Chapter 1

INTRODUCTION

1.1 Motivation

All countries need a defence system for protecting their civilians and properties from enemies and terrorists. In this aspect three systems are working for protecting their countries army, navy and air force. They use many war weapons and ammunition for the same purpose. Penetrator is one of such ancient weapons used to control the enemies distantly; hence nowadays it is used in all three systems (army, navy and air force system).

Traditionally, armour against anti-tank weapons consists of very thick high-performance steel. The development of warheads has increased the penetration capability to such an extent that the use of homogeneous armour steel has become impossible in vehicle applications. At the same time there is an increased demand for lower weight and better protection of military vehicles. To achieve weight-efficient armour against the capable threats by long-rod projectiles and shaped charge warheads, modern armour makes use of arrangements of weight-efficient materials and components that are intended to disturb the threat before it hits the target.

1.2 Purpose of Ammunition

To protect, the system needs weapons, missile, targets, and armour equipments. The ballistic targets include a variety of projectiles and missiles that can perform exo-atmospheric penetrators. Usually they carry a payload of instrumentation or high explosives [1, 2] and must survive the violent actions that accompany impact and sudden deceleration, all the while protecting and preserving the payload. Examples are penetrators built to attack buried military targets surrounded by thick concrete ceilings and walls, or penetrators built to carry instrumentation to measure the geologic character of the earth or properties of arctic ice as they pass through it. However, in this work, the trajectories / projectiles of short-range ballistic targets which are endo-atmospheric penetrator, is physically
smaller/lighter [3, 4], high strength [5, 6] and easier to move and deploy to be more specific and simple.

1.3 Functional Segmented Penetrator

However, constraints imposed by currently fielded gun systems and the possibility of future; high-velocity gun systems have prompted researchers to examine other penetrator concepts. Segmented rods [7, 8], in principle, provide an advantage over unitary rods because they offer multiple benefits from the transient high-pressure phase of penetration, while the delay between multiple impacts allows time for the penetration cavity to enlarge. The segmented, kinetic energy projectile is formed by stacking various liners in a single weapon, for effectively producing a long penetrator able to do significantly enhancing penetration. Every individual liner forms a separate penetrator, so that the liners are successively fired and allow for a greater overall target penetration. The assembly includes multiple liners that are separated by multiple separators. Monolithic and segmented impactor having the same mass for hypervelocity penetration into various media were conducted in numerous studies [9,10,11].

1.4 Targets Geometry

The study of the interaction between a long segmented penetrator and an angled plate is extremely helpful for understanding the segmented rod interaction with an explosive reactive armour cassette. The result of this interaction is influenced by numerous factors like rod and plate velocity, diameter, density, strength, obliquity angle, thickness. The penetration and perforation of fixed, angled steel plates by hypervelocity tungsten-alloy projectiles are examined.

1.5 Type of Analysis on Penetrators

The layered penetrator is one of the modern weapons to acquire military and efficiently replaced monolithic rods. In this direction some research works were focused on mulit-layered rods and targets experimentally [9,12,26], numerically [7, 13-15] and analytically [16-22]. Some research works are available in experimental verification. Corran [12] showed that in some cases multilayered contact targets are stronger than monolithic targets provided that the layers setup changes the target
response from shearing to bending and membrane stretching. Franz [20] investigated the penetration resistance of multi-layered targets. The ballistic penetration of multiple thin plates was separated by an air gap experimentally. Backman [21] worked on soft aluminium targets and multilayered target and his work layer target showed better resistance to impacts. Borvik [15] investigated the penetration of blunt, conical and hemispherical-nosed projectiles on steel plates; it was found that the nose shape of the projectile considerably affected both the energy absorption mechanism and the failure mode of the target during penetration. The ballistic limit velocities were about equal and close to 300m/s for hemispherical and conical projectiles, while they were considerably lower for blunt projectiles. Blunt projectiles caused failure by plugging, which is dominated by shear banding, while hemispherical and conical projectiles penetrated the target mainly by pushing the material in front of the projectile aside.

Most research work has been focused on the effect of external parameters on impact performance, but to the author’s knowledge none of the work is focused on internal parameters, i.e. shape eccentricity, manufacturing defects, pits, etc. The defects also influence the performance of penetrators. Defects in nose geometry cause projectile bending, yawing and breakage when it strikes the target usually at very high velocity [22-24].

1.6 Scope of the project

In this research work the performance of the monolithic and segmented penetrators is optimized to achieve better penetration depth by varying the L/D and S/D ratios with different nose shapes keeping the velocity of impact, orientation of impact normal and materials constant.

An impact is a high force or shock applied over a short time period when two or more bodies collide. Such a force or acceleration usually has a greater effect than a lower force applied over a proportionally longer time period. The effect depends critically on the velocity of the body relative to one another. At normal speeds, during a perfectly inelastic collision, an object struck by a projectile will deform, and this deformation will absorb most, or even all, of the force of the collision. Viewed from the conservation of energy perspective, the kinetic energy of the projectile is changed
into heat and sound energy, as a result of the deformations and vibrations induced in the struck object. However, these deformations and vibrations cannot occur instantaneously. A high-velocity impact does not provide sufficient time for these deformations and vibrations to occur. Thus, the struck material behaves as if it were more brittle than it is, and the majority of the applied force goes into fracturing the material. In other words, it is that materials actually are more brittle on short time scales than on long time scales. Different materials can behave in quite different ways in impact when compared with static loading conditions. Ductile materials like steel tend to become more brittle at high loading rates, and spalling may occur on the reverse side to the impact if penetration doesn't occur. The way in which the kinetic energy is distributed throughout the section is also important in determining its response. The most materials are weaker in tension than compression, this is the zone where cracks tend to form and grow.

Terminal ballistic impact behaviour of the target and penetrator material is complex and interesting. Depending on the application people are working to improve the impact resistance of target and to optimize the performance of the penetrator to achieve maximum depth of penetration, i.e., the penetrator should damage the target to the maximum extent. While designing a protective shield (military tanks, nuclear reactors, spacecraft body etc) the objective is to improve impact resistance of the target and while designing the missile we should work to optimize the performance of the missile by optimizing many factors such as nose shape, L/D ratio, impact velocity, orientation of impact and for different target and penetrator materials.

The physicist Sir Isaac Newton first developed an idea to obtain rough approximations for the impact strength for projectiles travelling at high velocities. Newton's approximation for the impact strength for projectiles at high velocities is based only on momentum considerations. Nothing is said about where the impactor's kinetic energy goes, or about what happens to the momentum after the projectile stops. At high velocities, most materials start to behave like a fluid. It is then important that the projectile stays in a compressed shape during an impact.
1.7 Ballistics and Types of Ballistics

Ballistics is the science of mechanics that deals with the flight behaviour and effects of projectiles, especially bullets, gravity bombs, rockets or the like; it is the science or art of designing and accelerating projectiles so as to achieve a desired performance.

Types of Ballistics are as follows,

1. **Internal Ballistics**: The study of the processes originally accelerating the projectile, for example the passage of a bullet through the barrel of a rifle;

2. **Transition Ballistics**: The study of the projectile's behaviour when it leaves the barrel and the pressure behind the projectile is equalized.

3. **External Ballistics**: The study of the passage of the projectile through space or air; and

4. **Terminal Ballistics**: The study of the interaction of a projectile with its target, whether that be flesh (for a hunting bullet), steel (for an anti-tank round), or even furnace slag (for an industrial slag disruptor).

This study deals more with terminal ballistics.

1.8 Classifications of Penetrators

There are two methods of classification of penetrators. One is based on the mechanism and the other is on the structural design.

1.8.1 Classification based on Mechanism

a) **Kinetic Energy Penetrator**

It is a type of ammunition that does not contain explosives, and uses kinetic energy which is a function of mass and velocity, to force its way through armour. The term can apply to any type of armour piercing shot but is commonly used for the most

Fig. 1.1 (a) French anti-tank (b) APFSDS at the point of separation of sabot
common modern type of armour piercing weapon, the Armour piercing fin-stabilized discarding sabot (APFSDS), a type of long-rod penetrator (LRP), and not for small arm bullets as shown in Fig. 1.1.

The modern KE weapon maximizes KE by:

- Being fired with a very high muzzle velocity;
- They trade mass for velocity as the kinetic energy increases with the square of the velocity of the projectile.
- Concentrating the force in a small impact area while still retaining a large mass.
- Maximizing the mass of whatever (albeit small) volume is occupied by the projectile, that is, using the densest metals practical, which explains why depleted uranium is often used.

This has led to the current designs, which resemble a long metal arrow.

The improvement of the KE penetrator combines two aspects of artillery design: high muzzle velocity and concentrated force. High muzzle velocity is achieved using a projectile with a low mass and large base area in the gun barrel. Firing a small-sized projectile wrapped in a lightweight outer shell, called a sabot, and raises the muzzle velocity. Once the shell clears the barrel, the sabot is no longer needed and falls off in pieces. This leaves the shell travelling at high velocity with a smaller cross-sectional area and reduced aerodynamic drag during flight to the target. Concentration of the force into a smaller area was approached by replacing the single metal (usually steel) shot with a composite shot using two metals. A heavy core (based on tungsten) is introduced inside a lighter metal outer shell. These designs were known as “Armor Piercing Composite Rigid” (APCR).

The sabots also travel at a huge velocity and upon separation may continue for many hundreds of meters at speeds that can be lethal to troops and damage light vehicles. The Fig.1.2 Chemical energy penetrator
counterpart of APFSDS in rifle ammunition is the saboted flechette. A rifle firing flechettes, the Special Purpose Individual Weapon, was under development for the US Army, but the project was abandoned.

b) Chemical Energy Penetrator

They have been widely used against armor in the past and still have a role but are less effective against modern composite armor. These penetrators contain chemicals (mostly explosives) which are used as the chief source of energy required for destruction. There are two of these shells in use: $3/4$ High Explosive Anti-Tank (as shown in Fig. 1.2) (HEAT) and $3/4$ High Explosive Squash Head (HESH). HEAT rounds are made of an explosive-shaped charge that uses the Munroe effect to create a very high-velocity jet of metal in a state of super plasticity that can punch through solid armour. A shaped charge is an explosive charge shaped to focus the effect of the explosive’s energy. Explosive energy is released directly away from the surface of an explosive, so shaping the explosive will concentrate the explosive energy in the void. If the void is properly shaped (usually conically), a high-velocity jet of plasma will form. HESH is a type of explosive ammunition designed to defeat tank armour. HESH rounds contain a warhead filled with plastic explosive that spreads out to form a disk on the surface of the vehicle armour. The base fuse then detonates the explosive, creating a shock wave that propagates through the armour, causing flakes of metal to spall off the armour’s interior surface.

1.8.2 Classification Based on Structure:

a) Monolithic Penetrator

It is a penetrator whose entire body including the nose is made of the same material. Common materials used are tungsten, depleted uranium (DU). Here the main parameter of interest is the L/D ratio as shown in Fig. 1.3.
b) Segmented Penetrator

It is a penetrator consisting of sections made of different materials with segments present along its body separated from each other by spacers. Common segment materials used are tungsten, depleted uranium and the spacer materials are titanium and steel. The strength of the spacer materials is lesser than the segment materials. Here the parameters to be considered are L/D, S/D, and P/L\textsubscript{col} ratios as shown in Fig. 1.4.

1.9 Scope of Research Work

The project is confined to investigation of the ballistic performance penetration of segmented rods and unitary projectiles of nose shape (blunt, conical, hemispherical) on an vertical and 45°, 55° inclined plate with impact velocity of 300m/s, 350m/s and 400m/s. The numerical study is carried out for the different shape and angle of attacks. The results are compared with existing experimental results to check the performance of numerical model. Also the experimental tests were conducted for bullet penetration for comparison and validation of the FE model.

1.10 Objectives

Researches show that several parameters influence the penetration of unitary and segmented projectiles on mono and multi-layered targets. The objective of the thesis was to numerically investigate (FE) the effect of several factors such as impact velocity, materials properties, thickness of the target, nose shape, number of layers and distance between the layers, oblique angle of target on the quality and quantity of impact damage. Based on numerical results the work optimized the parameters on the basis of high performance of the penetrator.

✓ Optimize the performance of monolithic and segmented penetrator used as ammunition.
✓ Compare the performance of monolithic and segmented penetrators of two
different nose shape
✓ Optimization of L/D (length – diameter ratio) and S/D (segment spacing –
diameter ratio) taken together for computation
✓ Modelling and simulation of successful penetration into the target without any
interface defeat.
✓ To carry out the stress distribution and damage caused around the target and
projectile with different nose (blunt, hemi, cone) head and segmented projectiles.

Ballistic perforation and numerical analysis of unitary projectiles with the nose
head blunt, conical, and hemispherical type and segmented 3:2 projectile on the
vertical plate and inclined angles of 45° and 55° for impact velocities of 300m/s,
350m/s, and 400m/s are performed. The material used for the unitary projectile is
tungsten and for the segmented type a combination of tungsten and titanium is used.
A segmented projectile is a rod where the main material is separated by spacers,
which are usually made of a different material. In the present analysis the main
material is tungsten and the spacers are titanium (here 3 tungsten materials are
separated by 2 titanium spacers) and target is RHA steel, which used for perforation.

1.11 Limitation of the research work
✓ The speed of the penetrator is very high (more than 300 m/s) and hence it is
difficult to conduct the conduction of experimental studies as no facility was
available for the same in and around the Bangalore. Hence the experimental work
was conducted for bullet firing to verify the FEM analysis.

✓ The segmented technology is not yet implemented in the army and hence getting
information from the navy was very difficult; thus, the data were collected from
literature survey.

✓ Penetrating angle and speed of impact velocity were assumed as per previous
literature review and the materials for segmented penetrators were selected as per
previous literature review.
1.12 Outline of the thesis

The body of the text is divided into nine chapters. The first chapter **INTRODUCTION** provides motivation, and types of incremental modes, applications, scope and objectives of the work.

The second chapter **LITERATURE SURVEY** provides the latest development in the field of penetrators. More specially, it introduces the process, presents an overview of its practical implementation and experimental setup requirements, and provides its benefits and limitations. Then, the chapter focuses on the latest developments in terms of finite element modelling and analytical computations.

The third chapter **ANALYTICAL INVESTIGAITION** profiles the scope of the present research work focused on the development and verification of the mathematical models.

The four chapter **VERIFICATION OF THE FE MODEL BY EXPERIMENTAL RESULTS** provides an overview of the experimental setup and measuring devices used during the experiential tests performed. Verification of FE simulation with experimental studies was conducted.

The fifth chapter **ANALYSIS OF MONOLITHIC AND SEGMENTED PENETRATOR.** For investigating the ballistic impact, which is a very complex phenomenon, in the current study various assumptions have been made to simplify the problem. It also focuses on the optimization of penetrator shape.

The six chapter **FE IMPACT ANALYSIS FOR DIFFERENT ANGLES OF ATTACK** investigates the ballistics impacts with various angles.

The seven chapter **CONCLUSIONS AND SCOPE FOR FUTURE STUDIES** presents the conclusions on the research studies undertaken on the topic. Scope for extending the research on the topic is also included for further studies.