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Possibilities and Contribution to the Automated 1A18 Device Modernization

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Abstract:

One subsystem of the Czech GBAD system 2K12 which is currently being modernized is the automated 1A18 device for missile aiming and positive target-in-zone indication. Its contemporary construction is according to the mid-20th century technology. The device is an analogue electro-mechanical computer which does not meet today's needs of reliability and operational demand factor. This paper concisely deals with a possibility of this device replacement by a more universal digital computing device. Here, the definition of tasks solved by starting device, its mathematical formulation, solution strategy and verification results through MATLAB simulation are stated.

Keywords:

1A18 device, SA-6, modernization

1. Introduction

1A18 device is an automated electro-mechanical analogue computer used for missile launch preparation tasks [1]. Namely, the target speed vector calculation, target-missile point of collision calculation, missile flight time to the point of collision calculation, aiming of missile carriage of launcher to the point of collision calculation, aiming of missile seeker to the target direction calculation and definition of distance between the point of collision and the maximum range of the weapon system.

As inputs for the 1A18 device serves variables that characterize the target position and movement according to weapon system, which means target bearing, target elevation and its derivation, variables that characterize mutual position and orientation of guidance and control radar with launcher, angles that specify actual shift of upper carriage in bearing and elevation.

Input variables have the form of changing DC voltage or angles of turning transformer rotors. Other inputs for the 1A18 device are variables that characterize

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current state of missiles, as well as launcher and signals defining device mode of operation.

The target position and movement data are transformed to the spherical system of coordinates connected with the launcher. According to kinematic equations of target movement defined within this system of coordinates and with respect to target constant altitude, target speed vector course angle is calculated. To perform this task, a specific feedback servo system is used. Calculated target speed vector direction is then transformed to parametric system of coordinates where the point of collision is calculated according to missile maximum range. Also the missile flight time to point of collision is calculated.

Actual target position and point of collision data are then used to the calculation of launcher missile carriage aiming variables, first to the target direction, then to the point of collision direction. Next, missile seeker aiming to the target direction is calculated. Last, signal of the target in range is indicated.

Development of modern digital technologies and vision of the launching device 2P25 modernization according to already realised 2K12 weapon system radar modernization gives possibilities to 1A18 device digitalization and modernization. It is possible now to use specialised computer composed from one board computer Compact PCI together with developed interface between CPU board and separate subsystems of the launcher (e.g. upper carriage servo drives, etc.).

2. Tasks Conducted by 1A18 Device

Basic tasks for modernized (digitalized) 1A18 device are the transformation of longitudinal target coordinates from the coordinate system of guidance and control radar SURN (see Fig. 1) to the coordinate system of launching pad, as well as the calculation of launcher upper carriage and missile seeker aiming angles.

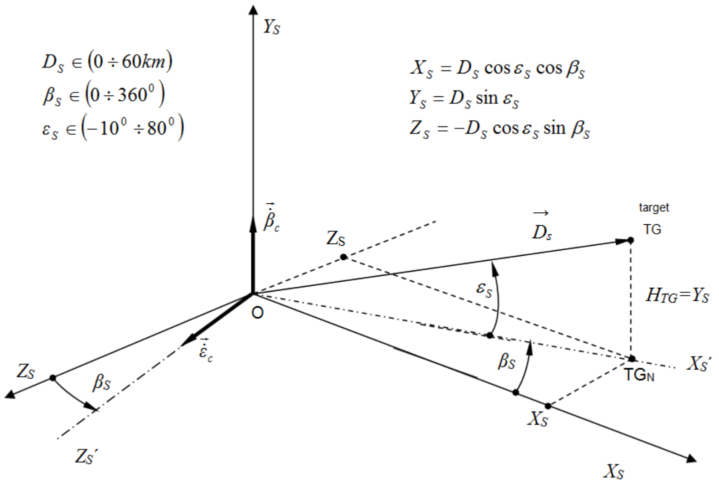


Fig. 1 Coordinate systems connected with SURN vehicle

Now, in accordance with better one-board computer capabilities, it is possible to solve not only the point of collision in accordance with missile maximum effective range, but also to model the whole missile effective area and efficiently solve the target-missile point of collision and receive other data (e.g. missile flight time to target, time in effective range) for effective fire control on incoming or retreating targets.

2.1. Target Coordinates Transformation

Transformation of longitudinal target coordinates from the SURN vehicle coordinate system to the coordinate system of launching pad is a standard operation which is conducted within two parts and with the application of known direction cosines.

In the first stage, it is necessary to turn X_S, Y_S, Z_S coordinate system of SURN CZ vehicle around Y_S axis to angle ψ_1 and to shift it in the SURN CZ – Launcher direction to range B (see Fig. 2). Then the new X_1, Y_1, Z_1 coordinates appear in the centre of the launcher. For this stage of transformation then applies:

$$X_1 = X_S \sin\varphi_1 - Z_S \cos\varphi_1 \tag{1}$$

$$Y_1 = Y_S \tag{2}$$

$$Z_1 = X_S \cos\varphi_1 + Z_S \sin\varphi_1 - B \tag{3}$$

At the same time, the transformation of target speed vector coordinates is conducted. This is done via SURN CZ computer from X_S, Y_S, Z_S coordinate system to X_1, Y_1, Z_1. Then the following equations apply:

$$V_{X1} = V_{SX} \sin\varphi_1 - V_{SZ} \cos\varphi_1 \tag{4}$$

$$V_{Y1} = V_{SY} \tag{5}$$

$$V_{Z1} = V_{SX} \cos\varphi_1 + V_{SZ} \sin\varphi_1 \tag{6}$$

In the second stage, first the turning of X_1, Y_1, Z_1 coordinate system around Y_1 axis to angle ψ_2 is conducted. The main point is to direct the X_T axis of new coordinate system to longitudinal plane of launcher vehicle symmetry (see Fig. 2). Then the turning around Z_1 axis to angle υ of longitudinal slope of the launcher is conducted, in addition to the turning around X_T axis to angle γ of cross slope of the launcher (see Fig. 3).

X_T axis is the launcher longitudinal axis; X_T and Z_T axes are in the plane of upper carriage rotation, Y_T axis is the axis of launcher upper carriage rotation. The following relationships are used for the transformation of X_1, Y_1, Z_1 coordinate system to X_T, Y_T, Z_T coordinate system:

$$X_T = X_1 \sin\varphi_2 \cos\upsilon + Y_1 \sin\upsilon + Z_1 \cos\varphi_2 \cos\upsilon \tag{7}$$

$$\begin{aligned} Y_T = &-X_1(\cos\varphi_2 \sin\gamma - \sin\varphi_2 \sin\upsilon \cos\gamma) + Y_1 \cos\upsilon \cos\gamma + \\ &+ Z_1(\sin\varphi_2 \sin\gamma - \cos\varphi_2 \sin\upsilon \cos\gamma) \end{aligned} \tag{8}$$

$$\begin{aligned} Z_T = &\ X_1(\sin\varphi_2 \sin\upsilon \sin\gamma - \cos\varphi_2 \cos\gamma) - Y_1 \cos\upsilon \sin\gamma + \\ &+ Z_1(\sin\varphi_2 \cos\gamma + \cos\varphi_2 \sin\upsilon \sin\gamma) \end{aligned} \tag{9}$$

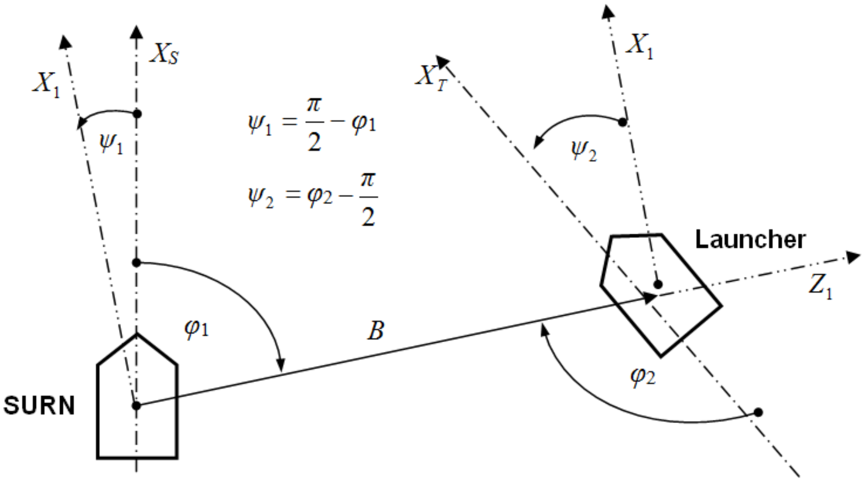


Fig. 2 SURN and Launcher mutual position

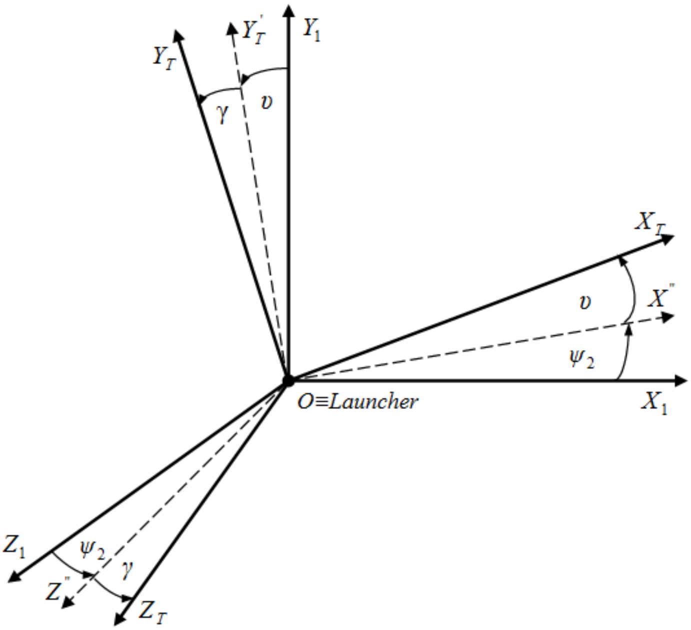


Fig. 3 Angles between X_1, Y_1, Z_1 and X_T Y_T Z_T coordinate systems of the launcher

According to Eqs (1) to (6) and (7) to (9), the transformation of target position is done from X_S, Y_S, Z_S of SURN vehicle to X_T, Y_T, Z_T coordinates of the launcher. Now, it is not difficult to determine angles β_T (bearing) and ε_T (elevation). These angles determine rotation of upper carriage to the target direction.

2.2. Missile Effective Range Area

For extended solution of firing tasks it is necessary to have mathematical model of missile effective area [2, 3]. Missile effective area is defined through elemental surfaces (plane, sphere surface, cylinder surface, cone surface) which generates its borders. Specific shape of missile effective range area is defined via type of weapon system, its characteristics and fire conditions.

Missile effective range area is defined in the rectangular parametric coordinate system with the origin at the launcher position and with axes *S, H, P* (see Fig. 4). Parametric coordinate system vertical plane *SH* is always parallel with the target speed vector ground projection to the horizontal plane.

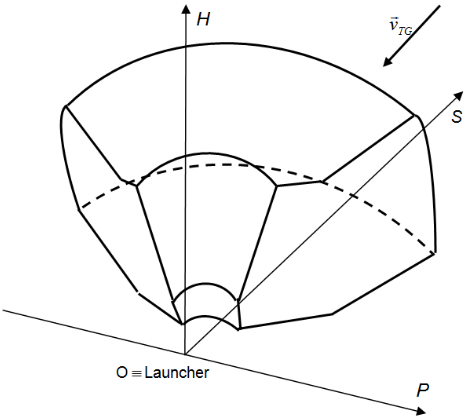


Fig. 4 Parametric coordinate system and missile effective area

To solve the problem of mutual position of the target and missile effective range area, it is necessary to continually transform the coordinates of actual target position from the coordinate system of the SURN vehicle (X_S, Y_S, Z_S) to the coordinate system *S, H, P* (see Fig. 5). This is done within two stages.

The first stage is the same as the first stage of the transformation to coordinate system X_1, Y_1, Z_1 (Eqs (1) to (3)).

Next, the rotation of coordinate system X_1, Y_1, Z_1 around Y_1 axis to angle α (see Fig. 5); axis *S* of new coordinate system *S, H, P* is now parallel with the ground projection of target speed vector to the horizontal plane. The following equations are used for this transformation:

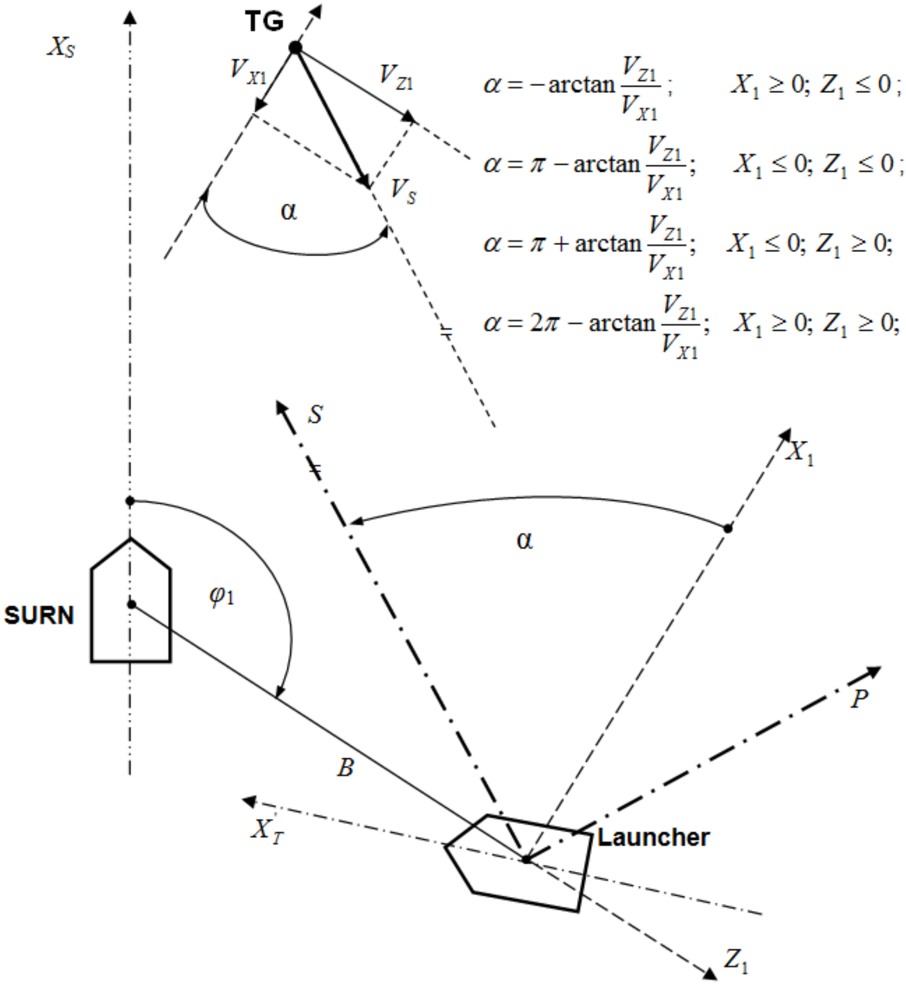
$$S = X_1 \cos\alpha - Z_1 \sin\alpha, \tag{10}$$

$$H = Y_1, \tag{11}$$

$$P = X_1 \sin\alpha + Z_1 \cos\alpha \tag{12}$$

3. Calculation of Point of Collision

To choose the proper method for the calculation of the point of collision, the stage of the whole guiding process is important. An optimal method is continuous simulation of missile to target guiding process after each target position update. This simulation is conducted under the premise that a target flies with a constant speed and heading. For the calculation are used kinematic equations of advance target movement in X_1, Y_1, Z_1 coordinate system.



$$\alpha = -\arctan\frac{V_{Z1}}{V_{X1}}; \qquad X_1 \geq 0;\ Z_1 \leq 0;$$

$$\alpha = \pi - \arctan\frac{V_{Z1}}{V_{X1}}; \qquad X_1 \leq 0;\ Z_1 \leq 0;$$

$$\alpha = \pi + \arctan\frac{V_{Z1}}{V_{X1}}; \qquad X_1 \leq 0;\ Z_1 \geq 0;$$

$$\alpha = 2\pi - \arctan\frac{V_{Z1}}{V_{X1}}; \qquad X_1 \geq 0;\ Z_1 \geq 0;$$

Fig. 5 Geometric relationships between coordinate systems

Kinematic equations of advance target motion in the X_1, Y_1, Z_1 coordinate system are:

$$\frac{\mathrm{d}X_1}{\mathrm{d}t} = V_{X1} \tag{13}$$

$$\frac{\mathrm{d}Y_1}{\mathrm{d}t} = V_{Y1} \tag{14}$$

$$\frac{\mathrm{d}Z_1}{\mathrm{d}t} = V_{Z1} \tag{15}$$

where V_{X1}, V_{Y1}, V_{Z1} are orthogonal parts of target speed vector in the X_1, Y_1, Z_1 coordinate system defined in Eqs (4) to (6).

Through integration of (13) to (15) with the initial conditions defined by actual target position, we gain coordinates X_{1N}, Y_{1N}, Z_{1N} of predicted target position on its simulated trajectory according to launcher. Predicted coordinates X_{1N}, Y_{1N}, Z_{1N} of tracked target have to be transformed according to (7) to (9) to the coordinate system X_T, Y_T, Z_T as well as length D_T target radius vector:

$$D_T = \sqrt{X_T^2 + Y_T^2 + Z_T^2} \tag{16}$$

Missile motion is then expressed as kinematic equation for radius vector length that means the distance from the coordinate system origin X_T Y_T Z_T:

$$\dot{D}_{TR} = V_R(t) \tag{17}$$

where $V_R(t)$ is defined as the progression of missile speed in time or its median.

The integration of all kinematic equations (13) to (17) will end in the moment $t = t_N$ where the lengths of radius vectors of the target and missile are equal, that means when $D_T = D_{TR} = D_{TN}$. Quantity t_N is then the time of missile flight to the point of collision. Coordinates X_{TN}, Y_{TN}, Z_{TN} of terminal point of simulated target trajectory are also the coordinates of predicted missile-target point of collision. These coordinates will be used to the calculation of launcher upper carriage rotation angle to the point of collision.

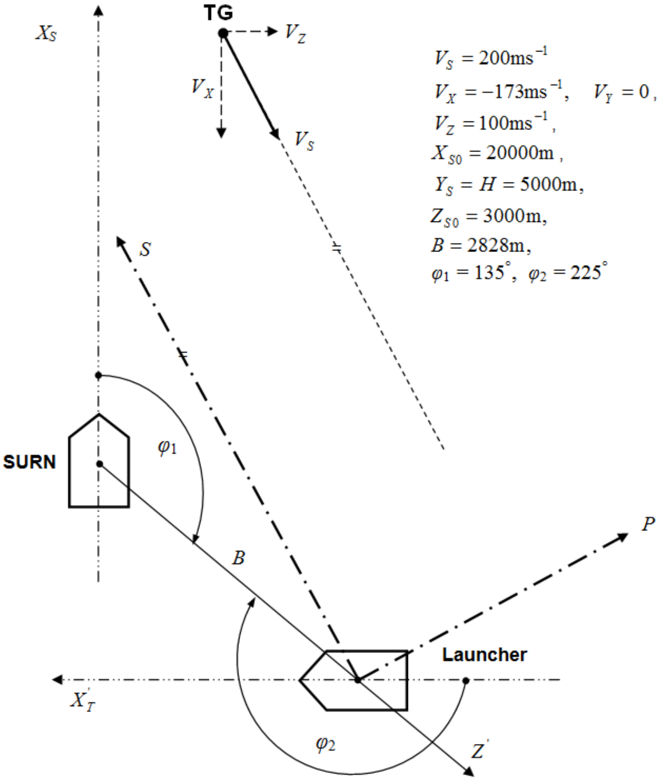


Fig. 6 Situational layout for algorithm functionality verification

The coordinates of predicted missile-target point of collision transformed to the coordinate system S, H, P will be used for the decision of entry point or presence of target in the missile effective range area. In this case, the following conditions are valid [3]:

$$-P_{\mathrm{mez}} \le P_N \le +P_{\mathrm{mez}} \tag{18}$$

$$-P_0 \ge P_N \ge P_0 \tag{19}$$

$$H_{\min} \le H_N \le H_{\max} \tag{20}$$

$$S_b \le S_N \le S_d \tag{21}$$

where

S_N, H_N, P_N are the coordinates of predicted point of collision in the parametric coordinate system,

P_{mez} is a maximum bearing parameter of missile effective range area,

P_0 is a border parameter of missile effective range area,

H_{min}, H_{max} are minimal and maximal altitudes of missile effective range area,

S_{b}, S_{d} are distances of inner and outer missile effective range area.

4. Conclusion

In case of high-performance processor in modernized 1A18 device, it is possible to simulate (in real time) the target flight through the missile effective range area via several alternatives. Besides standard straight target flight, it is also possible to simulate the flight of manoeuvring target and to prepare the unit for shooting according to current attack characteristics.

All described operations that the 1A18 device conducts were formulated into the algorithms and their functionality was verified in MATLAB environment (see Figs 7 to 10).

Digitalisation of the 1A18 device helps to improve decision-making process and surface to air missiles shooting at manoeuvring targets.

References

[1] *Technical documentation of 1A18 device*. Praha: Ministry of Defence, 2010.

[2] ŽÍŽEK, J. *Theory of SAM shooting, part II* [textbook] (In Czech). Brno: Military Academy, 1993. 227 p.

[3] FARLÍK, J. *Missile effective range area modelling in accordance with target characteristics* [Diploma thesis] (In Czech). Brno: Military Academy in Brno, 2000. 56 p.

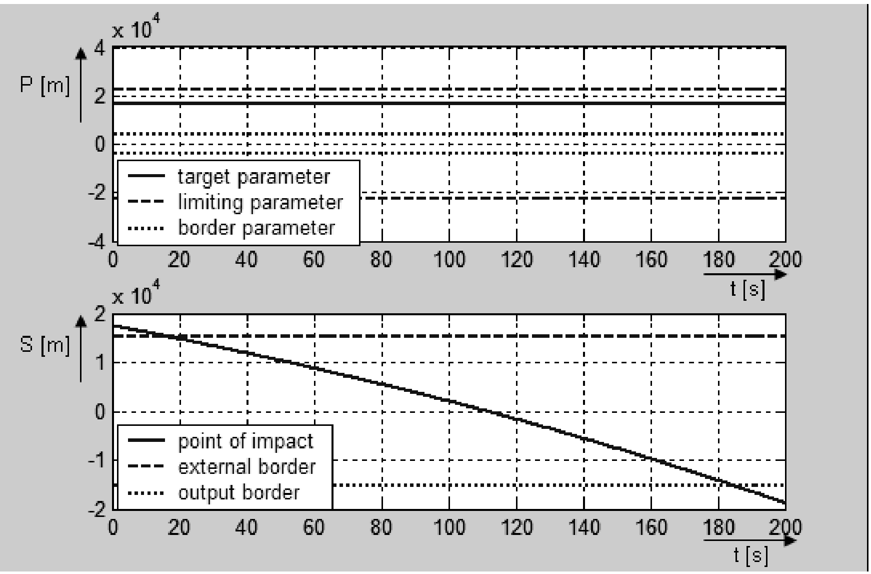


Fig. 7 Non-manoeuvring target – point of collision position in the missile effective range area

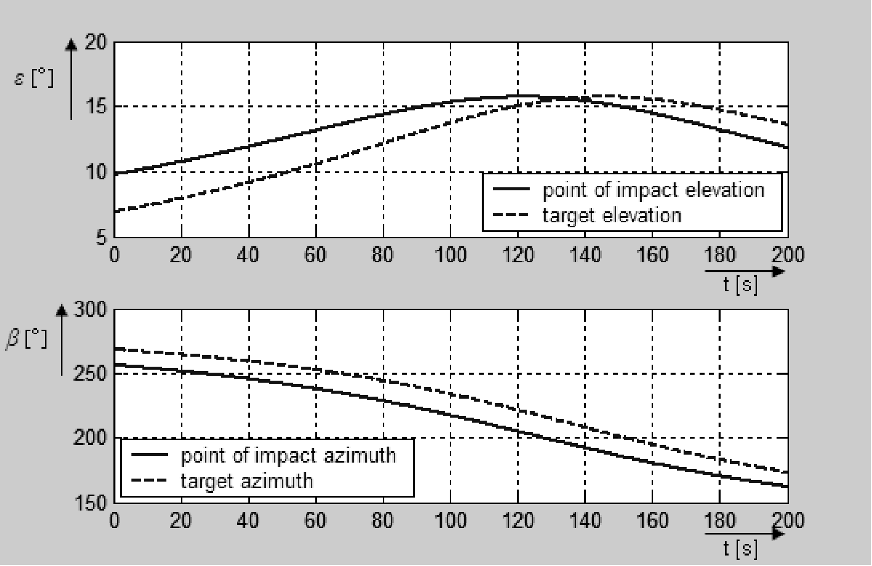


Fig. 8 Non-manoeuvring target – launcher upper carriage rotation angles

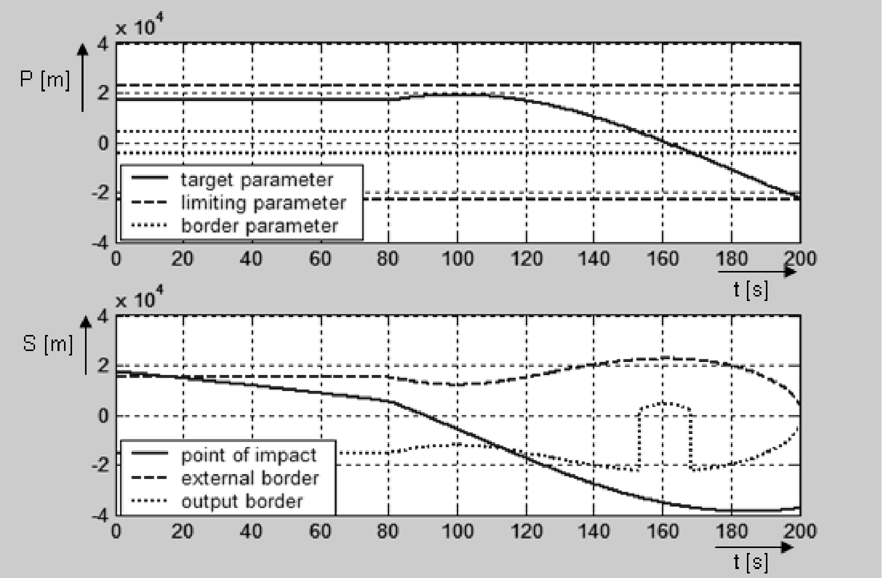


Fig. 9: Manoeuvring target – point of collision position in the missile effective range area

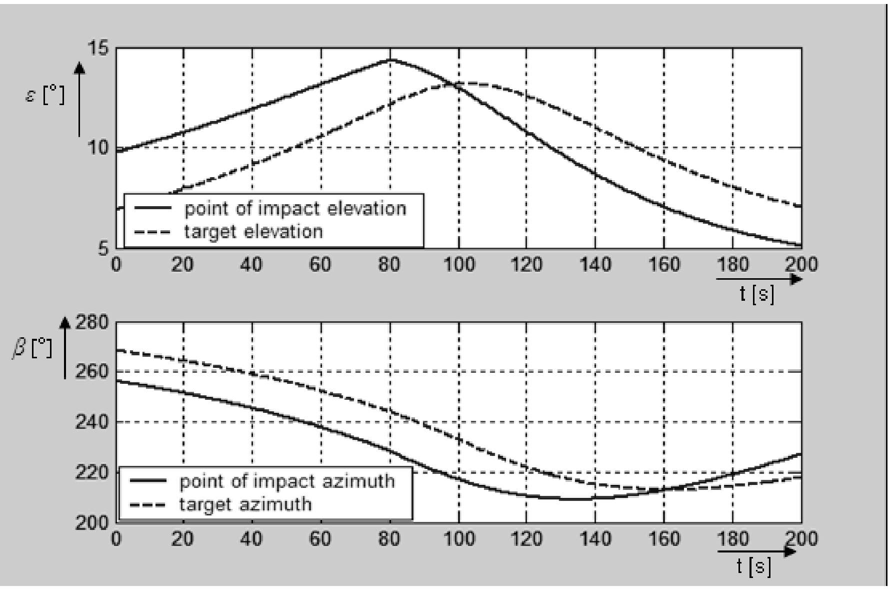


Fig. 10: Manoeuvring target – launcher upper carriage rotation angles