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FEATURES OF THE USE OF NEURAL NETWORKS IN THE DESIGN OF UAVS FOR FLIGHT IN THE STRATOSPHERE

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Abstract

Problems of application of neural networks during UAV design, and also questions of development of methods and algorithms of synthesis of neural network.

Keywords: neural networks, machine learning, power supply, stratospheric UAVs, energy efficiency, battery, solar battery

1. Introduction

At the present stage of development of society, information technology is becoming the main reason for the significant increase in the relevance of areas of scientific activity related to mathematical modeling of processes and phenomena. Modeling real objects around the world is usually accompanied by significant difficulties that arise at the stage of problem statement Recently, the problem of manufacturing and using stratospheric UAVs is the lack of effective technologies in Ukraine that can find a compromise between the low efficiency of known energy sources (solar films and batteries) and the requirements for the design and power scheme of aircraft of different sizes and weights. In this context, the question of the certainty of small values of traction and specific load per unit area of UAVs seems important

2. The main part

The specific load of modern stratospheric UAVs is in the range of 2-5 kg/m2, which compared to the load of the famous reconnaissance RQ-4 Global Hawk (USA) in 230 kg/m2 requires new approaches to structural strength and weight culture, due to high sensitivity of the structure to horizontal and vertical wind loads of small orders - 5-20 m / s [1]. Traction determines the rate of ascent of the aircraft. Given the world practice, this parameter of stratospheric UAVs are in the range of 0.09-0.15 kGs / kg, which in itself is the lowest of all known types of aircraft. For example, it is considered that the rate of 0.5 kgf / kg in aviation is low. Accordingly, such a UAV should have a high aerodynamic quality in the range of 30-40 units, i.e. should be perfect in terms of aerodynamic performance. High-performance HALE high-performance solar panels can solve many problems. The complexity of the design is due to the high altitudes and low available energy to power the engines. During the day, solar energy is converted by photovoltaic cells and then used to power electric motors and payloads. There is a need to optimize the ratio of the maximum payload to a fixed total mass of the stratospheric UAV. In addition, it is worth noting the mass model for each component of the aircraft separately [2]. The model of sunshine gives the power to use photovoltaic cells per unit area (P_S). (Only the normal part of the sunshine is converted, and the other part is displayed. This radiance-power is a function of the height of the plane *h*, the latitude of the plane *φ*, the day of the year *d* and the solar time *h*, which can be written in the following form [3]:

$$\widehat{P_S} = \frac{G_{SC}}{d^2} A_s (\sin\delta \sin\varphi + \cos\delta \cos\varphi \cos\frac{\widehat{\pi h}}{12} \quad);$$

$$d^2 = (1 + 0.033 \cos\frac{2\pi\hat{d}}{365}) \quad ^{-1};$$

$$\varphi = 23.45 \sin\left(\frac{2\pi(284+\hat{d})}{365}\right);$$

$$A_s = \frac{1}{2}(e^{-0.65\Pi} + e^{-0.095\Pi});$$

$$\Pi = \frac{p}{p_0}(\sqrt{1229 + (614\cos(\varphi - \delta))^2} -$$

$$614\cos(\varphi - \delta)),$$

where: G_{SC} – solar constant (≈1374 W: m-2);

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A_S is the coefficient of reduction of solar radiation through the atmosphere;
d is the relative distance Earth – Sun in astronomical units;
p is the considered static pressure at height;
p0 is static pressure on the ground.

The UAV uses only solar radiation. This energy is converted into electrical energy by photovoltaic cells, and then distributed to electric motors, payload and battery (Fig. 1-2).

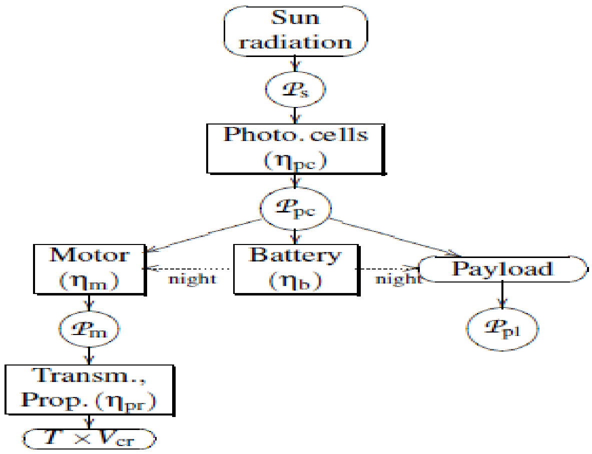

Fig.1. Block diagram of power distribution

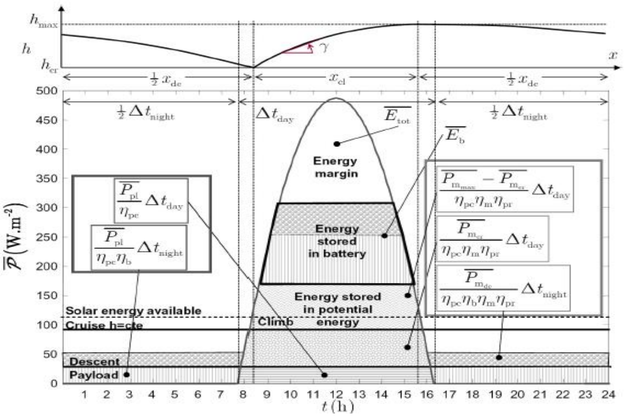

Fig. 2. Solar radiation per unit of available space, time and energy distribution for engines, battery and payload battery

At night, the UAV flies only with the energy stored in its battery. To reduce the weight of the battery, you can store extra daytime solar energy in the potential energy by lifting. The descent during the night is realized with reduced engine power compared to cruising power [4]. The mass of the electric motors is determined by the value of the maximum useful power for the ascent maneuver Pm_{max}. This power is assumed to be proportional to the cruising force:

$$Pm_{max} = \xi P_{max} Pm_{cr};$$
$$Pm_{cr} = \frac{T_{cr}V_{cr}}{\eta_{pr}} = \frac{mgV_{cr}}{\eta_{pr} f_{cr}},$$

where *Vcr*, *Tcr*, *hpr*, *fcr*, *m* and *ξPmmax* – cruising speed, cruising thrust, propeller, lift and tractor ratio, aircraft weight and propeller efficiency, respectively. For the specific mass of the engine ($\overline{m_m}$,) , the mass of the motor, which can be written in the following form:

$$m_m = \overline{m_m} \frac{\xi Pm_{max} mgV_{cr}}{\eta_{cr} f_{cr}}.$$

Ascent and descent maneuver. The purpose of the ascent and descent maneuver is to store potential energy to reduce the size of the energy storage system (ESS). Consider the examples in which the optimization of these maneuvers is proposed. The first maneuver: UAVs rise from the cruising height to the maximum height with the maximum available power. The second phase corresponds to the descent at night with a decrease in power. These two phases are guided by the assumption of the term ($pV^2 = p_{cr}V^2_{cr}$) which is constant. This choice gives a constant rise to the drag factor. Then the linear equation of motion is [5]:

$$\gamma = \frac{T}{mg} - \frac{1}{f_{cr}} = \frac{\eta_{pr} Pm}{mgV_{cr}\sqrt{p_{cr}}}\sqrt{p} - \frac{1}{f_{cr}}$$

with $Pm = Pm_{max}$ for ascent and $Pm = Pmdc$ for descent, where g is the inclination of the aircraft and r is the density of air. To simplify the integration of the equation, consider and calculate the square root of the air density linear with respect to the height in the considered range [6]:

$$\sqrt{p} = \frac{\sqrt{p_2} - \sqrt{p_1}}{h_2 - h_1} h + \frac{h_2\sqrt{p_2} - h_1\sqrt{p_1}}{h_2 - h_1},$$

where p_i is calculated at altitude h_i by the values of the American standard atmosphere. This approximation is quite accurate for the previous project ($\Delta p/p < 7\%$ in the range from 20 km to 24 km). Then for the climbing maneuver you can get the height in analytical form [7]:

$$h = (h_{cr} - hce_{cl})e^{Aclax} + hce_{cl};$$
$$hce_{cl} = \frac{1}{A_{cl} a f_{cr}} - \frac{b}{a},$$

where h_{cr} – cruising altitude, respectively. The inverse preliminary equation gives the distance traveled by the aircraft during takeoff:

$$x_{cl} = \frac{1}{A_{cl} a} \ln\left(\frac{h_{max} - h_{ce_{cl}}}{h_{cr} - h_{ce_{cl}}}\right).$$

The duration of the ascent from the cruise to the maximum altitude (t_{cl}) can be calculated by the following expression:

$$\frac{dx}{dt} = V \quad \Rightarrow \quad \int_0^{x_{cl}} \frac{\sqrt{\rho}}{V_{cr}\sqrt{\rho_{cr}}} dx = \int_0^{t_{cl}} dt$$

and after calculation:

$$t_{cl} = \frac{1}{V_{cr}\sqrt{\rho_{cr}}}\left(\frac{h_{cr}-h_{ce_{cl}}}{A_{cl}}\left(e^{A_{cl}ax_{cl}}-1\right) + \left(ah_{ce_{cl}}+b\right)x_{cl}\right).$$

As we considered $t_{cl} = \Delta t_{day} = t_{ss} - t_{sr}$ (where t_{sr} and t_{ss} are the time of sunrise and sunset, respectively), we can obtain hmax using a combination of equations.

$$h_{max} + \frac{1}{A_{cl}af_{cr}}\ln\left(h_{max}-h_{ce_{cl}}\right) = F_{cl};$$

$$F_{cl} = A_{cl}V_{cr}\sqrt{p_2}\Delta t_{day}+h_{cr} + 1/Aaf_{cr}ln(h_{cr} - hce_{cl}).$$

The real root of the equation is obtained numerically. The same equations are obtained for the descent of the maneuver. In this case, the problem is to find the *Pmdc* during the descent duration from the maximum to the cruise altitude Δt_{night}. The distance traveled during the descent is [8]:

$$x_{dc} = \frac{1}{A_{dc}a}\ln\left(\frac{h_{cr}-h_{ce_{dc}}}{h_{max}-h_{ce_{dc}}}\right);$$

$$\Delta t_{night} = \frac{1}{V_{cr}\sqrt{\rho_{cr}}}\left(\frac{h_{cr}-h_{ce_{dc}}}{A_{dc}}\left(e^{A_{dc}ax_{dc}}-1\right) + \left(ah_{ce_{dc}}+b\right)x_{dc}\right);$$

$$hce_{cl} = \frac{1}{A_{cl}af_{cr}} - \frac{b}{a}.$$

The duration of the descent are the equations above, which can be combined to obtain engine power for the ascent maneuver:

$$\mathcal{P}_{m_{dc}}^2 - \frac{mg\left(h_{cr}-h_{max}\right)}{\eta_{pr}\Delta t_{night}}\mathcal{P}_{m_{dc}} - \mathcal{P}_{m_{cr}} \times \frac{mg\sqrt{\rho_{cr}}}{\eta_{pr}a\Delta t_{night}}\ln\left(\frac{\mathcal{P}_{m_{dc}}-\mathcal{P}_{m_{cr}}}{\sqrt{\frac{\rho_{max}}{\rho_{cr}}}\mathcal{P}_{m_{dc}}-\mathcal{P}_{m_{cr}}}\right) = 0.$$

The real root of this equation is obtained numerically. Then you can calculate the efficiency for these two maneuvers compared to a constant altitude flight.

$$\eta_{cl/dc} = \frac{\left(\Delta t_{day}+\Delta t_{night}\right)\mathcal{P}_{m_{cr}}}{\Delta t_{day}\mathcal{P}_{m_{max}}+\Delta t_{night}\mathcal{P}_{m_{dc}}}$$

Photovoltaic cells. The power of solar radiation per unit area *Ps* is converted into electricity *Ppc* by solar energy with an efficiency of ηPC. Then the electricity is consumed by the payload (*Ppl*), the battery (Pb) with efficiency η_b and the power of the motor during the lifting maneuver (Pm_{max}) with efficiency η_m. At noon, we have the following values [9]:

$$\mathcal{P}_{pc} \approx \frac{\mathcal{P}_{m_{max}}}{\eta_m} + \mathcal{P}_{pl} + \frac{\mathcal{P}_b}{\eta_b} = \eta_{pc}\overline{\mathcal{P}_{s_{max}}}S_{pc},$$

where *Spc* is the surface of solar panels.
Thus, you can get a lot of cells:

$$m_{pc} = \frac{\widetilde{\rho}_{pc}}{\eta_{pc}\overline{\mathcal{P}_{s_{max}}}}\left(\frac{\xi_{\mathcal{P}_{m_{max}}}}{\eta_{pr}\eta_m}\frac{mgV_{cr}}{f_{cr}} + \mathcal{P}_{pl} + \frac{\mathcal{P}_b}{\eta_b}\right),$$

where $p_{pc}=m_{pc}/S_{pc}$ is the cell surface density. Fuel chamber. Various studies show that regenerative fuel cells, including pressure vessels for H_2 and O_2 tanks for H_2O and other systems, have a very high specific energy. This size and mass of the ESS has an effect only on the energy required for night flight. The stored E_{ESS} is used to power the engines during descent maneuvers and payloads [10].

$$\mathcal{E}_{ESS} = \Delta t_{night}\left(\frac{\mathcal{P}_{m_{dc}}}{\eta_m} + \mathcal{P}_{pl}\right).$$

In general, we can calculate the mass of ESS specific energy *(E_ESS)ˆ= EESS / mESS.*
Drag model. The total wear factor CD_0 is the sum of the zero rise of the drag factor CD_0 and the induced drag [11]:

$$CD = CD_0 + \frac{1}{\pi\lambda}CL^2$$

where $\lambda=b/c$, *CL*, *b* and *c* are aspects of the wing lift factor, lift factor, wing span and wing chord, respectively. The drag coefficient without an elevator is considered to be equal to the amount of drag due to the shape of the airfoil and the shape of the body. The HALE (High Altitude High Endurance) UAV can be used for many missions, such as: Earth monitoring (forest mapping, flood control, hurricane tracking and remote sensing of agriculture, border control) and the replacement of telecommunications satellites (stationary). orbits or over long distances, inexpensive platform, low maintenance). For such operations, these UAVs must be able to fly for weeks and months [12]. Optimization procedure. The total mass of the UAV is:

$$m=m_w+m_m+m_{pc}+m_b+m_{rem}+m_{pl}$$

where m_{pl} is the payload mass. This mass is a maximization variable. Then, the merit of the MF function, where to minimize you can get [13]:

$$\frac{m_{pl}}{m} = 1 - \frac{m_w+m_m+m_{pc}+m_b+m_{rem}}{m} = 1 - MF$$

It is clear that $m_{pl} > 0$, i.e. $MF \leq 1$

The second limitation - the total surface area of solar panels *Spc* must be inferior to the surface of the wing [14]:

$$S_{pc} / S_w = T \leq T_{max}$$

where *Tmax* is the maximum employment rate. Preliminary research shows that the optimal UAV is obtained when the maximum occupancy of the cells is reached. The third limitation is energy consumption, which must be inferior to the total available solar energy within one day [15]:

$$\mathcal{E}_{tot} \leqslant \mathcal{E}_s = \int_{t_{sr}}^{t_{ss}} \overline{\mathcal{P}_s} S_{pc} dt ,$$

where the total energy consumption of the UAV for one day is determined by the following equation [16]:

$$\mathcal{E}_{tot} = \frac{1}{\eta_{pc}}\left(\Delta t_{day}\left(\mathcal{P}_{pl}+\frac{\mathcal{P}_{m_{max}}}{\eta_m}\right) + \frac{\Delta t_{night}}{\eta_b}\left(\mathcal{P}_{pl}+\frac{\mathcal{P}_{m_{dc}}}{\eta_m}\right)\right) .$$

This optimization process corresponds to the Thorenbeck Method. The maximum take-off of weight and endurance are fixed, therefore the weight of payload should be the maximum (Fig. 3).

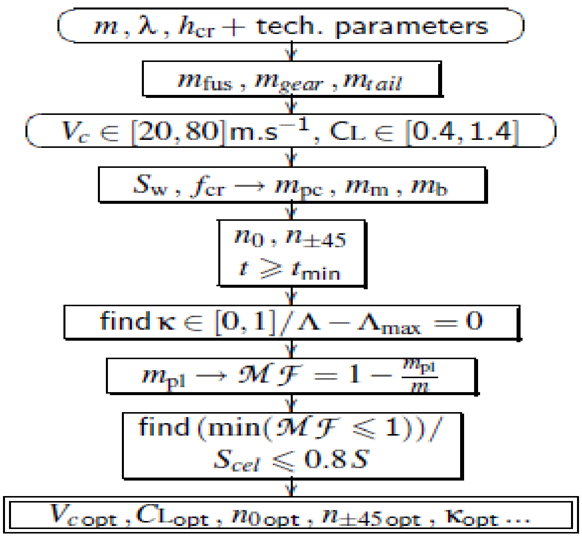

Fig.3. Diagram of the algorithm for calculating the optimized UAV

Since the number of parameters is too large, the choice is made to select the appropriate conceptual parameters. The parameters are scanned using an algorithm - cruising speed *Vcr* and lift coefficient C_L, which are directly proportional to the surface wings. Endurance is not considered because it is not an appropriate parameter.

3. Conclusions

Conditions of flights in the stratosphere (11-40 km) have significant differences from flights in the troposphere (8-10 km.). This is caused by the following factors: temperature range from -56.5 °C to + 0.8 ° C; the presence of ozone; increased levels of solar and cosmic radiation; the density of air in the stratosphere is ten times less than at sea level; low pressure (0.1-0.01 atm.); almost complete absence of air currents and clouds; possible icing; the presence of zones of turbulence during ascent and descent.

The main advantages of UAVs over traditional manned vessels when flying in the stratosphere are:

- reduction of material consumption and energy consumption;
- reduction of mass and size indicators of aircraft;
- reduction of risks from the presence of a person on board;
- reduction of costs for fuels and lubricants and other direct operating costs;
- in the commercial use of UAVs, the key indicator of their efficiency;
- the cost of a flight hour, becomes many times less for different classes of aircraft;

In addition, the use of unmanned stratospheric platforms makes it possible to solve strategic problems, which are currently solved only with the help of a group of spacecraft.

The main factors of influence and features of the structural - power scheme of the unmanned aerial vehicle for flights in the stratosphere are: low availability of energy to power the engines during daylight and its complete absence at night in the case of solar panels; the need to ensure the strength of the structure and the culture of weight, due to the high sensitivity of the structure to horizontal and vertical wind loads of small orders; the need for energy sources with a high efficiency (solar films and batteries); light weight and significant size of the stratospheric UAV; the need to use ultra-light and ultra-strong modern composite materials; too low value of traction and specific load per unit area; due to the low values of traction and specific load per unit area, the stratospheric UAV must be a perfect aerodynamic product;

It can be concluded that the most viable aerodynamic scheme for this task is a normal aerodynamic scheme, which provides the easiest design solution for longitudinal stability and longitudinal controllability. The power plant of such UAVs must be of a combined nature: in daylight, solar energy is converted by photovoltaic cells - solar panels - films, and then used to power electric motors and payload. Some of the energy is stored in batteries. At night, the batteries provide the energy needed for the engines. Given the presence in the world of advanced and most successful developments in the direction of stratospheric UAVs - HAPS (prototype "Zephyr-8"), we can consider this area the most promising for its development in Ukraine. This will allow them to gain independence in the control of their territories from the use of space images transmitted from other possessing countries.

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Особливості використання нейронних мереж при проектуванні бпла для польотів в стратосфері

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У статті досліджено особливості використання нейронних мереж при розробці конструктивно-силової схеми безпілотного літального апарата. Проаналізовано алгоритм синтезу штучних нейронних мереж для досягнення балансу між коефіцієнтом корисної дії енергоджерел БПЛА та його розмірів. Деталізовано процес живлення електроенергією стратосферного БПЛА в різноманітних умовах польоту.

Ключові слова: нейронні мережі, машинне навчання, живлення, стратосферні БПЛА, енергоефективність, акумулятор, сонячна батарея.

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Особенности использования нейронных сетей при проектировании бпла для полетов в стратосфере

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В статье исследованы особенности использования нейронных сетей при разработке конструктивно-силовой схемы беспилотного летательного аппарата. Проанализированы алгоритм синтеза искусственных нейронных сетей для достижения баланса между коэффициентом полезного действия энергоисточников БПЛА и его размеров. Детализировано процесс питания электроэнергией стратосферного БПЛА в различных условиях полета.

Ключевые слова: нейронные сети, машинное обучение, питание, стратосферные БПЛА, энергоэффективность, аккумулятор, солнечная батарея

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