Defence Technology 13 (2017) 200–205

Contents lists available at ScienceDirect

Defence Technology

journal homepage: www.elsevier.com/locate/dt

Effect of firing conditions & release height on terminal performance of submunitions and conditions for optimum height of release

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ARTICLE INFO

Article history:
Received 18 January 2017
Received in revised form
5 April 2017
Accepted 24 April 2017
Available online 27 April 2017

Keywords:
DPICM
Submunitions
Forward throw
Height of release/burst
Ejection velocity
Firing altitudes
Firing conditions
Point mass model
6 DOF

ABSTRACT

Submunitions should exhibit optimum terminal performance at target end when released from certain pre-determined height. Selection of an optimum height of release of the submunitions depends on the terminal parameters like forward throw, remaining velocity, impact angle and flight time. In this paper, the effects of initial firing conditions and height of release on terminal performance of submunitions discussed in detail. For different height of release, the relation between range and forward throw is also established & validated for a number of firing altitude and rocket configurations.
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1. Introduction

The family of scatter-able submunitions adds new dimension to the munition warfare. Submunitions can force the enemy in kill zones, change their direction of attack and spend time in clearing/breeching operation. Submunitions have always played a major role in denying battlefield & obstacle in mobility to armed forces and very effective to provide tactical advantage to the commander in the field. To gain tactical advantage, the submunition fields have to be pre-selected and laid. Laying of submunition fields manually is a time consuming and manpower intensive operation. An artillery rocket with Dual Purpose Improvised Conventional Munition (DPICM) warhead contains around 220 submunitions. The rocket with DPICM warhead follows the same ballistic trajectory similar to the rocket with a conventional high explosive warhead upto a predetermined height wherein it an electronic-time fuze is initiated to release the submunitions. An ejection mechanism eject submunitions from the warhead. A complete salvo firing of such rockets can lay around 2600 submunitions in the target area, in less than a minute. This provides high maneuverability with rapid, flexible means of delaying, harassing, paralyzing, canalizing or wearing down the enemy forces in both offensive and defensive operations [1,2].

Except for a very short duration after release, the submunition follows a steep trajectory until it reaches the designated target or ground. The trajectory of submunitions mainly depends on height, velocity and the flight path angle of the rocket at the point of release. Further, it also depends on the shape, size, mass, ejection velocity of the submunition, the aerodynamics of parachute, firing altitude and prevailing meteorological conditions [3,4].

The submunition trajectory will not be exactly vertical from burst point. The submunition will move forward due to the release velocity, release angle and ejection velocity. This additional travel in down range of the submunition is called the forward throw (see Fig. 1). The forward throw of the submunitions is an essential parameter while computing the fire parameters using either Firing Tables or Fire Prediction Software. This paper describes the effect of height of release, firing altitude and rocket configuration on the

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Peer review under responsibility of China Ordnance Society.

http://dx.doi.org/10.1016/j.dt.2017.04.005
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terminal parameters like impact velocity, impact angle, flight time and forward throw of the submunition at different map range. Achievable minimum and maximum ranges, near vertical impact angle, minimum impact velocity and time of flight are the parameters which govern the selection of an optimum height of release of the submunitions. This paper establishes the relation of forward throw with ranges for given rocket configuration, firing altitude and optimum height of release.

2. Simulation matrix

A six degree of freedom (6-DOF) Trajectory Model used to simulate the rocket trajectory from launch to height of release (HoR) and a Point Mass (PM) Trajectory Model used to simulate the trajectory of a single submunition from the point of its release from the rocket, at a given release height to the target/ground impact. 6 DOF trajectory model computes positions and velocities of the rocket up to given height of release which serves as initial conditions to PM along with ejection conditions and aerodynamics of submunitions. The point mass model simulates the trajectory of a submunition and forward throw and impact parameters of submunition are computed (see Fig. 2).

The simulation of submunition trajectory is carried out for following different cases and their combinations, as discussed in the subsequent paragraphs:

2.1. Height of release

Height of release of the submunitions is a crucial parameter determining the proper functioning of the submunition at an impact. The following six heights of release are selected for the study.

(a) 250 m.
(b) 500 m.
(c) 750 m.
(d) 1000 m.
(e) 1250 m.
(f) 1500 m.

2.2. Firing altitude

The following firing altitudes for both launcher and the target are considered for simulation to take into account of the meteorological effects.

(a) 0 m (Mean Sea Level - MSL).
(b) 2000m.
(c) 4000 m.
(d) 6000 m.

2.3. Effect of braking ring

Effect of two types of braking rings small and big, on the terminal performance of the submunitions is studied at different ranges along with rocket without any braking ring. A brake ring is a simple metallic annular ring attached to the ogive nose of the rocket to increase the drag that reduces the range to achieve steeper angle of descent.

3. Submunition trajectory inputs

The rocket is fired from a launcher and at a pre-designated height, the fuze initiates the warhead wherein the warhead casing splits into three petals with the help of a flexible linear shaped charge (FLSC) system. The submunitions are also given an initial ejection velocity with the help of an ejection mechanism, further aided by rocket's roll. After ejection, the ribbon attached to the submunition gets deployed which causes substantial reduction in the velocity of submunition, and further helps in attaining a steady state velocity.

3.1. Physical & initial inputs

Various inputs and initial conditions of submunition considered for the simulation are given below:

a) Mass = 0.23 kg.
b) Diameter = 25 mm.
c) Length = 50 mm.
d) Stabilization Mechanism = Ribbon.
e) Ejection Velocity in Lateral direction = 4 m/s.
f) Ejection Velocity in Forward direction = 50 m/s.

It is assumed that ejection velocities are constants at all release conditions (see Fig. 3).

3.2. Other inputs

Other inputs that play a significant role in the submunition trajectory are trajectory elements computed by 6-DOF of the rocket at desired height of release and ejection velocity. The C_D-Mach profile of DPICM with ribbon is shown in Fig. 4. All simulations were carried out under ICAO Std. Meteorological conditions. The summary of the input conditions given in Table 1.

4. Analysis of input to submunition trajectory from 6-DOF

The artillery rocket considered for this study can be fired in three different configurations i.e., without brake ring (WBR), with small brake ring (SBR) and with big brake ring (BBR) to achieve optimal angle of impact.

The remaining velocity of rocket at predetermined height of release of submunitions for mean sea level conditions and at high altitude conditions are shown in Figs. 5 and 6. The average rocket velocity at the time it releases the submunitions is ~350 m/s at sea level, for ranges between 20 km and 40 km. At high altitude conditions, the average rocket velocity at release is ~500 m/s for ranges between 40 km and 70 km.

5. Simulation results

The submunition trajectory is terminated as it reaches the firing altitude at the target end. The trajectory chart of submunitions, impact velocity, impact angle and time flight of submunition for different conditions are discussed in subsequent sections.

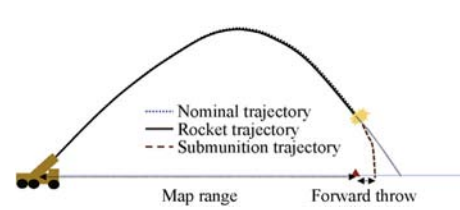

Fig. 1. Sketch of flight trajectory of a rocket with munition warhead.

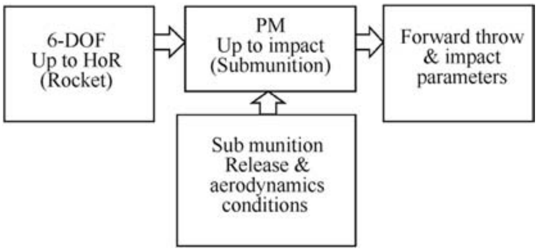

Fig. 2. Flow chart of simulation.

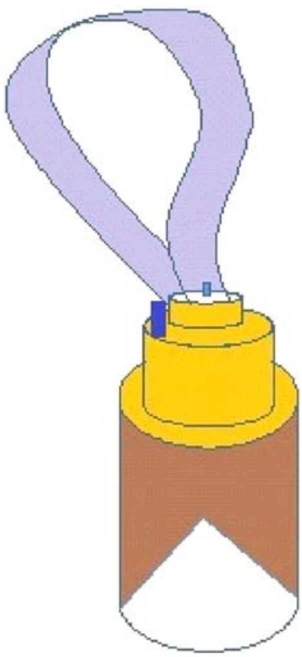

Fig. 3. DPICM.

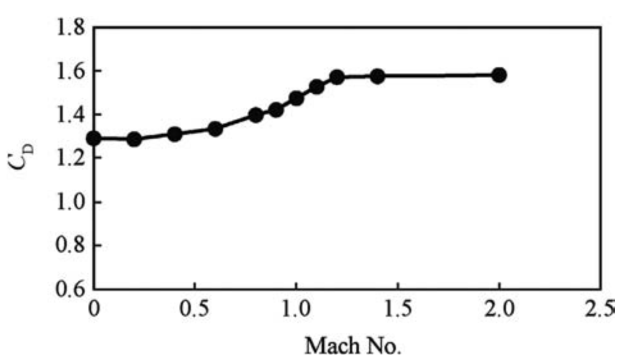

Fig. 4. Munition CD-Mach profile.

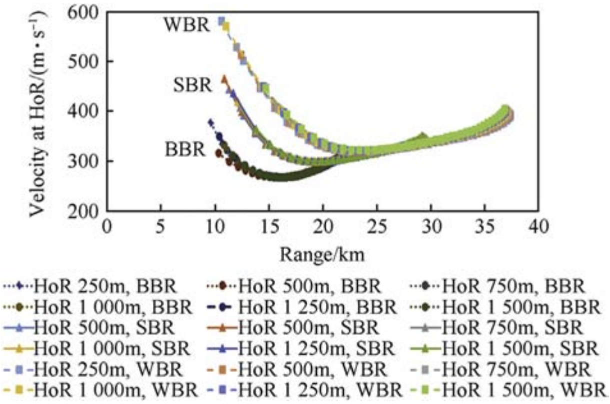

Fig. 5. Release velocity vs. range altitude = 0 m from MSL.

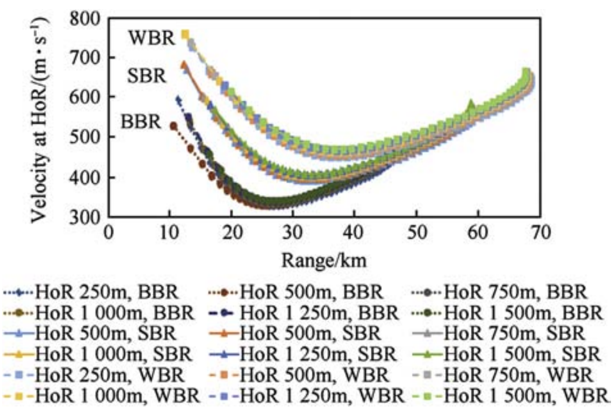

Fig. 6. Release velocity vs. range altitude = 6000 m from MSL.

Angle of descent at release height increases with respect to range. For maximum range, it reaches to ~ 70° at sea level and 63° at high altitude conditions as shown in Figs. 7 and 8, for different conditions.

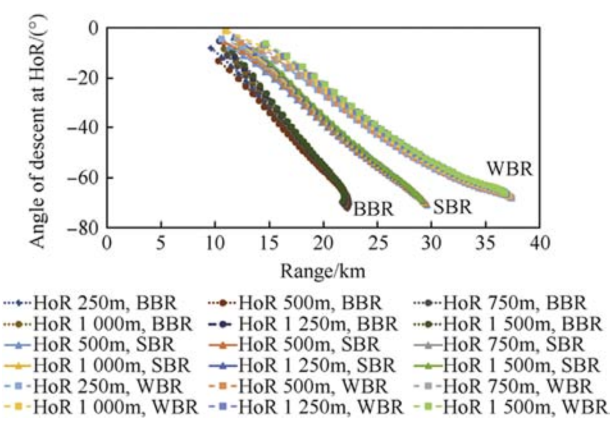

Fig. 7. Release angle vs. range altitude = 0 m from MSL.

5.1. Trajectories of submunitions

The trajectory of submunition is simulated using Point Mass model. The trajectory envelope of the submunitions for different release angles and height of release are shown in Figs. 9 and 10.

5.2. Impact velocity of submunitions

The submunitions are released with velocity around 350 m/s at sea level conditions and 500 m/s at 6000 m firing altitude. The submunitions start descending and stabilizes after some distance due to the drag offered by the ribbon. The velocity profile of submunition for sea level is shown Fig. 11. It is observed that velocity for the submunitions at time of landing is between 50 and 70 m/s which is sufficiently safe for its structure.

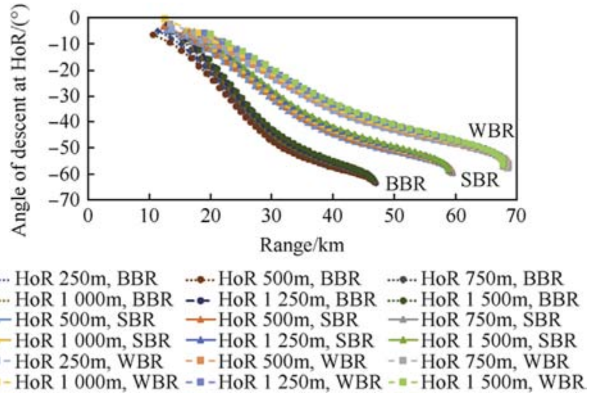

Fig. 8. Release angle vs. range altitude = 6000 m from MSL.

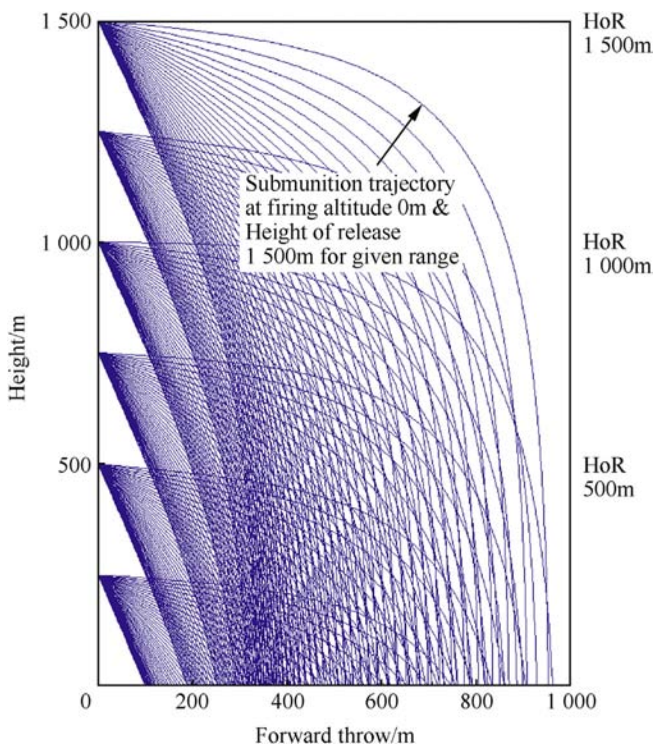

Fig. 9. Trajectory envelope of submunition for different heights and release angles. Altitude = 0 m from MSL.

5.3. Time of flight of submunitions

Time of flight is also another vital terminal parameter which is considered during the design, to decide the optimum height of release of the submunitions. The time of flight of submunition should be less than ~20s to avoid air burst due to self-destruction mode. Self-destruction mode is necessary as per international moratorium on anti-personal submunition to nullify undesirable consequence to friendly troops and civilians [5]. Based on this constraint, the maximum release height of the submunitions wherein the time of flight would remain less than 20s is approximately 1250 m (see Table 3).

5.4. Impact angle

This is an important parameter, as this submunition is meant for top attack to achieve enhanced shape charge performance. The minimum height of release of the submunition should be not less than 1000 m to ensure an impact angle of 70° for better terminal performance (see Fig. 12).

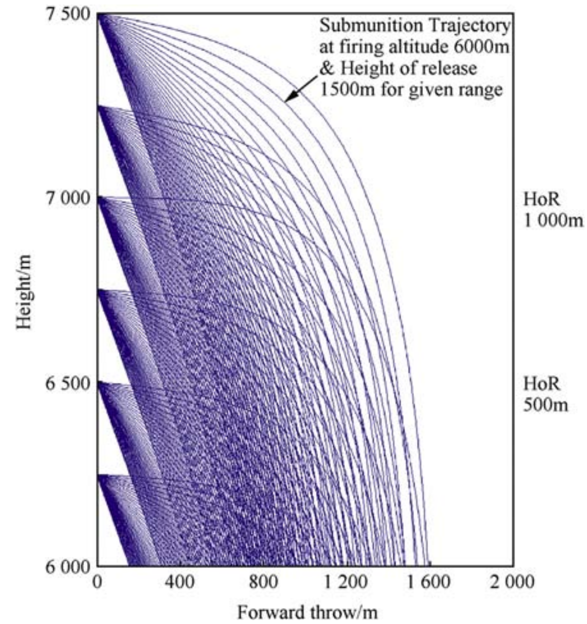

Fig. 10. Trajectory envelope of submunition for different heights and release angles. Altitude = 6000 m from MSL. The trajectory height (Y) of the submunitions at different height of release is plotted in the vertical axis against the distance travel by submunitions (X) or forward throw, in the horizontal axis. It is observed that, the forward throw increases with higher firing altitude as compared to sea level firing for all height of release.

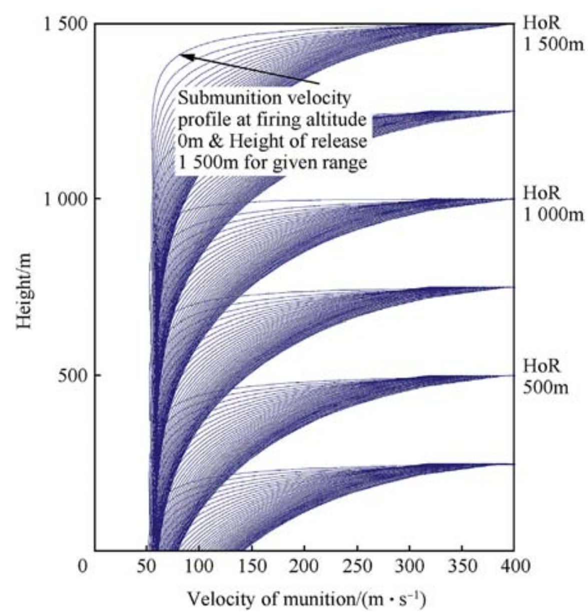

Fig. 11. Velocity vs. release height at various ranges. Altitude = 6000 m from MSL (see Table 2).

5.5. Achievable ranges

The rocket system should be capable of deploying submunitions at all operating ranges. The minimum range achieved using the

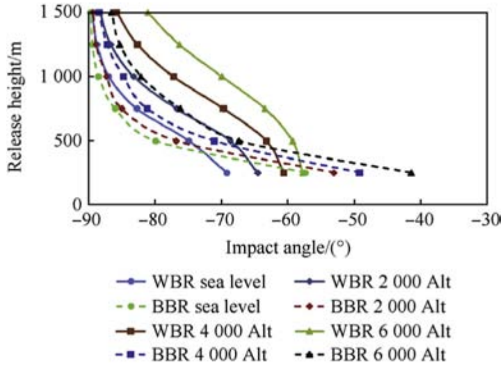

Fig. 12. Release height vs. impact angle.

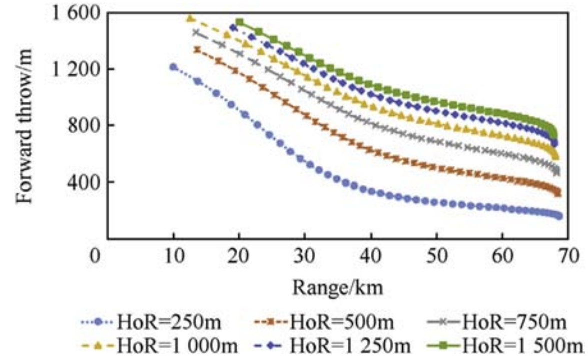

Fig. 15. Forward throw vs. range altitude: 6000 m from MSL.

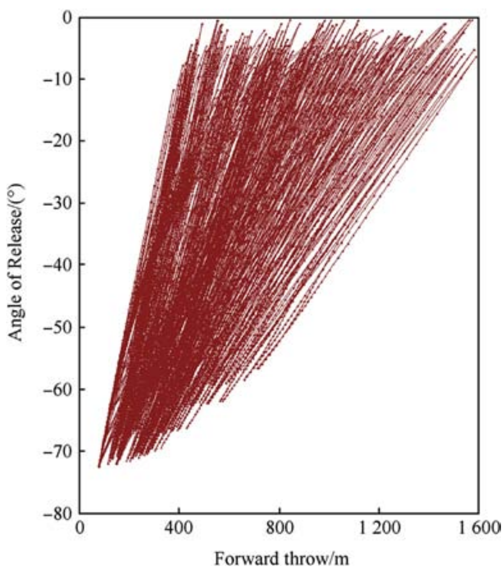

Fig. 13. Release Angle vs. Forward throw.

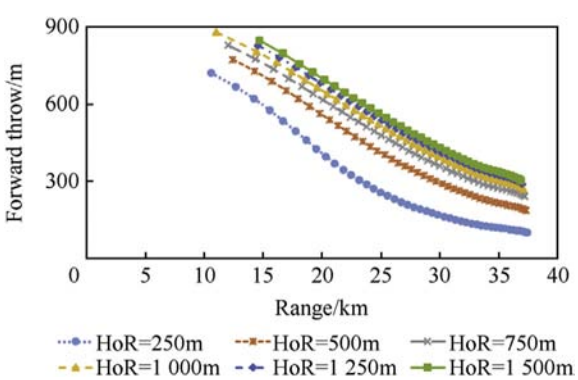

Fig. 14. Forward throw vs. range atltitue: 0 m from MSL.

rocket with big brake ring (BBR) and rocket without brake ring gives maximum range. Apex of trajectory for minimum range will decide the lower limit of height of release. The achievable ranges analysis is carried out for Mean Sea Level, 2000m, 4000 m and 6000 m altitude conditions for different height of release. It is observed that the minimum range for the deployment of DPICM for 1000 m height of release is around 11.2 km at sea level and 13 km at 6000 m altitude. The maximum range for 1000 m height of release is 37 km at sea level conditions and 67 km at 6000 m altitude conditions. The lower height of release gives more advantages for minimum and maximum range coverage.

5.6. Relationship between release angle and forward throw

Forward Throw of the submunitions is inversely proportional to its release angle and it is linear. When release angle is less, the trajectory is shallow and hence, the forward throw is more and as the release angle increases, the trajectory becomes steeper and the forward throw decreases, irrespective of submunitions and rocket configurations (see Fig. 13).

5.7. Relationship between range and forward throw

The forward throw is higher at minimum ranges than the maximum range because at minimum ranges the release angle is very shallow and for maximum ranges the release angle is steeper. Moreover, the horizontal velocity components for lower ranges will be higher than the maximum ranges at release point. (see Figs. 14 and 15).

5.8. Numerical expression of forward throw & trial results

Forward throw can be expressed as a function of range or firing angle for given set of conditions. For fire prediction, the correction in range due to forward throw is required to be carried out. In fire prediction process, map range is the main input to compute firing angle and hence it is necessary to build the forward throw relation with respect to map range instead of firing angle to cater its correction. A third degree polynomial expression in term of range (x) is fitted. The sample of polynomial coefficients is shown in Table 4.

$$Forward\ Throw(x) = a_3x^3 + a_2x^2 + a_1x + a_0$$

The forward throw for a desired range, at firing altitude 1500 m & at height of release 1000 m, can obtained by interpolation after evaluating case A & B. Similarly, forward throw for height of release 1100 m at firing altitude 4000 m can obtained by interpolation after evaluating case C & D. The polynomial of degree 3 chosen to keep the error minimum within ±10 m in map range. The same is implemented in fire prediction software, to predict fire parameters during dynamic trials. The accuracy of the conventional high

Table 1
Input variable and their sources.

No.	Variable	Source
1	Initial position (*X*, *Y*, *Z*)	Output of 6-DOF at predetermined height
2	Initial velocity (*V*)	
3	Initial release angle (θ)	
4	Ejection velocity (v)	Ejection mechanism
5	Aerodynamics coefficients	Fig. 4
6	Atmospheric Conditions	ICAO Standard

Table 2
Impact velocity of munitions.

Height of release/m	Impact velocity/($m \cdot s^{-1}$)			
	Altitude = 0 m from MSL		Altitude = 6000 m from MSL	
	Min	Max	Min	Max
250	52	135	67	306
500	50	62	65	168
750	49	55	65	107
1000	49	52	64	70
1250	49	52	64	67
1500	49	52	64	67

Table 3
Time of flight of submunitions.

Height of release/m	Time of flight/s			
	Altitude = 0 m from MSL		Altitude = 6000 m from MSL	
	Min	Max	Min	Max
250	1.1	7.5	0.6	7.5
500	3.6	11.9	1.6	11.1
750	7.4	16.6	1.0	14.9
1000	11.3	21.8	5.9	18.7
1250	15.5	24.6	8.7	20.1
1500	19.5	28.9	11.4	23.0

Table 4
Coefficients of polynomial for wbr.

Case	Configuration	a_3	a_2	a_1	a_0
A	Firing altitude = 0 m Height of release = 1000 m	2.28E-11	−1.42E-06	0.001	1009.7
B	Firing altitude = 2000 m Height of release = 1000 m	7.03E-12	−2.11E-07	−0.028	1447.9
C	Firing altitude = 4000 m Height of release = 1000 m	−3.47E-12	7.26E-07	−0.055	1956.3
D	Firing altitude = 4000 m Height of release = 1250 m	−4.15E-12	7.97E-07	−0.058	2031.3

explosive rocket system is less than 1.5% of range for all ballistic variations. Explicit and exact forward measurement of throw is difficult, but overall accuracy including forward throw and other ballistic variations achieved was less than 1.5% of range for sample map ranges and with different brake ring configurations at different firing altitude. The precise functionality of the submunitions and the accuracy level of high explosive warhead is upheld for submunition type warhead at height of release 1000 m indicates the simulated forward throw and impact parameters are in order.

6. Conclusions

In this study, a generic hybrid trajectory model is developed to optimize the submunition parameters as well as its release conditions. The model being generic, it can be used for any type of submunition with minimum modifications. Extensive simulations carried out using this model for DPICM warhead, indicated that, height of release of the submunitions is an important parameter to achieve safe landing and optimum performance of submunitions at the target end. Height of release is optimized based on the higher impact angle and lower time of flight. At the same time, selected height of release give maximum achievable range coverage. This study shows for designed DPICM configuration, 1000 m height of release of the submunitions have better terminal performance.

Similarly, the forward throw of the submunitions depends mainly on the release conditions, submunition aerodynamics and atmospheric conditions. Shallow trajectories have more forward throw than the steeper trajectories and forward throw increases with increase in height of release. Further, due to atmospheric conditions, forward throw at higher altitude is more as compared to sea level. The polynomial relation between forward throw and range is established for a given rocket configuration, height of firing altitude and height of release. This relation is used in firing tables and fire prediction software and validated in field trials.

Acknowledgement

The authors sincerely acknowledge the support and encouragement of Warhead Group, HR Council Members and Director ARDE for preparing and publishing this work.

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