The parameter's optimization of the meteorological rocket's correcting engine to reduce the zone of the used blocks' falling

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Abstract. On the example of the meteorological rocket MMR-06, the optimum parameters of the trajectory correction engine to reduce the zone of the used blocks' falling was selected. It is shown that the optimum mass and optimal maneuvering time are achieved for engines with the medium-thrust. Low-thrust engines, despite the minimum weight, provide a long maneuver time and because of their large number, the total mass increases. The large-thrust engines are very heavy and capable of causing dangerous lateral overloads.

1 Introduction

The Meteorological rockets are widely used for meteorological and geophysical researches. They have the greatest value in the study of the upper layers of the atmosphere, inaccessible for ordinary balloon atmospheric sounding [7]. The effectiveness of the flight task of a meteorological rocket is determined by the time of its presence on the altitude range [5, 8]. And in this case, the issues of public safety come into conflict with the flight task [2].

Meteorological rockets, as a rule, are triggered on a ballistic trajectory with large initial angles of pitch (about 85-90°), and are not corrected in flight. In this case, even when reached the upper layers of the stratosphere, the size of the exclusion zone, into which the blocks or fragments of the rocket can fall, do not exceed a dozen kilometers. However, in the study of certain high-altitude echelons this is not always justified. Thus, the optimal program for researching the upper layers of the stratosphere, in order to reach the desired level and stay there for a maximum time, the rocket must to have an angle of pitch of about 5-10° at the entrance to the lower boundary of the echelon. For such parameters, the range of the rocket, and hence the size of the exclusion zone, should be about 200 km and above. But the launch of meteorological rockets is usually the most necessary for a densely populated European part of Russia and therefore the size of the exclusion belt for the possible dropping of rocket's blocks and parts is very limited [2].

The trajectory correction engines may to be one of the ways to overcome this crisis. In this case, it is possible to launch the rocket with pitch angles of 85-90°, and when entering the required altitude level, it can to be corrected to 5-10° (Fig. 1).

The task of this research was based on optimization of parameters of the trajectory correction engine for an

uncontrolled meteorological rocket to reduce the size of the exclusion zone.

Fig. 1. The trajectories of the meteorological rockets (h – height, x – range): 1 – traditional rocket (range x_1); 2 – rocket for investigation of a certain altitude level (range x_2); 3 – rocket with a trajectory's correction (range x_3); 4 – examined altitude level. Note: x is a maximum range of a missile's fragments fall.

2 Research methodology

The methods of optimization theory were used in this work. There was a virtual design of the engine for the correction of the trajectory of the MMP-06 meteorological rocket with variation of initial parameters and determination of the mass and ballistic parameters [4]. The objective function was the condition of minimum mass for a given maneuvering time (changing the pitch angle from 85° to 10°).

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3 Virtual engine design

The main dimensions of the engine are shown in Fig. 2. Usually unguided rockets are stabilized on the trajectory by rotation. The rotation period of the rocket determined the operation time of the engine (size $d_1 - d_2$). If the operating time exceeds a quarter of a revolution, there were unwanted lateral impulses. Therefore, each engine starts to work when there was 45° before the shooting plane and ends when it is turned more the 45° after the shooting plane. The outer diameter of the solid propellant charge (d_1) and its length were determined from the condition of the arrangement. Thus, two variable parameters that determined the thrust and appearance of the engine were obtained: the pressure in the combustion chamber, which affects the diameter of the critical section of the nozzle (d_{kp}) and the initial combustion surface, which affects the dimensions of the solid propellant charge (and the length L_3).

Since the effect of the appearance of the correction engine on the mass-dimensional characteristics is not unambiguous, the virtual design of the engines was carried out with a variation of the chamber pressure and the surface of combustion area.

Fig. 2. Calculation scheme of the correcting engine.

4 Determination of the required number of the engines

Since the impulse from one engine was too small for the complete correction of the trajectory, it was necessary to determine the number of pulses equal to the number of engines.

The engine starts its operation at the time t_0 , when the heeling angle is $\varphi = -45^\circ$ before the shooting plane. The time to enter to the nominal parameters is comparatively small to the operation time of the engine, therefore the cyclogram of the thrust P can be considered rectangular, since the turn-off time is also too small, the engine stops operating at the time t_k , when the heeling angle is $\varphi = 45^\circ$. However, for the correction pulse, the thrust it is not important, but the projection of thrust on the plane of firing is more important (Fig. 3):

$$P_b = P \sin \varphi. \quad (1)$$

To determine the required number of pulses (and the engines), there was produced the numerically integrated of the equation of rotation of the rocket relative to its center of mass:

$$\frac{d^2\theta}{dt^2} = \frac{1}{\mathfrak{I}}(P_b \ell_\tau - R \ell_a), \quad (2)$$

where θ – is the pitch angle; $\mathfrak{I}$ – is the moment of inertia of the rocket relative to its center of mass; ℓ_τ – the thrust arm of the correcting engine (the distance between the point of application of thrust and the center of mass); R – aerodynamic lifting force; ℓ_a – the arm of the lifting force (the distance between the center of mass and the center of pressure).

The cyclogram of correcting force for one variant of the engine's design is shown in Fig. 4. Since the correcting engines are uniformly distributed around the perimeter of the shell, one engine is being run after the next, which is at this moment in the most suitable position, and it is switched on. At the altitude where the trajectory is corrected, the density of air is too small, and the value of the lifting force is not large [1], [3]. Therefore, it can perform the task of stabilizing the missile, and it is necessary first to give pulses to increase the angular velocity, and then to reduce, so that at the end of the cycle of work the angular velocity is zero (Fig. 5). In this case, the law of pitching is obtained as it is shown in Fig. 6 [6].

Fig. 3. Working cyclogram of the one correction engine.

Fig. 4. The dependence of the thrust P_b (H) on the time t (c) of one of the engine variants.

Fig. 5. Dependence of the angular velocity $d\theta/dt$ (rad/s) on the time t (c) of one of the engine variants.

Fig. 6. Dependence of the pitch angle θ (rad) on the time t (c) of one of the engine variants.

5 Solving the problem of optimizing the appearance of the engine

Most clearly, the calculations results are presented in the form of a three-dimensional surface. In Fig. 7 the surface of the engine mass from the variable parameters p and S is shown. It can be seen that the chamber pressure has

relatively little effect on the mass. On the other hand, the effect of the combustion area S is not unique. The quantity of the large-thrust engines is not much, but they are heavy themselves, which is displayed on the plane of Fig. 7 as a sharp increase in mass for large areas. On the other hand, the low-thrust engines are light, but a great number of these engines is necessary for correction, which also leads to an increase in the total mass in the region of small burning surfaces S . And thus, medium-thrust engines in the "failure" of the surface in the region $S = 3.847 \text{ cm}^2$.

Fig. 8 shows the correction time surface t from the variable parameters p and S . In the topside view, this surface is shown in Fig. 9. It can be divided into two critical areas. Region I is the region of low-thrust engines. At a certain maximum value of t , the system passes into a critical state, when the momentum is insufficient to overcome the aerodynamic moment. Area II is the area of powerful engines. At some minimum critical value of t , dangerous lateral accelerations start acting on the rocket, which can lead to destruction. The isoline of the optimal turn times is between them. In this case it was taken equal to 1 second. As a result, the optimal geometry of the engine is obtained in the lower part of the plane, at the intersection of the lines 1 s and 3.847 cm^2 .

Fig. 7. Mass of correction engine m from the chamber pressure p and the burning area S .

Fig. 8. Time of trajectory correction t from the chamber pressure p and combustion area S .

Fig. 9. Time of trajectory correction t as isolines.

5 Conclusions

On the example of the MMR-06 meteorological missile, the optimal parameters of the trajectory correction engine were chosen to reduce the size of the falling zone of the used blocks. It is shown that the optimum mass and optimal maneuvering time are achieved for medium-thrust engines. Low-thrust engines, despite the minimum weight, provide a long maneuver time and because of their large number, the total mass increases. The engines of large traction themselves are heavy and capable of causing dangerous lateral overloads.

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