



A Computer Software Application for the Design and Simulation of Unguided Rockets

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Abstract. The paper presents a specification and performance characteristics of a computer software application developed for rocket design engineering. The methodology for the determination of aerodynamic characteristics by the software application is based on the Chernabrovkin-Lebyadyev's experimental and theoretical method. The computer simulation results presented in the paper were generated for two types of 122-mm calibre rockets, M-21OF Grad and M-21FHE Feniks. The simulation results were verified with the results produced using other calculation methods.

Keywords: computer simulation, aerodynamic coefficients, rocket

1. INTRODUCTION

This paper focuses on the external ballistics and aerodynamics of rolling-symmetrical rockets. The definition of the laws of motion of rockets in near-Earth space and the determination of mass-inertial and aerodynamic characteristics of rockets are the essential problems to be solved in the design process of every rocket. Ballistic tunnel tests and live-fire experimental tests are time-consuming and require considerable financial resources. It is normal to do both types of testing in the final stages of a rocket design engineering cycle. The preliminary stages of rocket design engineering involve analytical methods based on commercial or proprietary computer software applications intended for preliminary design and determination of flight parameters of unguided rockets in simulated atmospheric conditions.

The paper presents a specification and performance characteristics of a computer software application developed in C++ and QtCreator graphic libraries for rocket design engineering. The methodology for the determination of aerodynamic characteristics by the software application is based on the Chernabrovkin-Lebyadyev's experimental and theoretical method [1, 2]. The computer simulation results presented in the paper were generated for two types of 122-mm calibre rockets, M-21OF Grad and M-21FHE Feniks. The simulation results were verified with the results produced using other calculation methods.

2. DESIGN AND PRINCIPAL ASSUMPTIONS OF THE COMPUTER SOFTWARE APPLICATION

The computing module of the computer software application was developed in C++ with Dev-C++ software suite. The graphical user interface was developed with QtCreator. According to its principal assumptions, the computer software application was to be capable of determining the aerodynamic characteristics of rockets and solving systems of differential equations which defined the flight of a single-stage unguided rocket. The computer software application was provided with a proprietarily developed GUI to aid in the design of rockets and the presentation of calculation results.

The operating principle and the general design of the computer software application are shown in Figure 1. The application includes three basic file sections: **Engine**, **Interface**, and **Plotting**. The **Engine** file section contained a set of source and header files written to enable the calculation of geometric and aerodynamic characteristics of rockets, the determination of flight parameters, and the modelling of the Earth's atmosphere. The **Plotting** file section drives the graphical presentation (plots) of simulation results.

The **Interface** file section handles the HMI interaction with the application user, acquisition of input data, display of diagrams and graphical content, and data writing and reading. The computer software application also uses **Pictures** and **Save** file sections which store the required graphic files and written data.

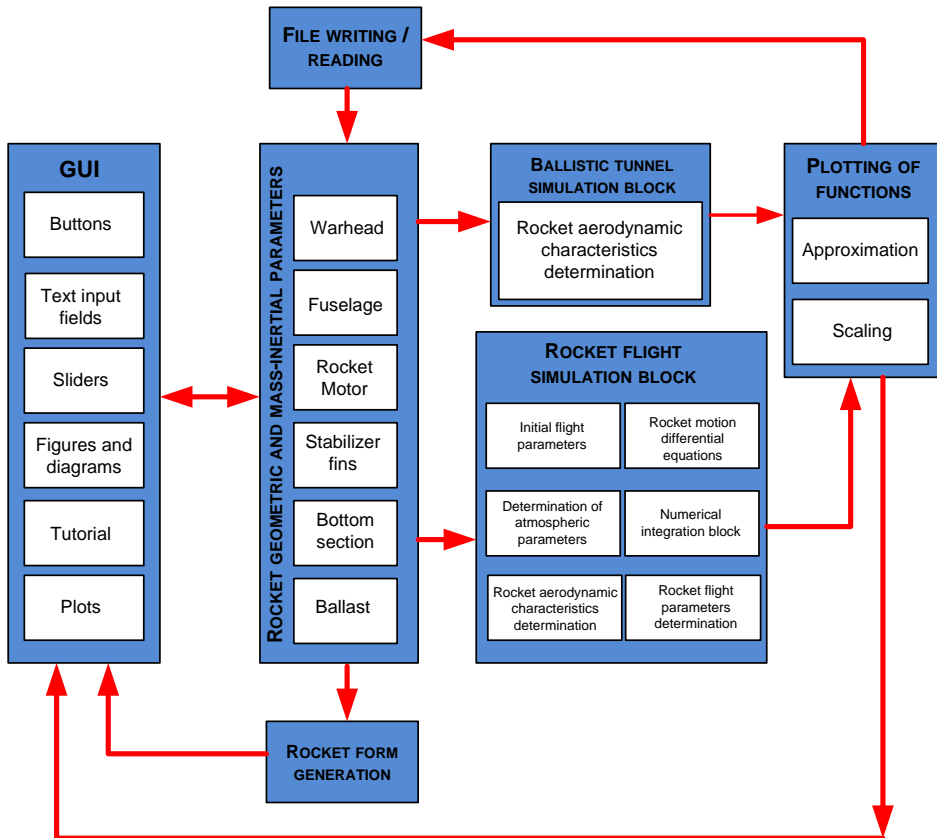


Fig. 1. Operating block diagram of the computer software application developed for rocket design and flight simulation [3]

3. GUI (GRAPHICAL USER INTERFACE)

The GUI of the computer software application was designed to facilitate the use of the application. The implemented text input fields, tables, sliders and a variety of buttons markedly reduce the time required to design a rocket in the application. The interactive graphic features, images, and hints made the use of the software application intuitive to individuals unfamiliar with the concepts of rocket engineering.

The graphical representation of the shape of a rocket in the design process helped verify the geometrical data inputs, including the COG (centre of gravity). The scalable plots of the relationships calculated in the software application provided a straightforward overview of the calculation results, facilitating analysis of specific ranges of the data. The GUI was divided into four main tabs with a menu bar and a data update bar (Fig. 2). The sequence of the main tabs (Design, Simulation, Ballistic Tunnel, and Tutorial) could be rearranged according to user preferences.

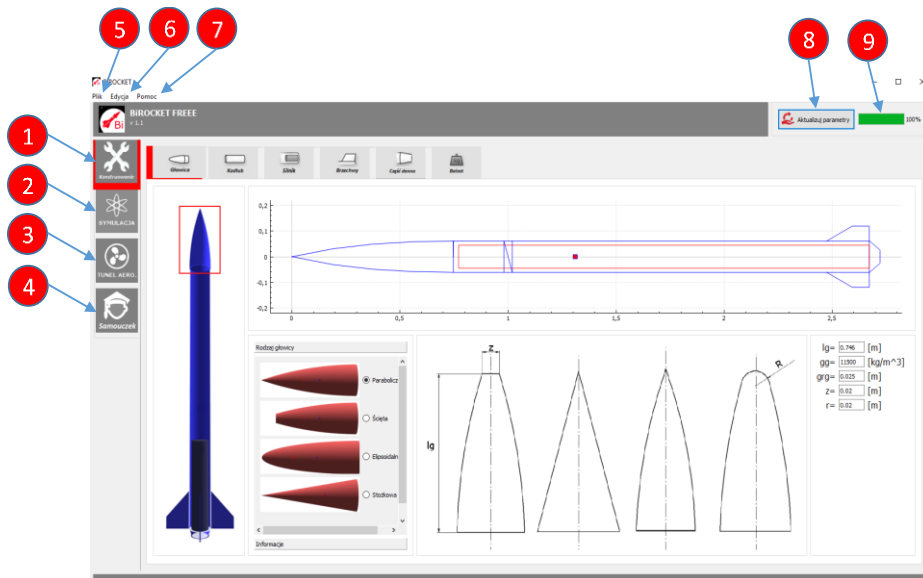


Fig. 2. GUI with its main components highlighted [3]

(1 – Design tab; 2 – Simulation tab; 3 – Ballistic Tunnel tab; 4 – Tutorial tab;
5, 6, 7 – Menu bar tabs; 8 – Update Data button; 9 – Data update progress bar)

Opening the Design tab displayed the rocket design interface with six sub-tabs (Fig. 3). The sub-tabs (Warhead, Fuselage, Motor, Stabilizer Fins, Bottom Section, and Ballast) enabled editing the geometric, mass-inertial, and auxiliary characteristics and parameters of respective main components of the rocket in design. The common features of all sub-tabs included the following: 1 – Graphical representation of the rocket form; 2 – Text input field pane; 3 – Edited component engineering drawings; 4 – Auxiliary information pane; 5 – Overview plan with the highlighted rocket components open in the editing mode (Fig. 4). Each sub-tab featured panes specific to the rocket component in the design editing mode (Fig. 5).

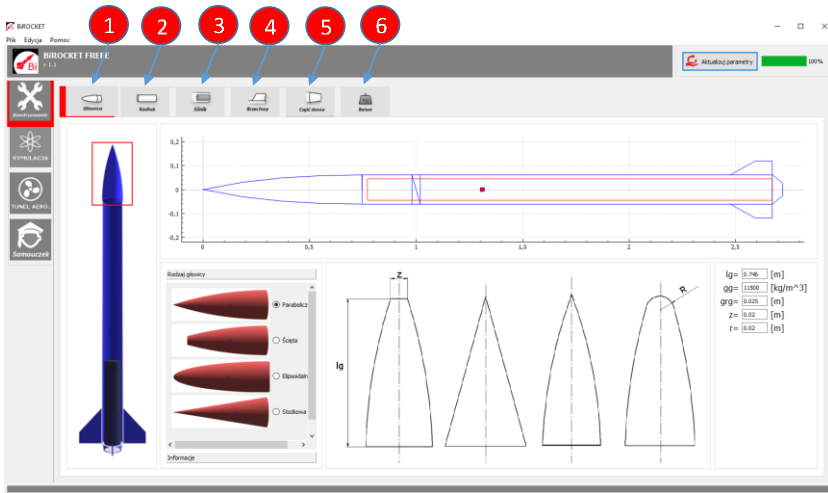


Fig. 3. Sub-tabs [3]

(1 – Warhead; 2 – Fuselage; 3 – Motor; 4 – Stabilizer Fins; 5 – Bottom Section; 6 – Ballast)

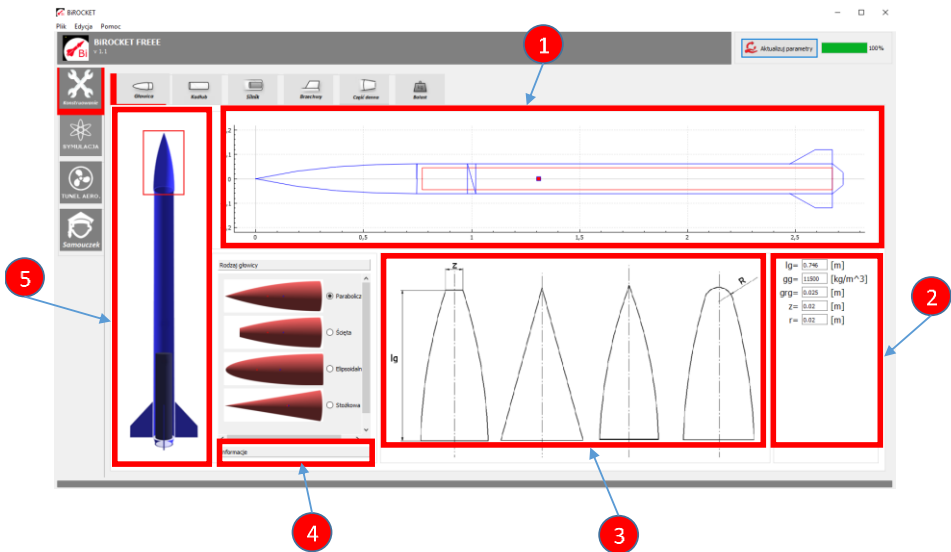


Fig. 4. Common features of all sub-tabs [3]

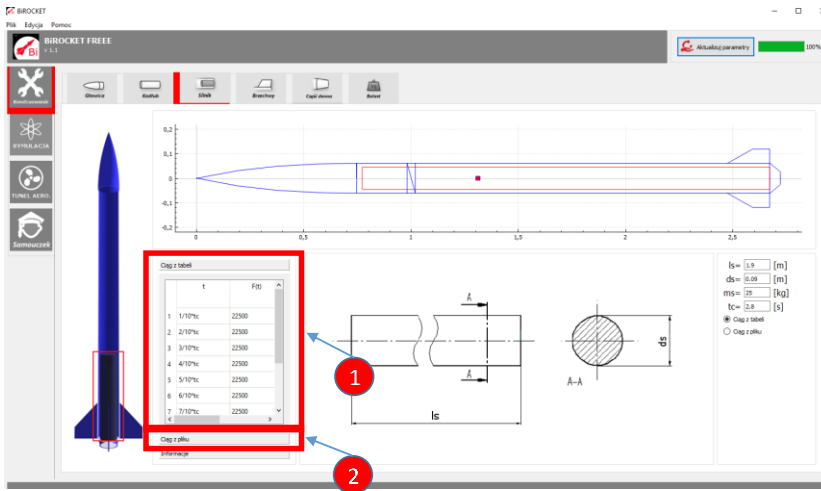


Fig. 5. The Motor sub-tab with its specific panes highlighted [3]
(1 – Tabulated thrust value input; 2 – Thrust value file input)

The Simulation tab (Fig. 6) and the Ballistic Tunnel tab (Fig. 7) provided access to the display of calculation results in the form of plotted graphs. Both tabs feature input panes for the initial data, the configuration of plotting parameters, and auxiliary information.



Fig. 6. The Simulation tab with its specific panes highlighted [3]
(1 – Plot; 2 – Input pane for initial simulation parameters and plotting configuration;
3 – Auxiliary information drop-down pane)

4. INPUT DATA FOR ROCKET DESIGN AND FLIGHT SIMULATION

The Design tab is the main GUI feature which handled the input of data. This GUI feature included text input fields and tables for the input of geometrical and mass-inertial data of the rocket in design. The subroutine source file *Pocisk.cpp* featured six data classes, *Głowica*, *Kadlub*, *Brzechwy*, *Silnik*, *Denna*, and *Balast* (Warhead, Fuselage, Stabilizer Fins, Motor, Bottom Section, and Ballast, respectively), which represented the respective components of the rocket in design. The data classes contained a series of objects in which the following data was stored: dimensions, material densities, and additional characteristics corresponding to the specific components of the rocket in design. Each data class included the method *masa* (mass), which calculated the mass (weight) of the rocket component being edited. The source file also included definitions of separate functions (*masa* – mass, *momentbezwladnosci* – moment of inertia, *srodekmary* – centre of mass, and *dlugosc* – overall length [1]) for the calculation of the mass-inertial parameters of the complete rocket.

At the data input stage, the user could define the warhead outline type (tapered, parabolic, ellipsoid, or truncate), the stabilizer fin type (rhomboidal or lenticular), and the motor thrust definition data source (tabulated or from a file). The thrust data read from a file was automatically displayed in the Thrust File pane (Fig. 5) for the user to verify the data validity.

The computer software application also allowed reading and writing the input data from TXT files. If the data were loaded from a file, the software application would verify if the loaded file was originally created by it while writing design data; this feature offered protection against reading incompatible data. Another convenient feature provided in the software application was batch resetting of all text input fields to zero (0). It required opening the Edit tab and clicking the Reset Parameters button in the tab. This feature helped delete the input parameter values quickly to proceed with a new rocket design project. If the user wanted to load the input data for editing, they would always have to click the Update Parameters button. The data update progress bar was a graphical representation of the part of the data update operation that was already completed. The software application provided a visual inspection of the data inputs in the form of a graphical representation of the designed rocket cross-section and the rocket COG (centre of gravity).

5. AERODYNAMIC CHARACTERISTICS CALCULATOR AND SOLVING THE SYSTEM OF DIFFERENTIAL EQUATIONS

A source file, *Wspolczynniki.cpp*, was implemented to enable the determination of the aerodynamic characteristics of the rocket in design. It was a subroutine which used specific analytical methods (developed by L.S. Chernabrovkin and A.A. Lebyadyev [1-4]) to determine the aerodynamic coefficients, the pressure centre coordinate, and other parameters. The subroutine was the aerodynamic characteristics calculator of the software application. The input parameters of its functions included: geometric dimensions of the rocket, the velocity of flow around the rocket, and a set of tables which contained digitized functions essential for the calculator and established from ballistic tunnel tests [4, 5].

By calling out subsequent functions, the software application determined the following aerodynamic characteristics: zero-lift head resistance coefficient for the active and passive sections; second derivative of the head resistance-to-attack angle ratio; derivative of the lift force-to-attack angle ratio; rocket pressure centre coordinate; derivative of the pitching moment-to-attack angle ratio; and attenuation factor derivative of the pitching moment-to-roll velocity ratio.

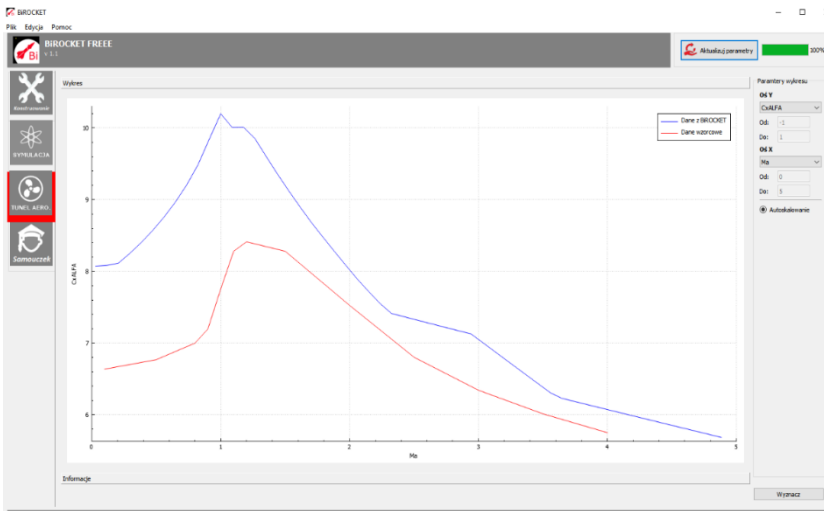


Fig. 7. GUI, the “Ballistic Tunnel” tab [3]

The GUI tab titled *Tunel Aero* (Ballistic Tunnel) (Fig. 7) could present the aerodynamic characteristics discussed above in the form of a graph with the calculated coefficient values plotted in the function of the Mach number.

The model of the Earth's atmosphere applied in the calculation of the simulated rocket trajectory was based on the standard AS-64 GOST 4401-64a. Its numerical implementation was stored in the subroutine source file *Atmosfera.cpp* [6, 7]. The input data of the relevant subroutine functions included: ambient temperature and barometric pressure at the rocket launch site and the reference elevation for the calculation of output parameters. The subroutine processed the input data and returned the magnitudes defining the atmosphere at a predefined elevation (i.e. the air density and barometric pressure, the velocity of acoustic wave propagation, and the acceleration of gravity). Another capability of the software application included solving of the system of differential equations which defined the motion of an unguided rocket within the plane of firing [8-10].

The numerical solution of the system of differential equations was processed by the subroutine stored in the source file *Trajektoria.cpp*. The subroutine source file featured three functions, *Balistyczna* (ballistic), *RK4* and *Trajektoria* (trajectory) [2]. The body of the first function, *Balistyczna*, had the foregoing system of equations implemented and the callouts of the functions stored in the source files *Wspolczynniki.cpp* and *Atmosfera.cpp*. The first function calculated the transient values of mass, motor thrust, the moment of inertia, aerodynamic coefficients, forces, and moments applied to the simulated rocket. The function *Trajektoria* (trajectory) determined the maximum duration of the rocket flight to allow the determination of the critical length of the tables which read the simulation results. The system of differential equations was solved by applying the fourth order Runge-Kutta method (RK4) with a variable integration step to reduce the calculation processing time [9, 11, 12]. Aside from all structural parameters of the designed rocket, the input data of the subroutine included the launch system elevation angle and the ambient temperature and barometric pressure at the launch pad.

The function *Trajektoria* (trajectory) included a loop whose start of execution was tantamount to the simulated launch of the rocket ($t = 0$ s). Each subsequent iteration of the loop execution increased parameter t by the respective integration step, called out the function *RK4* and overwrote the subsequent elements in the tables of results. The subroutine finished the simulation process when the flight altitude of the rocket, y , assumed a negative value (which was tantamount to the impact on the simulated ground surface). Moreover, if any of the variables implemented in the function code assumed the value *NaN* (infinite), a suitable conditional function terminated the loop execution and displayed a warning message of invalid input data. The simulation results were displayed as graphs in the Simulation tab of the GUI (Fig. 8). The user software could select the variables to be displayed on the axes x and y of the plotted $y=f(x)$ function.

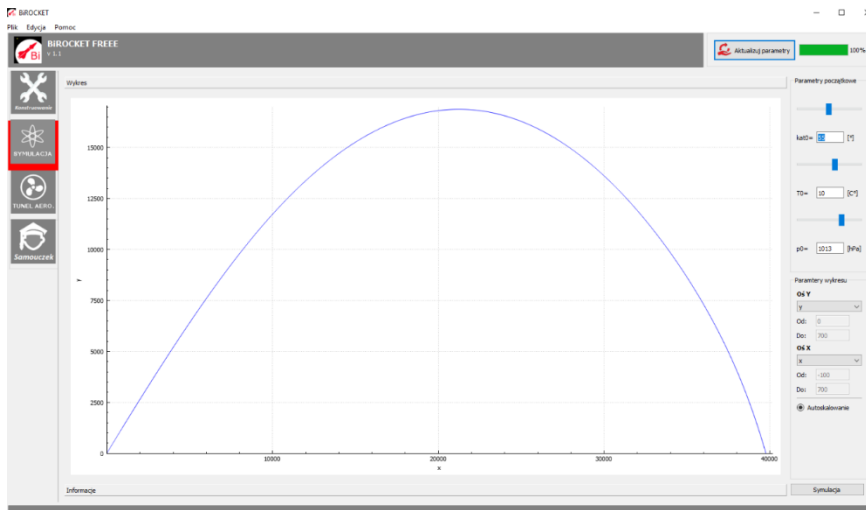


Fig. 8. GUI, the “Simulation” tab [3]

6. OTHER OPTIONS, APPLICATIONS AND DEVELOPMENT OPPORTUNITIES OF THE COMPUTER SOFTWARE APPLICATION

The software application featured the Save Graph command for exporting the simulation results (resulting in an export of the displayed graph into numerical values saved to a TXT file at a path specified by the application user). Another convenient feature were the Information tabs (each in every module of the GUI) with text descriptions of selected rocket engineering concepts, in addition to the essential explanation of notations and the operating principle of the application. A beginner user of the application could use the *Tutorial* to understand the correct way of using the software application. Yet another convenient feature was the pane titled *Parametry m/b* (mass-inertial parameters) in the *Ballast* tab. When the input data was entered in the application GUI, the panel displayed detailed mass-inertial parameters of the rocket in design (including the values of the mass of individual components, the centre of mass of the rocket, and more). Unauthorized access to the application was prevented by a user login input window displayed before accessing the main application window at every start of the application. The user was required to enter a valid user login and password, the latter of which could be modified in the Change Password tab of the GUI.

7. SIMULATION RESULTS FOR A SELECTED TEST OBJECT

The computer software application was tested with two types of 122 mm calibre rockets, M-210F Grad and M-21FHE Feniks. The flight parameter results generated for the rockets in the application were compared to the actual firing solution tables of the ordinance [13]. Examples of the simulation results with the firing range and velocity variations in time with reference to specific elevation angles of the launch system are shown in Fig. 9 and 10.

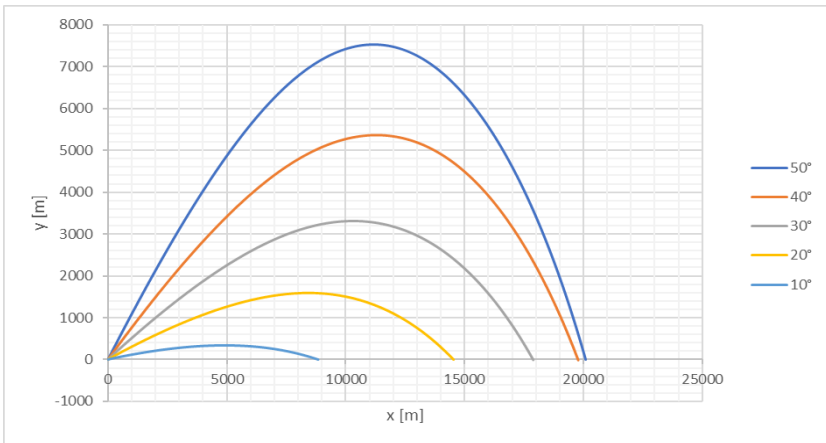


Fig. 9. Flight trajectories of the M-210F rocket with specific launch system elevation angles [3]

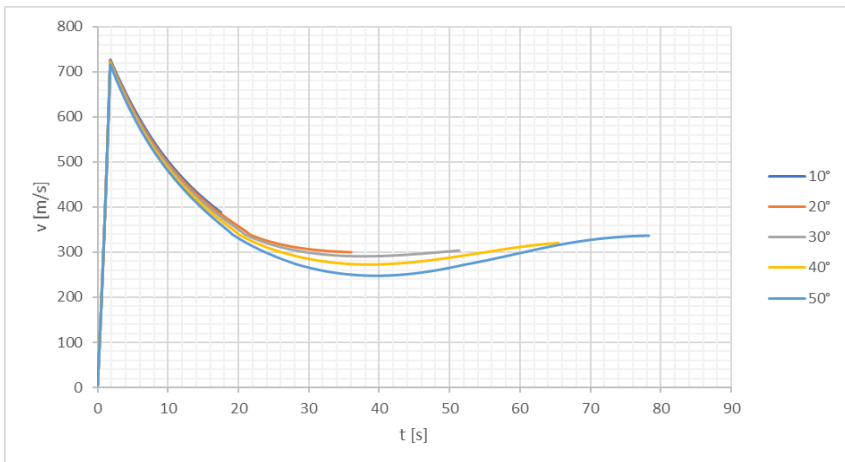


Fig. 10. Velocity of the M-210F rocket with specific launch system elevation angles [3]

8. CONCLUSIONS

The developed computer software application enables the design and simulation of structurally simple solid-propellant rockets. Therefore, the application can be used during the preliminary design of munitions for rocket artillery systems. The application can be useful in the rocket munitions model industry and laboratory exercises in rocket engineering learning studies.

The computer software application included a clear GUI, interactive modelling of rockets, information panes, and many more features for enhanced user convenience, enabling its application in scientific research and learning. The implementation of the software application code in C++ allowed deployment on various hardware platforms without any need for professional calculation suites. The presentation of results on graphs which could be exported to third-party applications favoured convenience of analysis of the designed and simulated characteristics.

Given that the software application uses an object-driven programming paradigm, it is possible to easily expand the application with more modules. Further development of the software application may enable design, simulation, and animation of guided missiles, both winged and multi-stage.

The aerodynamic characteristics determined in the software application for the M-210F Grad and M-21FHE Feniks rockets were largely approximate to their reference characteristics determined with other options.

The verification of the results obtained for the essential flight parameters of the rockets revealed high conformity with the reference firing solution tables, with an average error of 10%.

The developed computer software application should include algorithms for the determination of aerodynamic characteristics of any aerodynamic system and a module for 3D visualisation of rocket / missile flight, driven by graphical libraries. The application could be then used as a learning aid in rocket engineering, external ballistics, and rocket and missile aerodynamic engineering.

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Aplikacja komputerowa do projektowania i symulacji niekierowanych pocisków raketowych

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Streszczenie. W pracy zamieszczono opis i charakterystykę użytkową opracowanej aplikacji komputerowej do projektowania pocisków raketowych. Metodyka wyznaczania charakterystyk aerodynamicznych przez opracowane oprogramowanie bazuje na metodzie teoretyczno-doświadczalnej Czernabrowkina i Lebiadiewa. Zamieszczone w pracy wyniki symulacji komputerowej przeprowadzono dla 122 mm pocisku raketowego M-21OF Grad oraz M-21FHE Feniks i zostały poddane weryfikacji z wynikami uzyskanymi innymi metodami obliczeniowymi.

Słowa kluczowe: symulacja komputerowa, współczynniki aerodynamiczne, pocisk raketowy