DETERMINING THE OPTIMAL TIME BETWEEN LAUNCHINGS WHEN FIRING MULTIPLE UNGUIDED MISSILES FROM LAROM PLATFORMS

Neculai-Daniel Zvîncu, Cristian-Emil Moldoveanu, Pamfil Şomoiag, Alin Constantin Sava, Andrei-Daniel Mandache-Dodoiu, Florin-Marian Dîrloman

Faculty of Integrated Armament Systems, Military Engineering and Mechatronics, Military Technical Academy „Ferdinand I", Bucharest, ROMANIA, daniel.zvincu@mta.ro

Abstract: The LAROM is a Romanian mobile multiple unguided missiles launcher that can operate with the standard 122 mm rockets, as well as with the more advanced 160 mm rocket, having a strike range between 20 and 45 km. It has been successfully used by the Romanian Land Forces since 2010. The aim of our paper is to determine the calculation scenario that involves minimum forces, moments and oscillations when firing unguided reactive projectiles with the LAROM launch system.

Thus, we can determine the optimal time required between 2 launches considering the induced forces on the launch facility (tipping part, chassis).

Keywords: LAROM, launching platform, unguided missile, optimal launching time.

Introduction

The LAROM system was jointly developed by Aerostar (Romania) and Israel Military Industries (IMI) to meet requirements of Romanian Ministry of Defence. It is an upgrade of the APRA-40, which is an indigenously improved/enhanced version of the BM-21 Grad [1, 2].

Figure 1: LAROM launcher

The LAROM was revealed in 2000 and is capable of launching both standard 122 mm and IMI's LAR 160 mm unguided missiles. The vehicle has two launch pod containers. Depending on calibre, each container holds 13 or 20 missiles. Moreover, when compared to the Grad, The LAR Mk.4 has twice its range - about 45 km. The LAR Mk.4 are available with HE-FRAG or cluster warheads. The last mentioned carries anti-personnel or anti-tank submunitions. Operator can launch rockets from the truck cabin or up to 50 m away from the vehicle while firing single shots, partial or complete salvos. This multiple launch rocket system incorporates advanced artillery command and control system. The LAROM is based on a Roman DAC-25.360 6x6 military truck. Vehicle is reloaded by supporting ammunition resupply truck [2].

1. Mathematical model for LAROM launcher firings

The movement of the launcher-rocket system is determined if the position variables s, φ_y, φ_z, z_s, γ_x,γ_y are known. All variables of the launching platform are determined in relation to the $O_T X_T Y_T Z_T$ earth fixed reference system.

In order to determine the oscillations of the launching platform during firings, it shall be considered that an oscillating system is formed, which can be assimilated with a set of rigid or elastic bodies connected by elastic elements. The main components of the system are:

- the missiles that are currently on the launcher, including the one being launched;
- the launcher pod with the cradle;
- the chassis of the vehicle on which the pod base is placed with the pivoting support.

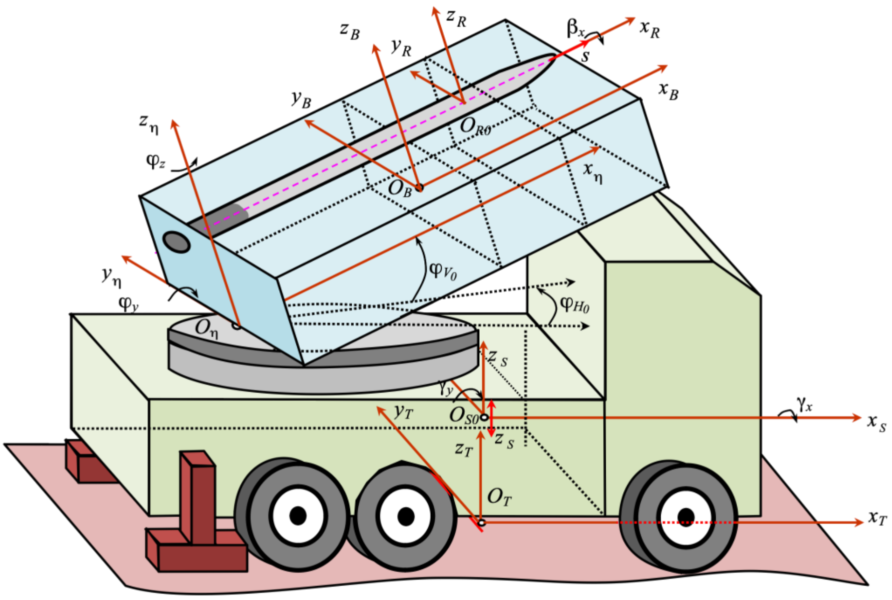

Figure 2: LAROM launcher

The geometric and mass parameters of the launcher platform are as follows:

- M_R, initial mass of the rocket [kg];
- g, gravitational acceleration [m/s^2];
- μ, coefficient of friction between the missile and the pod tube;
- v_r, the unguided missile velocity;
- F_{ret_r},missile retaining on the launcher force [N];
- s_{max}, maximum length of the launcher (distance traveled by the missile's center of gravity until leaving the launcher) [m];
- N, number of rotations made by the missile in the guidance tube;
- l_{tube}, length of the guidance tube [m];
- η_{R_x}, distance along the x-axis from the pod shoulders axis to the center of mass of the missile [m];

- η_{R_x}, distance along the y-axis from the pod shoulders axis to the center of mass of the missile [m];
- η_{R_z}, distance along the z-axis from the pod shoulders axis to the center of mass of the missile [m];
- J_{R_x}, moment of inertia of the missile along the x axis [kg·m^2];
- J_{R_y}, moment of inertia of the missile along the y axis [kg·m^2];
- J_{R_z}, moment of inertia of the missile along the z axis [kg·m^2];
- M_B: mass of the tipping part [kg];
- J_{B_x}, moment of inertia of the tipping part along the x axis [kg·m^2];
- J_{B_y}, moment of inertia of the tipping part along the y axis [kg·m^2];
- J_{B_z}, moment of inertia of the tipping part along the z axis [kg·m^2];
- φ_{H_0}, horizontal firing angle;
- φ_{V_0}, vertical firing angle;
- φ_y, angle of rotation of the tipping part along the y axis;
- φ_z, angle of rotation of the tipping part along the z axis;
- g_x, angle of rotation of the chassis along the x axis;
- g_y, angle of rotation of the chassis along the y axis;
- z_s, linear oscillation of the chassis along the z axis [3, 4].

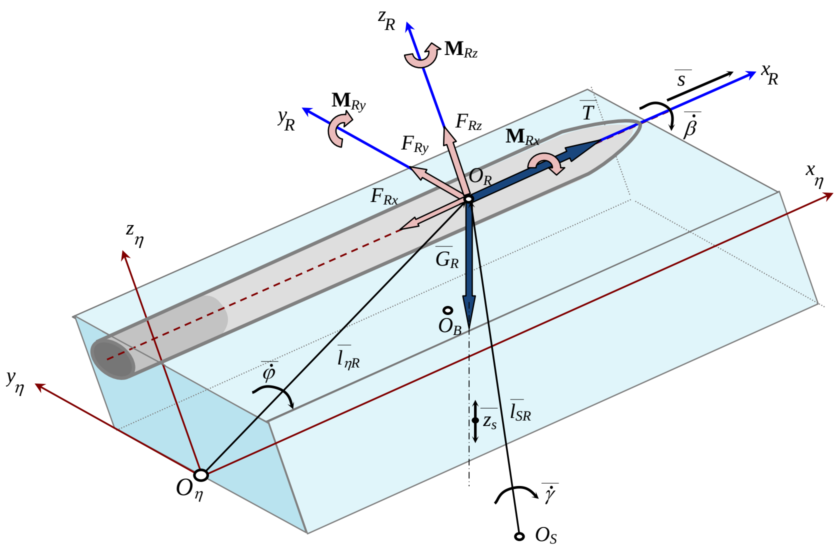

Figure 3: Applied forces and momentum on the unguided missile on a LAROM launcher

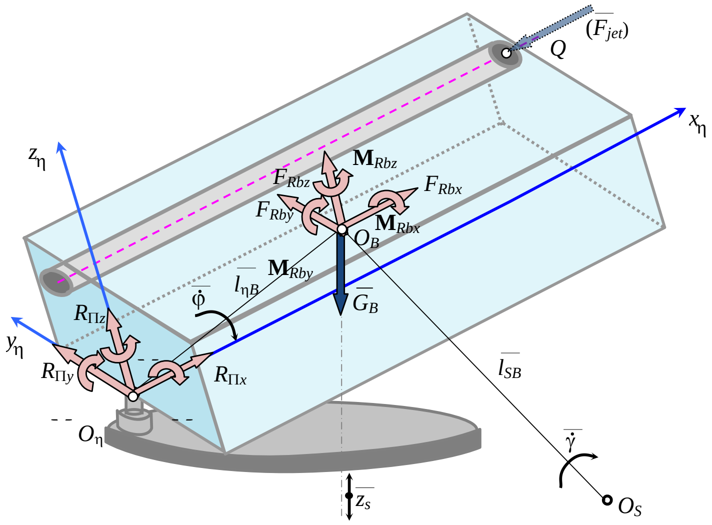

Figure 4: Applied forces and momentum on the tipping part of the LAROM launcher

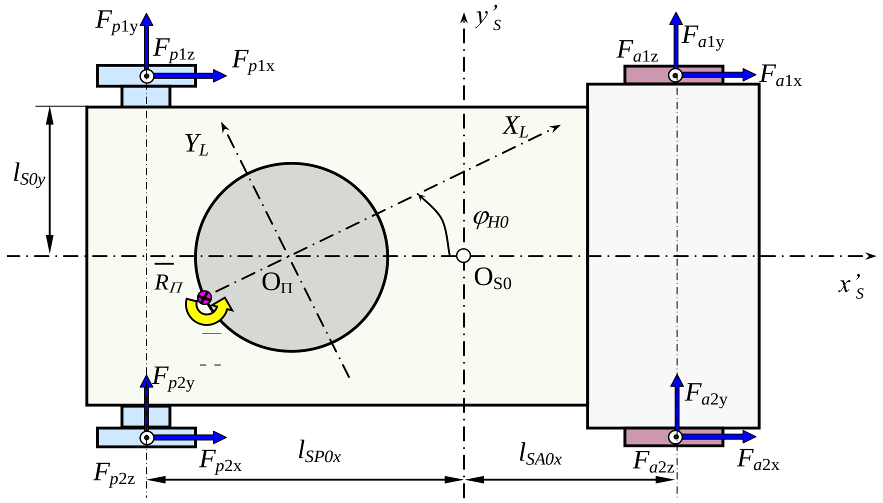

Figure 5: Applied forces and momentum on the chassis of LAROM launcher

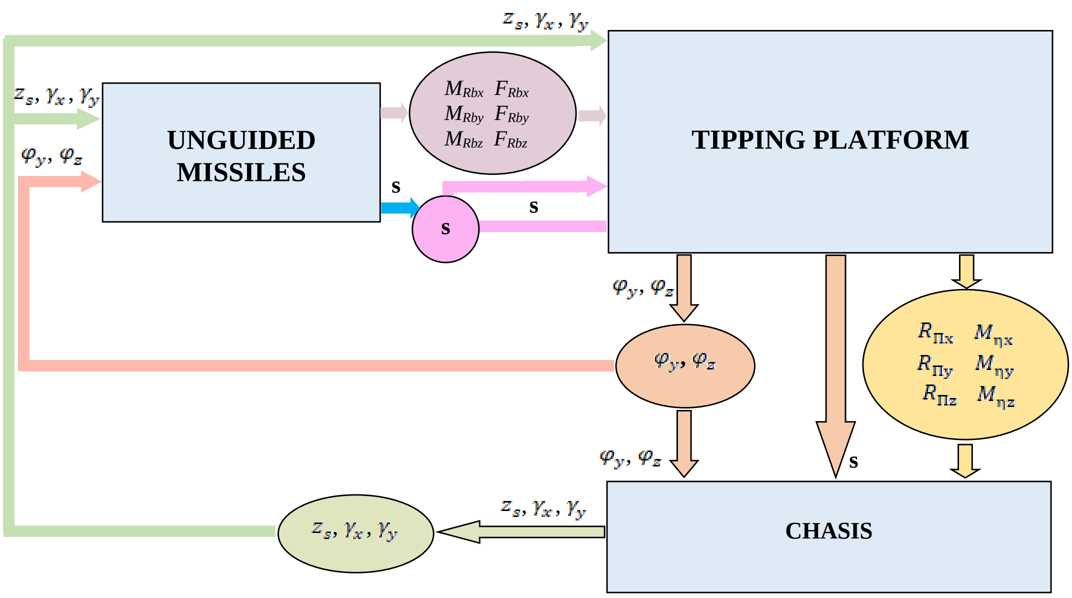

Figure 6: LAROM launcher parameters for MATLAB program

The algorithm for calculating the launch oscillations is the following (figure 6):

I^st^ approximation

- the position variables s, φ_y, φ_z, z_s, γ_x, γ_y and the binding forces and momentum F_{Rb_x}, F_{Rb_y}, F_{Rb_z}, M_{Rb_x}, M_{Rb_y}, M_{Rb_z}, R_{Π_x}, R_{Π_y}, R_{Π_z}, M_{η_x}, M_{η_y}, M_{η_z} are initiated with the zero value;

- the calculation is performed for the fired unguided missile, s (the movement in the launching tube) being determined;

For the other missiles in the containers, as well as for the launched missile, the binding forces and momentum transmitted to the tipping platform are determined, being applied in the center of mass of the tipping part (F_{Rb_x}, F_{Rb_y}, F_{Rb_z}, M_{Rb_x}, M_{Rb_y}, M_{Rb_z}).

- the numerical determinations are performed at the level of the tipping part, using data from the previous steps, in order to determine , φ_y, φ_z, R_{Π_x}, R_{Π_y}, R_{Π_z}, M_{η_x}, M_{η_y}, M_{η_z};

- the chassis calculation is performed based on previous determined data in order to determine the z_s, γ_x and γ_y variables

II^nd^ approximation

The position variables s, φ_y, φ_z, z_s, γ_x, γ_y are considered known from the first approximation. The obtained results are compared with those of the previous approximation, in order to verify the convergence of the algorithm. In order to obtain a satisfactory convergence of the results, it is necessary to go through at least 3 iterations [4].

The equation system solved in the previous approximation has the following form:

$$\begin{aligned}
s &= v_R \\
\varphi_y &= \omega_{\varphi_y} \\
\varphi_z &= \omega_{\varphi_z} \\
z_s &= v_{z_s} \\
\gamma_x &= \omega_{\gamma_x} \\
\gamma_y &= \omega_{\gamma_y} \\
v_R &= F_{v_R}(v_R, \omega_{\varphi_y}, \omega_{\varphi_z}, v_{z_S}, \omega_{\gamma_x}, \omega_{\gamma_y}) \\
\omega_{\varphi_y} &= F_{\omega_{\varphi_z}}(v_R, \omega_{\varphi_y}, \omega_{\varphi_z}, v_{z_S}, \omega_{\gamma_x}, \omega_{\gamma_y}) \\
\omega_{\varphi_z} &= F_{\omega_{\varphi_z}}(v_R, \omega_{\varphi_y}, \omega_{\varphi_z}, v_{z_S}, \omega_{\gamma_x}, \omega_{\gamma_y}) \\
v_{z_S} &= F_{v_{z_S}}(v_R, \omega_{\varphi_y}, \omega_{\varphi_z}, v_{z_S}, \omega_{\gamma_x}, \omega_{\gamma_y}) \\
\omega_{\gamma_x} &= F_{\omega_{\gamma_x}}(v_R, \omega_{\varphi_y}, \omega_{\varphi_z}, v_{z_S}, \omega_{\gamma_x}, \omega_{\gamma_y}) \\
\omega_{\gamma_y} &= F_{\omega_{\gamma_z}}(v_R, \omega_{\varphi_y}, \omega_{\varphi_z}, v_{z_S}, \omega_{\gamma_x}, \omega_{\gamma_y})
\end{aligned} \qquad 1.1$$

The approximations are performed in MATLAB using the ode45 solver based on the fourth and fifth order Runge - Kutta methods and algorithms. These methods use a weighted average of the estimated values of the derivatives in the area of interest so as to calculate a value y_{i+1}, having known the value y_i. Thus, if we consider a function $f\ x, y\ = \frac{dy}{dx}$ with initial conditions $y_I = y(0)$, using the Runge - Kutta method, y_{i+1} is determined with the relation:

$$y_{i+1} = y_i + \frac{h}{6}(k_1 + 2 \cdot k_2 + 2 \cdot k_3 + k_4) \qquad 1.2$$

where

- $k_1 = f(x_i, y_i)$ is the value of y' for x_i,
- $k_2 = f(x_i + \frac{h}{2}, y_i + \frac{h}{2} \cdot k_1)$ is the value of y' for $x_i + \frac{h}{2}$,

- $k_3 = f(x_i + \frac{h}{2}, y_i + \frac{h}{2} \cdot k_2)$ is the second estimated value of y' for $x_i + \frac{h}{2}$,
- $k_4 = f(x_i + h, y_i + h \cdot k_3)$ is the estimated value of y' for x_{i+1}.

Initial data for the optimal time between launchings determinations:
- initial horizontal firing angle, $\varphi_{H_0} = 45^{\circ}$;
- initial vertical firing angle, $\varphi_{V_0} = 45^{\circ}$;
- number of unguided missiles considered = 2 (figure 7);

- time periods considered between launchings
  - case I – 0.4 seconds;
  - case II – 0.8 seconds;
  - case III – 1.2 seconds;
  - case IV – 1.6 seconds;
  - case V – 2.0 seconds.

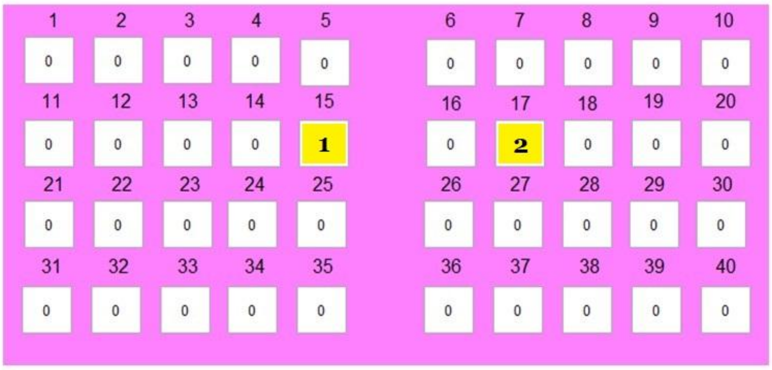

Figure 7: Unguided missiles considered for determinations

2. Optimal time between launchings determinations

Determining the optimal time between launchings requires to evaluate the oscillations determined by the rotations of the tipping part and the chassis of the firing platform when the second unguided missile is launched. The numerical determinations were conducted for the five cases detailed previously.

The formula used for different impulses determination is as follows:

$$I_\tau = \int_0^t \tau \, dt \qquad 2.1$$

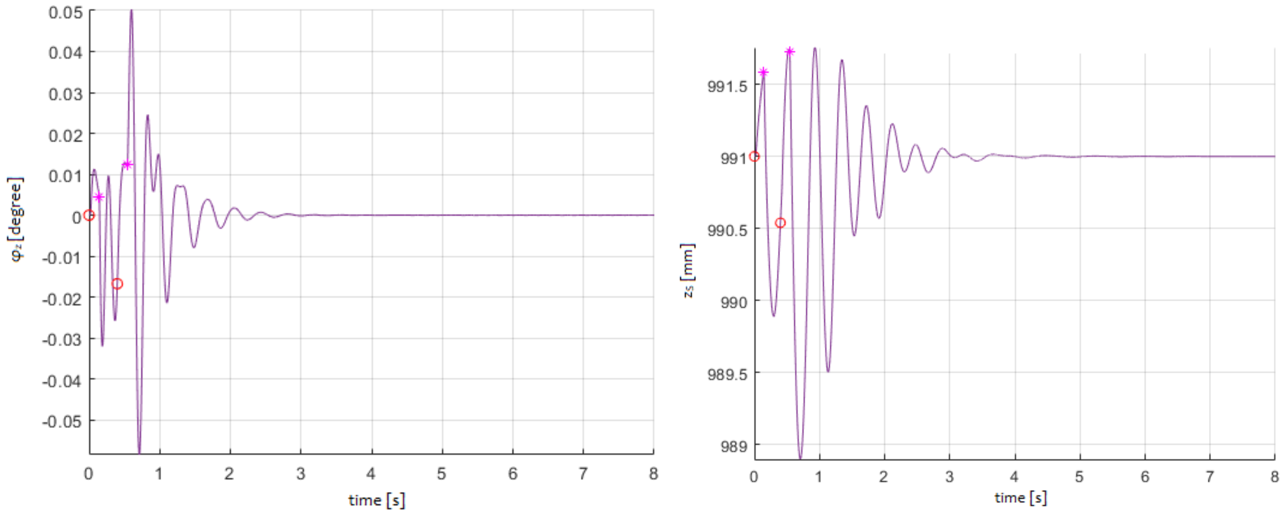

Figure 8: Oscillatory movements exemplifications (for the tipping part along the y axis and linear oscillation of the chassis along the z axis)

Table 1: Values obtained for the cases considered

	Case I	**Case II**	**Case III**	**Case IV**	**Case V**
Impuse of oscillation φ_y [N*s]	0,7163	0,74644	0,74931	0,75462	0,76482
Amplitude of oscillation φ_y [m]	0,74263	0,70021	0,59005	0,49958	0,4639
Impuse of oscillation φ_z [N*s]	0,0236	0,024405	0,025107	0,025508	0,026026
Amplitude of oscillation φ_z [m]	0.058491	0,054704	0,051396	0,051067	0,051647
Impuse of oscillation g_x [N*s]	0,11343	0,11821	0,11865	0,1189	0,12028
Amplitude of oscillation g_x [m]	0,13543	0,12392	0,10814	0,095112	0,091884
Impuse of oscillation g_y [N*s]	0,0399	0,044611	0,042892	0,044095	0,04532
Amplitude of oscillation g_y [m]	0,05302	0,043004	0,04282	0,036071	0,03837
Impuse of oscillation z_S [N*s]	1,6998	1,7503	1,7469	1,7264	1,7498
Amplitude of oscillation z_S [m]	2,0258	1,5771	1,3006	1,2778	1,2613

The equivalent impulse for the cases considered is determined next:

$$I_{tot} = \sqrt{I_{\varphi y}^2 + I_{\varphi z}^2 + I_{gx}^2 + I_{gy}^2 + I_{\varphi y}^2 + I_{zs}^2} \qquad 2.2$$

Based on previous assessment, applying formula 2.2, the resulting impulses for the cases considered are presented in table 2.

Table 2: Resulting impulse values

	Case I	Case II	Case III	Case IV	Case V
Total impuse of oscillation[N*s]	**1,84863**	**1,90717**	**1,90517**	**1,88856**	**1,91414**

The total equivalent impulse of the oscillations affecting the launching platform (the missile launching pods, the tipping part and the vehicle chassis) has the lowest value for a time interval between launchings of the unguided missiles of 0.4 seconds.

Acknowledgments

Numerical determinations were conducted using the MATLAB program in order to evaluate the effects of firing unguided missiles when considering different time intervals between launchings. It is considered the influence of the oscillatory movements given by the rotation angles of the tipping part and chassis along the x/y axis and the linear oscillation of the chassis along the z axis when the second unguided missile is launched.

From the point of view of the stress induced to the launching platform, when considering firing two unguided missiles from different sides of the launching pods, the optimal time between launchings is 0,4 seconds.

References

1. Şomoiag, P. – *Weapons Systems. Dinamics of self-propelled launching systems*, Military Technical Academy Publishing House, Bucharest, 2007;
2. Stroea, A.; Băjenaru, Ghe. – *Romanian artillery in data and images*, Technical-Editorial Center of the Army Publishing House, Bucharest, 2010;
3. McCoy, R. L. – Modern Exterior Ballistics, Schiffer Publishing Ltd., 1999;

Şomoiag, P.; Sava, A.C.; Moldoveanu, C.E.; Iancu, I. - Weapons systems. The firing action on missile launching systems, Military Technical Academy Publishing House, Bucharest, 2012.