Numerical Simulation and Experimental Study of Flow Field around a Bullet with a Partial Core

Usiel S. Silva
Juan M. Sandoval
Luis A. Flores
Narcizo M. Aguirre

1INSTITUTO POLITECNICO NACIONAL
Sección de Estudios de Posgrado e Investigación (SEPI),
Escuela Superior de Ingeniería Mecánica y Eléctrica (ESIME),
Av. de las Granjas 682, Col. Sta. Catarina Azcapotzalco, C.P. 02250, México
e-mail: jsandovalp@ipn.mx

1 Introduction

The most common types of small calibers are the jacketed and the unjacketed. The first ones are mostly constructed with Plumb and Antimony alloys to increase its hardness, and Stain to increase their feasibility for molding and casting [1]. Nowadays ammunitions are fabricated with strict and high quality standards with the purpose of meeting the international regulations, because of that, during the manufacturing process, out of range bullets are totally rejected and sent to re-foundry processes.

The X ray images of Fig. 1 shows this type of defect, which is mainly originated by the incorrect union between the core and the jacket, causing the displacement of the center of mass of the bullet, loss of aim, reduction of the length of the shot and reduction of the stopping force.

By analyzing the dynamical behavior of these rejected bullets, an interesting study will provide that, after some adequate manufacturing post-processing, the rejected bullets may become useful, especially in exceptional conditions of increased manufacturing demands.

Based on this idea, a numerical analysis of an incomplete core bullet was carried. The modeling considers this defect in the back side of the bullet with the purpose of maintain adequate stability conditions and considering the main characteristics of a 7.62x51mm FMJ, which is a worldwide used ammunition with specified international standards [2].

The geometry and density of the components of a typical small caliber bullet, for example the jacket and the core, are the main factors that stabilize its flight path, they have a direct influence in the length of the shoot and the impact force on the target. Weight variations during the manufacturing process indicate the presence of geometrical irregularities or damage of the bullet core, affecting its dynamic characteristics; they are then refused. The purpose of this work is to present the simulation of a 7.62x51mm caliber cartridge Full Metal Jacket (FMJ), which is an standardized ammunition worldwide used, subjected to a different air flow conditions like, transonic (0.8 – 1.2 Mach) and supersonic (1.4 Mach) speeds; and the simulation of the same cartridge but with a partial core design. This information will be useful to understand the stability of the warhead during its flight trajectory (external ballistics). Computational Finite Element Method (FEM) with the Computational Fluid Dynamic (CFD module was used for the simulation. Experimental test on wind tunnel were also conducted to obtain the Schlieren profiles at transonic (0.8 – 1.2 Mach) and at supersonic (1.4 Mach) speeds and an interesting correspondence was obtained with the numerical analysis. Field experimentations with a series of shoots were also conducted to determine speed and pressure values. The importance of this analysis is based on the fact that ammunitions fabricated out of the standard scope can be reproccessed for a proper use. As a result, the numerical and experimental images of the corresponding Schlieren curves were obtained and with the flow visualization principle, the behavior of the projectile during the trajectory of flight of a partial core bullet was also determined. It was found that in certain cases, partial core ammunition shoots maintain a stable spin during flight without a considerable variation in its length of flight, keeping constant speed conditions with respect to the full core bullets. The importance of this analysis is found in the fact that post processing activities can be implemented in certain ammunitions with imperfections to improve their use.

Keywords: Bullet with partial core, Compressible flow, External ballistics, Finite element method.
In external ballistics and impact analysis, there exist, several studies for the caption of flow field images (interferograms, isopictograms and Schlieren profiles) from numerical solutions based initially on the experimental flow visualization [6]. They can be numerically analyzed like in the case of the shock waves produced during the supersonic transition of flying projectiles. They are initially analyzed with the Euler equations under a controlled dispersion scheme in limited movement conditions [7, 8]. Differential equations (DOF’s) have also been used to predict the trajectory of a stabilized spin projectiles [9] and it’s opportune to mention the development of hybrid schemes of finite Element/Volume methods (TVD) [10].

The study of high amplitude waves solved with the Euler and Lagrange methods have been analyzed observing that in simple cases small differences are found depending on the established conditions [11]. Arbitrariant Lagrange-Euler (ALE) equations have also been used for the analysis of gas expansion, by using a second order precision solver ROE and the AUSMDV scheme [12, 13] obtaining interesting shadow graphs, quite similar to the ones obtained in experimental works, allowing the prediction of expansion air waves and the trajectory of gases produced during the expulsion of a projectile. Similarly, Navier–Stokes equations have been used under the Large Eddy (LES) scheme to determine the flow behavior around a projectile [14].

### 2 Governing equations

The selected system can be modeled as a non-viscous compressible fluid which is characterized by the Euler equations for gas dynamics, as for this case the Streamline Upwind Petrov–Galerkin Stabilization (SUPG) in order to stabilize the system and make the convergence of the solution as a function of the density changes in the fluid. In the compressible type solution for non-viscous fluids, the shock waves are considered as discontinuities of the solution, in this case an artificial viscosity term is used, which tends to zero for the conservation law equation [15].

### 3 Experimental analysis

Six experimental tests considering air speed increments over the specimen were carried on. The specimen is an infinite width type model based on a 7.62mm caliber bullet with a partial core design. The supersonic tunnel were the specimen was mounted has an area of 100x25mm as shown in Fig. 3. Low density artificial smoke was used to enhance the generated profile stream lines and the Schlieren profiles which appear by the instantaneous density change of the fluid when makes contact with the specimen at the transonic and supersonic speeds.

The characteristic Schlieren images were obtained for each regime and are compared in the next section with the computational numerical analysis by the principle of experimental flow visualization [6].

The most critical condition that the partial core type bullet can support to maintain its stability during fly and preserving its center of mass is at a minimum portion of the core condition or in absence of core or nucleus. Shooting conditions were properly modified in tests with 7.62x51mm caliber, by shooting only the jacket of the bullet without core as shown in Fig 4.

Table 2 indicates the averaged results of pressure and speed that were obtained after a series of shoots, showing an increment on the speed caused for the reduction of mass and a decrement on the pressure in the chamber due an increment in the volume of the ignition chamber were the deflagration of the gunpowder in comparison with the specified parameters for 7.62x51mm FMJ caliber ammunitions [2].
Table 2: Average values obtained from ballistic tests 7.62x51mm caliber warheads operation with partial core

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>905 m/s</td>
<td>Measured at a distance of 23.77m with ammo conditioned to 21.11 °C</td>
</tr>
<tr>
<td>Pressure average</td>
<td>100 MPa</td>
<td>In the chamber of the barrel with ammo conditioned to 21.11 °C</td>
</tr>
<tr>
<td>Maximum pressure</td>
<td>120 MPa</td>
<td></td>
</tr>
</tbody>
</table>

In Fig 5 the pressure curve obtained from the tests are presented. They were acquired with a piezoelectric transducer located in the chamber of a standardized testing cannon. A reduction on the maximum pressure peak was also observed as well as a heterogeneous ignition of the initialization capsule and the gunpowder load.

Fig. 5  Pressure curve characteristic of the shots made with 7.62mm ammunition, with no core warheads

With the results of pressure tests and speeds, it is possible to determine that despite the decrement of pressure, the core less 7.62mm bullet is stable for the flight path, which is corroborated by the numerical analysis shown in the next section.

4 Numerical analysis.

In order to validate the proposed method, numerical analysis was initially performed using the FEM of the bullet of a caliber ammunition 7.62x51mm FMJ, including its core and considering the speed and pressure values described in table 3, as these three major ballistic parameters that are affected by the air flow conditions and that can be simulated.

Table 3: Aerodynamics range for the caliber 7.62x51mm FMJ ammunition [2]

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>838.2 ± 9.14 m/s</td>
<td>Measured at a distance of 23.77m with ammo conditioned to 21.11 °C</td>
</tr>
<tr>
<td>Pressure average</td>
<td>365 MPa</td>
<td>In the chamber of the barrel with ammo conditioned to 21.11 °C</td>
</tr>
<tr>
<td>Maximum pressure</td>
<td>400 MPa</td>
<td></td>
</tr>
</tbody>
</table>

In Fig 6, the pressure curve obtained from a 7.62x51mm FMJ caliber ammunition shoot is shown. It is characteristic for this ammunition and it is possible to observe heterogeneous ignition in the initiation chamber as well as loss of pressure along the testing cannon tube.

Fig. 6  Pressure curve characteristic of firing a 7.62mm FMJ ammunition

According to the supersonic speed reached by the bullet, the simulation was conducted for subsonic conditions (0.8 – 1.2 Mach) and supersonic conditions (1.6 Mach) by using the computational CFD module, considering a compressible and turbulent fluid. The reference pressure was an input of 1 atm and a stagnation temperature of 3000°K. Different sequences were subsequently executed mainly by varying the values of viscosity of air, to converge on a representative result.

Applying the principle of experimental flow visualization [6], the numerical Schlieren images obtained by computer analysis were initially compared with the Schlieren images of air flow on .50 caliber, which corresponds to a described geometry established on NACA No. 24 and that are also reported on the specialized literature[4].

Figure 7 also shows the flow conditions and particularly the shockwaves presented intermittently, because it is a transitional stage, and the flow is not stable, having repeated variations from the subsonic stage to the transonic stage and vice versa.

Fig. 7  (a) Experimental Schlieren of transonic flowfield over .50 ball M33 bullet [4], (b) Numerical Schlieren of transonic flowfield over 7.62mm bullet
Representative images were also obtained for the supersonic flow as shown in Fig. 8, were the shock waves are clearly defined because during the supersonic regime the air flows with enough speed avoiding free propagation of the waves around the profile, they are then compressed and the flow density variations are limited in this case as a function of the temperature.

![Fig. 8](image1)

**Fig. 8** (a) Experimental Schlieren of supersonic flowfield around .50 ball M33 bullet [4], (b) Numerical Schlieren of supersonic flowfield over 7.62mm bullet

Once that the computational methods were validated with the experimental tests, the partial type core bullet or proposed design was then simulated in a transonic scenario, considering similar reference parameters to the ones used in the full core analysis. In this case, the experimental flow visualization principle was again applied, and comparing the results with the images obtained in the experiment for an infinite width profile specimen of a 7.62mm caliber of partial nucleus.

In Fig. 9, color changes and curves represent variations in the flow density as a function of the temperature and that are also affected for the geometry of the projectile because the compression of the air along the profile does not let the air to flow freely generating shock waves.

![Fig. 9](image2)

**Fig. 9** Transonic flowfield over 7.62mm bullet with partial core (a) Experimental Schlieren, (b) Numerical Schlieren

It is estimated that in this flow, the speed of the air is mainly between 39.77 y 248.59 m/s (0.12 – 0.75 Ma), which was validated with the numerical analysis were the results are close approximated as shown in the general contour profiles as well as in the subgrid or punctual results (Fig. 10).

![Fig. 10](image3)

**Fig. 10** Mach number of transonic flow over 7.62mm bullet with partial core

A numerical simulation was also conducted for a supersonic flow obtaining more defined shockwaves which are characteristic for this flow type and similar to the ones obtained in the experimental test.

Fig. 11 shows the compression of the air flow on the profile, which was observed during the test keeping the supersonic speed constant. The observed behavior lines are representative of the real operative conditions.
Fig. 11 Supersonic flowfield over 7.62mm bullet with partial core (a) Experimental Schlieren, (b) Numerical Schlieren

The maximum speed of the air flow was considered of 530.33 m/s (1.6 Ma) corresponding to a supersonic flow and in relation to the tunnel capacity, being this valid for the contour results and for the punctual obtained values as shown in figure 12.

Fig. 12 Mach number of supersonic flow over 7.62mm bullet with partial core

Also, the variations of fluid density, similar to those obtained previously and that are characteristic for the transonic and supersonic flow, provided the basis to validate the numerical results and to obtain other quantities from the same calculation, such as pressure, speed (Fig. 13), Mach number, temperature, energy, and viscosity among others, which cannot be measured directly from the tunnel experimental tests, because of that the numerical simulation is a reliable solution, and enables modification on the profiles and in the external conditions, evaluating the reduction of costs and time respectively.

Fig. 13 Sum of the velocity vectors of supersonic flow over 7.62mm bullet with partial core

5 Conclusions

The results obtained in this study, from the FEM and experimental analysis; allows the determination of the behavior of the compressible air flow around the profile for a 7.62x51mm caliber ammunition with a partial core. In this case, no significant variations in the aerodynamics stability of the bullet during its flight trajectory were found. Because of that, it is possible the use of partial core bullets by considering its limitations in stopping force and penetration, and maximum flight length, as well as the production needs by considering a manufacturing post processing for out of range fabricated ammunitions.

Acknowledgment

The authors gratefully acknowledge the financial support from the Mexican government by the Consejo Nacional de Ciencia y Tecnología and the Instituto Politécnico Nacional.

References


