Medium Calibre Gun Ammunition Effectiveness Studies

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ABSTRACT

This paper deals with a particular aspect of Vulnerability and Lethality (V/L) assessments, namely the modelling of new threat mechanisms. Three examples of munitions with such mechanisms are the frangible payload projectiles, the Penetrator with Enhanced Lateral Efficiency (PELE) and the Air Burst Munitions (ABM). The terminal ballistics effects of these rounds cannot be accurately described with most presently available V/L models.

An essential input for any V/L model is an accurate description of the key properties that constitute the (primary) damage mechanism. Some modern anti-aircraft munitions apply a radical different approach when it comes to damage due to penetration and fragmentation. Traditionally, anti-aircraft munitions damage the target either by means of a single penetrator, or fragments initiated by an explosive charge. The munition types discussed here share a common characteristic, namely the introduction of a laterally directed damaging effect at impact with little or no use of an explosive.

Frangible projectiles are designed to break up into smaller fragments, each time a (part of) the initial penetrator hits a target. The fragmentation of PELE projectiles is also directly dependent on the resistance of the target material. ABM produce a similar overall damage pattern compared to frangible and PELE projectiles, albeit that the ABM payload release requires a preset initiation. These new munitions require new terminal ballistic models for use in V/L models. Some of the implications for future modelling efforts are discussed.

The examples provided in this paper are ample proof of the growing importance of medium calibre munition developments, also in applications other than ground-to-air and air-to-air warfare. An up-to-date V/L environment is not only of importance to the military user, but equally so for the designer of new munitions. Dedicated munition models are a valuable aid in the early identification of feasible concepts and contribute to the reduction of development costs.

1.0 INTRODUCTION

TNO Defence, Security and Safety has a long-standing tradition of research into target vulnerability, ammunition lethality and weapon system effectiveness. While the majority of studies in this area are still performed under assignment from the Netherlands' Ministry of Defence, a growing portion occurs under assignment from defence industry. A combination of advanced experimental techniques and computer simulations is applied to study the Vulnerability and Lethality (V/L) of land, sea and air systems.

This paper deals with a particular part of the V/L assessment, namely the modelling of modern threat mechanisms. Recent history has shown some remarkable new developments in medium calibre anti-aircraft munitions. In a sense, these developments are in response to an ongoing trend in modern fighter design. The well-known 'layers of survivability' (don't be seen, don't be hit, don't be killed) are often implemented from the outside in by means of such examples as stealth technology, improved countermeasures and improved agility. Furthermore, metallic airframe structures continue to become replaced by composite ones. In response to this trend, medium calibre ammunition designers improved on its threat potential. One example is the development of low drag projectiles. Another, potentially more far-reaching development is the introduction of a laterally directed damaging effect at impact [1].

Three different types of these modern medium calibre anti-aircraft munitions will be discussed in more detail. This paper highlights some terminal ballistic characteristics of the munitions, implications for modelling in the V/L environment, and an application in the context of firepower studies.

2.0 NEW MUNITION TYPES

Conventional fragmenting threats for aircraft are missile warheads or medium calibre fragmenting projectiles. These threats create fragments in order to damage and kill internal components. Newly developed medium calibre munitions tend to become more insensitive, with little or no explosive charges, and containing a special 'fragmenting payload'. Munitions with such a payload create a directed cloud of fragments upon impact, although without an explosive initiation. Three examples of such munitions are the frangible payload projectiles, the Penetrator with Enhanced Lateral Efficiency (PELE) and the Air Burst Munitions (ABM). The terminal ballistics effects of these rounds cannot be accurately described with most presently available V/L models.

2.1 Frangible projectiles

The first available frangible projectiles were sub-calibre projectiles and therefore used for ground-to-air warfare. Due to their apparent good penetration capabilities they also came operational in some ground-to-ground warfare applications. Subsequently, full-calibre frangible projectiles were developed for aircraft gun systems in air-to-air and air-to-ground warfare. The calibre range of frangible payload projectiles is currently between 20 to 35 mm. A 12.7 mm calibre is under development.

The frangible penetrator is similar to a conventional armour piercing penetrator in both construction and flight characteristics. The main difference lays in the material properties of the heavy metal alloy penetrator. While details may differ, all frangible munitions share a penetrator, which consists totally or in part of a frangible material (e.g. tungsten alloy). A cross-section view of both a sub-calibre and a full-calibre projectile are shown in Figure 1.

FIGURE 1: Cross sections of a sub-calibre (FAPDS) and a full calibre (FAP) frangible projectile.

Against light armour, where the effect of an armour piercing penetrator is to punch straight through, the frangible penetrator is meant to break up into smaller fragments, without the aid of an explosive charge inside the projectile. From firing trials against plate array targets it was found that the fragmentation process of the frangible penetrator takes place within a relatively confined cone. Plate array targets are well-suited to simulate the perforation resistance of an aircraft structure. A typical illustration of the penetrator break-up is shown in Figure 2. The frangible projectile strikes a target, and as a result the projectile breaks up into a number of fragments. As these fragments hit another target plate, they will break up again. This process repeats for each of the fragments until the kinetic energy of the fragments is too small to perforate the next target plate.

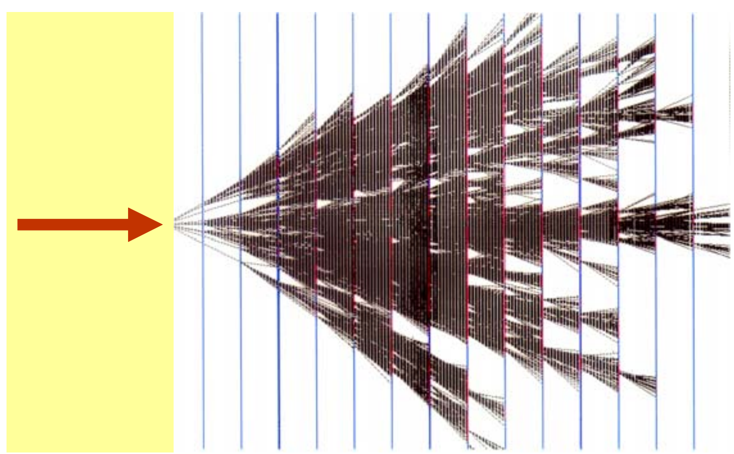

FIGURE 2: Side view of penetrating frangible fragments in a plate array (projectile from left).

2.2 PELE projectiles

The development of PELE projectiles followed the development of frangible projectiles, and their potential application in modern warfare is similar to the frangible ones. The currently available calibre range of PELE projectiles is between 12.7 and 120 mm.

PELE ammunition is a fragmenting munition. Fragmentation of the projectile is achieved by means of some type of tube made from a high density material (e.g. tungsten or steel), filled with an inner core from a low density material (e.g. plastic or aluminium). The PELE effect is such that the stresses at impact build inside the inner core, pushing the higher density material outwards. This results in a mushrooming effect, shown in Figure 3. The PELE design can further by optimised against specific targets by adjusting the material densities between inner core and outer tube, or even by using two different materials in the design of the tube.

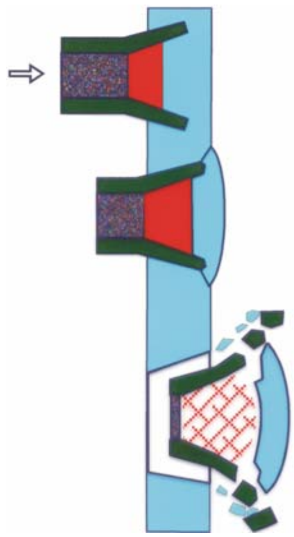

FIGURE 3: Illustration of the PELE effect.

2.3 Air Burst munitions

ABM are available for some time as air-to-ground anti-aircraft ammunition. In contrast to the frangible and PELE types discussed in the previous sections, ABM are not completely inert. The payload of ABM consists of a number of pellets of a certain mass, geometry and material type. The working principle of ABM is such that the payload is released after a certain period of time, in such a way that the pellets remain in a relatively confined cone. This is accomplished by a release mechanism that uses a small explosive charge. The spread of the pellets is subsequently accomplished by the spin of the projectile (i.e. a rifled gun barrel) combined with its forward velocity. The pellets release time is determined by a timer, which is programmed when the projectile travels through the gun barrel. Hence, air burst type munition is essentially an integral part of a dedicated weapon system. An illustration of ABM is shown in Figure 4.

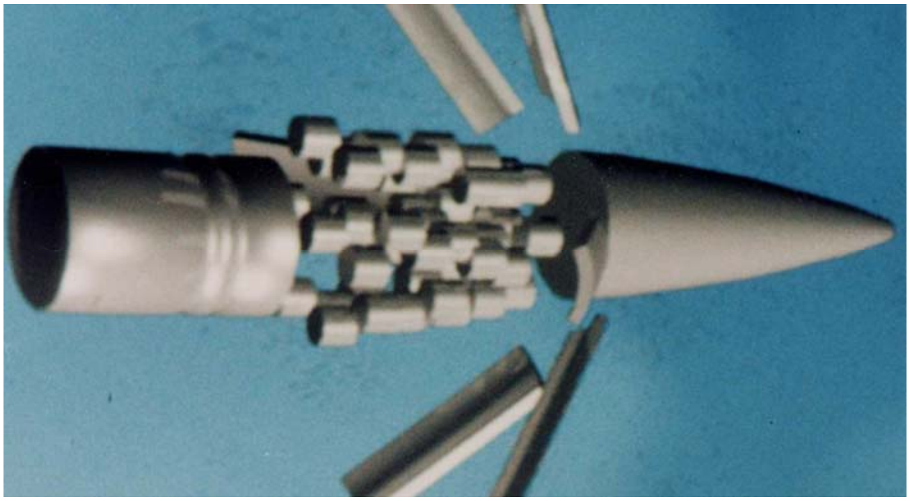

FIGURE 4: Illustration of the air burst principle.

3.0 VULNERABILITY AND LETHALITY ENVIRONMENT

Over many years, TNO Defence, Security and Safety has developed and continues to improve its own V/L model, called TARVAC (TARget Vulnerability Assessment Code) to investigate the ammunition effects against a target. TARVAC is designed to calculate the effectiveness of specific ammunition and/or the vulnerability of a specific target. TARVAC is a tri-service code, able to deal with ships, tanks, infantry fighting vehicles and aircraft, and several kinds of threats, like missile warheads, CE, KE, AP and HE munitions. TARVAC is based on the so-called shot line approach. The trajectory of a projectile (e.g. a fragment, a KE penetrator, or a shaped charge jet) is represented by a straight line, the shot line, which is traced through the target. Along the shot line, calculations are performed, indicating whether the projectile is able to penetrate the target, and what kind of damage is inflicted to critical components. The extent of the inflicted damage eventually determines the ammunition effectiveness or the vulnerability of the target.

TARVAC is an important node in a more comprehensive V/L environment. For instance, research into the survivability of the individual soldier system can also be assessed with tools like ComputerMan (a model originating from the United States) and combined with TARVAC output. An example of combined tooling in this manner may occur when research is conducted into the survivability of personnel inside vehicles.

TNO Defence, Security and Safety adops a systems approach to its research and continuously matches its V/L environment with the requirements from specific studies. Figure 5 illustrates the systems approach by showing that munition characteristics that ultimately yield certain effectiveness, originate from the properties of specific components. TARVAC typically comes into play when the effects of the projectile-target interaction are to be assessed. However, the key performance of the projectile may ultimately be contained in components like the ignition train or the aerodynamic properties. It is of great importance for a sound assessment to be aware of the influence of individual munition components on the ammunition as a whole, and to be able to describe that influence in the model environment. The approach of linked models is not new to TNO; it is put into practice for many years in related research areas like lifetime assessment and surveillance of many types of munitions.

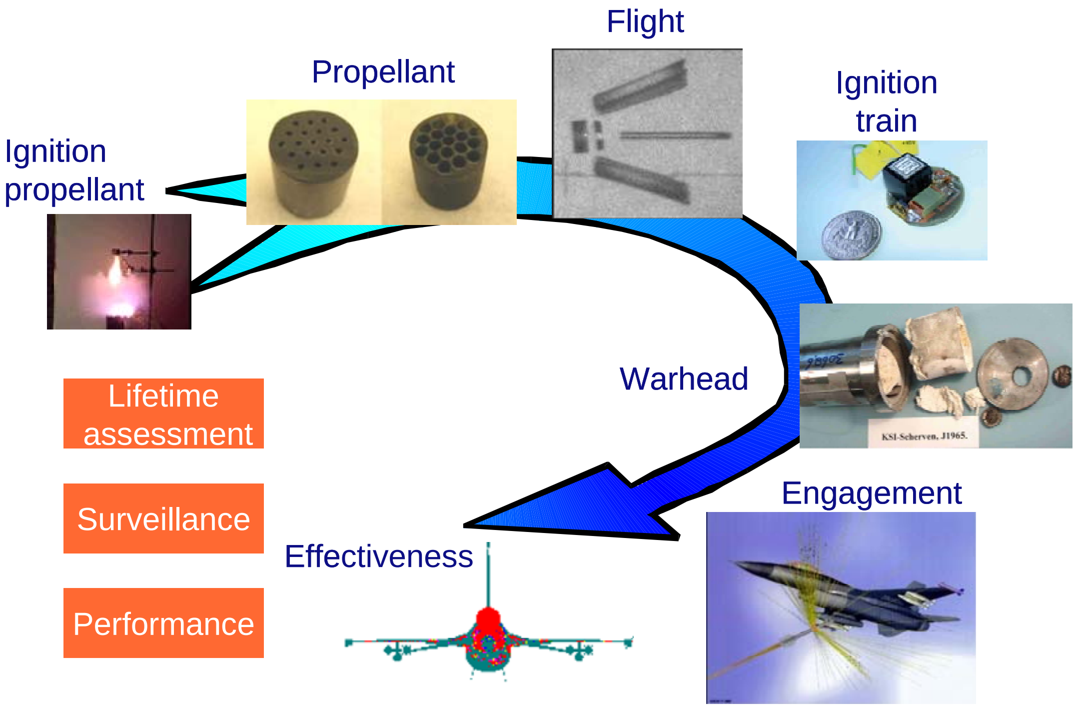

FIGURE 5: A systems approach in munition modelling.

4.0 MUNITION MODELS DEVELOPMENT

An essential input for any V/L environment is of course an accurate description of the key properties that constitute the (primary) damage mechanism. Section 2 has shown that modern anti-aircraft munition types may apply a radical different approach when it comes to damage due to fragments. Some implications for the modelling of terminal ballistic munition characteristics are discussed in the following.

4.1 Frangible munition models

As discussed in Section 2.1, an impacting frangible projectile breaks up into a number of fragments and as these fragments hit another target plate, they will break up again. This cascade-type process repeats for each of the fragments until the kinetic energy of the fragments is too small to perforate the next target plate. At the start of the fragmentation process, the relatively high fragment density inside a small cone causes many fragments to be ‘parasitic’. This means that such fragments will pass the target plate through holes created by the perforation from preceding fragments. Hence, parasitic fragments will pass without interaction and without breaking up, and will consequently conserve their mass and velocity until they hit some other plate deeper inside the target array. The cascade process results in many (typically thousands) of fragments. A typical damage pattern caused by a frangible penetrator is shown in Figure 6.

FIGURE 6: Damage inside a target plate array due to a frangible penetrator.

Frangible munition models should account for (ideally) all influencing factors that contribute to the overall damage pattern. Influencing factors as far as the penetrator is concerned are the overall configuration and the characteristics of the material from which it is made. Regarding the fragmentation process, influencing factors are at least the penetrator configuration and material, the impact velocity and impact angle of the frangible parts, together with the thickness of the target and the characteristics of the material from which it is made. Furthermore, the behaviour of parasitic fragments should be made explicit in any model. Note that the number of parasitic fragments is also influenced by the spacing of the plates in a plate array target.

TNO Defence, Security and Safety is involved in the development of frangible projectiles since the first firing trials in 1984. From 1987 onwards TNO conducted or witnessed extensive experimentation with 25 mm and 35 mm sub-calibre frangible projectiles against plate array targets. The results were used to develop a terminal ballistic model that is continuously improved as new insights and test results emerge. Over the years, TNO incorporated results from firings with other calibres and frangible Fragment Simulating Projectiles (FSP). Also, the terminal ballistic model is validated with firings on real targets. Hence, effectiveness assessment of frangible projectiles is well within TNO's current research capabilities.

4.2 PELE munition models

A PELE projectile bears some similarities with a frangible projectile from a modelling perspective. The fragmentation process depends strongly on the interaction of the penetrator with the target. For instance, a well-known phenomenon regarding the mushrooming effect shown in Figure 3 is that the extent of the mushrooming depends on the impact velocity (more at higher velocity) and hardness of the target (more with higher hardness). PELE munition models should account for (ideally) all influencing factors that contribute to the overall damage pattern. Influencing factors as far as the penetrator is concerned are the overall configuration and the characteristics of the material from which it is made. Regarding the fragmentation process, influencing factors are at least the penetrator configuration and material, the impact velocity and impact angle of the fragments, together with the thickness of the target and the characteristics of the material from which it is made. A damage pattern from a PELE penetrator is shown in Figure 7.

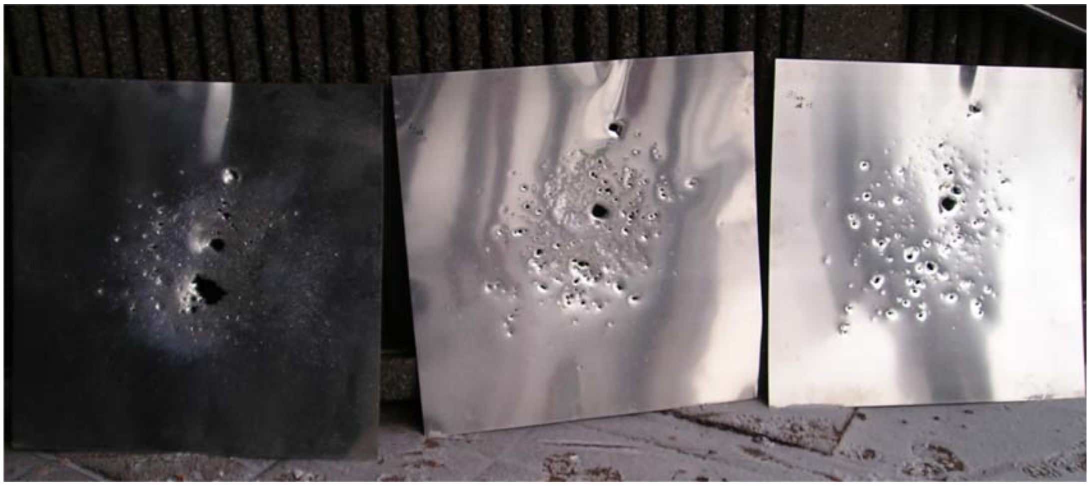

FIGURE 7: Damage of a plate array target due to a PELE penetrator.

TNO Defence, Security and Safety has been involved in several trail series with PELE munitions. However, in the development of the PELE concept, many different configurations have been tested. Because of the large variability in the properties of these configurations, it proves difficult to establish a terminal ballistic model of a general nature. To date, TNO is able to perform effectiveness simulations for specific PELE projectiles which are based on inputs from a limited set of dedicated firing trails.

4.3 Air burst munition models

The particular manner in which ABM disperses its pellets on the target involves the development of two special features in any ABM terminal ballistic model, namely a sub-projectile dispersion model and a sub-projectile penetration model. To be able to come up with the right dispersion of the pellets, input is required from a ground firing table, the spin of the projectile as function of the range, and the shape of the pellets (because of the drag properties). A typical damage pattern caused by ABM is shown in Figure 8, together with the output of a sub-projectile dispersion model. The sub-projectile penetration model basically consists of a relationship between the penetration capacity of an individual pellet, and its impact velocity. However, note that this relationship is influenced by the impact angle of the pellet on the target.

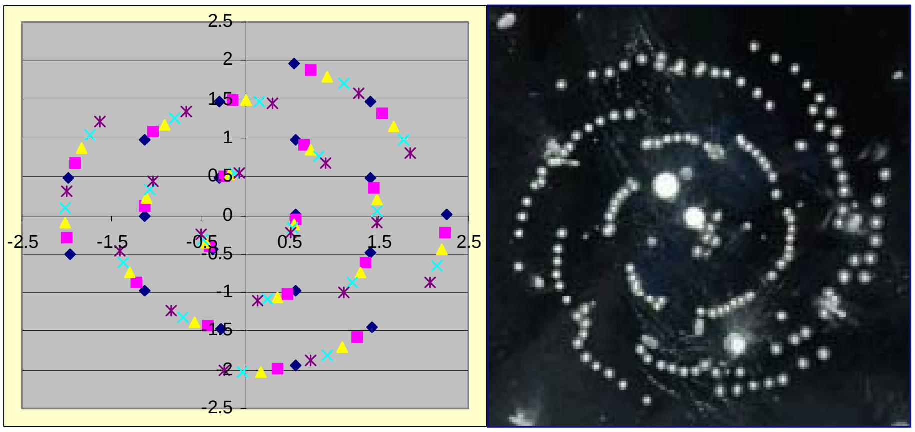

FIGURE 8: Typical damage pattern for ABM pellets (right) and corresponding dispersion model.

5.0 INCORPORATION IN V/L ASSESSMENTS

The terminal ballistic condition is the starting point for the TARVAC V/L model. From the engagement onwards the attention is focused on the interaction of the threat with the target, the damage to components of the target, the change of the threat characteristics, the functional behaviour of the components and the consequences for the technical system functionalities of the target. Finally, this information is combined in platform kill probabilities. The two most basic inputs for any V/L assessment are the munition model (i.e. the topic of this paper) and the target model. The latter involves a detailed description of the target's geometrical, physical, functional and system properties. The following is partly taken from [2] and is intended to show the impact of the munition model on the overall V/L assessment.

To cover the broad and complex spectrum of V/L interest, TNO has defined a number of 'spaces' inside TARVAC to enable a better understanding of the ongoing processes, the expertise required, as well as the transformation from one space into another. The (time dependent) spaces to be considered are:

- $Space_1(t)$: the physical space;
- $Space_2(t)$: the functional component space;
- $Space_3(t)$: the technical system space;
- $Space_4(t)$: the technical-operational system space.

5.1 Physical space

The physical space includes the actual munition-target interaction process, the determination of physical damage to components and the altering of threat characteristics. At this moment the physical space is able to handle threat mechanisms which propagate along a straight line. The mathematical intersection of the threat in the target can be determined with for instance a ray trace library. The penetration capability of the penetrator combined with the ballistic resistance of the intersected armour, structure and components enables an assessment of the penetration depth in the target.

The component damage process gathers information to enable the description of the physical state of a component. This information comprises parameters directly related to the threat, such as (degradation of) mass, velocity, energy, and momentum. Additionally, it comprises parameters in terms of hole size, hole volume, and suchlike. These parameters are determined for every impact on the component. Of course, not all components are essential for the performance of the target. The damage state is determined for the components essential for the functioning of the target. Similarly, not all information is relevant for the functioning of a specific component. Depending on the type of component one may decide that only hole sizes greater than a certain minimum value should be considered or that the striking momentum should be more than a certain value. To this end, TARVAC filters the information based on criteria that are typical to a certain component. In case of multiple threats and threat mechanisms, the information is aggregated to overall physical parameters that determine the physical damage to the component.

5.2 Functional component space

Each component may possess one or more functions. For each of these functions TARVAC determines the probability of kill of that component's functionality, based on the physical state of the component. As most components are sensitive for various types of damage processes, TARVAC enables the user to identify one or more relations between a characteristic parameter and the probability of kill of that particular function. To this end, the user may define a relationship for the probability of a functional failure. The probability of a functional kill of the component is determined for each parameter describing the physical damage state of that component. The outcome of the individual functional assessments is subsequently combined into an overall probability of kill of that specific component function.

5.3 Technical system space

For each target (platform), a system failure tree is drawn up, which combines the component's functional states through a construct of logical operators. Examples of such operators are AND, OR, NOT, but also semi-logical operators like MIN or MAX. The system state of a (sub)system can subsequently be expressed in a probability of system kill (e.g. a firepower kill for a battle tank).

5.4 Technical-operational system space

In TARVAC, the system technical state and the system operational state are split up explicitly. The ratio behind this approach is that it becomes increasingly difficult to define what is actually meant by the operational user when he/she for instance requires a firepower kill in a particular operational context. With this feature it is possible to match the specific need without having to restart calculations.

6.0 APPLICATION IN FIREPOWER STUDIES

An example of the application of modern terminal ballistic munition models in present-day V/L assessments is the establishment of munition payload optimisation for the new CV9035 infantry fighting vehicle of the Netherlands' armed forces. Starting point for the firing doctrine study was a specific 35 mm ABM, the so-called Kinetic Energy Time Fuze (KETF). Figure 9 illustrates the result for a representative air threat, the Mi-24 'Hind' attack helicopter. In this case, the KETF round was fired at the target from three different orientations and a slant range of 2000 m. The figure shows a notable depression in the curves representing the number of pellets for a particular initiation distance (i.e. the distance between the intended payload release point and the target). This indicates that there is a minimum number of pellets to obtain a given lethality.

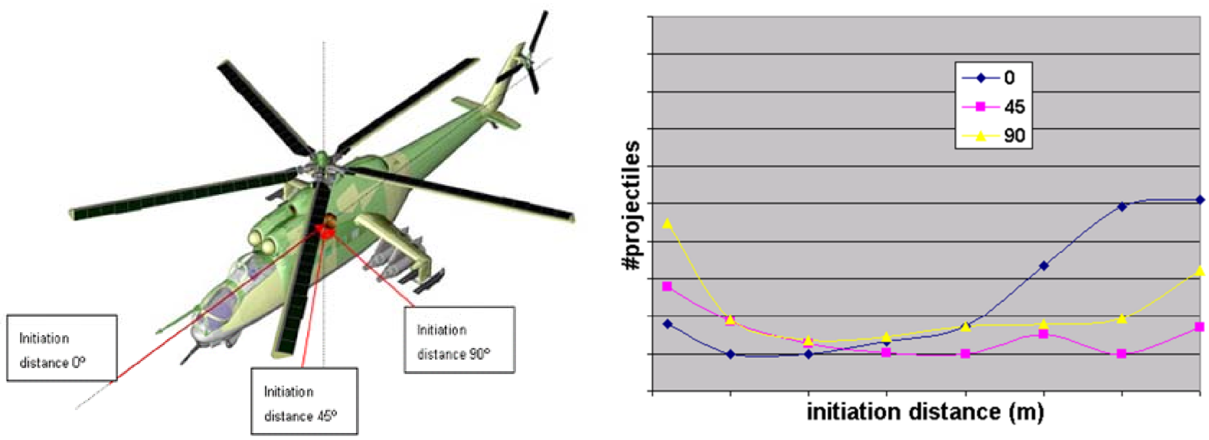

FIGURE 9: Effectiveness assessment of 35 mm KETF against a Mi-24 'Hind'.

In a similar manner, the optimal effectiveness of 35 mm KETF was established against other targets, eventually resulting in firing doctrines for the CV9035. However, another notable result was that fact that the KETF design could be further optimized as a direct result of the effectiveness calculations.

7.0 CONCLUSIONS

The examples provided in this paper are ample proof of the growing importance of medium calibre munition developments. The search for munition types that can successfully engage modern aircraft had resulted in such new developments as frangible, PELE and air burst projectiles. However, it is duly noted that these new munitions also become increasingly popular in ground-to-ground warfare, against land vehicles and urban targets, and in a maritime environment.

It is therefore essential to keep the V/L environment up-to-date, since the quality of the assessments depends so heavily on the quality of the munition models, the target models, and the way that all of the relevant parameters are processed into information that the military user actually requires.

Additionally, in-depth knowledge of the effectiveness of modern munition types is equally of benefit to the developers of these munitions. The employment of V/L tools early in the munition design cycle enables a rapid identification of feasible and indeed desirable concepts. Later on, development costs can be further reduced through the optimal use of models, replacing at least some of the expensive firing trials.

8.0 REFERENCES

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