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Configuration of Design and Engineering Parameters of Aircraft

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ABSTRACT: Designing of long-distance aircraft (AC), in particular at preliminary stage, requires for comparison and analysis of numerous design alternatives and searching for optimum solution on the basis of selected efficiency parameters. At this stage the issue of configuration of rational design and engineering parameters is solved, which is an urgent problem of the preliminary stage in AC design. The developed method, implemented in the form of application software, allows one to conduct a multidimensional ordered parameterization process, which ensures the achievement of an extremum of a given criterion and determines the vector of AC parameters. Thus, the authors propose introducing a global criterion -AC gross weight, and the partial criteria are lift-to-drag ratio at cruising regime and fuel efficiency. In such formulation of design problem, it is required to solve certain interrelated problems, whereas some of them are formalized and the other ones are not supported by mathematical toolsand software, allowing automating the process. Unifying base of the proposed approach to searching for design solution is correlation and factor analysis with subsequent development of polynomial models and predictions by the Brandon method implemented in unified IT environment using Fortran V and C++ languages.

Keywords: aircraft, formal model, identification of parameters, multiparameter approach, parametric synthesis, vector of parameters.

I. INTRODUCTION

Currently, the priority areas in the world and Russian aircraft (AC) manufacturing, considering the implementation of the state program of the Russian Federation "Development of the aviation industry for 2013-2025", include [1]:

– decreasing the accident rate and increasing the safety factor;

– increasing the resource and decreasing the weight of the AC structure due to the use of new structural and composite materials;

– reducing fuel consumption due to the use of efficient power plants with a high bypass ratio;

– improvingthe AC aerodynamics (currently the least studied area),allowing achieving significant changes in the AC flight performance.

The general trends in perspective design include the solution of particular optimization problems and the improvement of aerodynamic characteristics of AC. The issue of improving the aerodynamic characteristics of long-distance AC is directly related to the appearance of AC and the system of bearing surfaces in particular [2-5]. In the current design practice, the combination of a wing and power plant is called the "main working body of AC".The process of designing and constructing a wing must be carried out based on the adopted aerodynamic scheme specified in the "first ACdrawing", considering promising structural materials, production technologies and achievements in the field of aerohydrodynamics and aeromechanics.

Improving the aerodynamic characteristics of a long-distance AC wing is associated with providing the required value of the lifting force with the lowest possible drag coefficient for steady-state flight modes, as well as the required flight performance at the take-off and landing stages.

The main difference between the proposed approach and the existing ones is the developed scientific and methodological support, which allows improving the design of long-distance AC based on the selected performance criterion at one hierarchical design stage.

To achieve the set indicators based on the set of possible solutions, changing the sweep angle and narrowing and elongating the wing, area, geometric twist, as well as the cross-sectional shape along the wingspan (aerodynamic twist), we search for a rational design solution. Conventional designing of AC assumes draft drawing of future object: the initial AC drawing, and estimation of its applicability for implementation of the formulated problem. Peculiar feature of this stage is comparison and analysis of numerous design alternatives (vertical projections of AC, combination of elements, etc.). Comparison of design alternatives and selection of reasonable solutions are based on comparison of properties peculiar for this or that design alternative under various operational conditions (AC speed, flying altitude, flying range, and others). In this regard it is necessary to analyze considerable amount of statistic data, and the confidence degree for analyzed parameters is presented in certain confidence range. It is impossible to estimate and to highlight the most influencing parameters by non-automated method [6-9]. Upon formalized consideration of existing design concepts of long-distance AC and their elements, the term concept is interpreted as the object structure with efficiency performances for various levels of hierarchy; thus, the concept can be presented by a set comprised of efficiency criteria with specific for this level coefficient of importance (significance, contribution of the parameter).

Upon such approach to formalization of design procedure, it is necessary to estimate the importance of this or that efficiency criterion at certain level of hierarchy. Taking into account that applicability of implementation of formulated design target is estimated by draft (drawing) with projections of AC and its elements, such drawing is based on processing of statistical data (analogs of designed AC). At this stage, it is impossible to determine advantages of applied partial solutions, for instance, wing-to-fuselage fillet, additional aerodynamic surface (AAS) (winglet), stagger and shape of nacelle, etc.

II. METHODS

In the existing practice of AC design, a special mathematical apparatus is used, as well as software for analyzing and systematizing the results of special flight tests, conceptual design technologies based on a consistently expanding scientific and technical reserve and methods of statistical analysis. However, the complex task of finding the optimal design solution in the form of applied software has not yet been solved.

The method proposed in this work includes the traditional principles of designing software implemented in a single information environment combined with methods of statistical information processing, namely, correlation and factor analysis and subsequent construction of polynomial models, as well as forecasting using the Brandon method.This allows finding a vector of parameters that would satisfy the requirements and restrictions imposed on AC with the selected performance criteria at the preliminary design stage.

Concept ualization of long-distance AC at the stage of draft proposal can be formulated as follows: to determine such vector of parameters characterizing shape, structure, and dimensions of AC which would meet the requirements and constrains to AC and achieve minimum (maximum) of target function. Design procedure starts on the basis of conditions of physical implementation and conformance with fundamental interrelations between equations of weight balance, gravitation balance, energy balance, AC stability and balance.

$$\sum m_i - 1 = 0;\ n_y m_q - Y = 0;$$
$$P - X - m\frac{dV}{dt} = 0; \bar{\bar{x}}_T - \bar{\bar{x}}_F + m_z^c y = 0;\ m_z = 0. \quad (1)$$

AC gross weight is selected as global efficiency criterion, m_0, since flying range, cruising speed, useful load, cost and lifetime of components, as well as predefined runway length are commensurable.

Partial criteria of technical efficiency are lift-to-drag ratio at cursing regime K_{cruise} and fuel efficiency G_{fuel}.

The combination of parameters to be predicted and optimized form the vector of parameters characterizing AC concept.

$$\vec{\mathbf{X}} = (x_1, x_2, x_3, \dots x_m) \quad (2)$$

AC properties depending on the parameters x_1, x_2, x_3,… x_m, form the vector of AC properties.

$$\vec{\mathbf{Y}} = (y_1, y_2, y_3, \dots y_n) \quad (3)$$

Conceptual parameters and properties are interrelated by certain dependences. Upon mathematical formulation, the requirements of Eqn. (1) are met by a set of constraints comprised of the vector of parameters $\vec{X}$ and the vector $\vec{Y}$described as follows.

$$\begin{cases} x_i^L \le x_i \le x_i^U, i = 1,2,3, \dots m \\ y_j^L \le y_j(\vec{X}) \le y_i^U, j = 1,2,3, \dots n \end{cases} \quad (4)$$

where x_i^L is the lower allowable limit of conceptual parameter; x_i^U is the upper allowable limit of conceptual parameter; y_j^L is the lower allowable limit of property; y_i^U is the upper allowable limit of property.

Any vector $\vec{\mathbf{X}}$, belonging to the region of allowable solutions $(\vec{\mathbf{X}} \in \vec{\mathbf{X}}_{supp})$, defines allowable design alternative of AC. Then, with the selected efficiency criteria m_0, among the allowable design alternatives of AC, there can exist such vector of parameters $\vec{\mathbf{X}}$ providing extreme optimality criterion, at which $m_0 \to \min$ with retention of the vector of properties $\vec{\mathbf{Y}}$ meeting the requirements in the scope of selected constraints, is as follows.

$$\vec{\mathbf{X}}_{supp} = \min_{\vec{X} \in \vec{X}_{supp}} F(\vec{\mathbf{X}}, \vec{\mathbf{Y}}) \quad (5)$$

Under established conditions, it is required not to adjust further the existing coefficients but to develop a new approach, as well as the procedure with the basic principles not related strictly with empiric dependences and existing computation equations; herewith, it is necessary to provide interrelation with validation basis aiming at estimation of conformance between design alternative in the limits of implied physical sense and boundary conditions.

III. RESULTS

The considered set of alternative vectors of schematic solutions with consideration for Eqn. (2) and parameters describing the concept, form the matrix of vectors of schematic solutions:

$$\vec{\mathbf{X}} = \begin{vmatrix} & & / & \\ x_{11}, & x_{12}, & x_{13},\cdots x_{1m} \\ x_{21}, & x_{22}, & x_{23},\cdots x_{2m} \\ x_{31}, & x_{32}, & x_{33},\cdots x_{3m} \\ & & \cdots & \\ x_{i1}, & x_{i2}, & x_{i3},\cdots & x_{im} \end{vmatrix} \quad (6)$$

Properties depending on the parameters for Eqn. (6) form the matrix of properties depending on the vectors of parameters $\vec{\mathbf{X}}$.

The limits are a set of properties predefined by project specifications. For long-distance AC characterized by ton/kilometer function, such properties are as follows: L, V_{cruise}, m_{pass}, H, L_{RW} and etc.

$$\vec{\mathbf{Y}} = \begin{vmatrix} & & / & \\ y_{11}, & y_{12}, & y_{13},\cdots y_{1n} \\ y_{21}, & y_{22}, & y_{23},\cdots y_{2n} \\ y_{31}, & y_{32}, & y_{33},\cdots y_{3n} \\ & & \cdots & \\ y_{i1}, & y_{i2}, & y_{i3},\cdots & y_{in} \end{vmatrix} \quad (7)$$

Taking into consideration Eqn. (5), let us transform Eqns. (6), (7) on the basis of assumption that each alternative variant of the vector of design solutions $\vec{\mathbf{X}}$describes single design alternative (8). Parameters of medium-distance AC are taken as alternative variants of design solutions.

$$\vec{\mathbf{X}}_{\text{supp}} = \begin{vmatrix} x_{11}, & x_{12}, & x_{13},\cdots x_{1m}, & y_{11}, & y_{12}, & y_{13},\cdots y_{1n} \\ x_{21}, & x_{22}, & x_{23},\cdots x_{2m}, & y_{21}, & y_{22}, & y_{23},\cdots y_{2n} \\ x_{31}, & x_{32}, & x_{33},\cdots x_{3m}, & y_{31}, & y_{32}, & y_{33},\cdots y_{3n} \\ & \cdots & & & \cdots & & \\ x_{i1}, & x_{i2}, & x_{i3},\cdots & x_{im}, y_{i1}, & y_{i2}, & y_{i3},\cdots & y_{in} \end{vmatrix} \quad (8)$$

The following group of parameters was considered: wing span, wing area, projected fuselage area, wing area under pylons, root chord, tip chord, sweep angle by 1/4 wing chord, wing taper ratio, wing aspect ratio, dihedral angle; performance characteristics: Mach number, cruising flying altitude, flying range; weight properties: AC gross weight, specific wing loading; aerodynamic properties: drag-due-to-lift factor, effective wing aspect ratio, lift-to-drag ratio. The allowable limits of conceptualized parameters for selection of medium-distance AC are in the limits of Eqn. (9), the limits of properties are defined by Eqn. (10).

$$x_i \begin{cases} 5.91 \le \lambda \le 11.37 \\ 2.34 \le \eta \le 5.34 \\ 21.33 \le \chi \le 36.55 \\ 0.17 \le \bar{c} \le 0.32 \\ 28.71 \le S_w \le 184.17 \\ 6.42 \le S_{\text{belly}} \le 25.94 \\ 1 \le S_{eff} \le 2.91 \\ 13.96 \le l \le 41.81 \\ 2.61 \le b_0 \le 8.51 \\ 0.75 \le b_k \le 2.11 \\ 1.21 \le \varphi \le 10.21 \end{cases} \quad (9)$$

$$\mathbf{y}_j \begin{cases} 9752 \le m_0 \le 108000 \\ 11200 \le H \le 15500 \\ 0.75 \le M \le 0.89 \\ 336 \le p_0 \le 638 \\ 2.43 \le \lambda_{eff} \le 15.64 \\ 0.021 \le A \le 0.113 \\ 11.28 \le K \le 28.61 \end{cases} \quad (10)$$

Applying the developed software, we identify the parameters characterizing to the utmost the concepts and properties of AC: the basic parameters. With known basic parameters and developed by the software polynomial models, it is possible to obtain predictions for other parameters. With preset constraints (L, V_{cruise}, m_{pass}, H, L_{RW}), parameters characterizing the AC concept ($X_i^L \le X_i \le X_i^U$) and properties depending on the vector of parameters ($Y_i^L \le Y_i \le Y_i^U$), we analyze parametric model by forecasting behavior of the target function (5) in the vicinity of optimum upon preselected partial criteria of efficiency [7, 8]. The basic parameters for the presented sampling are summarized in Table 1 [10-13].

While setting basic parameters (Table 1) in the range of applied constraints by upper and lower allowable limits, Eqns. (9) and (10), we obtain accurate predictions for other parameters defined by user in the software.

Table 1: Basic parameters.

No.	Description	Contribution
1	Wing aspect ratio, λ	0.42674
2	Wing taper ratio, η	0.21759
4	Relative thickness of wing airfoil, $\bar{c}$	0.03460
6	Total airfoil area, S_{total}	0.02733
14	Airspeed, M	0.26351
18	Lift-to-drag ratio, K	0.03023

For each predicted parameter, the application software displays average absolute error of prediction with regard to initial model of parameter as well as the contribution of basic parameter to regression model [13-15].

For instance, the regression model for determination of wing area S_k is described by Eqn. (11). The model accuracy is 0.0000000048690833. The contributions of basic parameters are summarized in Table 1.

```
y(i,j5)=+
+( -0.24027074428336e1)*(x(i,j1))**3+
+( 0.64993340925421e2)*(x(i,j1))**2+
+( -0.56252961254156e3)*(x(i,j1))**1+
+( 0.15675099196579e2)*(x(i,j2))**3+
+( -0.16829976851017e3)*(x(i,j2))**2+
+( 0.56567791075881e3)*(x(i,j2))**1+
+( 0.22553122128366e4)*(x(i,j4))**3+
+( 0.52855350089931e4)*(x(i,j4))**2
y(i,j5)=y(i,j5)+
+( -0.27296074533104e4)*(x(i,j4))**1+
+( -0.24303434620509e-1)*(x(i,j6))**3+
+( 0.12167554502326e1)*(x(i,j6))**2+
+( -0.13848148105156e2)*(x(i,j6))**1+
+( 0.15253265223630e4)*(x(i,j14))**3+
+( -0.44474298172343e4)*(x(i,j14))**2+
+( 0.41947538627132e4)*(x(i,j14))**1+        (11)
+( -0.17895797513960e-1)*(x(i,j18))**3
y(i,j5)=y(i,j5)+
+( 0.93225827308657e0)*(x(i,j18))**2+
+( -0.12696418649272e2)*(x(i,j18))**1+
+( 0.10769019126818e3)
```

where * is the multiplication; ** is the raising to power.

Combination of regression models for each parameter makes it possible to solve optimization problem by configuration selection of vector of rational parameters. Fig. 1 illustrates the AC gross weight as a function of wing aspect ratio and wing loading.

The presented plots obtained by the application software illustrate that with the increase in wing aspect ratio, the lift-to-drag ratio increases, though AC gross weight also increases. In the case when wing area remains fixed, then the specific wing loading increases.

The proposed approach based on the forecasting principles of polynomial models makes it possible to carry out multidimensional ordered parametrization when extreme preset criterion is achieved and the vector of AC parameters is determined.

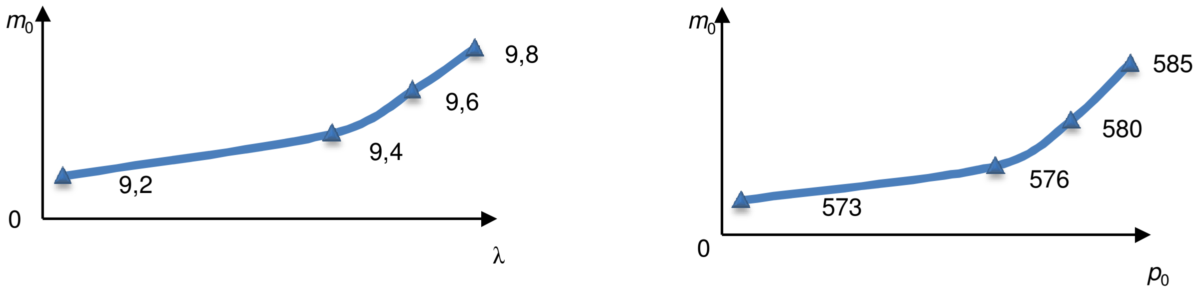

Fig. 1. AC gross weight as a function of wing aspect ratio and wing loading: m_0 – AC gross weight; λ – wing aspect ratio; p_0 – wing loading.

Reliability of the obtained results is supported by:
- the developed application software upon development of single AC elements with the error regarding results of physical and mathematical simulation in the range of 7%;
-application of certified and verified instruments in experiments;
- application of certified commercial software ANSYS Fluent and opened integral platform SALOME verified by projects based on building block method.

In order to determine accurate values of the considered parameters of long-distance AC or its constituents with accounting for implied constraints, it is required to carry out predictions by developed polynomial models with basic parameters. This is exemplified by solution of optimization problem of rational configuration of wing parameters of medium-distance AC and arrangement of Wing+Pylon+Gondola elements of medium-distance AC; the considered variables of long-distance AC sampling are determined by main drawings (Fig. 2).

Table 2: Variable parameters.

Parameter	Value				
(25.*h*)	4.8	5.03	5.2	5.4	5.8
(28. *k*)	1.4	1.643	1.8	2	2.2
(16. Effective wing aspect ratio, λ_{eff})	11.5	11.7	11.93	12.2	12.4
(26.*i*)	0.3	0.4	0.568	0.6	0.7
(28. *k*)	1.2	1.4	1.643	1.8	2

Software implementation of automated configuration selection of design and engineering parameters of AC is performed in the package of algorithmic language Fortran V and C++, Fig. 3.

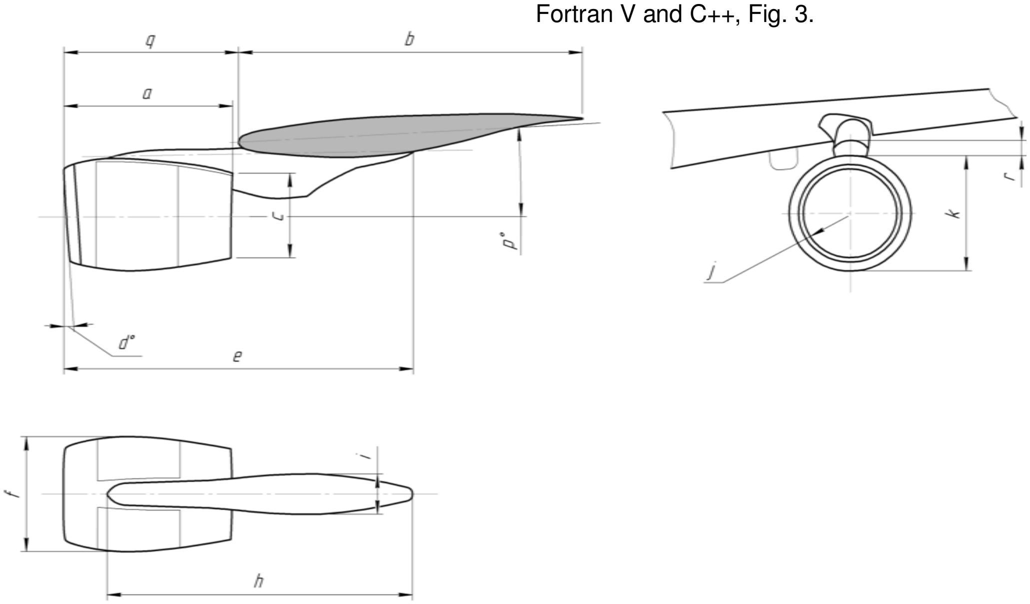

Fig. 2. Vertical projection Wing+Pylon+Gondola.

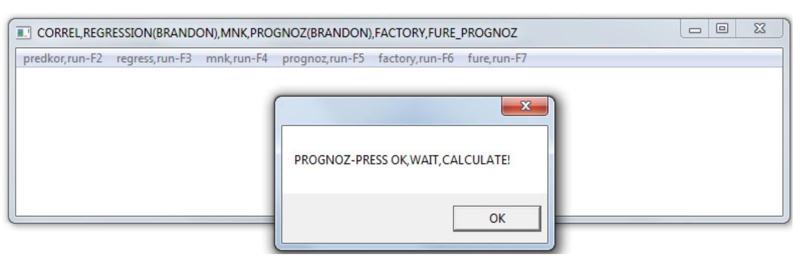

Fig. 3. Software dialog box.

The formulated procedure exemplified by elements of long-distance AC and application software performing selection and searching for rational configuration of parameters at early design stages of AC make it possible to provide predefined specifications for designed AC and its constituents.

IV. DISCUSSION

The proposed selection method of configuration of rational design and engineering parameters makes it possible at early stages of designing of long-distance AC to obtain preset specifications for its constituents [6, 7, 11, 15, 16]. The results were approved for implementation by AO PO Strela, KB Orion (affiliate of AO VPK NPO Mashinostroenie), as well as by AO Rostech state corporation, RT Techpriemka.

V. CONCLUSION

On the basis of the developed principles of automated designing comprised of procedures, models of design objects, and algorithm of parametric synthesis, the application software has been developed for configuration of design and engineering parameters of long-distance AC, which is capable to carry out conceptual and front-end engineering in unified IT environment characterized by comprehensiveness of considered parameters in estimation of AC efficiency under similar conditions of operation, and invariant to the type of AC and constituents.

The presented results of the study formed the basis of the conceptual model, software and application software that implement the methodology for choosing the composition of rational design parameters.This allows us to give commonality from the standpoint of the complexity of the parameters considered in assessing the effectiveness of AC under the same operating conditions, invariant to the type of AC and its constituent elements.The use of the C++ programming language allowsintroducing the developed software at the enterprises of the aviation and defense industries.

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The accuracy degree of project alternative obtained after the software end is determined by correct entry of statistical data on similar AC or constituents, high accuracy mathematical simulation, physical simulation and previously acquired data of R and D projects.

Conflict of Interest. There are no conflicts of interest to declare.

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