Optimization of Tolerances for the External Surfaces of the Uav Design

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Aerodynamic performance of modern and perspective unmanned aerial vehicles (UAV) demands perfection of forms. The low tolerances result in surfaces close to the ideal form. The expensive manufacturing techniques are required to achieve low tolerances. As a result the cost increases substantially. The optimization of tolerances is important to meet the target cost with minimum compromise on aerodynamic performance. A statistical model based on available data for more than thirty UAE of different type has been proposed for determining the criteria of tolerances of external surfaces of UAV. An algorithm and a computer program have been developed for predicting optimal tolerance for UAE forms. The statistical model has been validated with the standard specifications for different dimensions of rivets, ledges, cracks and fixture heads.

Nomenclature

B_c = production cost

B_H = the cost of ground handling and support of UAV flights

C_{x0} = drag resistance

C_{XH_∞} = drag resistance, a function of flight altitude

H = altitude

M = Mach number

$\bar{S}$ = specific area

T = Time (hours)

α = angle of attack

ω = range error

δ = dimension indicating surface quality

I. Introduction

Increase of efficiency of UAV is caused by the good quality of fuel and by change of structure for a desired life cycle target cost. Aircraft engineering practice marks the following basic ways of increasing the UAV efficiency [1]:

1. Application of new manufacturing techniques and materials (10-20%).
2. Perfection of engines (20-30 %).
3. Aerodynamics perfection (0-40 %).

The importance and urgency of improving the aerodynamic efficiency by improving the forms of modern and advanced UAV, by improving the quality of exterior surfaces is confirmed by the entire aviation history. An additional resistance of 2-10% can be caused due to limitation of manufacturing techniques at zero upward force [2]. The greatest share of approximately 5% is due to the deviations that increase the lateral sections acting in a stream. Significant resistance is attributed due to other reasons as well - 1.2-1.5% on rivets and bolts connections, 0.5% on joints of sheets, 1.0-1.5% due to leaky position of shutters and hatches and rough coloring (over 20 microns) . At speed above $M>1.5$, the size of all components increases approximately twice and resistance from a sinuosity increases more than 5 times that of $M<1.5$. For the reasons specified above, the resistance increase through technological roughness is approximately 5-6 % for subsonic UAV and 10-16% for supersonic ($M=2-3$) UAV [2]. Perfection of quality of external surfaces requires expensive manufacturing technology which leads to additional expenses. Therefore, it is important to define the quantitative estimations of quality of external surfaces**.** A criterion for a quantitative estimation of losses from additional resistance is useful in predicting the acceptable increase in fuel cost. The expediency of an estimation of such kind is obvious because the fuel consumption, a unique and precisely measured parameter at the given design stage of UAV, directly reflects infringement of aerodynamics of a surface- both in manufacture and in operation [3].

The development of the designs of UAV and the development of the corresponding manufacturing technology is crucial due to constant increase in speeds of flight [1]. Growth of speeds of flight not only causes the application of new and highly heat-resistant materials, but is also accompanied by importance for development of the production technologies [4]. First of all, it concerns change of forms of units of UAV [5-6]. Simple rectilinear forms of surfaces of units of an airframe needs to be designed as complex surfaces of double curvature for increasing speed. To the production technology, the total disappearance of cylindrical formations of fuselages is essential almost at speeds from M≥0.85 and linear surfaces of wings and plumage, at speeds M≥2.0. Deviations of elements of a surface from a theoretical contour due to heads of bolts, rivets, screws, steps and a roughness on UAV are included in the specifications for design and development of UAV. Maximum deviations on elements of aerodynamic surfaces are defined based on admissible sizes of additional resistance, C_{x_0} and flow conditions on various modes. As a rule, specifications on the form and quality of a surface of the airplane provide division of units into zones according to their importance in formation of a streamline stream. Typical requirements to the parameters of quality of surfaces of UAV are in the range of $\delta = \pm 2.0$ мм [1].

II. Technique of tolerance definition on external contours of UAV.

For the purpose of general definition of the specifications of the design and manufacturing requirements of UAV, the specifications of 30 UAV of various types and tolerances [9] are analyzed to study the effect of various parameters on the aerodynamic performance of UAV. The results are plotted in Fig. 1-6 that show the permissible deviation at different Mach number

Figure 1 shows the acceptable deviation of carry surfaces of units for high speed and medium speed UAV. High surface quality is required for a wing $(\delta = \pm 1{,}0 mm)$ and low surface quality is required for a fuselage at high Reynolds numbers and high thickness of an interface. Condition of preservation of a laminar flow is considered the basis of requirements at small Reynolds numbers since the roughness is affected due to increase of surface deviation above the thickness of local laminar boundary layer [7]. Additional resistance from a surface sinuosity (Fig. 2) depends on the size of the deviation of a surface and the location of the deviation from forward edge [8]. This is considered in the specifications of definition of zones of surfaces of UAV. Similarly, the restrictions of size of local roughness due to type of ledges, ledges, cracks and fixture heads (Figs. 3-6) are accounted for (δ= ±0.1-0.5 mm) [1]. By working out of constructive and technological decisions, it is necessary to define the requirements shown to quality of object of manufacturing and technological processes to achieve desired quality of surfaces. Tolerances on a relative positioning of global surfaces of separate units and units among themselves in this case are not considered.

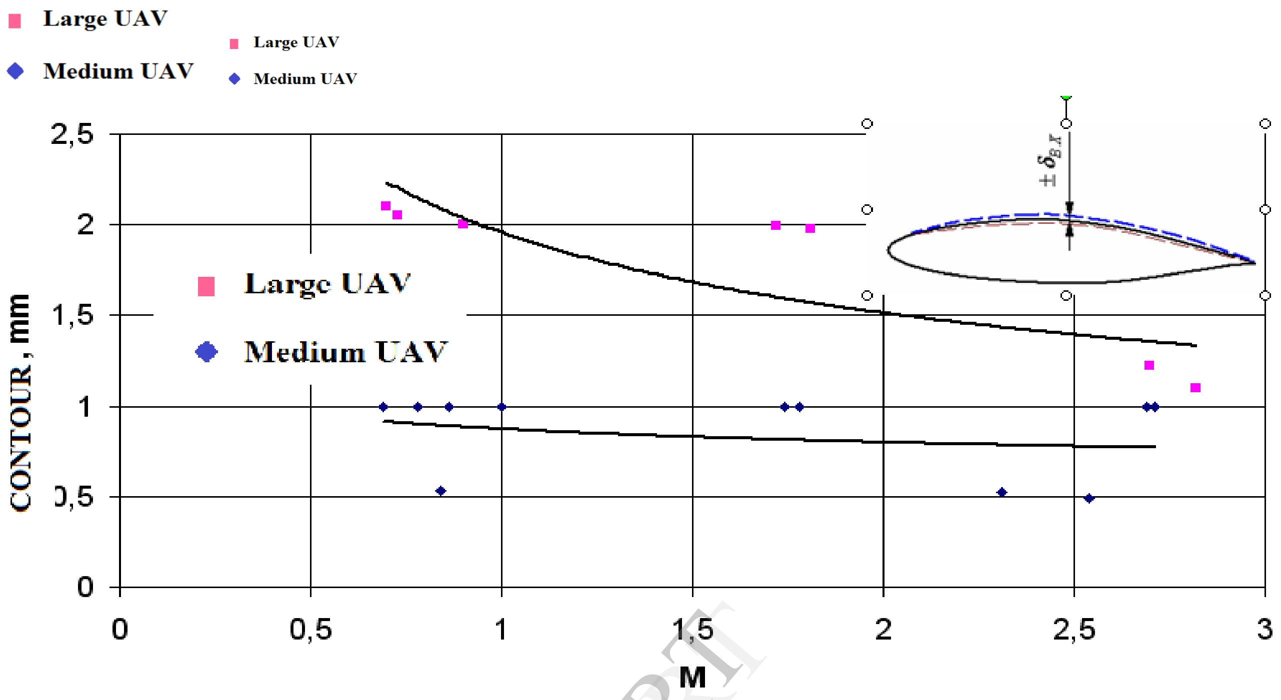


Fig.1 Dependence of allowed deviations from a contour on speed.

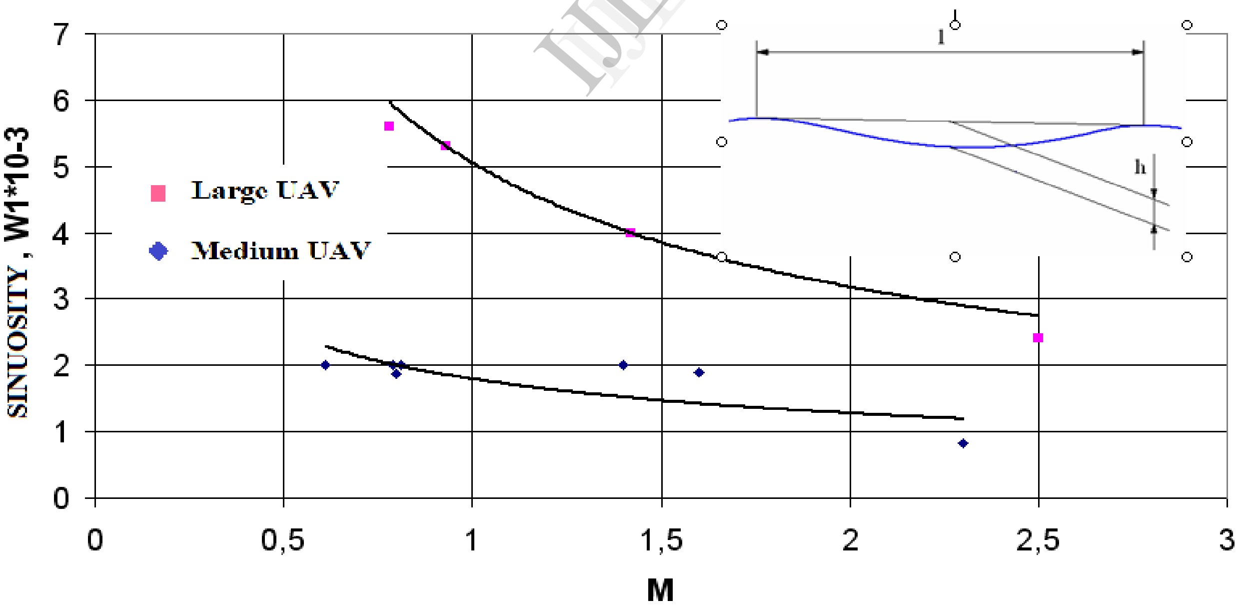


Fig.2 Dependence of allowed sinuosity of a surface on speed.

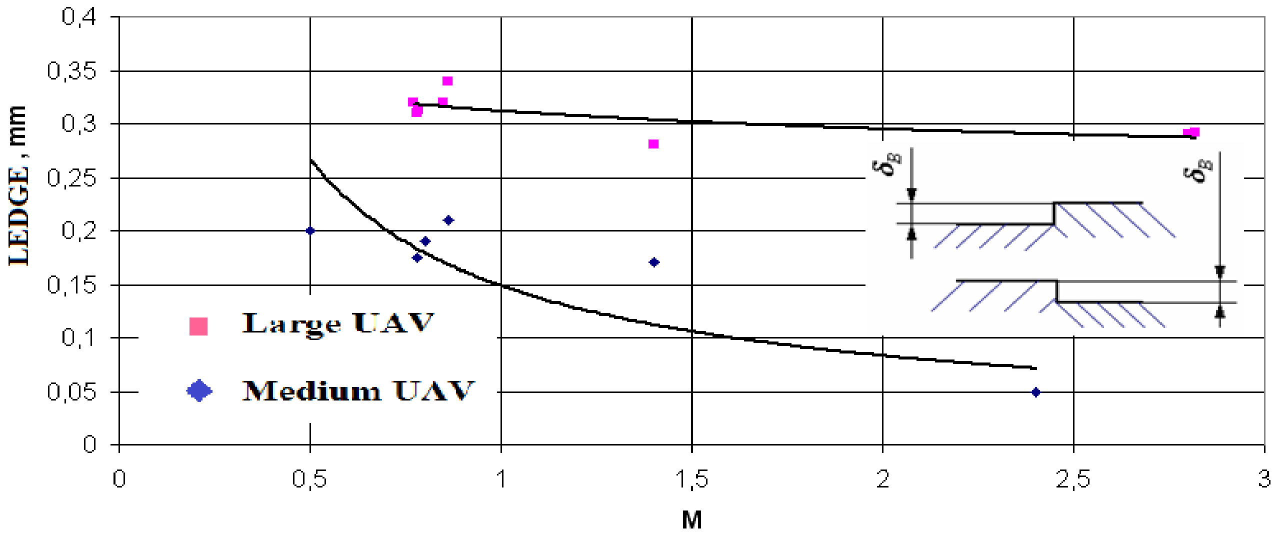


Fig.3 Dependence of allowed ledge of a surface on speed.

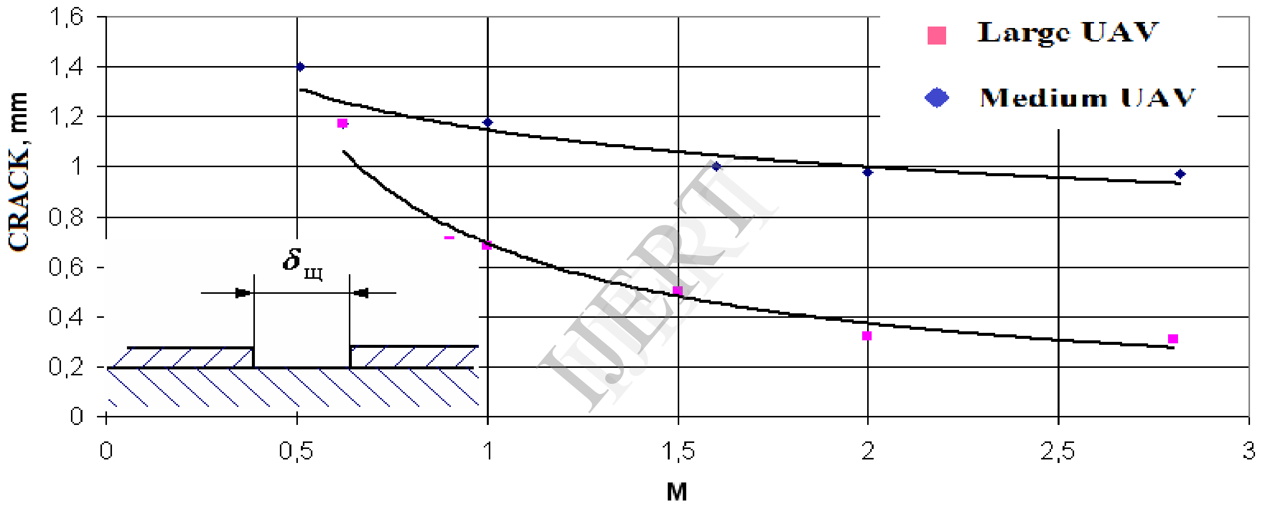


Fig.4 Dependence of allowed crack of a surface on speed.

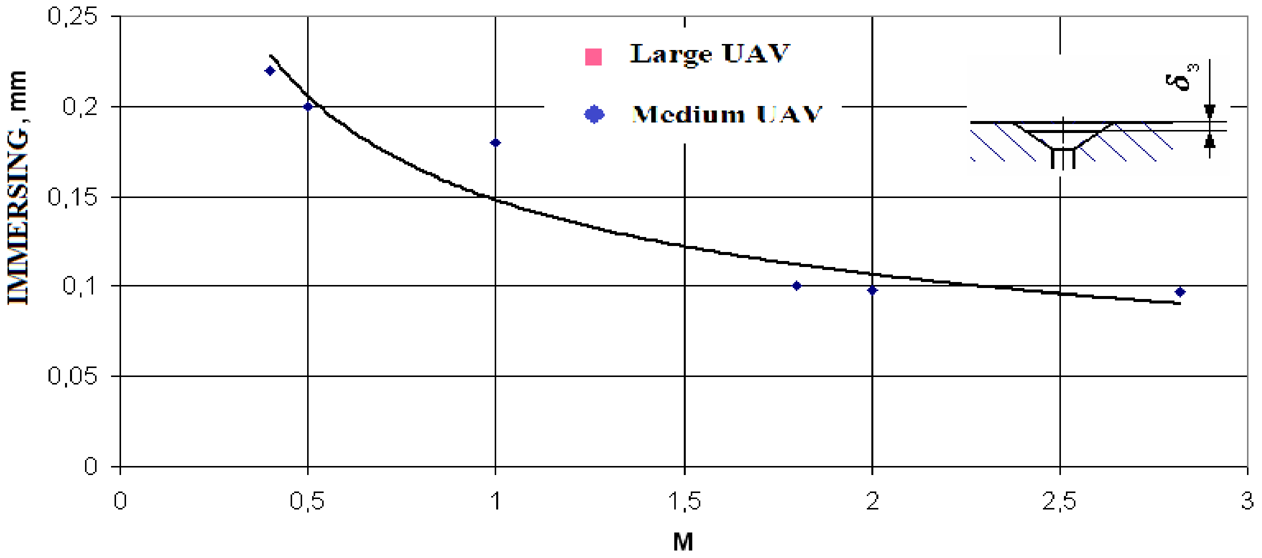


Fig.5 Dependence of allowed on immersing in a surface on speed.

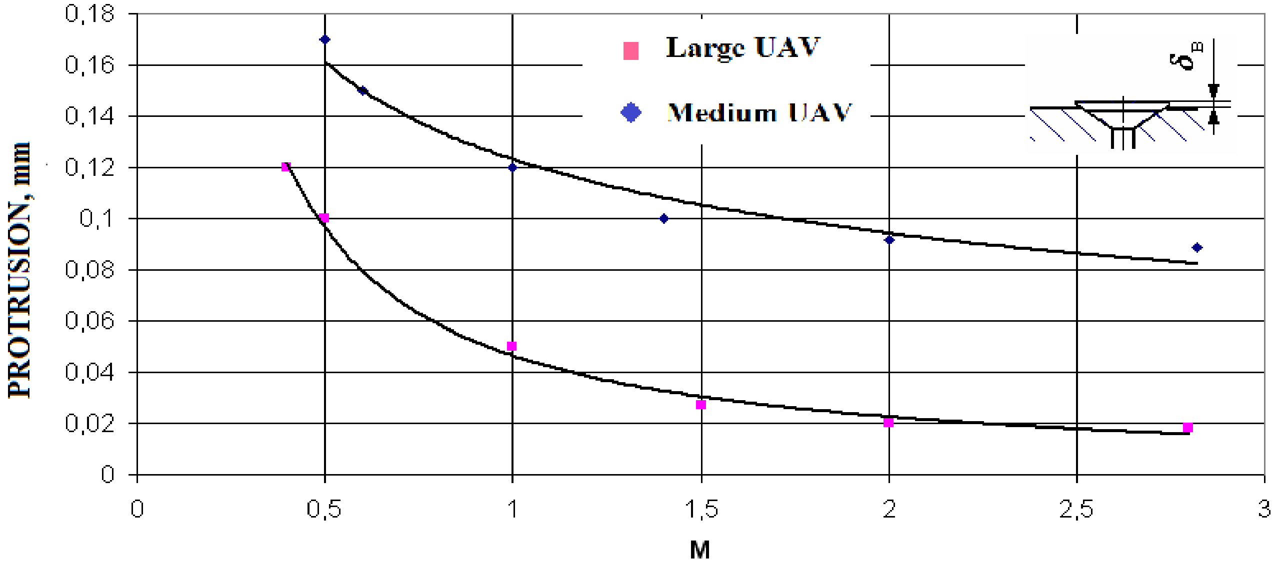


Fig.6 Dependence of allowed protrusion on a surface on speed.

III. Criteria for choosing tolerances for contours

Qualitative performance indicator, as noted in [1], is a ratio of target impact cost to the whole lifecycle. Since, the improvement of surface quality of a targeted output, generally, does not change; the improvement in the efficiency is possible by changing the value of the life cycle. Hence, the condition for selection criterion of tolerance is assumed as [10]:

$$\{B_{mc} + B_m\} \longrightarrow \min \qquad (1)$$

Where, B_{mc} - manufacturing cost; B_m - maintenance costs for the entire lifecycle; $B_m = B_{ss} + B_H + B_r + B_f$; $B_{ss} -$ staff salaries; $B_H -$ the cost of ground handling and support of UAV flights; $B_r -$ the cost of UAV repairing; $B_f -$ fuel costs.

Surface quality has direct impact on UAV fuel costs. The deviation from ideal surface, in majority cases, increases the resistance at zero lift, i.e. C_{x_0}. Therefore, $\Delta B_r = B_f(\Delta C_{x_0})$, where $\Delta C_{x_0} = f(\omega)$, $\omega -$ range (field) of error.

The cost of production depends on the achieved level of precision determined by the methods applied and the industrial facilities with the characteristic of the tendency of rising costs with increased accuracy [11]. The cost is a function of tolerances and can be defines as, $B_{mc} = B_{mc}(\omega)$. According to Eq. (1), the optimal value of tolerance can be defined as:

$$\frac{\partial B_{mc}(\omega)}{\partial \omega} + \frac{\partial B_m(\omega)}{\partial \omega} = 0 \qquad (2)$$

The above equation is correct for the case when the UAV target cost is constant.

Depending upon variants of the problem, the criterion $\{B_{mc} + B_m\}_{\min}$ may be modified and added:

1. At the stage of conceptual design, a solution is chosen from the set of possible constructive and technological decisions, The solution provides value of permissible error not greater than the given directive, and simultaneously satisfies the minimum cost criterion, i.e. $\omega \le K\delta$.
2. At the stage of conceptual design, constructive solutions shall be selected for $\{\omega_{opt}\}_{\min}$. It is necessary to calculate the aerodynamic deviations due to choice of the most contemporary solution under the given production and exploitation conditions. In this case, the condition $\{B_{mc} + B_m\}_{\min}$ corresponds to a minimum of fuel consumption $\{B_H + B_f\}_{\min}$.
3. At the stage of conceptual design from an array, potential solution is determined by the standpoint of the highest cost. The criterion $\{B_H + B_f\}_{\min}$ provides minimal life cycle costs. But minimal fuel consumption is not guaranteed.
4. At the stage of detailed engineering, the value of optimal criterion (1) is determined for the tolerances for technical requirements (TR) in development.
5. At the stage of manufacturing, value of corrected tolerance is provided for TR, taking into account physical costs of the manufacturing. Also possible on correction of inverse problem of production costs to ensure the tolerance specified in TR.

The criterion for last two options is given in [1].

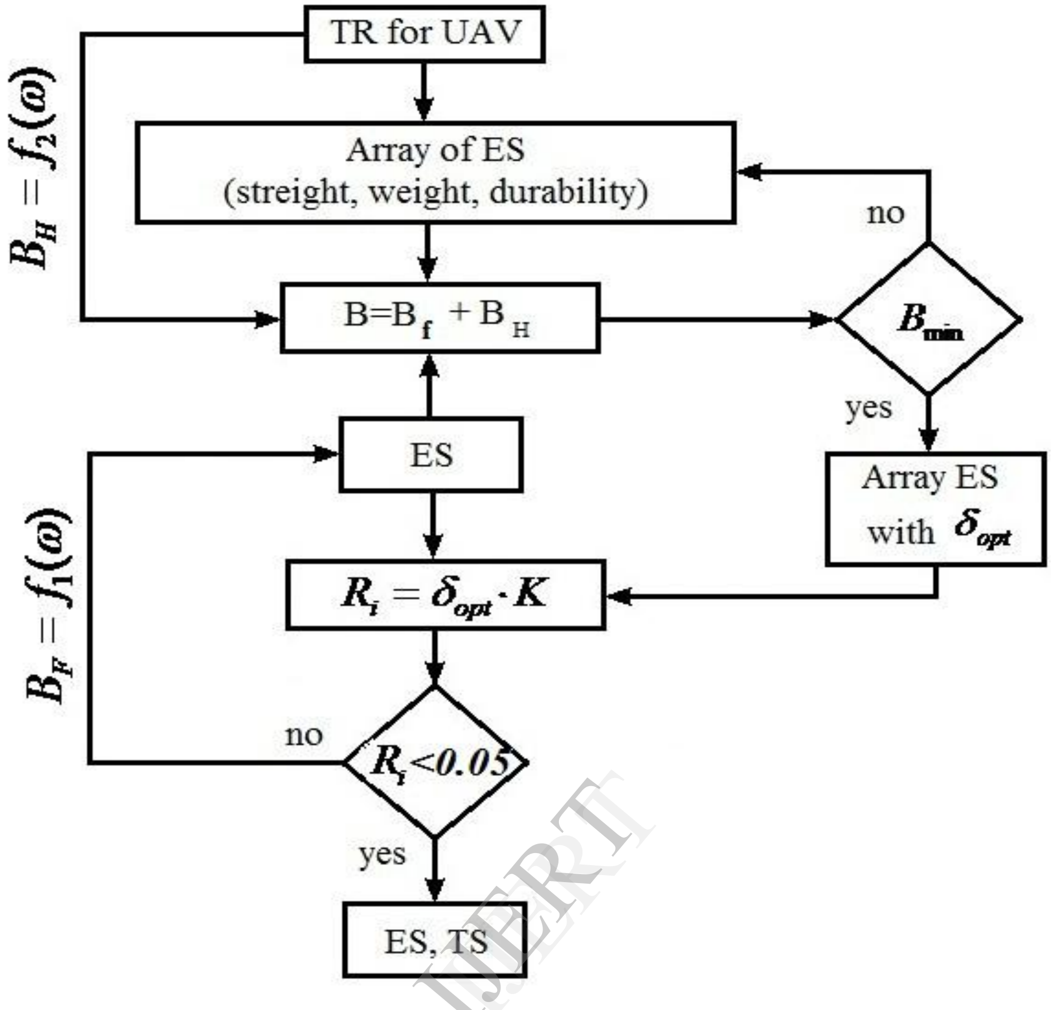


Fig.7 The algorithm of choosing structural and technological solutions in implementation of tolerances (TR – technical requirements; ES –engineering solution; TS –technological solution).

The above criteria (Fig. 7) for the tolerances should be checked for the conditions of current implementation and newly adopted technological processes. Practically, it means selecting from an array of possible technological solutions to the most suitable one which must result in minimum production costs. Thus, the selection process for constructive and technological solutions, for improving the external contours of UAV, includes a number of consistently carried decisions (levels) with special constraints (Fig. 7).

IV The factors determining value for deviation of contours

The magnitude of external outline tolerance influences range of factors which determine the value derived from operating costs and depend on the quality of the external surface. The cost of the additional fuel is expressed as [3]:

$$B_f(\omega) = m_h b_f \frac{\Delta C_{X_0}}{2C_{X_0}} T, \tag{3}$$

Where, $m_h -$ fuel consumption per hour; b_f – coefficient dependent on fuel characteristics; $\Delta C_{X_0} -$ increment value of resistance due to surface defects.

In order to reduce the amount of calculations for comparing various designs and technological solutions, the concept of costs per unit of surface area ($/m^2) is introduced [12]:

$$B_f = \frac{m_h b_f T}{2C_{X_0}} \Delta C_{X_0}.$$

Taking into account the additional resistance for irregularities such as wave, step, slit, etc., ΔC_{X_0} can be described by the following equation:

$$\Delta C_{X_0} = \alpha C_{XH_\infty}(M)\Phi(M)F(H)\bar{S}x_k^{-\beta}h^{n_2}, \tag{4}$$

where $C_{XH_\infty} -$ drag coefficient of isolated irregularities; $\Phi(M)F(H)-$ functions reflecting the influence of speed and altitude; $h-$ maximum height of the surface that is equal to scale of error; $x_k -$ the coordinate characteristic parameter roughness (in m, for example, maximum amplitude of wave, a step, etc.); $\bar{S} -$ relative area occupied by local irregularities; $\beta, n_2 -$ the exponents.

According to the equations (3) and (4), the simplified expression for additional fuel cost can be written as:

$$B_f(\omega) = b_2\omega^{n_2}, \tag{5}$$

where, $b_2 = b_f \alpha C_{XH_\infty}(M)\Phi(M)F(H)\bar{S}x_k^{-\beta}$.

Thus the additional cycle costs are defined by basic parameters of UAV and conditions of its exploitation. Expenses of manufacturing, in general, depend on pre-production method adopted; level of the cost of one hour defined by accepted methods and means. Establishment of functional relation between cost of production and size of the construction errors is important task. The present paper considers only the final results to principal design solutions. Proceeding from the results of statistical analysis, manufacturing costs may be given as:

$$B_{m,c} = \alpha\omega^{-n}. \tag{6}$$

Equations (1), (5) and (6) allow establishing a quantitative correlation between the described forms' factors, i.e. to present the process of choice of tolerances as mathematical models. These equations enable us to establish the quantitative relationship between the described form factors and define the process of selecting tolerances as a mathematical model (Fig. 8) [13].

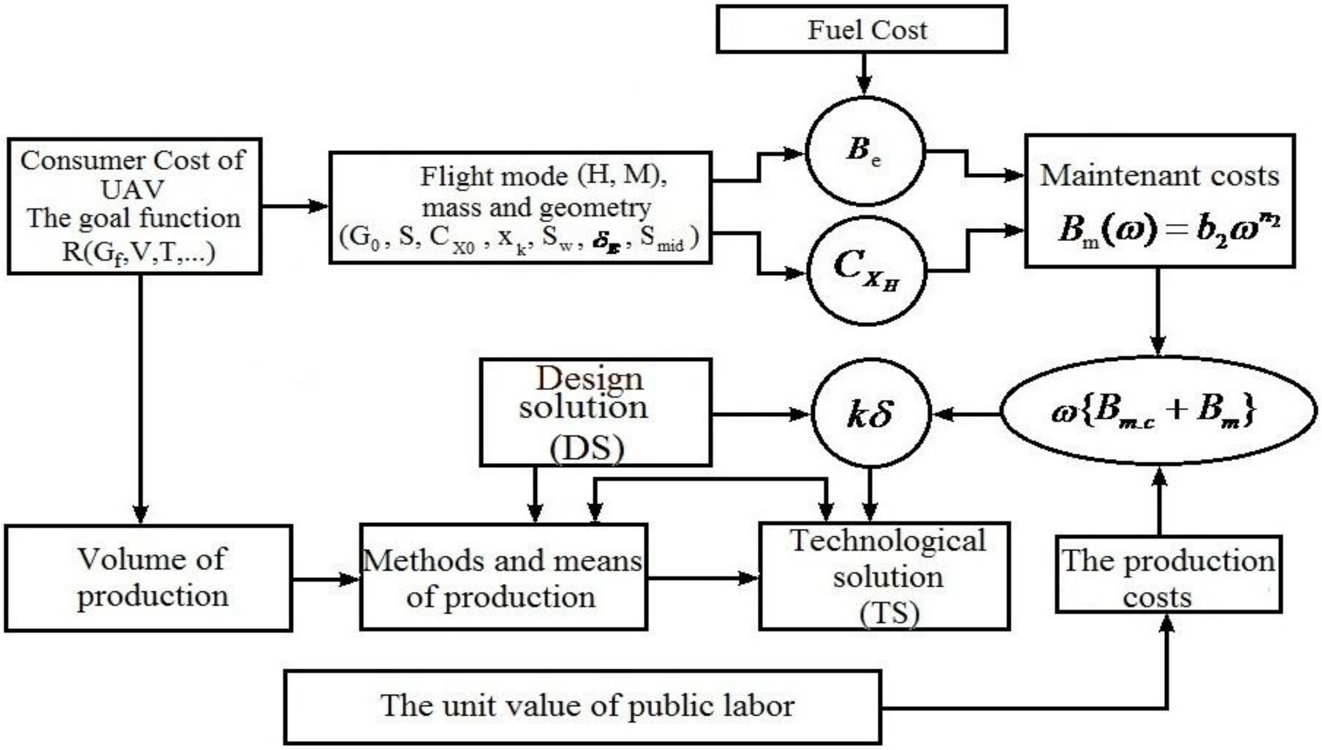


Fig. 8. Method of predictions of tolerance on the external contours

In general the mathematical model should be supplemented by description of the effects of external factors (Φ) on the goal function, represented in the form of fuel prices, the unit cost of labor, etc. [14]. The optimal value of tolerance according to accepted criteria is given by the following equation [15]:

$$\omega = \left[\frac{an}{b_2 n_2} \right]^{\frac{1}{n+2}}, \tag{7}$$

Using above equation, one can find an estimate of each factor relative to the base value, i.e.

$$\omega = \omega_0 \left(\frac{a}{a_0} \frac{n}{n_0} \frac{m_{Hour_0}}{m_{Hour}} \frac{b_{Fuel_0}}{b_{Fuel}} \frac{T_0}{T} \frac{C_{X_H}(M_0)}{C_{X_H}(M)} \frac{\Phi(M_0)}{\Phi(M)} \frac{\Phi(H_0)}{\Phi(H)} \frac{C_{X_0}}{(C_{X_0})_0} \frac{S}{S_0} \frac{n_{20}}{n_2} \right). \tag{8}$$

The equation (8) allows recalculating the tolerance when you change the flight modes, design and technology implementations (DTI) and external conditions. For example, the service life changes are determined by the ratio T_0 / T [13, 15]. For $T > T_0$, a close tolerance ($\omega < \omega_0$)is needed. Influence of the speed estimated by the flight ratio [1] is given as:

$$\frac{C_{XH_\infty}(M_0)}{C_{XH_\infty}(M)} \frac{\Phi(M_0)}{\Phi(M)}. \tag{9}$$

In the case of monotonic change, toughening of the tolerance is required with the rising of M. For the calculation of the tolerance, the algorithm and program developed based on the mathematical model given in this paper can be used for more than 30 UAV for various flight conditions.

V Development an algorithm for determining the optimal tolerance

According **to t**he procedure of determination of the optimal tolerance by $\{B_{mc} + B_m\}_{\min}$ for a particular design, the tasks enumerated in the previous section must be solved. Equation (3) and (4) characterize the influence of various factors on the operating costs, and describe the effect of structural and technological factors (STF) (6). The final result for optimal tolerance for different STF can be calculated (Eq.7) as an array of data [15].

The sequence of calculations

1. Determine the typical design solutions, the area of their placement on UAV $(\bar{S})$, coordinates x_k.
2. Find the possible technological implementations and parameters ‘a’ and ‘n’ depending on expenses due to manufacturing tolerances.
3. Find the specific geometrical parameters of roughness n/S or $l_{roughness}/S$ in the case of waviness i.e. the allowable wavelength [1].
4. Determine the normative data depending on the type of UAV and flight mode: $T, m_h, C_{x_0}, F(H), \Phi(M), C_{x_H}(M)$ and compute $B_f = \frac{m_h b_f}{2C_{X_0} S}$.

Where, b_f – price fluctuation of the fuel

5. Define type roughness coefficient $\varphi(h)$, which takes into account the probabilistic nature of value h.
6. Calculate parameters b_2 and n_2. Obtain the waviness by $b_2 = 8{,}8 B_T \bar{S}_b \bar{L}_K^{0,3} \bar{l}^2 C_{x_{H_{cylinder}}} F_2(H)\Phi_2(M)\varphi(H)$; $n_2 = \frac{7}{3}$. For the remaining unevenness use, $b_2 = 1{,}03 B_T \bar{S}_H F_3(H)\Phi_3(M)\varphi(H)\bar{C}_{x_H}$; $n_2 = \frac{4}{3}$.
7. Compute $\omega_{opt} = \left[\frac{an}{b_2 n_2}\right]^{\frac{1}{n+2}}$.

8. Check the possibility of realization ω_{opt}.
9. Compute the quantities of losses or effect compared with the analogue as the difference between the above costs, i.e. $B_f = B_{mc} + B_m = a\omega^{-n} + b_2\omega^{n_2}$.

An example of implementation of the algorithm for the wing of a UAV [9] using MS Excel is shown in Table 2. Computer program can be developed according to the block diagram shown in Fig. 11 and 12.

Table 2 Calculation algorithm the optimal tolerance for the wing of UAV

Attribute	**Options**	**The calculated values**
$S_{wing} = 0.0117\ m^2$	$\bar{x}_k$	0.08
$b_{CAX} = 0.042$ m	$L_K = \bar{x}_k b_{CAX}$	0.00336
$G_{T_{Hour}} = 0.36\ \frac{kg}{h}$		
$c_{X_0} = 0.021$		
H=0		
M=0.2	$l_{step}\ [m]$	1.0
$T = 0.5$	l_{step} / S	1.0
$B_{\exp} = \beta_T = \frac{G_{Fuel} b_m}{2C_{X_0} S} = 4.259$	G / S	1.0
	B_T	4.259
	F(H)	1.02
	$\Phi(M)$	1.0
$K_A = 8.8 c_{X_\infty} \varphi \Phi(M) F(H)$	c_{X_∞}	1.5
$K_G = l_b^2 L_k^{-0,286}$	$\varphi(h)$	0.6
$b_2 = B_T K_A K_G T$	K_A	8.078
	$L_k^{-0.286}$	1.373

l_b^2	1.0
K_G	1.373
b_2	4.186
n_2	2.33
$b_2 n_2$	9.753
a	0.683
n	0.018
an	0.0123
$(n+n_2)^{-1}$	0.426
$\left(\frac{an}{b_2 n_2}\right)^{\frac{1}{n+n_2}}$	0.0582
$\delta = 0.5\omega$	0.6
$\delta = \omega / L$	0.0028

In accordance with the purpose of the program, the output information contains the values of b_2, a, n and code of design decision ω_{opt}.

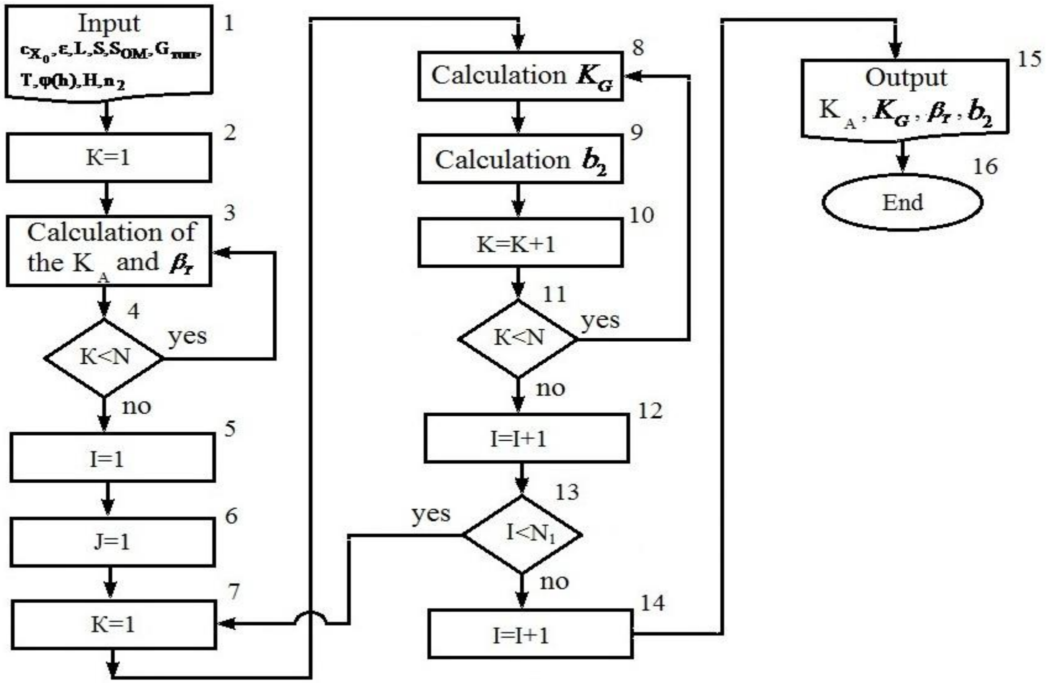


Fig.11 Block diagram of calculation of parameter b$_2$.

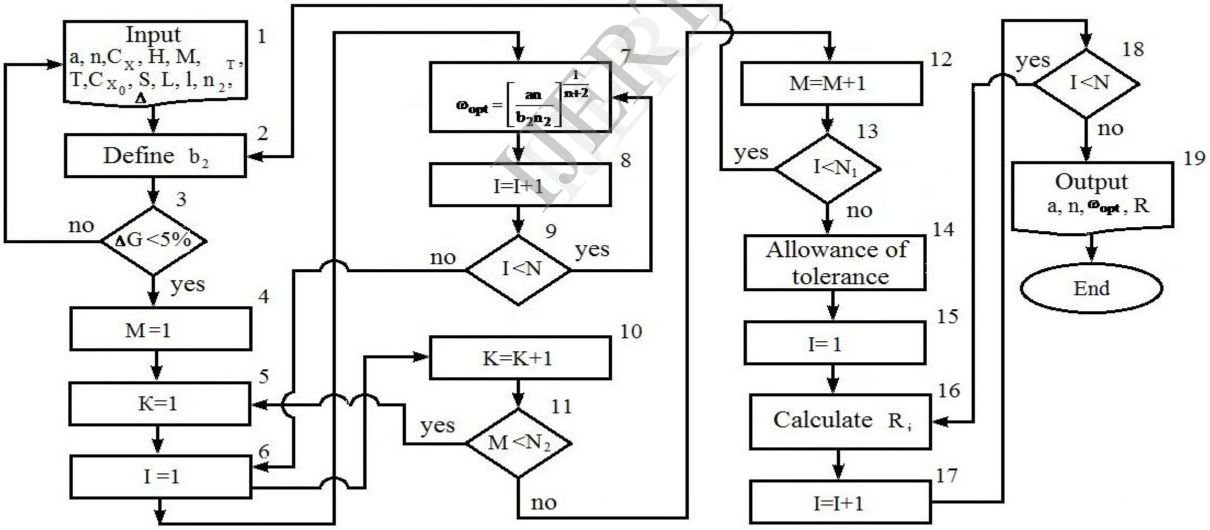


Fig.12 Block diagram of calculation of ω_{opt} **.**

Purpose of the program units (Fig.12)

Unit 1. Input information parameters are defined. UAV is defined as array and characteristics

($m_{Fuel_i}, L_i, b_{T_i}, s_i, C_{x_0}$ etc.) are assigned for each UAV.

Unit 2. Calculation routine has its own input and output. In general case, the calculation can be presented in an independent block diagram (Fig. 8). In this case each particular UAV has its b_2.

Unit 3. The possibility of calculating the optimal tolerance for the proposed procedure is examined. If the result of additional resistance to mass of UAV changes more than 5%, it will lead to global changes in the design of propulsion system. In his case, the following version of the source data is considered.

Unit 4. The first level of wages is equal to 20.00 $ /hr.

Unit 5. Designed to do calculation for the first UAV.

Unit 6. Designed to do calculation for the first DTI.

Unit 7. Unit the direct calculation of the optimal tolerance to specify the wage levels, or a particular UAV, or a particular DTI.

Unit 8. Intended for the next DTI.

Unit 9. Logical unit. Designed to compare the calculated number of DTI with the specified one.

Unit 10. Is intended for transition to the new UAV.

Unit 11. Intended for consideration of comparing the calculated number of UAV with the specified one.

Unit 12. Is intended for move up the level of wages.

Unit 13. Designed to compare computed number of wage levels with a given one.

Unit 14. To calculate the error in due to shrinkage and distortion

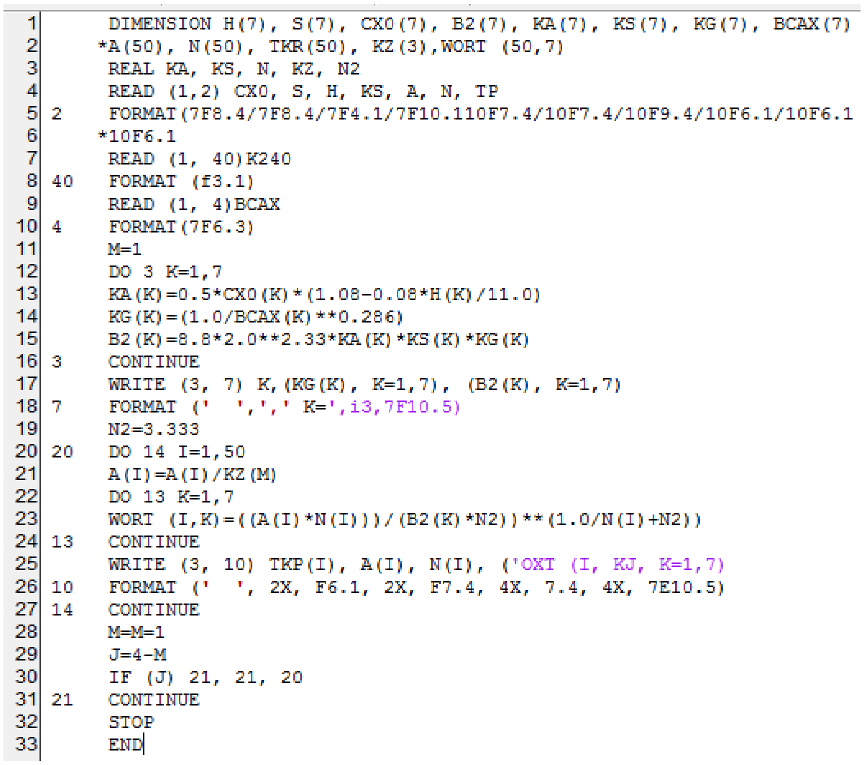
Unit 15. Intended for definition of the reserve for the first tolerance of DTI.

Unit 16. Intended for calculation the reserve tolerance for each DTI according to the equations given above.

Unit 17. Is intended for the following DTI.

Unit 18. Designed to compare the numbers DTI set with the number of practical ones.

Unit 19. The values a, n, b_2, ω_{opt} and reserve of admission are printed. If the reserve is less than zero tolerance, such tolerance in contemporary conditions is not impossible.



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      DIMENSION H(7), S(7), CX0(7), B2(7), KA(7), KS(7), KG(7), BCAX(7)
     *A(50), N(50), TKR(50), KZ(3),WORT (50,7)
      REAL KA, KS, N, KZ, N2
      READ (1,2) CX0, S, H, KS, A, N, TP
2     FORMAT(7F8.4/7F8.4/7F4.1/7F10.110F7.4/10F7.4/10F9.4/10F6.1/10F6.1
     *10F6.1
      READ (1, 40)K240
40    FORMAT (f3.1)
      READ (1, 4)BCAX
4     FORMAT(7F6.3)
      M=1
      DO 3 K=1,7
      KA(K)=0.5*CX0(K)*(1.08-0.08*H(K)/11.0)
      KG(K)=(1.0/BCAX(K)**0.286)
      B2(K)=8.8*2.0**2.33*KA(K)*KS(K)*KG(K)
3     CONTINUE
      WRITE (3, 7) K,(KG(K), K=1,7), (B2(K), K=1,7)
7     FORMAT ('  ',',' K=',i3,7F10.5)
      N2=3.333
20    DO 14 I=1,50
      A(I)=A(I)/KZ(M)
      DO 13 K=1,7
      WORT (I,K)=((A(I)*N(I)))/(B2(K)*N2))**(1.0/N(I)+N2))
13    CONTINUE
      WRITE (3, 10) TKP(I), A(I), N(I), ('OXT (I, KJ, K=1,7)
10    FORMAT ('  ', 2X, F6.1, 2X, F7.4, 4X, 7.4, 4X, 7E10.5)
14    CONTINUE
      M=M=1
      J=4-M
      IF (J) 21, 21, 20
21    CONTINUE
      STOP
      END
```

(***Symbols:*** *H(7) – flight altitude, km; S(K) – characteristic area, m*^{2}*; KA – index of UAV; CX0(7) – additional resistance factor for a roughness* C_{XH_∞} *in the equation (4); B2(7) -* b_2 *in the equation (5); KS(7) -* B_T *in the Table 2; KG(7) -* K_G *in the equation* $K_G = l_b^2 L_k^{-0,286}$*; BSAX(7) – characteristic dimension in the equation (3): A(50) – coefficient* α *in the equation (6); N(50) - coefficient* n *in the equation (6); TKP(50) – DTI code; I – DTI index; KZ(3) – level of wages, \$/Hour; WORT(50,7) – optimal tolerance, mm; 2 - coefficient* n_2 *in the equation (6)*)

Fig. 13. Calculation of optimum tolerance for roughness

Fig. 13 shows the software for computation of optimal tolerance for roughness type of a wave. The problem was solved to obtain the optimum level of tolerance for the specific DTI [14].

VI Preparation of initial data for calculating tolerance on external contours

According to the procedure of calculation, the initial data for determining the unit cost of fuel are [1]:

i. Parameters, coefficients, and the functions determining the value of the additional resistance due to irregularities

ii. The coefficients and functional relationships of cost-tolerance for typical design solutions without building berth method of production preparation and typical errors of external contours.

Initial data are being prepared for a particular product based on the results of technological analysis for aircraft structures and flight and technical data.

Initial data for calculation operational costs

The calculation of the cost of production for known and advanced DS is recommended using equations [10] given below:

1) for a smooth deviation of wave type

$$B_{np} = a\omega^{-n} S_{кр}; \tag{10}$$

2) for a step-like irregularities

$$B_{np} = 2^{-n} a\omega^{-n} l_{cm} b_{cm}; \tag{11}$$

3) during manual drilling and riveting

$$B_{np} = (0.075...0.1) a h^{-n} S_{кр}; \tag{12}$$

4) with automated riveting

$$B_{np} = (0.0375...0.06) a h^{-n} S_{кр}; \tag{13}$$

5) for bolts

$$B_{np} = (0.015...0.03) a h^{-n} S_{кр}. \tag{14}$$

Factor values a and power exponents n depend on the kind of structural design (Table 4) [10].

Table 4 **Parameters a and index n (for basics DS)** [10]

№	DS of panels	Parameters	
		a	n
1	Composite with thin skin, a set of rigid, assembly	0.825	0.29
2	Composite with thin skin, a set of non-rigid, assembly	0.67	0.02
3	Composite with thin skin, set of monolithic	0.828	0.29
4	Composite with thin skin, stamped from a sheet of, a set of rigid	0.683	0.018
5	Composite with thin skin, connection with the set of compensators	0.81	0.174
6	Monolithic wafer, the set of all groups	0.90	0.10
7	Monolithic with radial beams	1.62	0.28

8	Monolithic molded cylindrical set of all groups	0.587	0.11
9	Monolithic прессованные, with the set of compensators	0.61	0.17
10	Cellular with a frame and flat	0.0299	3.25
11	Cellular with a frame and the curvilinear	0.1018	0.31
12	Cellular without a frame and flat	0.1561	0.146
13	Cellular without a frame and the curvilinear	0.1387	0.40
14	Composite, metallic set of glued	0.482	0.18
15	Composite, metallic set of without the compensators	0.672	0.74
16	Composite, metallic set of with the compensators	0.356	0.59

VII. Conclusion

The analysis of tolerance for external surfaces of units UAV and realization in manufacture allow to draw the following conclusions:

1. The allowed deviations of external surfaces are same for UAV operating in certain Mach number range. However, as Mach number range increases, the deviation decreases. The highest surface quality is required for wing which produces lift for carrying a payload.
2. Necessity for decrease in weight and increase in durability has caused transition from a traditional modular design for power compartments to the monolithic one. Application of composite materials has led to the change of conditions of realization of the tolerances on external contours. Due to manufacturing automation methods, it is necessary to consider two main aspects: design requirements of formation of contours and accuracy of manufacturing process and equipments.
3. Experimental data of isolated roughness is the basis for resistance calculations. The roughness height is defined by admissible size of additional resistance. Consumption of fuel increases with roughness. The low resistance decreases fuel consumption and can be achieved with low tolerances, but the manufacturing cost will increase. Therefore, and optimum tolerance need to be defined.
4. The additional life-cycle costs are determined by the basic parameters of UAV and conditions of its operation. Production costs in general depend on pre-production methods and the cost per hour.
5. A mathematical model and algorithm were developed for computation of optimum tolerance for the external surfaces of UAV.

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