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PARAMETRIC ANALYSIS OF LONGITUDINAL STABILITY UNMANNED AERIAL VEHICLE

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Abstract. *We consider the aerodynamic characteristics of unmanned aircraft container type, which were obtained in a wind tunnel and refined amended by soot blowing elements propeller system and the influence of the earth's surface. The estimation of longitudinal static stability and its dependence on altitude, damping, coordinates of center of gravity, shoulder horizontal tail, wings rejection of mechanization. The variation of these parameters enables to optimize balancing system with minimal losses.*

Keywords: analysis; longitudinal static stability in overload; soot blowing propellers; Unmanned Aerial Vehicle.

1. Introduction

Unmanned Aerial Vehicle (UAV) is one of the most promising areas of modern aviation. This rapid growth is associated primarily with the benefits that this device is compared to manned aircraft, with a wide range of problems that are addressed to devices, both civilian and military sectors, as well as significant development of control systems, navigation, artificial intelligence and microprocessor computing. Efficiency is determined by their UAV flight - specifications.

Resistance to UAVs has treated more stringent requirements than manned aircraft, besides requirement should be easy to control [Sylkova 2009]. Stability and control characteristics UAV differ from traditional aircraft data, for which there is a significant statistic. Manage aircraft meets the specifications that meet the requirements of ergonomics and good for the average pilot. UAVs can have individual characteristics, such as the criteria for longitudinal stability and control. Stability criterion longitudinal motion is the sum of static stability and component, which depends on the rotational derivative aircraft. The first aircraft is provided by centering the second depends on the damping properties, which are provided with a horizontal shoulder plumage and its center of mass relative to the aircraft. Static resistance is associated with abnormal control surfaces for balance, respectively, based on balancing. Dan element for UAV can be done a minimum and increase the damping effect due to the shoulder area of the horizontal tail and vertical position of center of gravity.

Characteristics of static stability are important in assessing the aircraft, but their impact on the movement of an aircraft under the influence of external disturbances occurs only in combination with others, as important design parameters. The advantage of the characteristics of static stability over other options is that the designer is quite simple you can change the static stability to be able to act in the desired direction on the behavior of the aircraft in the air, i.e. its stability and controllability [Ostoslavskyy, Kalachev 1951].

2. Analysis of Research

Development and design of the UAV is a complex iterative process. Due to the large number of these types of devices, today there is no single methodology for their design. However, there are common steps taken by design: exterior design (design specification) technical offer (pilot project), schematic design and detailed design [Sylkova 2009]. In this work the stage of conceptual design - namely, the stage of aerodynamic design. It is assumed that this approach can be used in the calculation of the characteristics of the designed UAV of all types, in the presence of the corresponding output. Step aerodynamic design is based on the use of modern methods of computational aerodynamics and results of experimental research models in a wind tunnel. In order to save time cost in the design can be used statistics such aircraft, the method of optimal design, which is based on the comparative evaluation of different layout options UAV. In most cases, allowing for the experimental aerodynamics and size UAV, study characteristics performed in a wind tunnel for geometrically similar models. Modern UAVs have several structural differences, which are defined by their purpose. However, all such devices are common signs of classical scheme of the aircraft, in terms of the layout of the apparatus.

In the process of designing the UAV can specify the desired degree of longitudinal static stability in different ways. The first method is a change in the external form of UAVs, so you can shift the focus of aircraft. The second method, change the internal layout of the UAV at constant external forms, which in turn leads to a change alignment aircraft. Both the first and the second method lead to a change in static stability [Lebedev, Chernobrovkyn 1973].

At present, the issue of stability sufficiently studied for manned aircraft also developed a number of methods to determine these characteristics, which cannot be said of UAV [Lebedev, Chernobrovkyn 1973].

3. Purpose

Calculation methods to study the impact of changing external and internal layout of the UAV, the external factors of the propellers (GHG) emissions of the power plant on its longitudinal static stability.

4. Solving this problem

Assessment of longitudinal static stability of the UAV with the influence of factors such as soot blowing elements UAV emissions; screen effects the earth's surface; deflection flaps; the position of the center of mass of the UAV; weight of the UAV; distance from the center of gravity of the UAV to the axis of the rudder hinge height; altitude UAV and longitudinal moment coefficient derivative aircraft in non-dimensional angular velocity pitch for fixed handlebars height will produce an example of classical scheme aircraft. General view of the aircraft shown in Fig. 1.

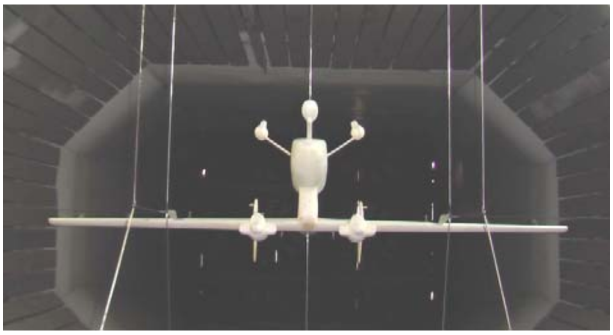

Fig. 1. General view of UAV

Given the circuit in its layout UAV has two reductions placed on the wing, wings and tail of the blown air flow over the wing hosted fuselage, tail has a classic pattern.

According to research UAV model (Fig. 1) in a wind tunnel, there are following aerodynamic characteristics of Fig. 2.

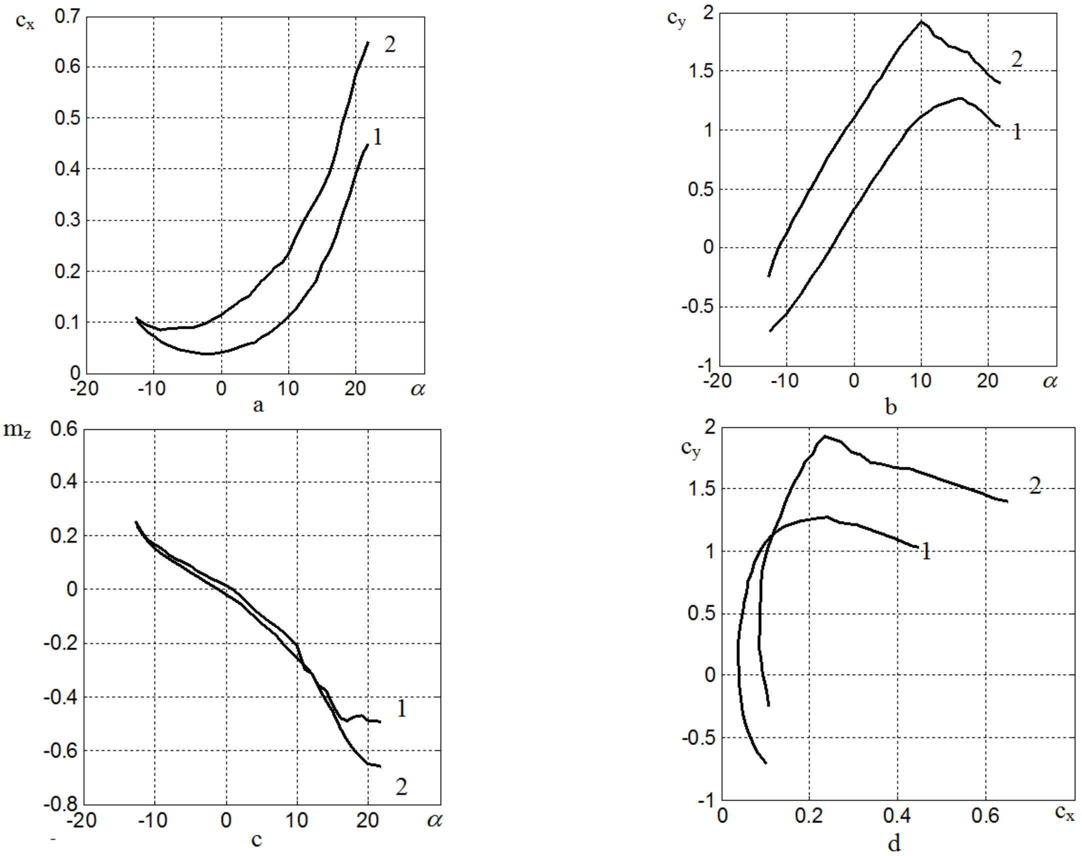

Fig. 2. UAV Aerodynamic characteristics: *a* – dependence of the coefficient of resistivity on the angle of attack; *b* – dependence of the coefficient of lift angle of attack; *c* – dependence of the moment of longitudinal stability of the angle of attack; *d* – dependence of the coefficient of lift drag coefficient of resistance; *1* – $\delta_3 = 0^\circ$; *2* – $\delta_3 = 25^\circ$

According to the method given in [Mikeladze 1996, Sylkova 2009] characteristics are shown in Fig. 2 were listed on the basis of soot blowing GHG calculation results are shown in Fig. 3.

When flying an aircraft near the ground physical conditions of flow airflow wing significantly changed: the surface of the earth limits the flow from the wing slant and will not wrap around the wing just as it is the distance from the surface. Through a screen of ground bevel flux in the wings is reduced, resulting in decreased inductive reactance. Screen action affects not only the inductive reactance, but also on the power winder. According to the method given in [Mkhitaryan 1976] properties Fig. 2, 3 have been restated for the earth Fig. 4.

As you know the degree of longitudinal stability overload is defined as [Mikeladze 1996]:

$$\sigma_n = m_z^{C_y} + \frac{m_z^{\overline{w}_z}}{\mu},$$

or

$$\sigma_n = \bar{x}_T - \bar{x}_{F_c} + \frac{m_z^{\overline{w}_z}}{\mu}, \qquad (1)$$

where $m_z^{C_y}$ – longitudinal moment coefficient derivative aircraft for the lift force coefficient;

$m_z^{\overline{w}_z}$ – longitudinal moment coefficient derivative aircraft in non-dimensional angular velocity pitch for fixed handlebars height;

μ – coefficient of relative density of the aircraft:

$$\mu = \frac{2m}{\rho S b_A};$$

m – estimated weight of the aircraft;

ρ – density of air;

S – the area of the wing aircraft;

b_A – mean aerodynamic chord of the wing;

$\bar{x}_T$ – the position of the center of mass of the aircraft as a percentage of the mean aerodynamic chord;

$\bar{x}_{F_c}$ – focus on aerodynamic position angle of attack as a percentage of the mean aerodynamic chord.

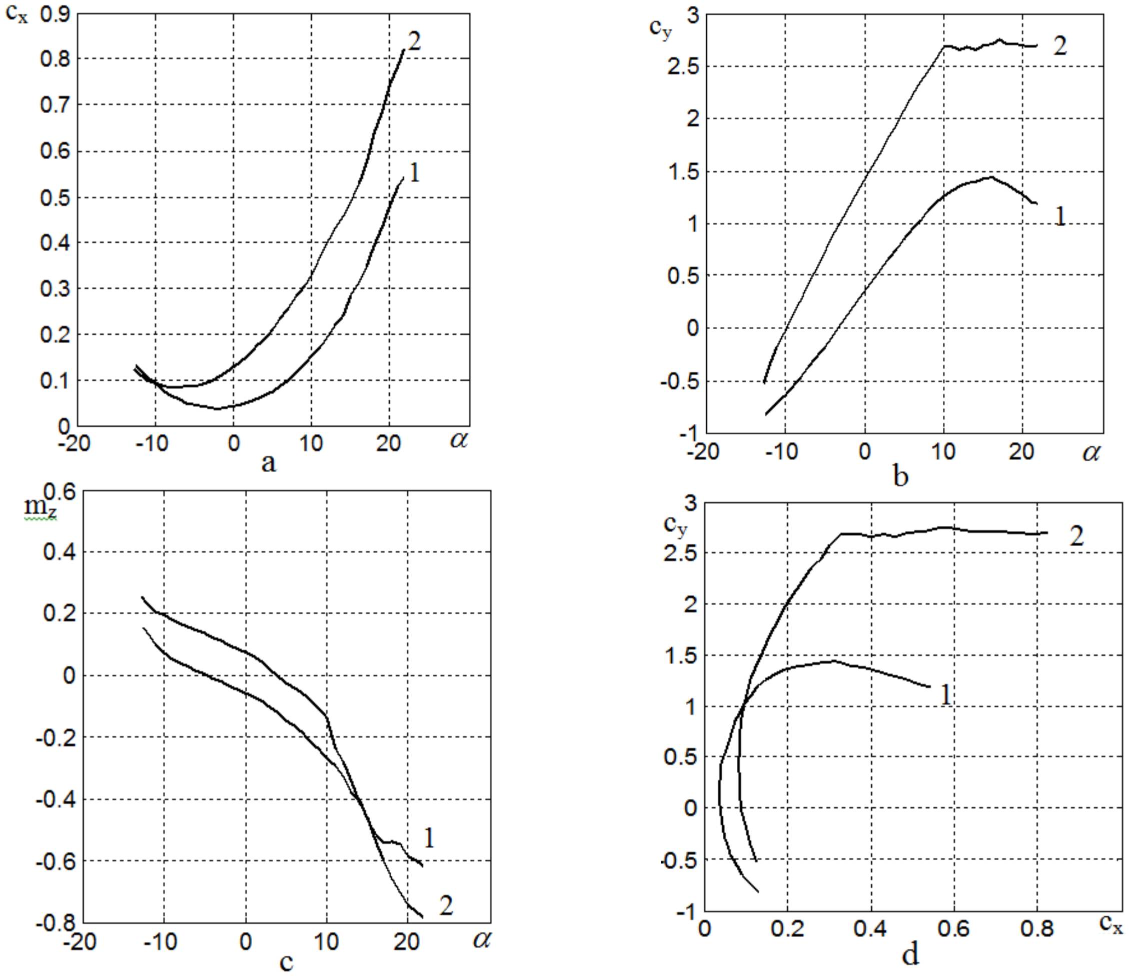

Fig. 3. Aerodynamics UAV based soot blowing of emissions: *a* – dependence of the coefficient of resistivity on the angle of attack; *b* – dependence of the coefficient of lift angle of attack; *c* – dependence of the moment of longitudinal stability of the angle of attack; *d* – dependence of the coefficient of lift drag coefficient of resistance; *1* – $\delta_з = 0^\circ$; *2* – $\delta_з = 25^\circ$

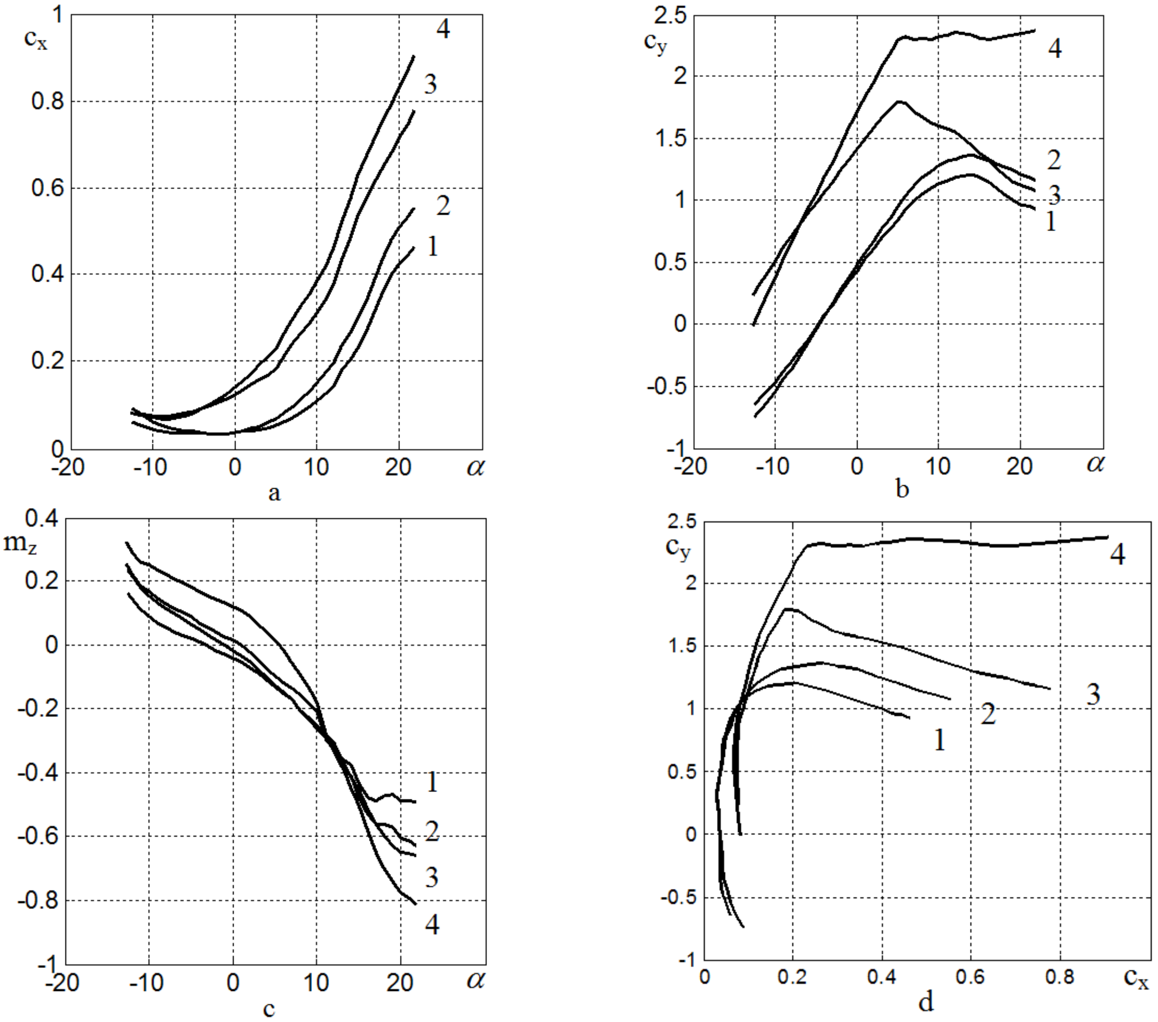

Fig. 4. Aerodynamics UAV with the influence of the earth's surface: *a* – dependence of the coefficient of resistivity on the angle of attack; *b* – dependence of the coefficient of lift angle of attack; *c* – dependence of the moment of longitudinal stability of the angle of attack; *d* – dependence of the coefficient of lift drag coefficient of resistance; *1* – $\delta_{\text{flaps}} = 0^\circ$, without soot blowing propeller; *2* – $\delta_{\text{flaps}} = 0^\circ$, with soot blowing propeller; *3* – $\delta_{\text{flaps}} = 25^\circ$, without soot blowing propeller; *4* – $\delta_{\text{flaps}} = 25^\circ$, with soot blowing propeller

As we know the value $m_z^{\bar{w}_z}$ determined by the expression [Ostoslavskyy, Kalachev 1951; Ostoslavskyy, Strazheva 1965]:

$$m_z^{\bar{w}_z} \approx -1{,}2 \cdot c^{\alpha}_{y_a ht} \cdot \frac{S_{ht} \cdot L^2_{ht}}{S \cdot b^2_A} \cdot \sqrt{k} -$$

$$-\left\{\left[\frac{c^{\alpha}_{y_a}}{4} \cdot (1 - 2 \cdot \bar{x}_T)^2 + \frac{6 - c^{\alpha}_{y_a}}{16}\right] +\right.$$

$$\left. + 0{,}019 \cdot c^{\alpha}_{y_a} \cdot \lambda^2 \cdot \mathrm{tg}^2\chi\right\} \cdot \cos\chi , \qquad (2)$$

where $c^{\alpha}_{y_a ht}$ – the original ratio lift horizontal tail without soot blowing of the propeller;

S_{ht} – the area of horizontal tail;

$L_{ht.}$ – shoulder of horizontal tail (distance from center mass of the aircraft to joints steering axle height);

k – flow rate of inhibition zone containment:

$k = 1 - 5c_x$;

c_x – coefficient of drag force;

$c^{\alpha}_{y_a}$ – original ratio lift aircraft without soot blowing emissions;

λ – lengthening wings;

χ – angle of sagittal wings.

For adopted in calculating layout UAV, with a height equal to 0 value. For given (Fig. 2) obtained dependences (Fig. 3, 4), and constructed by (1, 2) were calculated quantities, results of calculations are summarized in Table.

Fig. 5 shows the change in degree of longitudinal stability (1) of altitude based on aircraft emissions soot blowing aircraft by the propeller.

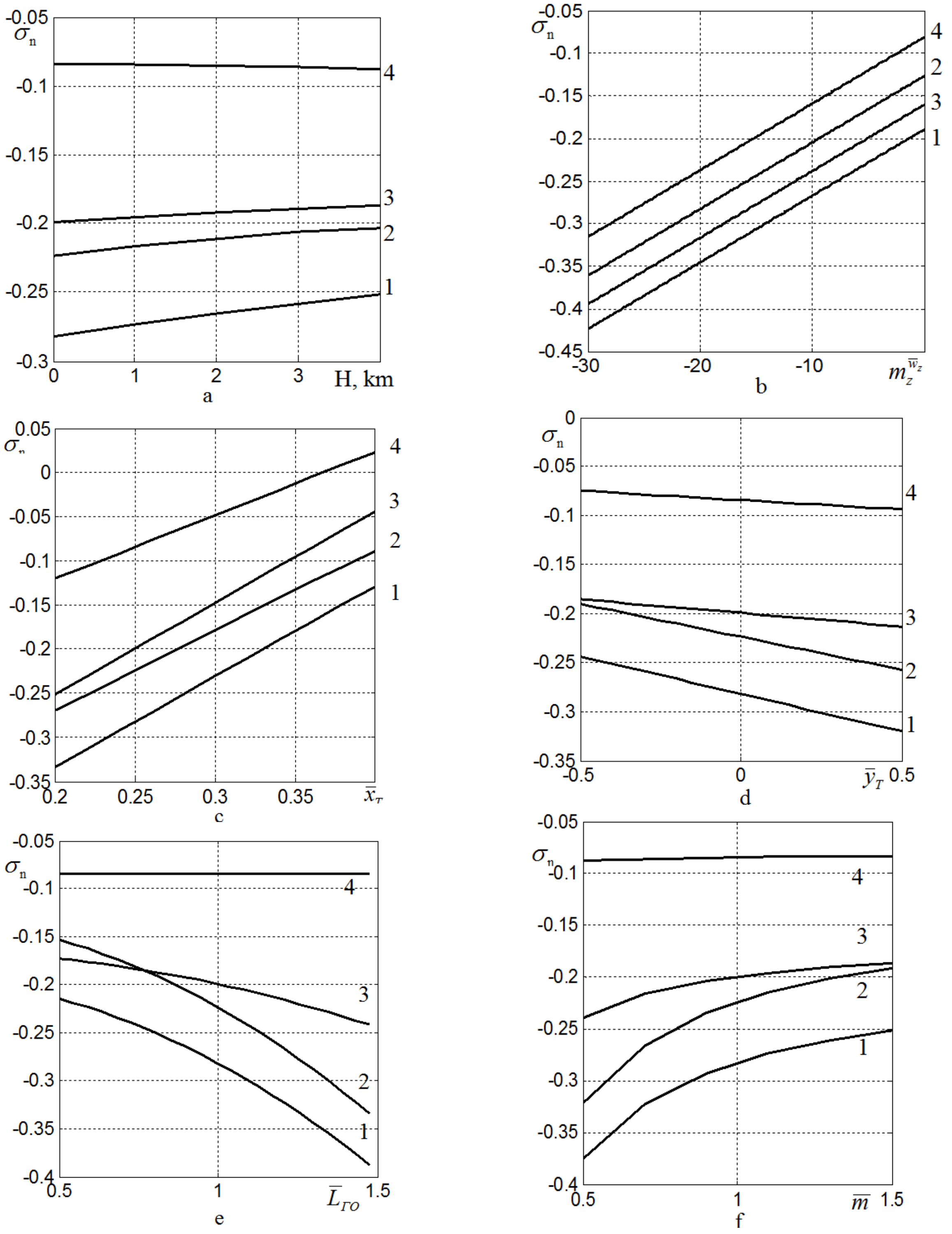

Fig. 5. Degree of longitudinal stability UAV depending on:
a – altitude; *b* – longitudinal moment coefficient derivative in non-dimensional angular velocity pitch for fixed handlebars height; *c* – coordinates of the center of gravity; *d* – shoulder; *e* – horizontal tail; *f* – weight system;
1 – $\delta_{\text{flaps}} = 0^\circ$, without soot blowing propeller;
2 – $\delta_{\text{flaps}} = 0^\circ$, with soot blowing propeller;
3 – $\delta_{\text{flaps}} = 25^\circ$, without soot blowing propeller;
4 – $\delta_{\text{flaps}} = 25^\circ$, with soot blowing propeller

Results of calculations

Soot blowing propeller	Not included		Included		Not included		Included	
Iinfluence of the earth's surface	Not included		Not included		Included		Included	
Angle of the flaps	0°	25°	0°	25°	0°	25°	0°	25°
$m_z^{c_y}$	-0,19	-0,16	-0,13	-0,08	-0,19	-0,16	-0,12	-0,10
$m_z^{\overline{w}_z}$	-11,88	-5,02	-12,43	-0,44	-12,17	-0,44	-13,68	-0,44
σ_n	-0,28	-0,20	-0,22	-0,08	-0,28	-0,16	-0,23	-0,10

For a more complete analysis values σ_n were obtained depending on a change the $m_z^{\overline{w}_z}$ in the range of -30 to 0, as $m_z^{\overline{w}_z}$ for unmanned aircraft can vary within wide ranges, the results shown in Fig. 5.

As shown in the dependences (1, 2), the value σ_n also depends on parameters such as $L_{ht.}, m$ and $\overline{x}_T$ In addition, the offset center of gravity of the aircraft relative to the wing height, changes the dependence $m_z = f(c_y)$ for large values $\overline{y}_T$ possible even change the behavior of the curve, which in turn leads to changes σ_n.

In view of the foregoing parametric analysis was carried σ_n out by changing these parameters, the results shown in Fig. 5. The values $\overline{L}_{ht}$ and $\overline{m}$ are relative and relative to the set L_{ht}, m.

5. Conclusions

As a result of studies on the impact of changes in the external and internal layout of the UAV, the external factors of the propellers emissions of the power plant on its longitudinal static stability is established that:

- soot blowing element wings, tail UAV by propellers, mechanical deflection of the wing and the impact on the screen effect the earth surface leads to a decrease of σ_n;
- with increasing altitude σ_n is also reduced, although the natures $\sigma_n = f(H)$ of the relationship, the flap deflection changes, and at the same time taking into account soot blowing propellers and $\delta_{з} = 25^\circ, \sigma_n$ increases;
- at the rear position alignment σ_n reaches minimum values, although with increasing coordinates of the center of mass in the vertical plane σ_n reaches a maximum;
- an increase supply UAV leads to a marked reduction σ_n in deflection and flap and consideration soot blowing propellers practically does not change this value.

The criterion of static stability in a longitudinal movement due to damping may increase to 0.4 $m_z^{\overline{w}_z}$ =-30, compared with σ_n=-0,2 centering = 0.25 at H = 0 . Effect of the length of the shoulder horizontal tail may increase σ_n to 0.4 at $\overline{L}_{ГО}$=1,5. The vertical coordinate $\overline{y}_T$ increases σ_n to -0.25 at $\overline{y}_T$=-0,5.

Variation of parameters such as $\overline{L}_{ht}$, $\overline{y}_T$, $\overline{m}$ and H allows to find the optimal balance UAV with minimal expenses for balancing.

References

Lebedev, A.A.; Chernobrovkyn, L.S. 1973. *Flight dynamics of Unmanned Aerial Vehicles*. Moscow, Engineering. 616 p. (in Russian).

Mikeladze, V.G. 1996. *General aviation, recommendations for designers.* Moscow, Aerokon. 298 p. (in Russian).

Mkhitaryan, A.M. 1976. *Aerodynamics*. Moscow, Mechanical Engineering. 446 p. (in Russian).

Ostoslavskyy, I.V.; Kalachev, G.S. 1951. *Longitudinal Stability and upravlyaemost Airplane*. Moscow, State Publishing House of Defense Industry. 367 p. (in Russian).

Ostoslavskyy, I.V.; Strazheva, I.V. 1965. *Flight dynamics. Stability and control of aircraft*. Moscow, Mechanical Engineering. 468 p. (in Russian).

Sylkova, V.I. 2009. *Unmanned aerial vehicles.* Methods of approximate calculations of the main parameters and characteristics. Kyiv, CSRI AF UKRAINE, 2009. 302 p. (in Russian).

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Є.П. Ударцев[1], О.В. Бондар[2], Є.С. Плахотнюк[3]. Параметричний аналіз поздовжньої стійкості безпілотного літального апарата
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Оцінено поздовжню статичну стійкість безпілотного літального апарата контейнерного типу. Детально розглянуто її залежність від висоти польоту, демпфування, координат центру ваги, плеча горизонтального оперення, відхилення засобів механізації крила. Виконано аналіз отриманих в аеродинамічній трубі та уточнених поправками на обдув елементів апарата повітряними гвинтами аеродинамічних характеристик даного безпілотного літального апарата.

Ключові слова: аналіз; безпілотний літальний аппарат; обдувка повітряними гвинтами; поздовжня статична стійкість по перевантаженню.

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Оценена продольная статическая устойчивость беспилотного летательного аппарата контейнерного типа. Подробно рассмотрена ее зависимость от высоты полета, демпфирования, координат центра тяжести, плеча горизонтального оперения, отклонения средств механизации крыла. Выполнен анализ полученных в аэродинамической трубе и уточненных поправками на обдувку элементов аппарата воздушными винтами аэродинамических характеристик данного беспилотного летательного аппарата.

Ключевые слова: анализ; беспилотный летательный аппарат; обдувка воздушными винтами; продольная статическая устойчивость по перегрузке.

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