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The Modelling of a Body's Flight and Animation of the Process in the Mathcad Environment, Using an Operational-Tactical Missile as an Example

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Abstract. *The authors have developed an animation programme in the Mathcad environment which provides a visual representation of the motion process and allows the change in a body's position over time to be observed. The resulting animation complements the traditional mathematical presentation of the problem with a graphical representation of the dynamics of a mechanical system and can be used as demonstration material when teaching sections of theoretical mechanics.*
Keywords: *Mathcad, animation, software, theoretical mechanics*.

The current development of digital technologies is creating new opportunities for improving teaching methods in theoretical mechanics. The use of computer modelling and animation makes it possible to combine the mathematical description of motion with its direct visualisation [1–5].

The use of animation is being considered not only for the mechanics developed by O.L. Sedykh and S.V. Makovetsjka, but also for other sectors of mechanical engineering [1].

The benefits of using Mathcad in the teaching process stem from its ability to allow users, within a single environment, to write mathematical models, perform analytical and numerical calculations, solve systems of differential equations, plot graphs and investigate the effect of input parameters on the result [6]. In particular, A. V. Kurilin demonstrated the application of Mathcad in a course on theoretical mechanics, using the example of a Lagrangian problem and a numerical study of mechanical motion, followed by computer animation [7].

Broman, G. and Ostholm, S. described the use of Mathcad in teaching the dynamics of rotating and structural systems and noted an increase in students' interest in mathematics and mechanics. Many publications also provide examples of using Mathcad for computer modelling of the mechanical motion of a body moving at an angle to the horizontal, with the ability to vary the initial velocity, angle, geometric and other parameters of the model [8].

A separate area of research concerns the modelling and animation of the flight of missile objects. Zygmunt B. and Motyl K. examined the procedure for constructing physical and mathematical models of a missile's flight, the implementation of kinematic and dynamic equations in Mathcad, and the generation of computer animations of the modelling results [9, 10].

The aim of this work is to develop a mathematical model and computer animation of a body in flight, simulating the motion of an operational-tactical missile both without taking air resistance into account and with air resistance described by linear and quadratic relationships, as well as to conduct a visual investigation of the influence of the model's parameters on the trajectory of motion.

For a simplified model (after the engine has been switched off, or if the flight is regarded as the motion of a body after being given an initial velocity), it is sufficient to consider the initial conditions: initial velocity: $v_0 = 300$ m/s, launch angle $\alpha = 45$ degrees, acceleration: $g = 9.81$ m/s^2, mass $m = 100$ kg, air density $\rho = 1.225$ kg/m^3, drag coefficient $C_d = 0.25$, diameter $D = 0.20$ m, cross-sectional area $A = (\pi \cdot D^2)/4$, $A = 0.031$ m^2, drag coefficient $k = \rho \cdot C_d A/2$, $k = 4.811 \cdot 10^{-3}$.

1. Model A: the ideal unimpeded throw (baseline).

Equation of motion (1):

$$t_0 = \frac{2 \cdot v_0 \cdot \sin(\pi \cdot \frac{\alpha}{180})}{g}; \; t_0 = 43{,}248 \text{ c.} \tag{1}$$

2. Model B: linear resistance k = 0.05 N/m.

Equation of motion:

$$\begin{aligned} &\text{along the axis X: } m\frac{dv_x}{dt} = -kv_x, \\ &\text{along the axis Y: } m\frac{dv_y}{dt} = -mg - kv_y. \end{aligned} \tag{2}$$

3. Model C provides a better physical description of the process and takes into account the quadratic dependence of air resistance.

We shall use a system of differential equations

$$\frac{dx}{dt} = v_x, \frac{dy}{dt} = v_y, \frac{dv_x}{dt} = -\frac{k}{m}\sqrt{v_x^2 + v_y^2}\,v_x, \frac{dv_y}{dt} = -g - \frac{k}{m}\sqrt{v_x^2 + v_y^2}\,v_y. \tag{3}$$

Based on the differential equations obtained, we developed an animation programme in Mathcad (Figs. 1 and 2).

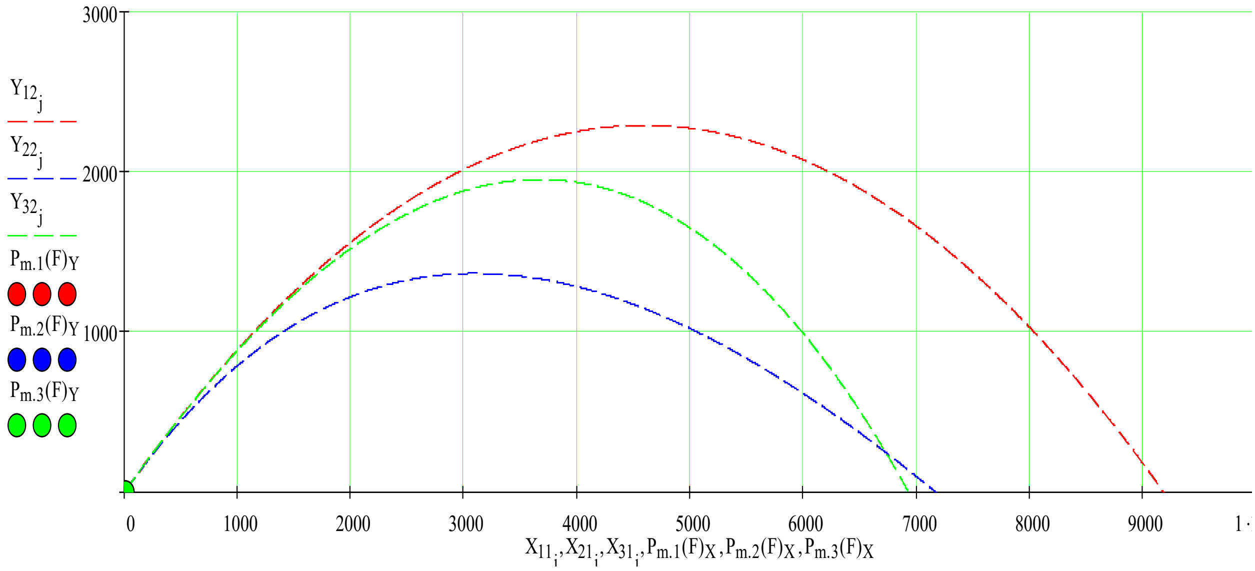

Fig. 1. Graph showing the rocket's flight path (on the x and y axes, distance in metres). Model A – red, Model B – green, Model C – blue [11]

Fig. 2. Animation of a body's flight path based on a QR code;
programme in Matcad Professional 2001 based on a QR code [11]

Conclusions. The scientific novelty of this work lies in the development of an education-oriented model and a software-based animation tool within the Mathcad environment, which makes it possible not only to obtain a motion trajectory but also to conduct a virtual experiment by changing the parameters of the mathematical model and directly observing their effect on the nature of the motion.

Consequently, the proposed approach demonstrates the value of using Mathcad and computer animation as tools for combining mathematical modelling, numerical experimentation and the visual presentation of results in the teaching of theoretical mechanics.

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