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Energy output of the solar stratospheric platform electrical plant in a flight with course maneuvering

Abstract. *The main direction of the article is to establish the power dependence of the stratospheric platform solar power plant when the platform position is changing relative to the Sun. It is known that along with other parameters, namely cloudiness, the presence of dust in the atmosphere, the temperature of the converter, etc., the key to the energy output from the photovoltaic converter is the angle at which the Sun irradiates it. For a moving object, the issue is complicated by the fact that its movement is primarily dictated by the aerodynamic factor, namely the speed of movement relative to the air. In addition, the difficulty lies in the fact that photovoltaic transducers are mounted on the upper surface of the wing, which has its own curvature, which must be maintained for reasons of aerodynamics. In addition, the movement of the object is also determined by the current angle of attack of its wing. Thus, the elements of the future strategy of bringing the stratospheric platform to height in the conditions of changing the energy output from photovoltaic converters due to the influence of the above factors required a separate study and justification.*
The article presents the results of calculations and experimental verification of the power plant on the upper surface of the wing of the stratospheric platform depending on the direction of its movement relative to the Sun.

Accepted terms and abbreviations: *SSP* – stratospheric platforms or pseudo-satellites; P_0 – the maximum power of the unit plane of the photocells under normal lighting; γ_m – the maximum angle of inclination at the point $x=1$; β – angular height of the Sun, calculated from the zenith.

Introduction. Photovoltaic converters of power plants in SSP are located mostly on its horizontal surfaces, the main of which is the wing surface [1].

The greatest power of the SSP requires in flight during altitude gain. Due to restrictions on the area of flight, namely, allocated airspace, national borders, restrictions on radio systems, etc., the solar stratospheric platform is forced to change course, accompanied by a change in the orientation of photovoltaic converters relative to the Sun.

In this paper, an analysis of the power of the power plant on the upper surface of the wing of the SSP, depending on the direction of movement relative to the Sun.

Formulation of the problem. Figure 1 shows a typical aerodynamic profile of the SSP wing, for example, type PS-11 «CROCUS» [2], and the zone of photoelectric converters, which is due to the minimum radius of their bending [3].

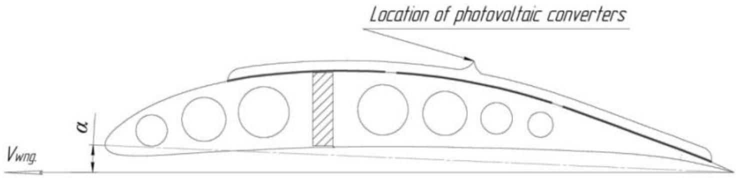


Fig. 1. Aerodynamic profile of SSP wing and location of photoelectric converters: $V_{wng.}$ – SSP velocity vector; α – is the angle of attack

Due to the asymmetry of the airfoil and the available angle of attack α when climbing, the power of the power plant depends on the direction of the SSP movement relative to the Sun: the movement of the SSP from the Sun has a significant advantage over the movement towards the Sun, because the angle of illumination is closer to normal.

Solving the problem. To substantiate this position, it is assumed that P_0 – the maximum power of the unit plane of the photocells under normal lighting; accordingly, the largest potential electric power of the solar cell in the plane S is [4].

$$P_{\max} = P_0 \times S \cdot \quad (1)$$

When constructing an analytical model of the power plant, a quadratic approximation of the line of location of photovoltaic converters was used [5]. A point is chosen as the origin of coordinates, where is the front edge of the photoconverters (fig. 2):

$$y = -(1/4)x^2, \quad (2)$$

where ($x = z/z_0$) – relative coordinate of aerodynamic profile; z_0 – the length of the location of the photoconverters in the horizontal direction *x*, taking into account the angle of attack.

With this approximation, the angle of inclination of the photocells relative to the vertical γ changes according to a linear law, namely:

$$\gamma = -(x/2) \times \gamma_m \quad (3)$$

where γ_m – the maximum angle of inclination at the point x=1.

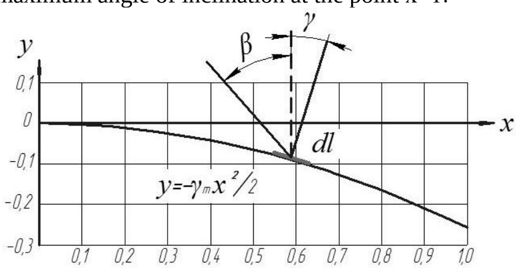


Fig. 2. Quadratic approximation of the area of the wing surface on which the photoelectric transducers are located

In this example, taken $\gamma_m = 0,5$ radians, which corresponds to the inclination of the chord of the wing relative to the horizontal by 7^0. In the General case, the formula for the approximation looks like this [6]:

$$y = -\gamma_m x^2 / 2 \cdot$$

The power of the elementary wing fragment *dl* of the photoconverters was calculated as follows:

$$dP = P_0 \times W \times \cos(\beta + \gamma) dl \text{ , (4)}$$

where W – the span of the wing fragment with the available photovoltaic converters; β – angular height of the Sun, calculated from the zenith; $\gamma = -\gamma_m\ x$ – local angle of deviation of the fragment from the horizontal.

If the length of an elementary section is plotted in a rectangular coordinate system (Fig. 2), then based on the formula $\gamma = -\gamma_m \cdot x$ the total power of the power plant from photoconverters will be equal to:

$$\overline{P} = P_0 \times W \int_0^1 \cos(\beta - \gamma(x)) dx \cdot \text{ (5)}$$

The integral (5) is solved in elementary functions. Applying the relationship $\gamma = -\gamma_m \cdot x$ to the subintegral expression and its limit values, we obtained the following result:

$$\overline{P} = \frac{P_0 W}{\gamma_m} \left[\cos\beta \int_0^{\gamma_m} \cos(\gamma) d\gamma + \sin\beta \int_0^{\lambda_m} \sin(\gamma) d\gamma \right].$$

After integration, the previous relationship takes the form:

$$\overline{P} = \frac{P_0 \times W}{\gamma_m} [\sin(\beta + \gamma_m) - \sin(\beta)] \text{ (6).}$$

Figure 3 shows the graphs of the relative power of the solar power plant calculated by formula (6) for the values (28°) and (14°), if the angular height of the Sun from the horizon $90^0 - \beta$ varies from 30^0 to 65^0.

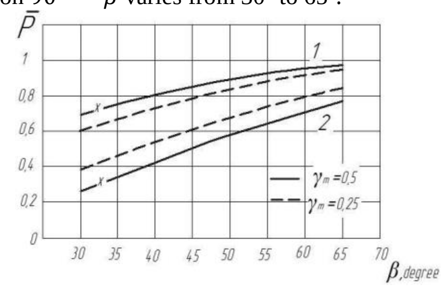


Fig. 3. The relative power of the solar power plant on the surface of the wing of the SSP in terms of climb ($\gamma_m = 0,5$) and horizontal flight ($\gamma_m = 0,25$): *1* – the movement of the SSP from the Sun; *2* – SSP movement on the Sun; the sign «x» marks the results of the experiment

From the applied point of view in Ukraine the angular height of the Sun on the day of the summer solstice does not exceed 63,5° at the latitude of Kiev and 67° at the latitude of Odessa; at noon on March 23 at the latitude of Kyiv it is 40°, and on May 23 it exceeds 40° from 9:30 a.m. to 4:20 p.m.

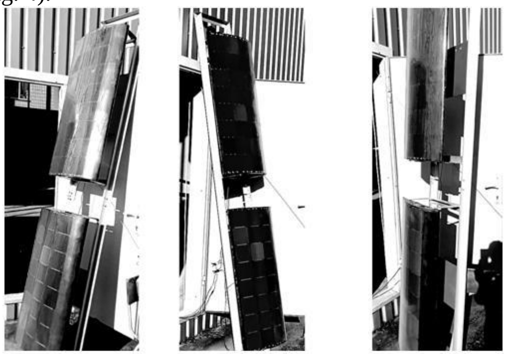
Due to the asymmetry of the aerodynamic profile, the power of the power plant significantly depends on the direction of movement of the SSP relative to the Sun.

With the increase in altitude (γ_m = 0,25), the power of the power plant, if moving on the Sun and from the Sun, changes approximately twice, at an angular height of the Sun 40°…50°. In the case of horizontal flight (γ_m = 0,25), the power variation is 35…50 %.

Accordingly, for practical use, the recommended and most advantageous mode of altitude gain during the ascent to the stratosphere is a flight with altitude gain in the direction «from the Sun» to the boundary of the airspace (flight zone), and reversal in the direction «to the Sun» with movement on the opposite side of the flight zone at maximum speed without gaining altitude.

Next, you need to make a U-turn for the next stage of lifting the aircraft, moving in the direction of maximum power of the power plant.

Experimental evaluation of the dependence of the power plant SSP PS-11 «CROCUS» on the flight course, relative to the direction of the Sun, was performed using a life-size wing model with the application of photoelectric converters on the wing surface (Fig. 4).



a) б) c)

Fig.4. The model of the SSP wing is located at different angles relative to the direction of irradiation indicated by the arrows:
a – the direction of irradiation of maximum power; b – imitation of flight «from the Sun»; c – imitation of flight «to the Sun»

The number of series-connected photoelectric converters (48 pieces) is equal in voltage to the full voltage of the power plant, and corresponds to 1/6 of the total power in terms of power. Measurements were performed in winter conditions. The wing model was placed in such a way as to be able to change the angle at which the sun illuminates the photovoltaic converters (Figs. 4 *a*, 4 *b*, 4 *c*), by setting the wing deviation angle from the maximum power to about 50°, which corresponds to the Sun’s angular height of about 40°.

Fig. 5. Wattmeter with maximum power mode parameters

The maximum measured power in the experiment was 119W (Fig. 4 *a*). According to the orientation of the wing, for the case of Fig. 4 *b*, i.e the flight from the Sun, the electric power was 65W. In the case of Fig. 4 *c* (solar flight) the electrical power was 47W. The results of experimental measurements are shown in Fig. 3, indicating a confidence interval of about 5° for angles and 4 % for power. Electrical indicators were measured with an electronic wattmeter (Fig. 5).

Conclusions

As can be seen from the results of the study, the experimental evaluation corresponds to the results of theoretical calculations. Some decrease in the measured power relative to the calculated one is explained by the reflection of radiation from the surface of the existing protective coating of photoelectric converters.

The electrical power supply of PS-11 «CROCUS» significantly depends on the direction of flight relative to the Sun. Thus, the thesis about the need to maneuver the aircraft at the stage of climbing is confirmed: the highest vertical speed should be set when moving along the course «from the Sun» to the border of the flight zone. However, when heading for the Sun, in order to reduce the time spent in an unfavorable orientation, it is advisable to maintain the highest horizontal speed without gaining altitude, to the point of reversal.

The actual power values of the power plant PS-11 «CROCUS» in the morning, given the angular height of the Sun about 40°, will be 300…400 W, depending on the direction of movement.

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