UDC 629.735.016:3:629-7:014-519(045)

Ievgen Udartsev[1]
Alexandr Bondar[2]
Ievgen Plakhotniuk[3]

NAVIGATION RANGE AND DURATION OF FLIGHT OF UNMANNED AERIAL VEHICLE

National Aviation University
Kosmonavta Komarova avenue 1, Kyiv, Ukraine, 03680
E-mails: [1]aerodyn@nau.edu.ua; [2]bondar@nau.edu.ua; [3]iesp@i.ua;

Abstract. *The problem of calculation of navigation range and the flight duration, different from estimated technical range by the accounting of operational features in balancing, influence of atmospheric flight conditions and the specific features influencing aerodynamic resistance of unmanned aerial vehicle is considered.*
Keywords: balancing resistance; navigation range; pilotless flying vessel.

1. Introduction

Calculation of range and duration of flight is the necessary section defining flight technical characteristics of aircraft.

In numerous sources [1, 2, 5] in which methods of calculation of range and flight duration are stated, the problem of calculation is set as an assessment of technical range under the set conditions of simplification of a task.

Generally range and duration of horizontal flight is defined at realization of the maximum aerodynamic quality, or aerodynamic perfection.

Navigation range differs from technical by the accounting of losses from balancing and meteorological factors.

The most exact are variation methods of optimization of range and durations of flight [6, 7] providing optimum modes of piloting of unmanned aerial vehicle.

2. Analysis of Research

In all methods aerodynamic characteristics are set in the form of constant coefficients of forces and the moments.

Specific features of balancing, such as the balancing resistance, hydro-meteorological conditions of flight – a rain, snow a wind usually aren't considered.

Balancing resistance changes aerodynamic quality and moment characteristics of unmanned aerial vehicle.

The accounting of balancing resistance on balancing polars, received as a result of aerodynamic researches in tunnels or finally confirmed in flight tests, will significantly specify calculations of range and flight duration.

The calculation of distance and duration of horizontal flight of an aircraft with propeller engines is calculated by the following equations:

$$L_{\text{гп}} = \frac{3,6}{g} \int_{m_2}^{m_1} \frac{K\eta_{в}}{Ce} \frac{dm}{m}; \tag{1}$$

$$T_{\text{гп}} = \frac{1}{g} \int_{m_2}^{m_1} \frac{K\eta_{в}}{CeV} \frac{dm}{m}, \tag{2}$$

where m_1 *and* m_2 – the mass of fuel at the beginning and at the end of flight;

K – aerodynamic quality;

V – flight speed;

Ce – specific fuel consumption which develops the engine on a power unit at hour.

Kilometre and hour fuel consumption define depending on screw efficiency in a form:

$$q_{км} = \frac{Ce}{3.6\eta_{\text{pr}}} \left(\frac{N}{V}\right);$$

$$q_{км} = \frac{Ce}{3.6\eta_{\text{pr}}} \left(\frac{N}{V}\right).$$

Or for horizontal flight:

$$q_t = \frac{Ce}{\eta_{\text{pr}}} \frac{mg}{K} V;$$

$$q_{км} = \frac{Ce}{3.6\eta_{\text{pr}}} \frac{mg}{K}$$

where η_{pr} – efficiency.

Modes of flight define dependences of power on speed and flight height (Fig. 1, 2):

$$N_{hf} = f(V_{hf}, H).$$

Characteristic speeds are economic speed V_{ek} for $T_{\max}$ and the most favourable, corresponding to value of the maximum quality

$$K = \frac{Cy_a}{Cx_a},$$

for $L_{\max}$.

The maximum quality taking into account blowing equally 15 for $\delta_f = 0°$ and 18.5 for $\delta_f = 10°$.

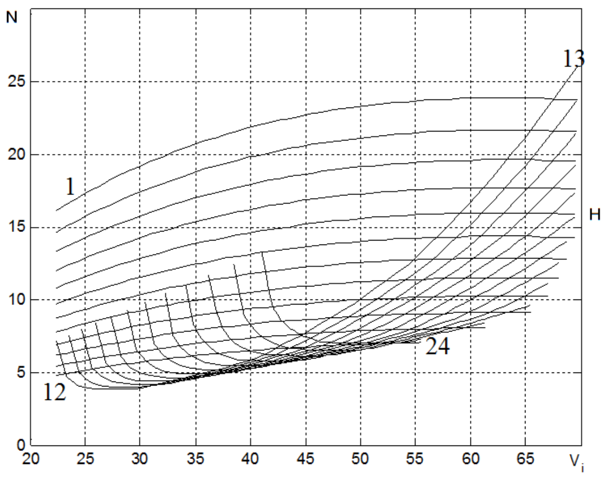


Fig. 1 Settlement FTC in horizontal flight for the mass unmanned aerial vehicle 150 kg provided that the requirements and available power:
1-24 – from 0 to 11 km

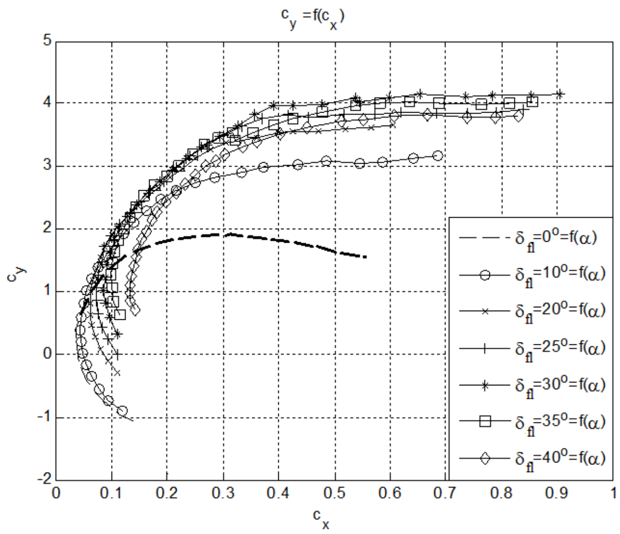


Fig. 2. The polar of unmanned aerial vehicle with the blowing screws

3. Solving this problem

Economic speed corresponds to the minimum power and therefore to the minimum hour fuel consumption, and the maximum duration of flight.

For horizontal flight economic capacity is determined by a formula:

$$N_{ek} = P_{hf}V = \frac{mg}{K}\sqrt{\frac{2mg}{\rho C_y S}} = 1{,}41\frac{Cx}{\sqrt{Cy^3}}\frac{\sqrt{(mg)^3}}{\sqrt{\rho S}}, \quad (3)$$

where $\frac{Cx}{\sqrt{Cy^3}}$ – coefficient of power .

Dependence (3) allows defining influence of specific features of aerodynamic resistance on duration of flight of the aircraft. It is an important component at determination of navigation range and flight duration.

Value of coefficient of resistance taking into account various factors shows in:

$$Cx_{н} = Cx_0 + \Delta Cx_b + \Delta Cx_{met},$$

where

$\Delta Cx_b = f(\delta_{pr}, \delta_{ail}, \delta_{dir}, \delta_f,)$ – balancing resistance;

ΔCx_{met} – resistance from meteoconditions (a rain, a wind).

Balancing resistance appear when maneuvering or as individual from a difference in thrust of the left and right engines, a difference of weight of fuel in a torsion boxes, centring changes in the course of flight.

This type of resistance can reach 10% from the full resistance (Fig. 3).

Resistance from meteoconditions arises at influence of a wind, torrential rain, hoarfrost on a wing surface.

Resistance from a wind arises at slanting blowing of a glider, as leads to growth of balancing resistance.

According to dependence (3) economic capacity is directly proportional to resistance, but in the presence of additional resistance speed required for horizontal flight at constant thrust, decreases:

$$V = \sqrt{\frac{2P}{\rho(Cx + \Delta Cx)S}}.$$

Thus, the curve $N = f(V)$ is displaced up and to the left.

For preservation of former speed it is necessary to increase thrust, or to fly at a smaller speed, unmanned aerial vehicle on a mode of economic power corresponds to a minimum on a curve $N = f(V)$.

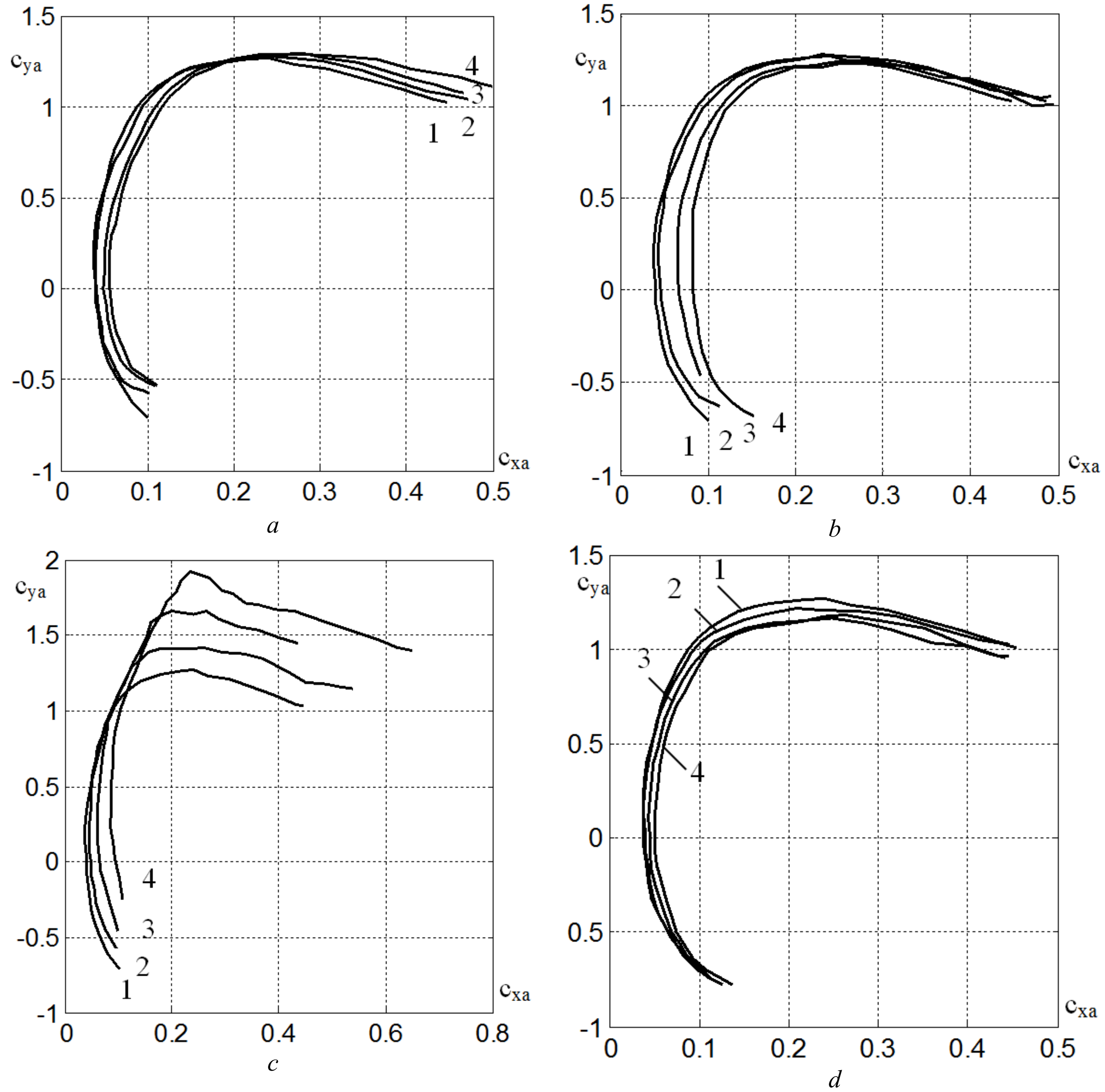


Fig. 3. The polar of the unmanned aerial vehicle with the influence of the deviation of the controls and with the blowing of screws for the conditions:

a – angles of deflection of the elevator:

1 – $\delta_{el} = 0^\circ$; *2* – $\delta_{el} = 8^\circ$; *3* – $\delta_{el} = 18^\circ$; *4* – $\delta_{el} = 23^\circ$; ;

b – angles of deflection of the rudder:

1 – $\delta_{rud} = 0^\circ$; *2* – $\delta_{rud} = -11^\circ$; *3* – $\delta_{rud} = -20^\circ$; *4* – $\delta_{rud} = -25^\circ$;

c – angles of deflection of the flaps:

1 – $\delta_f = 0^\circ$; *2* – $\delta_f = 10^\circ$; *3* – $\delta_f = 20^\circ$; *4* – $\delta_f = 30^\circ$;

d – angles of deflection of the right flapper:

1 – $\delta_{fl} = 0^\circ$; *2* – $\delta_{fl} = -7^\circ$; *3* – $\delta_{fl} = -17^\circ$; *4* – $\delta_{fl} = -26,5^\circ$

Practically piloting on duration of flight possibly only by means of automatic keeping of speed of flight with a set accuracy.

According to (1) and (2) ranges and duration of flight depends on aerodynamic characteristics of K and K/V.

To K_{max} value corresponds to flight conditions on the most favourable angle of attack that is steadily realized in practice of flights.

K/V value has a maximum which depends on height of flights (Fig. 4).

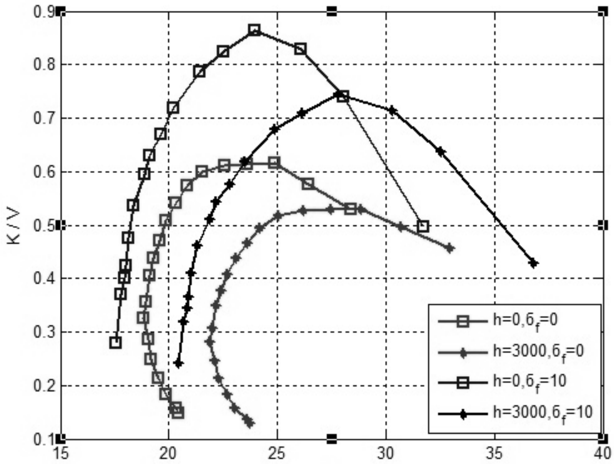


Fig. 4. Dependence of aerodynamic characteristics K, K/V

To flight on the maximum duration corresponds to the maximum K/V value.

At the height of H=0, the speed of the horizontal established flight 25m/s, at the height of 3000 m 28 m/s.

These speeds have to correspond to economic power and be realized practically on angles of attack big the most favourable angle (Fig.5).

In Fig. 6 parameters and characteristics which need to be considered at calculation of optimum navigation range and flight duration are schematically shown.

Balancing of the plane determine by a deviation of the wheel, the corresponding speed of flight and centering (Fig. 7).

On balancing polars (Fig. 8) we determine settlement resistance for horizontal flight of unmanned aerial vehicle.

Results of calculation of range and duration of flight are given in Fig. 9, 10 taking into account a deviation of an elevator, a rudder, flaps and flappers.

The maximum range is reached at the most favourable speed at height 8000–14000 m; the maximum range when flying at the earth with the released flaps – 12.7 h.

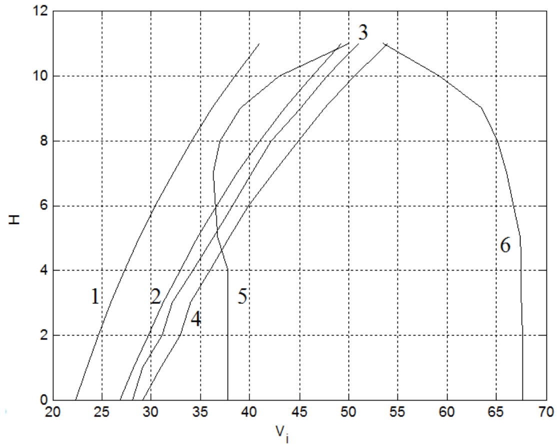


Fig. 5. Characteristics of speed in horizontal flight for the average weight of unmanned aerial vehicle at: *1* – V_{min} ; *2* – $V_{a/c}$; *3* – V_{ek} ; *4* – $V_{m.a}$; *5* – V_{cl} ; 6 – V_{max}

Calculation is carried out for the flight weight of 150 kg.

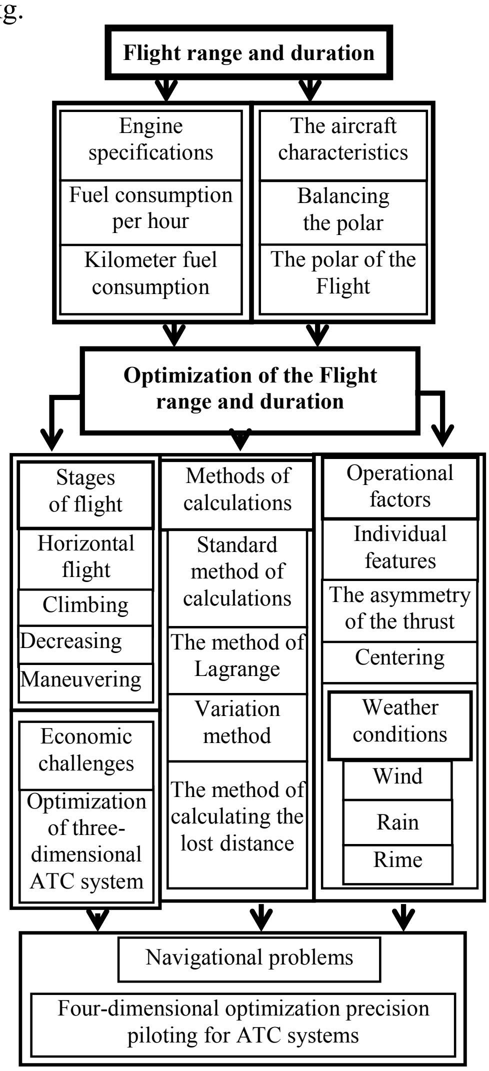


Fig. 6. Flowchart of determination of navigation range and flight duration

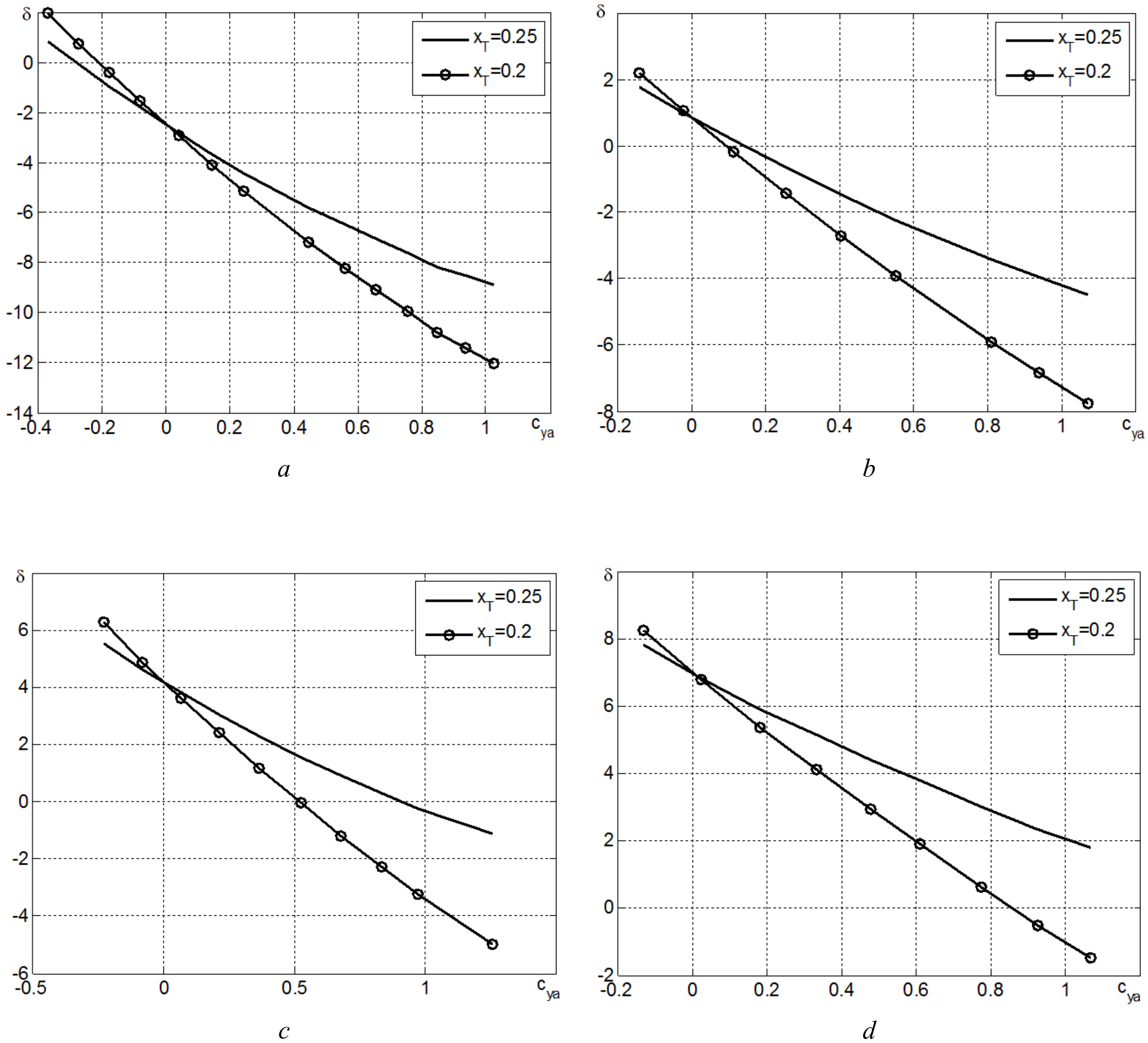


Fig. 7. Balancing δ_{pr} deviations with constant speed of an elevator at various centring:

a – $\delta_f = 0^\circ$;

b – $\delta_f = 10^\circ$;

c – $\delta_f = 20^\circ$;

d – $\delta_f = 30^\circ$

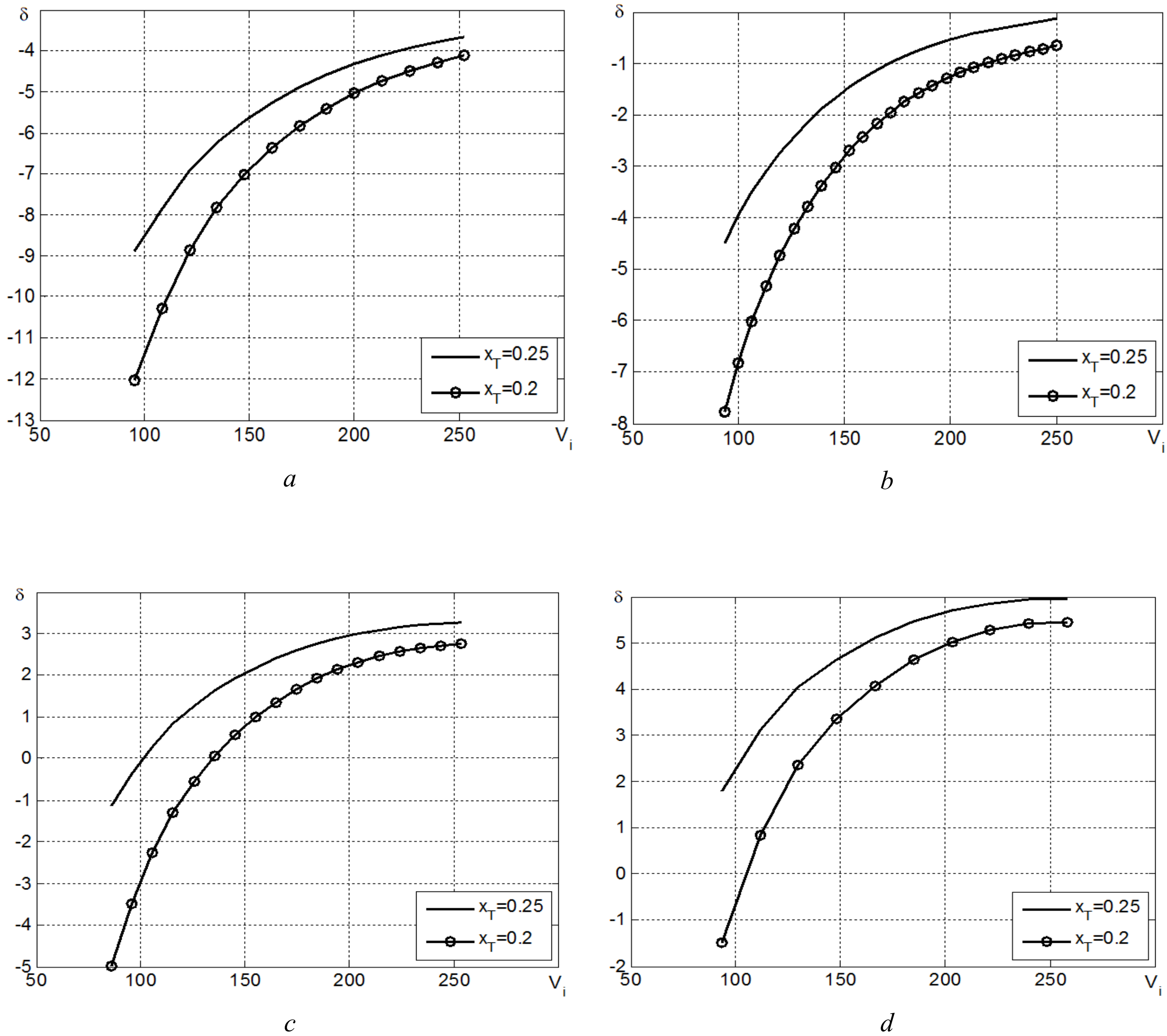


Fig. 8. Balancing δ_{pr} deviations at a constant overload of an elevator at various centring:

a – $\delta_f = 0^\circ$;

b – $\delta_f = 10^\circ$;

c, d – $\delta_f = 20^\circ$

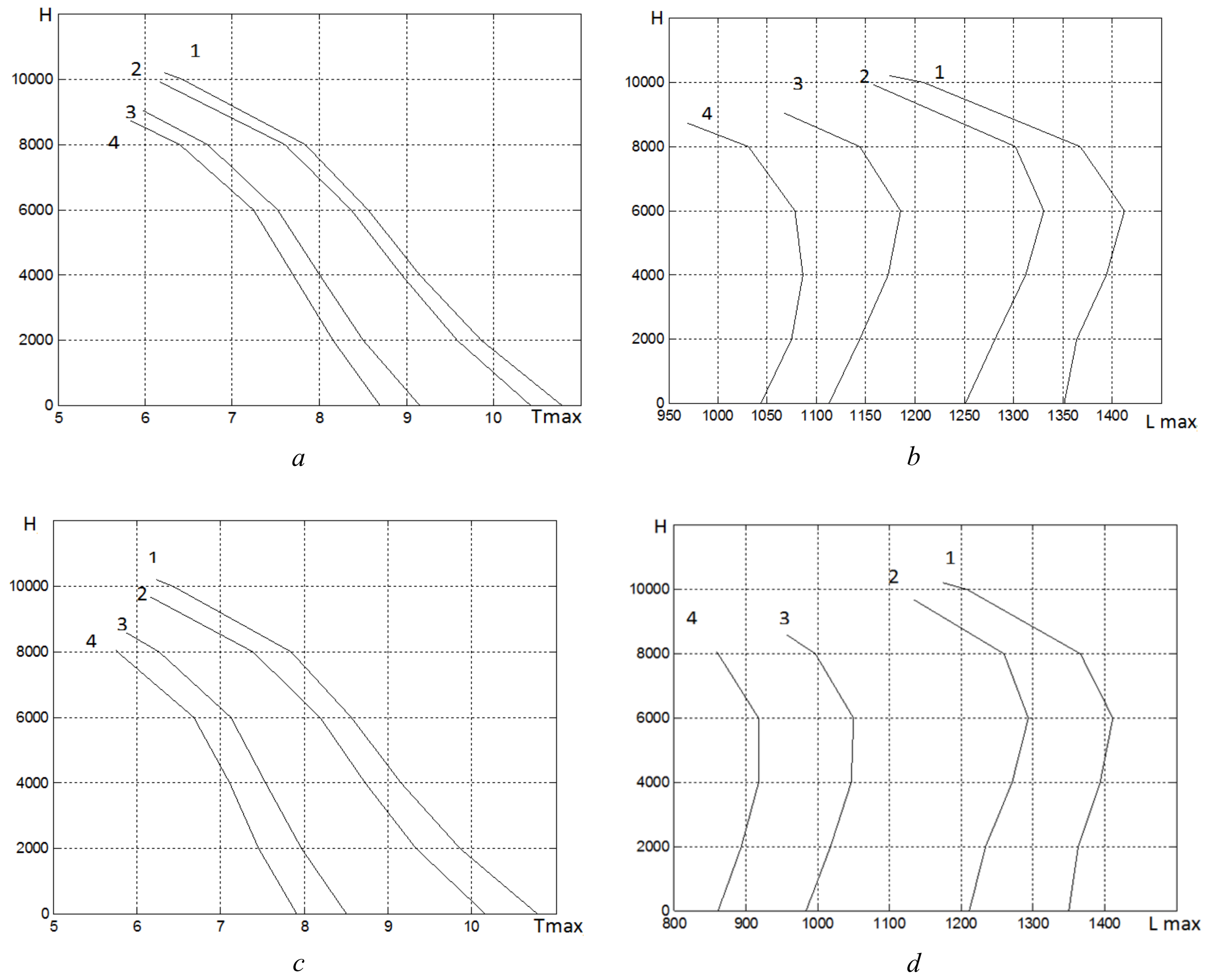


Fig. 9. Calculation of the maximum range and flight duration angels of a deviation of an elevator and a wheel of direction:

a, b – an elevator :

1 – $\delta_{el} = 0^{\circ}$;

2 – $\delta_{el} = 8^{\circ}$;

3 – $\delta_{el} = 18^{\circ}$;

4 – $\delta_{el} = 23^{\circ}$;

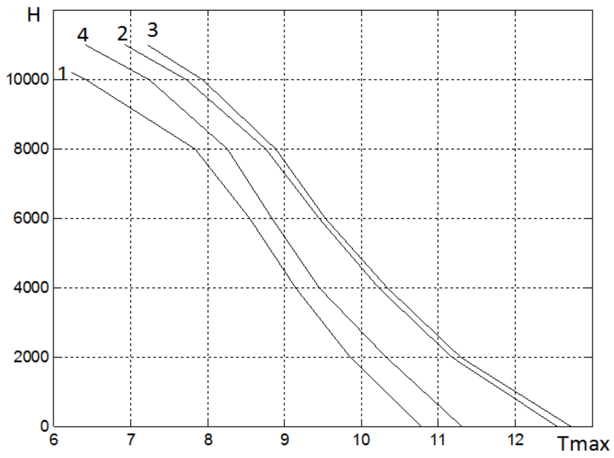
c, d – a wheel of the direction:

1 – $\delta_{rud} = 0^{\circ}$;

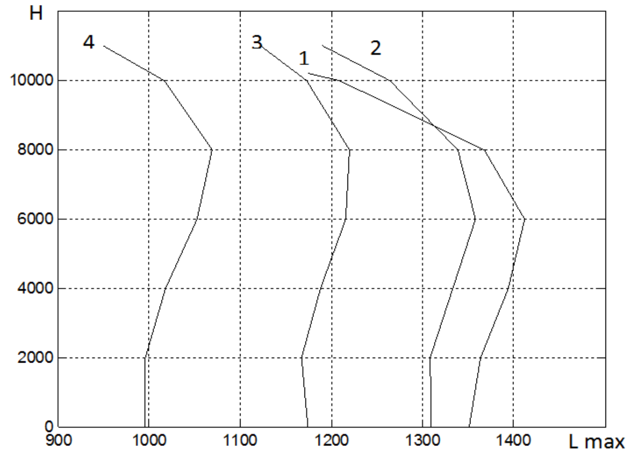
2 – $\delta_{rud} = -11^{\circ}$;

3 – $\delta_{rud} = -20^{\circ}$;

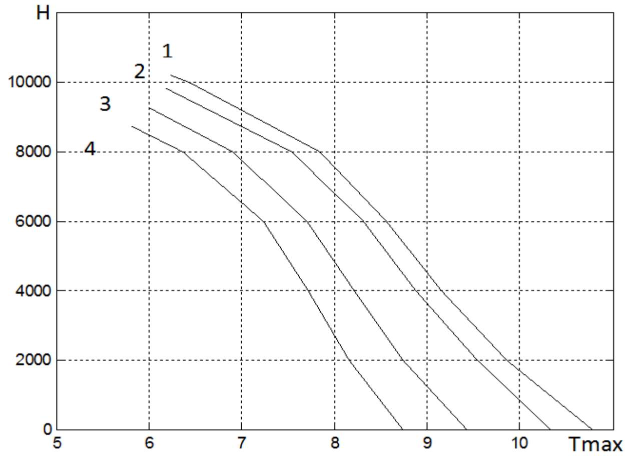
4 – $\delta_{rud} = -25^{\circ}$



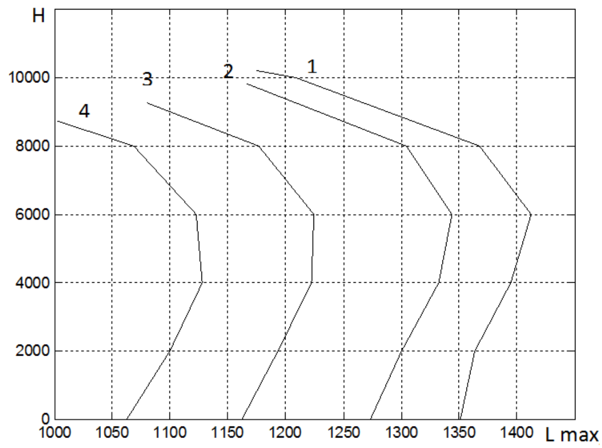
a



b



c



d

Fig. 10. Calculation of the maximum range and flight duration of angels of a deviation of flaps and the rigt flaperon:

a, b – flaps:

1 – $\delta_f = 0^\circ$;

2 – $\delta_f = 10^\circ$;

3 – $\delta_f = 20^\circ$;

4 – $\delta_f = 30^\circ$;

c, d – the right flaperon:

1 – $\delta_{fl} = 0^\circ$;

2 – $\delta_{fl} = -7^\circ$;

3 – $\delta_{fl} = -17^\circ$;

4 – $\delta_{fl} = -26,5^\circ$

4. Conclusions

1. Operational range of flight of unmanned aerial vehicle taking into account balancing losses is reached at height 8000 m ($\delta_f = 0^\circ$).

2. To increase in operational duration of flight of unmanned aerial vehicle taking into account balancing losses by means of flaps ($\delta_f = 10^\circ$, $\delta_f = 20^\circ$) at all considered heights of flight.

3. It is similarly observed the maximum losses of operational range of flight of unmanned aerial vehicle when balancing in the cross direction.

4. Unmanned aerial vehicle balancing in longitudinal, cross and lateral motions leads to loss of height of flight on a practical ceiling and only the deviation of mechanization of a wing – flaps leads to some increase in such heights.

The greatest losses of height of flight on a practical ceiling also it is observed when balancing unmanned aerial vehicle in the cross direction (Fig. 9, *c, d*).

5. The given approach can be used at the initial stages of development of unmanned aerial vehicle for a quantitative assessment of indicators operational ranges and flight durations taking into account balancing losses.

6. Results given in Fig. 9, *a, b* and, would show that speed at which is reached the greatest possible operational range and duration of horizontal flight are various and the difference of speeds can reach 15 m/s.

The specified speeds, according to Fig. 5, are in limits the most favorable and a little big speeds of flight. the treated result testifies to possible further optimization of the sizes $L_{h.f.}$ and $T_{h.f.}$.

Taking into account shown flight conditions, such as time of arrival of unmanned aerial vehicle in the specified point, at the appointed time, and also at taking note of a condition of the atmosphere (a wind, a rain).

On the basis of the provided data the problem of optimization of flight of unmanned aerial vehicle is solved by variation methods [3, 4, 6].

References

[1] *Badiagin, A.A.; Muhamedov, F.A.* Design of light aircraft. Moscow, Mashunostroenie. 1978. 208 p. (in Russian).

[2] *Biushgens, G.S.* Aerodynamics, flight dynamics haul aircraft. Moscow, Publishing Department TSAGI. 1995 (in Russian).

[3] *Kosmodemyanskii, A.A.* Course of Theoretical Mechanics. Part II. Moscow. 1966 (in Russian).

[4] *Silkova, V.I.* Unmanned aerial vehicles. Methods of approximate calculations of the main parameters and characteristics. Ryiv, CNII VVT VS Ukraine. 2009. 302 p. (in Russian).

[5] *Udartsev, E.P.; Pereverzev, A.M.; Ischenko, S.A.* Operating aerodynamics. The trajectory problem: Textbook. Kyiv. KMUGA. 1998. 136 p. (in Russian).

[6] *Ugov, O.K.; Selivanov, O.D.* Coordination between aircraft and engine. Moscow. Mashunostraenie. 1975. P. 204 (in Russian).

[7] *Zykov, A.Y.; Ermakov, V.I.; Ermakov, A.L.* Dynamics of flight of transport aircraft. Moscow. Transport. 1996. 326 p. (in Russian).

Received 27 June 2014.

Є.П. Ударцев[1], О.В. Бондар[2], Є.С. Плахотнюк[3]. Навігаційна дальність та тривалість польоту безпілотного літального апарата
Національний авіаційний університет, просп. Космонавта Комарова, 1, Київ, Україна, 03680
E-mails: [1]aerodyn@nau.edu.ua; [2]bondar@nau.edu.ua; [3]iesp@i.ua
Наведено розрахунок навігаційної дальності та тривалості польоту, що відрізняється від розрахункової технічної дальності. Розглянуто експлуатаційні особливості балансування, атмосферні умови польоту та індивідуальні особливості, що впливають на аеродинамічний опір безпілотного літального апарата.
Ключові слова: балансувальний опір; безпілотний літальний апарат; навігаційна дальність.

Е.П. Ударцев[1], А.В. Бондар[2], Е.С. Плахотнюк[3]. Навигационная дальность и продолжительность полета беспилотного летательного аппарата
Национальный авиационный университет, просп. Космонавта Комарова, 1, Киев, Україна, 03680
E-mails: [1]aerodyn@nau.edu.ua; [2]bondar@nau.edu.ua; [3]iesp@i.ua
Приведён расчет навигационной дальности и продолжительности полета, отличающийся от расчетной технической дальности. Рассмотрены эксплуатационные особенности балансировки, атмосферные условия полета и индивидуальные особенности, влияющие на аэродинамическое сопротивление беспилотного летательного аппарата.
Ключевые слова: балансировочное сопротивление; беспилотный летательный аппарат; навигационная дальность.

Udartsev Ievgen.Doctor of of Engineering. Professor.
Department of Aerodynamics and Flight Safety of Aircraft, National Aviation University, Kyiv, Ukraine.
Education: postgradute student at the Kyiv Civil Aviation Engineers Institute, Kyiv, Ukraine (1987).
Research area: unsteady aerodynamics.
Publications: 120.
E-mail: aerodyn@nau.edu.ua

Alexandr Bondar. Researcher Assistant.
Research Unit, Department of Aerodynamics and Flight Safety of Aircraft, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2010).
Research area: aerodynamics of aircraft.
Publications: 15.
E-mail: bondar@nau.edu.ua

Plakhotniuk Ievgen. Postgraduate student.
Department of Air Navigation Systems, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine (2010).
Research area: unmanned aircraft.
Publications: 5.
E-mail: iesp@i.ua