be assembled together, in such a manner that the space and these objects would consist of the elementary volumes – *receptors* (or *voxels* in accordance with the western terminology) – see Figure 4. Each of such receptors (as a rule, it is a parallelepiped) within this geometrical model "has its own independent life". There milliards of such receptors within the configuration environment, but this situation is very simplified due to the fact of existence of the exceptionally simple algorithms of analysis of their mutual location. Such approach makes it possible to solve many applied problems in the sphere of the automated configuration [13], [14], [18], [29], [30].

The apparatus of normal equations is another non-traditional method of description of the form of the objects that are to be assembled together. *Normal equations* are meant as the special method of description of the form of objects (the method was proposed by Academician V. L. Rvachev [17]), and this method ensures simple and easy determination of the shortest distance to the nearest objects provided that these objects are described by the normal equations as well. In accordance with the determination, which was proposed by V. L. Rvachev, normal equation of the geometrical object $F$ ("drawing" under the terminology of V. L. Rvachev) is the special case of the nondenumerable set of R-functions of this object in the space $\Re^n$ (where n is dimensionality of the geometrical object). This special case is described by the following equation:

$$\omega = \rho(A,L) = \inf_{N\epsilon F}\|A-N\| = \inf_{N(x_N,y_N,z_N)\epsilon F}\sqrt{(x_A-x_N)^2+(y_A-y_N)^2=(z_A-z_N)^2} \quad (3)$$

This equation is a unique equation for any geometrical object (drawing). This term ("normal equation") was selected by analogy with another term ("normal equation of a line"), which is known from the analytical geometry. In this case, "normal" is the key word, because of the shortest distance from a point to a line is always determined by the normal.

Both utilisation of the conceptual apparatus of normal equations and determination of their geometrical meaning make it possible to develop the methodological basis for geometrical simulation of configuration problems. Figure 5 presents geometrical meaning of a normal equation.

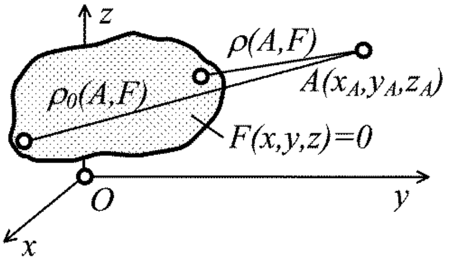



Fig. 5 – Geometrical interpretation of the normal equation of the spatial object *F*

Suppose that there exists the arbitrarily-spaced surface in the space. This surface limits the object *F* and this surface is described by the equation $F(x, y, z) = 0$. Let us assume that it is possible to put this surface into correspondence with the certain equation $f(x, y, z) = 0$, which is the appropriately defined normal equation of this object. If there exists a certain point $A(x_A, y_A, z_A)$ in the space, then the shortest distance in the space from point *A* to the object *F* (in accordance with the determination of the normal equation of the object) will be determined by the equality $\rho(A, F)=f(x_A, y_A, z_A)$.

Therefore, value of the normal function in the certain point of the space *A* is equal to minimum distance from this point *A* to the object *F*, that is, in order to determine the shortest distance from a point to an object it is sufficient to enter coordinates of this point instead of the relevant variables in the normal equation of the object.

In addition, Academician V. L. Rvachev has introduced the concept of the upper normal function

$$\rho(A,F) = \sup_{N\epsilon F}\|A-N\|, \quad (4)$$

Geometrical meaning of the upper normal function is connected with possibility of determining the distance from the point *A* to the most distant point of the object *F* (see Figure 5).

Utilisation of apparatus of normal equations in the problems of the automated configuration is the extremely interesting task: as if the object itself determines distance and direction to the point, which is the point of our interest. Therefore, the algorithms, which are based on application of this method, include certain components of the artificial intelligence, which determines the rational direction of the object movement in order to obtain the densest configuration. Algorithm itself determines the minimum distance to another composable object, as well as the direction, in which it is necessary to move in order to come in contact with this object. “Plus” of normal equations is the possibility of development of the “smart” algorithms of configuration on their basis. “Minus” of normal equations is the necessity of an additional description of the form of objects by the normal equations.

Although such approaches open new possibilities for development of the smart algorithms of configuration [16], [26], [27], which make it possible to avoid “blind enumeration”, authors fully realize that in order to ensure practical implementation of these approaches, it is necessary to install relevant software application to the standard systems of the geometrical simulation in the form of additional calculated modules.

Assessment of the configuration quality is performed in accordance with partial criteria of the aircraft effectiveness. Such procedure makes it possible to exclude from consideration those alternatives, which are knowingly inefficient ones. Majority of the partial criteria are interrelated with one another, and this fact does not let to use them in the course of assessment of various projects, because of necessity of introduction of weighting factors results in subjective estimates.

In the course of configuration, it is possible to determine both geometrical characteristics of the aircraft in its entirety, and characteristics of inner positioning of each aggregate of the aircraft. This is necessary condition for calculation of the aircraft take-off weight in the second approximation, as well as for performance of the centre-of-gravity. In the second approximation, the aircraft take-off weight is determined as the sum of masses of individual aggregates and systems, masses of which were calculated in accordance with various empirical dependencies taking into account results of configuration. That is, it is possible to determine dimensionality of the aircraft (for example, take-off weight) if and only if the geometrical conceptual design is formed.

In the third approximation, mass of the airframe structure is determined in accordance with the finite-element model taking into account the relevant loading spectrums, as well as taking into consideration the information on the mass/inertia characteristics, which were obtained in the course of previous approximations. Process of transfer from one stage to another one is accompanied by excessive complication of models [19], [20], [31], [32] and by increase in the volume of the input information, however, accuracy of calculations is increased as well (Figure 6).

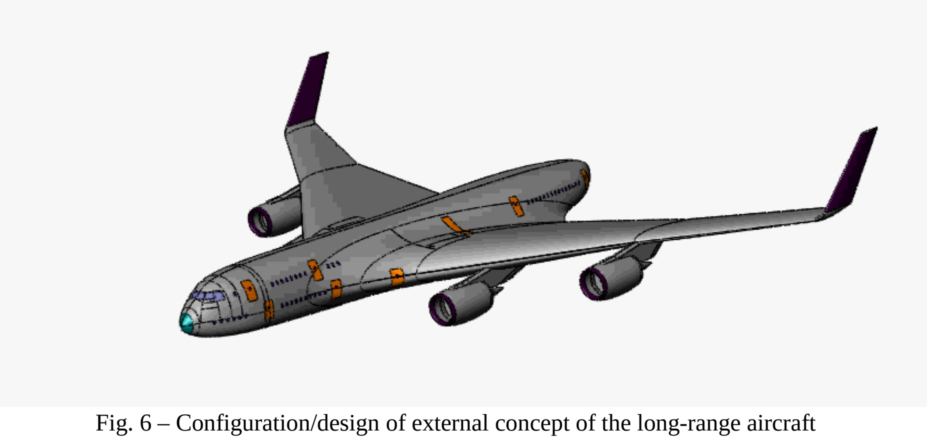


Fig. 6 – Configuration/design of external concept of the long-range aircraft

The end stage of configuration process it is necessary to check conditions of reducing the actual centre of mass to the virtual centre of mass (check of coincidence), which is necessary but not sufficient condition of convergence of the process of the aircraft configuration.

## 4. CONCLUSIONS

1. Effectiveness of the inner configuration of the aircraft defines possibilities and effectiveness of subsequent aerodynamic, volume-weight and structural-force configuration procedures in many respects.
2. Process of inner configuration requires application of the specific geometrical models of the objects that are to be assembled together provided that such models are specially adapted for solution of configuration problems.
3. New approaches (receptor models and normal geometrical models) make it possible to develop “smart algorithms” (on the basis of geometrical models), which combine the designer's experience, which is already implemented in these models (in the form of the programmed heuristic devices), with the possibility of use of the computational horsepower of the state-of-the-art computers.
4. Despite of the certain decrease in the accuracy of description of the geometrical form of the objects, which are to be assembled together, we obtain new possibilities as follows: immediate assessment of minimum distances to the already existing objects; possibility of the preliminary estimation of forms of free spaces (almost sphere with a certain radius, almost parallelepiped with certain dimensions, etc.), as well as many other possibilities.

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