Penetration Enhancement of Kinetic Energy Penetrators After Precision Hit

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[1]**Abstract:** Purpose – The main purpose is to enhance the probability of **Kinetic Energy Penetrators (**KEP) hit and subsequent defeat of the hardened buried targets (Bunkers) by using modern techniques in missions to ensure precise neutralization of th e high valued target in cost effective manner in all-weather capabilities. These bunkers are becoming high value targets to be neutralized.

Design/Methodology/Approach - The modeling and simulation approach to validate the design and operational configuration and its warfare efficacy. The scenario is modeled using Matlab in minute details. The aerodynamic performance based upon rocket motor thrust data was achieved. The effectiveness was assessed using Bar's criteria of perforation in concrete structures. After considering the effect of all the parameters, KEP is designed.

Findings – It is observed that hitting of modified vehicle with a speed of 130 m/s will be able to perforate the specified target. For this purpose, selection of propulsion, drop height and wind/perturbation modeling etc. need to carefully chosen to achiev e the success of campaign.

Limitations – The centre of gravity is assumed to be fixed during entire flight. No roll motion is assumed.

Results - The designed Criteria of penetration is successfully achieved to defeat the target by achievement of hit velocity (139.7 m/s), which is greater than critical velocity V_c (129.76 m/s). To attain the penetration, projectile drop at different heights has been performed on the same RCC plate emulating bunker. Conclusions were drawn iteratively that drop of the KEP from 500 m by using rocket motor of 200 Kgf / 2 sec thrust has resulted in optimal defeat of the target.

Originality/value – The work is based addressing issue of defeat hardened targets using home developed KEP by adding unique reinforcements in design, which are aided by software simulation work.

***Index Terms* -** Kinetic Energy Penetrator, Guidance and Control, Warhead, Trajectory, 6 degrees of freedom.

I. INTRODUCTION

KEP is armament weapon system and aerospace Vehicle (AV), which is used against hard RCC targets like underground trenches and bunkers in all types of terrains (Ismail Abdul Rahman, Ahmad Zaidi, Qadir Bux Alias Imran Latif et. al., 2011), (G.J.H.H. Peskes, TNO, 2001) and (G. Weihrauch, H.F. Lehr, ISL, 1977). It was decided to enhance the probability of KEP hit on the target by using modern techniques in missions to ensure precise neutralization of the high valued target in cost effective manner in all-weather capabilities. These targets are underground bunkers with RCC top in battle hardened configurations. To defeat these targets, penetration type weapons need to be deployed. Many types of options are available in this application worldwide in small and long stand-off launch mechanisms (R. Jeanquartier, W. Odermatt, 1995). However, in small stand-offs, KEP offers feasible cost-effective solution with simple handling features. The limitation of recent KEP systems is accuracy of hit, which is enhanced by propo sed control and guidance reinforcements in quick turn-around time as per this approach paper (P. Garnell, 1980) and (SK Ray, 2007).

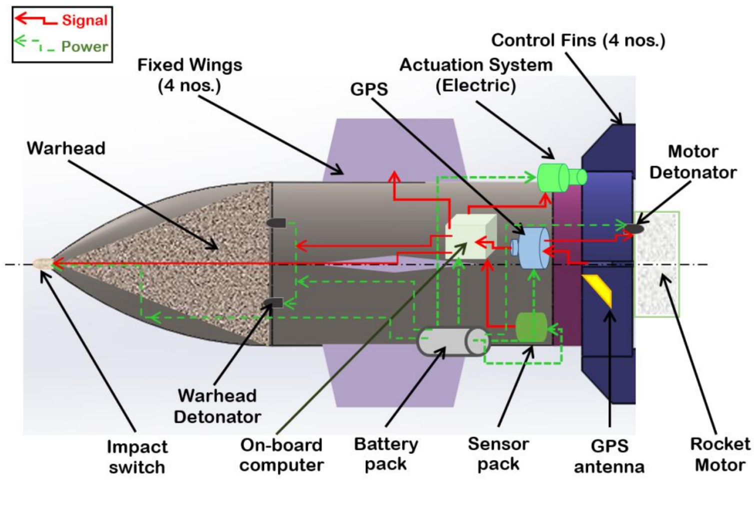

Fig. 1 Proposed KEP Configuration

1.1 Objectives

To reinforce design of KEP (fig. 1) to augment its precision hit capabilities by implementing novel modifications in hardware, mission and battle damage assessment including related follow up actions. This involves the KEP trials data and carries out f easibility study of lethality enhancements using design improvement iterations.

1.2 KEP Existing Configuration

KEP device should be a small, low-cost autonomous weapon, which can be fired from aircraft, drone, hot air balloon, LTA aircraft etc. It penetrates into target to defeat it by perforation followed by explosive detonation. Its constructional details and s ubsystems are as per figure 1(SS Chin, 1961) and (Subhash Chander, 2021).

2. KEP TARGET PATTERN STUDIES

The impact on target is detailed by empirical relations using the featured data values (Ismail Abdul Rahman, Ahmad Zaidi, Qadir Bux Alias Imran Latif et. al., 2011). It explains few formulae are very important to predict KEP performance mathematically.

3. THEORETICAL & EXPERIMENTAL INVESTIGATION

The self-explanatory trial configuration & sequence used in existing trials is as follows (fig.2). It involves meticulous plan to be executed in order to access the performance of KEP in the role of defeat of the target, which is estimated theoretically fore hand. The scenario is consisting of following operations:

- Preparation of KEP in the desired configuration and integrating into drone in proposed launch configurations after mandatory self-health checks of KEP and drone
- Energization of batteries and its activation after suitable checklist of pre-trial checks
- Design of trajectory of drone and drop plan and its execution to reach target location, which also involve double check of ta rget location and drop arming.
- Drop of KEP after release command initialization with all safeties and fire of rocket motor after appropriate sequencing.
- Hit of target at its centroid and ensure its defeat by utilizing achievement of damage pattern as per design
- Battlefield damage assessment of the target and execution of post-trial sequencing including post-trial analysis

3.1 Target Details

The normal strength concrete mixtures were developed with maximum aggregate dimensions of 2000 mm, 2000 mm and 120 mm (thickness) typically (fig. 2). The aggregate was limestone gravel from a local quarry, which followed the grading curve A/B 16 according to DIN 1045. The ratio between aggregate and cement matrix was kept constant. The binder was Portland cement with a characteristic compressive strength of 25 MPa/mm^2. The w/c-ratio was 0.60.

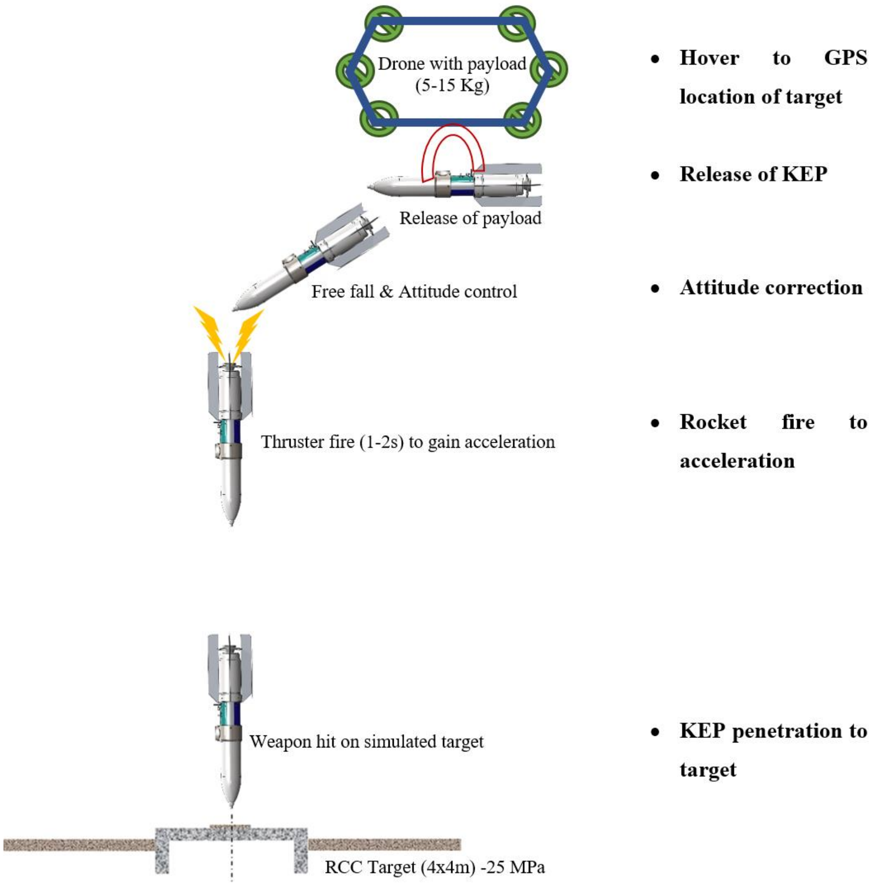

Figure 2 Trial scenario

3.2 Trial Observations

KEPs were tested to access its efficacy simulated by RCC plates of 2000x2000 mm (thickness is varied from 25-650 mm). KEP was dropped from a drone at a height of 100-150 m. This was done by taking GPS co-ordinates of the target. During analysis of this data, few observations are recorded as follows:

- Attitude angles and profile of the KEP can be improved by providing stabilization system and attitude hold/control autopilot
- Accuracy of target hit can be worked better by embedding some new technologies
- Launch mechanisms can be bettered to increase the reliability of the systems
- Handling characteristics, preparedness time, safeties and target diversification can be carried out by inception of innovative modifications in key systems

3.3 The Launch Sequence

The conceptual solution to the problem, which has been explained earlier will be a Rocket propelled Projectile, which needs to be released from a drone just over an identified building (target) from a height of about 100 m (This height varied in simulation).

3.4 Modeling & Simulation Approach

To analyze the entire problem of KEP firing, modeling and simulation approach is also applied. It was achieved by using Mathworks Matlab software.

3.4.1 RCC plate penetration based on Barr's equation

A case study of RCC plate penetration test cases was designed and analyzed for Barr's equation. It was decided to vary the RCC plate thickness to obtain an operational band of target defeats under various types of proposed KEP configurations.

Barr's equation is true in the circumstances with following assumptions:

- The RCC plate and KEP is monolithic and homogeneous
- No drift is observed during trials
- Perforations in the RCC plate are due to impact of KEP

The test cases are created as follows as per standard calibers of artillery by using varied diameter of KEP

- 68 mm
- 100 mm
- 120 mm
- 155 mm
- 170 mm

Further, RCC Slab thickness variation from 10 mm to 1000 mm was done in steps of 20 mm.

Under these varied conditions, the valid theoretical velocities test data is obtained. The data is merged and cross plotted in fig. 3.

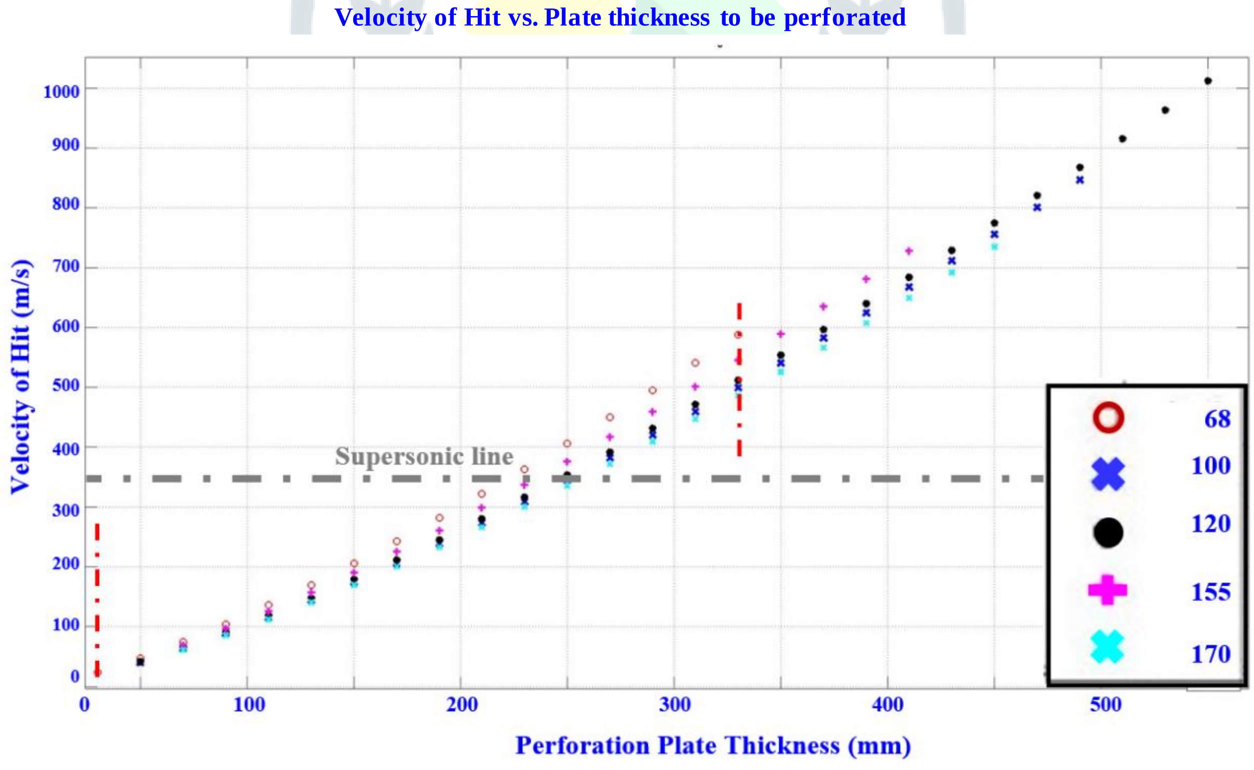

Fig. 3 Cross plot of Slab thickness penetrated and Velocity of Impact

The start portion of the plot in fig. 3 is zoomed and shown in fig. 4 for better clarity. The data obtained show that theoretically; 68 mm diameter KEP can defeat 10-335 mm RCC plate of specified reinforcements.

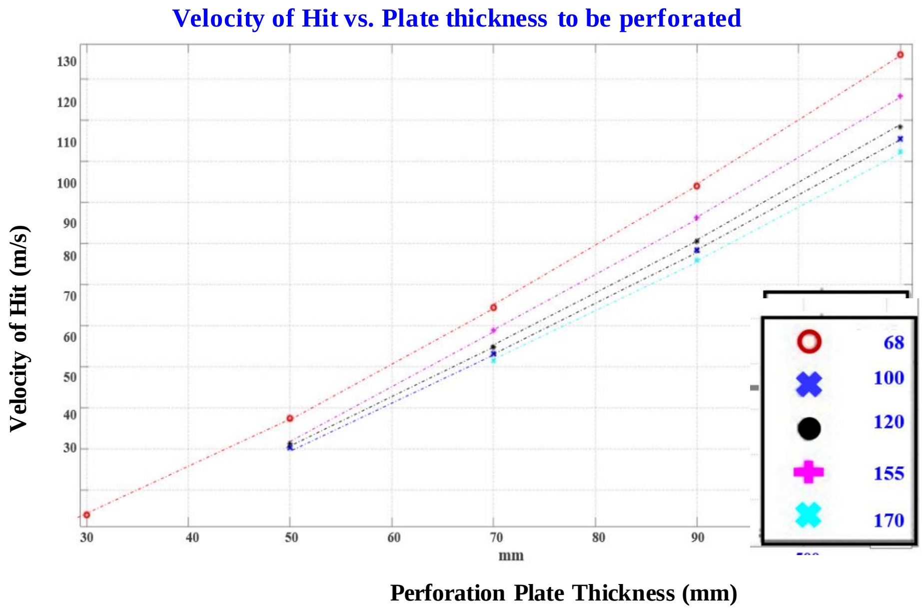

Fig. 4 Cross plot of Slab thickness penetrated and Velocity of Impact (Zoomed Start)

3.4.2 Development of RCC penetration criteria

A RCC plate penetration by dropping KEP is developed using Mathworks Matlab GUI programming. This is designed and analyzed on the basis of Barr's equation. Assumptions are same as para 3.4.1 with few additional assumptions.

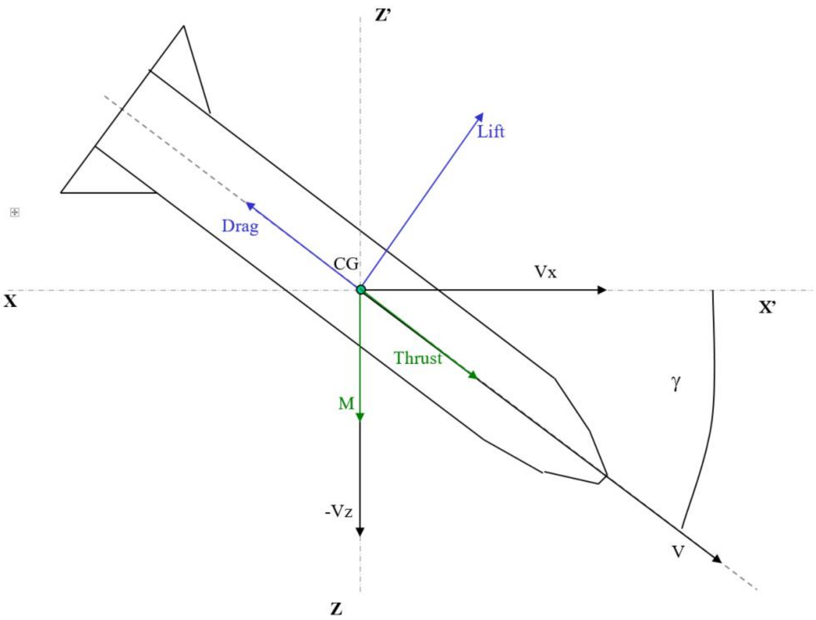

Fig. 5 Simplified force diagram of KEP

The simplified force diagram (figure 5) is as under (P. Garnell, 1980). Varied thrust conditions using different types of rocket motors.

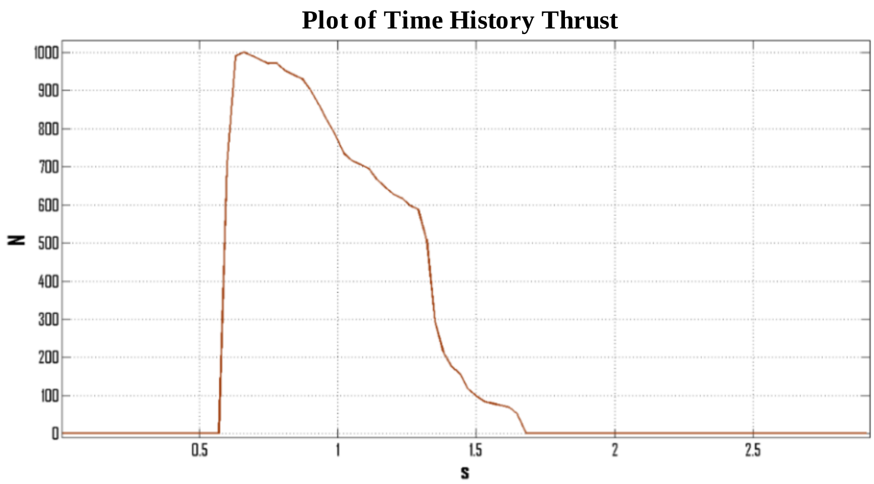

Fig. 6 Thrust generated plot

3.4.3 Performance Analysis of typical case

Typical performance 100 kgf/1s thrust case is examined through the graphs obtained (fig. 6 to fig. 7) above. These graphs show height, range, slant range, attitude angle γ and other allied parameters were plotted to show the simpler case. But actually, drag is major parameter in trajectory. So, 1 **DOF** was **added** with realistic **drag**. The results are obtained by ignoring thrust. Later on, 100 kgf/200 kgf thrust is added to change the dynamics (SS Chin, 1961) & (Subhash Chander, TK Jindal, 2014).

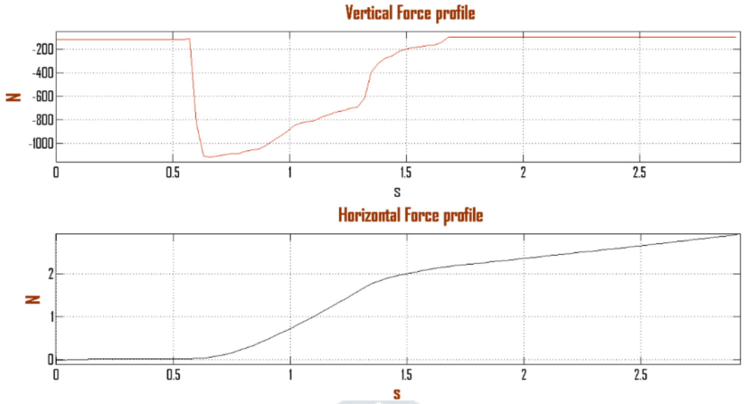

Fig. 7 Forces generated plot

The release ang vas varied from -30° to 90°. For doing this exercise, the vehicle is released from various heights by fixing release angle (γ). Optimal height for a particular case (A parameter set including drop angle, Drone speed, winds, dynamics etc.) was obtained. Further, optimal release angle was identified. This result in down range and slant range were also optimized. The time of flight was also tweaked for optimized results. The various parameters are shown in graphs. These graphs show Height, range, slant range, attitude angle γ and other allied parameters variations, so they are plotted to show the trend pictorially (Subhash Chander, TK Jindal, 2013).

After getting the new optimum launch angle, γ and release height H_{rel}, change of drag coefficient C_{d0} (from 0 to 0.35), was forced and the effect was studied in detail through specially designed computer software designed for this purpose and plotted. The extracted data collected is put in a table also for ready reference**.** In short, from this exercise, it is clear that if the C_{d0} can be reduced say from 0.3 to 0.2, the advantage in range extension will be achieved. Also, by this exercise optimum launch height is increased, this will prove to be crucial for safety of carrier. These variations are quite significant. **So, it makes a point that if C_{d0} should be restricted to achieve high performance from KEP.**

The next para deals with comparative study of tweaked release heights and other related parameters in detail and its impact on mission planning and goals achievement exercises (Subhash Chander, TK Jindal, 2014) & (G. Weihrauch, H.F. Lehr, ISL, 1977).

3.4.3.1 Comparative Performance Analysis of typical case with drop height variations

In the present case, the KEP is dropped from 150 m & 500 m, the achieved performance parameters are cross-plotted for performance evaluation after using computational processes. To cover the process of enhancement of lethality of existing KEP and various futuristic aspects related to technology to take up design / development process as per findings of this simulation.

Key parameters selected are as per table 1:

Parameter	Unit	Option 1	Option 2
Set 2 - Propulsion	Kgf/s	200 / 1	
Set 2 – KEP Diameter /mass	Mm / Kg	100/10	
Fuel	Kg	4.00	
Plate Thickness of RCC slab	mm	120	
RCC Density rho	Kg/m^3	2300	
Reinforcement in RCC_qty	%	0.5	
Ultimate compressive strength of concrete used	MPa	25	
Drop height	m	150	500
Hit Vel	m/s	120.20	142.15
Critical Vel., Vc	m/s	129.76	
Mission		Fail to penetrate	Success

Table 1 Parameters settings

3.4.3.2 Simulated Lethality Analysis

Matlab based GUI is designed to access the performance of the KEP by embedding the relevant equations at back end. Superimposing Barr's equation on aerodynamic performance simulation can predict, whether it can penetrate the target or not.

Case 1:

Fig. 8 shows the failed mission simulations as the velocity of KEP is less than desired V_c, wherein projectile fail to penetrate in RCC plate due achievement of less hit velocity (120.2 m/s) as compared to critical velocity (129.76 m/s).

Fig. 8 Penetrable Velocity and achieved velocity cross-plot

Case 2:

Another case is examined, which is as shown in fig. 9, wherein projectile is successful to penetrate in same RCC plate due achievement of hit velocity (139.7 m/s), which is greater than V_c as compared to critical velocity (129.76 m/s). (V. Hohler, A.J. Stilp, EMI, 1977) & (G.J.H.H. Peskes, TNO, 2001)

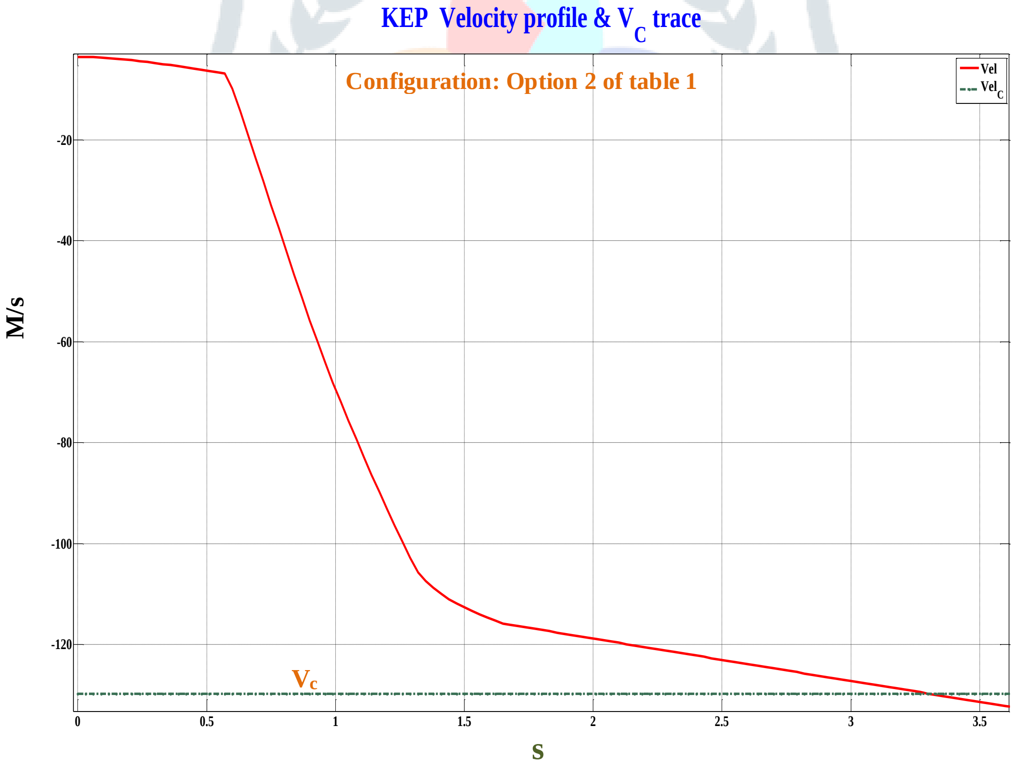

Fig. 9 Penetrable Velocity and achieved successful velocity cross-plot

4.0 SUGGESTED KEP FIRING SCENARIO IMPROVEMENTS (DROP HEIGHT -150M)

4.1 Main Steps of Trial Mission (Amended)

The trial configuration is as per fig. 10 and following amendments are proposed to be implemented after careful study of the existing trial mission:

- Mark the centroid of the target
- Place a position sensor at the centroid & acquire the position (Latitude, longitude & Elevation etc.)
- Feed this position co-ordinates to the GPS of drone (manually or through software by data link)

- Take the drone to launch point

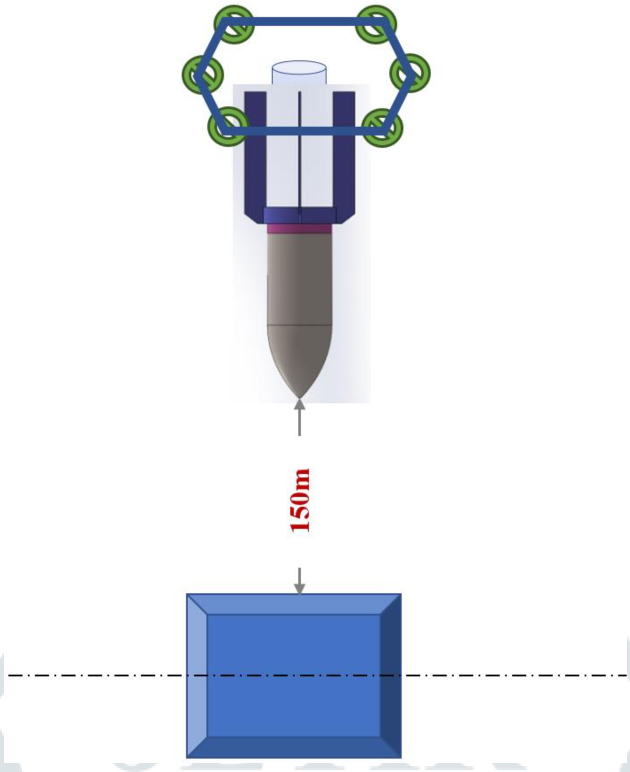

Figure 10 Simplified Firing Scenario Diagram

- Mount the KEP & carryout checkout
- Fly the drone through GPS navigation to the target
- Remote releasing of the KEP after reaching overhead target
- KEP travels through air and hits target PCC plate
- Impact cum delay fuze is fired to make a hole in plate and KEP penetrate inside bunker
- BDA can be observed through Drone's on-board camera, which may be configured to provide feed to launch station/drone pilot or observation tower or other consoles

4.2 Issues observed in previous trials & handling remedies

After analysing the observations of previous trials, the issues were recorded and follow-up remedial proposals were made as per table 2.

S. No.	Issues	Remedial proposals
1	Target co-ordinators	Use high precision master device
2	Drone navigational errors	Use better piloting skills & aids
3	Drop stabilization	Improve drop mechanisms
4	Attitude, Spin & drift during drop	• Better build quality and packaging plan to ensure better CG & weight distribution techniques • Better release mechanism to ensure correct attitude and spin arrest mechanism • Better/automated drop to preclude drop drift errors
5	Winds drift affects	Issues correctional commands (Control is needed)
6	Warhead lethality	• Ensure correct firing sequencing with improved detonator reliability • Timely & proper precursor firing • Monolithic entry of KEP inside PCC plated bunker can affect mission • Main charge firing timing/delay operations will also affect the outcome of trial • Timely & proper main charge firing

Table 2 Remedial proposals

5. CONCLUSIONS

With the above modifications incorporated in KEP, overall system performance has improved, as key problem areas have been addressed by improving glide and flight trajectory to achieve the desired terminal performance. Perforation and lethality are also significantly enhanced and can be better further too. 3 degrees of freedom model can be enhanced to 6 degrees of freedom mode to run to estimate the performance of the KEP and suggest corrective actions. It is inferred as follows:

- The rocket motor thrust/thrust duration increase will enhance the penetration depth
- Drop height increases can also benefit penetration depth and enhance hit accuracy due more homing time.

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BIOGRAPHIES

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