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# ESTIMATION OF THE MAIN FLIGHT-TECHNICAL CHARACTERISTICS OF THE UNMANNED PLANE M6-3T FOR CARRIAGE OF SMALL VALUABLE CARGOES

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**Abstract**

*The paper is devoted to application of methods of estimations of flight technical characteristics of an unmanned aircraft M6-3T «Zhayvir» for the transport of small cargoes. The aircraft has small values of the Reynolds number which imposes certain restrictions on its FTC and creates difficulties during the adaptation of on-board automatics to the main stages of flight: take-off, cruise flight, maneuvering and landing. As all these stages are performed automatically, there was a need for a considerable amount of calculation and experimental work to specify the baseline factors entered into flight controller that affect the entire range of velocities and their limitations. The purpose of the research is to clarify the flight characteristics of the model of an unmanned transport aircraft M6-3T «Zhayvir» in automatic mode at the stages of flight. The results of calculations on the M6-3T project and interpretation of data of the on-board recorder have been applied. The article presents the results of comparison of calculated and experimental data for a wide range of characteristic speeds of the M6-3T aircraft. In the process of preparing automatic flights, the final values of the variables need to be adjusted taking into account the experimental values obtained from on-board recorder.*

**Keywords:** the flight technical characteristics (FTC); the unmanned aircraft for the transport; the Reynolds number; the main stages of flight; flight controller; aerodynamic quality of the wing; the assessment of the complete aerodynamic layout; take-off Speed cruising speed; the landing reference speed or threshold crossing speed

## 1. Introduction

Unmanned aircraft (unmanned aircraft; abbreviated UAV M6-3T «Zhayvir» (in the following text UAV M6-3T) is designed to transport valuable cargo weighing up to 4kg over a distance of 700km in dedicated airspace at altitudes up to 1200m and at a temperature of -20$^0$C to +40$^0$C (Fig.1).

The headwindlimitations are up to 20m/s and the side wind is 8m/s. The use of this UAV M6-3T for transportation is assumed within the framework of the existing infrastructure of civil aviation. The main control mode is automatic. Taxiing on the runway and taxiing into the parking lot is performed in “manual” mode by an external pilot.

Fig. 1. View on the left on the UAV M6-3T«Zhayvir»

Brief technical characteristics of the M6-3T. Unmanned aerial vehicle M6-3T «Zhayvir» (Fig. 2) is a single-engine free-carrying mid-plane with a V-tail. All power parts of the airframe are made mainly of glass and carbon; the most loaded structural elements are made of aluminum alloys.

The fuselage is a semi-monocoque with a three-layer power cap. Between the fuselage frames are located the main UAV systems. The top of the fuselage is covered by panels, which contain electronic equipment, radio signal receivers and a rescue parachute.In turn, this equipment is covered with upper covers. The middle lid covers the compartment of a special cargo container.Front frame - power. The engine ignition unit is located on the opposite side of the front frame.

The landing gear is tricycle, it does not retract and is equipped with a front guide support. The wheels of the chassis rotate on ball bearings. To reduce the harmful aerodynamic drag wheel covers are provided. The main support is made of fiberglass. Spring front support material D16T.

Single-spars wing design consisting of two removable planes. Spars wing spars made of fiberglass.

The sheath is rigid and made of two layers; outer layer of made fiberglass.The mechanization of the wing consists of two sections of a simple flaps. Elerons can also perform flaperone function (flaperone mode).

The V-shaped tail is described further. Stabilizer is performed with filler and rigid sheathing; outer layer of fiberglass. Rudder without spars and technologically executed similarly to the stabilizer.

The power plant includes a single-cylinder piston engine MVVS-50 IRS with a constant pitch propeller. Engine - gasoline, carburetor, two-stroke, air-cooled; it is fixed on the through the silent - blocks to the power frame. The engine compartment in the fuselage is separated by a antifire partition, i.e. a frame.Running an engine begins from a plug-in electric starter.

Fuel is located in the fuselage in two tanks totaling 8liters, connected by fuel lines. The fuel system is equipped with a fuel filter. Filling of fuel tanks is carried out with the help of an external gear pump.

Electrical syste includes following elements.The power of the electric on-board system is carried out from full-time battery-operated batteries with a rated voltage of 14.2V, capacity of 4.8A×h, as well as from a regular electric generator, which is driven from the crankshaft of the engine.The wiring consists of signal and power lines connected to the combined cables.

The UAV M6-3T control is carried out in automatic, semi-automatic and manual modes. The main mode is automatic.

The onboard part of the control system UAV M6-3T consists of the necessary sensors, acquisition and processing units of information, flight controller, telemetric transceiver of the communication line and control, antenna device as well as servo drives of the steering, height control,flapperons, flaps, servo drive of the throttle of the engine power plant, servo drives for controlling the release and decoupling of the parachute.Permanent target load is the special cargo container for cargo up to 4 kg.

In the course of performing test flights on a sample of transport UAV M6-3T revealed some deviations from the estimated values of FTC.

Accordingly, there was a need to establish the reasons for the deviations of the FTC and provide recommendations for their correction.

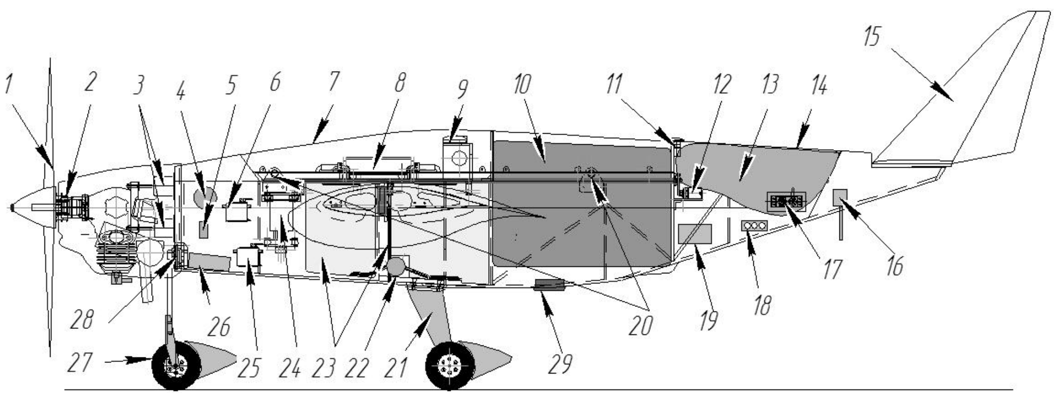


Fig. 2. The main functional elements and blocks of UAV M6-3T

1–air screw, 2– electric generator, 3–silent - block sengine, 4 – fuel flow meter, 5– onboard filling station, 6– servo the drossel, 7– front cover, 8 – the flight controller, 9 – signal receivers, 10– special cargo container, 11– servo opening the rear cover, 12– servo separation of parachute, 13– rescue parachute, 14– back cover, 15– V-tail, 16 – telemetry unit and telemetry modem antenna, 17– servos of the V-tail, 18– panel of switches, indicators and electrical connectors, 19 – accumulator, 20– fastening hinges of the parachute launcher, 21– the main supporting support, 22– fuel filter, 23– fuel tanks, 24– onboard power supply unit, 25 – front wheel servo, 26 – the engine ignition unit, 27– front guide support, 28 – the mechanism of rotation of the front support chassis, 29 – landing altimeter.

## 2. Problem solving

### 2.1. Calculated part

The calculation of individual FTC is based on certain modes, namely take-off, climb, cruise flight, coordinated turnovers on the route, loss of altitude and landing. To calculate the FTCUAV, the following input data is applied:

- range of operating speeds: 20 - 33 m/s
- average aerodynamic chord - 0,261 m.

In this flight, the UAV had an assigned cruising speed of 33m/s. Accordingly, the numbers Re for the characteristic flight speeds of an airplane are:

$Re_{VS1}$ = 70xVx b = 70 x 20 x 261 = 365 400;

$Re_{VC}$= 70xVx b = 70 x 33 x 261= 602 910;

$Re_{VNO}$ = 70xVx b = 70 x 45 x 261= 822 150,

where

$V_{S1}$ - min. operating speed;

Vs - cruising speed;

$V_{NO}$ - max. operating speed.

A profile has been applied in the wing of the aircraft *Wortmann* FX61-184 (Kashafuddinov& Lushin 1994). The values of the aerodynamic quality $K_{max}$ of the specified profile for these Re numbers are as follows: $K_{max.VS1}$= 70 and $K_{max.VNO}$= 130.

#### 2.1.1. Assessment aerodynamic quality of profile

We calculate the values for the number Re $V_{NO}$. Accordingly, for this profile at $K_{max}$=130, the lifting force coefficient is equal to $C_y$ =1,6 and the resistance coefficient: Cx - 0,0123.

The plane the wingshas an angle of fixing $0^0$, which, according to the structure of the plane, corresponds to the tangaqe pitch angle of $0^0$.

For the angle of attack 00, the coefficients (profile) are: $C_y$=0,7 and $C_x$= 0,009. Profile aerodynamic quality in mode: $C_y$ / $C_x$ = 78 (Fig. 3a,b).

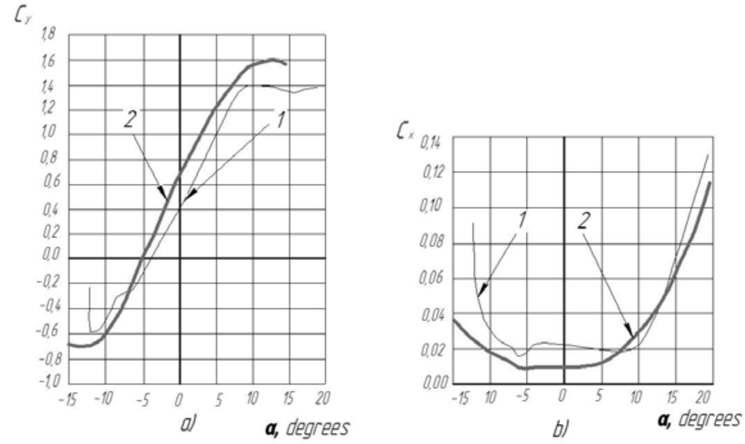


Fig. 3. Value of coefficients $C_y$*(a)*and $C_x$*(b)*of the *Wortmann FX61-184* for different Re numbers: line *1* - min. the value of the speed of the aircraft; line *2* - max. importance for the speed of the aircraft

All of the above values are for the wing of an infinite magnitude. Table 1 shows the main geometric characteristics of this profile (Resource: polars for FX 61-184 airfoil).

*Table 1*

**Basic geometric characteristics of profile Wortmann FX61-184**

| Parameter | $\bar{c}$ | $\bar{X}_c$ | $\bar{f}$ | $\bar{x}_f$ |
|---|---|---|---|---|
| **Value** | 0,184 | 0,371 | 0.032 | 0,629 |

**Parameters in Table 1.:* $\bar{c}$ *– relative thickness profile:* $\bar{X}_c$ *- relative position of position max. thickness;* $\bar{f}$ *– relative curvature profile;* $\bar{x}_f$ *– relative position of coordinate max. curvature.*

The aerodynamic layout of the aircraft is shown in Fig. 4.As can be seen from Fig. 4, the wing of the aircraft is equipped with a simple flap and flapperons, as well as wings of *Whitcomb,* which are projected along the flow and turned outward with a vertical angle of $18^0 40'$. The main data of the wings are given in Table 2.

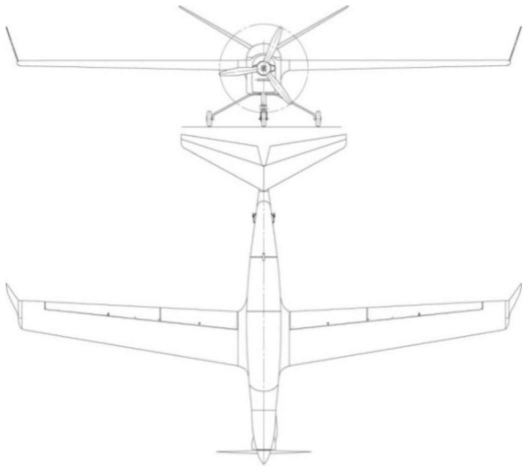

Fig. 4. Aerodynamic scheme of an unmanned transport aircraft M6-3T (projections)

*Table 2*

**Basic geometric data of the wing of an unmanned transport aircraft M6-3T**

| Indicator | Unit | Value |
|---|---|---|
| Full Wing Area | m$^2$ | 0,706 |
| Full Wing Span | m | 3,0 |
| Average aerodynamic chord of the wing | m | 0,261 |
| Elongation wing | un. | 11,5 |
| Ultimate chord | m | 0,168 |
| Root Chord (in the plane of symmetry M6-3T) | m | 0,332 |
| Wing narrowing | un. | 1,976 |
| Angle of wing installation | degrees | 00 |
| Angle of transverse "V" | degrees | 0,80 |
| Angle of arrows wing:<br>– along the front edge<br>– on the back edge<br>– along the line of focus | <br>degrees<br>degrees<br>degrees | <br>9°30'<br>2°53'<br>70 50' |
| Area of flaperons | m$^2$ | 0,08 |
| Area of flaps | m$^2$ | 0,08 |

### 2.1.2. Assessment of the aerodynamic quality of the wing

According to Table 1 and Table 2, and referring to the source (Resource: polar graphs FX 61-184 airfoil from Re500000) and source (Resource: polar graphs FX 61-184 airfoil from Re500000), the aerodynamic quality of a specific UAV M6-3T wing is calculated, taking into account the corresponding harmful resistances.

The coefficient of resistance of the wing was calculated by the formula:

$$C_{xa.w} = C_{xa.p} + \sum \Delta C_{xa}, \qquad (1)$$

where $C_{xa.p}$– coefficient of profile resistance;

$\Delta\ \Sigma C_{xa}$– the amount of harmful resistance.

The coefficient of profile resistance was determined from the formula:

$$C_{xa.p} = 0{,}925 k_1 C_f \eta_c \eta_м, \qquad (2)$$

where $k_1$ – a coefficient that takes into account the presence/absence of a gondole (motogondole) on the wing;

$C_f$ – coefficient of friction of a flat plate;

$\eta_c$– the coefficient taking into account the transition from a flat plate to a wing profile;

$\eta_м$–coefficient taking into account the effect of compression of air on the profile resistance.

To determine the coefficient $C_f$, it is assumed that for the *Wortmann FX61-184* laminarized profile the transition point of the laminar flow in the turbulent is approximately at the point of maximum thickness, that is:

$$\bar{x}_T \approx \bar{x}_c$$

The coefficient $C_f$ is determined from the formula:

$$C_f = C_{fl}\ \bar{x}_т + C_{fт}(1 - \bar{x}_т), \qquad (3)$$

where $C_{fl}$ – coefficient of friction under conditions of laminar flow;

$C_{fm}$ – coefficient of friction in conditions of turbulent flow.

The coefficient $C_{fl}$ is determined from the formula (Gudmundsson, 2014):

$$C_{fl} = 1{,}328\sqrt{Re_l}. \qquad (4)$$

The number $Re$ for the laminar flow is determined from the following relation:

$$Re_l = V_{кр} MAC \bar{x}_т v, \qquad (5)$$

where $v$ – kinematic coefficient of viscosity of air;

MAC – mean aerodynamic chord.

The number Re for the laminar flow is determined from the relation:

$$Re_т = V_w MAC(1 - \bar{x}_т)v. \qquad (6)$$

The coefficient $\eta_c$is found from the graph shown in Fig. 5.

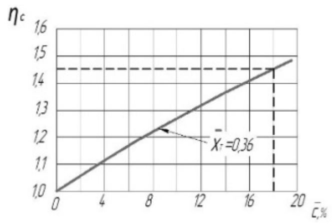


Fig. 5. Finding the value of the coefficient $\eta_c$

The coefficient $\eta_m$ is found from the graph in Fig.6.

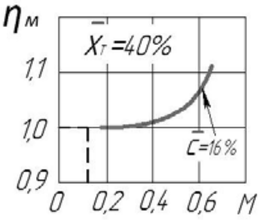


Fig.6. Finding the value of the coefficient $\eta_m$

As a result of calculations by the formula (2), the coefficient of profile resistance has the following value: $C_{xa.p}$= 0.008. To calculate we accept the value of 0.0085 in connection with the fact that the coefficient of profile resistance, obtained from the graph (Fig. 3b) reaches the value of 0.009.

Further calculated harmful supports that arise on the real wing. These include:

– harmful supports from crevices and flapperons;

– resistance from the air pressure receiver and its bracket (on the right wing);

– brackets for suspension brackets and flapperons;

– cracks between the halves of the wing and the rivulet;

– resistance from the protruding heads of the screws of the lids of the covers, hatches and so on;

– resistance from the levers and drives of the moving surfaces of the wing.

The calculations of $C_{xa.h}$ were carried out according to the method shown in the source (Badagin & Mukhamedov, 1978). Also, the inductive resistance that arises as a result of the flow of a stream from under the wing over its surface in the region of finiteness followed by the formation of a harmful vortex was taken into account. The coefficient of inductive resistance was calculated by the formula (Nikolaev, 1990):

$$C_{xi} = \frac{C_{y\alpha}^2}{\pi \lambda_{ef}}, \quad (7)$$

where $C_y$ – lifting factor on the corner of the attack $0^0$;

$\lambda_{ef}$– effective Wing elongation.

The effective elongation of the wing was determined from the formula:

$$\lambda_{ef} = \frac{\lambda}{1-\sigma}, \quad (8)$$

where $\sigma$ – taking into account the geometry of the wing (lengthening $\lambda$, narrowing end angle of the arrowhead $\chi$).

The value of $\sigma$ is found from the formula:

$$\sigma = 0{,}02 \frac{\lambda}{\cos \chi}\left(3{,}1 + \frac{14}{\eta} + \frac{20}{\eta^2} + \frac{8}{\eta^3}\right). \quad (9)$$

However, the given inductive resistance estimation is incomplete, since it does not take into account the application of the winglete design - the small wing of the *Whitcomb* type, which is installed on the finite element and has a symmetrical thin profile (Figure 4). According to the source (Scholz, 2017), the use of the *Whitcomb* wings reduces the inductive resistanceby 4-9%, especially for take-off and lift modes. For the cruise flight mode, the inductive resistance reduction was chosen to be 5%, that is, the multiplication of the obtained value of $C_{x.i}$on the coefficient of 0.95 was applied. Also, the interference resistance (influence) of the conjugation between the wing and the fuselage was taken into account. This resistance is characterized by the coefficient $C_{x.interfer.}$

Since the middle part of the *wings blow round* air propeller, was introduced the coefficient of resistance to blowing, which statistics were selected at the level:$C_{x.b.r.}$= 0,0003. The results of calculating the total $C_x$ of the wing are given in Table 3.

*Table 3*

**The results of calculations $\Sigma C_x$ and aerodynamic quality of the wing M6-3T**

| Coefficient | The Wing M6-3T |
|---|---|
| $C_{xa\ .p}$ | 0,0085 |
| $C_{x.i}$ | 0,0032 |
| $C_{xa.h}$ | 0,00286 |
| $C_{x.interfer.}$ | 0,00004 |
| $C_{x.b.r.}$ | 0,0003 |
| $\Sigma\Delta C_x$ | 0,0149 |
| $K_{wng}$ | 0,7/0, 0149 $\approx$ 47 |

As can be seen from Table 3, the estimated aerodynamic quality of the wing of the transport M6-3T is within 47 units.

### 2.1.3. Assessment of the complete aerodynamic layout of the M6-3T aircraft

The resistance coefficient for the V-tail was adopted as follows:

$$C_{x.v.t.} = 0{,}01.$$

Assessment ofairplane fuselageis summarized. Taking into account the features of the fuselage contours, namely the straight side walls, the lower surface of the tail beam and the flat bottom, the coefficient of resistance of the fuselage equals:

$$C_{x.f.} = 0{,}017.$$

The obtained data from the resistance coefficients are summarized in the corresponding a note (Table 4).

Thus, the aerodynamic quality of this specimen UAV M6-3T on the angle of attack $\alpha = 0^0$ from chassis that are not hidden reaches the value of:

$$K_{\alpha 0.ch} = C_y / \Sigma\, C_{xa} = 0{,}7/0{,}055 = 12{,}41.$$

For the configuration, when the chassis is hidden, the aerodynamic quality of the M6-3T will be equal to:

$$K_{\alpha 0.w\text{-}t\ a\ ch\text{-}s.} = C_y / \Sigma\, C_{xa} = 0{,}7/0{,}042 = 18{,}5.$$

### 2.1.4. Determination of the required draft of air propeller and characteristic flight speeds

The characteristic flight speeds were determined according to the requirements put forward in the source (STANAG 4671, ed.2, 2017). The calculated coefficient of resistance M6-3T is: $\Sigma C_{xa} = 0{,}055$ (on the corner of the angle attack $0^0$). The resistance strength at 33m/s in cruising mode (for $V_S$ speed) is equal to: $X_{Vs} = \frac{\rho \times V^2}{2} \times C_{Xa} \times S_{mid}$=1,34x33$^2$/2 x 0,055x 0,25 = 1459,26/2 x0,055 x 0,32 = 1,284 kGf (kilogram of force).

The values of air density $\rho$were taken for a temperature of -10$^0$C and a height of 0m. For these parameters, the air density is: $\rho=1{,}34 kg/m^3$.

Accordingly, the required traction at a speed of 33 m/s should be at least 1,284 kGf. The required power for a horizontal flight at a given speed and altitude is determined from the known formula:

$$N_{H_{hf}} = \frac{P_{F_{hf}} V}{75} = \frac{GV}{75K} = \frac{17 \times 33}{75 \times 12{,}41} = 0{,}61 hp. \quad (10)$$

Table 4

**Summary table of resistance coefficients**

| № | Part name | Number | Area/midele, m² | Σ area/midele,m² | $C_{xa}$ | $C_{xa}S_i$ |
|---|---|---|---|---|---|---|
| 1 | Wing | 1 | 0,706 | 0,706 | - | 0,0149 |
| 2 | Fuselage | 1 | 1,0/0,052 | 1,0/0,052 | - | 0,017 |
| 3 | Landing gear: | | | | | |
| | - wheels | 3 | 0,0021 | 0,0063 | 0,07 | 0,00045 |
| | - front support | 1 | 0,003 | 0,003 | 1,5 | 0,01 |
| | - main support | 1 | 0,0088 | 0,0088 | 1,1 | 0,004 |
| 4 | V-tail | 1 | 0,146 | 0,146 | 0,008 | 0,01 |
| 5 | Separate details: | | | | | |
| | - telemetric antenna | 1 | 0,00085 | 0,00085 | 0.012 | 0,000012 |
| | - exhaust pipes of silencer | 2 | 0,00061 | 0.00122 | 0,02 | 0,000018 |
| | | | | $\Sigma S_{mid}$ =0,32 | | $\Sigma C_{xa}$= **0,057** |

### 2.1.5. Finding characteristic speeds

Stalling speed (at $C_{ya.max}$ =1,6and $G$ = 17 kg)

$$V_S = \sqrt{\frac{2G}{\rho C_{ya.\max} S}} = 15{,}67 m/s. \quad (11)$$

Lifting speed of the front support:

$$V_R \geq 1.1 \cdot V_S = 17{,}2 m/s.$$

Safe Take-off Speed:

$$V_2 \geq 1.1 \cdot V_s \geq 17{,}24 m/s.$$

Safe approach speed is:

$$V_{REF} \geq 1.3 \cdot V_s = 20{,}37 m/s.$$

Safe climb speed:

$$V_{FTO} \geq 1.3 \cdot V_s \geq 20{,}37 m/s.$$

Minimum speed (operational) of the cruising flight:

$$V_{S1} = 1.3 \cdot V_s \approx 21 m/s.$$

Estimated speed of maneuvering (Udartsev et al., 1998):

$$V_A = \sqrt{\frac{2mg}{C_y \rho S}} \times \sqrt{\frac{1}{\cos \gamma_\alpha}} = 25 m/s, \quad (12)$$

where $C_y$ – lifting factor in mode (0,7); $\rho$ – air density over ISA; $S$ – wing area; $cos\gamma_\alpha$– cosine of the permitted angle of the roll (30$^0$).

Running distance is:

$$L_p = \frac{G}{2g} \frac{V_R^2}{(P_{md} - fG)}, \quad (13)$$

where $f$ = 0.05 – coef. rolling friction for solid soil/low-quality concrete runway;

$P_{md}$ – the average thrust of the air propeller in the course of the run, taken equal to the draft at 0.7 safe take-off speed:

$$P_{md} = \frac{N_0}{0.7 V_R} = 6{,}62 \text{ kGf}. \quad (14)$$

Accordingly, the calculated take-off distance M6-3T is 45 m (according to formula 13).

**3. Experimental part**

The experimental assessment of the flight technical characteristics of the unmanned aircraft M6-3T was made on the basis of telemetric test flight data that was carried out during 2017-2018 to confirm the airworthiness of the aircraft. Analysis of experimental data was conducted to:

– assess the actual airplane thrust, including the characteristics of the power plant and the development of recommendations on the choice of runways and planning take-off modes;

– assess the aerodynamic quality of the aircraft and making recommendations for unmanned airplane flight operator at the stage of automatic landing;

– measure the actual dimensions of the touching area during automatic landing;

– estimate of the speed parameters of the M6-3T on different flight modes.

Fig. 7 shows the typical data of the UAV M6-3T at the run-up stage: the speed of rotation of the air propeller (1), longitudinal overload (2), air velocity (3), pitch of the air propeller (4) and distance from the runway surface (5). The rise of the front steering wheel (a) is carried out at speed of 20.2 m/s, separation (b) is performed at speed of 22.6 m/s.

Fig. 8 shows the typical data of the M6-3T at the take-off stage, the safe take-off altitude is 40 meters. Changing the barometric altitude at the start of the run (a) occurs due to the fusion of the fuselage. The maximum speed of rotation of the air propeller is 5930 rpm, vertical speed at the take-off stage reaches 6m/s. Completion of take-off procedure (b) after reaching a height of 40 meters is accompanied by lifting the ban on maneuvering the course, the distance from the start of the run is 230 meters.

The estimation of the actual traction was carried out on the basis of the following data: longitudinal overload at run-off, trajectory and air velocity at take-off, speed of rotation of the air propeller with known parameters (20"x12", profile RAF-6) (Resource: apcprop.com). The results of processingaresummarized in Table 5. The mileage and the size of the take-off zone were determined on the basis of the road speed and according to the satellite navigation system. Integrating the measured values of the velocity, we obtain the actual distances of the run, shown in Table 6 together with the measured values of the take-off Speed.

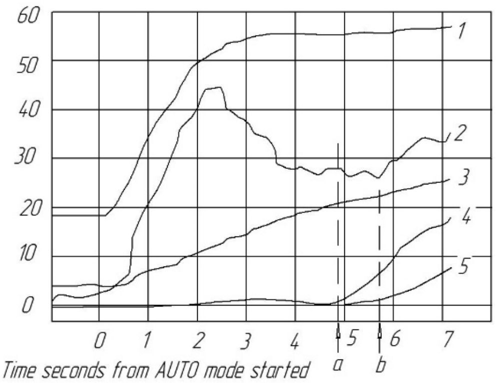


Fig. 7. Typical characteristics of the M6-3T during the run: *1* - speed of rotation of the air propeller (x100 rpm), *2* - longitudinal overload (/100), *3* - air speed (m/s), *4* - pitch (degrees); *5* - height from the surface of he runway according to the laser altimeter (meters)

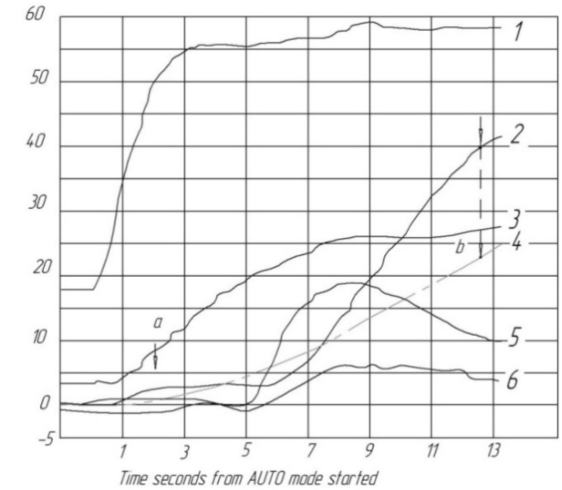


Fig. 8.Typical characteristics of the UAV M6-3T at the take-off stage: 1– the speed of rotation of the air propeller (x100 rpm), 2 – height according to the barometer (m), 3 – air speed, 4 – distance from the onset of the run (x10 m), 5 – pitch (degrees), 6 – vertical speed (m/s); the altitude curve according to the laser altimeter is not indicated by the figure

Thus, summarizing the data from Table 5, for this UAV M6-3T with a take-off weight of 17 kg, it is possible to accept the average value of the propulsion of 0.35. Proceeding from this value, at a separation speed of 20m/s, the calculated take-offdistance will be 63m. Based on runway statistics, recommended take-off zone is determined by the parameters in Fig. 9.

The actual aerodynamic quality of UAV M6-3T is evaluated in the following ways:

– at the rectilinear horizontal flight - by the ratio of the propeller thrust and mass UAV;

– at the landing approach with zero draft - by the ratio of horizontal and vertical velocities.

Fig. 10 shows the typical values of the UAV M6-3T parameters in the rectiltinear flight at an air speed of 33 m / s, in which the average speed of the air propeller is 5460 rpm. Calculated values of the propeller thrust, according to various models (Teush & Sidorov, 1943), range from 1.3 to 1.6 kgf.

Fig. 11 shows the typical values of the UAV M6-3T parameters in the reduction mode with the propeller pull near the zero value (before touching the runway).

Results of assessing the aerodynamic quality of UAV M6-3T by calculated and experimental methods in different flight modes are summarized in Table 7.

*Table 5*

**Estimation of thrust of an unmanned aircraft M6-3T**

| | | | | |
|---|---|---|---|---|
| Traction according to the longitudinal overload at the stage of run | 6,8…8,1 kgf at the beginning of the run | 5,2…5,7 kgf at the take-off Speed 19,5 m/s | no data | no data |
| Thrust at a given height, set by the angle of inclination of the trajectory | no data | no data | 4,7 kgf at slope angle 10,2˚ | 6,1 kgf at slope angle 14,7˚ |
| Estimated draft for the measured speed of the screw | 8,4 kgf at 5470 rpm at the beginning of the run | 5,8 kgf at 5640 rpm at a speed of 19.5 m/s | 4,9 kgf at 5900 rpm at a speed of 26 m/s | 6,2 kgf at 6000 rpm at a speed of 24 m/s |

*Table 6*

**Actual parameters of flight of an airplane**

| Flight number | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Speed of the counter wind, m/s | 4 | 6 | 5 | 2 |
| Take-off distance, m | 54 | 42 | 55 | 57 |
| Safe take-off speed (air speed), m/s | 20,4 | 20,8 | 21,1 | 22,6 |

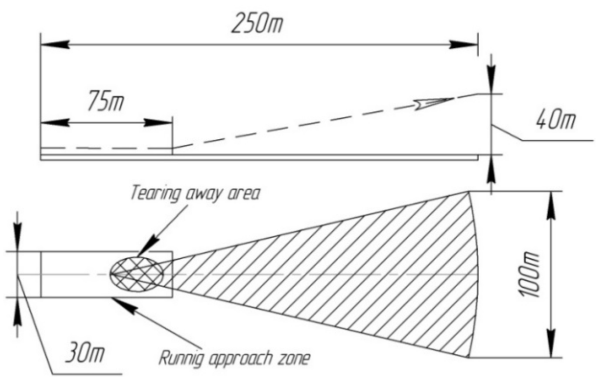


Fig. 9. Recommended take-off zone of the UAV M6-3T, taking into account the deviation oftake-off direction caused by lateral wind

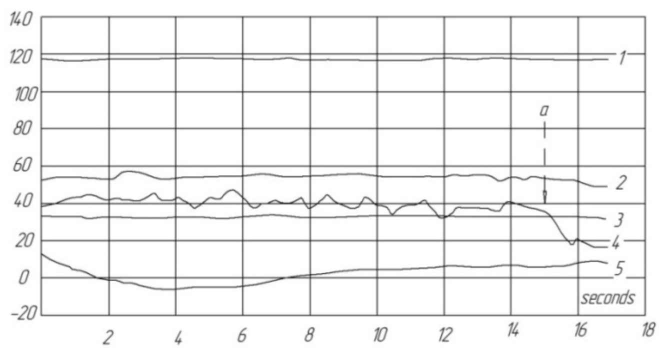


Fig. 10. Typical example of recording of horizontal flight data: *1* - height, m; *2* - speed of rotation of the air propeller, (rpm) x100; *3* - air speed, m/s; *4* - throttle position of the engine in percents relative to the maximum; *5* - yaw (at time (a) was performed a command to reduce the flight speed)

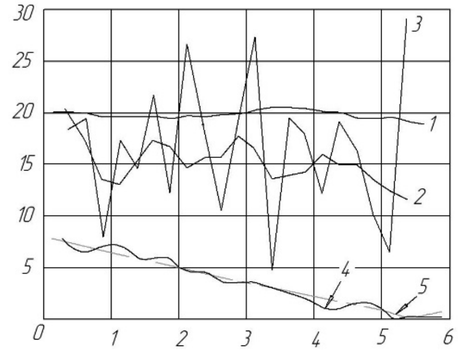


Fig. 11. Typical example is recording of flight data with a descent and the propeller thrust near the zero value: *1* – air speed; *2* – vertical speed (x0,1m/s) according to the optical altimeter;*3* – vertical speed according to barometer;*4* – height by barometric data; *5* – height according to the optical altimeter

*Table 7*

**Assessment of aerodynamic quality of UAV M6-3T**

| Flight Mode (17kg) | Horizontal air speed, m/s | Vertical speed, m/s | Speed ofrotationscrews, rpm (average) | Estimated value of air propeller thrust, kgf | Aerodynamic quality K |
|---|---|---|---|---|---|
| Straight horizontal | 33 | 0 | 5560 | 1,3…1,6 | Between 10.6 and 13 |
| Straight horizontal | 26 | 0 | 4920 | 1,35…1,6 | Between 10.6 and 12,6 |
| Straight line with diminution | 33 | 3,0 | 5300 | Thrust near zero | 11,0 |
| Straight line with diminution | 26 | 2,3 | 4140 | Thrust near zero | 11,3 |
| Straight line with diminution | 20 | 1,56 | 3320 | Thrust near zero | 12,8 |

The basic scheduled and experimental flight technical characteristics of the UAV M6-3T for take-off/landing and cruise flight modes on the declared cruise speed of 33 m/s are given in Table 8.

*Table 8*

**Results of the calculation and experimental estimates of individual flight technical characteristics (FTC) UAV M6-3T**

| Parameter / Name | Marking | Unit of measurement | Meanings received by calculation ($R_{FTC}$) | Values are obtained by experiment ($E_{FTC}$ ) |
|---|---|---|---|---|
| Aerodynamic quality | $K_{\alpha0.ch}$ | without unit | 12,41 | Between 10.6 and 13 |
| Stall speed | Vs | m/s | 15,67 | Does not exceed 15,9 |
| Rotation speed | $V_R$ | m/s | 17,24 | 18,6…19 |
| Takeoff safety speed | $V_2$ | m/s | 17,24 | Actually 20,8 |
| Landing reference speed or threshold crossing speed | $V_{REF}$ | m/s | 20,27 | 20 |
| Final takeoff speed | $V_{FTO}$ | m/s | ≥ 20,37 | 22,2 |
| Stall speed or minimum steady flight speed | $V_{S1}$ | m/s | 21 | 21,3 |
| Design maneuvering speed (min) | $V_A$ | m/s | 25 | 21,3 |
| Design cruise speed | $V_C$ | m/s | 33 | 33+/-1,2 |
| Running distance | Lp | m | 45 | 63 |
| Average thrust during the run | $P_{md}$ | kGf | 6,62 | 6,0 |
| Need for speed 33 m/s | $P_{Vc}$ | kGf | 1,284 | 1,3…1,6 kGf |

## 4. Conclusions

The profile of the Wortmann FX61-184 is characterized by high values of profiled aerodynamic quality for declared Re numbers, which reaches 130 units in cruise mode.

However, in this aircraft, the high qualities of the profile could not be fully utilized due to insufficient quality of the outer surface of the wing and the presence of a significant number of protruding elements, namely: Pito bracket, aileron brackets and flaps, traction and levers of the drive of moving surfaces, as well as cracks between moving elements and between the onboard ribs and wings console.

To some extent reduce harmful wings succeeded in using winglets, but in the future it is necessary to pay more attention to the reduction of harmful resistances, arising from the protruding elements on the surface of the wings as well as reducing gaps as generators of unwanted vortices along the surface of the wing.

The fuselage of the UAV M6-3T is a relatively comfortable body, which, according to the aerodynamic resistance, is well "embedded" in the theory and statistics of such solutions. However, the use of a large number of protruding elements, namely, antennas, exhaust pipes of the engine, unclosed lever thrust to the V-tail as well as a triaxial chassis, results in a fall of more than 5 units of aerodynamic quality, which in this configuration UAV M6-3T (from the chassis that is not hiding) is equal to 12.41 units. Obvious is the fact, that for the further development of the project the best solution will be the use of the hidden chassis.

Based on experimental data on the determination of aerodynamic quality, it can be argued that the automatic control mode maintaining the given air speed imposes certain restrictions on the vertical speed at approach. The approach trajectory should include enough distance to reduce altitude before going to the point of contact with the runway. For example, with a decrease in this UAV M6-3T at a speed of 25m/s from a height of 1m, a plot of at least 12 m should be provided for reduction.

The size of the touch zone and mileage of the UAV M6-3T with automatic landing is determined by positioning errors and control system dynamic errors. In turn, the dynamic error is determined by the strength of the wind and the quality of the adjustment of tracking systems. The lateral deviation at landing is mainly determined by the errors of satellite positioning. The mean square deviation of the point of contact of this UAV M6-3T in the lateral direction is 2.8m. The length of the touching area in the longitudinal direction is actually 160...180m.

The vertical positioning error is determined by the barometric altimeter, and only at the stage of reducing the vertical velocity - a laser altimeter. At an angle of inclination of a trajectory of about 4° and a barometric error of 2 m, the point of contact shifts along the trajectory by about 30 meters. The dynamic error in height, according to telemetric data, has a mean square deviation of 3,5 m. Thus, for this UAV M6-3T the guaranteed size of the touching area is 17 m in the transverse direction and 165 m in the longitudinal direction, without taking into account the measurement error/setting of the height of the runway at the point of contact. Measured mileage of UAV M6-3T after touching does not exceed 60 meters.

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**Оцінка основних льотно-технічних характеристик безпілотного літака М6-3Т для перевезення малих цінних вантажів**

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Стаття присвячена застосуванню методів оцінки льотно-технічних характеристик безпілотного повітряного судна М6-3Т «Жайвір» для перевезення дрібних вантажів. Літак має невеликі значення числа Рейнольдса, що накладає певні обмеження на його ЛТХ і створює труднощі під час адаптації бортової автоматики до основних етапів польоту: зльоту, крейсерського польоту, маневрування та посадки. Оскільки всі ці етапи виконуються автоматично, виникла потреба у значній кількості розрахункових та експериментальних робіт, щоб визначити базові коефіцієнти, що вводяться в польотний контролер та які впливають на обмеження швидкостей у всьому їх діапазоні. Мета дослідження - уточнити льотно - технічні характеристики безпілотного повітряного судна М6-3Т «Жайвір» в автоматичному режимі на всіх етапах польоту; застосовано результати розрахунків за проектом М6-3Т та інтерпретація даних бортового самописця. У статті представлені результати порівняння обчислених та експериментальних даних для широкого діапазону характерних швидкостей літака М6-3Т. У процесі підготовки автоматичних польотів кінцеві значення змінних необхідно коригувати з урахуванням експериментальних значень, отриманих із бортового самописця.

**Ключові слова**: льотно - технічні характеристики (ЛТХ), транспортне безпілотне повітряне судно, число Рейнольдса, основні етапи польоту, польотний контролер, аеродинамічна якість крила, оцінка повного аеродинамічного компонування, швидкість зльоту, крейсерська швидкість, безпечна швидкість заходу на посадку, швидкість звалювання

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**Оценка основных летно-технических характеристик беспилотного самолета М6-3Т для перевозки малых ценных грузов**

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Статья посвящена применению методов оценки летно-технических характеристик беспилотного воздушного судна М6-3Т «Жаворонок» для перевозки мелких грузов. Самолет имеет небольшие значения числа Рейнольдса, что накладывает определенные ограничения на его ЛТХ и создает трудности при адаптации бортовой автоматики к основным этапам полета: взлета, крейсерского полета, маневрирования и посадки. Поскольку все эти этапы выполняются автоматически, возникла потребность в значительном количестве расчетных и экспериментальных работ, чтобы определить базовые коэффициенты, вводимые в полетный контроллер и влияющие на ограничение скоростей во всем их диапазоне. Цель исследования - уточнить летно - технические характеристики беспилотного воздушного судна М6-3Т «Жаворонок» в автоматическом режиме на всех этапах полета; применены результаты расчетов по проекту М6-3Т и интерпретация данных бортового самописца. В статье представлены результаты сравнения вычисленных и экспериментальных данных для широкого диапазона характерных скоростей беспилотного самолета М6-3Т. В процессе подготовки автоматических полетов конечные значения переменных необходимо корректировать с учетом экспериментальных значений, полученных с бортового самописца.

**Ключевые слова:** летно-технические характеристики (ЛТХ), транспортное беспилотное воздушное судно, число Рейнольдса, основные этапы полета, полетный контроллер, аэродинамическое качество крыла, оценка полной аэродинамической компоновки, скорость взлета, крейсерская скорость, безопасная скорость захода на посадку, скорость сваливания

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