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Design of Missile Models for Testing on Numerical Control Measurement Machines

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Abstract- The most important fact for this paper is that, in addition to the common machine industry measuring devices, a manually operated coordinate measuring machine (DEA Beta) was used for the first time. Airfoil controls at the desired sections of the model for wind tunnel testing were performed manually by bringing the machine to the desired X, Y positions and by probe contact in the negative Z direction. The model design required a new generation of machine tools with 3-5 axis simultaneous control. The last missing piece was CMM DEA Epsilon 2304. Geometric similarity is the primary requirement defined in the project request for model production. Wind tunnel tests are laboratory tests, so the accuracy requirements of the model design are very high. The aim of the testing is to determine the character and values of the aerodynamic force and moment in the flow around the missile model type M.

Index Terms- numerically controlled measuring machines, measurement error

I. Introduction

Wind tunnel testing model was designed on CAD / CAM SolidWorks computer aided design system, one of the most popular 3D software for computer-aided design (CAD) on the contemporary market. Since its introduction in 1995, SolidWorks has become a favorite design tool of many of today's engineers, mechanical and industrial designers. At its core, SolidWorks provides the capability of creating parametric 3D solid geometry, which is subsequently used to create drawings, draft instructions, manuals, produce animations, full-color rendering, as well as other types of documents.

First, a sketch is created and converted into a base of functions. The base is then further refined with functions added or removed by using materials from the base. Individual parts of the model can then be used to build forms of the final design. After creating a 3D model or assembly of the model, the drawings are made in the way that the document contains both the design and the production process.

The aim of the technological procedure optimization is to produce a model of the required quality and within the specified timeframe:

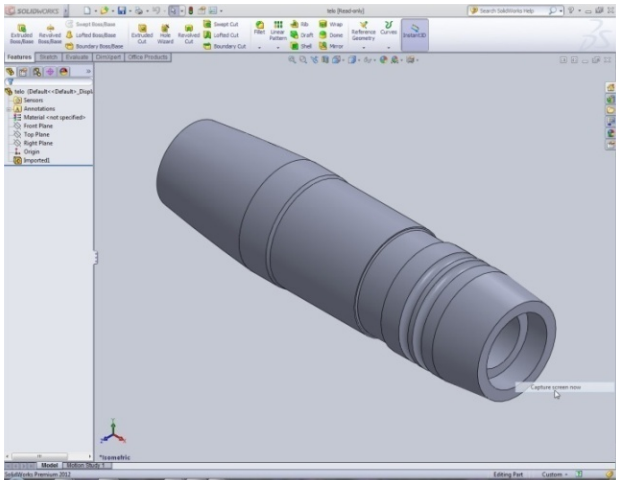
- manage the production without defect or rejection,
- reduce the number of machining operations,
- shorten the time of machining,
- shorten, or if possible, eliminate all non-production (manipulative) time,
- minimize all preparatory-finishing periods in the technological process
- minimize the time of mid-phase measurements,
- speed up the decision-making process when creating machining operations.

II. Model Design in CAD Software

Following the production of the model, the measurement of real missile models of will be performed on the coordinate measuring machine (CMM), with the following outputs:

- Geometry comparison between the real model and the model created in SolidWorks CAD software,
- Presentation of measurement and geometry readings of the measured model.

The following pictures show parts of the model measured on the coordinate measuring machine on Fig 1.



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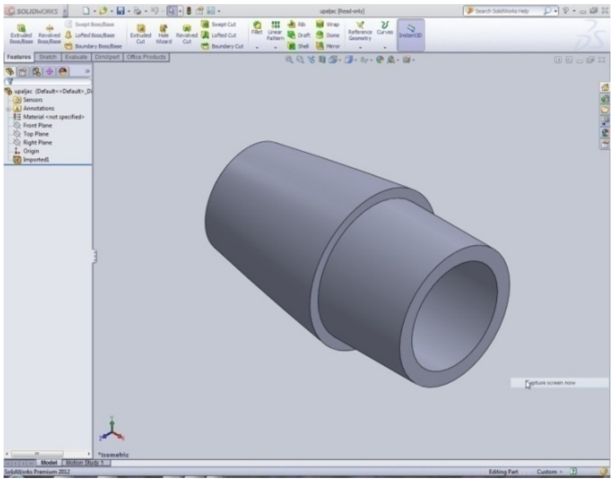

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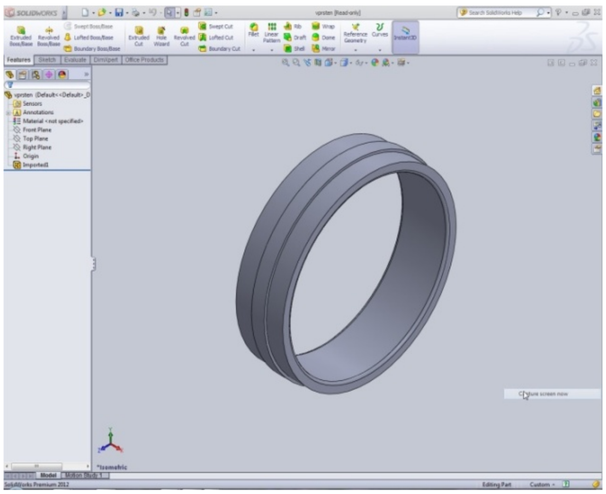

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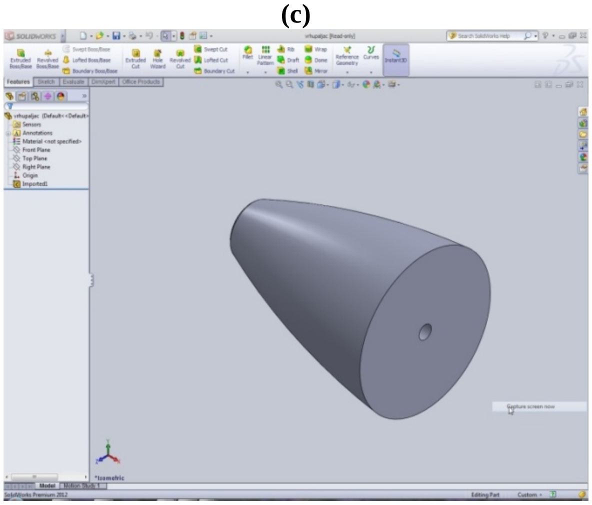

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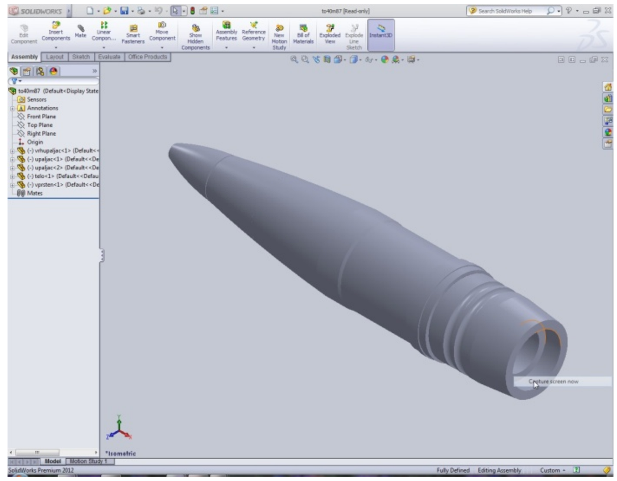


(e)

Fig. 1. ***SlidWorks missile model in: (a) missile body model, (b) missile fuse model, (c) Missile driving band model, (d) missile fuse top model (e) missile model assembly***

Following the production of the model presented on Fig. 1, the CMM measuring starts on DEA *Epsilon 2304*, and the measurement procedure is performed in the following way:

- **STEP 1:** Set up the actual model on the mount located on the marble plate of the same CMM type DEA Epsilon 2304 (Fig. 2.);

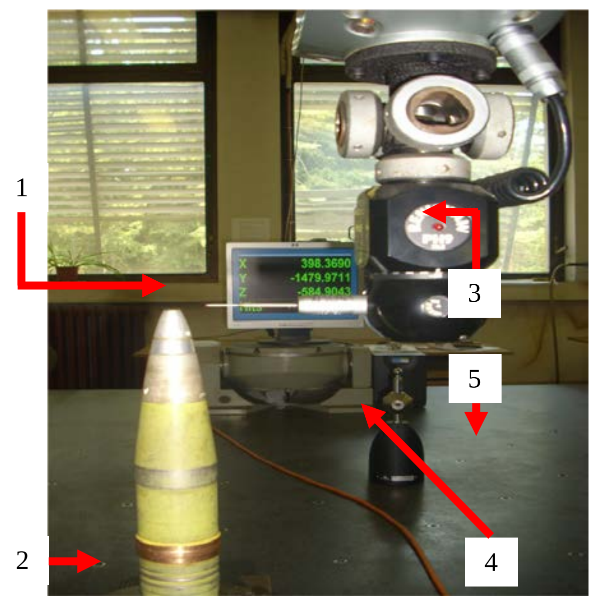


Fig. 2. ***Start of measurements using the measuring probe and reading the data with Renishaw measuring sensor***

Legend (Fig. 2.):
1 - Monitor tracking the probe head on X, Y, Z axes,
2 - Measured object,
3 - Measuring sensor Renishaw PH9,

4 - Calibration sphere and
5 - Marble plate CMM.

- **STEP 2**: Place the appropriate measuring sensor for the tested model;
- **STEP 3**: Calibrate the measuring probe sensors;
- **STEP 4**: Start measuring the model geometry by the probe:

  1) top of the fuse;
  2) body of the fuse;
  3) driving band and;
  4) bottoms of the missile.

- **STEP 5**: The results are graphically rendered in STEP and IGES files and shown in tables containing data on geometry of the measured model in SolidWorks.

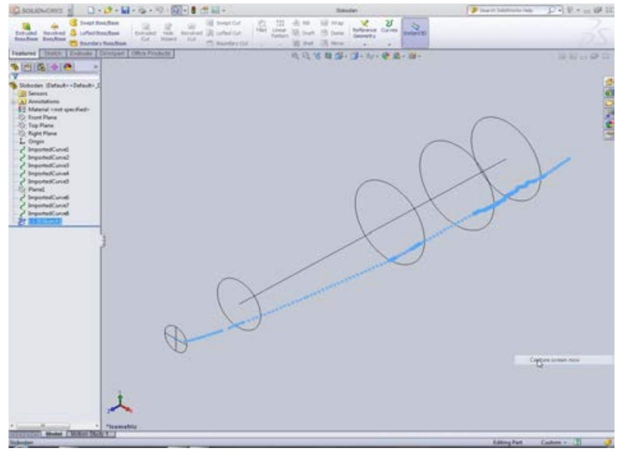


Fig. 3. ***Graphical presentation of the measurement results in a STEP file (Isometric view)***

The results of the model M missile measurement on the coordinate measuring machine DEA Epsilon 2304 are shown in Table 1., and only for some typical sections where measurement was performed.

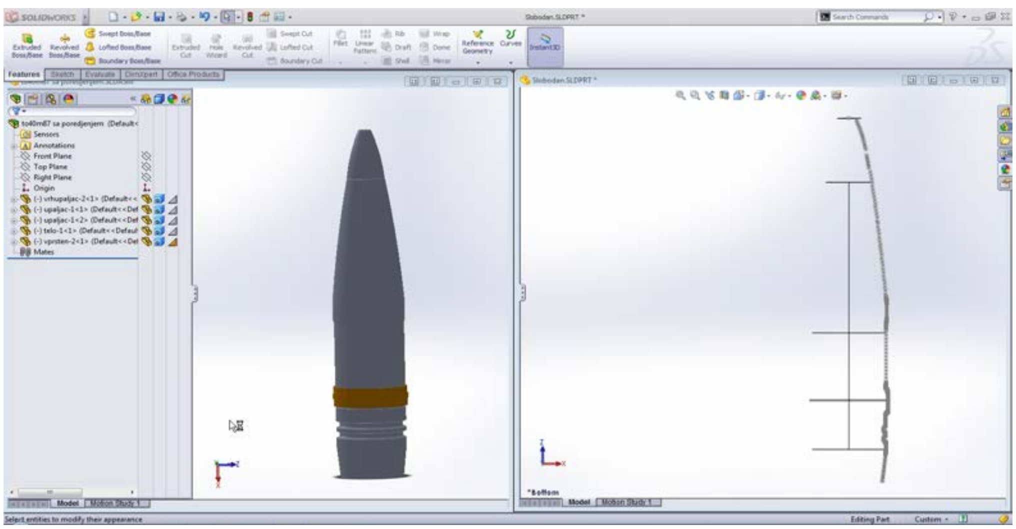


Fig. 4. ***Comparative presentation of the constructed M_1 missile model in CAD software and M_2 missile model measured on CMM***

III. EXPERIMENTAL DETERMINATION OF THE AERODYNAMIC COEFFICIENTS OF THE MISSILE MODEL

Determination of the aerodynamic coefficients of the forces and moments was performed in relation to the position of the missile body by changing the angle of attack. The value of the angle of attack at which the motion of this missile type is stable is approximately 10 °. The range of the angles of attack applied in the experimentation was from -10 ° to + 10 °. Recording of the characteristics of the flow around the axisymetrical body was performed on the basis of the image of the flow using the adequate optical method of flow visualization - Schlieren method.

Experimentally determined values of coefficients were compared with the values obtained through calculations of symmetric and axisymmetric flows around the missile and the table values of similar missiles (type M and M_1).

2.1 Measurement of Aerodynamic Forces and Moments

The strain gauge balance was selected on the basis of its measuring range in relation to the expected value of the strain on the model, that is, in accordance with the expected transitional strain occuring in the wind tunnels of this type.

To measure the forces and moments, the internal six-component balance ABLE 1.0 MKXXIII A was used, (Fig. 5a and 5b). The gauge balance was mounted on a sting - holder with 32 mm diameter. The accuracy of the balance is 0.3% of the full range.

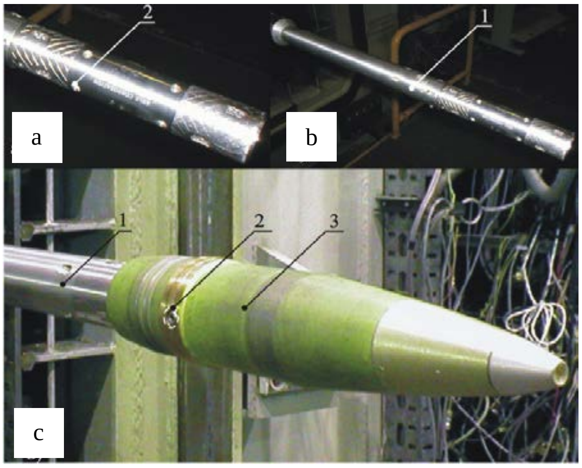
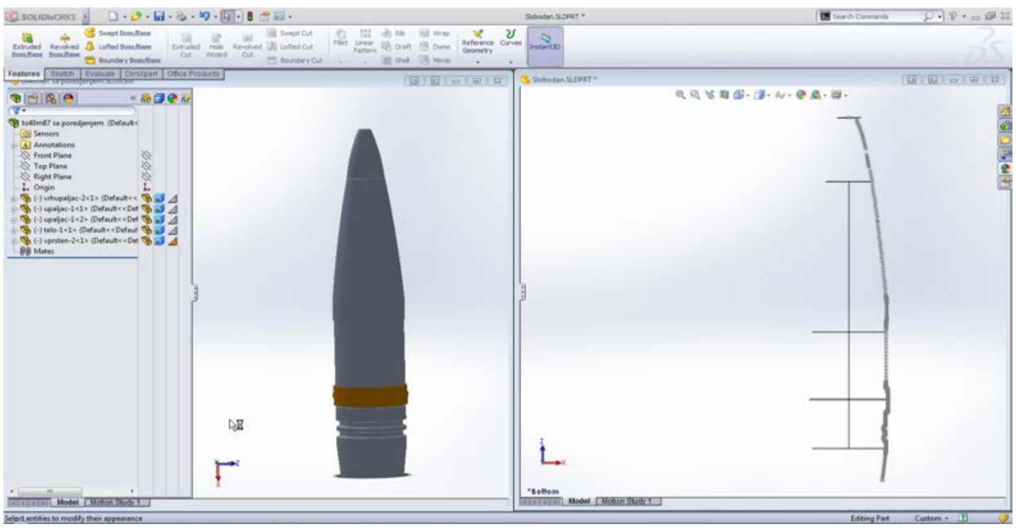


Fig. 5. ***Six-component strain gauge balance with the type M missile model in the test section of the wind tunnel a) balance ABLE 1.0 MKXXIII A; b) gauge balance with a mount; c) a model with a strain gauge balance on the moun 1 - mount with adapter, 2 - pin for connecting model and the balance, 3 - model (type M missile)***

The balance was calibrated on a small calibration frame in the calibration hall of the T-38 wind tunnel on Fig. 5. Weights of 1 kg, 4.5 kg, and 11.5 kg manufacterd by ABLE, as well as 1 kg weights from the sets for calibration of FFA scales, and were used for calibration.

The calibration matrix for this balance was established on the basis of the data obtained from the calibration performed in the laboratory of the experimental aerodynamics of the Military Technical Institute (MTI). The balance was calibrated immediately prior to the test.



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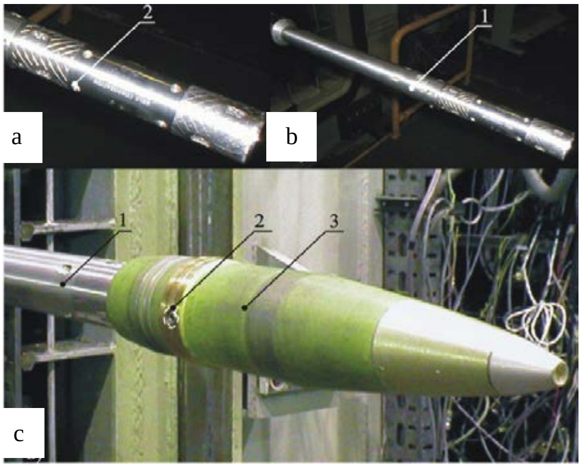

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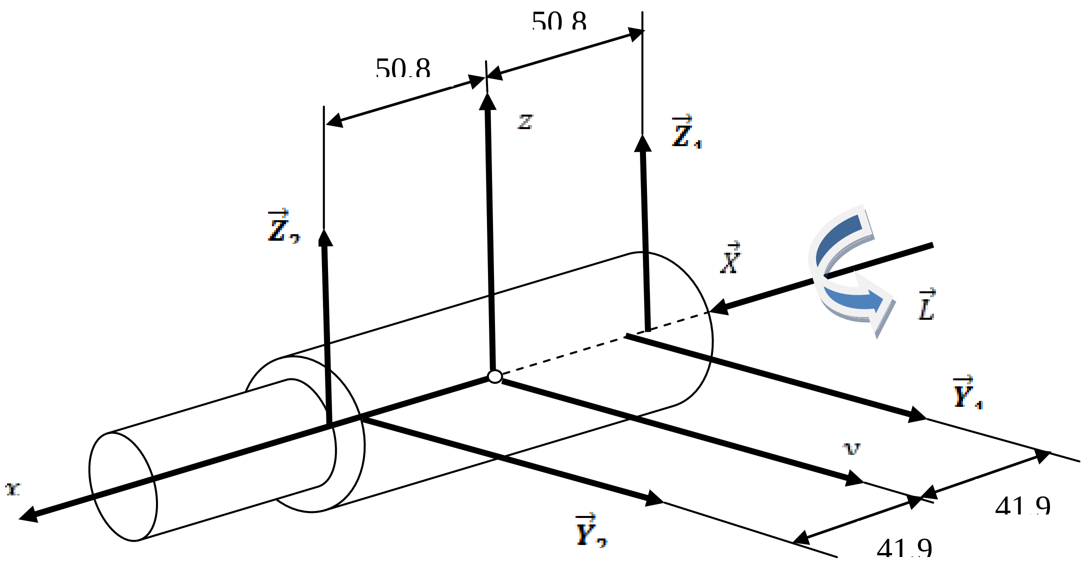


Fig. 6. ***Model of strain of the six-component gauge balance ABLE 1.0 MKXXIII A***

IV. ANALYSIS OF THE RESULTS OBTAINED FROM MEASURING AERODYNAMIC COEFFICIENTS OF AXISYMMETRIC FLOWS

The input geometric and dynamic data were defined for the given construction parameters of the type M missile model, and the data were consolidated and presented in Table 2. In accordance with the given aerodynamic calculation ADK0, characteristic changes of the components of the drag force - axial force aerodynamic coefficient, were obtained in accordance with the **theoretical values calculation model.**

Table 2. ***Input calculation database ADK0 for model M with theoretical values***

reference projectile diameter	projectile length	front part length	the ogive radius ratio	back cone length	base diameter	projectile top diameter	driving band diameter	position of mass center from the top
mm	caliber	caliber	-	caliber	caliber	caliber	caliber	caliber
1	2	3	4	5	6	7	8	9
39,9	5,203	2,589	0,57	0,461	0,882	0,180	1,053	3,333

Output data on the values of the aerodynamic coefficients of the axial resistance force with components as a function of Mach number are given in Table 3. for the **theoretical values model**.

Column 1 of Table 3. gives the range of Mach numbers with calculated components and the total coefficient of the aerodynamic force in the axisymmetrical flow, as follows:

- Column 2 - overall coefficient of the aerodynamic force C_{X0},
- Column 3 - coefficient of the front of the missile C_{X1},
- Column 4 - coefficient of friction of the missile C_{Xf},
- Column 5 - coefficient of the driving band C_{X4},
- Column 6 - coefficient of the back cone of the missile C_{X3},
- Column 7 - coefficient of the bottom of the missile C_{Xd}, and
- Column 8 - values of the relation between the subpressure behind the missile bottom and the free air stream pressure p_d/p_∞.

Deviations of the calculated values of the aerodynamic axial coefficient from the presented types of missiles (M_2 and M_1) are less than 1%. This discrepancy confirms the compliance of the calculation with practical solutions.

The average deviation of the axial coefficient in the axisymmetrical flow around the missile model type M compared with the missile model type M_1 is as follows (Table 4.):

- for the subsonic regime: lower by about 2%,
- for the transonic regime: lower by about 1% and
- for the supersonic regime: lower by about 0.2 %.

Compared to the missile type $M_{2,}$ these deviations are reversed, so the coefficient is higher for each flow regime, as follows (Table 4.):

- for the subsonic regime: higher by about 4 %,
- for the transonic regime: higher by about 3 % and
- for the supersonic regime: higher by about 0.5 %.

Table 3. ***Output calculation database ADK0 for model M with theoretical values***

Ma	C_{X0}	C_{X1}	C_{XF}	C_{X4}	C_{X3}	C_{Xd}	P_d/p_∞
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
0.500	0.155	0.000	0.063	0.000	0.000	0.092	0.979
0.600	0.156	0.000	0.060	0.000	0.000	0.096	0.969
0.700	0.159	0.000	0.058	0.001	0.000	0.100	0.956

Table 4. ***Comparative presentation of M,M_1 i M_2 models axial coefficients difference***

Mach number *Ma*	Axial coefficient for type M by ADK0 calculation C_{X0}^{M}	Axial coefficient for type M_1 C_{X0}^{M1}	Axial coefficient difference between type M and type M_1 (%)	Axial coefficient for type M_2 C_{X0}^{M2}	Axial coefficient difference between type M and type M_2 (%)
1	2	3	4	5	6
0.500	0.155	0.156	-0.64	0.162	-4,51
0.600	0.156	0.157	-0.64	0.164	-5,12
0.700	0.159	0.160	-0.64	0.166	-4,40

subsonic regime deviation	**-2.46**	**-4,03**
transonic regime deviation	**-0,61**	**-3,27**
subsonic regime deviation	**-0,18**	**-0,54**
transonic regime deviation	**-1,08**	**-2,61**

3.1 Analysis of the Results From the Calculation of Missile Types M, M_1 i M_2 Motion and Stability

The calculation of the motion characteristics and motion stability parameters in accordance with the six degrees freedom of motion missile model, on the basis of the presented equations of motion and stability model was performed using the software solution SB6 according to [9]. The solution is based on the system of equations for the six degrees freedom of motion of the classic missile.

The original software solution was translated into the software package Matlab, and for the purposes of this paper, a modification of input routines was performed, and they are presented in the appendix of this dissertation.

Organization of the inputs for the missile types M, M_1 and M_2 was established in the database form, that is, input routines of the software solution, and they were classified as follows:

- the first set of data is about the starting and border conditions for the calculation of the missile flight: start time, the calculation step, the way of stopping the calculation - border data, range and the step of calculation of the stability parameters, wind components, the initial position of the missile, the initial velocity of the missile, the initial angular velocity of the missile and the angular initial position of the projectile (attitude),
- the second set of data is about the geometric and dynamic properties of the missile: the position of the center of mass, the principal moments of inertia, diameter and weight of the missile model,
- the third set of data is about the aerodynamic properties of the projectile: aerodynamic coefficients and derivatives of forces and moments in relation to the Mach number value.

For the purpose of comparison of the obtained values of the elements of the trajectory and the flight stability parameters of the missile model, the second set of data is not changed and they represent the constant properties of the missile model type M. The thirs set of data changes depending of the type of the obtained data on aerodynamic characteristics for missile models M_1 and M_2 - by calculation and testing.

The result of the software solution calculation are three sets of data in funcional dependence on time as an independent variable:

- trajectory elements – motion characteristics:

1) missile mass center coordinates (x , y i z),
2) time of flight – missile motion (t),
3) angular position of the missile in space (χ i γ),
4) velocity components – missile motion (u , v i w),
5) components of the angular velocity of the missile motion (p , q i r),

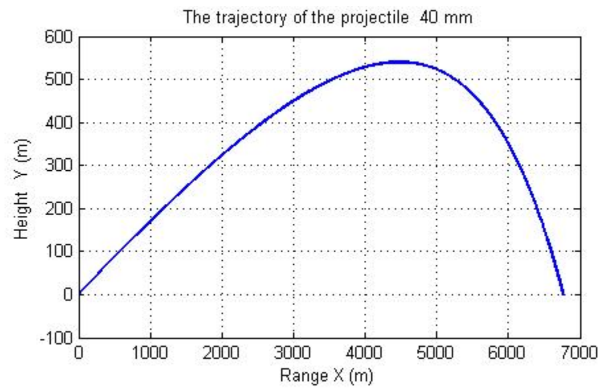
- stability parameters:

1) damping coefficients - roots of the stability equation solutions (λ_1 i λ_2),
2) gyroscopic stability factor in the form ($1/Sg$),
3) dynamic stability factor in the form ($Sd\,(2-Sd\,)$),
4) angle of attack on the vertical plane and slip angle (α i β),

Dynamic properties of the missile model M were determined using the software package SolidWorks 2012. In addition to the position of the center of mass relative to the top of the projectile, the inertia moments along the main axes of the missile model were also determined:

1) position of the center of mass from the missile top, X_{CM} = 133mm,
2) longitudinal moment of the the model inertia, I_{XX} = 263,6 kgmm^2,
3) transverse moments of the model inertia, $I_{YY} = I_{ZZ}$ = 3,052*10^3 kgmm^2.

The summary of the used values and marks, that is, the initial and border values for the calculation of trajectory elements and stability parameters in Matlab programming solution is in the appendix of this doctorate, together with the results.



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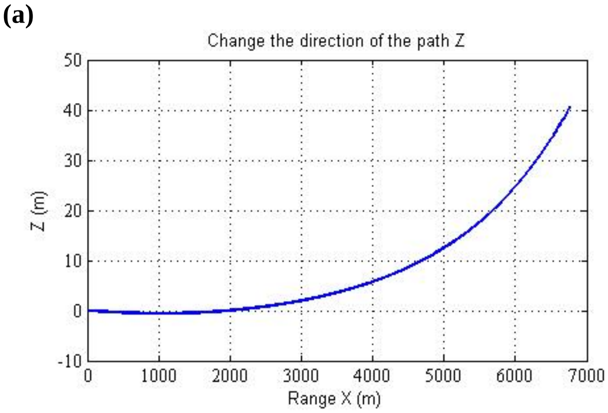

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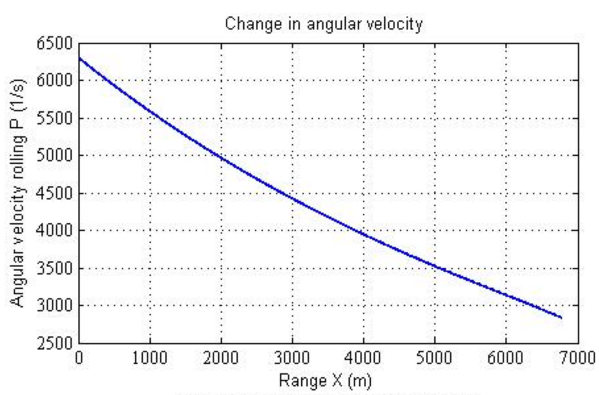

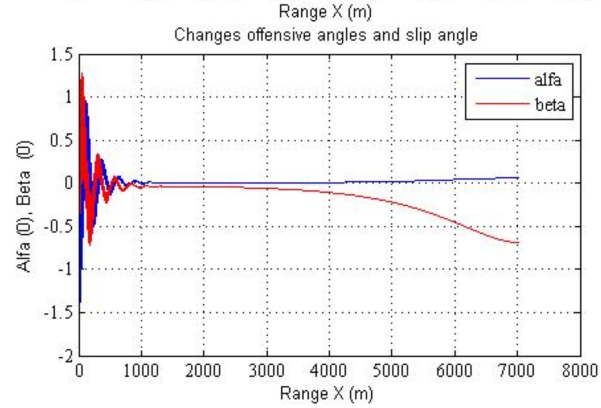

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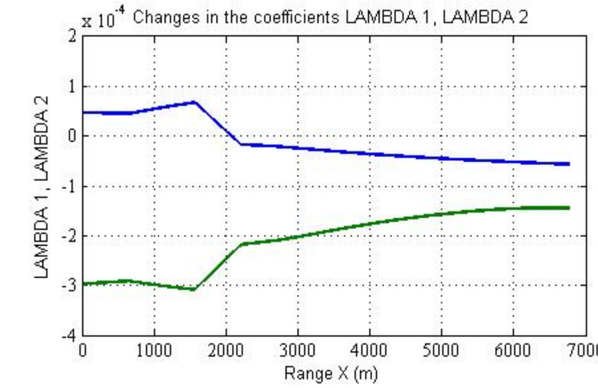

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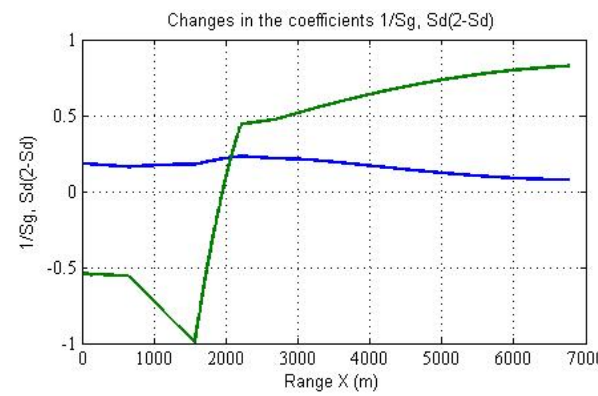

(e)

Fig. 7. ***(a) Missile trajectory on the vertical plane; (b) Missile trajectory direction on Z trajectory;***

(c) Change of longitudinal angular velocity along the trajectory; (d) change of coefficients LAMBDA 1 and LAMBDA 2 on the trajectory (e) Change of coefficient of gyroscopic 1/Sg and dynamic stability Sd(2-Sd) along the trajectory and (f) Change offensive angles and alip angle on the trajectory

The difference in the obtained flight time values to the vertex t_s ranges from 1.5% to 2.5%. The difference in the values of the horizontal distance to the vertex x_s ranges from 2.6% to 3.8%. The difference in the values of the vertical position of the vertex y_s ranges from 1.4% to 3.1%.

Larger deviations occur for the vertex position relative to the vertical plane z_s, for smaller starting angles, where the difference is over 20%. The difference of the absolute values of the derivative z_s is small (1 to 1.5 m). The relative difference between the value of the derivative on smaller starting angles is more pronounced because the integration step is higher than the calculation values.

The values of velocity in the vertex V_S vary from 0.1% to 3.8%. This range of deviation is partly affected by the size of the integrative step relative to the values of the velocity calculation. There is a high correlation between the values of the longitudinal angular velocity at the vertex p_s, and the average difference is about 1%.

The difference in the obtained values of the trajectory elements for the fall point can be considered to be more representative information, because the border conditions were exactly the same (position of the fall point in the horizontal plane), for which the trajectory elements were calculated for all three types of aerodynamic coefficients (calculation, experimental and values obtained with CMM). The deviation value of the total flight time t_c ranges from 1.5% to 2.4%, and of the final range x_c from 1% to 3%. All these deviations are very small and show a strong congruence of values of the aerodynamic coefficients obtained by calculation, experimentation and measurement by the CMM.

T he values of the longitudinal angular velocity in the fall point p_c *differ* by 1.3% to 4.5%. By increasing the starting angle, that is, the range, the difference between these values is also increased. The values of the aerodynamic coefficients of the axial force in the subsonic velocity range, which occurs at the end of trajectory, affects such increase in differences of the values of the missile longitudinal angular velocity. On the other hand, very close values of the aerodynamic coefficient of the rolling moment prevent the difference from increasing.

V. CONCLUSION

The presented solution of coordinate inspection of complex spatial shapes applied to the missile models for wind tunnel testing, represents a rounded functional whole. It is reflected in the developed and verified procedures applied during the implementation of the missile models projects. It is the primary characteristic of the described solution, because these requirements are frequent. The solution is rounded; however it is still open to further upgrade or improvement. The primary set objectives of optimization and production management with minimal defect and variations in the geometry, as well as the actual implementation of the system, have been achieved.

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