Computer Application to Simulate the Flight of a GROM Type Anti-Aircraft Guided Missile

Krzysztof MOTYL[*1,] Karol GĄSIOR[2]

[1]*Military University of Technology, Faculty of Mechatronics and Aerospace,
2 Sylwestra Kaliskiego Str., 00-908 Warsaw, Poland
[2]3rd Warsaw Air Defence Missile Brigade
45 Kaźmierów Str., 96-500 Sochaczew, Poland
[*]Corresponding author's e-mail address and ORCID*:
krzysztof.motyl@wat.edu.pl; https://orcid.org/0000-0001-7399-8455

Abstract. The paper presents the features of the computer application developed in the RAD Studio XE4-10.1 Berlin programming environment for the simulation of guided flight of the GROM type missile. The application uses an integrated algorithm to solve a system of differential equations, as well as a dynamics model for the missile, target and atmosphere. Further to this, simulation tests have also been conducted.
Keywords: computer simulation, guided rocket missile, MANPADS

1. INTRODUCTION

Infrared-guided portable anti-aircraft missiles have been introduced as an individual weapon of infantry soldiers to combat low-flying means of air attack from both the front and rear hemispheres.

The GROM Man-Portable Air Defence System (MPADS) is a VSHORAD platform which has been manufactured by the Polish defence industry since the year 1998. By mastering the manufacturing technologies of this armament type, Poland has become one of the world's very few producers of VSHORADs. The GROM MPADS is intended for engagement of low-altitude aircraft (air planes and helicopters) in the presence of natural and artificial thermal interference and on interception or pursuit trajectories within an identified striking zone [3, 4, 5, 7, 8]. The GROM MPADS performance ranks among similar air defence systems from leading global manufacturers.

The paper presents the features of a computer application software developed in the RAD Studio XE4-10.1 Berlin programming environment for the simulation of guided flight of the GROM type missile. The application uses an integrated algorithm to solve a system of differential equations, as well a dynamics model for the missile, target and atmosphere. Further to this, simulation tests have also been conducted.

2. PHYSICAL MODEL OF THE GROM ROCKET MISSILE

The physical model of the GROM rocket missile includes the following characteristics: geometric & mass-inertia, aerodynamic, propulsion system and motion centre [1, 2].

2.1. Geometric characteristics of the GROM rocket missile

The concept of geometric characteristics is understood to mean the physical quantities defining the external shape of the projectile. The geometric characteristics shown in Fig. 1 and Table 1 included the length, outer diameter, control fin span, destabiliser span, and stabiliser span of the rocket missile. The accuracy of the geometric parameters affected the accuracy of the numerical model.
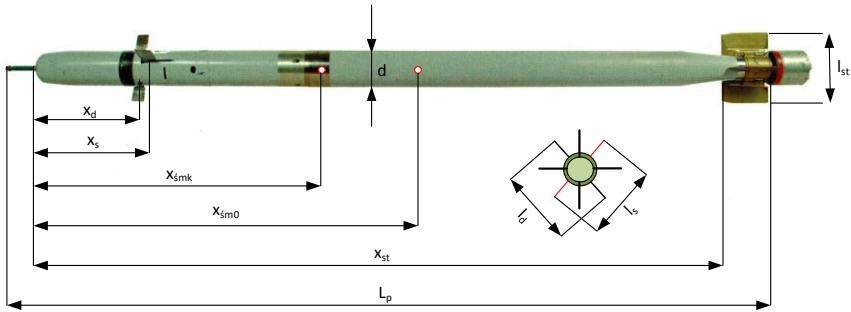
Fig. 1. Geometric characteristics of the GROM MPADS missile [4]

Table 1. Geometric characteristics of the GROM MPADS missile [4]

Parameter	Designation	Value
Rocket missile length	L_p	1.5960 m
Rocket missile O.D.	d	0.072 m
Destabiliser attack edge coordinate	x_d	0.271 m
Control fin attack edge coordinate	x_s	0.295 m
Stabiliser attack edge coordinate	x_{st}	1.409 m
Destabiliser span	l_d	0.142 m
Control fin span	l_s	0.166 m
Stabiliser span	l_{st}	0.145 m

2.2. Mass-inertia characteristics of the GROM missile

Due to the fuel charge burn during the flight of the GROM MPADS rocket missile, its overall weight, moments of inertia and mass centre location change by approximately 50% each. Table 2 shows the mass and inertia parameters of the GROM MPADS rocket missile.

The atmosphere model covering the troposphere up to a height of 11 km was implemented in accordance with the AS-81 Standard Atmosphere according to the GOST-4401-81 standard. The coordinate systems applied complies with GOST 2058-80. The flight dynamics model has been simplified to a model with three degrees of freedom, without the influence of missile rotation around its own axes. A central gravity field model has been adopted because of the missile range not exceeding 10 km.

Table 2. Mass and inertia characteristics of the GROM MPADS rocket missile [4]

Parameter	Designation	Value
Rocket missile initial weight	m_0	10.25 kg
Rocket missile weight after fuel depletion	m_k	5.75 kg
Rocket missile initial mass centre location	$x_{śmo}$	0.750 m
Rocket missile mass centre location after fuel depletion	$x_{śmk}$	0.574 m
Stabiliser attack edge coordinate	x_{st}	1.409 m
Rocket missile initial moment of inertia relative to transverse axis z	I_{z0}	1.6736 kgm^2
Rocket missile moment of inertia relative to transverse axis z after fuel depletion	I_{zk}	1.0212 kgm^2

The characteristics of the propulsion system depending on the temperature of the rocket fuel, which have a significant impact on its speed and range, have been adopted for the physical model of the missile. The aerodynamic characteristics of the missile adopted in the model were reduced to the frontal resistance coefficient as a function of Mach number, at zero angle of attack. The kinematic link of the control system presents mathematical relations describing the movement of the target in relation to the guided missile [12]. It is an element which, although physically absent from the system, is necessary to compile a mathematical model of the missile's movement towards a potentially moving target.

3. MATHEMATICAL MODEL OF THE GROM MISSILE

The adopted guidance method is designed to bring the missile to the point of contact with the target with an error no bigger than the warhead blast radius. The choice of the guidance method is a particularly complex task, as it depends on the following factors: the manoeuvrability of the target and the missile, the ability to measure the parameters of target and missile movement, the impact of interference on the process of steering the rocket flight, the dynamic properties of the guidance circuit, and the warhead blast radius.

The kinematic guidance circuit used in the model does not take into account the dynamic phenomena and guidance errors occurring during the missile guidance process. The missile is treated as a point moving in space at a speed which is a known function of time, and the guidance circuit is treated as a non-inertial status-failure-free system.

The differential and algebraic equations (1÷19), recorded as per GOST 200058-80, are a mathematical model of short-range anti-aircraft missile flight according to the selected method of guidance towards a moving air target. The mathematical model of guided missile movement contains the following differential and algebraic equations [9, 10, 11]:

a) dynamic equation of the motion of the missile's progressive centre of mass

$$\frac{dV}{dt} = \frac{1}{m(t)} \cdot \left(F(t) - c_x \cdot \rho \cdot \frac{V^2}{2} \cdot S - m(t) \cdot g \cdot sin(\theta)\right) \tag{1}$$

b) kinematic equations of the motion of the missile's centre of mass

$$\frac{dx_p}{dt} = V \cdot \cos(\Theta) \cdot \cos(\Psi) \tag{2}$$

$$\frac{dy_p}{dt} = V \cdot \sin(\Theta) \tag{3}$$

$$\frac{dz_p}{dt} = -V \cdot \cos(\Theta) \cdot \sin(\Psi) \tag{4}$$

c) equations for target location

$$\frac{dV_c}{dt} = g \cdot [n_{xc} - \sin(\Theta_c)] \tag{5}$$

$$\frac{d\Theta_c}{dt} = \frac{g}{V_c} \cdot [n_{yc} - \cos(\Theta_c)] \tag{6}$$

$$\frac{d\Psi_c}{dt} = -\frac{g}{V_c} \cdot \frac{1}{\cos(\Theta_c)} \cdot n_{zc} \tag{7}$$

$$\frac{dx_c}{dt} = V_c \cdot \cos(\Theta_c) \cdot \cos(\Psi_c) \tag{8}$$

$$\frac{dy_c}{dt} = V_c \cdot \sin(\Theta_c) \tag{9}$$

$$\frac{dz_c}{dt} = -V_c \cdot \cos(\Theta_c) \cdot \sin(\Psi_c) \tag{10}$$

where:

t_{xc}, t_{yc}, t_{zc} – the times of the beginning of the target manoeuvre,

n_{xc}, n_{yc}, n_{zc} – components of the target overloads in a system related to its trajectory, successively: tangential, normal, and transverse overload.

d) kinematic equations of relative motion of the missile and target:

$$\frac{dr}{dt} = V_c \cdot \cos(\Theta_c) \cdot \cos(\Psi_c - \chi) \cdot \cos(\varphi) + V_c \cdot \sin(\Theta_c) \cdot \sin(\varphi) \\ - V \cdot \cos(\Theta) \cdot \cos(\Psi - \chi) \cdot \cos(\varphi) - V \cdot \sin(\Theta) \\ \cdot \sin(\varphi) \tag{11}$$

$$\frac{d\varphi}{dt} = \frac{1}{r} \cdot (-V_c \cdot \cos(\Theta_c) \cdot \cos(\Psi_c - \chi) \cdot \sin(\varphi) + V_c \cdot \sin(\Theta_c) \\ \cdot \cos(\varphi) + V \cdot \cos(\Theta) \cdot \cos(\Psi - \chi) \cdot \sin(\varphi) - V \\ \cdot \sin(\Theta) \cdot \cos(\varphi)) \tag{12}$$

$$\frac{d\chi}{dt} = \frac{1}{r \cdot \cos(\varphi)} \cdot (V_c \cdot \cos(\Theta_c) \cdot \sin(\Psi_c - \chi) \cdot \sin(\varphi) - V \cdot \cos(\Theta) \\ \cdot \sin(\Psi - \chi)) \tag{13}$$

e) steering right for proportional navigation method:

$$\frac{d\Theta}{dt} = a \cdot \frac{d\varphi}{dt} \tag{14}$$

$$\frac{d\Psi}{dt} = a \cdot \frac{d\chi}{dt} \tag{15}$$

f) in-flight missile overloads:

$$n_x = \frac{1}{g} \cdot \frac{dV}{dt} + \sin(\Theta) \tag{16}$$

$$n_y = \frac{V}{g} \cdot \frac{d\Theta}{dt} + \cos(\Theta) \tag{17}$$

$$n_z = -\frac{V}{g} \cdot \frac{d\Psi}{dt} \cdot cos(\Theta) \tag{18}$$

$$n_w = \sqrt{n_x^2 + n_y^2 + n_z^2} \tag{19}$$

These equations have been implemented in a computer application that allows advanced calculations for two-point guidance methods such as proportional navigation, chase and parallel approach.

Explanations:

g	gravity acceleration
$h = y_g$	missile flight height
ρ	density of the motion centre
c_x,	non-dimensional coefficients: frontal resistance, lateral force, lifting force
S	characteristic surface
F	rocket engine thrust
V	the velocity vector of the centre of mass relative to the undisturbed atmosphere
Θ, Ψ	yaw and pitch angles of the missile velocity vector
r	missile-to-target distance
φ, χ	yaw and pitch angles of the target's observation line
V_c	target velocity
Θ_c, Ψ_c	yaw and pitch angles of the target velocity vector
x_c, y_c, z_c	target location coordinates
x_g, y_g, z_g	rocket missile coordinates
n_x, n_y, n_z, n_w	overload components: tangential, normal, lateral and resultant

4. DESCRIPTION OF A COMPUTER PROGRAM SIMULATING THE FLIGHT OF A GUIDED VERY SHORT-RANGE ANTI-AIRCRAFT MISSILE

On the basis of the developed physical and mathematical model of the GROM type rocket missile, a simulation model was made in the form of a computer program implemented using the RAD Studio 10.1.1 Berlin programming environment.

The user operates the software via an interface that allows them to select the position of the target in three-dimensional space relative to the firing point, the target manoeuvre, the orientation of the launcher at the moment of firing, the missile possible overloads, the selection of the guidance method and the detonator activation distance.

The program enables visualisation of the simulation results in the form of tables and diagrams, and their export to a spreadsheet. It is possible to use software to simulate the flight directed at the manoeuvring target of any projectile under the condition that the files in the program folder containing the geometric, mass-inertia, and aerodynamic characteristics of the projectile are changed. The software is made up of three function blocks: model class, interface block, and "compDiagram" class.

Each of the blocks has its own functions: the interface block is responsible for data management and the input of the missile, target and firing point data into the model class. In the model class, the digital data necessary to simulate the missile guidance is generated from these data and missile characteristics loaded into the model class from separate files.

The "compDiagram" class functions similarly to that of diagram plotting components in popular calculation programs. This class was developed based on the basic components of the VCL library.

4.1. Description of the class representing the numerical model of the missile

The model class is an implementation of the missile's mathematical model. It consists of three classes: "Missile", "Environment" and "Numeric". In the "Missile" class, all information about the missile necessary to conduct a computer simulation is collected. It consists of "Propulsion System" and "Airframe" classes. The "Propulsion System" class refers to the characteristics of the starter and sustainer engine versus temperature. The "Airframe" class is composed of the "Aerodynamics" class, which comprises all aerodynamic characteristics, and the "Dynamics" class with the missile's mass and inertial characteristics.

The "Environment" class is responsible for the model of the atmosphere and gravitational field. The "Numeric" class includes a function to solve any system of differential equations. Using the functions and data available from the Environment and Missile classes, the "Numeric" class resolves a system of first order differential equations constituting a mathematical model for the type of missile under consideration.

4.2. Description of the missile flight simulation computer application

The application consists of the following forms built on the basis of the VCL library: formIntro, formMainWindow, formTarget, formMissile, formCreateDiagram, formNewDiagram, and formAuthor.

FormIntro is used to launch the program, which starts with a welcome screen with the logo of the Military University of Technology and a film showing GROM missiles. It is possible to skip the film by pressing the space bar.

FormMainWindow launches the main program window. The main menu of this form allows the user to display the other forms. The "Application" menu object is another menu containing two objects, the "Save" and "Finish" objects. Clicking the "Save" object displays Explorer's dialogue box and is used to select the location and name of the file to which the simulation data will be exported. The data is saved in "*.csv" format.

Saving in this format makes it possible to open the created file using a spreadsheet. The object becomes available after the first simulation. The view of the compiled form is shown in Fig. 2.
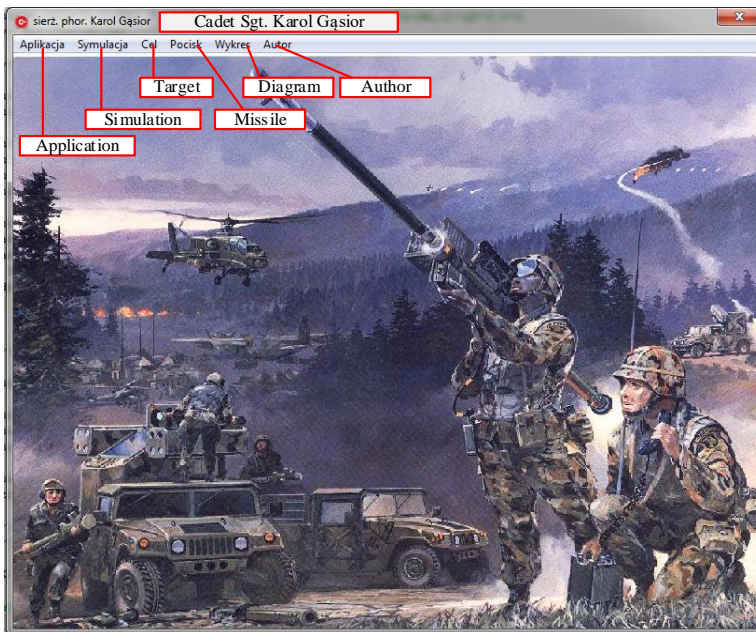

Fig. 2. View of the main window [12]

FormTarget is displayed after pressing the "Target" main menu object. It allows the user to set the parameters of the air target such as: location, velocity vector, target manoeuvre. The numerical values of each of these parameters can be set with the corresponding sliders. Each of the parameters is in a separate table.

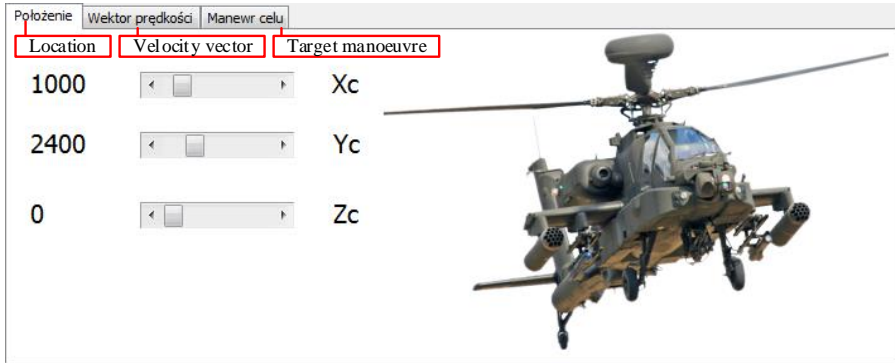The view of the "Target" window with the active Target's coordinate tab is shown in Fig. 3.

Fig. 3. View of the "Target" window [12]

FormMissile is used to set the input parameters of the guided missile, such as: elevation angle and pitch angle of the launcher, meteorological and weather conditions, available missile overloads, proportional navigation factor, and detonator trip distance. It also allows the user to view the engine thrust diagram for selected weather conditions. The view of the "Missile" window is shown in Fig. 4.
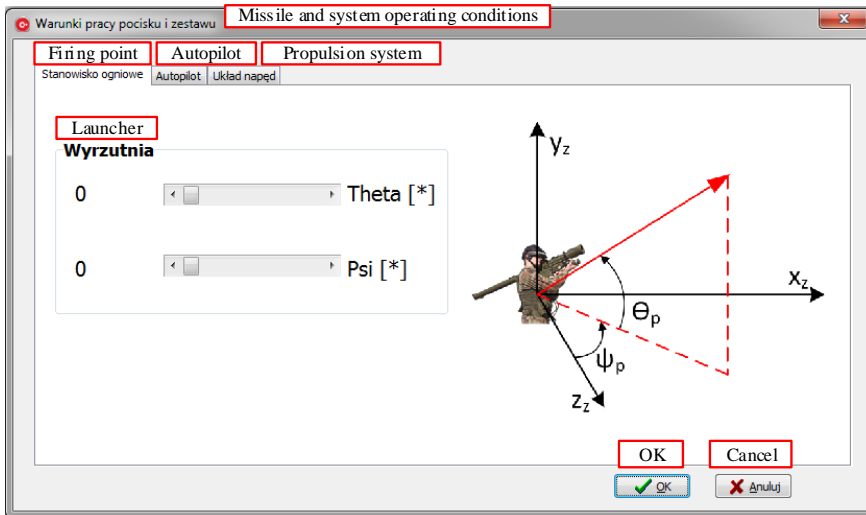
Fig. 4. "Missile" window with active "Firing point" tab [12]

FormCreateDiagram allows the user to select two data tables for the purpose of plotting a diagram. The following tables are available for selection: target or missile location, target and missile vector parameters, orientation of the missile in space, angular velocity of the missile in a boundary system, location of the target relative to the missile in a spherical system, missile overload and missile flight time. In addition, two buttons are available to open the missile trajectory diagram and cells in the XY and ZX planes. The diagrams are plotted using the "compDiagram" component, which is an object of the "formNewDiagram" form. The view of the "formCreateDiagram" window is shown in Fig. 5. The application allows you to create several windows with diagrams or even several diagrams from different simulations.

Pressing OK saves, the selected parameters, and pressing the Cancel button reverts to the previous ones. Pressing the Simulation object expands its menu, which contains the Start item for the simulation.
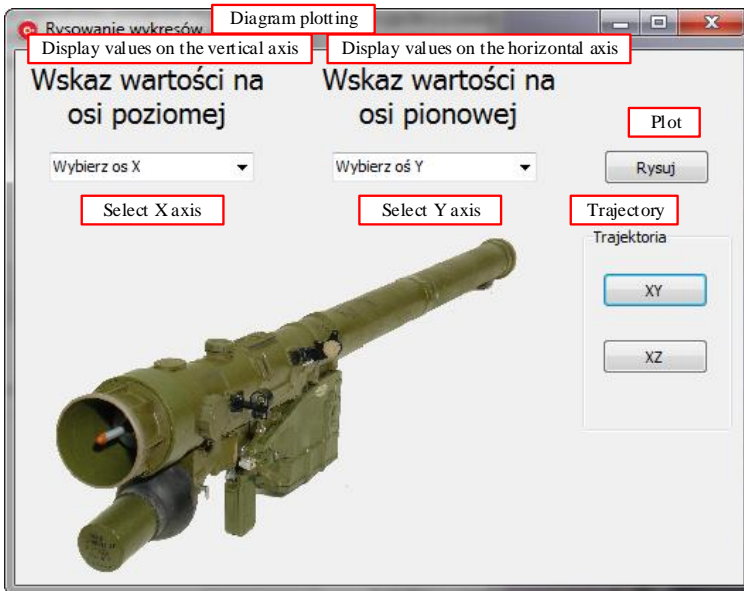

Fig. 5. View of the CreateDiagram window [12]

5. SAMPLE SIMULATION RESULTS

Sample results of the computer simulation presented in Fig. 6÷9 show: initial conditions for the simulation, change of thrust versus time, change of velocity versus time and kinematic tracks of the missile and the air target.
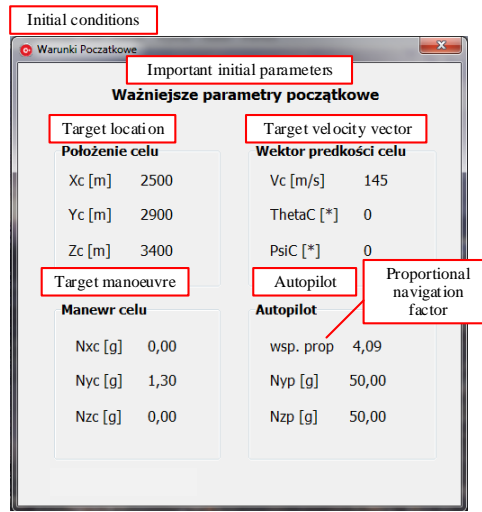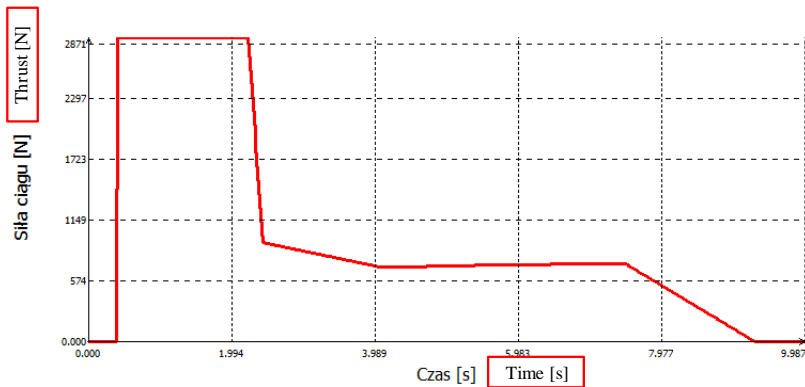
Fig. 6. Selected initial parameters [12]

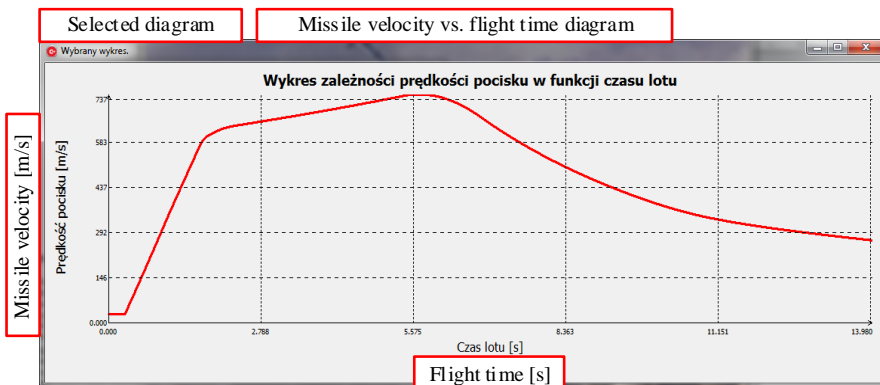Fig. 7. Thrust diagram versus temperature [12]

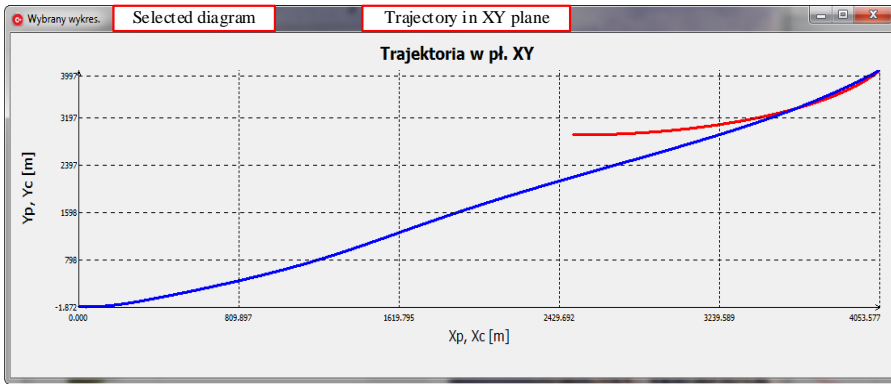Fig. 8. Diagram of missile velocity versus flight time [12]

Fig. 9. The missile and target trajectory diagram in the vertical plane [12]

6.   CONCLUSION

The main objective of the work was to develop a program to simulate the flight of the GROM very short range anti-aircraft missile. Developed in the RAD Studio XE4-10.1 Berlin programming environment, the program has implemented algorithms to solve systems of differential equations based on the trapezoid method. The graphical user interface is based on ready-made components from the VCL library, as well as on original components for drawing diagrams. This solution was adopted because the libraries included in the basic version of RAD Studio do not allow for direct plotting of diagrams.

The interface allows parameters to be entered defining the initial orientation of the launcher, the overloads of the autopilot, the coefficient of proportional navigation, the temperature of the rocket engine, the initial location and the movement parameters of the target. In terms of graphical representation of the data, the interface allows the user to display animations showing the trajectory of the flight in both the horizontal and vertical planes.

The program will plot a trajectory diagram in the vertical and horizontal planes and plot any combination of variables defining the target and projectile locations, the velocity vector of the target and the missile, missile location vs. target position, missile overloads, and missile flight time. The interface also allows the user to export simulation results as a spreadsheet file.

Further development of the software should take into account the missile model with six degrees of freedom, a module calculating the aerodynamic ratios, the single-channel steering system and its effects on the guidance process.

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Aplikacja komputerowa do symulacji lotu przeciwlotniczego pocisku kierowanego typu GROM

Krzysztof MOTYL[1,] Karol GĄSIOR[2]

[1]Wojskowa Akademia Techniczna,
Wydział Mechatroniki i Lotnictwa, Katedra Mechatroniki
ul. gen. Sylwestra Kaliskiego 2., 00-908 Warszawa,
[2]3 Warszawska Brygada Rakietowa Obrony Powietrznej
ul. Kaźmierów 45, 96-500 Sochaczew

Streszczenie: W publikacji przedstawiono możliwości opracowanej aplikacji komputerowej w środowisku programistycznym RAD Studio XE4-10.1 Berlin do symulacji lotu kierowanego pocisku rakietowego typu Grom. W aplikacji zaimplantowano algorytm do rozwiązywania układu równań różniczkowych, model dynamiki pocisku, celu i atmosfery oraz przeprowadzono badania symulacyjne.
Słowa kluczowe: symulacja komputerowa, kierowany pocisk rakietowy, MANPADS