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TURBULENCE IMPACT ON THE CONTROL OF GUIDED BOMB UNIT

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Abstract: *The study presents the method for the control of the guided bomb unit operating in turbulent atmosphere. The proportional navigation method was used to guide the bomb onto a ground target. The investigations included the analysis of the effect of atmospheric disturbances on target hitting accuracy and flight trajectory profile, and also of the values of generated control forces. Numerical simulations were conducted using Matlab software. The results of some investigations are presented in a graphic form***.**

Keywords: Dynamics, Homing, Bomb, Control, Athmospheric turbulence.

1. Introduction

The guidance of target homing flying object of the guided bomb unit type occurs in the Earth's atmosphere in which different atmospheric phenomena are observed. They include turbulence, wind sheer and wind gusts. Atmospheric disturbances that are random in character cannot be easily predicted, and the effect they produce may lead to the combat mission failure. Atmospheric phenomena can be described only in the approximate manner. In a flight, the flying object is subjected to different disturbances, including those originating from the medium in which the object moves. The task of the guided bomb unit is to perform the flight according to the implemented control algorithm developed in the automatic pilot (Baranowski et al., 2016 and Dziopa et al., 2015). The autopilot on the basis of data from scanning and seeking head (Gapiński et al., 2015) forces the deflections of aerodynamic control surfaces, on which control forces are generated. That control surfaces, as well as wings, to reduce mass, may be made of light composite materials (Paramonov et al., 2012).

The guidance method is intended to minimise the deviation of the current flight variables from the assigned ones, i.e. to compensate atmospheric disturbances in the best way.

2. The turbulence model

Although atmospheric phenomena cannot be predicted in advance and occur suddenly, it is possible to model them in such a manner so that models closely represent natural phenomena. The mathematical description of the turbulence phenomenon was based on the theory of stochastic processes. Dryden model of turbulence was applied (Moorhouse, 1982). The values of power spectral density in the coordinate system related to the bomb can be presented as follows:

$$\Phi_{u_g}(\omega) = \frac{2\sigma_u{}^2 L_u}{\pi V_{bu}} \frac{1}{1+\left(L_u \dfrac{\omega}{V_{bu}}\right)^2}, \qquad \Phi_{v_g}(\omega) = \frac{\sigma_v{}^2 L_v}{\pi V_{bu}} \frac{1+3\left(L_v \dfrac{\omega}{V_{bu}}\right)^2}{\left[1+\left(L_v \dfrac{\omega}{V_{bu}}\right)^2\right]^2},, \qquad \omega = V_{bu}\Omega \tag{1}$$

where: Ω – spatial frequency; V_{bu} – velocity in steady flight of the bomb ; $L_{u,v}$ – turbulence scale lengths; σ – turbulence intensities.

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Model each component of turbulence so that it would have zero mean value and white noise distribution. As a result, a random output signal with a specified power spectral density was produced. The dependence between power spectral density of the input signal obtained from the linear filter and power spectral density of the output can be written as follows:

$$\Phi_{u_g,v_g}(\omega) = \left|G(s)\right|^2_{s=j\omega} \Phi_F(\omega) \tag{2}$$

For white noise having Gaussian distribution $\Phi_F(\omega)=1$, turbulence signals were generated that take the following form:

$$G_{u_g}(s) = \sigma_u \frac{\sqrt{\frac{2}{\pi}\tau_1}}{s+\tau_1}, \qquad \tau_1 = \frac{V_{bu}}{L_u}, \qquad G_{v_g}(s) = \sigma_v \sqrt{\frac{3}{\pi}\tau_2}\,\frac{s+\frac{\sqrt{3}}{3}\tau_2}{(s+\tau_2)^2}, \qquad \tau_2 = \frac{V_{bu}}{L_v} \tag{3}$$

3. Bomb equations of motion

Figure 1 shows the set of coordinate systems for which flight equations for the hypothetical guided bomb unit were derived. An exemplary bomb assault on a ground moving target is shown in Fig. 2. The following notations were adopted (Koruba, 2016): α, β – attack angle and sideslip angle [rad]; ψ, ϑ, φ – pitch angle, yaw angle and roll angle of the bomb [rad]; γ, χ – flight-path angle in vertical plane and horizontal plane – pitch angle and yaw angle of bomb velocity vector [rad], $S\xi\eta\zeta$ – coordinate system for the bomb; $Sxyz$ – velocity coordinate system; $Sx'_g y'_g z'_g$ – coordinate system with the bomb as an origin, parallel with the starting system; $\vec{V}_b$ – bomb velocity vector; $\vec{V}_t$ – target velocity vector.

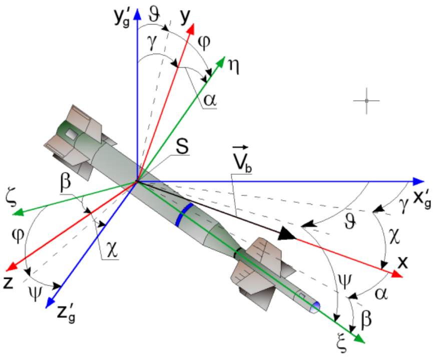

Fig. 1: Coordinate system with angles of rotation.

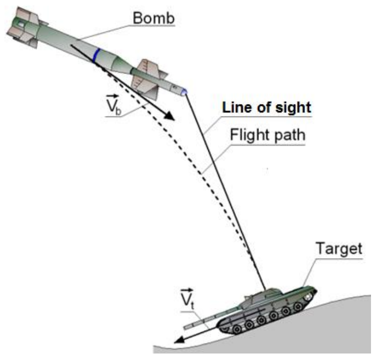

Fig. 2: Example of bomb attack on target.

In the study, it was assumed that the bomb is a rigid body that does not rotate around its longitudinal axis. The flight dynamics equations for the guided bomb unit are as follows (Grzyb, 2011 and Krzysztofik, 2014):

$$\dot{V}_b = -g\sin\gamma - \lambda_x V^2, \qquad \dot{\gamma} = \frac{1}{V}\left(\frac{Q_y}{m} - g\cos\gamma\right) + \lambda_y V\alpha, \qquad V = V_b - U_g \tag{4a}$$

$$\ddot{\vartheta} = V\left(-D_1\frac{V}{l_b}\alpha - D_2\dot{\alpha} - D_3\dot{\vartheta}\right) + \frac{Q_y e}{J_k}, \quad \lambda_x = \frac{c_x S_x \rho}{2m}, \quad \lambda_y = \frac{c_y S_y \rho}{2m}, \quad D_{1,2,3} = \frac{C_i l_b}{J_k} \tag{4b}$$

where: l_b – length of the bomb body [m]; ρ – air density [kg/m^3]; S_x – cross-sectional area of the bomb; S_y – lifting area [m^2]; m – mass of the bomb [kg]; J_k – moments of inertia of the bomb in relation to its transverse axis [kg.m^2]; Q_y – bomb flight control force [N]; e – distance between control force and aerodynamic pressure centre [m]; g – acceleration of gravity [m/s^2]; $\lambda_x, \lambda_y, D_{1,2,3}$ – relative aerodynamic coefficients of aerodynamic forces and moments [1/m] (Koruba, 1999 and Koruba, 2010); c_x, c_y – coefficients of aerodynamic forces; C_i – coefficients of moments of aerodynamic forces; U_g – velocity of turbulence [m/s].

4. Digital simulation results

Numerical simulations were conducted for the hypothetical guided bomb unit in backward hemisphere attack on a ground target. The following numerical values were used: starting bomb position: $x_{b0} = 0$ m, $y_{b0} = 5000$ m; starting target position: $x_{t0} = 4000$ m, $y_{t0} = 0$ m; angle of a bomb launch: $\gamma_0 = 0$ rad; starting angle of pitch of a target velocity vector: $\gamma_{t0} = 0.1$ rad; starting bomb velocity: $V_{b0} = 250$ m/s; target velocity: $V_c =$ const $= 20$ m/s; $l_b = 1.5$ m; $m = 100$ kg; $J_k = 18.75$ kg.m^2; $\lambda_x = 0.00044$ 1/m; $\lambda_y = 0.0067$ 1/m; $D_1 = 0.0551$ 1/m, $D_2 = 0.121$ 1/m, $D_3 = 0.061$ 1/m; t – time. The flight path of the target was described as follows: $\gamma_t(t) = \gamma_{t0} - 0.05 \cdot t$.

For the bomb guidance to the target, a proportional navigation algorithm was used, whereas the control forces were determined using a classic PID controller (Takosoglu et al, 2016b). Graphical representation of the results is shown in Figs. 3 – 8.

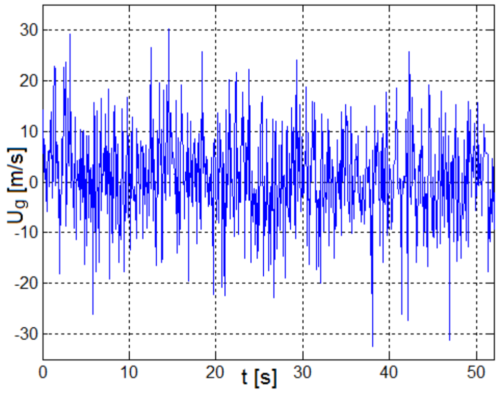

Fig. 3: Velocity of turbulences.

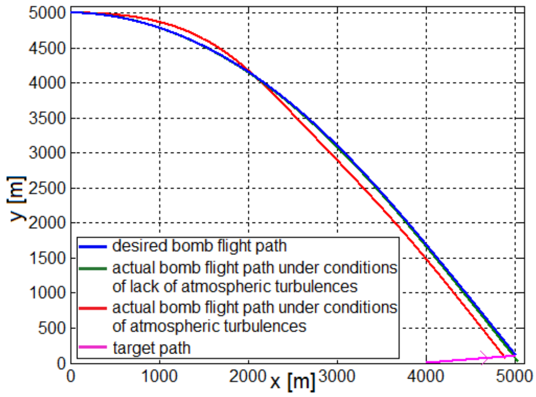

Fig. 4: The bomb flight path and target motion path.

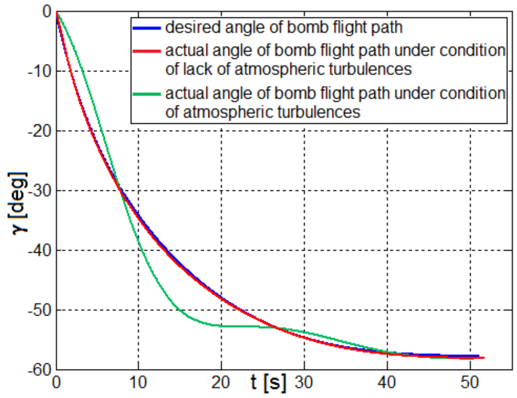

Fig. 5: Desired and actual angles of bomb flight path.

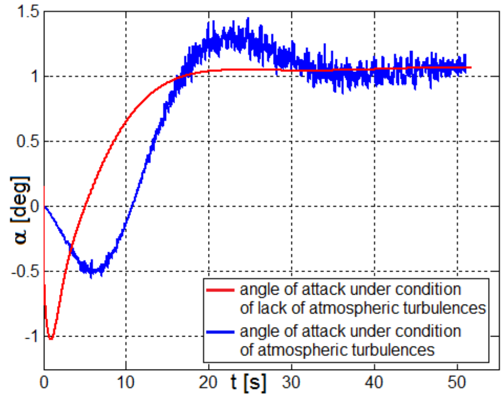

Fig. 6: The angle of attack realized during the bomb flight.

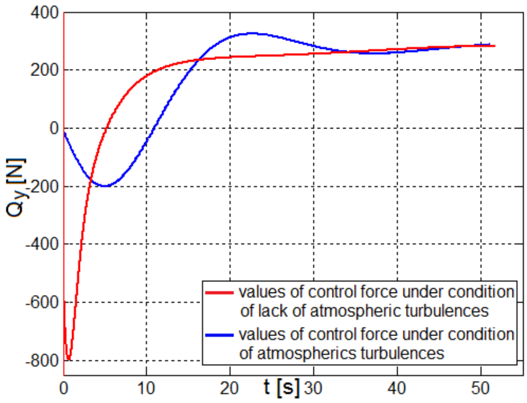

Fig. 7: Values of control forces required for homing the bomb on the target.

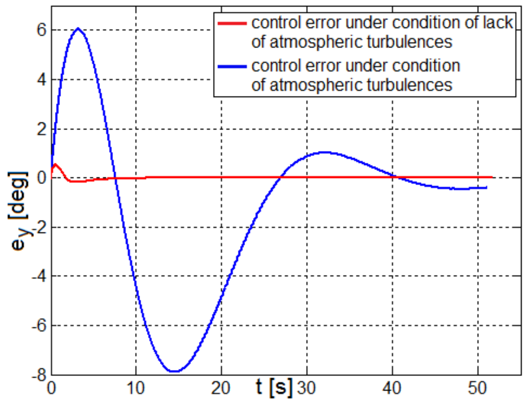

Fig. 8: Values of control errors.

5. Conclusions

The effect of atmospheric disturbances on the flight was analysed in many studies for flying objects of various types, including: a plane (Lungu et al. 2016), unmanned aerial vehicle (Jafar et al., 2016) and guided bomb (Kowaleczko, 2009).

This study focused on the modelling of random atmospheric phenomena, namely vertical turbulence and on the analysis of the effect produced by this phenomenon on the flight profile of the guided bomb unit. For that purpose, the spectral representation of turbulence, i.e. the Dryden model was employed. At the model input white noise was used. It was assumed that the level of turbulence intensity is the same regardless of the altitude of the guided bomb unit flight. Based on the investigations conducted for the study, it can be stated that atmospheric disturbances distort all the parameters of the guided bomb unit flight (Figs. 3 – 8). The control method proposed in the study allows delivering the bomb onto a ground target with the accuracy of 5 metres. The control force that is generated to compensate random disturbances takes on real values. In spite of the turbulence occurring throughout the guided bomb unit flight, all flight parameters have acceptable values.

It is assumed that in further studies spatial model of turbulence will be employed. It will be accompanied by a system for the system for reducing the effects of random disturbances in which Kalman filter, among others, will be used.

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