# COMPARATIVE EVALUATION OF PROJECTILE'S DRAG COEFFICIENT USING ANALYTICAL AND NUMERICAL METHODS

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***Abstract:*** *In this paper is presented an algorithm for projectile's drag coefficient evaluation using empirical and semi empirical relations. The algorithm can be useful for engineers who work in design, maintenance or experimental testing of ammunitions, when drag coefficient for a projectile is necessary. The paper offer an evaluation of drag coefficient using the algorithm and the numerical determination using a numerical application for the flow around the projectile configuration. This validated algorithm for drag coefficient evaluation can be implemented in a standalone application.*

***Keywords:*** *drag coefficient, ammunition, aerodynamics, projectile, aerodynamic configuration, finites volumes method*

## 1. INTRODUCTION

The application of an analytical method for drag coefficient calculation gives us the possibility to anticipate in a scientific manner the results for design, maintenance or testing with low resources consumption.

In fact this kind of studies offers to engineers a powerful instrument in evaluate the influence of their choices in: products design, experimental data interpreting or products evaluation in different stages of their lifetime cycle.

Some of these studies are to evaluate the projectile's point-mass motion in air and evaluate the influence of changes in projectile structure on projectile's point – mass trajectory.

This study is based on the evaluation of drag coefficient for an aerodynamic configuration of 30 mm caliber projectile. using an analytical algorithm and a numerical method. The drag coefficient is evaluated using its geometrical dimensions, Mach number, Reynolds number and initial conditions for the numerical simulation. The study from this paper has two main objectives as follows: drag coefficient evaluation using the proposed analytical algorithm and drag coefficient using simulation CFD software.

The evaluated drag coefficient is for Mach values between 0.8 and 3.0.

The projectile aerodynamic configuration is a 30 mm projectile and presented in Fig.1.

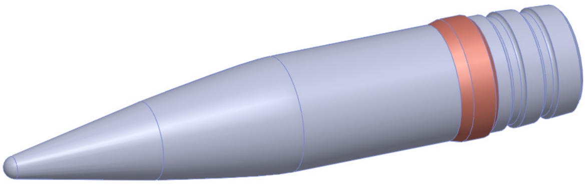

Fig. 1 Aerodynamic configuration of 30 mm caliber projectile used

The study is based on projectiles geometrical dimensions and his flight conditions.

The purpose of the study is to evaluate drag coefficient comparing the results for it obtained by the two methods the validated one which is numerical and the analytical one.

The numerical method is time and resources high consummator and is not proper for our goals so we want to evaluate the analytical method for further use.

## 2. MATHEMATICAL MODELS USED

The study has two main objectives as we mentioned before and for these objectives are two different mathematical models: drag coefficient evaluation through simulation uses a VOF (finites volumes method) to solve the pressure and velocity filed around projectile configuration and the analytical algorithm that use simple empirical relations to evaluate the drag coefficient. In this case, the mathematical model for the analytical evaluation for drag coefficient is the main subject of the study, so in the following we will present the mathematical model for it.

The mathematical model [1, 2, 3] for drag coefficient estimation uses projectile's geometrical dimensions (Fig. 2).

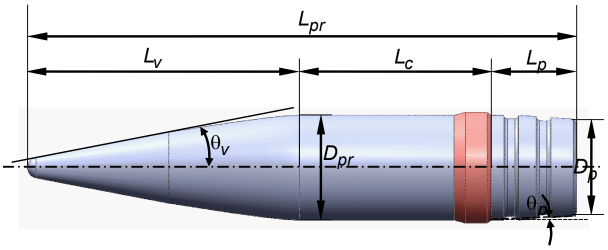

Fig. 2 Projectile's dimensions used

These dimensions are: $L_{pr}$ – projectile's total length, $L_v$ - ogive length, $L_c$ – cylindrical length, $L_p$ - tronconical length, $D_{pr}$ - transversal section diameter, $D_p$ projectile back – side diameter, $\theta_v$ – ogive half angle, $\theta_p$ –half angle for projectile's tronconical part.

For the algorithm of drag coefficient estimation, we use the following relations [1,2]:

$$\lambda_{pr} = \frac{L_{pr}}{D_{pr}} \tag{1}$$

$$\lambda_v = \frac{L_v}{D_{pr}} \tag{2}$$

$$\lambda_c = \frac{L_c}{D_{pr}} \tag{3}$$

$$\lambda_p = \frac{L_p}{D_{pr}} \tag{4}$$

$$S_f = \frac{\pi \cdot D_{pr}^2}{4} \tag{5}$$

$$S_{lat} = K \cdot \pi \cdot D_{pr} \cdot L_{pr} \tag{6}$$

$$K = 0,688 + 14,5 \cdot 10^{-3} \cdot \lambda_{pr} \tag{7}$$

Where $\lambda_{pr}$ is projectile's relative length, $\lambda_v$ is ogive relative length, $\lambda_c$ is cylindrical part relative length, $\lambda_p$ is relative length of tronconical part. $S_f$ is transversal projectile's area. $S_{lat}$ is projectile's lateral area [1,2].

$$C_x = C_{x0} + C_{xi} \tag{8}$$

Where $C_x$ is the drag coefficient [1,2] as sum from $C_{x0}$ - the drag coefficient at zero incidence angle and $C_{xi}$ induced drag coefficient [1,2].

$$C_{x0} = C_{x0}^f + C_{x0}^u + C_{x0}^{post} \tag{9}$$

Where $C_{x0}^f$ is the friction drag coefficient, $C_{x0}^u$ is the pressure drag coefficient, $C_{x0}^{post}$ is zero pressure from projectile's bottom drag coefficient [1,2].

$$C_{x0}^f = C_f \cdot \eta_\lambda^* \cdot \eta_M \cdot \frac{S_{lat}}{S_f} \tag{10}$$

This coefficient for supersonic flows is very small and can be zero value [1,2].

$$C_{x0}^{post} = k_c \cdot \frac{0,0155}{\sqrt{\lambda_f \cdot C_f}} \cdot \left(\frac{S_{pf}}{S_f}\right)^{3/2} \tag{11}$$

Where $k_c$=0.5.

$$C_{x0}^u = C_{xu}^v + C_{xu}^p \tag{12}$$

Where ogive's drag coefficient is $C_{xu}^v$ and backside of the projectile's drag coefficient is $C_{xu}^p$ [1,2].

$$C_{xu}^v = \frac{0,6825}{\lambda_v} + \frac{0,1186}{0,21 \cdot \lambda_v^2 + M^2 - 1} \tag{13}$$

$$C_{xu}^p = \left(0,0016 + \frac{0,002}{M^2}\right) \cdot \theta_p^{1,7} \cdot \alpha \tag{14}$$

$$\alpha = \sqrt{1 - \frac{S_{pf}}{S_f}} \tag{15}$$

$$C_{xi} = K_x^* \cdot C_z^\alpha \cdot \alpha^2 \tag{16}$$

with $K_x^* = \dfrac{2,5 + \lambda_v}{1 + \lambda_v}$.

## 3. NUMERICAL RESULTS

Initial data used to make the simulation and calculate the drag coefficient are in Table 1.

Table 1. Initial data for numerical model

| Parameter | Value |
|---|---|
| Caliber [mm] | 30 |
| $L_{pr}$ [mm] | 150.28 |
| $L_v$ [mm] | 69 |
| $L_c$ [mm] | 70.8 |
| $L_p$ [mm] | 5.2 |
| $D_p$ [mm] | 26.8 |
| Mach number [-] | 0.8 to 3.0 |
| $\theta_v$ [deg] | 11 |
| $\theta_p$ [deg] | 4 |

Drag coefficient values for obtained by numerical simulation and analytical calculation are exposed in Table 2.

Table 2. Numerical results

| Crt. No. | Mach number value | Simulation Drag coefficient value | Analytical method drag coefficient value |
|---|---|---|---|
| 1 | 1.2 | 0.211866705 | 0.213342729 |
| 2 | 1.3 | 0.229140652 | 0.237542381 |
| 7 | 1.4 | 0.242002676 | 0.247089692 |
| 8 | 1.5 | 0.23395962 | 0.237404203 |
| 9 | 1.6 | 0.209559464 | 0.213008992 |
| 10 | 1.7 | 0.191938139 | 0.199917306 |
| 11 | 1.8 | 0.180461835 | 0.184917575 |
| 12 | 1.9 | 0.173554289 | 0.182381161 |
| 13 | 2 | 0.166293308 | 0.169964721 |
| 14 | 2.1 | 0.16142056 | 0.16571252 |
| 15 | 2.2 | 0.15577706 | 0.16394538 |
| 16 | 2.3 | 0.151776531 | 0.151947723 |
| 17 | 2.4 | 0.147041135 | 0.156343951 |
| 18 | 2.5 | 0.143698138 | 0.152558084 |
| 19 | 2.6 | 0.140540984 | 0.141941886 |
| 20 | 2.7 | 0.140657387 | 0.142356453 |
| 21 | 2.8 | 0.134699216 | 0.138538851 |

Mach number contours are presented in Figure 4. Contours are results from simulation method.

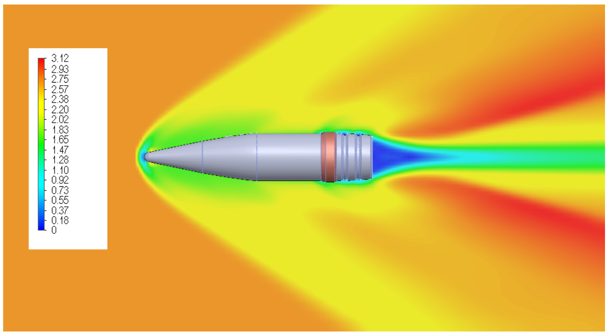

Fig. 4 Mach number contours

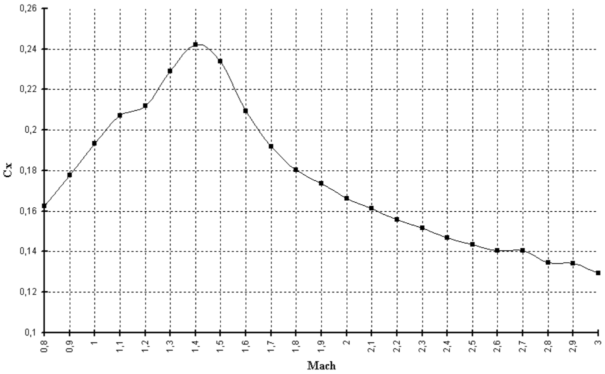

Fig. 5 Drag coefficient evolution with Mach number – simulation –

From simulation drag coefficient is calculated and its values are represented in Table 2. Drag coefficient evolution with Mach number is presented in Fig. 5.

Drag coefficient evolution with Mach number resulted from analytical calculation is represented in Fig. 6.

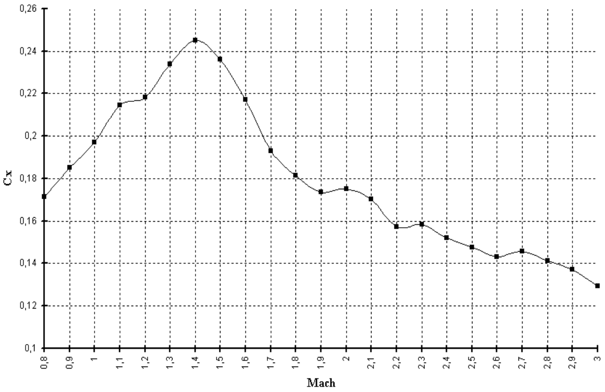

Fig. 6 Drag coefficient evolution with Mach number – analytical determination

In Fig. 7 are exposed the drag coefficient evolutions with Mach number together. As we can see from this graph are not big differences.

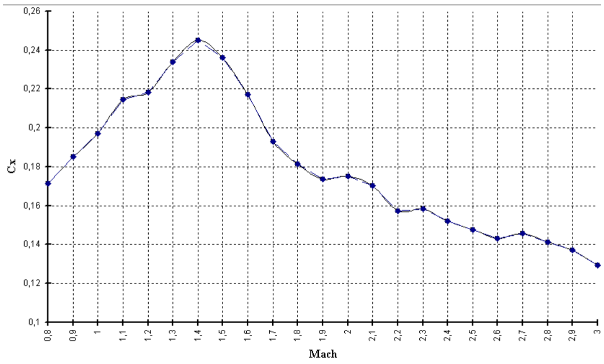

Fig. 7 Drag coefficient evolution with Mach number simulation vs. algorithm

The differences between the two set of data are presented in Fig. 8.

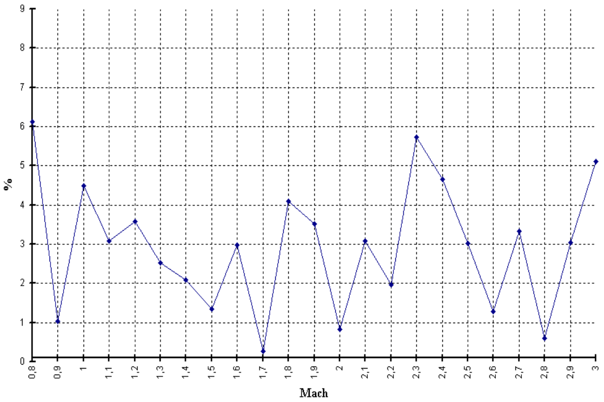

Fig. 8 Drag coefficient evolution with Mach number

As we can see, we have an absolute difference between 0 to 6 % for the presented methods. In the same time we have can approximate a 3% mean value for error.

In this situation, we can consider for preliminary calculations the simplified method by the presented algorithm to calculate the drag coefficient for aerodynamic configuration of projectiles.

## 4. CONCLUSIONS

The Mach contours are calculated using a VOF simulation software, see Fig. 4 and drag coefficient was calculated using this method.

On the other hand, the drag coefficient was calculated using the algorithm presented in chapter 2, and the results obtained for it were pretty good compared with the simulation ones.

The errors between the presented methods were small and this gives us assurances that we can use for a preliminary drag evaluation the analytical method. This kind of study can be used to implement the presented analytical method in a software module for projectiles drag coefficient evaluation. The usefulness of this type of study can be seen in experimental testing, design of different type of products.

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