"In – house" software module for projectile's drag coefficient evaluation in case of small geometrical dimension tolerances: A solution for cost reducing

George SURDU[*]

Abstract: *Drag coefficient is an important parameter in exterior ballistic which is used to evaluate the shape of projectile trajectory. The purpose of this study was to create a simple instrument for drag coefficient preliminary evaluation using the existing drag laws: 1943 law, 1930 law or Siaccis's law and his geometrical dimensions important for ballistics. The instrument mentioned before is represented by a software module which is based on an existing theoretical model, properly ajusted, for drag coefficient evaluation. This software module has the ability to evaluate also the influences for some geometrical dimension tolerances of projectile's shape against drag coefficient.*

Keywords: *true value, statistics, efficiency, software module, ballistics, geometrical tolerances*

JEL Classification*: Y80*

The projectile's testing and evaluation represents an important step in ammunition design. In these kind of activities the consumption of resources is very high, because of aerodynamic tests or field tests.

Aerodynamic tests are done to evaluate the projectile's aerodynamic coefficients. The most important of these coefficients is the drag coefficient. To be evaluated, the drag coefficient needs many tests which are made in aerodynamic tunnels or in special shooting range facilities, using a great amount of ammunition and other necessary resources.

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[*] *Ph.D. Researcher Eng. , Research Center for Navy,* surdugeorge@gmail.com

Field test for projectile's exterior ballistics are very important to estimate the projectile's trajectory, projectile's impact on targets and projectile's effect on the target. These tests are done independently from the aerodynamics tests and needs additional ammunitions and resources consumption.

The influence of the geometrical dimesion tolerances on projectile's drag coefficient and exterior ballistics can be studied by aerodynamic tests and field tests. The number of aerodynamic tests and field tests can be reduced by simulation. This simulation can be made using comercial software which can evaluate the flow around projectile configuration and aerodynamic coefficients. Comercial software is multipurpose designed and high costs prices, for this reason it is better to develop an "in-house" solution for projectile's aerodynamic coefficient evaluation. This type of solution is also recomanded by military standards like STANAG 4315 edition 1, 2006. Also for the first stage of projectile's shape design the use of direct purpose software instruments helps the designer to verify a wide range of solutions at a low cost of design.

This paper reveals „in-house" software's importance in projectile and ammunition aerodynamic design and testing work. This view is sustained in this paper by "in-house" software developed by the author with the purpose to offer an instrument in aerodynamical evaluation impact of projectile's geometrical dimensions on its drag coefficient. This type of software modules can make easier the preliminary evaluation and testing of projectile's aerodynamic capabilities.

In this context, the design and the use of this type of instruments promote and sustain the folowing:

a) reduction in the necessary resources for ammunition experimental testing, in general and ammunition consumptions in experimental tests, in particular;

b) reduction in the consumption of resources in ammunitions design and testing activities other then ammunition (human resources, material resources);

c) statistical estimations in exterior ballistic ammunition parameters design, in particular;

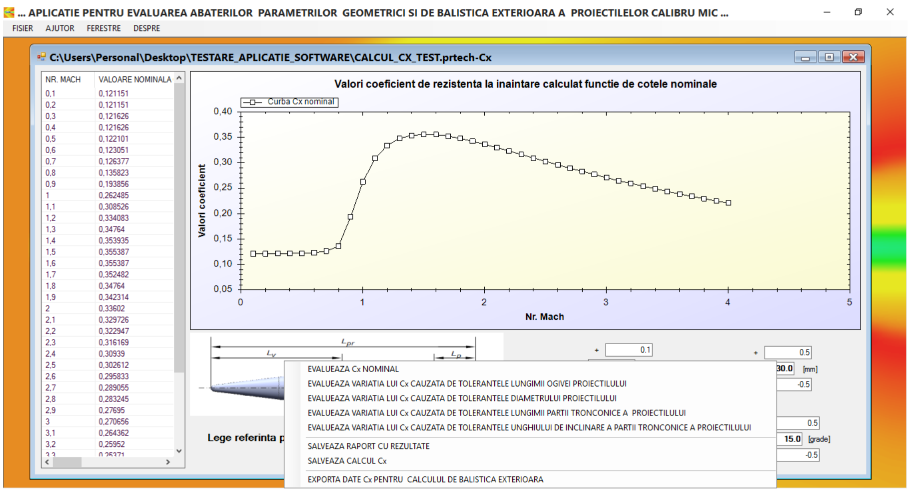
d) ammunition ballistic design theory with punctual estimation and reliable intervals for true value of aerodynamic coefficients for an imposed level of trust condition.

General description of the software module

The drag coefficient evaluation module is part of the complex "in-house" software named **PROTech** which is developed by the author. PROTech software is developed using Visual Basic 2010 Express. This software makes use of a few numerical and graphic libraries like MathNet Numerics, ZedGraph and the author's numerical libraries, too.

ProTech main form frame is presented in Figure 1. This software consists of three main modules for projectile's aerodynamic evaluation and field test simulation. One of them is the drag coefficient evaluation module.

Figure 1. PROTech "in-house" software main frame



Source: Own images of PROTech graphic module (Romanian language user interface).

PROTech software has a main menu consisting of:

a) File submenu for opening, saving calculations and also exiting from application;
b) Help submenu with PROTech software description and usage;
c) Window submenu for solution window arrangement in case of multiple studies made in the same time;
d) About submenu with the Acknowlegment and authors' rights.

PROTech "in-house" software in this configuration can help the users evaluate, using statistical methods, the nominal minimal and maximal value of a measured parameter.

In case of projectile's aerodynamics we are interested in geometrical configuration dimensions like ogive length, tonconical part length, tronconical part angle, projectile diameter. This dimensions are important in projectile's drag coefficient evaluation and projectile's exterior ballistics.

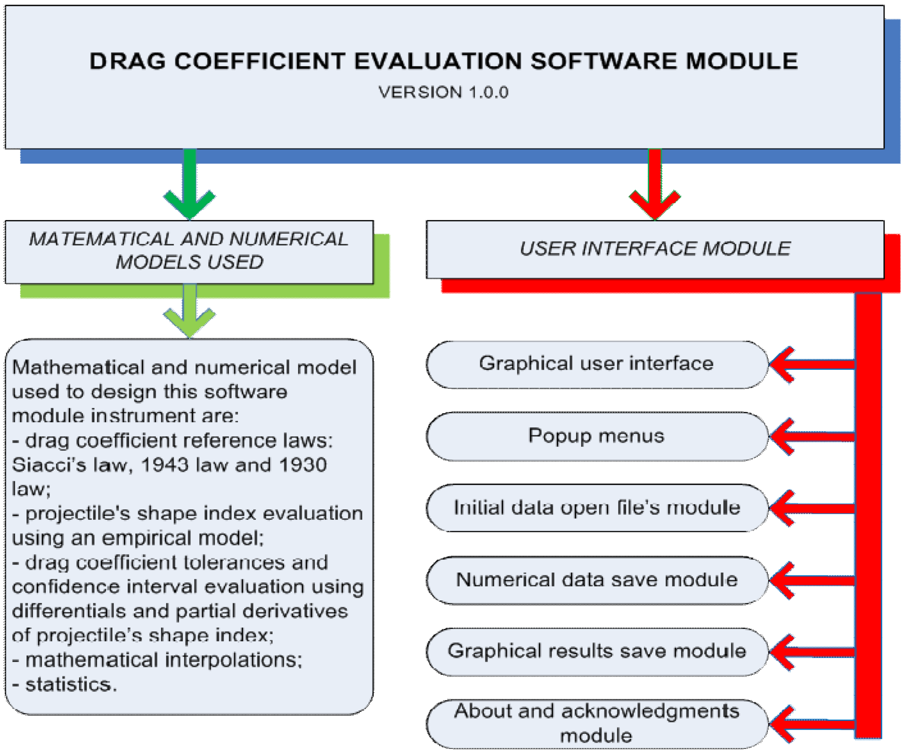
In this configuration PROTech software is a modular product which can be easly upgraded with new software modules.

A module of this "in-house"software is represented by "Drag evaluation software module". This module has two main components (see Figure 2.):

a) mathematical and numerical component;

b) user interface module.

Figure 2. Drag coefficient module components



Source: Own images of module components.

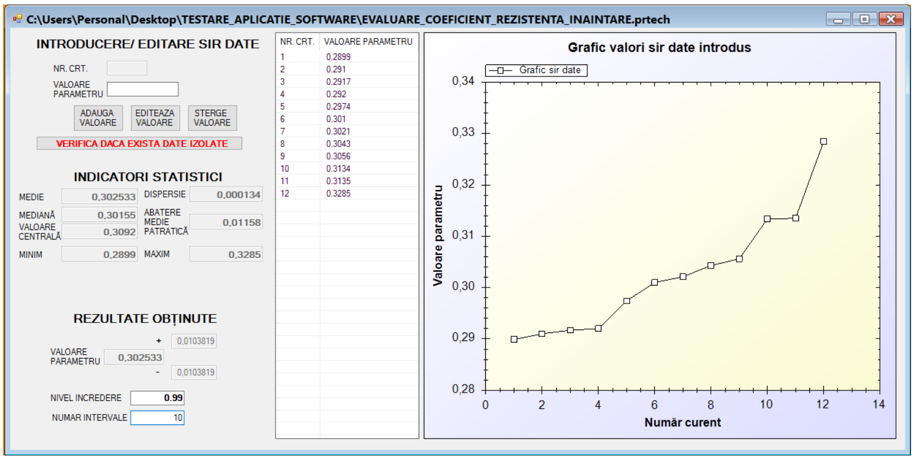
The mathematical model of this module is implemented in a software module library named "Protech.vb" which is included in PROTech software.

This software module implemented tree reference laws for drag coefficient evaluation. These laws are: 1930, 1943 and Siacci's. These laws are the most common ones used in projectiles design.

The drag coefficient is evaluated using the projectile's shape index and the above drag reference laws. The shape index is evaluated using the Hellie's method and empirical relations (Antonescu, I (1977)) for corection. This model is improved by using the diferential form of shape index function to evaluate the influence of projectile's geometrical dimensions on his drag coefficient (Surdu, G. (2015); Surdu, G. et al. (2015)). Geometrical dimensions of projectiles are represented by their nominal and toleranced values.

The geometrical values can be measured based on the real configuration, and in this case PROTech software can evaluate the experimental results and calculates the nominal value and tolerances for the geometrical dimension measured data. This can be done by its statistical module presented in Figure 3.

Figure 3. PROTech statistic module for parameters evaluation



Source: Own images of module software statistics Romanian language interface.

The software module presented in Figure 3 enables the user to evaluate the true value and tolerances for a measured parameter using statistics.

Software module user interface and menus

The main frame form of the module interface is presented in Figure 1 and as we can observe the module has the following components for:

a) numerical results visualization;

b) graphical results visualization;

c) drag reference law selection;

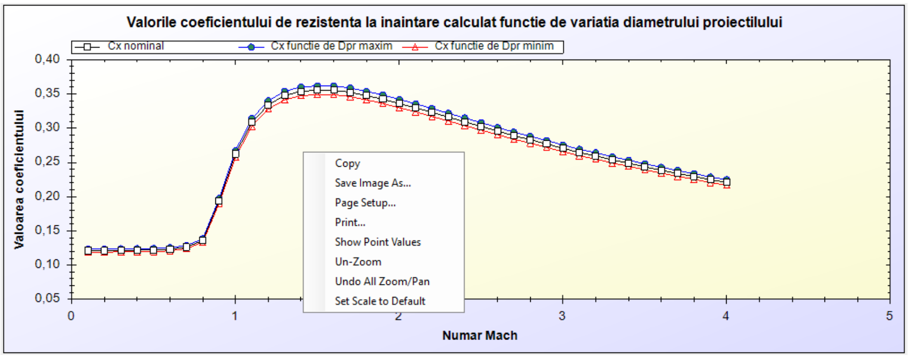
d) drag coefficient evaluation initiation, results and case solver save;

e) entering the geometrical data for projectile.

Numerical results can be viewed in a listview table with results, see Figure 1.

The graphical results visualization module is shown in Figure 4.

Figure 4. Software module graphic component for visualizing, analyzing and saving data results



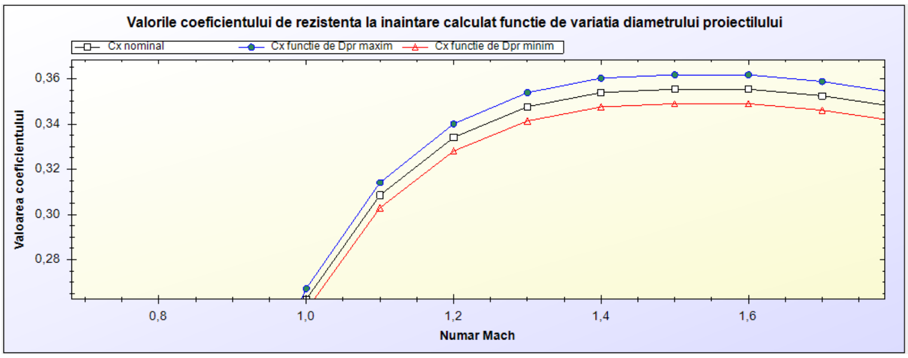
Source: Own images of module software statistics Romanian language interface.

This graphic component of the software module has a popup menu which enables the user to: zoom the represented data, view data point, save the image as a file for a later use in a report.

This 2D graphic module is Zedgraph dynamic linked library for .NET framework. For example, in Figure 4 we can see the evaluation data for projectile drag coefficient when we consider his diameter tolerances.

An image with the zoomed data representation was saved and presented in Figure 5.

Figure 5. Software module graphic component for visualizing, saving and zooming data picture



Source: Own images of module software statistics, Romanian language interface.

In Figure 5 we can observe:

a) values line for the drag coefficient for the true value of the geometrical dimensions, black line representation with hollow squares;

b) values line for drag coefficient for the case of diameter maximum tolerance, blue line representation with full circles, and the value;

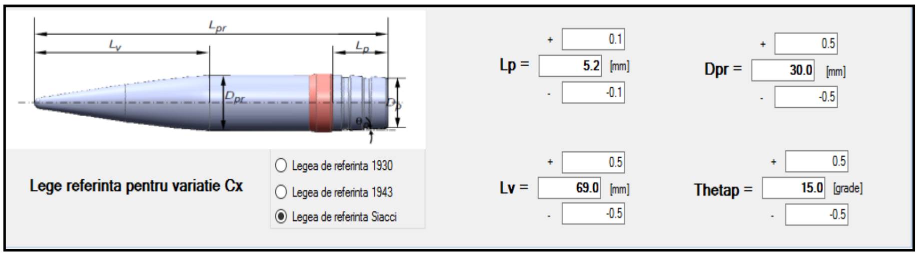
c) values line for drag coefficient for the case of diameter minimum tolerance, red line representation with full triangles.

This kind of representation helps the user to easily evaluate the impact of projectile's diameter tolerances on drag coefficient.

The component for reference drag law selection consists of tree radio buttons which allow the evaluation of the drag cofficient in real time when selected. This component is presented in Figure 6.

The component for projectile's geometrical dimensions initial data insertion represents an array of input boxes and labels which helps the user insert the reference data for projectile geometry. This data can be automaticaly inserted using the PROTech main menu file open submenu. The submenu of PROTech software allows user to select the file with the case saved and open it to be used for calculations. This component can be seen in Figure 6 with the reference drag selection component.

Figure 6. Software module graphic components for initial data inseration and reference drag law selection

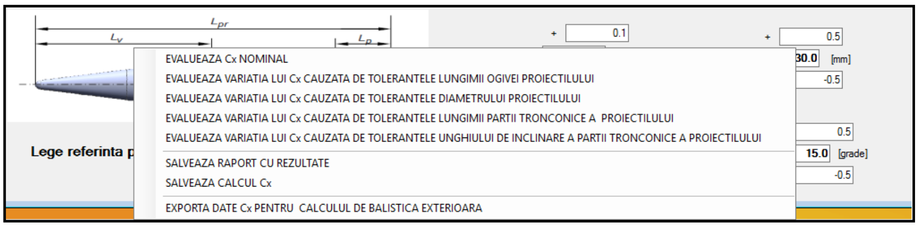


Source: Own images of module software statistics Romanian language interface.

The components presented in Figure 6 gives the user all necessary options for initial data inseration for ogive length, projectile diameter, projectile's tronconical part length, projectile's tronconical part angle. The user has also an image with the geometrical dimensions representation.

The sotfware module component for drag coefficient evaluation initiation, results and case solver save is presented in Figure 7.

Figure 7. Software module for drag coefficient evaluation



Source: Own images of module software statistics Romanian language interface.

This software module component is represented by a popup menu which is divided in tree sections:

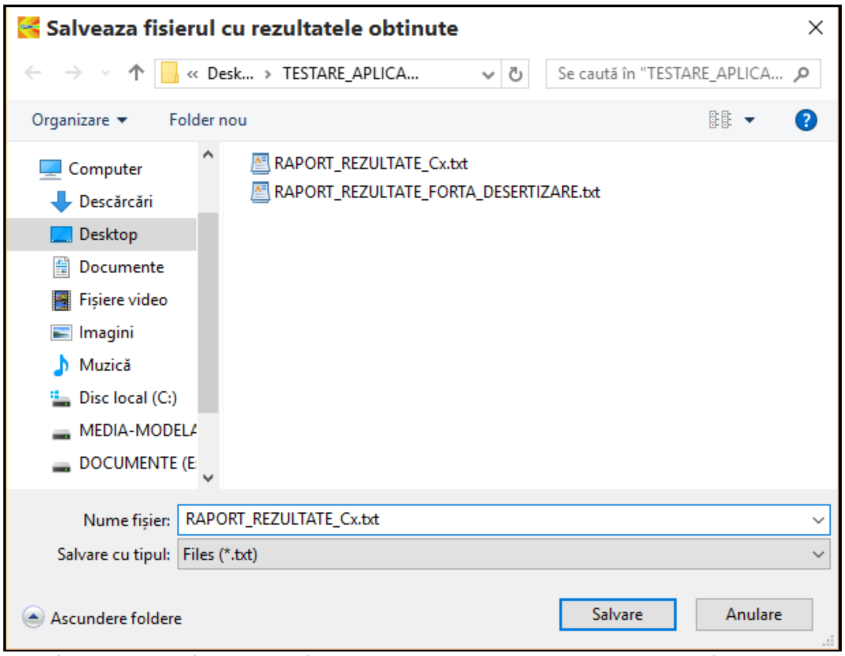
a) evaluation section for drag coefficient evaluation;

b) saving section for report results save and case solver data;

c) exporting data section for drag coefficient file for exterior ballistic analysis.

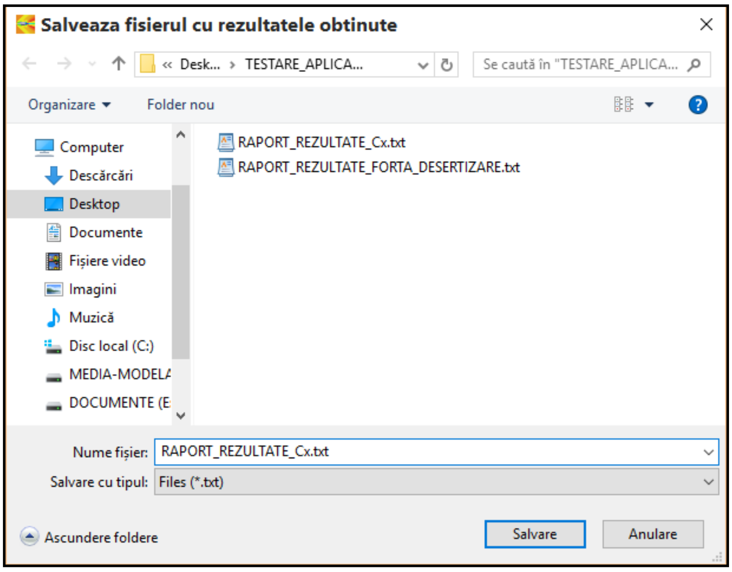
The saving section b) for these components is represented by a “save dialogue” window which allows the user to name the report file or the case data file.The dialogue window for report data results file is presented in Figure 8, and for case data file in Figure 9.

Figure 8. Software module dialogue window for data report results save



Source: Own images of module software statistics, Romanian language interface.

Figure 9. Software module dialogue window for case data file save



Source: Own images of module software statistics Romanian language interface.

The data results report saved (Figure 10) have all the results for the drag coefficient calculated by means of the selected geometrical dimension tolerances. This report is a text format file which can be easily used in different reports.

Figure 10. Frame form for the report file with results

```
***************************************************************************
*                                                                         *
*         REZULTATE OBTINUTE COEFICIENT DE REZISTENTA LA INAINTARE        *
*                                                                         *
***************************************************************************


       REZULTATE OBTINUTE PENTRU COEFICIENTUL DE REZISTENTA LA INAINTARE
                               - rezultate -

|-------------------------------------------------------------------------|
|  NR. MACH  |  Cx NOMINAL  |  Cx TOLERANTA MAXIMA  |  Cx TOLERANTA MINIMA  |
|-------------------------------------------------------------------------|
     0,1        0,087894             0,08739               0,08739
     0,2        0,087894             0,08739               0,08739
     0,3        0,087894             0,08739               0,08739
     0,4        0,087894             0,08739               0,08739
```

Source: Own images of module software report generated with the software module.

The formats of the saved or exported files with results in numerical format are text file type, but have the following extensions:

a) ".txt" for reports with results data;

b) ".prtech-Cx" for case data file;

c) ".bex-CD" for the drag coefficient data files exported for exterior ballistic analyses.

Data inputs and results of software module functionality tests

We consider a case file for a 30 mm projectile with the initial data presented in Table 1. The case problem for solving is the influence of projectile diameter tolerances on drag coefficient.

Table 1 – Projectile's geometrical input data

Parameter	Value
Lv [mm]	69±0.5
Dpr [mm]	30±0.5
Lp [mm]	5.2±0.1
Thetap [degree]	15±0.5

Source: Own data source based on PROTech software statistical module.

For initial data presented in Table 1, we obtain the following results for drag coefficient evaluation considering the projectile's diameter tolerances.

Table 2 – Drag coefficient evaluation based on projectile's diameter tolerances influence

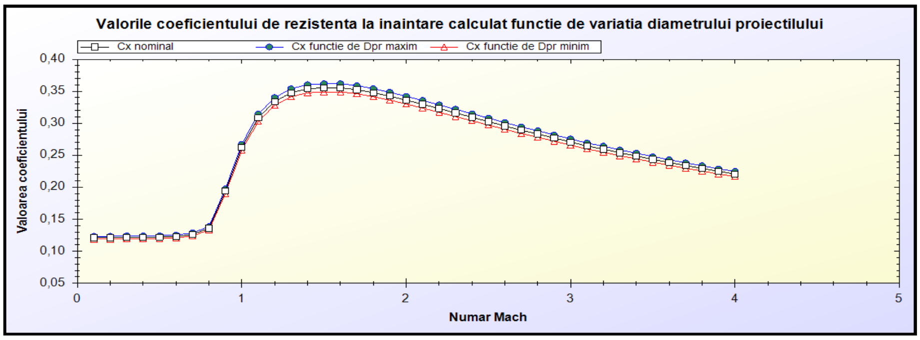
Mach	Drag coefficient for diameter nominal value	Drag coefficient for diameter maximum value	Drag coefficient for diameter minimum value
0.1	0.121151	0.123409	0.11888
0.2	0.121151	0.123409	0.11888
0.3	0.121626	0.123893	0.119346
0.4	0.121626	0.123893	0.119346
0.5	0.122101	0.124377	0.119812
0.6	0.123051	0.125345	0.120745

Mach	Drag coefficient for diameter nominal value	Drag coefficient for diameter maximum value	Drag coefficient for diameter minimum value
0.7	0.126377	0.128733	0.124008
0.8	0.135823	0.13834	0.133293
0.9	0.193856	0.197418	0.190275
1	0.262485	0.267268	0.257677
1.1	0.308526	0.314101	0.302923
1.2	0.334083	0.340087	0.32805
1.3	0.34764	0.353888	0.341362
1.4	0.353935	0.360295	0.347542
1.5	0.355387	0.361774	0.348969
1.6	0.355387	0.361774	0.348969
1.7	0.352482	0.358816	0.346116
1.8	0.34764	0.353888	0.341362
1.9	0.342314	0.348466	0.336132
2	0.33602	0.342059	0.329951
2.1	0.329726	0.335651	0.323771
2.2	0.322947	0.328751	0.317115
2.3	0.316169	0.321851	0.310459
2.4	0.30939	0.31495	0.303802
2.5	0.302612	0.30805	0.297146
2.6	0.295833	0.30115	0.29049
2.7	0.289055	0.294249	0.283834
2.8	0.283245	0.288335	0.278129
2.9	0.27695	0.281927	0.271948
3	0.270656	0.27552	0.265768
3.1	0.264362	0.269112	0.259587
3.2	0.25952	0.264184	0.254833
3.3	0.25371	0.258269	0.249128
3.4	0.248868	0.25334	0.244373
3.5	0.243542	0.247919	0.239143
3.6	0.2387	0.24299	0.234389
3.7	0.233858	0.238061	0.229635
3.8	0.229501	0.233625	0.225356
3.9	0.224659	0.228696	0.220601
4	0.220786	0.224753	0.216798

Source: Own data source based on PROTech software drag coefficient module evaluation.

Based on Table 2 numerical data the graphical representation for the drag coefficient is saved in Figure 11.

Figure 11. Software module's drag coefficient graphical results for geometrical parameter diameter tolerances



Source: Own images of drag coefficient results generated using drag coefficient software module.

As we can see in Table 2 and Figure 11 we have large differences for drag coefficient values caused by projectile's diameter deviations. In case of the maximum tolerance for projectile diameter we have a value of 0.361774 for drag coefficient compared to 0.348969 obtained for the minimum tolerance for this parameter. This increase in drag coefficient value is normal considering that in reality we have a surface exposed directly to air for the maximum diameter tolerance greater than the one given by the minimum tolerance.

These differences in the drag coefficient have a major impact on projectile's exterior ballistics elements. The values for drag coefficient were calculated using the Siacci reference drag law.

Concluding remarks

The software module presented in this paper can be used to evaluate experimental or theoretical data for aerodynamics of ammunition design and testing process.

This is based on the software module capabilities presented and the normal requirements in projectile design and evaluation tests. The presented module can sustain the reduction in ammunition consumption by its capability to evaluate the drag coefficient only using its geometrical dimensions without any suplementary experimental tests or field tests.

The geometrical dimensions of a series of projectiles can be measured without distructive tests and so the projectiles measured can be used for future tests. In this case the consumption of ammunition is reduced.

Normally to evaluate the drag coefficient for projectile tests are made in special shooting range facilities. In the same time all these resources not taking into acount the ammunition for tests are reduced when using this software module.

Testing and evaluation of ammunition is used also in:

a) ammunition acquisition when the producer must prove by tests to potential buyer that the ammunition complies with specifications;

b) ammunition lifecycle experimental tests for parameter constancy;

c) reuse or adapt firing ammunition to other weapons than those for which they were initially designed.

All these three cases justify the need for this type of software instruments as the one developed and presented in this paper to estimate the drag coefficient in different geometrical configurations of projectile with low cost.

The software module has a very simple and intuitive user interface. This make possible to this software module to be used also by someone who is not an expert in ballistics or aerodynamics.

This software module can be used not only for design but can be used to give examples for design of ammunition with education purposes.

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