Determination of external power factors influencing unmanned aerial vehicle of “flying wing” type

A N Smirnov¹, A S Govorkov ¹², I V Fokin¹

¹ Irkutsk National Research Technical University, Irkutsk, Russian Federation
² e-mail: govorkov_as@istu.edu

Abstract. This article touches upon the issue of determination of external force factors influencing an unmanned aerial vehicle or drone in critical flight modes for further transition to the full-scale engineering development. A brief review of the design of the developing vehicle is given. A simplified three-dimensional model is created. On the basis of the 3d model and with the help of the FloEFD computer complex, the aerodynamic analysis of the chosen design of the developed unmanned aerial vehicle is carried out. The dependences of the available speed and disposable tangential overloads of flight acceleration are obtained. The minimum permissible horizontal flight acceleration is calculated. The aerodynamic coefficients of the used wing profile are given. The value of the available tangential overload for different flight speeds is defined. The relation of the maximum trajectory angle of inclination against the flight speed when flying above the ground is calculated. The maximum allowable catapulted take-off speed is calculated. This speed allows determining an allowable trajectory angle of the incline for the rectilinear altitude gain. The pressure distribution over the outer surface of the fuselage and the wing consoles of an unmanned aerial vehicle is obtained. The value of the acting axial force is calculated for take-off modes with different angles of inclination of the trajectory and for a horizontal straight-line flight at a constant speed.

1. Introduction

According to the data of international consulting companies such as J’son & Partners Consulting and Euroconsult, nowadays there is a rapid growth in the unmanned aerial vehicle (UAV) market. This is explained by the fact that UAVs are a fairly universal tool with a wide scope of their application [16, 12].

If we talk about the civil segment, in recent years, the use of drones in agriculture in order to increase yields has gained popularity. The most well-known and widely used method for the assessment of the state of vegetation cover applied to data collected by aerial photography is the calculation of the so-called normalized difference vegetation index (NDVI). It is a relative indicator of the amount of photosynthetically active biomass [11]. The use of UAVs makes it possible to obtain the necessary information, identifying problem areas of the cropped area where adjustments are required on the part of farmers.

This article presents a self-engineered UAV design. A structural electronic model is presented in Figure 1.

When designing a UAV, we consider that the flight speed is significantly lower than the sound one. With wing areas and loads equal to other wings, the design of the triangular wings is lighter and more rigid [3]. The increased rigidity of such wing is reasoned by the larger cross-section of the wing. The
larger cross-section of the triangular wing allows free positioning of elements of mechanization on the wing, the use of which is important at low speeds [17].

2. Designing of UAV
In order to design this unmanned aerial vehicle, the configuration of the triangular wing was chosen [17].

The choice of the right profile determines the correct behavior of an aircraft in the air. Optimal lifting force is created by biconvex wings with the least frontal resistance [3]. The greatest lift force is demonstrated by concave-convex wings; however it is much more difficult to produce them. Therefore, the biconvex profile of the NAVY N60 was chosen. The wing design should provide sufficient lifting force for the weight of an aircraft and additional loads associated with the maneuverability and placement of the equipment.

![Figure 1. Structural electronic model of developed UAV.](image)

In our case, this is achieved by a set of ribs and a central stringer. The performance characteristics of the developed UAV are presented in Table 1.

At the stage of engineering design of an unmanned aerial vehicle, there is the need to determine critical flight modes, including those aimed at reducing the mass of a structure through the optimization and increase in stability [4].
Table 1. The performance characteristics of the developed UAV.

| Characteristics, unit                  | Value        |
|----------------------------------------|--------------|
| Inflight altitude, m                   | 100 - 3000   |
| Speed at planned altitude, km/h        | 100          |
| Action radius of radio channel, km     | 40           |
| Take-off type                          | Catapulted   |
| Landing type                           | Parachuted   |
| Maximum wind speed, m/s                | 12           |
| Environmental temperature, °C          | -20 ... +45  |
| Wing spread, m                         | 1.8          |
| Takeoff weight, kg                     | 5            |
| Disposable load, kg                    | <1           |
| Flight endurance, h                    | 2.5          |

The computations were carried out in the Siemens NX FloEFD system using the method of virtual purge. The input values are given in table 2.

Table 2. The input values for computations.

| Parameter, unit            | Value     |
|----------------------------|-----------|
| UAV mass, kg               | 5         |
| Input altitude, m          | 0         |
| Pressure, MPa              | 101.325   |
| Air density, kg/m³         | 1.225     |
| Air temperature, K         | 288.15    |
| Flight speed, m/s          | 14.5      |
| Incidence angle, degree    | 7         |
| Wing size, m²              | 0.595     |

In this research, a horizontal rectilinear flight with a constant speed and a rectilinear inclined takeoff are simulated without landing because it is carried out using the parachute system.

In the course of virtual analysis, a detailed grid was created in the wing zone in order to ensure the accuracy of obtaining flow results around the wing surface. The 3rd level of resolution is chosen by the grid of surface curvature [9]. The resulting simulation model consists of 181,000 cells (Figure 2).
The similar grid was made in a research work [13], but since within the framework of it, the distribution of the gas-dynamic flow parameters after the flow past the wing is less interesting than their direct values of the surface. The process of cell crushing was not carried out.

The angle of incidence of 7 is selected as permissible for the applicable NAVY N60 profile (Figure 3) [5].

3. Calculations of maneuverability
Next, we proceed to the calculation of the characteristics of maneuverability. Without changing the mass and altitude, we will conduct a series of calculations to determine frontal and ascension forces. According to the results of the calculations, the graphs of the disposition of the normal speed and tangential overload against the flight speed are plotted (Figures 4 and 5).

On the basis of the test results, the minimum disposable horizontal flight speed is $v_{\text{min per}}=14$ m/s. To determine the speed of takeoff, we use the following formula [14]:

$$v_{tkf} = k \cdot \sqrt{\frac{2 \cdot (m_{tkf} \cdot g - P \cdot \sin(\alpha))}{c_{ya} \cdot \rho \cdot S}},$$

where $k = 1.15$ – safety factor;
$m_{tkf}$ – take-off mass, kg;
$P = 45$ H – propulsion draft, H;
$\rho$ – Air density, kg/m$^3$;
$c_{ya} = 0.758$ – lift coefficient;
$S$ – wing size, m$^2$;
$\alpha$ – incidence angle.
We believe that at the moment of separation of the UAV from the ground, the angle of inclination of the trajectory was 0. The value of the lift coefficient for the wing was obtained experimentally. The used engine was EMAX GT5325 / 09. As a result of calculations, we obtained $v_{tkf} = 14.5 \text{ m/s}$.

Let us consider several trajectory incline angles in a rectilinear altitude gain. In order to determine the critical value, we use the graph of the dependence of the maximum angle of inclination of the trajectory against the flight speed, Figure 6.

The calculations are carried out according to the following formula [15]:

$$\theta_{\text{max}} = \arcsin(n_{\text{disp}}),$$

where $n_{x\text{disp}}$ – disposable tangential overload.

The values of disposable tangential overload for different flight speeds are also obtained in previous aerodynamic tests (table 3). For the calculated take-off speed, we obtain the value of the maximum trajectory angle $\theta_{\text{max}} = 65^\circ$. 
Finally, we conduct a series of aerodynamic tests for the following trajectory inclination angles: 0, 15°, 30°, 45°, 60°, 65°. The results are presented in Figure 7 and Table 4.

The Reynolds number for small UAVs varies from 104 to 105 [6]. The pressure distribution over the surface is of particular interest since it slightly differs from the distribution on larger devices [8]. The pressure varies from 100.759 MPa on the upper surface of the wing to 102.313 MPa on the leading edge.

Table 3. The values of disposable tangential overloads for various speeds flight.

| v, m/s | n_{disp} |
|--------|----------|
| 10     | 0.91     |
| 15     | 0.90     |
| 17.5   | 0.89     |
| 20     | 0.89     |
| 22     | 0.88     |
| 25     | 0.86     |
| 26     | 0.86     |
| 27.78  | 0.85     |
| 28.5   | 0.85     |
| 30.5   | 0.84     |

Table 4. The value of the longitudinal force for different angles of trajectory inclination.

| θ*   | X, H   |
|------|--------|
| 0    | 0.71   |
| 15°  | 13.39  |
| 30°  | 25.21  |
| 45°  | 35.36  |
| 60°  | 43.14  |
| 65°  | 45.12  |
Figure 5. Rectilinear inclined flight at different inclination angles of the trajectory.

4. Conclusion
Thus, in the course of the research, data on the pressure distribution of the surface of the unmanned vehicle in various flight modes (straight horizontal, straight oblique) have been obtained. The maximum resulting longitudinal force during take-off (45.12 N) for further strength analysis and implementation of optimization of the structure has been calculated. The relative error in the calculation of the longitudinal force has been 0.267%. Based on the obtained results, it is possible to conclude that the increase in the engine thrust is required to perform a takeoff.

References
[1] Krastyaninov P M and Khusainov R M 2016 Selection of equipment for machining processing of parts using NX and TEAMCENTER programs IOP Conf. Series: Materials Science and Engineering 134 012041
[2] Khusainov R M and Sharafutdinov I F 2016 Methods of assessing the dynamic stability of the cutting process using UNIGRAPHICS NX IOP Conf. Series: Materials Science and Engineering 134 012042
[3] Austin R 2011 *Unmanned aircraft systems: UAVs design, development and deployment* (New Jersey: John Wiley & Sons).

[4] Fahlstrom P and Gleason T 2012 *Introduction to UAV systems* (New Jersey: John Wiley & Sons) p. 61

[5] George L. Defoe 1931 *A comparison of the aerodynamic characteristics of the normal and three reflexed airfoils in the variable density* (Washington: Langley Memorial Aeronautical Laboratory) p. 13

[6] Mueller T J and DeLaurier J D 2003 Aerodynamics of small vehicles *Annual review of fluid mechanics* 35(1) 89-111

[7] Nickel K and Wohlfahrt M 1994 *Tailless aircraft in theory and practice* (Washington, DC: American Institute of Aeronautics and Astronautics) p. 498

[8] Shyy W. et al 1997 A study of flexible airfoil aerodynamics with application to micro aerial vehicles In *Proceedings of 28th Fluid Dynamics Conference* (Washington, DC: American Institute of Aeronautics and Astronautics)

[9] Bobarika I O and Molokova S V 2013 The use of mathematical modeling tools for aerodynamic design of aircraft In *Reshetnev Readings* (Krasnoyarsk: SibGU publishing house named after M.F. Reshetnev)

[10] Bobarika I O and Gusev I N 2013 Numerical simulation of aerodynamics of bearing elements of aircraft with incompressible fluid flow at low Mach numbers *Vestnik MATI* 21(93) 59-65

[11] Vasin K V and Gerasimov S G 2014 Use of unmanned aerial vehicles - a new word in progressive agriculture *Geoprofi* 5 46-50

[12] Voropaev N P 2014 The use of unmanned aerial vehicles in the interests of the Russian Emergencies Ministry *Bulletin of Saint Petersburg University of State Fire Service of Emercom of Russia* 13 1-7

[13] Gurov L V, Dumnov G E and Ivanov A V 2015 Application of the FLoEFD computer complex for the calculation of aerodynamics of drones with gas-jet controls *Bulletin of the Almaz-Antey Air Defense Concern* 61-68

[14] Krivel S M 2016 *Flight dynamics. Calculation of aircraft performance and flight characteristics* (Moscow: Lan Publishing House) p. 25

[15] Mednikov V N 1976 *Flight dynamics and aircraft piloting* (Monino: Publishing house of Air Force Academy named after Yu.A. Gagarin) p. 155

[16] Petrov M V 2013 *Practical experience of using UAV swinglet produced by senseFly (Switzerland)* (Novosibirsk: SGUiT Publishing house) p. 42

[17] Smirnov A N, Govorkov A S 2018 Kinematic analysis of the movement of an elevon in a wing of UAV In *Proceedings of the X International Scientific and Technical Conference of Aviation Engineering and Transport of Siberia* pp.95-102 (Irkutsk: IR-NITU Publishing House)

[18] Smirnov A N, Govorkov A S 2018 Development of an elevon for an unmanned aerial vehicle In *Proceedings of the 1st All-Russian Scientific Conference on Information Technologies in Modeling and Management: Approaches, Methods, Solutions* pp.223-239 (Tolyatti: TSU Publishing House)