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N.V. ZOSIMOVYCH, R.K. SINGLA

Sharda University, Greater Noida,UP, India

INFLUENCE OF FACTORS DETERMINE THE VALUE OF TOLERANCE ON THE OUTBOARD SIDE UNMANNED AERIAL VEHICLES

As a result of perfection of forms modern and perspective unmanned aerial vehicles (UAV) probes of typical geometrical parameters of a surface have been made and the technique of appointment of admissions on external surfaces is offered. In this paper analyzed the selection criteria tolerances on contours of UAVs, proposed a model choice structural and technological solution in implementing tolerances and explored factors that determine the value of tolerance for the external contours of UAV.

Key words: *Unmanned aerial vehicle (UAV), surface, aerodynamic quality, sinuosity, technological roughness's, ledge, indent, constructive and technological actions, fuselage, fuel consumption, specifications, flying vehicle (FV), mathematical model (MM).*

Introduction

Increase of efficiency UAV is caused, on the one side, by a problem of fuel resources, and with another side a tendency of change of structure of expenses for life cycle aside reduction of a share of initial FV cost. Aircraft engineering practice marks following basic ways of increase of FV efficiency [1]:

1) application of essentially new constructive decisions and materials (10…20%);

2) perfection of engines (20…30 %);

3) aerodynamics perfection (to 40 %).

The importance and urgency of improving the aerodynamic efficiency by improving the forms of modern and advanced FV, including by improving the quality of exterior surfaces, confirmed by the entire history of aviation.

Detailed consideration the dependence of resistance from quality of performance of external surfaces by manufacture shows that additional resistance can reach 2…10% at zero upward force [2]. The greatest share is brought by the deviations increasing a lateral section, details for example acting in a stream (approximately 5 %). Nearby 1.2 … 1,5 % are necessary on rivets and bolts connections; 0,5 % on joints of sheets; leaky position of shutters and hatches gives 1,0…1,5 %; rough coloring (over 20 microns) – up to C_{x_0}.

At speed from above M=1,5 the size of all components increases approximately twice and resistance from a sinuosity - more than in 5 times. For the reasons specified above the resistance increase through technological roughness's for subsonic FV makes approximately 5…6 %, and for supersonic (M=2-3) - 10…16% [2].

Analysis of publications and researches

Perfection of quality of external surfaces probably at the expense of constructive and technological actions that in turn can lead to additional expenses [3-7]. Therefore an important question at definition of quality of external surfaces is the choice of criterion for quantitative estimations of similar actions [8-12]. As such criterion for a quantitative estimation of losses from additional resistance it is possible to accept the expense or fuel cost [13-18]. The expediency of an estimation of such kind is obvious, as fuel consumption is unique precisely measured parameter at the given design stage UAV, directly reflecting infringement of aerodynamics of a surface, both in manufacture, and in operation [19 – 26].

Problem statement

In development of designs FV and, accordingly, technologies of their manufacture always crucial importance had constant increase in speeds of flight [1]. Growth of speeds of flight not only causes of application of new, more and more heat-resistant materials (Fig. 1), but also is accompanied still nearby important for development of the production technology of tendencies [27-28].

It first of all concerns change of forms of units FV [5, 29]. Simple rectilinear forms of surfaces of units of a glider in process of growth of speeds pass in complex surfaces of double curvature. To the production technology the total disappearance of cylindrical formations of fuselages is essential almost at speeds from above M=0,85 and linear surfaces of wings and plumage, since the speeds from above M=2,0. On change by their surfaces characterized by complex enough laws of formation of the form come [2].

The proceeding increase in speeds (at least to M=3,5…4,5) causes toughening of requirements to accuracy of the external contours, interfaced to serious problems in the field of technology and designing of units [29].

Deviation of elements of a surface from a theoretical contour, a raising of heads of bolts, rivets, screws in a stream, steps, a roughness etc. on everyone concrete FV or group of planes are appointed in specifications developers.

Maximum deviations on elements of aerodynamic surfaces are defined proceeding from 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 parameters of quality of surfaces UAV are in a range of $\delta = \pm 2,0$ мм [1].

To the first zone carry surfaces of units to which increased requirements on quality of a flow are shown. Higher requirements are accepted for a wing $(\delta = \pm 1,0)$ мм, less high ones for a fuselage at great numbers Re and thickness of an interface. Conditions of preservation of a laminar flow are put in a basis of requirements at small numbers Re, as there is an opinion that roughness's start to influence, if their height exceeds a thickness of a laminar local layer [28].

Additional resistance from a surface sinuosity is in sedate dependence on size of a deviation of a surface and its position concerning a forward edge [30]. This circumstance is considered in specifications at definition of zones of surfaces of units.

Taking into account similar reasons restrictions of size of local roughness's of type of ledges, cracks and fixture heads are generated $\delta = \pm(0,1...0,5)$ mm [1].

Result of researches

By working out of constructive and technological decisions it is necessary to define the requirements shown to quality of object of manufacture and technological processes, in particular to appoint maximum deviations of aerodynamic surfaces.

To typical deviations of geometrical parameters of elements carry out next [1]:

1) smooth deviations from the theoretical contour, measured by comparison of an actual surface from the ideal. In practice as the ideal accept a surface set in one of systems:

a) the measuring machine on the basis of mathematical model of a surface;

b) reference surface in the form of its breadboard model;

c) flat carriers of the form and the sizes at use plaza and sample methods, means of spatial coordination, control templates or assembly equipment;

2) eminence of one part of a surface over another against a stream (so-called ‘step’) or on a stream (‘ledge’). Geometrical parameters appreciate by results of excess measurements;

3) smoothness of transition of one part of a surface in another (so-called ‘sinuosity’), characterized in the length of a wave and amplitude. The sinuosity is classified on character of display [1] - cylindrical or spatial. This kind of an error of an external surface is defined by discrepancy of manufacturing and design assemblage in which result there are the internal pressure covering all sections or its parts. Local deformations occur owing to formation of connections (rivets, welded seams). Sinuosity measure or concerning a base line, a tangent to the maximum roughness (ruler), or by results of comparison of an actual surface with ideal [1]. At a smooth deviation of contours on ω sinuosity size on base L makes ω / L, where ω is scope of an error. At the set size of the admission $\pm\delta$ it is necessary to accept $\omega = 2\delta$;

4) local excess of elements of a surface in the form of acting (sinking down) heads of fixture. These errors are registered by means of universal and special measuring instruments. The basic geometrical parameters of deviations are the height h and diameter d [12];

5) cracks through or without an exit between elements of a surface of the unit. These errors also are measured by universal tools or special templates and characterized by the relation of width b to depth h, or b / h, or the admission for width of a through crack [12];

6) punching of an external surface of the unit owing to defects of a surface. These errors are limited by an equivalent aperture on area unit [1] (Fig. 2).

Admissions on a relative positioning of global surfaces of separate units and units among themselves in this case are not considered.

Technique of appointment of admissions on external contours of flying vehicles

For the purpose of definition of a generality of the constructive and technological decisions accepted in specifications, revealing of the reasons defining size of the admission have been analyzed specifications for more 30 FV various types and appointment.

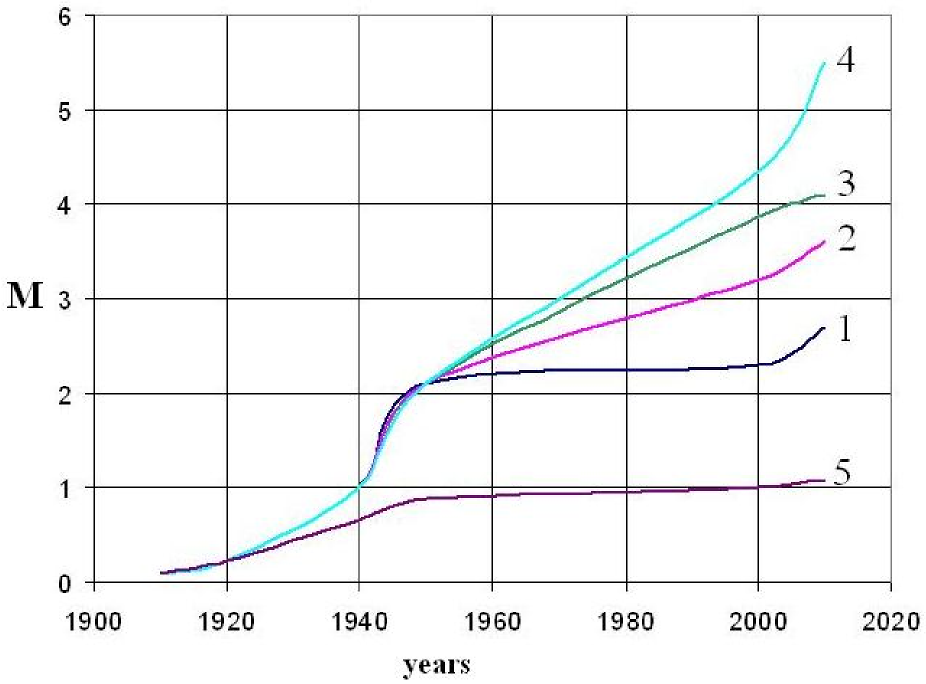

Fig. 1. Growing of speeds on flight of FV [11]: 1 – for aluminum designs; 2 – for titanium designs; 3 – for designs from special steels; 4 – for designs from special alloys; 5 – for subsonic UAV

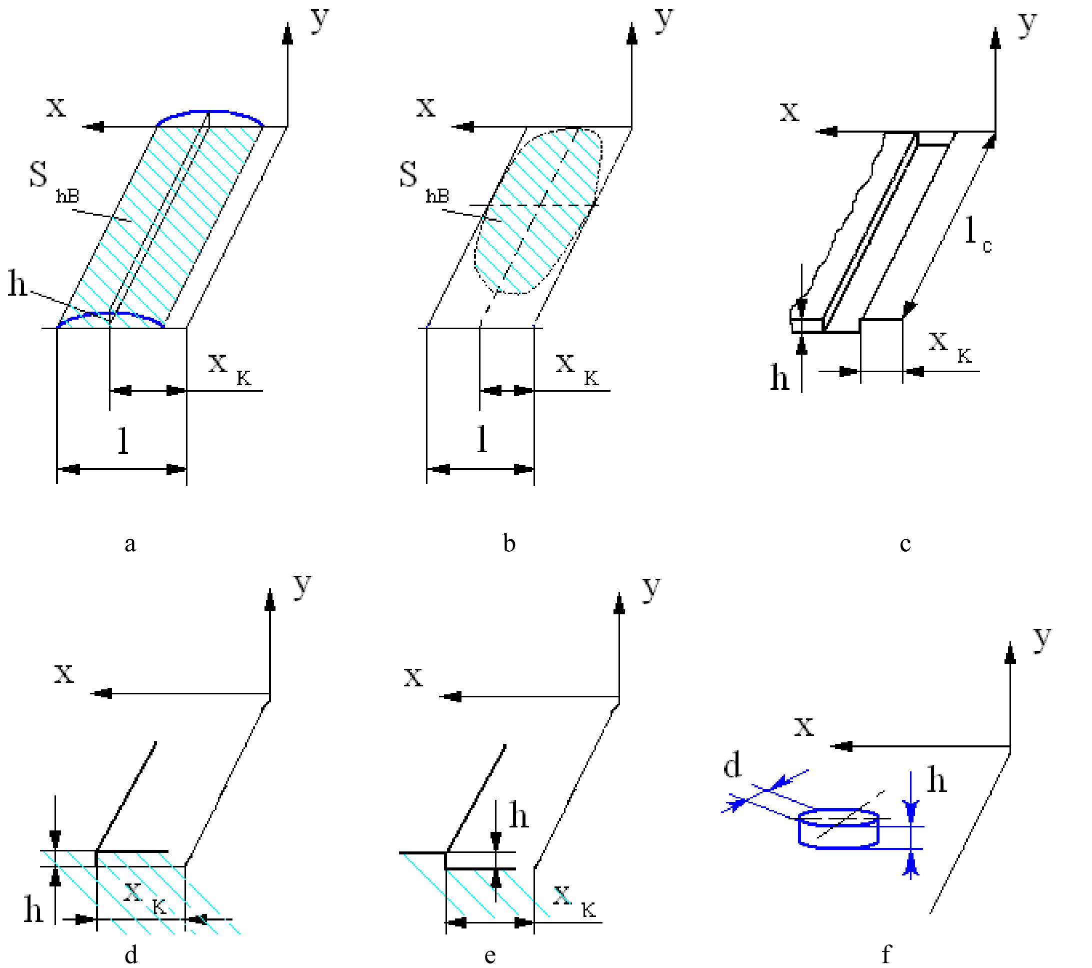

Fig. 2. The typical geometrical parameters of a surface limited to admissions [8]: a – cylindrical sinuosity; b – spatial sinuosity; c – crack (a backlash); d – ledge against a stream; e – ledge on a stream; f – punching

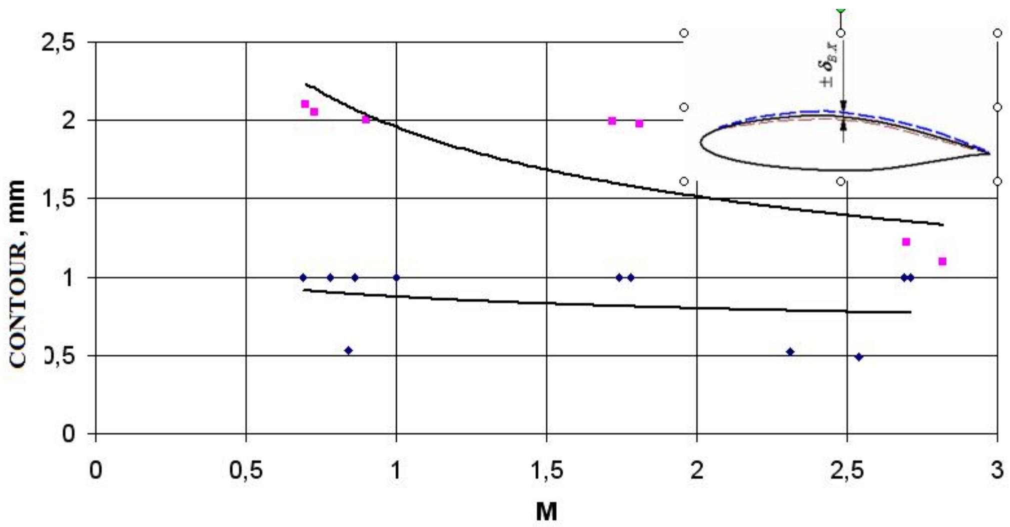

Fig. 3. Dependence of change of the admission on a deviation from a contour of the unit from speed

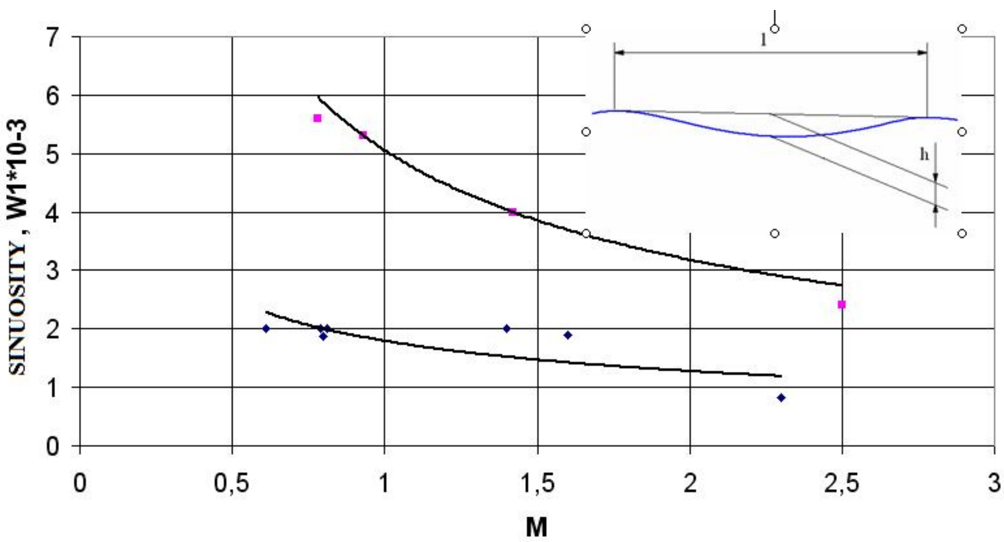

Fig. 4. Dependence of change of the admission on parameters of a sinuosity of a surface from speed

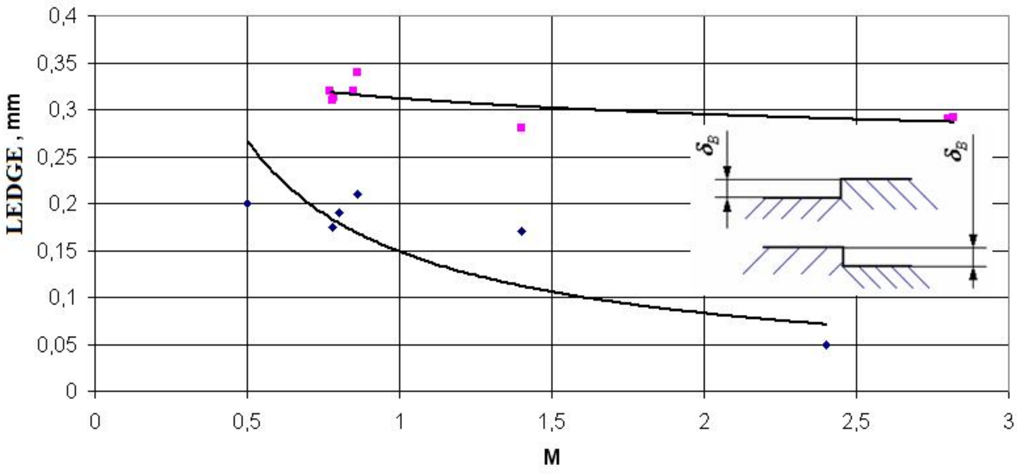

Fig. 5. Dependence of change of the admission on parameters of a ledge of a surface from speed

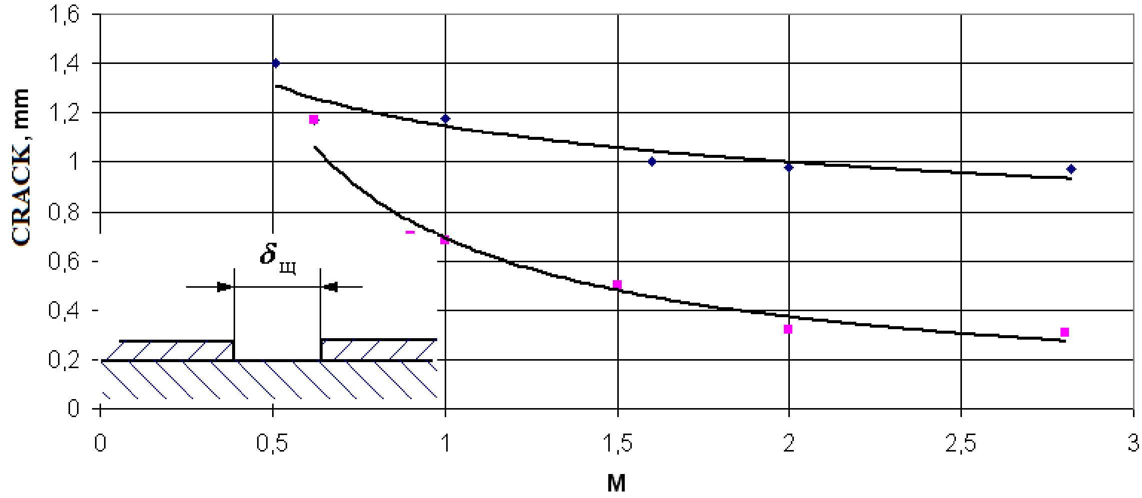

Fig. 6. Dependence of change of the admission on parameters of a crack of a surface from speed

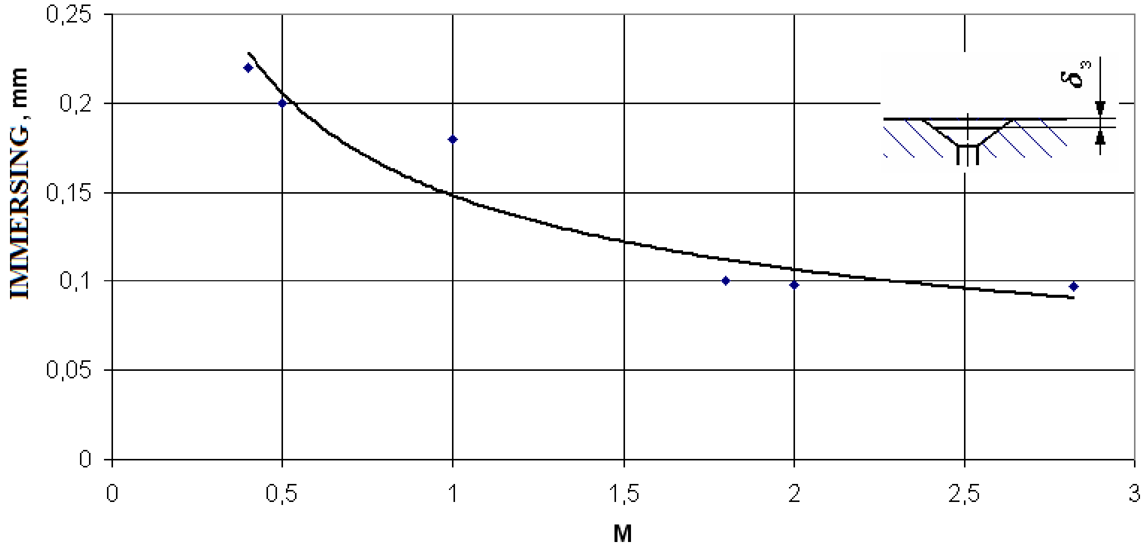

Fig. 7. Dependence of change of the admission on immersing parameters in a surface from speed

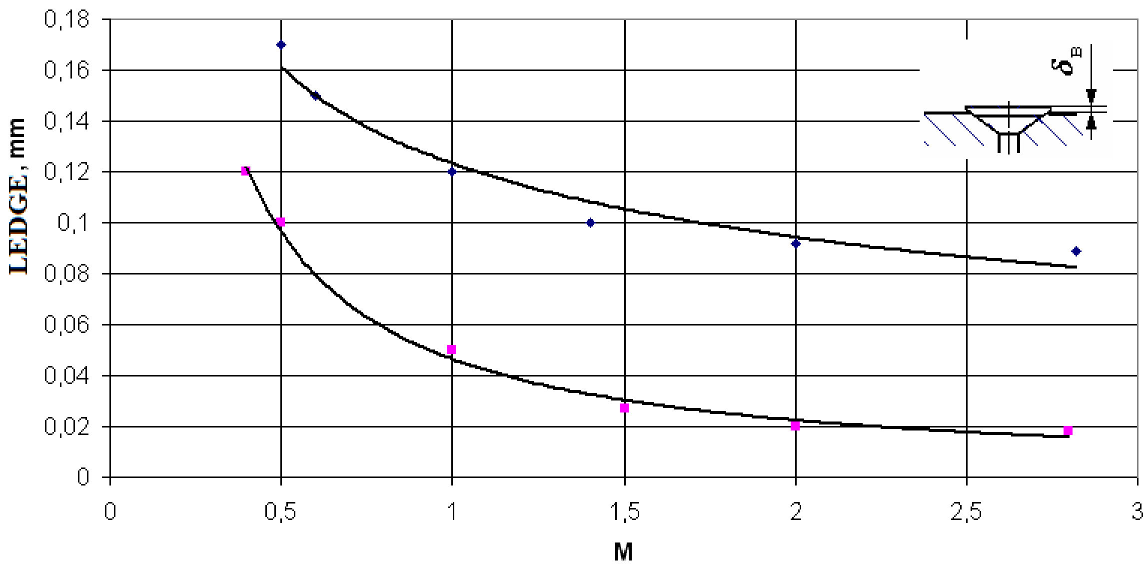

Fig. 8. Dependence of change of the admission on parameters of a ledge from a surface in from speed

On Fig. 3-8 the schedules constructed by results of statistical processing set in specifications of admissions are presented [12].

Criteria for choosing tolerances for contours of the UAV

Qualitative performance indicators, as noted in [1], is a ratio of the target impact to cost for the whole lifecycle B, is $\eta = \frac{W}{B}$. As for improvement of quality surface of targeted output are generally does not change $(W = \text{const})$, that improving the efficiency is possible due to changing the value of the life cycle. Hence as a selection criterion tolerance assume the condition [12] as:

$$\{B_{\text{пр}} + B_m\} \to \min,$$

where $B_{\text{пр}}$ – manufacturing cost;

B_m – maintenance costs for the entire lifecycle, equal to $B_m = B_{ss} + B_H + B_r + B_f$;

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 a direct impact on UAV fuel costs, because deviations from ideal surface in majority cases helps to increase the resistance at zero lift, i.e. C_{x_0}. Then $\Delta B_m = B_m(\Delta C_{x_0})$, where $\Delta C_{x_0} = f(\omega)$, ω – the scale of error.

The same time cost of production depends on the achieved level precision that determined by the methods applied and industrial facilities with the characteristic tendency of rising costs with increase accuracy [11]. Noted suggesting that dependence of cost the function can be described $B_c = B_c(\omega)$ according to (1) the optimal value of tolerance is defined by equation [1]:

$$\frac{\partial B_c(\omega)}{\partial \omega} + \frac{\partial B_H(\omega)}{\partial \omega} = 0 \qquad (2)$$

and depends upon the intensity rising costs when the ω. Given equation is correct for the case when the UAV target output unchanged.

Depending upon variant of the problem the criterion $\{B_c + B_H\}_{\min}$ may be modified and added:

1. At the stage of conceptual design from the set of possible constructive and their corresponding technological decisions is chosen a solution that provide value of permissible error not greater than the given directive, and simultaneously satisfies minimum cost criterion, i.e. $\omega \le K\delta$ (in fractions of the displacement thickness).

2. At a stage of conceptual design shall be selected constructive solutions providing $\{\omega_{opt}\}_{\min}$. Necessary to calculate due to choice of most contemporary solution, under the given conditions production and exploitation, aerodynamics. In that case the condition $\{B_H(\omega)\}_{\min}$ corresponds to a minimum of fuel consumption.

3. At the stage of conceptual design from an array potential solution is determined by from the standpoint highest cost. In that case the criterion is condition $\{B_c + B_H\}_{\min}$ of provides minimal life cycle costs. But is not guaranteed minimal fuel consumption.

4. At the stage of detailed engineering determined the value of optimal criterion (1) tolerance for the technical requirements (TR) development.

5. At the stage of manufacture value is corrected tolerance provided for TR, taking into account physical costs of in the manufacture. Also possible on correction of inverse problem of production costs to ensure the tolerance specified in TR.

The criterion for last two options is (1).

Solutions above criteria for the tolerances values should be checked for the conditions of current implementation or newly adopted technological processes. Practically it means selecting from an array of possible technological solutions to the most suitable which must simultaneously provide minimum production costs, i.e. B_c or $(B_c)_{\min_{\min}}$ allowance and non-zero value the tolerance field.

Thus, 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. 9).

The factors determining value for admission to contours of the Unmanned Aerial Vehicles

The magnitude external outline tolerance influences range of factors which determine the value derived from operating costs which depend on the quality the external surface defined as the cost an additional fuel [16]:

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

where m_h – hours fuel consumption;

ΔC_{X_0} – increment value of resistance due of surface defects.

In order reduce the amount of calculations for comparing various design and technological solutions

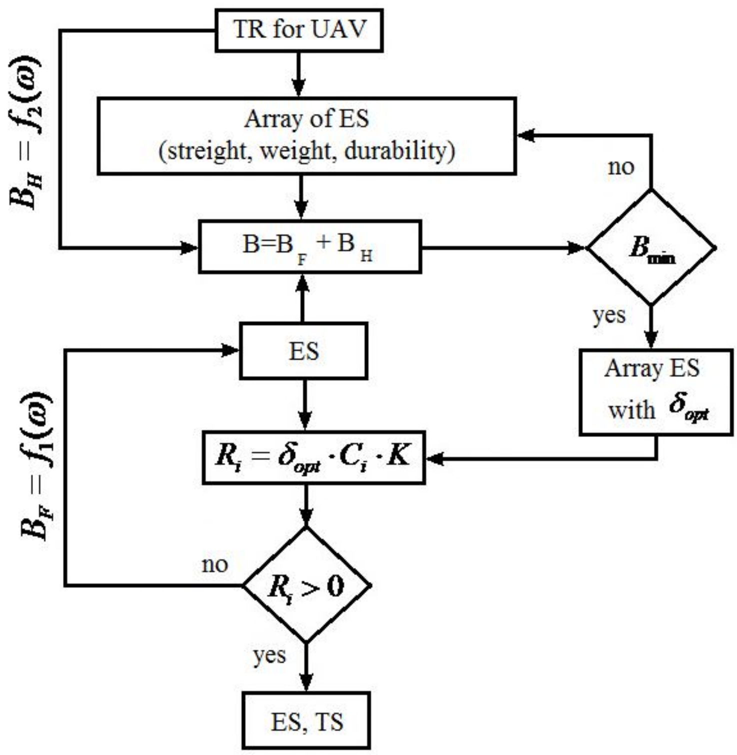

Fig. 9. The algorithm of choosing structural
and technological solutions in implementation of tolerances
(TR – technical requirements; TS –technological solution; ES –engineering solution)

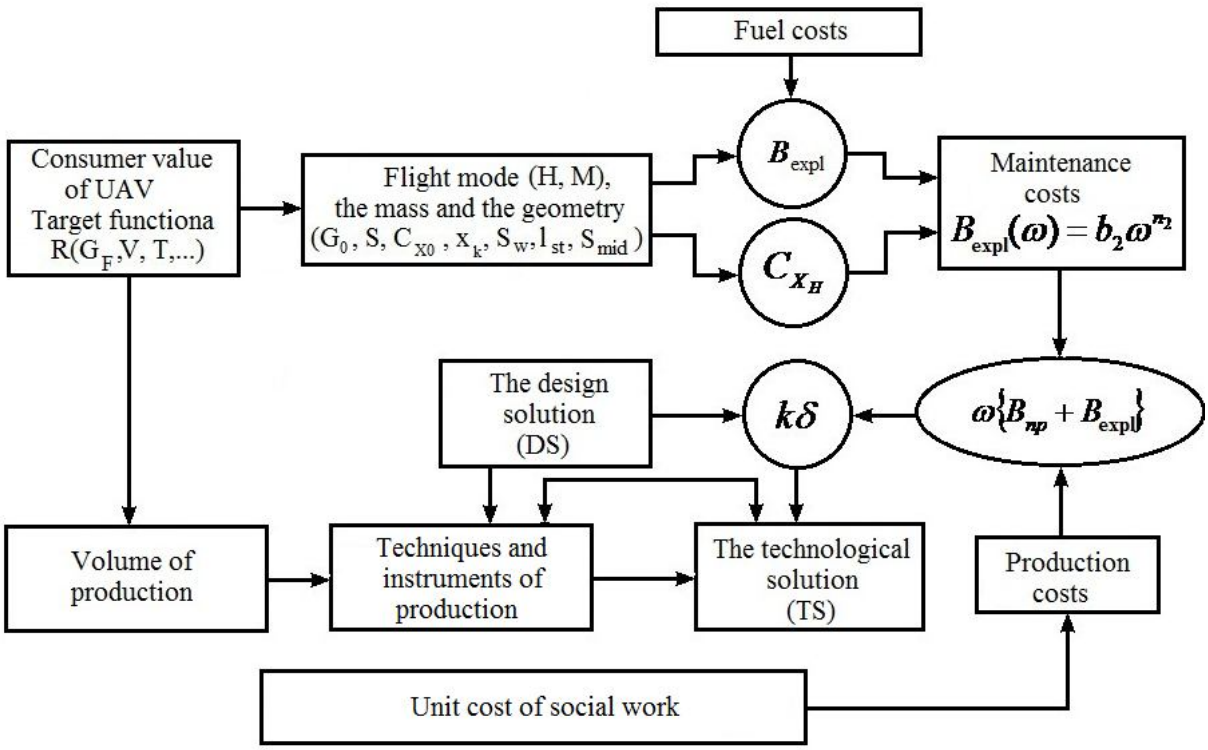

Fig. 10. The structure of the mathematical model
the choice of tolerances to external contours

expedient to introduce the concept costs per unit of surface area ($/m²) [13]:

$$B_c = \frac{m_f b_h T}{2C_{X_0}} \Delta C_{X_0}.$$

Taking into account that the additional resistance for irregularities such wave, step, slit, etc. may be described by the equation:

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

where C_{XH_∞} – 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.); $\bar{S}$ – относительная площадь, занимаемая исследуемой неровностью relative area occupied by roughness of investigated; β, n_2 – показатели степени the exponents.

According to the equations (3) and (4):

$$B_c(\omega) = b_2 \omega^{n_2}, \quad (5)$$

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 for manufacture in general depend on method adopted pre-production, level of the cost of one hour defined accepted methods and means. In general, this set of determines the technological solutions which used to implement the some set design solutions.

Establishment of functional relation between cost of production and size the construction errors are self-task. In the present paper considers only the final results to principal design solutions. Proceeding from the results of statistical analysis manufacturing costs may be recommended dependence types of:

$$B_c = \alpha \omega^{-n}. \quad (6)$$

These dependences (1), (5) and (6) allow establishing a quantitative correlation between forms of factors in described, i.e. to present the process choice of tolerances as mathematical model (MM) (Fig. 10).

In general case this MM must be supplemented a description of the impact of external factors on target function provided to the form of fuel prices, unit cost of work, etc. [14]. Optimal value of tolerance according to the accepted criteria determined by the equation:

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

using which possible to find an estimate each factor relative to the base value, i.e.

$$\omega = \omega_0 \left(\frac{a}{a_0}\frac{n}{n_0}\frac{m_{h_0}}{m_h}\frac{b_{f_0}}{b_f}\frac{T_0}{T}\frac{C_{X_H}(M_0)}{C_{X_H}(M)}\frac{\Phi(M_0)}{\Phi(M)} \cdot \frac{\Phi(H_0)}{\Phi(H)}\frac{C_{X_0}}{(C_{X_0})_0}\frac{S}{S_0}\frac{n_{20}}{n_2} \right). \quad (8)$$

Given equation (8) allows you to recalculate the tolerance when changing flight conditions, engineering and technology implementations (ETI) and the external environment. For example, changes in service life defined by the ratio T_0/T [31]. Then when $T > T_0$ be taken more close tolerance, as $\omega < \omega_0$. Influence of flying speed estimated by the ratio [1]:

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

In case of monotonic changes the incoming parameters $M > 1$ require to tightening tolerance with M growth. For the solution problems of choosing tolerance (especially in case of iterate through possible options), for example, over 30 and the different flight conditions), you can use the algorithm and calculation program developed on the basis suggested MM.

Conclusion

The analysis of appointment of admissions on external surfaces of units FV, practice of their appointment and realization in manufacture allow drawing following conclusions:

1. Practically FV in one interval of numbers M admissions on performance of geometrical elements of an external surface are identical to all and decrease with growth M. Admissions for supersonic UAV ($M = 2...3$) approximately twice it is less, than admissions for the subsonic ones. The general feature is the task of various requirements for a wing, plumage, a fuselage, gondolas and flows. The highest requirements to quality of an external surface are shown to a wing, as to the unit creating carrying force.

2. Necessity of decrease in weight and durability increase has caused transition from a traditional modular design for power compartments to the monolithic. Application of composite materials that has led to change of conditions of realization of the admissions set on external contours extends. In due to manufacture automation methods of the task and means of reproduction of surfaces forming contour UAV will change. In these circumstances of a condition of realization of admissions it is necessary to consider in two aspects: in design, i.e. according to the possibilities of formation of the set accuracy of contours put in a design, and in industrial and technological, i.e. according to possibilities

of existing and perspective technological processes and the equipment providing set accuracy.

3. Experimental researches of the isolated roughness are put in a basis of calculation of resistance from roughness's taking into account its site in the boundary layer. The roughness height is defined by admissible size of additional resistance ΔC_{x_0}. Practical technique to an establishment of dependences and functional communications between values of admissions and expenses by the generalized criterion and consequently, and to a choice of economically optimum admissions, still it is not defined unequivocally. Therefore for the generalized criterion accept additional fuel consumption because of resistance of roughnesses, as influence of additional resistance on speed almost slightly.

4. To solve the choice problems tolerance algorithm and design procedure developed on the basis the proposed mathematical model.

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Рецензент: д-р техн. наук, проф., проф. каф. химии, экологии и экспертизных технологий А.В. Бетин, Национальный аэрокосмический университет им. Н.Е. Жуковского «ХАИ», Харьков.

ВПЛИВ ФАКТОРІВ, ЯКІ ВИЗНАЧАЮТЬ ЗНАЧЕННЯ ДОПУСКУ НА ЗОВНІШНІ ОБРИСИ БЕЗПІЛОТНИХ ЛІТАЛЬНИХ АПАРАТІВ

М.В. Зосімович, Р.К. Сінгла

Дослідження форм сучасних та перспективних безпілотних літальних апаратів (БЛА) дозволило дістати оцінку типових геометричних параметрів поверхні та призначення допусків на зовнішні поверхні апаратів. У статті проаналізовано критерії вибору допусків на зовнішні контури БЛА, запропонована модель обрання конструктивних і технологічних рішень під час призначення допуску та вивчено фактори що визначають значення величини допускав на зовнішні контури БЛА.

Ключові слова: природоресурсний та екологічний моніторинг, безпілотний літальний апарат, авіаційний комплекс, інформаційна панель, льотчик-оператор, монітор, стимул, математична модель.

ВЛИЯНИЕ ФАКТОРОВ, ОПРЕДЕЛЯЮЩИХ ВЕЛИЧИНУ ДОПУСКА НА ВНЕШНИЕ ОБВОДЫ БЕСПИЛОТНЫХ ЛЕТАТЕЛЬНЫХ АППАРАТОВ

Н.В. Зосимович, Р.К. Сингла

Исследование форм современных и перспективных беспилотных летательных аппаратов (БЛА) позволило получить оценку типичных геометрических параметров поверхности и назначения допусков на внешние поверхности аппаратов. В статье проанализированы критерии выбора допусков на внешние контуры БЛА, предложена модель выбора конструктивных и технологических решений при назначении допуска и изучены факторы, которые определяют значения величины допусков на внешние контуры БЛА

Key words: природоресурсный и экологический мониторинг, беспилотный летательный аппарат, авиационный комплекс, информационная панель, летчик-оператор, монитор, стимул, математическая модель.

Зосимович Николай Владимирович – канд. техн. наук, профессор кафедры инженерной механики Университета Шарда, Грейта Нойда, Индия, e-mail: n.zosimovych@sharda.ac.in.

Singla Rohit Kumar– магистр инженерной механики и производственных технологий, ассистент-профессор кафедры инженерной механики Университета Шарда, Грейта Нойда, Индия.