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Ballistics: As an Olden Physical Science

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Abstract. Ballistics (Internal, Intermediate, External, Terminal and Wound) a generic term is intended for various engineering and technological applications, which deals with the properties and interactions of matter and energy, space and time. Discovery via experiment provides an essential link between physics and applied system problems. The approach is similar to that of ballistics, which is the name of the applied scientific field. Competence in Physics and Ballistics (PB) is important interdisciplinary research areas in armaments. Because of their interdisciplinary nature, the PB is inseparable from physical, mathematical, experimental and computational aspects. In this context, this paper will provide a brief review into the PB, their important role in the artillery research and also summarize some of the current PB activities in academia, artillery research institute and industry.

1. Introduction: Scopes and Objectives

Physics is a branch of physics that concerns itself with the applications of physical knowledge to other domains. It is the discipline that deals with concepts such as matter and energy, space and time. It is the most fundamental science, and enabling discipline underpinning much of our engineering and technology. Physics and Ballistics (PB) consist of physical laws and experiments and results, including those from "*pure*" physical areas, which are used to assist in the investigation of problems or questions originating outside of physics. Physics and Ballistics (PB) are closely related disciplines, with ballisticians using physical principles to understand various ballistics problems in weapon designs. Studying physics is important in weapon technology undergoing rapid technological change, and requiring innovative problem solving. This is because applied physics studies develop critical thinking skills and the understanding of fundamental scientific principles of wide applications and lasting value.

As over the last two millennia, physics has sometimes been synonymous with philosophy, chemistry and certain branches of mathematics and biology but it emerged as a modern science in the 16th century as an applied physics. Applied physics is now generally distinct from these other disciplines, even though its boundaries remain difficult to define rigorously, especially in areas such as mathematical physics, computational physics, experimental physics, numerical physics, biophysics, chemical physics, engineering physics and so on.

Physics and Ballistics(PB) are both significant and influential in part, because advances in its understanding have often translated into new technologies in weapon systems, but also because new ideas in applied physics often resonate with the other sciences, mathematics, chemistry, computer science and biology. For example, advances in the understanding of electromagnetism led directly to the development of new products that have transformed artillery field (including electromagetic gun, high speed computers and so on); advances in thermodynamics led to the development of advanced electrothermal gun and high energy matereials or propellant; and advances in mechanics inspired the development of the various trajectory modelling, and so on.

Similarly, the understanding and use of acoustics principle will result in better blast wall for safe testing environment ; similarly, the use of optics creates better optical devices like high speed cameras. An understanding of applied physics makes for more realistic trajectory modelling simulators, as well as in forensic investigations (what do we know and when do we know it; what did the subject know and when did the subject know it).

Studying a multidisciplinary field is challenging. Not only must we learn more than one discipline, we must also work with the separate languages and styles the different disciplines. In particular, our objective is to study and develop various physical systems and its mathematical models e.g. thermodynamics system for high energetic materials like propellant or gyroscopic system for stability behavior of projectiles and so on. In view of above, this paper discusses a review of various aspects of role of Physics and Ballistics(PB) in artillery industry.

1.2 Disciplines of Physics and Ballistics (PB)

There are many fields of Physics and Ballistics(PB)which have strong branches, as well as many related and overlapping fields from other disciplines that are closely related to Physics and Ballistics(PB).

(a) **Aerophysics** is study of the properties and characteristics and the forces exerted by air in motion over a body.

(b) **Acoustics**, the study of sound waves, is used for various shock wave phenomenon of a projectile system, and muzzle devices for intermediate ballistics.

(c) **Fluid mechanics** is the study of fluids (liquids and gases) at rest and in motion. The Navier-Stokes equations are used in supercomputers to model internal ballistics phenomena.

(d) **Chemical physics** studies the structure and dynamics of ions, free radicals, polymers, clusters, and molecules, using both classical, chemical and mechanical viewpoints for internal ballistics.

(e) **Biophysics** is the interface of biology and physics for studying various wound ballistics phenomena.

(f) **Engineering physics** such as optics, nanotechnology, control theory, aerodynamics, or solid-state physics for various ballistic instrumentations.

(g) **Materials science** is the systematic study of the properties of materials for terminal ballistics;

(h) **Optoelectronics** creates devices which use light rather than current for development of ballistic instruments.

(i) **Physics of computation** used for solving of various nonlinear problems of internal, intermediate, external, terminal and wound ballistic phenomena.

(j) **Medical physics** includes the standards for radiation exposure and infrastructure for radiology for wound ballistics.

(k) **Lasers and radar** are used for various projectiles tracking purposes.

(l) **Nanotechnology** studies the creation of machines less than a micrometer in size for advance weapon systems.

2. Ballistics: Basics and Concepts

Ballistics, as a science, that deals with the motion, behavior, and effects of projectiles. It relates to a great variety of phenomena that occurs from the moment as object (projectile) is fired until its effects are observed on a target. A ballistic body is a body which is free to move, behave, and be modified in appearance contour, or texture by ambient conditions, substances, or forces, as by the pressure of gasses in a gun by rifling in a barrel, by gravity, by temperature, or by air particles. Ballistic studies include applications as varied as the study of the structural and control behaviour of rockets and satellites; strikes on aircraft, terrorist attacks and automobile crashworthiness modeling, to name but a few. Many of the basic problems of ballistics are similar to those in other fields of applications, such as combustion, heat conduction, in-flight structural behaviour, trajectory related issues, contact, impact, penetration, structural response to shock waves and many others.

Ballistics as a human endeavor has a long history. Ballistics, rooted as it is in the study of motion and indispensable as it has become in the affairs of nations, has held the interest of scientists, engineers, generals, and rulers. From the earliest developments of gunpowder in China more than a millennium ago, there has been an intense need felt by artillry developers to know how and why a gun works, how to predict its output in terms of the velocity and range of the projectile it launched, how best to design these projectiles to survive the launch, fly to the target and perform the functions of lethality, and the destructions intended. Physicists and mathematicians have made fundamental contributions to this science, including many of the most significant contributions.

Ballistics is inherently a branch of engineering physics. Not only are there a distractingly large number of physical factors present in the problem, but the number of independent variables that are actually taken into account in firing is so large, and these variable factors are to a great extent so uncontrollable, that simple accurate formulae are universally regarded as out of the question. Rules based on the normal probability curve are used in actual field conditions, and the numerical tables upon which original computations are constructed are themselves obtained by statistical methods involving more or less arbitrary assumptions. The only methods used in the past have been to relegate the less important variations to a secondary place (not to be ignored, but to be treated as linear differential perturbations) and to incorporate only the most important features into the fundamental differential equation' for a trajectory. What this equation is, depends in part on the particular problem, but is in no case as simple today as it was before the World War. In the sense of "rational mechanics", there is no rational ballistics.

For ballistics, as for every other developing branch of engineering, there is a group of present-day problems involved on the one side in seeking to test present-day assumptions, and if possible to establish these on a rational basis, and on the other side in devising means for application of these accepted principles with an accuracy consistent with the data and yet with the greatest possible simplification concordant therewith.

An excellent survey of the history of ballistics, replete with illustrative comparisons, explicit data, and critical comments on physical assumptions, is given by the long classical work of C. Cranz. The only criticism is that despite supplementary notes in later editions, the work closes essentially with the period before the World War, which changed the perspective even on old problems.

The discipline over the centuries, ballistics has divided itself into three natural regimes internal ballistics, external ballistics and terminal ballistics, but subsequently it is added with transitional ballistics, wound ballistics or forensic ballistics and hydro or underwater ballistics as per understanding and various applications and usefulness. Let us discuss each branch of its physical concept briefly as:

2.1 Interior Ballistics

Interior ballistics deals with the temperature, volume, and pressure of the gases resulting from combustion of the propellant charge in the gun; it also deals with the work performed by the expansion of these gases on the gun, its carriage, and the projectile, which is shown in Figure 1. Some of the critical elements involved in the study of interior ballistics are the relationship of weight of charge to the weight of projectile; the length of bore; the optimum size, shape, and density of the propellant grains for different charge system in guns; and the related problems of maximum and minimum muzzle energy.

Gun system, which is one of the propulsion units, has remarkable capacity to accelerate projectile by supersonic velocity instantaneously. In gun systems, a projectile is propelled by pressurization of the chamber caused by combustion of solid propellant. For this analysis, the interior ballistics has been used. The interior ballistics predicts the phenomena in gun firings by means of physical modeling and simulations of solid propellant combustion and gas generation. The calculation starts with ignition of solid propellant, and the end of calculation is the time when a projectile reaches the gun muzzle. These phenomena in gun system should be analyzed on the basis of fluid dynamics, thermodynamics, thermo chemistry and kinematics.

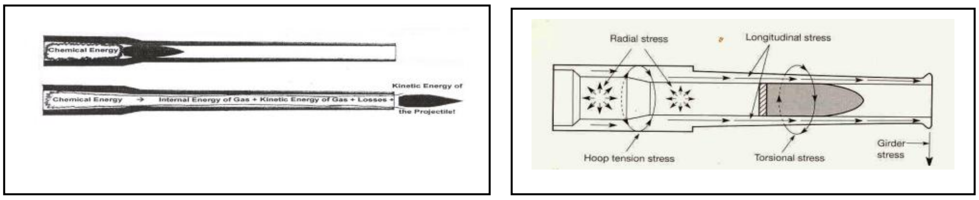

Figure 1: Interior Ballistics Environment

2.2 Intermediate ballistics

Intermediate Ballistics, also known as transitional ballistics, is study of a projectile's behavior from the time it leaves the muzzle until the pressure behind the projectile is equalized, so it lies between internal ballistics and external ballistics, which is shown in Figure 2. Intermediatel ballistics is a complex field that involves a number of variables that are not fully understood; therefore, it is not an exact science. What is understood is that when the projectile leaves the muzzle, it receives a slight increase in muzzle velocity from the expanding propellant gases. Immediately after that, its muzzle velocity begins to decrease because of drag.

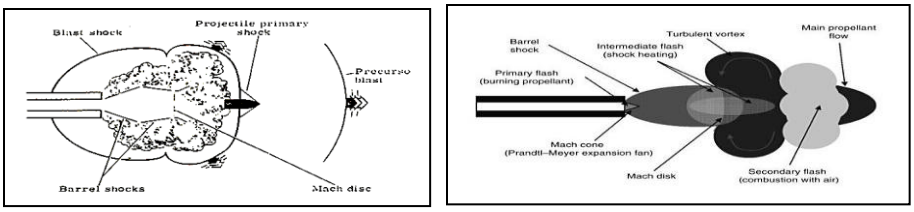

Figure 2: Intermediate Ballistics Environment

2.3 External Ballistics

Exterior Ballistics is a generic term used to describe a number of natural phenomena, which is founded on the physics of a projectile, that tend to cause the projectile in flight to change direction or velocity or both as it moves through air, which is shown in Figure 3. In external ballistics, elements such as shape, caliber, weight, initial velocities, rotation, air resistance or drag, gravity, wind, drift (when considering spin-stabilized weapons) and Coriolis effect help determine the path of a projectile from the time it leaves the gun until it reaches the target. These phenomena are gravity, drag, wind, drift (when considering spin-stabilized weapons) and Coriolis effect.

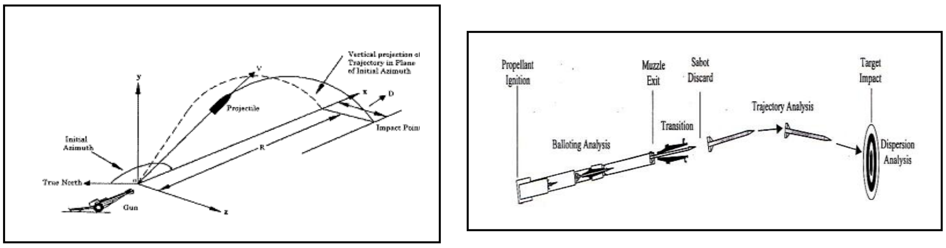

Figure 3: External Ballistics Environment

2.4 Terminal Ballistics

Terminal ballistics, a special domain of the third branch/a sub-field of ballistics, is the study of the behaviour of a kinetic energy projectile-when it impacts with its target. Terminal ballistics is relevant for both small caliber projectiles as well as for large caliber projectiles. The study of extremely high velocity impacts is still very new and is mostly applied to spacecraft design. The study of the bullet that causes impact is the main aim of this branch of ballistics. There are three basic classes of bullet: one that are designed for maximum penetration of the target, one that are designed to penetrate a specific depth and stop, and one that are designed specifically for short range target shooting. It involves many empirical formulae. Theoretical investigations and experiments, however, are carried on in penetration, fragmentation, detonation, shape of charge, and related blast phenomena, including combustion and incendiary effects. Ballisticians derive the principles governing the elements such as number, size, velocity, and spatial distribution of fragments produced by detonations of cased high-explosive charges, which is shown in Figure 4.

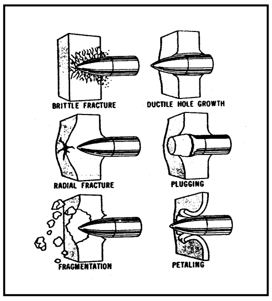

Figure 4: Terminal Ballistics Environment (Hard Target)

2.5 Wound Ballistics

In broad terms, wound ballistics is the study of the interaction of wounding agents (such as bullets and fragments from explosive weapons) with tissue. The laboratory aspect of wound ballistics is the simulated and measurable physical interaction of wounding agents with tissue. Ballistic trauma, which overlaps with wound ballistics, includes the pathophysiological reaction of the body to the physical process, which is shown in Figure 5. Therefore, ballistic trauma includes blood loss, shock, wound infection and death.

Figure 5: Wound Ballistics Environment (Soft Target: Tissue)

2.6 Physics of Hydro Ballistics

Hydro ballistics is a branch of continuum mechanics, which deals with the laws of motion of an incompressible fluid and of the interaction of the fluid with its boundaries in systems of water-borne vehicles like ships, boats and submarines. Because of scientific curiosity, the subject has achieved at high state of practical, analytical and computational developments, which is shown in Figure 6.

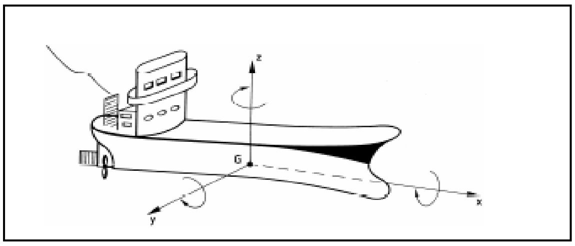

Figure 6: Hydro Ballistics Environment

2.7 Ballistic Measurements

The development of high-speed photography and other imaging and measuring devices have led to greater understanding in all six branches of ballistics. By means of such devices quantitative and qualitative behaviors of any projectile can be photographed and measured in flight, thus permitting accurate studies not only of its position to study and determine degree of stability and integrity and even of the shock waves it produces, which is shown in Figure 7.

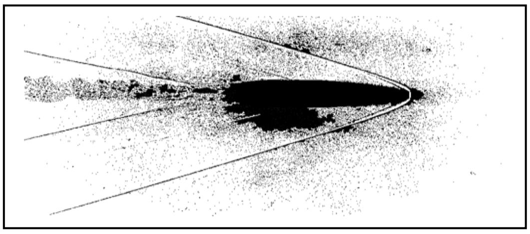

Figure 7: Shockwave of a Projectile by High Speed Imaging

In few decades, the most important recent development in ballistics is the use of computers and the state-of-the-art computational techniques. The calculus of exterior ballistics generally involves sets of second-order partial differential equations. Solving such a set of equations typically involves hundreds of thousands of computations. To find the position of the projectile at various points along the trajectory, dozens of such solutions are required. For each of various elevations of the gun, the entire process must be repeated. Even with the aid of slide rules and ordinary calculating machines, such an operation would take a mathematician an inordinate amount of time. Electronic computers compile complete solutions within a few seconds. Computers are used also for simulation of missile flights.

The design, development, and calibration of a wide variety of highly specialized optical and electronic equipments in recent years have furthered considerably the advance of all ballistics research, particularly with respect to the performance of guided projectiles and missiles. Examples of these instruments are long-focus tracking telescopes, photogrammetric cameras, and miniature radio transmitters and receivers installed in projectiles and missiles.

3. Developments of Physics and Ballistics

There is a tendency to insist on the affinity between these two sciences and still more an idea of utilizing them together in a sort of collaboration. These ideas are recent, owing their rise essentially to the various applications and to the consequent diffusion of ballistical knowledge among physicists or related technical people. From a scientific point of view, it is enough to enunciate the idea of such a comparison to understand the possibilities opened up. Ballistics is a science hundreds of years old and during its long life it has accumulated a valuable stock of theoretical and experimental materials. This has now to be considered under a new aspect and placed at the disposal of a new science which has not much material of its own because, in former times, there was not much interest in making physical experiments, computer simulation and also because the knowledge of applied physics was mathematical rather than physical.

One of the various applications of applied physics is ballistics where the concepts and methods of physics are used to develop and analyse the fields of ballistics. Further information on this application of applied physics can be obtained from the armament related laboratories and organizations. The kind of information needed to explore the flight of a projectile crosses several scientific disciplines. One is the classical dynamics of Isaac Newton; another is the field of fluid dynamics, more specifically aerodynamics. Ballistics is the name of the specific scientific field that encompasses the areas of science that we need to address.

As in all applications of physical and its mathematical models to concrete problems, we can discern three stages of developments. First, with non-availability of reliable experimental data, empirical methods suffice to yield crude approximations to the desired solutions. Second, with the accumulation of more and more data and a better understanding of the phenomena, more sophisticated physical and mathematical models with its computational methods are invoked leading to more satisfactory solutions. Third, the subject has reached a level of maturity where it throws up genuine physical problems, which may lead to new developments in applied physics itself.

The principal problem of ballistics (whether internal or intermediate or external or terminal or wound or hydro) is the solutions of a system of nonlinear differential equations, not merely a solution but a whole family of solutions corresponding to a. range of values of the occurring parameters (propellant parameters, gun dimensions, M.V., ballistic coefficient, Met. conditions etc.). The entire emphasis in the application of physical concepts and its mathematical models has therefore been on the development of suitable approximation procedures for reducing the labour of computing such extensive tables of solutions.

The advent of the high-speed computer has done away with the necessity of making such simplifying assumptions and has even radically altered the structure of the numerical computation procedure itself. The computer can turn out in a very short time thousands of solutions corresponding to a large variety of prescribed conditions. The ultimate in this line of development is the guided missile equipped with guidance and control systems, which provide mid-course corrections again with the help of the computer to keep the missile on a collision trajectory. It is clear that sophisticated mathematical methods are no longer as relevant as before for providing ballistic solutions. The present day ballistician will look to the physicists with computer background rather than to the mathematician to solve his problems.

The motion of a supersonic projectile after it leaves the gun barrel gives rise to a similar flow problem, *viz.* the analytical determination of the resulting flow pattern at the base of the projectile and a turbulent wake of nearly constant cross-section, there is an attached curved front shock and a main rear shock which possibly arises by the running of several shocks. The mathematical analysis of such a complex shock system and the derivation of an expression for the drag is a most fascinating problem, which has been studied, by different scientists, physicists and others. The extension of this work to include the effects of gravity and to the region of hypersonic velocities constitutes interesting physical and mathematical problems.

The problem of computing the trajectory of a projectile is the central problem of external ballistics. The problem of the dynamics of a spinning artillery shell has a famous counterpart in classical dynamics - the motion of the spinning top. The motion relative to the C.G. of the spinning shell is a natural generalization of the spinning top problem, with the addition of new forces and moments (of Magnus type), the forces and moments all being dependent on the instantaneous state of motion. Various mathematical models like point mass, modified point mass, six-degree of freedom and universal models have been developed by different academicians and ballisticians for such problems. The motion of the C.G. itself is far more complicated than in the case of the spinning top moving on a smooth horizontal plane, it will be recalled that even in the latter case the equations can be integrated only in terms of hyper elliptic functions. Apart from constructing approximate particular solutions and deriving criteria of stability, it would be of interest to investigate general theorems.

Another interesting problem that may be mentioned, here is that of "Scabbing" of a plate by an impulsive load applied on one face of the plate. The compression wave produced by the applied load when reflected at the opposite face gives rise to a tension wave and as a result of the interaction of the two wave systems, the tensile stress along a certain surface within the plate may fall below the critical yield stress of the material. A corresponding portion of the plate is then thrown off as a 'scab'. Different national and international experts have carried out the complete analysis of the elastic wave-system generated in the plate by the applied load.

In case of wound ballistics is very important in the criminal investigation of an offence that includes the use of firearms. With wound ballistics one can study those emerging trends of the firearms use, nature of firearms, different aspects of a firearm that causes destructions etc. In ballistics one can study those emerging trends of the firearms use, nature of firearms, different aspects of a firearm that causes destructions etc. This helps a lot in the criminal investigations as it finds out the type of firearm used by the offender, nature of its impact etc specially when the firearm in question is not located or has been hidden by the offender, it also helps in the determination of the range of fire, from which angle the trigger has been pulled, when was the shot fired, what kind of bullet was used etc.

Similarly, by referring to the subject of underwater ballistics, viz. the problem of the underwater trajectory of a projectile accompanied by its cavitations bubble. The size and shape of the bubble are determined by the motion of the projectile' and on the other hand the motion of the projectile is itself profoundly affected by the accompanying bubble. The cavitations: bubble has already been the subject of some high-grade mathematical research. But the dynamical problems of the projectile motion under water such as those of cavitational and fully wetted motion, conditions for ricochet etc. have hardly been touched upon, except under drastically restrictive assumptions.

3.1 Limitations of the Ballistics Simulations

The outstanding development of the computing techniques allowed not only the description of the behavior of physical systems in different conditions, but also the simulation of some physical and technical processes produced in special (difficult) conditions. Because this method allows a considerable decrease of the expenses necessary to experiment various technical models, as well as the simulation of some phenomena produced in inaccessible conditions, it presents a considerable interest both from the didactic and technical point of view. Taking into account the future improvement of the computing abilities by means of the parallel computers, there appeared also some special simulation techniques as the

Local Interaction Simulation Approach, intended especially to such computing techniques. The main difficulty met by the simulation techniques refers to the appearance of some numerical phenomena: instability, divergence, and dispersion, distortions, which lead sometimes to considerable inaccuracies of some obtained numerical simulations. A correlation between computational aspects of applied physics and ballistics is shown in Figure 8.

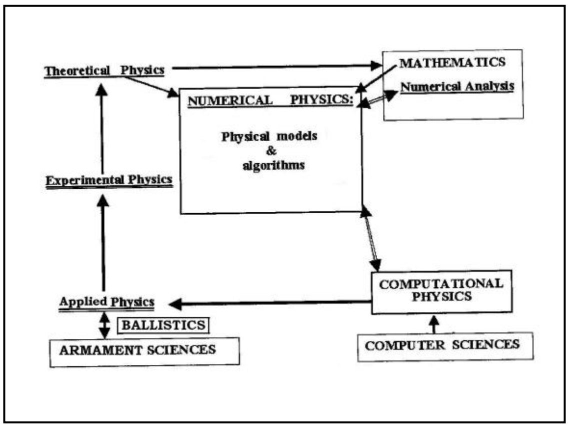

Figure 8: Correlations between Physics and Ballistics

3.2 Physics and Ballistics: Interdisciplinary Studies

Applied Physics is a relatively young discipline than ballistics. During the last few decades, researchers in the academic field of applied physics and computing have brought together a varierty of scientific disciplines and methodologies. The resulting science i.e. applied physics, offers a variety of unique ways of explaining phenomena, such as computational physics or computational ballistics.

"Interdisciplinary studies" is an academic programme or process seeking to synthesize broad perspectives, knowledge, skills, interconnections, and epistemology in an educational setting.

Although interdisciplinary and interdisciplinarity are frequently viewed as twentieth century terms, the concept has historical antecedents, most notably Greek philosophy. Julie Thompson Klein attests that "the roots of the concepts lie in a number of ideas that resonate through modern discourse-the ideas of a unified science, general knowledge, synthesis and the integration of knowledge" to further understand their own material. Examples include computational ballistics, an amalgamation of applied physics and ballistics combining fluid dynamics with computer science.

3.3 Futuristic Problems in Physics and Ballistics

3.3.1 Internal Ballistics

(a) Mathematical modeling of gas discharge and heat exchanges in a gun barrel after the projectile leaves the barrel;

(b) Estimation of force constant, density function and instabilities of gas burning in an ETC gun;

(c) Development and mathematical modelling of insensitive high energy propellants for advanced gun concepts;

(d) Development and mathematical models for high/ low pressure chambers;

(e) Identification of parameters affecting the accuracy in internal ballistics such as:

- chamber volume and shape;
- shape and location of ignition charge;
- shape and location of main charge;
- shot mass;

3.3.2 Launch Dynamics

(a) Development of mathematical models needed to estimate the structural parameters. (examples are extrusion force, incision force, spin up force, normal force to the barrel wall, friction force and force due to curvature of the barrel, forces acting on the subcomponents of the launcher).

(b) Development of mathematical models to study the sabot discard dynamics of the FSAPDS projectile fired from a ETC gun, the sensitivity of motion due to change in muzzle velocity is quite significant and the effect due to it during discarding phase is to be effectively parameterized.

3.3.3 Intermediate Ballistics

The state-of-the-art *Computational* Fluid Dynamics (CFD) models are the need to overcome the limitations to increasing its accuracies levels in subsequent motions for implementation. Parametric estimation of aero-coefficients during this flight is highly desirable.

3.3.4 External Ballistics

(a) Development of Modeling in FAE and FSAPDS (non-conventional aspects of ballistics);

(b) Free flight aspects in ICBM and space related bodies;

(c) Parametric estimation of aero-coefficients during flight trajectories;

(d) Projectile design along with booster for extended range;

(f) Development of Neural network models for trajectories modeling and range tables;

(g) Development of CFD for estimation of various aero-ballistic coefficients.

(h) High Speed Ballistic Computers for long rage range table compilation;

(i) Development of virtual reality modeling language for trajectory modeling and simulation;

3.3.5 Terminal Ballistics

(a) Multi point initiated chemical energy warheads;

(b) Flow parameters of a shape charge;

(c) Development of Hyper codes;

(d) Technology for HE warheads;

(e) Ceramic armours;

(f) Endgame Technologies;

4. Conclusions

If physics is a unique field separate from ballistics; if physics poses unique questions, comes up with unique explanatory models, utilizes unique methods, and leads to unique realistic physical problems; then it is easy to argue that those unique things are probably not answered in the philosophy of ballistics, hence, there is a need for field that addresses those unique things- the philosophy of applied physics. The philosophy of physics is an important part of understanding. We should know what is physics, why it is necessary, what are various methods of applied physics. From the above discussions we conclude that the applications of Physics and Ballistics demonstrate the potential for physicists for industrial benefits from such degree that is unique to a physics graduate. This fascinating but difficult subject presents an open challenge to the applied physicists and ballisticians.

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