ASPECTS REGARDING THE UNGUIDED ROCKET EFFECTIVENESS

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Abstract: *The inaccuracy on the unguided rockets impact can be caused by many factors, like initial conditions perturbations as a small displacement of the firing pods between two launches due to its oscillations. As a consequence, all those parameters have to be taken into account in order to obtain an efficacy firing. This paper will focus on the unguided rocket effectiveness. Using the physical model for the trajectory, we will study the accuracy of the unguided rocket through a statistical analysis and several target models.*

Keywords: *Ballistics, unguided rocket, accuracy, impact probability and destruction*

1. INTRODUCTION

The unguided rockets are mainly used for missions such us: destroying personnel, military devices, and making target inoperative on large area; slowing down enemy movements, or imposing to enemy troops a specific move; preventing access to specific tactical areas through barrage firing; and providing support by fire tactical maneuvers to friendly troops.

The use of the unguided rockets implies the study of the problematic of their efficiency. Through a preliminary physical and ballistic study completed by some simulations, we tried to set up a model evaluating the efficiency of the weaponry system, in terms of impact accuracy on target [8]. We managed to set up a physical system of trajectories, considering the ballistic parameters. By implementing this theoretical model in numerical methods, we have created a simulating interface for calculating the ballistic results and statistical data. It focuses mainly on the accuracy of multiple rocket launching systems [1]. This algorithm returns useful results and allows to handle different cases corresponding to missions.

2. THE MATHEMATICAL MODEL FOR THE UNGUIDED ROCKET TRAJECTORY

The main goals of external ballistics are to set up equations whose solutions will describe as realistically as possible the unguided rockets trajectory [2]. This requires firstly to have in mind all the aerodynamic forces that are applied to the rockets. Thereupon, this part aims to describe the physical problematic of an unguided rocket flight, by calculating its trajectory system of equations. In addition, a second aim of this paragraph is to realize a numerical model solving this mathematical complex system for one unguided rocket trajectory [3].

As an object moving in the air, the rocket is subject to aerodynamic forces [5]. Those are consequences of the rocket moving in the air. The dynamic pressure distribution P_g on the rocket surface is $P_g = \frac{1}{2}\rho V^2$, which is generated by the movement of the rocket in the air [6]. The aerodynamic forces result from this dynamic pressure, moreover three resultant forces are deduced on each direction from the velocity referential system. All those forces are applied on the centre of pressure [6].

The first is called drag $\overrightarrow{F_x}$, it's opposed to the rocket velocity $\vec{v}$

$$\overrightarrow{F_x} = -\frac{1}{2}\rho V^2 S C_x \overrightarrow{x_v} \tag{1}$$

The second is the lift $\overrightarrow{F_y}$, this force is perpendicular to the velocity:

$$\overrightarrow{F_y} = \frac{1}{2}\rho V^2 S C_y \overrightarrow{y_v} \tag{2}$$

The third is $\overrightarrow{F_z}$, horizontally deviating the rocket :

$$\overrightarrow{F_z} = \frac{1}{2}\rho V^2 S C_z \overrightarrow{z_v} \tag{3}$$

where C_x , C_y C_z are coefficients linked to α angle between velocity and rocket longitudinal axis.

The mathematical model of the unguided rocket trajectory [2], [4] is done by the following system of differential equations:

$$\begin{aligned}
&\frac{dV}{dt} = -K_x V^2 - g\sin(\theta_v) + a_r\cos(\alpha_v)\\
&\frac{d\theta_v}{dt} = K_y^\alpha \alpha_v V - K_y^\omega \frac{d\eta}{dt} - \frac{g}{V}\cos(\theta_v)\\
&\frac{d\theta_h}{dt} = K_z^\alpha \alpha_h V - K_z^\omega \frac{d\xi}{dt}\\
&\frac{d\alpha_v}{dt} = \frac{d\eta}{dt} - K_y^\alpha \alpha_v V + K_y^\omega \frac{d\eta}{dt} + \frac{g}{V}\cos(\theta_v)\\
&\frac{d\alpha_h}{dt} = \frac{d\xi}{dt} - K_z^\alpha \alpha_h \alpha_h V + K_z^\omega \frac{d\xi}{dt}\\
&\frac{d^2\xi}{dt^2} = -K_m^\alpha \alpha_h V^2 - K_m^\omega V \frac{d\xi}{dt} - \frac{K_\xi}{J_\xi}\frac{d\xi}{dt}\\
&\frac{d^2\eta}{dt^2} = -K_m^\alpha \alpha_v V^2 - K_m^\omega V \frac{d\eta}{dt} - \frac{K_\eta}{J_\eta}\frac{d\eta}{dt}\\
&\frac{dx}{dt} = V.\cos(\theta_v).\cos(\theta_h)\\
&\frac{dy}{dt} = V.\sin(v)\\
&\frac{dz}{dt} = V.\cos(\theta_v).\sin(\theta_h)
\end{aligned} \tag{4}$$

where:

$$a_r = \frac{T_{thr}}{m};\ K_x = \frac{1}{2m}\rho S C_x;$$
$$K_y^{\alpha} = \frac{1}{2m}\rho S C_y^{\alpha};\ K_y^{\omega} = \frac{1}{2m}\rho l_{ref} S C_y^{\omega};$$
$$K_z^{\alpha} = \frac{1}{2m}\rho S C_z^{\alpha};\ K_z^{\omega} = \frac{1}{2m}\rho l_{ref} S C_z^{\omega}$$
$$K_m^{\alpha} = \frac{1}{2J_\xi}\rho S l_{ref} C_m^{\alpha} = \frac{1}{2J_\eta}\rho S l_{ref} C_m^{\alpha};\ K_m^{\omega} = \frac{1}{2J_\xi}\rho S l_{ref}{}^2 C_m^{\omega} = \frac{1}{2J_\eta}\rho S l_{ref}{}^2 C_m^{\omega}.$$

The equation systems (4) is solved using a program presented in Fig. 1

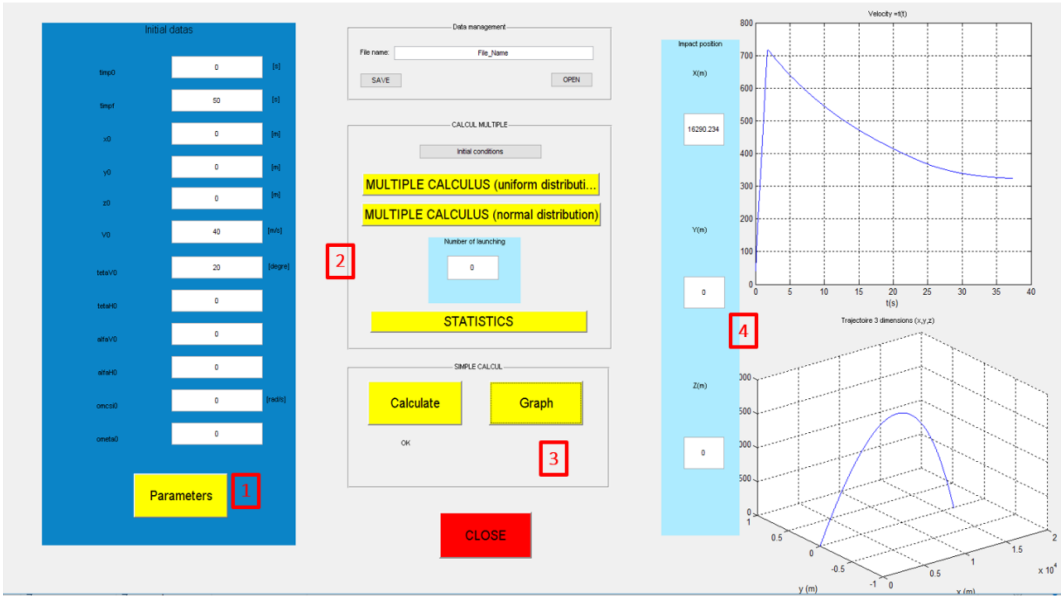

FIG 1. The interface of the computer program used for trajectory model

The program has the following modules:

(1) Initial conditions module;
(2) Multiple launching module;
(3) Single launching module;
(4) The results.

3. NUMERICAL RESULTS

We will use the unguided rocket trajectory (4) solved by the program presented in Fig 1. We have a precise model of target with health gauges, and we will analyze the effectiveness of firing. In this study, a 64 launching campaign will be used with a large scale of perturbation.

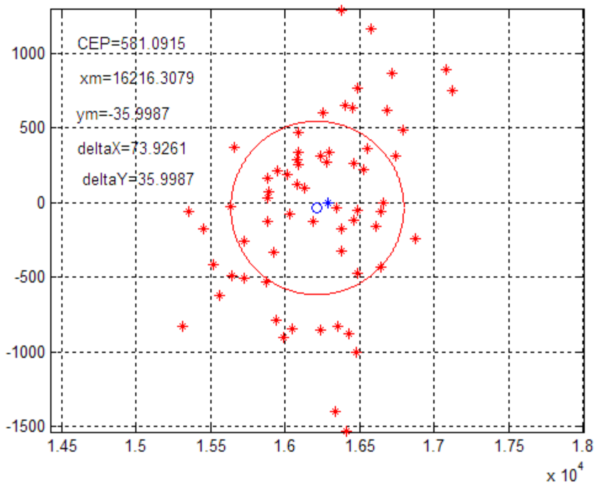

FIG. 2 General 64 rockets fire campaign used for statistic study

Next we will change the number of parts inside the target. We will consider a target with an uncertain position. Therefore the mean point of impact will be situated at 357 m from the centre of the target. Here are the 3 types of target used, seen in Fig 3.

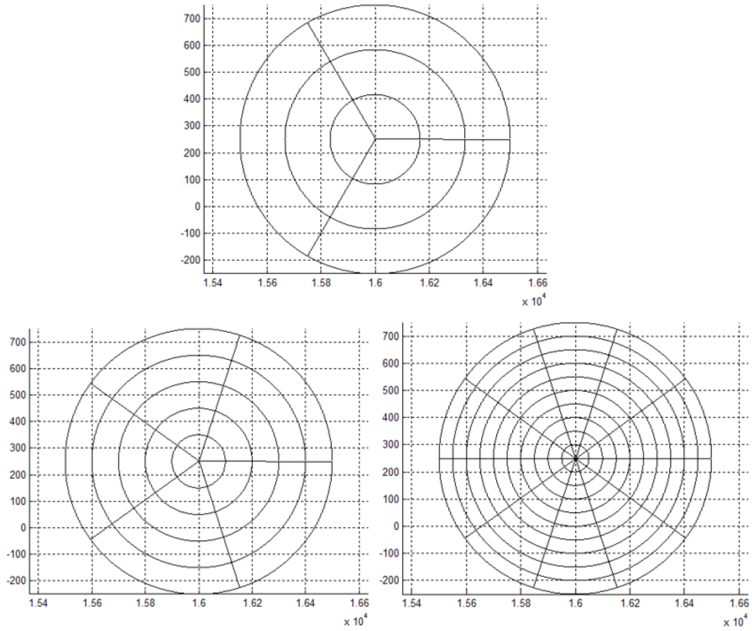

FIG. 3 Target used for comparative study : (3x3), (5x5) and (10x10)

With a small number of parts, the target is totally destroyed with this firing campaign. We see that all the parts suffer hit and even the ones suffering one hit are destroyed because of the shrapnel effect. This target has a total of 180 life points.

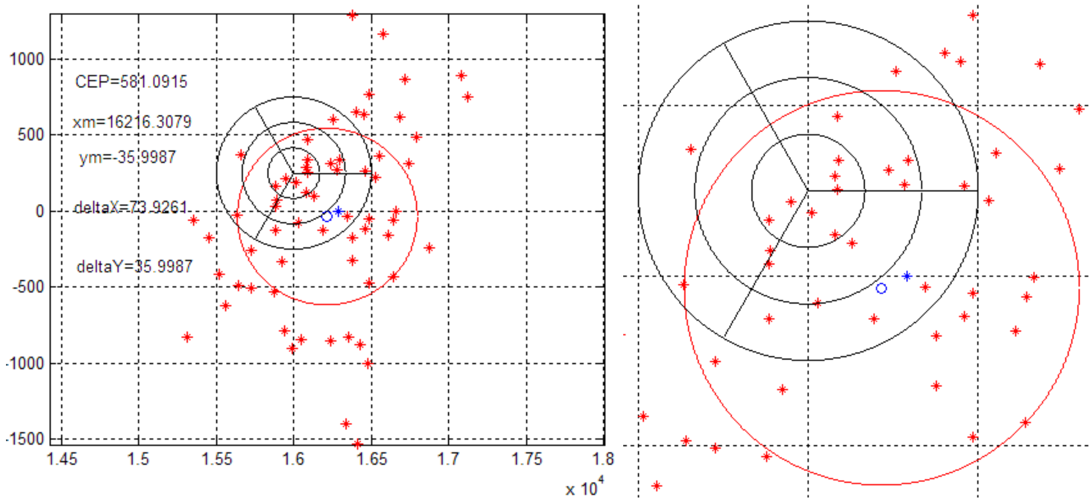

FIG. 4 Large scale target with (3 x 3) parts

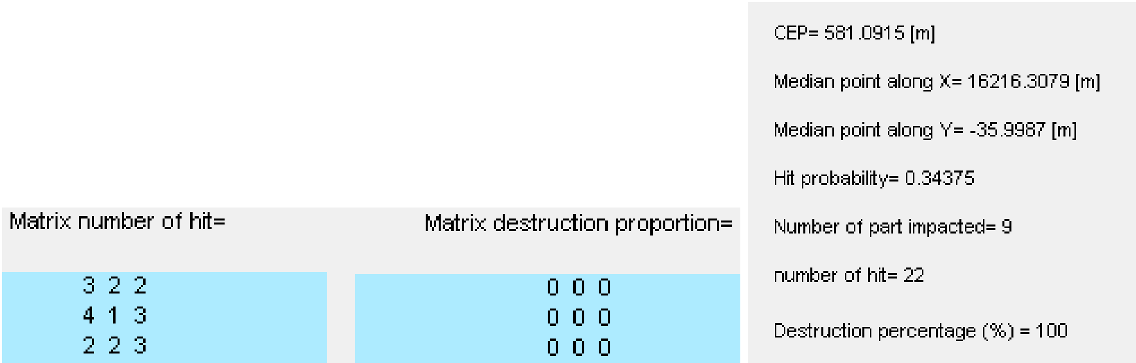

FIG. 5 Results in the case of a large scale target with (3 x 3) parts

Therefore we could add that, to entirely destroy the target with a 34% probability to hit, the first statistical number $D_{95\%}$ of rockets launching in order to obtain a 95% destruction of the target, is:

$$D_{95\%} = \left(\frac{95 * \text{number of life}}{100}\right) * \text{hit percentage}$$
$$D_{95\%} = \left(\frac{95 * 180}{100}\right) * \frac{34}{100} = 58 \tag{5}$$

As we can see on those different schemes results, from 64 launches, only 22 reach the target in 15 parts (Fig. 6 and 7). The hits are distributed on all the rings composing the target. The hit probability is about 34. The additional data of this simulation is the destruction percentage which is about 41%. In that case the target has a total of 3040 life points, $D_{95\%} = 242$.

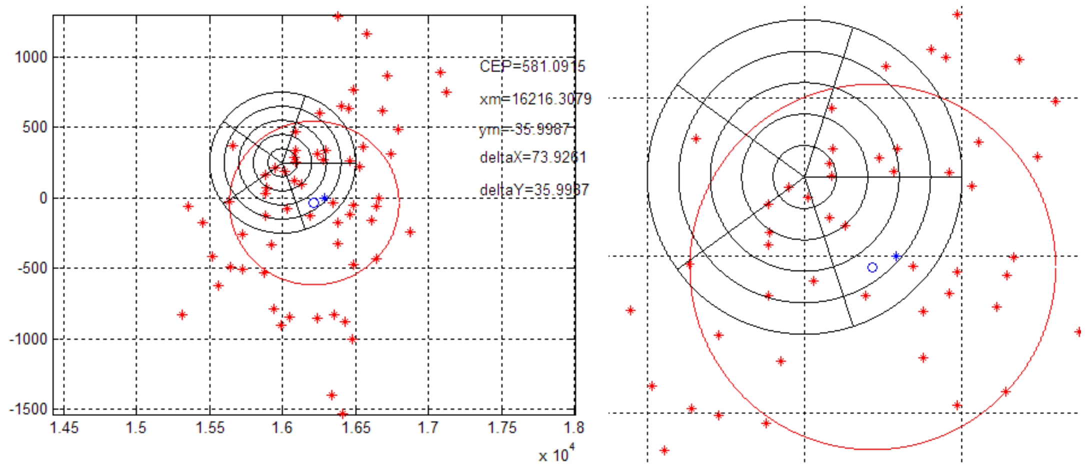

FIG. 6 Large scale target with (5 x 5) parts

CEP= 581.0915 [m]

Median point along X= 16216.3079 [m]

Median point along Y= -35.9987 [m]

Hit probability= 0.34375

Number of part impacted= 15

number of hit= 22

Destruction percentage (%) = 41.0667

Matrix number of hit=

2	0	1	1	0
1	0	0	1	1
3	0	0	2	1
1	0	1	2	0
2	0	0	1	2

Matrix destruction proportion=

28	44	38	36	46
20	38	36	22	26
0	24	24	2	14
0	16	6	0	10
0	6	6	0	0

FIG. 7 Results in the case of a large scale target with (5 x 5) parts

With a large number of parts (Fig. 8 and 9), the destruction percentage reaches only 6%, because only 19 parts are impacted and an even fewer number are impacted several times. Therefore only some peripheral ones reach 100% destruction, and the target remains quite unaffected. With a total of 5500 Life points, we have: $D_{95\%} = 1776$.

In this part we have mainly studied the algorithm capacity on several cases. We have seen the way the algorithm was creating random disruption in the initial conditions of launching. How it was able to compute several disturbed trajectories and the impacts on the ground. Furthermore we have conducted a statistic study on the effect of the disruption on the unguided rocket accuracy [7]. In addition the durability of various kinds of targets on several situations has been examined.

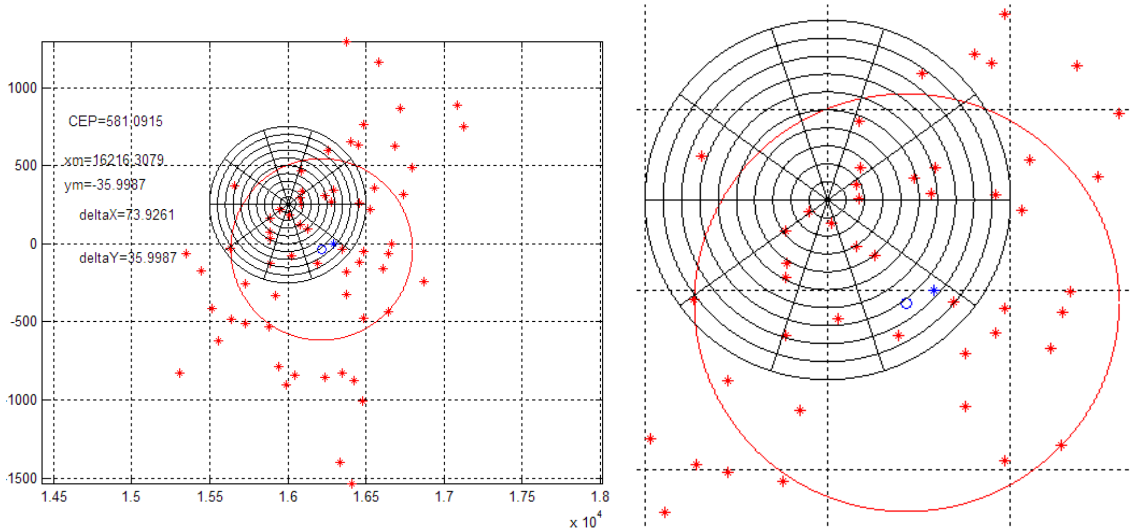

FIG. 8 Large scale target with (10 x 10) parts

Matrix number of hit=

0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	1	0	1	0	0
0	1	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	0	1	0
1	1	0	0	0	0	2	0	1	0
1	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	1	0	0
0	0	0	0	1	0	0	1	0	0
0	1	0	0	0	0	0	0	2	0
1	0	0	0	0	0	1	0	0	0

Matrix destruction proportion=

96	100	100	100	100	98	100	98	100	100
70	84	90	90	88	80	84	80	88	90
74	70	78	80	80	76	70	76	78	80
68	66	70	70	70	70	64	68	58	68
46	48	58	60	60	56	40	54	48	58
36	46	50	50	50	50	46	48	48	50
28	38	40	40	38	40	38	28	38	40
28	28	30	28	20	28	28	18	24	30
16	10	18	20	18	20	18	14	0	16
0	6	10	10	10	8	0	8	6	10

CEP= 581.0915 [m]

Median point along X= 16216.3079 [m]

Median point along Y= -35.9987 [m]

Hit probability= 0.34375

Number of part impacted= 19

number of hit= 22

Destruction percentage (%) = 6.9091

FIG. 9 Results in the case of a large scale target with (10 x 10) parts

This model remains limited by its targets panel, it can only generate circular ones. Furthermore the dividing logic of the targets can be improved, likewise the general geometry. Another way of improving this model would be to realize a Probability to Kill study. For this purpose, the condition when the target is considered killed has to be established. Two kinds of conditions can be chosen. The first one would be hit on some vital points. The second would involve reaching one pre-decided destruction percentage from which the target is considered destroyed.

CONCLUSIONS

In this study we ran a physical analysis conducting to a final equation system whose parameters were included in a ballistic model. Implementing it on computer program by creating a code with an interface, enabled us to find an approximate solution of the system thanks to Runge-Kutta method. It can simulate a trajectory whose order of magnitude in terms of range and velocity is matching with real launching parameters and results. This first code validates our previous ballistic theoretical system.

The last part of the study focused more precisely on validating an algorithm by analyzing multiple launchings [1] campaigns trajectories. This algorithm is able to simulate several launches sequences with initial conditions disturbed. This model aimed to describe the influence of perturbations in the initial conditions that could have big consequences on their accuracy on impact [7].

It also described how the nature of the target according to its position and its capacity to endure direct hits influenced the final results of a multiple rocket launching. The various and precise data resulting from those tests also allowed us to validate this program.

This program can also be developed in several ways. The model describing the probability to kill if hit can also be implemented on the algorithm. In addition, the statistical model more generally used in this program fits with the simple type of target and could be modified according to more realistic parameters.

REFERENCES

[1] C. Aramă, C. Rotaru, M. Aramă, E. Mihai, *A Comparative Analysis Between Two Types of Vehicles Which Could Be Used as UAV Launchers Mobile Platform,* Review of the Air Force Academy, No. 3(30), 2015;

[2] R. Brouchu, R. Lestage, *Three-Degree-of-Freedom (DOF) Missile Trajectory Simulation Model and Comparative Study with a High Fidelity 6DOF Model,* DRDCVALCARTIER-TM-2003-056, Technical Memorandum, Defence R&D, Canad-Valcartier, 2003;

[3] M. Khalil, H. Abdalla, O. Kamal, *Trajectory Prediction for a Typical Fin Stabilized Artillery Rocket,* Proc. Of the 13th International Conference on Aerospace Science&Aviation Technology ASAT-13, pp.1-14, Cairo, Egypt, 2009;

[4] C.E. Moldoveanu, S. Buono, P. Șomoiag, *Study of the Unguided Rocket Effectiveness,* MTA Review, Vol. XXVI, No. 1, 2016;

[5] C. Rotaru, G.C. Constantinescu, O. Ciuica, I. Circiu, E. Mihai, *Mathematical Model and CFD Analysis of Partially Premixed Combustion in a Turbojet,* Review of the Air Force Academy, No. 2(32), 2016;

[6] C. Rotaru, R.I. Edu, *Lift Cpability Prediction for Aerodynamic Configurations,* Review of the Air Force Academy, No. 3(27), 2014;

[7] T. Sailaranta, A. Siltavuori, S. Laine, B. Fagerstrom, *On Projectile Stability and Firing Acuracy,* Proc. Of the 20th International Symposium on Ballistics, pp. 195-202, Orlando, Fl, 2002;

[8] A.C. Sava, C.E. Ionescu, C. Enche, A.D. Poa, M. Cîmpeanu, *Analysis of Impact Between Piercing-Incendiary Bullets and Armoured Plate,* MTA Review, Vol. XXVI, No. 1, 2016.