UDC 629.7 (045)
DOI: 10.18372/2306-1472.82.14608

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METHOD OF EXPRESS-SELECTING THE PROFILES OF WING OF THE STRATOSPHERIC QUASI-SATELLITE

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Abstract

The article deals with the method of selecting in the first approximation of a wing profile for a stratospheric quasi-satellite- a high-altitude solar-powered aircraft that has a "normal aerodynamic scheme".The peculiarities of this type of aircraft regarding the choice of a specific wing profile with maximum values of aerodynamic quality, which is the basis for obtaining high perfection of the future layout of the quasi-satellite, are noted. Examples of existing aircraft are given, the wing profiles of which can be analogues in this study. During the study, the method of direct placement of weight coefficients is used. Significant factors that influence the decision on the choice of profile are determined and their values are established. It is indicated that the maximum profile quality for a given Re number, among other things, has the highest weight coefficient. Instead, the maximum relative thickness, which was considered to be the determining factor, becomes the second most important factor, given the use of modern composites as a key technological tool. Even less important is the complexity of the technical reproduction of the profile contour. Based on the study, the geometric and aerodynamic characteristics of the FX 76 MP-120 profile for Re numbers within 0.2… 1x10^6 are presented.

Keywords:quasi-satellite; profile aerodynamic quality; relative thickness profile; radius of the leading edge; complexity of technical reproduction of the profile contour; coefficient of lift; coefficient of aerodynamic resistance; angle of attack; coefficient of longitudinal moment of profile; aerodynamic quality plane

1. Formulation of the problem

At the stage of preliminary design of a solar-powered aircraft, a quasi-satellite intended for high-altitude flights in the stratosphere, the question arises of the selection of wing profiles, which can provide a solution to the complex set of requirements for aerodynamics and strength of the specified type of aircraft. Among other things, in the process of preliminary verification, you can use the statistics of Reynolds numbers similar aircraft, which are also typical for a quasi-satellite.

These categories of aircraft are quite specific because they combine model aircraft of certain classes, aircraft, super-lightweight gliders, and similar designs for high-altitude solar-powered aircraft. This article discusses the application of the method of weighting coefficients to select and determine the characteristics of the wing profile of a quasi-satellite – a high-altitude solar-powered aircraft.

2. Problem solving

2.1. Profile requirements the wing for the stratospheric quasi-satellite

The following assumptions were used when choosing the quasi-satellite wing profile:

- the highest profile aerodynamic quality of K_{prof} in the range of numbers Re = 0,2…1x10^6 at low speeds of movement (5-30m/s);
- a relative thickness $\overline{c}$ which is sufficient to satisfy the requirement of a suitable construction height of the wing from the location of the double shelf spar as the main force element of the wing;
- relatively large radius of the leading edge to reduce the likelihood of disruption at large angles of attack (for $b_{0.c.}$=0,5m);
- relatively small complexity of technical reproduction of the profile contour.

The selection of the profiles of the stratospheric quasi-satellite wings inthe first approximation, due to its specificity and purpose, was carried out taking into account the practice of applying profiles in the following types of aircraft:

- sports models of gliders and motor models of free-flying classes, in particular classes F1A, F1B, F1C, as well as championship sports models of radio-controlled gliders of class F3B;
- implemented stratospheric aircraft powered by solar panels;
- мuscle-driven aircrafts;
- ultra-light manned gliders for long-term planning in thermal or dynamic ascending flows.

Free-flying models of classes F1A, F1B, F1C perform flights on small numbers $Re=0,1\ldots0,2x10^6$; for almost 80 years the aerodynamic scheme has hardly changed and the profiles have been brought to the highest level of perfection. Similarly, we can say about the radio-controlled models of F3B class gliders, with the exception of their "experience" - more than 40 years.

Attention is also given to the relatively new class of aircraft – the мuscle-driven aircrafts.

They have extremely low wing load and energy performance: for example, the famous Gossamer Albatross aircraft had a specific load of $2,1kg/m^2$ with a lifting weight of 98kg. Its energy efficiency can be estimated to be 0.0051kW/kg, which to date is beyond the requirements of energy armament to any type of known aircraft.

For the sake of maximum aerodynamic quality of plane Gossamer Albatross has been given the utmost care to maximize aerodynamic quality profile.

In recent years, the ultra-light Archeopteryx gliders from the Swiss company Ruppert Composite GmbH have gained popularity. At a starting weight of 160 kg gliders have an aerodynamic quality of about 30 units, which indicates the perfection of the wing and its profiles; The velocity of the dip is estimated to be 8-9m/s, which is commensurate with the velocities of the stratospheric quasi-satellite.

The choice of wing profiles for free-flying models of classes F1A, F1B, F1C has been thoroughly discussed in the source [1]. The following profiles are widely used in these classes: NASA 6309, NASA 6509, MVA301-75, Eiffel 431, and others. This ensures the highest possible aerodynamic quality at minimum flight speeds. Radio-controlled models of gliders F3B class and the selection of profiles for them are considered in the source [2]. The following types of wing profiles are recommended: E211, FX 63-137, B-10305b, G-593 and others. The requirements for this class of aircraft are slightly different from the previous ones; however, when performing the flight duration exercise, these profiles, when ballast is unloaded from the glider, achieve the corresponding results, indicating that it is desirable to include the profile data in the statistics database.

Muscle-driven aircrafts were considered in particular in the sources [3,4]. Their wing profiles must meet the highest requirements, since it is extremely difficult to fly such an aircraft, given its low energy performance and size; the wingspan of this aircraft can reach 30m. FX 76 MP-180 and FX 76 MP-120 profiles are recommended [8]. Ultralight manned gliders for long-term planning and their characteristics are given in the source [5].

For qualitative evaluation of specific profile characteristics, profile atlases [6,7] were used as well as the software product *"Xfoil",* which gives an opportunity to get a rapid express analysis of the profile by the numbers Re within the limits $Re=0,05\ldots 1x10^6$. The outer contours of the selected profiles are shown in Fig. 1a and Fig. 1b.

It should be noted that the technical data of profiles No. 10 and No. 11 are unknown, except for the relative thickness. The contours of these profiles are obtained by copying from open source side view photos; profiles No. 10 and No. 11 were analyzed to confirm the overall trend of the selection itself and its criteria, but were not used in comparison.

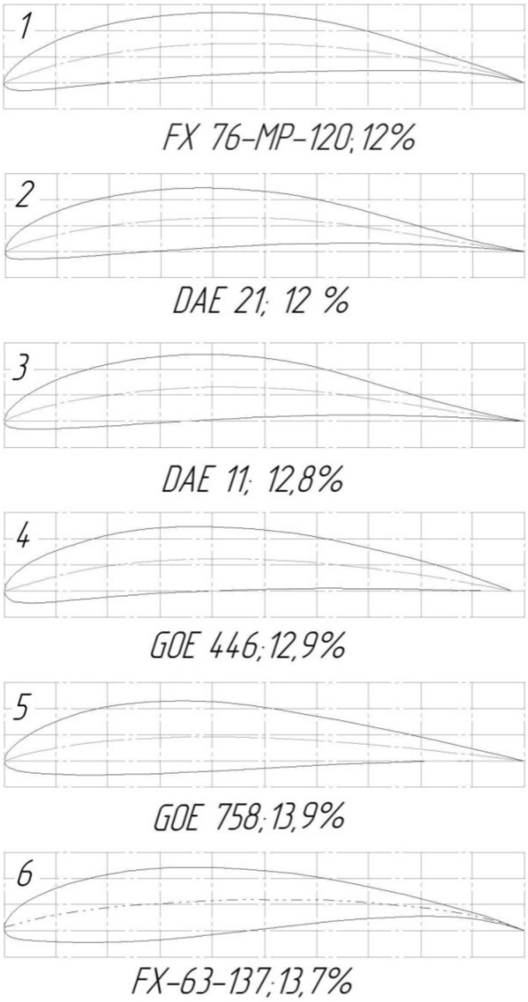

Fig. 1a. Exterior contours, name and relative thickness of wing profiles selected in the first approximation for the stratospheric quasi-satellite

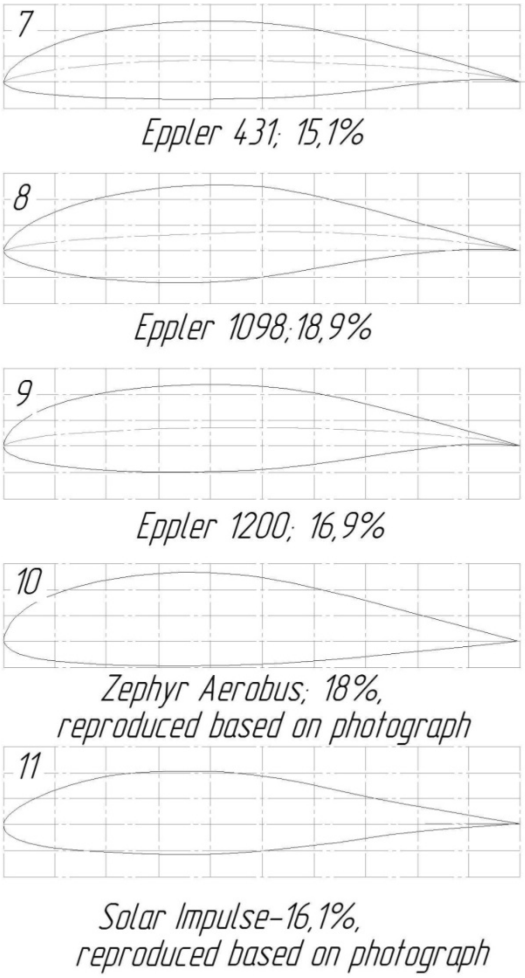

Fig. 1b. Exterior contours, name and relative thickness of wing profiles selected in the first approximation for the stratospheric quasi-satellite

2.2. Preliminary expert assessment of profile parameters used in comparison

Profile aerodynamic quality K_{prof} is a key parameter of the evaluation because it contains the ratio of the most important $C_{y.prof.}$ coefficients. and $C_{x.prof.}$, which make it possible to evaluate the future aerodynamic quality of $K_{comp.quasi\text{-}sat.}$in general. Addition, purge materials (the main source of $K_{prof.}$ receipt) provide data on angles of attack corresponding to certain K_{prof} values and the value of another important factor - $C_{m.prof}$, which used in calculations.

It on K_{pro} known profile almost impossible to influence without sophisticated hardware. As a rule, K_{prof}results are obtained in specialized organization - the aerodynamics complex, where, on the basis of physical experiment, the necessary databases are compiled, which later become the reference for developers. Accordingly, this parameter is the most important, so its relative weight can be estimated at least 0,6.

The relative thickness of the profile $\bar{c}$is a parameter that, among other things, also affects the structural and technological capabilities of the positioning in the thickness of the wings of its main force element - the spar. It is known that the higher the height of the wing structure, the easier the spar and easier to place there.

However, a set of state-of-the-art technological tools, including the regulation of strength characteristics in unidirectional composites, allows, at the developer's level, to maintain the parity between the mass, strength and dimensions of the spar. Therefore, due to the possibility of its correction, the weight estimate of this parameter may be 0,2.

The radius of the spout (which is reduced to a chord of profile 0.5m) mainly affects of flow failure of the on wing: with decreasing radius the probability of flow failure on the wing increases; also, as the radius decreases, the critical angle of attack of the profile decreases. However, due to the fact that the quasi-satelliteis equipped with a perfect flight controller, which, among other things, controls a given angle and speed limits, the probability of a flow failure is small, at least from the point of view of reliability the operation controller.

Therefore, there is a significant adjustment lever for this parameter, which allows it to be given a relative weight of about 0,1.

With regard to the complexity of the technical reproduction of the profile contour, the following can be stated: the profiles presented are asymmetrical, mostly concave-convex.

Accordingly, it will be more or less difficult to make a concave, lower part of the profile. Because it is similar in all profiles, the difference in playback will only be in the accuracy of playback using the same technology, and therefore the weight estimate of this parameter is 0,1. At the same time, all claimed profiles were respectively evaluated for the complexity of the contour from 1 to 5; the higher score corresponded to a more complex profile outline.

In the Table 1 shows the relative weight assigned to each parameter.

Table 1

A summary table of the weight estimates of the profile selection parameters for the quasi-satellite wing

No.	**Parameter name**	**The relative weight of the parameter**
1	Profile aerodynamic quality K_{prof}	0,6
2	The relative thickness$\overline{c}$	0,2
3	Front edge radius	0,1
4	The complexity of the technical reproduction of the profile outline	0,1

The profiles data selected in the first approximation is presented in Table 2.

Table 2

Comparative table of significant profile parameters for wings the stratospheric quasi-satellite

No.profile	1	2	3	4	5	6	7	8	9	The relative weight of the parameter
Profile name	FX 76-MP-120	DAE-21	DAE-11	GOE 446	GOE 758	FX 63-MP-137	E431	E1098	E1200	
Parameters										
Profile aerodynamic quality $K_{prof.max.}$	192,6	173,5	177,3	148,7	133,6	130	146	152	132	0,6
The relative thickness $\overline{c}$%	12	12	12,8	12,9	13,9	13,7	15,1	18,9	16,9	0.2
Front edge radius (a chord of profile 0.5m)	7	7,5	6,5	9	7,25	9	4,5	4,5	8	0,1
The technical ofdifficulty playback (score)	4	3	3	1	1	5	2	2	2	0,1

Estimates were calculated using the direct placement method. It is known that the sum of all weights must be equal [9,10]:

$$\sum_{i=1}^{n} k_i = 1, \qquad (1)$$

where k_i – weighting coefficients of the *i-th* parameter.

A separate estimate of the *i-th* parameter was obtained as follows:

$$O_{i.p.} = k_i \times B_{v.p.}\,, \qquad (2)$$

where $B_{v.p.}$ – dimensionless numerical value of the *i-th* parameter.

The input data for calculating parameter estimates for specific profiles are presented in Table 2.

The total rating of a particular profile was obtained as follows:

$$\sum \mathrm{O}_{i.p.} = \mathrm{O}_{i.1} + \mathrm{O}_{i.2} + \mathrm{O}_{i.3} + \mathrm{O}_{i.4} \qquad (3)$$

Table 3 shows the results of calculating the total estimates of significantparameters for the selected profiles.

Table3

Evaluation results and rating of selected profiles for the stratospheric quasi-satellit ewing

No.profile	1	2	3	4	5	6	7	8	9
Profile name **Parameters**	FX 76-MP-120	DAE-21	DAE-11	GOE 446	GOE 758	FX 63-MP-137	E431	E1098	E1200
Total score	119,06	107,55	109,89	92,8	83,705	82,1	91,45	95,98	83,58
Rating the profile	1	3	2	5	7	9	6	4	8

The rating, or ordinal priority, in the choice of a wing profile indicates that relatively "thick" profiles, such as E1098, have a significantly lower overall rating that is equal to a given O_{E1098}=95,98. However, relatively thin profiles of the DAE series received higher marks, in particular, $O_{DAE\text{-}11}$=109,89.

This can be explained by the high value of profile aerodynamic quality for E1098, which is equal to $K_{prof.max.E1098}$=152 compared to the profile aerodynamic quality for DAE-11, which is equal to $K_{prof.max.DAE\text{-}11}$=109,89.

2.3. General characteristics of the selected profile FX-76-MP-120

Geometric data:

- The maximum relative thickness, (% of b_a) – 12,1;
- Location of maximum thickness, (% of profile spout)–33,9;
- The maximum relative concavity, of the midline, (% of b_a) – 7,6;
- Location max. midline concavities, (% of profile spout)– 46,7.

Aerodynamic data (for number Re=0,5x10^6):

- Attack angle max. profile aerodynamic quality, deg.– 3,75;
- Maximum aerodynamic profile quality, $K_{prof.}$≈145–150;
- Maximum lift coefficient of profile (C_Y)≈1,65;
- Minimum aerodynamic drag coefficient (C_x)≈0,007;
- The minimum coefficient of longitudinal moment,C_m≈0,012.

Fig. 2 shows the dependence of the lift coefficient profile FX-76-MP-120, depending on the angle of attack ($C_y = f(\alpha)$).

The nature of the curves reflecting this dependence shows that within the limits of future (predicted) angles of attack from -6^0 to +10^0 there are no sharp fractures (peaks) that would indicate an unexpected occurrence of stall phenomena in flight. The transition to critical angles of attack is also smooth.

The dependence of the coefficient C_y on the coefficient of profile resistance shows (Fig. 3), within acceptable values for flight values of C_y, the coefficient C_x changes slightly, which also guarantees high aerodynamic quality within the applicable angles of attack.

Fig. 4 shows the dependence of the coefficient C_x, depending on the angle of attack. The figure shows that within the angles of attack from about -6^0 to +6^0, the coefficient C_x does not grow sharply, but retains relative uniformity in its values, namely from 0,008 to 0,015.

Fig. 5 shows the dependence of the aerodynamic quality of $K_{prof.}$ from angle of attack. The nature of the curves for the represented numbers *Re* shows that they are similar in configuration; therefore, in this range K_{prof} FX-76-MP-120, $K_{comp.}$ the future layout of the entire quasi-satellite will be predicted and will change smoothly. The difference for the two curves presented will only lie in the absolute values of $K_{prof.}$

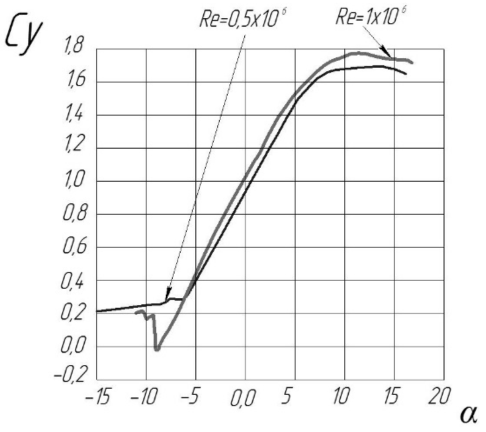

Fig. 2. The dependence $C_y = f(\alpha)$ for the profile FX-76-MP-120

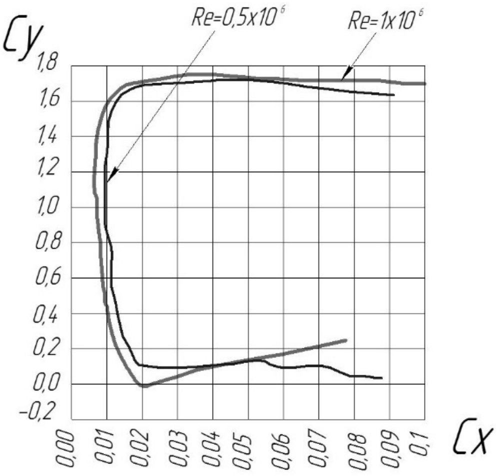

Fig. 3. The dependence $C_y = f(C_x)$ for the profile FX-76-MP-120

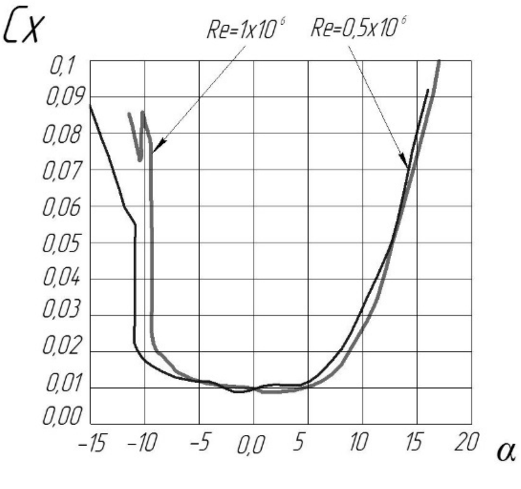

Fig. 4. The dependence $C_x = f(\alpha)$ for the profile FX-76-MP-120

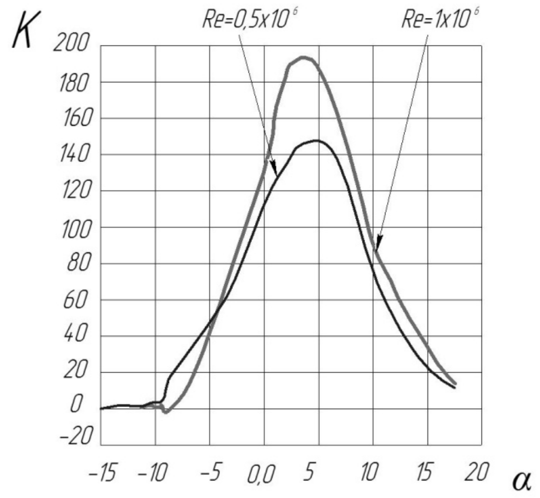

Fig. 5. K_{prof} aerodynamic quality for the FX-76-MP-120 profile depending on the angle of attack

The longitudinal moment coefficient and its dependence on the angle of attack for the FX-76-MP-120 profile are presented in Fig. 6. It can be noted that C_m values are stable for most projected angles of attack. In a cruise flight, it can be offset by a corresponding margin of the coefficient of longitudinal static stability as an aircraft "normal aerodynamic scheme" with a horizontal plumage of a large area, located on a relatively large shoulder.

In addition, the flight controller, taking into account its pitch PID value, will also adjust the corresponding C_m values for the entire aircraft (its aerodynamic design). The appearance of the contour of the profile FX-76-MP-120 is shown in Fig. 7.

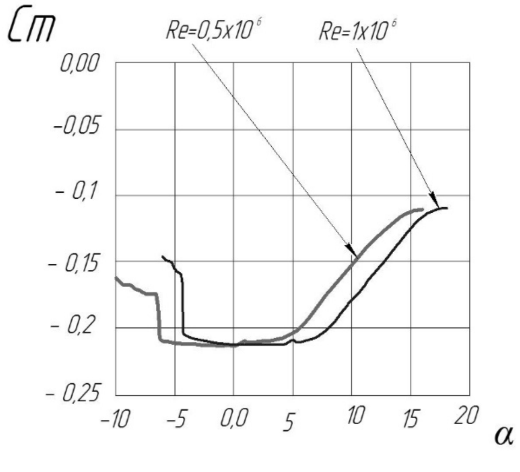

Fig. 6. Dependency of coefficient $C_{m.prof}$ of profile FX-76-MP-120 on angle of attack

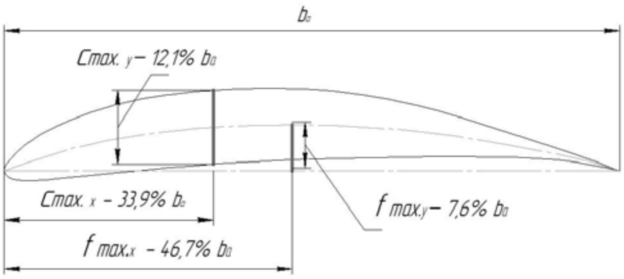

Fig. 7. Outline view of the FX-76-MP-120 profile contour and the locations of the maximum thickness and maximum concavity points of the midline

3. Conclusions

In view of the analysis and expert assessments of profiles No. 1-9, the most suitable for this sample of the stratospheric quasi-satellite can be called profile No. 1, namely the profile Wortmann FX-76-MP-120.

It was originally intended for use in muscular-powered aircraft (MP-manned power), in which the maximum aerodynamic quality of the wing as a whole and the profile quality of the wing in particular play a crucial role.

References

[1] Nestoi W. (1980). Profiles of flying models. WKL: - Warsaw, pp. 62-72.

[2] Merzlikin V.E. (1982). Radio-controlled models of gliders. - M.: DOSAAF, pp. 45-48.

[3] DaSH PA. En.Wikipedia. Available at: https://en.wikipedia.org/wiki/DaSHPA

[4] Barrenger C. Tasmanian RC Human - Powered Aircraft Project. Aeromodelling Digest 1993. ISSN 1039. 9224Published by Samaria Concepts, RMB 1798, Benalla, Victoria, 3673

[5] Ruppert Archaeopteryx. Available at: https://en.wikipedia.org/wiki/Ruppert_Archaeopteryx

[6] Kashafuddinov S.T., Lushin V.N. (1994). Atlas of aerodynamic characteristics of wing profiles. Publisher: SibNIA. - Nosvosibirsk, 69 p.

[7] Carles D.Harris. NASA Supercritical Airfoils. NASA Technical Paper 2969 March 1990. Available at:https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19900007394. pdf

[8] Profile FX 76-MP-120. Retrieved from: AirfoilTools. Available at: http://airfoiltools.com/airfoil/details?airfoil=fx76mp120-il

[9] Delov V.A., Fashchev V.V. (2017). The relevance of the correct placement of weighting coefficients in the problems of classification of radar targets.// ISSN 2542-0542. Bulletin of the Concern VKO «Almaz-Antey» No. 2, pp. 56-60.

[10] Korobov V. B. (2005). A comparative analysis of methods for determining the weighting factors of “influencing factors.” // Sociology: Methodology, Methods, Mathematical Modeling (4M), No. 20. pp. 54-73.

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Методика експрес-вибору профілів крила стратосферного псевдосупутника

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Стаття присвячена методиці вибору крилового профілю для стратосферного квазісупутника – висотного літака на сонячних батареях, що має «нормальну аеродинамічну схему» на етапі першого наближення. Враховано особливості даного типу літального апарату в частині добору конкретного, з максимальними значеннями аеродинамічної якості профілю крила, як основи високої досконалості всього майбутнього компонування. Подані приклади щодо існуючих літальних апаратів, профілі крила яких можуть служити аналогами в даному дослідженні. У процесі дослідження застосовано метод прямої розстановки вагових коефіцієнтів. Визначено значимі фактори, які впливають на рішення щодо вибору профілю та встановлено їх величини. Зазначено, що максимальна профільна якість для даного числа Рейнольдса, з посеред іншого, має найбільший ваговий коефіцієнт. Натомість максимальна відносна товщина, яка вважалась визначальним фактором, за умови застосування сучасних композиційних матеріалів як ключового технологічного інструменту, стає другим за вагою фактором. Ще меншу вагу має фактор складності технічного відтворення контуру профілю. На основі проведеного дослідження приводяться геометричні та аеродинамічні характеристики профілю FX 76 MP-120 для чисел Рейнольдса в межах 0,5…1x10^6.

Ключові слова: квазісупутник, аеродинамічна якість профілю, відносна товщина профілю, радіус передньої кромки, складність технічного відтворення контуру профілю, коефіцієнт підйомної сили, коефіцієнт аеродинамічного опору, кут атаки, коефіцієнт поздовжнього моменту профілю, аеродинамічна якість літака

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Методика экспресс-выбора профиля крыла стратосферного квазиспутника

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Статья посвящена методике выбора профиля крыла для стратосферного квазиспутника – высотного самолета на солнечных батареях, который имеет «нормальную аэродинамическую схему» на этапе первого приближения. Учтены особенности данного типа летательного аппарата в части отбора конкретного, с максимальными значениями аэродинамического качества профиля крыла, как основы высокого совершенства всей будущей компоновки. Представлены примеры относительно существующих летательных аппаратов, профили крыла которых могут служить аналогами в данном исследовании. В процессе исследования применен метод прямой расстановки весовых коэффициентов. Определены значимые факторы, влияющие на решение о выборе профиля и установлено их величины. Указано, что максимальное профильное качество для данного числа Рейнольдса, помимо прочего, имеет наибольший весовой коэффициент. Зато максималнa относительная толщина, которая считалась определяющим фактором, при условии применения современных композиционных материалов как ключевого технологического инструмента, становится вторым по весу фактором. Еще меньший вес имеет фактор сложности технического воспроизведения контура профиля. На основе проведенного исследования приводятся геометрические и аэродинамические хараетристики профиля FX 76 MP-120 для чисел Рейнольдса в пределах 0,5 ... $1x10^6$.

Ключевые слова: квазиспутник, аэродинамическое профильное качество, относительная толщина профиля, радиус передней кромки, сложность технического воспроизведения контура профиля, коэффициент подъемной силы, коэффициент аэродинамического сопротивления, угол атаки, коэффициент продольного момента профиля, аэродинамическое качество самолета

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