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Ballistics: Concepts and Connections with Applied Physics

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Abstract : Ballistics, a generic term, is intended for various physical applications, which deals with the properties and interactions of matter and energy, space and time. Discoveries theories and experiments provide an essential link between applied physics and ballistics problems. "Applied" is distinguished from "pure" by a subtle combination of factors such as the motivation and attitude of researchers and the nature of the relationship to the ballistics. It usually differs from ballistics in that an applied physicist may not be designing something in particular, but rather research on physical concepts and connected laws/theories with the aim of understanding or solving ballistics related problems. This approach is similar to that of ballistics, which is the name of the applied scientific field. Competence in Applied Physics and Ballistics (APAB) is important multidisciplinary research areas in armaments science. Because of their multidisciplinary nature, the APAB is inseparable from physical, mathematical, experimental and computational aspects. In this context, this paper discusses a brief review into the APAB, their important roles in the armament research. And also summarize some of the current APAB activities in academia, armament research institute and industry.

1. Introduction: Objectives and Scopes

Applied physics is a branch of physics that concerns itself with the applications of physical laws and theories with experimental its knowledge to other domains. It is the discipline that deals with concepts such as matter and energy, space and time. It is the discipline that deals with concepts such as matter and energy, space and time. Applied Physics and Ballistics (APB) are closely related with physical concepts in ballistics disciplines using physical laws, theories, principles and experimental results to understand various ballistics problems in armaments. Studying applied physics is important in ballistics undergoing rapid technological change, and requiring innovative problem solving techniques. Applied physics develops critical thinking skills and understand fundamental scientific principles of wide applications.

As over the last two millennia, physics has been synonymous with philosophy, other branches like mathematics, computer science and biology but it emerged as a modern science in the 16^{th} 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, and engineering physics and so on. APB are both significant and influential parts because advances in its understanding have often translated into new technologies in ballistics. For example, understanding electromagnetism and thermodynamic theories led directly to the development of new products like electromagetic gun, electrothermal gun etc and advances in mechanics and computational physics inspired the development of the various trajectory modelling, and so on. Similarly, understanding acoustics principle resulting better blast wall for safe testing environment and the use of optics creates better optical devices like high speed cameras. Studying a multidisciplinary field is challenging. Not only must we learn more than one discipline, we also work with the separate languages and style the different disciplines. In particular, our objective is to study and develop various physical systems, laws, theories and its mathematical models and applications in ballistics. In view of above, this paper discusses various aspects of applied physics and ballistics.

2. Concept of Ballistics

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. Ballistics, as a science, that deals with the motion, behavior, and effects of projectiles., which relates to a great variety of phenomena that occurs from the moment as projectile is fired until its effects are observed on a target. From the earliest developments of gunpowder in China more than a millennium ago, there has been an intense need felt by weapon 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 studies include applications 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 is inherently a branch of applied physics. Not only are there a distractingly large number of physical factors present in the problem, but also the numbers of independent variables that are actually taken into account in test firing are 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. 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, forensic ballistics and hydro ballistics as per understanding and various applications and usefulness.

2.1 *Physics of 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. 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.

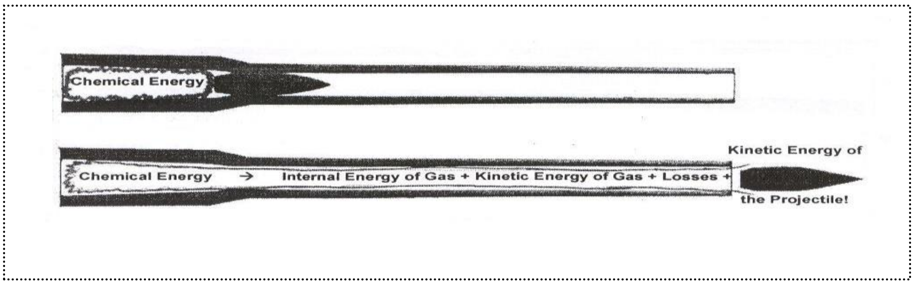

Fig. 1: Interior Ballistics Environment

2.2 *Physics of Transitional Ballistics*

Transtional Ballistics, also known as intermediate 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. Transtional 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.

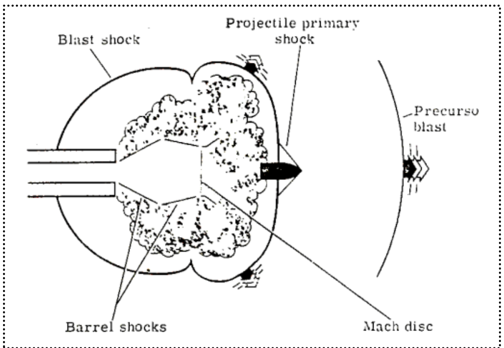

Fig. 2: Transitional Ballistics Environment

2.3 *Physics of 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.

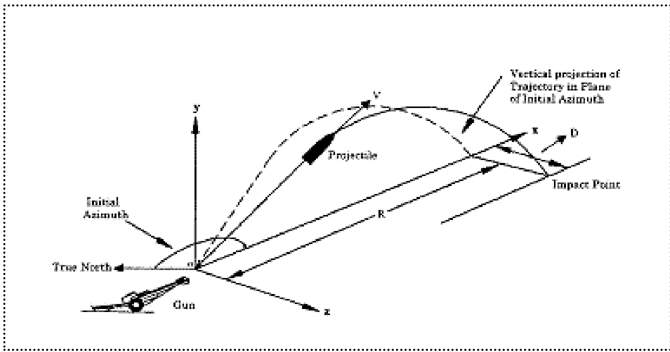

Fig. 3: External Ballistics Environment

2.4 *Physics of Terminal Ballistics*

Terminal ballistics is the study of the behaviour of a kinetic energy projectile- when it impacts with its target. The study of the projectile 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

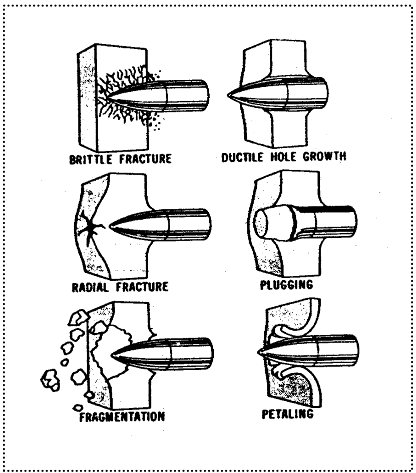

Fig. 4: Terminal Ballistics Environment

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.

2.5 *Physics of 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.

2.6 *Physics of Hydroballistics*

Hydroballistics 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.

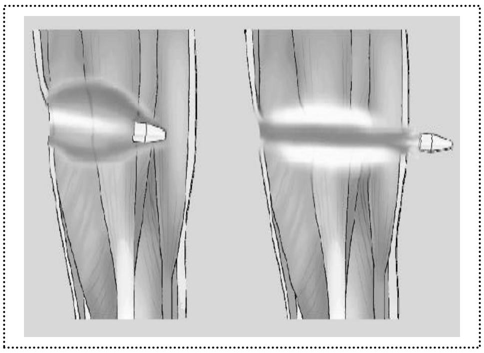

Fig. 5: Wound Ballistics Environment

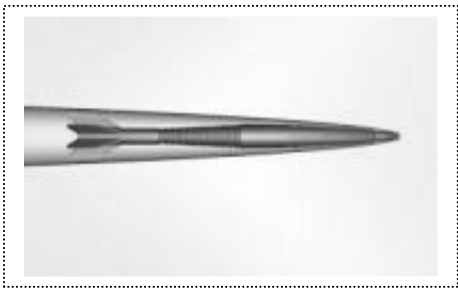

Fig. 6: Hydroballistics Environment

3. Developments of Ballistics Connected with Applied Physics

There is a tendency to insist on the affinity between these two sciences and still more ideas 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 ballistics knowledge among physicists or related technical people. From a scientific point of view, it is enough to enunciate ideas 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, modeling and computer simulation and also because the knowledge of applied physics.

The subject of ballistics draws upon several multi facets scientific disciplines for its developments. "Ballistics" is meant that part of the subject, which deals with the application of physical concepts along with its physical models to the solution of various ballistics problems. By its very definition, therefore, applied physics may fairly and closely relate to ballistics. One of the various applications of applied physics is ballistics where the concepts and methods of physics are used to develop and analyze the fields of ballistics. Further information on the applications of applied physics can be obtained from the ballistics 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.

Applied physics, for all its extensive employment of a variety of physical concepts along with mathematical models and its techniques is still *"Applied Physics"*. Similarly, classical mechanics, starting from the problem of determining the trajectory of a given dynamical system, has led to the extensive mathematical theory of differential equations and the associated theories transformations, etc. Many more such related examples can be given in support of the criterion stated above, viz. a subject can qualify as a branch of applied physics only if it is capable of generating problems which are of significance physically as well as mathematically. The thought of ballistics should therefore be looked at from this point of view.

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 families of solutions corresponding to a. range of values of the occurring parameters (propellant parameters, gun dimensions, muzzle velocities, ballistic coefficient, meteorological 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 labor 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. 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.

4. Modeling and Simulation in Applied Physics and Ballistics

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.

Among these numerical phenomena, we consider that the most misleading is that of pseudo convergence, because it leads to apparently correct simulations (their shape is even qualitatively correct), but considerably wrong from the quantitative point of view. That is why the present work considers that the numerical simulations must be studied in strong connection with the basic results of the data processing of the experimental results. A correlation between computational aspects of applied physics and ballistics is shown in Figure 7.

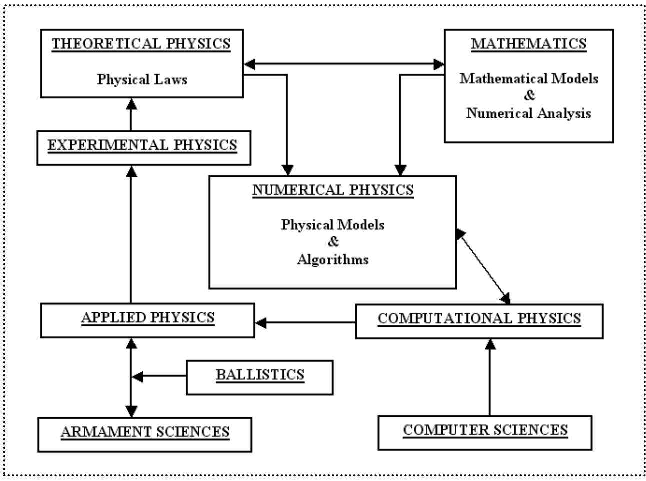

Fig. 7: Correlations Between Applied Physics and Ballistics

5. Applied Physics and Ballistics: A Multidisciplinary Study

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

Although multidisciplinary is 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.

Multidisciplinary programmes sometimes arise from a shared conviction that the traditional disciplines are unable or unwilling to address an important problem. For example, social science disciplines such as anthropology and sociology paid little attention to the social analysis of technology throughout most of the twentieth century. As a result, many social scientists with interests in technology have joined science and technology studies programs, which are typically staffed by scholars drawn from numerous disciplines. They may also arise from new research developments, such as nanotechnology, which cannot be addressed without combining the approaches of two or more disciplines. Examples include computational ballistics, an amalgamation of applied physics and ballistics combining fluid dynamics with computer science. Below are given some impotarnt subjects from Applied Physics, which are closely related to Ballistics:

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

(b) 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;

(c) Aerophysics: is study of the properties and charactristics and the forces exerted by air in motion over a body;

(d) Biophysics: is the interface of biology and physics for studying various wound ballistics phenomena;

(e) Computational Physics: used for solving of various nonlinear problems of internal, intermediate, external, terminal and wound ballistic phenomena;

6. Future Trends in Applied Physics and Ballistics

Due to advancement of various multidisciplinary fields globally, it has been realized that the understanding of the following subjects are primary need to study the various ballistic problems via applied physics for futuristic defence programmes. (a) Principles, Ideas and Methods in Mathematical Modelling (b) Fundamentals of Aero-ballistics design (c) Principles of combustion processes (d) Design philosophy of long rod penetrators (e) Qualitative studies of effective lethality and (f) Understanding of uncertainty models. In addition to above, the understanding of following topics are necessary:(a) Conservation of mass, energy (kinetic and heat); (b) Conservation of linear and angular momentum; (c)

Continuum relations for the motion of fluid/gas;(d) Equation of State of the fluid/gas.

Due to increasing of complex nature of information networking warfare strategies, the following emerging principles are to be considered. (a) **Conventional Principles -** It has been to increase weapon power to increase lethality; (b) **Peripheral Principle -** Here one destroys population by enemy like groups (militants), economics and natural resources; (c) **Select Target Principle -** Here one defeats the enemy militarily and politically. Weapons systems are designed which are precise to eliminate specific targets by zeroing on them and avoid collateral damage. The philosophies for select target principles are: (i) Directed energy weapons; (ii) Precision automation; (iii) Energetic explosives; and (iv) Super high speed data processing; (v) Electronic warfare equipments;

7. Conclusions

The aim of the "*Applied Physics and Ballistics (APB)*" is to give a broad and solid introduction to the theoretical, experimental computational and physical concepts that is the basis for much of today's high armament technology. The philosophy of applied physics is an important part of understanding. We should know what is applied physics, why it is necessary, what are various methods of applied physics. From the above discussions we conclude that the applications of Applied Physics and Ballistics demonstrate the potential for physicists for industrial benefits. Also, we opine that: "*APB"* is and will continue to be an active and fruitful branch of armaments as two sides of a coin. This fascinating but difficult subject presents an open challenge to the applied physicists and ballisticians.

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