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METHOD FOR DETERMINING COEFFICIENT POWER ERROR OF FRONT RESISTANCE MISSILE BY MEANS STATION OUTWARDLY TRAJECTORY MEASUREMENTS

The suggested method for determining the error coefficient of front resistance power of the missile, which results obtained from the use of outwardly trajectory measurements. In the method missile velocity and acceleration computed by cubic polynomials virtual coordinate systems. The comparative analysis estimates instrumental error values obtained by the results missile of outwardly trajectory measurements different stations.

Keywords: *instrumental error, coefficient of of front resistance power, station outwardly trajectory measurements.*

Introduction

Statement of an issue. For the calculation of ballistic trajectories of new parameters artillery missile, rockets multiple launch rocket systems missiles tactical (operational and tactical) purpose (hereinafter – the missile) and compiling tables of fire, accuracy of definition values of the of front resistance power $c_X(M)$ should be characterized by an error of not more than (0,2...0,3)% range throughout the flight speed missile [1].

Thus, during flight tests missile assess the feasibility of using stations outwardly trajectory measurements (OTM), forming the initial data for the calculation of the function $c_X(M)$ with specified allowable error is an actual scientific problem.

Review of last research and publications. Subjection $c_X(M)$ during schematic design obtained on the basis of analytical and numerical methods with a relative error to 10 % [2–5]. Also, the assessment the values $c_X(M)$ confirmed based on blowing missile models in subsonic and supersonic wind tunnels at some fixed values of Mach numbers relative to an accuracy of a few percent [3]. Conducted experimental research models missile specially equipped ballistic routes that can achieve relative error of 0.2%, but only for a narrow range of speeds [1].

The aim of the article is Develop a method for calculating the error calculation values of the of front resistance power missile using acceleration and velocity of the center of mass, calculated by cubic polynomials virtual coordinate systems based on the results OTM.

The basic material

Introduced following assumptions:

– Earth – an area that does not rotate with the central field of gravity;

– atmosphere – standard, no wind;

– model artillery missile – material point, which moves in the vertical plane of the starting coordinate system by the forces of front resistance and terrestrial gravity and missile trajectory height value is much less than the radius of the Earth.

Assessment of $c_X(M)$ conducted by a formula obtained by converting the differential equation describing tangential acceleration of the center of mass in the high-speed coordinate system [1]:

$$c_X(M) \approx -f_C\left(\dot{v} + g_0 \sin\theta\right), \quad (1)$$

where $f_C = c_0 \dfrac{m}{d^2} \dfrac{\exp\left(k_\rho h\right)}{a_{зв}{}^2 M^2}$, $M = \dfrac{v}{a_{зв}}$,

$c_0 = \dfrac{8}{\rho_0 \pi} = 2{,}08$; $k_\rho = 1{,}41 \cdot 10^{-4}$ m^{-1};

$R_з = 6371110$ m ; g_0=9,8066 m/s^2, m , d – projectile mass and diameter respectively; v , θ – module and the angle of the velocity vector to the home under the horizon; $R_з$ – the radius of the spherical Earth; g_0 – acceleration of gravity at the Earth's surface; ρ_0 – air density at the surface of the Earth; $a_{зв}$ – speed of sound; M – Mach number.

Value $a_{зв}$ sound speed can be calculated by the formula [2]:

$$a_{зв} = 20{,}046796\sqrt{T_V}, \ [m/s], \quad (2)$$

where $T_V = T\left(1 + 0{,}377\, e/p\right)$, $[K]$; e – the partial pressure of water vapor; p – pressure at height h; $T = 273{,}15 + t\,^0C$, $[K]$; T_V – virtual temperature; $t\,^0C$ – air temperature.

In the formula (1) value $\dot{v}$, M, θ, h evaluated the results of treatment results OTM.

For the determination of the calculation error the values $c_X(M)$ on the basis of OTM options missile trajectory various complexes (systems) OTM, with different levels of measurement accuracy, the relationship between the standard deviation (SD) σ_{c_x} and measuring errors characterized SD $\sigma_D, \sigma_\alpha, \sigma_\beta$ (where D – Slant range to the missile, α – azimuth, β – angle of elevation), proposed to establish three stages.

The first stage. The connection between σ_{c_x} and $\sigma_{\dot v}$, σ_M, σ_θ, σ_h, σ_m, σ_d .

The second phase will establish a link between SD $\sigma_{\dot v}, \sigma_M, \sigma_\theta$ and SD σ_S calculation s of the arc length of the trajectory missile and SD σ_t measuring the time t.

The third phase will establish a link between SD σ_S and SD $\sigma_Д, \sigma_\alpha, \sigma_\beta$.

The first stage. If the hypothesis that SD $\sigma_{\dot v}$, σ_M, σ_θ, σ_h, σ_m, σ_d calculating the values $\dot v,\ M,\ \theta, h,\ m,\ d$, included in the formula (1), statistically independent and normally distributed, and systematic errors are zero, $\sigma_{c_x}{}^2$ defined as [5]:

$$\sigma_{c_x}{}^2 \approx \left(\frac{\partial c_x}{\partial \dot v}\right)^2 \sigma_{\dot v}{}^2 + \left(\frac{\partial c_x}{\partial M}\right)^2 \sigma_M{}^2 + \left(\frac{\partial c_x}{\partial \theta}\right)^2 \sigma_\theta{}^2 + \left(\frac{\partial c_x}{\partial h}\right)^2 \sigma_h{}^2 + \left(\frac{\partial c_x}{\partial m}\right)^2 \sigma_m{}^2 + \left(\frac{\partial c_x}{\partial d}\right)^2 \sigma_d{}^2. \quad (3)$$

Thus, the partial derivatives are included in (3) are calculated by formulas:

$$\frac{\partial c_x}{\partial \dot v} = -f_C\ ;\ \frac{\partial c_x}{\partial M} = \frac{2}{M} f_C\, f_A\ ;\ f_A = \left(\dot v + g_0 \sin\theta\right); \quad (4)$$

$$\frac{\partial c_x}{\partial \theta} = -\,f_C\, g_0 \cos\theta\ ;\ \frac{\partial c_x}{\partial h} = -\,k_\rho f_C f_A\ ; \quad (5)$$

$$\frac{\partial c_x}{\partial m} = -\frac{1}{m} f_C f_A\ ;\ \frac{\partial c_x}{\partial d} = \frac{2}{d} f_C f_A\ . \quad (6)$$

Substituting (4–6) in the series (3), the formula for assessing value SD $\sigma_{c_x}{}^2$:

$$\sigma_{c_x}^2 \approx f_C^2 \left\{ \sigma_{\dot v}^2 + f_A^2 \left\langle C_h\, \sigma_h^2 + \frac{1}{m^2}\sigma_m^2 + \frac{4}{d^2}\sigma_d^2 + \frac{4}{M^2}\sigma_M^2 \right\rangle + \left(g_0\ \cos\theta\right)^2 \sigma_\theta{}^2 \right\};\ C_h = 2\times 10^{-8}. \quad (7)$$

In the formula (7) value $C_h\, \sigma_h{}^2 << 1$, so it may be ignored.

In preparation for flight tests of significance m i d missile can be determined with high accuracy, value $C_m\, \sigma_m{}^2 < 1,\ C_d\, \sigma_d{}^2 < 1$, so they also may be neglected.

After simplifications (7), the formula for estimating the value SD σ_{c_x} can be written as:

$$\sigma_{c_x} \approx f_C \sqrt{\sigma_{\dot v}{}^2 + F_M\, \sigma_M{}^2 + F_\theta\, \sigma_\theta{}^2}\ , \quad (8)$$

where $F_M = \left[\frac{2}{M}\left(\dot v + g_0 \sin\theta\right)\right]^2$; $F_\theta = \left(g_0\ \cos\theta\right)^2$.

From the analysis of the expression (8) concludes that the main effect on the SD σ_{c_x} have SD $\sigma_{\dot v}, \sigma_M, \sigma_\theta$, dependent instrumental errors stations OTM.

The second stage.

1. Value M_i Mach number in the i-th nodal point is calculated by the formula [4]:

$$M_i = \frac{-s_{i-3} + 5 s_{i-2} - 13 s_{i-1} + 13 s_{i+1} - 5 s_{i+2} + s_{i+3}}{12\,\Delta t\, a_{зв}}\ . \quad (9)$$

Assuming that the error calculation the values s_i, Δt statistically independent and normally distributed, and systematic errors are zero (further simplify use this), then

$$\sigma_M{}^2 = \left(\frac{\partial M_i}{\partial s_{i-3}}\right)^2 \sigma_{s_{i-3}}{}^2 + \left(\frac{\partial M_i}{\partial s_{i-2}}\right)^2 \sigma_{s_{i-2}}{}^2 + \left(\frac{\partial M_i}{\partial s_{i-1}}\right)^2 \sigma_{s_{i-1}}{}^2 + \left(\frac{\partial M_i}{\partial s_{i+1}}\right)^2 \sigma_{s_{i+1}}{}^2 + \left(\frac{\partial M_i}{\partial s_{i+2}}\right)^2 \sigma_{s_{i+2}}{}^2 + \left(\frac{\partial M_i}{\partial s_{i+3}}\right)^2 \sigma_{s_{i+3}}{}^2 + \left(\frac{\partial M_i}{\partial t}\right)^2 \sigma_t^2. \quad (10)$$

Partial derivatives that are (10), is calculated by the following formulas:

$$\frac{\partial M_i}{\partial s_{i-3}} = -\frac{\partial M_i}{\partial s_{i+3}} = -\frac{1}{12\,\Delta t\, a_{зв}}\ ; \quad (11)$$

$$\frac{\partial M_i}{\partial s_{i-2}} = -\frac{\partial M_i}{\partial s_{i+2}} = \frac{5}{12\,\Delta t\, a_{зв}}\ ; \quad (12)$$

$$\frac{\partial M_i}{\partial s_{i-1}} = -\frac{\partial M_i}{\partial s_{i+1}} = -\frac{13}{12\,\Delta t\, a_{зв}}\ ;\ \frac{\partial M_i}{\partial t} = -\frac{M_i}{\Delta t\, a_{зв}}\ . \quad (13)$$

Substituting (11) – (13) in (10) and given that $\sigma_{s_{i-3}} \approx \sigma_{s_{i-2}} \approx \sigma_{s_{i-1}} \approx \sigma_{s_{i+1}} \approx \sigma_{s_{i+2}} \approx \sigma_{s_{i+3}} = \sigma_s$, formula for estimating the value $\sigma_M{}^2$ can be saved:

$$\sigma_M{}^2 = \frac{1}{\left(\Delta t\, a_{зв}\right)^2}\left(5{,}42\ \sigma_s{}^2 + \left[M_i\, \sigma_t\right]^2\right). \quad (14)$$

2. Value $\dot v_i$ acceleration module missile center of mass in the i-th nodal point is calculated as [4]:

$$\dot v_i = \frac{-s_{i-3} + 4\ s_{i-2} - 3\ s_{i-1} - 3\ s_{i+1} + 4\ s_{i+2} - s_{i+3}}{4\,\Delta t^2}\ . \quad (15)$$

After simplification similar to the above is written:

$$\sigma_{\dot v}{}^2 = \left(\frac{\partial \dot v_i}{\partial s_{i-3}}\right)^2 \sigma_{s_{i-3}}{}^2 + \left(\frac{\partial \dot v_i}{\partial s_{i-2}}\right)^2 \sigma_{s_{i-2}}{}^2 + \left(\frac{\partial \dot v_i}{\partial s_{i-1}}\right)^2 \sigma_{s_{i-1}}{}^2 + \left(\frac{\partial \dot v_i}{\partial s_{i+1}}\right)^2 \sigma_{s_{i+1}}{}^2 + \left(\frac{\partial \dot v_i}{\partial s_{i+2}}\right)^2 \times \sigma_{s_{i+2}}{}^2 + \left(\frac{\partial \dot v_i}{\partial s_{i+3}}\right)^2 \sigma_{s_{i+3}}{}^2 + \left(\frac{\partial \dot v_i}{\partial t}\right)^2 \sigma_t^2. \quad (16)$$

Partial derivatives that are (16) are calculated as follows:

$$\frac{\partial \dot{v}_i}{\partial s_{i-3}} = \frac{\partial \dot{v}_i}{\partial s_{i-3}} = -\frac{1}{4\Delta t^2}\,;\; \frac{\partial \dot{v}_i}{\partial s_{i-2}} = \frac{\partial \dot{v}_i}{\partial s_{i-2}} = \frac{1}{\Delta t^2}\,; \quad (17)$$

$$\frac{\partial \dot{v}_i}{\partial s_{i-1}} = \frac{\partial \dot{v}_i}{\partial s_{i-1}} = -\frac{3}{4\Delta t^2}\,;\; \frac{\partial \dot{v}_i}{\partial t} = -2\frac{\dot{v}_i}{\Delta t}. \quad (18)$$

Substituting (17), (18) (16) formula for estimating the value $\sigma_{\dot{v}}^2$ we write:

$$\sigma_{\dot{v}}^2 = \frac{4}{\Delta t^2}\left(1{,}625\left[\frac{\sigma_s}{\Delta t}\right]^2 + \left[\dot{v}_i\,\sigma_t\right]^2\right). \quad (19)$$

3. The value of sine angle velocity vector $\sin\theta_i$, $3 \le i \le I-3$, in the i-th nodal point is calculated by the formula [4]:

$$\sin\theta_i = \frac{-y_{i-3} + 5y_{i-2} - 13y_{i-1} + 13y_{i+1} - 5y_{i+2} + y_{i+3}}{-s_{i-3} + 5s_{i-2} - 13s_{i-1} + 13s_{i+1} - 5s_{i+2} + s_{i+3}}.$$

When we write simplifications:

$$\sigma_\theta^2 \approx \left(\frac{\partial\theta_i}{\partial s_{i-3}}\right)^2\sigma_s^2 + \left(\frac{\partial\theta_i}{\partial s_{i-2}}\right)^2\sigma_s^2 + \left(\frac{\partial\theta_i}{\partial s_{i-1}}\right)^2\sigma_s^2 + \left(\frac{\partial\theta_i}{\partial s_{i+1}}\right)^2\sigma_s^2 + \left(\frac{\partial\theta_i}{\partial s_{i+2}}\right)^2\sigma_s^2 + \left(\frac{\partial\theta_i}{\partial s_{i+3}}\right)^2\sigma_s^2 + \left(\frac{\partial\theta_i}{\partial y_{i-3}}\right)^2\sigma_y^2 + \left(\frac{\partial\theta_i}{\partial y_{i-2}}\right)^2\sigma_y^2 + \left(\frac{\partial\theta_i}{\partial y_{i-1}}\right)^2\sigma_y^2 + \left(\frac{\partial\theta_i}{\partial y_{i+1}}\right)^2\sigma_y{}^2 + \left(\frac{\partial\theta_i}{\partial y_{i+2}}\right)^2\sigma_y{}^2 + \left(\frac{\partial\theta_i}{\partial y_{i+3}}\right)^2\sigma_y^2. \quad (20)$$

Partial derivatives included in the expression (20) are calculated as follows:

$$\frac{\partial\theta_i}{\partial y_{i-3}} = -\frac{\partial\theta_i}{\partial y_{i+3}} = -F_1\,;\; \frac{\partial\theta_i}{\partial y_{i-2}} = -\frac{\partial\theta_i}{\partial y_{i+2}} = 5F_1\,; \quad (21)$$

$$\frac{\partial\theta_i}{\partial y_{i-1}} = -\frac{\partial\theta_i}{\partial y_{i+1}} = -13F_1\,;\; \frac{\partial\theta_i}{\partial s_{i-3}} = -\frac{\partial\theta_i}{\partial s_{i+3}} = -F_2\,; \quad (22)$$

$$\frac{\partial\theta_i}{\partial s_{i-2}} = -\frac{\partial\theta_i}{\partial s_{i+2}} = -5F_2\,; \quad (23)$$

$$\frac{\partial\theta_i}{\partial s_{i-1}} = -\frac{\partial\theta_i}{\partial s_{i+1}} = 13F_2\,;\quad F_2 = F_1\sin\theta_i\,; \quad (24)$$

$$F_1 = \frac{1/\cos\theta_i}{\left(-s_{i-3} + 5s_{i-2} - 13s_{i-1} + 13s_{i+1} - 5s_{i+2} + s_{i+3}\right)}. \quad (25)$$

Taking into account the expressions (21–25), we write:

$$\sigma_\theta^2 \approx 390F_1^2\left(\sigma_y{}^2 + \left[\sigma_s\sin\theta_i\right]^2\right). \quad (26)$$

The third stage.

1. The value of the length of the trajectory calculated by the formula:

$$s = \sum_{i=1}^{I}\Delta s_i, \quad (27)$$

where $\Delta s_i = \sqrt{(x_i - x_{i-1})^2 + (y_i - y_{i-1})^2 + (z_i - z_{i-1})^2}$.

When we write simplifications:

$$\sigma_s^2 \approx \left(\frac{\partial s_i}{\partial x_i}\right)^2\sigma_x^2 + \left(\frac{\partial s_i}{\partial x_{i-1}}\right)^2\sigma_x^2 + \left(\frac{\partial s_i}{\partial y_i}\right)^2\sigma_y^2 + \left(\frac{\partial s_i}{\partial y_{i-1}}\right)^2\sigma_y^2 + \left(\frac{\partial s_i}{\partial z_i}\right)^2\sigma_z^2 + \left(\frac{\partial s_i}{\partial z_{i-1}}\right)^2\sigma_z^2. \quad (28)$$

Partial derivatives that are (28) are calculated as follows:

$$\frac{\partial s_i}{\partial q_i} = -\frac{\partial s_i}{\partial q_{i-1}} = \frac{\Delta q_i}{s_i}\,;\quad \Delta q_i = q_i - q_{i-1}. \quad (29)$$

Substituting (29) to (28) formula for estimating the value σ_s^2 get in the form of:

$$\sigma_s^2 \approx \frac{2}{\Delta s_i^2}\left[\left(\Delta x_i\sigma_{x_i}\right)^2 + \left(\Delta y_i\sigma_{y_i}\right)^2 + \left(\Delta z_i\sigma_{z_i}\right)^2\right]. \quad (30)$$

2. In the calculation error geodetic reference coordinate system measuring complex starting to write the value of the coordinate system:

$$x = x_0 + x\cos\phi - z\sin\phi\,;\; y = y_0 + y\,; \quad (31)$$
$$z = z_0 + x\sin\phi + z\cos\phi /$$

When we write simplifications:

$$\sigma_x^2 = \left(\frac{\partial x}{\partial D}\right)^2\sigma_D^2 + \left(\frac{\partial x}{\partial\alpha}\right)^2\sigma_\alpha^2 + \left(\frac{\partial x}{\partial\beta}\right)^2\sigma_\beta^2 + \left(\frac{\partial x}{\partial x_0}\right)^2\sigma_{X_0}^2 + \left(\frac{\partial x}{\partial z}\right)^2\sigma_z^2 + \left(\frac{\partial x}{\partial\phi}\right)^2\sigma_\phi^2; \quad (32)$$

$$\sigma_y^2 = \left(\frac{\partial y}{\partial D}\right)^2\sigma_D^2 + \left(\frac{\partial y}{\partial\beta}\right)^2\sigma_\beta^2 + \left(\frac{\partial y}{\partial y_0}\right)^2\sigma_{y_0}^2; \quad (33)$$

$$\sigma_z{}^2 = \left(\frac{\partial z}{\partial D}\right)^2\sigma_D{}^2 + \left(\frac{\partial z}{\partial\alpha}\right)^2\sigma_\alpha{}^2 + \left(\frac{\partial z}{\partial\beta}\right)^2\sigma_\beta{}^2 + \left(\frac{\partial z}{\partial z_0}\right)^2\sigma_{z_0}{}^2 + \left(\frac{\partial z}{\partial\phi}\right)^2\sigma_\phi{}^2, \quad (34)$$

where the partial derivatives (32–34) are determined:

$$\frac{\partial x}{\partial D} = \cos\beta\cos\alpha\cos\phi\,;\quad \partial z/\partial z_0 = 1\,; \quad (35)$$

$$\frac{\partial x}{\partial\alpha} = -\cos\beta\sin\alpha\cos\phi\,;\; \frac{\partial x}{\partial x_0} = 1\,;\; \frac{\partial x}{\partial z} = -\sin\phi\,; \quad (36)$$

$$\frac{\partial x}{\partial\phi} = -D\cos\beta\cos\alpha\sin\phi - z\cos\phi\,; \quad (37)$$

$$\frac{\partial x}{\partial\beta} = -D\sin\beta\cos\alpha\cos\phi\,; \quad (38)$$

$$\frac{\partial y}{\partial D} = \sin\beta\,;\; \frac{\partial y}{\partial y_0} = 1\,;\; \frac{\partial y}{\partial\beta} = D\cos\beta\,; \quad (39)$$

$$\frac{\partial z}{\partial D} = \cos\beta\cos\alpha\sin\phi + \cos\beta\sin\alpha\cos\phi\,; \quad (40)$$

$$\frac{\partial z}{\partial\phi} = D\cos\beta\cos\alpha\cos\phi - D\cos\beta\sin\alpha\sin\phi\,; \quad (41)$$

$$\frac{\partial z}{\partial \alpha} = -D\cos\beta\sin\alpha\sin\phi + D\cos\beta\cos\alpha\cos\phi\,; \qquad (42)$$

$$\frac{\partial z}{\partial \beta} = -D\sin\beta\cos\alpha\sin\phi - D\sin\beta\sin\alpha\cos\phi\,. \qquad (43)$$

The numerical rating the values $c_X(M)$ the formula (1), σ_{c_x} – the formula (8) Simulation results and measurements of missile trajectory various stations OTM.

As an example, flight simulation deals with high-explosive missile ОФ45 by firing a howitzer Г2А65 «Мста-Б» long-range charge. Parameters missile ОФ45:
mass m = 43,56 kg; caliber d = 152,4 mm; the initial velocity 810 m/s.

Missile trajectory parameters calculated by numerical integration of differential equations of spatial motion of its center of mass.

For OTM selected station:

1) radio engineering station «КАМА – Н»,

2) mobile information combined laser measuring system (ICLMS) laser, infrared and television channels [6–7].

Mobile ICLMS based on the use of two modules: laser and optoelectronic (OEM), which consists of television and infrared channels. With laser module that uses a powerful laser radiation carried angle automatic maintenance of the aircraft in a wide range of distance, since the beginning of its flight, while the high-precision measurement of angles azimuth and places slant range, radial and angular (tangential) velocity and – issue control commands to the aircraft. With an objective OEM control the aircraft in real time in day and night conditions. Also mobile ICLMS provides recognition aircraft.

The main purpose ICLMS This outwardly trajectory measurements (measurements of motion parameters) aircraft during a ground test to test complex.

Indexes measurement parameters, the values of the stations listed in Table 1.

Error of coordinate measuring station – $\sigma_{X_0(Y_0)} = 10^{-3}$ m . To simplify the calculations made angle φ = 0.

The results of calculations using ICLMS shown in Table 2, where

$$\delta c_X = \frac{\sigma_{c_X}}{c_X} 100\% \,.$$

When set to indicators measuring accuracy ICLMS value SD, the following calculation parameters missile motion:

$$\sigma_S = 0{,}57 \text{ m}; \qquad \sigma_V = 2{,}6 \text{ m/s};$$

$$\sigma_{\dot V} = 5{,}8 \text{ m/s}; \quad \sigma_\theta = 2{,}5\ 10^{-5} \text{ rad}.$$

The resulting calculations show that the accuracy station «КАМА – Н» allowing calculation of values σ_{c_x} with a relative error δc_X =(80…85) %.

Analysis of the impact of errors on the accuracy of measuring stations estimate the σ_{c_x} shows that for the relative error $\delta c_X \le 0{,}45$ % ceteris paribus required accuracy of measurement range $\sigma_D \le 0{,}01$ m. This calculation error motion parameters missile will form:

$$\sigma_{c_x} \le 0{,}0012; \quad \sigma_S \le 0{,}02 \text{ m};$$

$$\sigma_V \le 0{,}1 \text{ m/s};$$

$$\sigma_{\dot V} \le 0{,}2 \text{ m/s}; \quad \sigma_\theta \le 5{,}0\ 10^{-5} \text{ rad}.$$

Table 1

Value of performance measurements of accuracy

№	Name system	Appointment	The maximum opportunities	Characteristics accuracy
1	КАМА – Н	measurement motion parameters: D; α; β	D = 25 km; $\alpha = 0^0 \div 360^0$, $\beta = 5^0 \div 90^0$;	on the reflected signal: $\sigma_D = 8{,}14$ m, $\sigma_{\alpha,\beta} = 5'$.
2	ICLMS	measurement motion parameters: D; D'; α; β; α'; β';	D = 150 km	on the reflected signal: $\sigma_D < 0{,}4$ m; $\sigma_{\alpha,\beta} < 0{,}2''$; $\sigma_{D'} < 0{,}1$ m/s; $\sigma_{\alpha',\beta'} < 0{,}2''$.

Table 2

Results of calculations using the station ICLMS

	№ nodal point									
	0	1	2	3	4	5	6	7	8	9
C_x	0,267	0,283	0,301	0,321	0,343	0,368	0,396	0,427	0,462	0,501
σ_{C_x}	0,034	0,036	0,038	0,041	0,044	0,046	0,05	0,053	0,057	0,062
δC_x, %	12,8	12,8	12,8	12,7	12,7	12,6	12,5	12,5	12,4	12,3

Conclusions

Radio engineering station «КАМА – Н» not suitable for use during flight tests for clarifying values of $c_X(M)$ of front resistance power missile obtained in previous stages of design.

Applying ICLMS will provide the function $c_X(M)$ with a relative error δc_X = (10…15) %, but not accepted for high-precision ballistic calculations.

To meet the requirements for accuracy of ballistic calculations necessary to station outwardly trajectory measurements, which provide measurement error range not less than $\sigma_D \leq 0{,}01$ м.

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МЕТОД ВИЗНАЧЕННЯ ПОХИБКИ КОЕФІЦІЄНТА СИЛИ ЛОБОВОГО ОПОРУ СНАРЯДА ЗА ДОПОМОГОЮ СТАНЦІЇ ЗОВНІШНЬО-ТРАЄКТОРНИХ ВИМІРЮВАНЬ

О.О. Журавльов, О.В. Коломійцев, С.В. Герасимов

Запропонований метод визначення похибки коефіцієнта сили лобового опору снаряда, який отриманий із використанням результатів зовнішньо-траєкторних вимірювань. У методі швидкість і прискорення снаряду обчислені за методом кубічних поліномів віртуальних систем координат. Проведений порівняльний аналіз оцінок величин інструментальних похибок, що отримані за результатами зовнішньо-траєкторних вимірювань снаряда різними станціями.

Ключові слова: *інструментальна похибка, коефіцієнт сили лобового опору, станція зовнішньо-траєкторних вимірювань.*

МЕТОД ОЦЕНКИ ПОГРЕШНОСТИ КОЭФФИЦИЕНТА СИЛЫ ЛОБОВОГО СОПРОТИВЛЕНИЯ СНАРЯДА С ПОМОЩЬЮ СТАНЦИЙ ВНЕШНИХ ТРАЕКТОРНЫХ ИЗМЕРЕНИЙ

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Предложен метод оценки погрешности коэффициента силы лобового сопротивления снаряда, полученных с использованием результатов внешних траекторных измерений. В методе скорость и ускорение вычислены по методу кубических полиномов виртуальных систем координат. Проведен сравнительный анализ оценок величин инструментальных погрешностей, полученных по результатам внешних траекторных измерений снаряда разными станциями.

Ключевые слова: *инструментальная погрешность, коэффициент силы лобового сопротивления, станция внешних траекторных измерений.*