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MODIFICATIONS OF CONTROL ACTUATION SYSTEMS OF ATGM

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Abstract: *The paper presents the modifications of missile control actuation systems. The control actuation system was modified by adding a swiveling nozzle of the rocket engine. In that way, a hybrid control system consisting of aerodynamic rudders and gasodynamic rudders (i.e. change of the direction of the rocket engine thrust). The control effectiveness with the use of aerodynamic rudders alone was compared with ATGM control effectiveness with the use of the hybrid control actuation system. The results of the research are shown in a graphical form.*

Keywords: Anti-tank guided missile, Engine thrust vectorization, Control actuation systems, Homing.

1. Introduction

An anti-tank guided missile (ATGM) should consist of components cooperating well with each other and be characterized with great maneuverability which guarantees hitting the target effectively. The control actuation system, whose task is to respond to control signals effectively and quickly, is responsible for the maneuverability of the anti-tank guided missile. These signals are transmitted from the autopilot as a result of the homing algorithm, as e.g. in the article (Grzyb, 2016; Stefański et al., 2014 and Koruba, 2013). The autopilot is the brain of the whole missile. It is responsible for a rapid processing of information about the missile and target position in space. The scanning and tracking seeker (Gapinski, 2014a; Gapinski, 2014b; Koruba, 2010 and Koruba, 2013) is one of the main components transferring the data to the autopilot. It provides information about the angular position of the line of sight.

In urban areas and areas with a different topography, a missile capable of omitting the obstacles is required. Therefore, the control actuation system of the anti-tank guided missile needs to be facilitated and its maneuverability needs to be increased. A hybrid control actuation system consisting of aerodynamic rudders and a swiveling nozzle of the rocket engine was applied. Popular aerodynamic rudders are ineffective at the stage of starting and accelerating. Their effectiveness increases with the increase of the flight velocity (the control force is proportional to the square of the flight velocity). In the case of anti-tank guided missiles, the cruise velocity of which does not exceed 250 m/sec., providing the control with the thrust vector of the rocket engine can improve the maneuverability of the anti-tank guided missile. Thus, the anti-tank guided missile will be controlled effectively from the start, when the missile is at the stage of increasing its velocity. A booster engine of much greater thrust than during the stage of a marching flight operates in this phase. A marching flight is performed at a constant velocity, with the aerodynamic rudders and the swiveling engine nozzle cooperating well and stabile with each other. The essence of this paper is to check, whether the maneuverability of the anti-tank guided missile will be improved if a hybrid executive system is applied.

2. The object of control

A mid-range anti-tank guided missile, type: fire & forget, is the object of control (Fig. 1). The missile is stabilized along longitudinal axis $S\xi$ and does not perform any rotations on it. It is controlled by two

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channels: separately for the channel controlling the height, and separately for the channel controlling the flight direction. The aim of the dual control actuation system is to minimize the control angles and maximize the reproduction of the set flight trajectory. It is assumed that the missile moves in dense air streams.

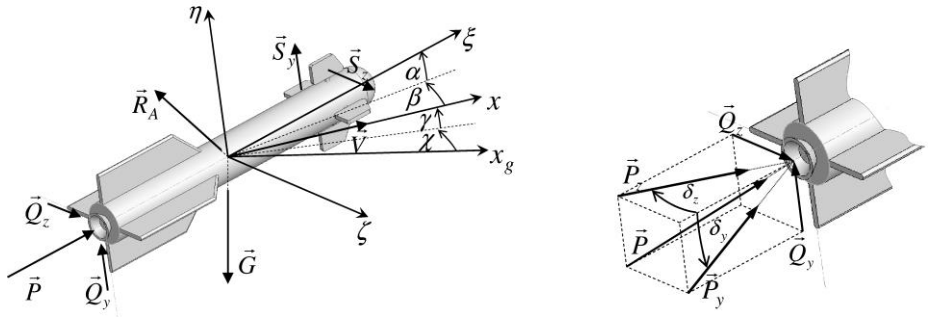

Fig. 1: The system of forces affecting the anti-tank guided missile with the accepted system of axes. The pattern of arising the control forces out of deviations of the nozzle of the rocket engine.

In Fig. 1 the following quantities and marking were introduced: $\vec{R}_A$ – vector of net aerodynamic forces; $\vec{P}$ – missile engine thrust; $\vec{G}$ – gravity; $\vec{Q}_Y$, $\vec{Q}_Z$, $\vec{S}_Y$, $\vec{S}_Z$ – controlling forces; $\vec{V}$ – missile velocity vector; $Sx_g y_g z_g$ - ground-fixed system; $Sxyz$ - system of coordinates connected with the flow; $S\xi\eta\zeta$ - system of coordinates connected with the missile (body-fixed system); $\alpha = \vartheta - \gamma$ - missile angle-of-attack; $\beta = \psi - \chi$ - missile sideslip angle; γ, χ - flight-path angles; δ_z - horizontal control angle of nozzle, δ_y - vertical control angle of nozzle.

The equations of dynamics (1a – 2c) of the missile flight are consistent with the accepted coordinate systems and the forces affecting the missile (Fig. 1) (Koruba, 2016 and Harris, 2009).

$$m\dot{V} = P\cos\alpha\cos\beta - G\sin\gamma - m\lambda_X V^2 \tag{1a}$$

$$mV\dot{\gamma} = P\sin\alpha - G\cos\gamma + m\lambda_Y \alpha V^2 + Q_Y + S_Y \tag{1b}$$

$$mV\dot{\chi}\cos\gamma = P\cos\alpha\sin\beta - m\lambda_Z \beta V^2 - Q_Z - S_Z \tag{1c}$$

$$\omega_\xi = \dot{\psi}\sin\vartheta, \quad \omega_\eta = \dot{\psi}\cos\vartheta, \quad \omega_\zeta = \dot{\vartheta} \tag{2a}$$

$$\dot{\omega}_\eta + \left(\frac{J_{ok}}{J_k} - 1\right)\omega_\xi \omega_\zeta = -D_1 \frac{\beta}{L} V^2 - D_2 V\dot{\beta} - D_3 V\dot{\psi} - e\frac{Q_Z}{J_k} + f\frac{S_Z}{J_k} \tag{2b}$$

$$\dot{\omega}_\zeta - \left(\frac{J_{ok}}{J_k} - 1\right)\omega_\xi \omega_\eta = -D_1 \frac{\alpha}{L} V^2 - D_2 V\dot{\alpha} - D_3 V\dot{\vartheta} - e\frac{Q_Y}{J_k} + f\frac{S_Y}{J_k} \tag{2c}$$

where: m – mass of the missile; λ_X, λ_Y, λ_Z – coefficients of aerodynamic forces; $D_i = (C_i L) / J_k$; C_1, C_2, C_3 – coefficients of aerodynamic moments (constans values were adopted); J_{ok}, J_k – main central moments of inertia of the missile in relation to vertical and horizontal axes of the missile; L – length of the missile; e, f – the distance of the missile centre of mass from the controlling force; ϑ i ψ – pitch and yaw angle of the missile body.

Deviations of the thrust vector of the rocket engine from the longitudinal missile result from the control forces in both surfaces (Fig. 1). In the vertical plane the force controlling the height of the flight is arising $\vec{Q}_Y$, and in the horizontal plane - the force controlling the direction of the flight $\vec{Q}_Z$ (Nocoń, 2016).

$$Q_Y = \sqrt{\frac{P^2\cos^2\delta_z \cdot \sin^2\delta_y}{1 - \sin^2\delta_z \cdot \sin^2\delta_y}} \approx P\cdot\delta_y, \; Q_Z = \sqrt{\frac{P^2\cos^2\delta_y \cdot \sin^2\delta_z}{1 - \sin^2\delta_z \cdot \sin^2\delta_y}} \approx P\cdot\delta_z \tag{3}$$

The aerodynamic rudders are located in the front part of the missile. A lightweight layered composite construction of the rudders (Chatys, 2013) guarantees a quick reaction to the control signals. For low angles of deviation of the aerodynamic rudders α_Y, α_Z it is true that lift and lateral (controlling) forces S_Y, S_Z which were formed on the rudder surface, take a simplified form of the equation:

$$S_Y = 2\alpha_Y S\rho \frac{V^2}{2}, \; S_Z = 2\alpha_Z S\rho \frac{V^2}{2} \tag{4}$$

where: S - surface of the rudders; ρ - air density.

The signals controlling the missile are calculated with the use of an implemented control algorithm developed in the articles (Koruba, 2016). A dual PID controller is applied. It was assumed that the control angles for both executive systems are the same but have opposite signs: $\delta_y = -\alpha_Y, \delta_z = -\alpha_Z$.

$$\alpha_Y = k_{y1}e_y + k_{y2}\frac{de_y}{dt} + k_{y3}\int_{t_0}^{t_k} e_y \, dt + h_{y1} f_y + h_{y2}\frac{df_y}{dt} + h_{y3}\int_{t_0}^{t_k} f_y \, dt \tag{5a}$$

$$\alpha_Z = k_{z1}e_z + k_{z2}\frac{de_z}{dt} + k_{z3}\int_{t_0}^{t_k} e_z \, dt + h_{z1} f_z + h_{z2}\frac{df_z}{dt} + h_{z3}\int_{t_0}^{t_k} f_z \, dt \tag{5b}$$

where: $e_y = \gamma^\circ - \gamma$; $e_z = \chi^\circ - \chi$; $f_y = y - y_p$; $f_z = z - z_p$; γ, χ, y_p, z_p – real coordinates of the ATGM; $\gamma^\circ, \chi^\circ, y, z$ – coordinates of the planned trajectory result of the homing algorithm.

3. The simulation results

The following figures present the results of the numerical simulation of the anti-tank guided missile passing through two points $P_1(100; 4; 0)$ and $P_2(300; 2; -8)$. The target starts from point $P_C(500; 1; 0)$ and moves at a velocity of 30 m/sec., and deviates by $\chi_C = 30\,^\circ$ in the horizontal plane. The simulation presents the results obtained for the hybrid control actuation system as well as for the single system consisting only of aerodynamic rudders.

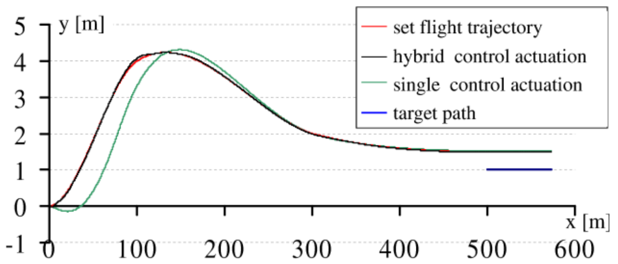

Fig. 2: The realized and set flight trajectory in the vertical plane detailing the hybrid and single control.

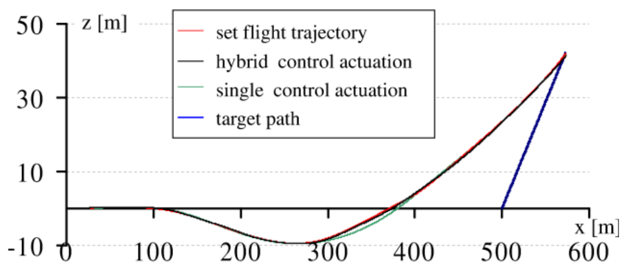

Fig. 3: The realized and set flight trajectory in the horizontal plane detailing the hybrid and single control.

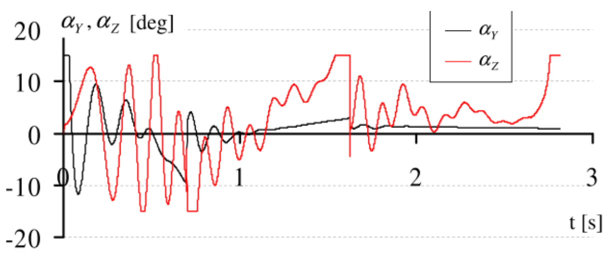

Fig. 4: The realized angles of the flight control in the channel of height and direction for the hybrid executive system.

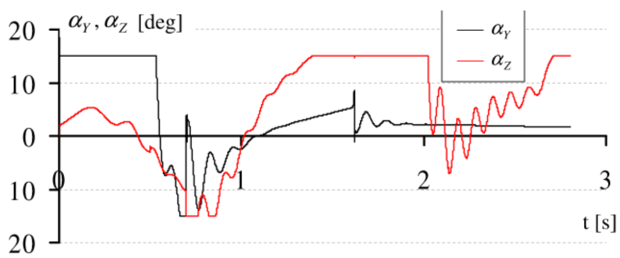

Fig. 5: The realized angles of the flight control in the channel of height and direction for the single executive system.

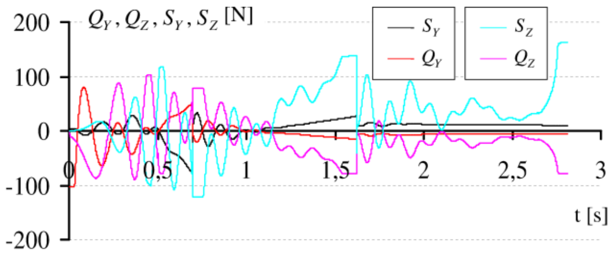

Fig. 6: The realized control forces of the anti-tank guided missile with the hybrid executive system.

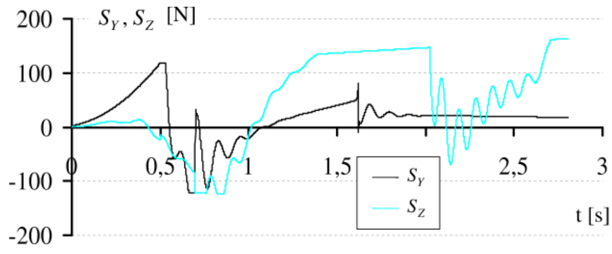

Fig. 7: The realized control forces of the anti-tank guided missile with the aerodynamic rudders alone.

4. Conclusions

Taking the above presented comparison of two control actuation systems into consideration, it might be concluded that a hybrid executive system consisting of aerodynamic rudders and a swiveling nozzle of the rocket engine performs the set trajectory in a better way that s single executive system consisting only of aerodynamic rudders. A hybrid control is effective right from the start of the anti-tank guided missile when its velocity is low (Fig. 2). The effectiveness of control only with the aerodynamic rudders is greater with the velocity increase of the anti-tank guided missile and thus, the first 0.5 sec. of control are ineffective. Control only with the aerodynamic rudders is effective after during the first 0.5 sec. Adding vectorization of the rocket engine thrust improves the maneuverability of the anti-tank guided missile significantly. Instead of two controlling forces – there are four. Two forces control the height, whereas the remaining two control the direction of the flight (Fig. 6). The rocket engine thrust is responsible for controlling the flight at its initial stage, even though the deviation angles of the rudders and the rocket engine nozzle are equal. Additionally, for the period of the booster operation, the deviation angles of the nozzle are limited to 10 % of the deviation possibilities.

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