INTRODUCTION

Digital manufacturing can be defined as a network of digital models and methods that define all phases of the product life cycle. It represents the integration of various tools for planning, designing, optimizing products and processes, such as tools for:
- Product design,
- Engineering analysis,
- Designing technological processes,
- Projecting and simulation of management information,
- Time management and business applications,
- Planning the layout of production systems,
- Ergonomics,
- Process simulation,
- Product life cycle management, etc.

The aerodynamic coefficients are dimensionless size of the components of the aerodynamic forces and moments. Determination of aerodynamic coefficients depending on the structural parameters of the missile is based on a theoretical approach to the equations of fluid mechanics. In the numerical solution of systems of partial differential equations, it is necessary to know the boundary conditions and the experimental results of wind tunnel and measure the parameters during the flight.

Modern display systems aerodynamic forces and moments acting on axisymmetric shells come from Fowler, Gallop, Lock and Richmond, 1920. year. Nielsen and Synge supplement the required forces and moments adjusting Fowler system into a logical whole.

Kent, Kelley and McShane build on the system of aerodynamic forces and moments, and to define two criteria of stability. Maple and Synge have examined the effects of aerodynamic force and moment on the rotational symmetric missiles.

The effect of air on the aircraft during its motion is tending in the aerodynamic force that creates the aerodynamic moment to the selected point. Aerodynamic force and moment, as the vector values, can be displayed with the components in one of the inserted coordinate systems.

Motion of axisymmetrical aircraft in space is consists of translation of mass center and rotation around its mass center. The flight of these aircrafts characterize conditions of small disturbances, whereby is presumed that angles of incidence not going over a few degrees. This fact enables the application of linear aerodynamic in calculation of aerodynamic characteristics or theirs derivatives.

For the aircraft which external surface of axisymmetrical shape, every area is, at the same time, the symmetric area of external surface. Because of this for a defining of aerodynamic coefficients is applied circuit coordinate system, because the circuit area is the singular special area through the axis of symmetry:

\[
R^S = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = q_{\infty} S \begin{bmatrix} C_X \\ C_Y \\ C_Z \end{bmatrix} \quad \text{and} \\
M^S = \begin{bmatrix} L \\ M \\ N \end{bmatrix} = q_{\infty} S d \begin{bmatrix} C_l \\ C_m \\ C_n \end{bmatrix}
\] (1.1)

Components of aerodynamic force and moment are proportional to dynamic pressure \( q_{\infty} = \frac{\rho_{\infty} V_{\infty}^2}{2} \) and they initially depend on square of aerodynamic velocity, caliber, air density, and then of the aerodynamic coefficients. In changing of aircraft height the aerodynamic components are smaller intensity because of reducing of air density.

Aerodynamic coefficients present dimensionless values of components of aerodynamic forces and moments. They are obtained when we divide the real components of aerodynamic forces and moments with reference force and reference moment. This force and moment have different values for different types of aircrafts. Reference force is product of reference pressure and reference surface, while the reference moment is product of reference force and reference length. Reference pressure is dynamic value:

\[ q_{\infty} = \frac{\rho_{\infty} V_{\infty}^2}{2} \]

For reference surface is taken the circle of diameter of one nominal projectile caliber:

\[ S_{\text{ref}} = \frac{\pi d^2}{4} \].
For reference length is accepted the value of nominal caliber $d$, except for angular velocity around the longitudinal axis, when is taken half of caliber. As the components of aerodynamic forces and moments correspond to some coordinate system, as that will the aerodynamic coefficients also will correspond to certain coordinate system.

Components along axes of dynamic coordinate system, the aircrafts have not particular marks. Aerodynamic coefficients for components of aerodynamic force in the dynamic coordinate system are marked with $C_x$, $C_y$, and $C_z$, and they are got when the components of aerodynamic force divide with dynamic pressure $q_x$ and reference surface $S_{ref}$.

Aerodynamic coefficients for components of moment are marking with $C_l$, $C_m$, and $C_n$, and they are got when the components of aerodynamic momenta along the certain axes divide with dynamic pressure $q_T$, reference surface, and nominal length $d$ (for rolling $d/2$).

In the table 1. are defined the aerodynamic coefficients for three mostly used coordinate systems.

Aerodynamic coefficients are function of:
1. aerodynamic parameters:
   - Mach’s number $Ma = \frac{V}{a}$,
   - Raynold’s number $Re = \frac{V \ell}{\nu}$ ($\ell$ is length of fluid flow, $\nu$ is kinematic coefficient of viscosity);
2. of position of aerodynamic velocity in relation to the aircraft:
   - angles $\alpha$ and $\beta$ or $\tilde{\alpha}$ and $\tilde{\beta}$ or $\phi$ and $\sigma$;
3. of dimensionless angular velocity change of position of aerodynamic velocity in relation to the aircraft:
   - $\alpha^*$ and $\beta^*$ or $\tilde{\alpha}^*$ and $\tilde{\beta}^*$ or $\phi^*$ and $\sigma^*$;
4. of dimensionless angular velocity of the aircraft:
   - $p^*$, $q^*$, $r^*$ ili $p^*$, $q^*$, $r^*$ ili $p^*$, $q^*$, $r^*$;
   - $p^*$, $q^*$, $r^*$ ili $p^*$, $q^*$, $r^*$ ili $p^*$, $q^*$, $r^*$;
5. for aerodynamic controllable aircrafts, except that parameters, we have and drifts of controlling surfaces, and that:

<table>
<thead>
<tr>
<th>Coordinate system</th>
<th>Dynamic coordinate system</th>
<th>Aeroballistic coordinate system</th>
<th>Circuit coordinate system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name of coefficient</td>
<td>$C_X = \frac{X}{q_x S_{ref}}$</td>
<td>$\bar{C}<em>X = \frac{\bar{X}}{q_x S</em>{ref}}$</td>
<td>$\bar{C}<em>X = \frac{\bar{X}}{q_x S</em>{ref}}$</td>
</tr>
<tr>
<td>Axial forces</td>
<td>$C_Y = \frac{Y}{q_y S_{ref}}$</td>
<td>$\bar{C}<em>Y = \frac{\bar{Y}}{q_y S</em>{ref}}$</td>
<td>$\bar{C}<em>Y = \frac{\bar{Y}}{q_y S</em>{ref}}$</td>
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<tr>
<td>Lateral forces</td>
<td>$C_Z = \frac{Z}{q_z S_{ref}}$</td>
<td>$\bar{C}<em>Z = \frac{\bar{Z}}{q_z S</em>{ref}}$</td>
<td>$\bar{C}<em>Z = \frac{\bar{Z}}{q_z S</em>{ref}}$</td>
</tr>
<tr>
<td>Normal forces</td>
<td>$C_m = \frac{M}{q_x S_{ref} d}$</td>
<td>$\bar{C}<em>m = \frac{\bar{M}}{q_x S</em>{ref} d}$</td>
<td>$\bar{C}<em>m = \frac{\bar{M}}{q_x S</em>{ref} d}$</td>
</tr>
<tr>
<td>Moment of rolling</td>
<td>$C_l = \frac{L}{q_y S_{ref} d}$</td>
<td>$\bar{C}<em>l = \frac{\bar{L}}{q_y S</em>{ref} d/2}$</td>
<td>$\bar{C}<em>l = \frac{\bar{L}}{q_y S</em>{ref} d/2}$</td>
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<tr>
<td>Moment of prance</td>
<td>$C_m = \frac{M}{q_x S_{ref} d}$</td>
<td>$\bar{C}<em>m = \frac{\bar{M}}{q_x S</em>{ref} d}$</td>
<td>$\bar{C}<em>m = \frac{\bar{M}}{q_x S</em>{ref} d}$</td>
</tr>
<tr>
<td>Moment of aberration</td>
<td>$C_n = \frac{N}{q_y S_{ref} d}$</td>
<td>$\bar{C}<em>n = \frac{\bar{N}}{q_y S</em>{ref} d}$</td>
<td>$\bar{C}<em>n = \frac{\bar{N}}{q_y S</em>{ref} d}$</td>
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</tbody>
</table>

$\delta_i$ - drift of flaps,
$\delta_m$ - drift around the axis $y$ of aircraft (elevator),
$\delta_n$ - drift around the axis $z$ of aircraft, and
$\delta_i$ - drift of wing flat (flaps).

1.1. Axial force

Aerodynamic coefficient of axial force $X$ is marked with $C_X$. Axial force is opposite sense of direction from the axis $x$, value $C_X$ is negative. Positive value is marked with $C_A$, i.e. $C_X = -C_A$. In the matching of external surface axis with main axis of inertia, there is no difference between $C_X$ and $C_A$.

Researches are shown that this coefficient depends on:
- Mach’s number $Ma$,
- resultant angle of incidence $\sigma$ and
- Raynold’s number $Re$.

Factor of dimensionless velocity of rolling $p^* = \frac{p d/2}{V}$ is usually ignored because of datas deficiency.
Dependancy $C_X(-\sigma) = C_X(\sigma)$ is even function of angle. With amplification in the order of that even function there is got:

$$C_X = C_{X0}(Ma) + C_{X\sigma^2}(Ma)\sigma^2 + \ldots$$

whereby:

$$C_{X\sigma^2} = \frac{1}{2} \left( \frac{\partial^2 C_X}{\partial \sigma^2} \right)_{\sigma=0}$$

For praxis we satisfy with second rate element. With $\sigma^2$ first element $C_{X0}(Ma)$ presents the value of coefficient of axial force when the aerodynamic velocity is in the direction of symmetry axis of rotary surface.

Aerodynamic coefficient has three parts:

$$C_X = C_{XP} + C_{XF} + C_{XD}$$

First element $C_{XP}$ is result of factor of normal pressure on the exernal surface and it is called wave drag. It depends on the shape of surface, and for certain shape of surface function is Mach's number. Wave drag $C_{XP}$ consists of:

- coefficient of top of projectile resistance $C_{X1}$,
- coefficient of back wing resistance $C_{X3}$ and
- coefficient of rotating band resistance $C_{XVP}$.

Second element $C_{XF}$ is result of air friction on the external surface, so on it affect the regularity of surface and its roughness, and it is called friction coefficient. It depends on Raynold's number, but that effect is small during the flight, because friction coefficient depends on Raynold's number, and changes of aerodynamic velocity during the flight are not so huge that Raynold's number logarithm to be essentially changed.

Third part is resistance because of underpressure behind aircraft, which we call the resistance of bottom, and it usually depends on Mach's number. Because of that, in all flight analyses (no matter it is calculation of trajectories, analysis of stability or projecting of autopilot) we do not take into consideration the dependancy of axial force coefficients from the Raynold's number. Though, in the comparing of axial force coefficients $C_X(M')$ of two aircrafts similar to shape, but of very different sizes (different length of fluid flow), Raynold's number can cause essential differences, especially in transonici. For example, artillery projectile and the gun projectile of same shapes, and in the same velocities, have Raynold's number 20 times different. In that cases, we can not say that those two projectiles, though they have the same shape, they have the same function $C_X(M')$.

Coefficient of resistance of the bottom $C_{XD}$ could be reduced by effusion of certain gas on the projectile bottom. That mass flow must not be in the main than one very small part of reference flow $\rho_{\infty} S_{ref} V$, as would not break fluid flow of back part of projectile. With installing of gas-generator in the back part of projectile, it is reducing the bottom resistance of one-third of value, and therefore it is reducing and coefficient of projectile axial force. Projectiles like that are different from the projectiles with base bleed.

**GENERAL THESIS AND THE WAY OF MARKING**

Symmetrical appearance of a missile at angle of attack $\sigma = 0$. The airport is semi-empirical method. It solves the basic system of equations corresponding mathematical procedure in its final form gives the relationship of the axial components of the aerodynamic coefficients for axisymmetric fluid flow. The total aerodynamic drag coefficient of axial force method AERODR is:

$$C_X = C_{X1} + C_{XSE} + C_{XVP} + C_{X3} + C_{XD},$$

wherein:

- coefficient of top of projectile resistance $C_{X1}$,
- coefficient of back wing resistance $C_{X3}$,
- coefficient of rotating band resistance $C_{XVP}$, and
- coefficient of resistance of the bottom. $C_{XD}$.

**2.1. THE COEFFICIENT OF WAVE RESISTANCE PEAK MISSILES**

The coefficient of wave drag projectile tip is:

$$C_{X1} = \frac{f(\beta \sqrt{M_e^2 - 1}, \beta)}{(M_e - 1)},$$

where $f(\cdot)$ is a function depending on the projectile shape and fluid flow characteristics.
\[ C_{x1} = \frac{(B_1 - B_2 \beta^2) \cdot (\beta \sqrt{M^2 - 1})^{(\beta + B_0 \beta)}}{(M^2 - 1)} \]  
(2.2)

\[ C_{x1} = C_{x1V} + C_{xZ} \]  
(2.3)

wherein:

\[ C_{x1V} = \frac{(B_1 - B_2 \beta^2) \cdot (\beta \sqrt{M^2 - 1})^{(\beta + B_0 \beta)}}{(M^2 - 1)} \]  
(2.4)

\[ b = \frac{d - d_M}{2L_N} \] - slope of the conical, and constants:

\[ B_1 = 0.6256 - 0.5313(R_i/R) + 0.595(R_i/R)^2 \]
\[ B_2 = 0.0796 + 0.0779(R_i/R) \]
\[ B_3 = 1.587 + 0.049(R_i/R) \]
\[ B_4 = 0.1122 + 0.1658(R_i/R) \]
\[ M = \sqrt{M^2 - 1} \]
\[ Z = \frac{1}{M^2 - 1} \]

\[ M_C = 1 + 0.9567\beta^{1.85} \] - critical Mach number.

For \( M_\infty < M_C \) introduces the label

\[ ZE = RF = \sqrt{M^2 - 1} \]  
i follows

\[ C_{x1} = \frac{M^2 - 1}{2.4M_C^2} \]  
(2.5)

For \( M_\infty < 1 \) introduces the mark

\[ P_{tp} = (1 + 2M_C^2)^{3.5} \]  
(2.6)

For supersonic flow \( M_\infty > 1 \), so the value of

\[ P_{tp} = (1 + 2M_C^2)^{3.5} \cdot \left(\frac{6}{7M_C^2 - 1}\right)^{2.5} \]  
(2.7)

\[ C_{x1P} = \frac{1.22 \cdot (P_{tp} - 1) \cdot d_M}{M_C^2} \]  
(2.8)

For subsonic flow \( M < 0.91 \) coefficient \( C_{xZ} = 0 \), and for supersonic flow at \( M > 1.41 \) coefficient

\[ C_{xZ} = 0.85C_{x1P} \]  
In the interval \( 0.91 < M < 1.4 \)

\[ C_{xZ} = (0.245 + 2.88C_{x1P})C_{x1P} \]

Radius tangent top

\[ R_T = \sqrt{c^2 + \frac{c^2 \cdot n^2}{(b - a)^2}} \]  

\[ a \text{ i } b \] - the base radius of the top,

\[ c = \frac{1}{\sqrt{4}} (b - a)^2 + n^2 \]

\( R \) - the actual radius of the cone \( R = \infty \).

Based on the dimensions of the radius tangent peak and the actual peak is given by:

\[ RT / R = 0 \] - the cone,
\[ RT / R = 1 \] - tangent to the top, and
\[ RT / R = 0 \div 1 \] - for variations secant top.

Equation resistance coefficient for conical top of \( C_{x1} \) is adjusted with changes in pressure coefficient \( C_{ps} \).

\[ C_{x1} = \frac{C_{x1} \cdot M_C^2}{M^2 - 1} \left[ \frac{\beta \sqrt{M^2 - 1}}{M_C^2} \right] + \frac{\pi}{4} d_M^2 C_{ps} \]  
(2.9)

wherein by Moru:

\[ C_{ps} = \frac{2}{\chi M_C^2} \left[ 0.9 \left( \frac{\chi + 1}{2} \right)^{2.5} \left( \frac{\chi + 1}{2} \right)^{2.5} \right] \]  
(2.10)

\[ C_{x1} = \frac{\pi}{4} C_{ps} = 1.122 \left[ (1.2M_C^2)^{3.5} \left( \frac{6}{7M_C^2 - 1} \right)^{2.5} \right] \]  
(2.11)

\( K \) - correction coefficient due to pressure changes on the surface of the projectile. Kartsen and Stein have proposed \( K = 0.9 \). Dickinson gave experimental results for the conical top ogival at supersonic speeds \( K = 0.75 \). For a slim top Cole, Solomon and Vilmarth suggested:

\[ \frac{C_{x1}}{\beta^3} \cdot \ln \beta = f \left[ \frac{M_C^2 - 1}{(\chi + 1)M_C^2 \beta^2} \right] \]  
(2.12)

The calculated values are approximately equal to the experimental. Von Karman is a two-dimensional transonic slender bodies gave a simplified formula:

\[ C_{x1} \sqrt{(\chi + 1) M_C^2} = f \left[ \frac{M_C^2 - 1}{(\chi + 1)M_C^2 \beta^2} \right] \]  
(2.13)

For axisymmetric three-dimensional shape of the transonic speed:

\[ C_{x1} = F(\beta) + f \left[ \frac{\beta (M_C^2 - 1)}{(\chi + 1)M_C^2} \right] \]  
(2.14)
for $M_\infty > M_c$ wherein $M_c = \frac{1}{\sqrt{1 + 0.552^5/\beta^4}}$.

## 2.2. The Coefficient of Wave Drag Rear Cone

At supersonic fluid flow conical bottom of the projectile, for small values of the cone angle of the rear $\varphi_d$ is proposed to the rear of the cone resistance equation:

$$C_{X3} = \frac{4Z_{_3}\tan \varphi_d}{\lambda \left(1 - e^{-\lambda_3} + 2\tan \varphi_d (e^{-\lambda_3} (L_{BT} + \frac{1}{\lambda} - \frac{1}{\lambda_3})\right)}$$

wherein:
- $C_{X3}$ - been calculated value of wave resistance of the last cone,
- $\varphi_d$ - rear angle of the cone (the negative value of the conical part),
- $L_{BT}$ - the length of the rear cone of the caliber,
- $Z_{_3}$ - correspond to the coefficient of pressure change Prandl-Mayer expansion,
- $\alpha$ - repair of pressure coefficient of the last cone.

The coefficients $Z_{_3}$ and $l$ obtained by the method of characteristics missile whose last part of the shape of the cone:

$$Z_{_3} = Z_2 = Z_2 \exp\left(-\frac{2}{\sqrt{M_{_3}^2}}l_{wcl}\right) +$$

$$\frac{2\tan \varphi_d}{\sqrt{M_{_3}^2} - 1} \left[(\chi + 1)M_{_3}^2 - 4(M_{_3}^2 - 1)\right] \tan \theta_d$$

where the correction factor resistance front rear cone for supersonic speeds:

$$Z_2 = \left[1 - \frac{3\pi R_T}{5M_{_3}}\right] \frac{5\beta}{6\sqrt{M_{_3}^2 - 1}} \left(\frac{\beta}{2}\right)^{3/2} \left(0.7435 M_{_3}^2 (\beta \cdot M_{_3})^3\right)$$

$$k = \frac{0.85}{\sqrt{M_{_3}^2 - 1}}.$$ (2.14)

## 2.3. The Aerodynamic Drag Coefficient of Friction

The coefficient of friction $C_{XSF}$ can be calculated on the basis of

$$C_{XSF} = \frac{C_{AXFL} \cdot S_{WN} + C_{AXSF} \cdot S_{WCYL}}{S_w},$$

where the turbulent boundary layer (IBLC = 2) value $C_{FL} = C_{FT}$

$$C_{XSF} = \frac{4}{\pi} C_{FL} S_w.$$ (2.15)

For a laminar boundary layer by Blasius (IBLC = 1) value

$$C_{FL} = \frac{1.328}{\sqrt{Re}} \left(1 + 0.12M_{_3}^2\right)^{-0.12}.$$ (2.15)

The total area is fluid flow:

$$S_v = S_{VV} + S_{VCIL}$$

wherein the surface of the cylindrical part

$$S_{VCIL} = p (L_T - L_N)$$

Top surface missiles:

$$S_{VV} = \frac{\pi}{2} L_N \left[1 + \frac{1}{8L_N^2}\right] \left[1 + \left(\frac{1}{3} + \frac{1}{5L_N^2}\right) \left(\frac{R_T}{R}\right)\right],$$

wherein: $D_{UM} = 1 + \left(\frac{1}{3} + \frac{1}{5L_N^2}\right) \left(\frac{R_T}{R}\right).$

Prandtl’s empirical formula for the turbulent boundary layer corrected for changes in pressure:

$$C_{FT} = \frac{0.455}{(log R_e)^3} \left(1 + 0.21M_{_3}^2\right)$$

wherein:
- $R_e = \frac{V_{\infty}}{V_{\infty}}$ - Reynolds number,
- $V_{\infty} = a_{\infty} M_{\infty}$ - velocity fluid flow,
- $l = L_T \times d_{REF}$ - fluid flow length and,
- $d_{REF}$ - caliber projectiles.

Slihting showed higher similarity Prandtl empirical formula and the results of Van Driest.

For values of $t=15^\circ C$, $m_{_3} = 1.7894 \times 10^{-5}$ kg/ms and $r = 1.225$ kg/m$^3$ value of the Reynolds number is: $R_e = 23296.3 \times M_{_3} \times L_T \times d_{REF}.$

## 2.4. Aerodynamic Drag Coefficient Floor of Missiles

Exact determination of the coefficient of resistance to the bottom of missiles was object of study of many analysts. Campanian watched the flat bottom of the acting base pressure at
supersonic speeds. Mach number determines the character of the boundary layer of air around the bottom. Most of the artillery projectile has a turbulent boundary layer around the bottom. The ratio of base pressure $p_B$ and pressure unchanged current $p_\infty$ based on theoretical and empirical research, is:

$$\frac{p_B}{p_\infty} = \left[1 + 0.09 M^2(1 - e^{-kx}) \right] \left[1 + \frac{1}{4} M^2(1 - d_B) \right]$$

(2.17)

wherein the $L_{CIL} = L_T - L_N$.

Because of the influence of Reynolds number on the character of the flow, there is no possibility of complete overlap of effective data base pressure obtained by theoretical and experimental means. A good correlation is achieved by the length of the rear cone $L_{BT} = 1.5d$ to the base diameter of $d_B = 0.65d$.

Aerodynamic drag coefficient floor of missiles is given by the relation:

$$C_{XD} = \frac{2d_B^2}{\chi M^2_\infty} \left(1 - \frac{p_B}{p_\infty}\right) = 1.4286 \cdot \left(1 - \frac{p_B}{p_\infty}\right) \frac{d_B^2}{p_\infty M^2_\infty}.$$  

(2.18)

Previous analysis applies to projectiles with conical bottom, maximum thickness $d_B = 1$, and shows a great similarity with the experimental.

### 2.5. AERODYNAMIC DRAG COEFFICIENT ROTATING BAND

The leading conventional projectiles generally ring is located at the rear of the cylindrical part of the projectile, with the curvature of the rear cone. For such a position as ring resistance value is less than the leading rings away from the rear of the cone. By changing the configuration of the projectile with a larger number of experiments would be lessened resistance rotating band. Based on the experimental and theoretical results obtained by semi-empirical analytical dependence of the aerodynamic drag coefficient rotating band as a function of the Mach number:

a) $C_{XVP} = M_\infty^{1.25} (d_{BND} - 1)$ za $M < 0.85$,  

(2.19)

b) $C_{XVP} = 0.76175M_\infty^{12.62529} (d_{BND} - 1)$ za $0.85 < M < 0.95$,  

(2.20)

c) $C_{XVP} = (0.21 + \frac{0.28}{M_\infty})(d_{BND} - 1)$ za $M > 0.95$.  

(2.21)

### 3. THE CONCEPT OF SOFTWARE SOLUTIONS

Software solution AERODR method for numerical calculation was made in the programming language FORTRAN on a personal computer. It consists of three parts - the file (FILE):

1. Program AERODR - the main program,  
2. File ULAZ10 - input and,  
3. File IZLAZ10 - calculation results with the comment.

Program the AERODR is organized so that the calculation carried out by units of aerodynamic coefficients of the axial resistance. READ command is retrieved from the input data file ULAZ10. Then the calculated aerodynamic resistance coefficients for different values Mach number. Based on the interval independent variables and the number of points defined by step calculation. Using the FOR-loop sequence for each step calculated the components of the total aerodynamic coefficient $C_x(M)$: $C_{X1}(M)$, $C_{XSF}(M)$, $C_{XVP}(M)$, $C_{X3}(M)$, $C_{XB}(M)$, and $P_B/P_\infty(M)$. At the end of the budget components are added together and calculated the total aerodynamic coefficients for different Mach numbers.

- The file contains ULAZ10 baseline comma separated and grouped into three lines:  
- The first row contains the number of projectiles that calculates,  
- The second row contains the characteristics of the projectile and,  
- Third row contains the type of the boundary layer around the projectile.

IZLAZ10 file is created during the execution of programs in it are stored the information received command WRITE program. These are the results of aerodynamic calculations. Are structured so as to provide at the beginning of the initial data then the tabular results for the total aerodynamic coefficients of axial force and
its components as a function of given Mach numbers.

This concept of a software solution is universal and can be used for all kinds of classic gyro-stabilized projectiles in axisymmetric fluid flow. For the numerical calculation of the new, desired gyro-stabilized projectiles necessary to file ULAZ10 modify or create a new one with initial data chosen projectiles.

### File calculation results „IZLAZ10“

Table 1. presents a comparative view of the axial aerodynamic coefficients for a hypothetical body 122 mm and M=0.5÷4.

<table>
<thead>
<tr>
<th>M</th>
<th>CX</th>
<th>CX1</th>
<th>CXSF</th>
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In Figure 2. presents a comparative view of the axial aerodynamic coefficient and its components for the gauge d = 122mm, L = 616mm, and the interval M=0.5÷4.

### 3.1. RESULTS AERODYNAMIC CALCULATIONS

Table 2. presents a comparative view of the axial aerodynamic coefficients for a hypothetical body 122 mm and M=0.5÷4.

**Baseline data files “ULAZ10”**

- DREF=122mm, LT=5.049, LN=2.582, RTR=0.76, LBT=0.787, DB=0.934, DM=0.062, DBND=1.022, XCGN=3.15 BLC=2.

In Figure 3. presents a comparative view of the axial aerodynamic coefficient for

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Dušan B. REGODIĆ  ●  NEW PRODUCT DESIGN AS PART OF THE DIGITAL FACTORY CONCEPT
different projectile 122mm length: \( L_T = 559 \text{mm} \), \( L_T = 560 \text{mm} \), \( L_T = 593 \text{mm} \), \( L_T = 598 \text{mm} \).

In Figure 4. presents a comparative view of aerodynamic coefficients \( C_x \) and its components for missile 152mm operational changes Mach number \( M = 0.5 \div 4.0 \).

**Baseline data files “ULAZ10”**

\[ \text{DREF} = 152 \text{mm}, \text{LT} = 4.66, \text{LN} = 2.499, \text{RTR} = 0.099, \text{LBT} = 0.503, \text{DB} = 0.828, \text{DM} = 0.132, \text{DBND} = 1.022, \text{XCGN} = 2.993, \text{BLC} = 2. \]

**CONCLUSION**

Projectile moving through the air environment, disturbs her condition, handing her some of the kinetic energy. From that moment on air mass moving waves by changing the parameters of the situation. Knowing the values of aerodynamic coefficients of an entirely determination of aerodynamic loads (force and torque), acting on the classical axisymmetric projectile. The force is a classic front drag aerodynamic force by the first explorers called” air resistance”. For axisymmetric flow missile longitudinal axis of the projectile coincides with the tangent to the path, ie. speed projectiles. In this case there is only one component of the aerodynamic forces of air resistance force-\( X \) [N].

Flow around the projectile can be divided according to the value of the Mach number in four categories:

- subsonic \( M < 0.8 \);
- transonic \( 0.8 < M < 1.2 \);
- supersonic \( 1.2 < M < 5 \);
- and hypersonic \( 5 < M < 10 \).

The calculated value of the aerodynamic coefficients allow the calculation of the air resistance force. The table 3 presents a comparative overview of the air resistance force and range missiles in the air and empty space for different calibers. The study confirms that the maximum value of the axial aerodynamic coefficients \( C_x \) to 0.4, in the transonic region \((0.8 < M < 1.2)\).

On factors that affect the force of air resistance are friction resistance vortices, wave resistance and shock wave. During movement of the body loses kinetic energy at the expense of decreasing speed. The aerodynamic force acting in the same direction but in the opposite direction relative to the projectile is called the frontal resistance force (axial force).

**Table 3.**

<table>
<thead>
<tr>
<th>Caliber</th>
<th>Speed</th>
<th>Weight</th>
<th>Weight</th>
<th>Drag force</th>
<th>Range</th>
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<tr>
<td>( d )</td>
<td>( V )</td>
<td>( m )</td>
<td>( G )</td>
<td>( X )</td>
<td>The airspace</td>
</tr>
<tr>
<td>( [\text{mm}] )</td>
<td>( [\text{m/s}] )</td>
<td>( [\text{kg}] )</td>
<td>( [\text{N}] )</td>
<td>( [\text{N}] )</td>
<td>( [\text{m}] )</td>
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<tr>
<td>7.62</td>
<td>765</td>
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<td>0.078</td>
<td>6.56</td>
<td>3600</td>
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<tr>
<td>30</td>
<td>1000</td>
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<tr>
<td>82</td>
<td>70</td>
<td>3</td>
<td>29.4</td>
<td>8.51</td>
<td>485</td>
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<td>122</td>
<td>690</td>
<td>21.76</td>
<td>213.5</td>
<td>1109</td>
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<td>890</td>
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</table>

Wave resistance affects the most to the total resistance of the air at supersonic speeds. The impact resistance of the individual to the overall air resistance to the different speeds is given in Table 4.
The need for quality-description of aerodynamic coefficients, the physical and mathematical terms, conditions their adequate and reliable budget. In contrast to the value obtained by Robert F. McCoy for transonic speeds ($C_x \geq 0.4$), the authors have obtained values of aerodynamic coefficients of the axial force not exceeding 0.4. Simply the results are a good basis for experimental testing.

The highest values of aerodynamic coefficients, according to the analysis of test results, with coefficients of axial force, normal force and pitching moment. This means they have the greatest impact on the overall aerodynamic drag during movement of the projectile. This paper analyzes the effects of axial aerodynamic coefficient. Aerodynamic effects of the other have not been considered in this paper. The values of coefficients works quantitatively smaller, but not insignificant, because it directly affects the stability parameters of the body in motion in the atmosphere.

<table>
<thead>
<tr>
<th>Speed</th>
<th>Resistance (%)</th>
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<tr>
<td></td>
<td>friction</td>
<td>vortex</td>
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<tr>
<td>$V &lt; a$</td>
<td>20–30</td>
<td>70–80</td>
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<tr>
<td>$V &gt; a$</td>
<td>10–15</td>
<td>35–40</td>
</tr>
</tbody>
</table>

REFERENCES

[1] Robert F. Lieske, Robert F. McCoy (1964), Equations of motion of ARIGID body, Ballistics research Laboratories, 1964, Maryland, USA.


