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Accuracy of Different Modes of Bomb Dropping from Aircraft

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Abstract: The development of targeting systems is carried out under the influence of the requirements set by the conditions of combat use of aircraft, which are characterized by high speed and dynamism. The emergence of new methods for solving the targeting task in targeting systems leads to the expansion of aircraft combat capabilities, as well as to changes in tactical techniques and maneuvers. Combat tactics themselves also develop as a result of improving old ones and developing new methods of combat use. To implement the new methods, it is necessary to improve targeting systems.To solve the targeting task in bomb dropping, the non-program method is used, implemented on the various existing types of aircraft targeting systems. The non-program method, depending on the attack modes (horizontal flight, dive, pitch up) and the field of view of the sighting system, is implemented through the Constantly Computed Release Point (CCRP) and Constantly Computed Impact Point (CCIP) modes. This article proposes a method for solving the targeting problem when dropping bombs by angular velocity from horizontal flight and dive.Bomb dropping by angular velocity is a method that has not been used so far for solving the targeting problem. The moment of bomb dropping is determined by comparing the angular velocities of tracking the target with the required ones. This method also allows the use of container type targeting systems. All this expands the areas of combat use of aircraft.To study the targeting process and determine the errors of bomb dropping, mathematical modelling of the targeting process is performed using the CCRP and CCIP modes for bomb dropping as well as bomb dropping by angular velocity. The probabilistic characteristics of the dropping error are determined, and a comparative analysis of the same is performed for different methods of bomb dropping.

Keywords: Accuracy, Targeting systems, Aircraft

Introduction

Modern targeting systems (TS) are automated systems with the integration of on-board equipment and the use of on-board digital computers (ODCs) (Biliderov & Kambushev, 2019).

Characteristic features of targeting systems are:

- Full automation of the measurement of data on the state and movement of the aircraft.
- Full automation of the target tracking systems, with the initial target designation being performed manually or automatically depending on the technological level of the aircraft's equipment.
- Primary processing of data from the sensors is performed by the subsystem computers.
- The ODC performs complex processing of incoming information for controlling the subsystems and coordinates the interaction between them.
- The algorithm for determining the coordinates of the point of impact of the means of destruction is synthesized on the basis of predicting the movement of the target and solves the main task of external ballistics.
- The display of targeting and piloting information is performed using optical-electronic devices.
- Control of aircraft in targeting modes is usually carried out manually by direct marks.

Currently, work is underway to improve the combat use modes of aircraft based on solving finite variation problems for intersecting the motions.

Mathematical Model of CCIP and CCRP Modes

In the non-program method, the drop moment is determined by comparing the target coordinates determined during the flight and their calculated values. When using a vertical maneuver, in addition to determining the drop moment, the start of the vertical maneuver must be selected. The mathematical dependencies of the aiming parameters for bomb-dropping can be obtained from the vector aiming equation (Figure 1).

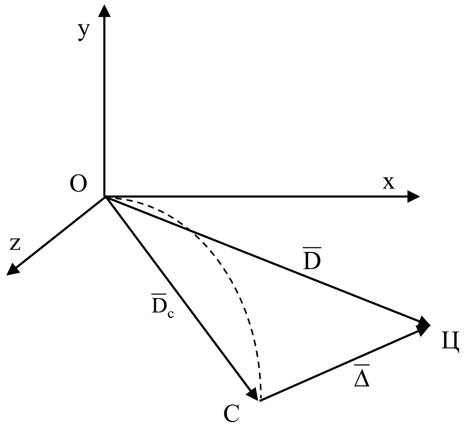

Figure 1. Bomb-dropping targeting vector scheme

$$\overline{\Delta} = \overline{D} - \overline{D}_c, \quad (1)$$

where $\overline{\Delta}$ is the aiming parameter.

In the general case, projecting equation (1) onto the axes of the coordinate system $O\eta'\zeta'\xi'$ is obtained:

$$\begin{aligned} \Delta_\eta &= \eta' - \eta'_c; \\ \Delta_y &= y - Y; \\ \Delta_\xi &= \xi' - \xi'_c, \end{aligned} \quad (2)$$

where Δ_η, Δ_y, Δ_ξ ($\zeta' \equiv Y$) are projections of the aiming parameters on the corresponding axes;

η', y, ξ' – the current coordinates of the target;

$\eta'_н$, Y, $\xi'_н$ – the calculated target coordinates at the time of dropping.

The current coordinates of the target can be determined by the sighting and information navigation subsystems. The calculated coordinates of the target are calculated by the ODC. In this case, it is assumed that each point of the combat trajectory is considered as a possible drop point. This allows the current flight parameters of the aircraft to be used as initial conditions: H, V1, λ, etc. to determine the ballistic elements of the bombs. With the assumption made, the current y and calculated Y coordinates of the target coincide and are equal to the flight altitude of the aircraft, i.e. y=Y= −H. Then the parameter Δ_y will be identically equal to zero. Therefore, in the aiming process, it is necessary for Δ_η and Δ_ξ to tend to zero.

Zeroing of $\Delta_\xi = \xi' - \xi'_c$ represents the task of aiming in direction (lateral aiming), and zeroing $\Delta_\eta = \eta' - \eta'_c$ constitutes the task of aiming in distance (determination of the moment of bomb drop).

The following designations are accepted:

$$\Delta_\xi = q; \\ \Delta_\eta = p, \tag{3}$$

където

q is the direction aiming parameter;

p – the distance aiming parameter.

Performing aiming during bomb-dropping (zeroeing the parameters q and p) can be done using two possible methods: CCIP and CCRP.

Constantly Computed Impact Point Modes

When using the CCIP method, the aiming grid is indicated, the central point of which shows the point of contact of the bomb with the ground, if the combat button is pressed at that moment. In this case, the position of the movable grid relative to the coordinate system connected to the aiming head $Ox_sy_sz_s$ is determined using the necessary angles B_s and E_s (Stoĭkov & Atanasov, 2009), which are calculated in discrete mode by the ODC based on the current flight parameters of the aircraft and the ballistic elements (A_0, T).

The target position relative to the same coordinate system is determined by the current angles β_s and ε_s.

When using this method the aiming parameters are:

$$q = \beta_s - B_s; \\ p = \varepsilon_s - E_s. \tag{4}$$

When aiming, the pilot strives to align the moving grid with the target (q=0, p=0) and press the fire button. This method is used when the target remains in the pilot's field of vision until the bomb is released. Such conditions exist when dropping bombs from horizontal flight and from a dive. A disadvantage of using this method of bomb dropping is that the target must be constantly monitored, and the angles of deviation of the aiming grid must be within the permissible limits for the specific type of targeting system, which in turn imposes restrictions on the initial conditions for bomb dropping. As an advantage, it can be emphasized that the pilot continuously monitors the target until the moment of release and the ODC determines the necessary angles of the aiming grid.

The ballistic task for the type of aviation bomb used is solved using the current flight parameters of the aircraft, the necessary coordinates of the target X, Z in the Oxyz coordinate system are determined. The calculated target sighting angles B and E in the considered coordinate system are determined using the following expressions (Stoĭkov & Atanasov, 2009):

$$B = \operatorname{arctg}\frac{Z}{X}; \\ E = \operatorname{arctg}\left(\frac{H}{X}\cos B\right). \tag{5}$$

Projections D_{cx1}, D_{cy1}, D_{cz1} are determined in the expression:

$$\begin{bmatrix} D_{cx1} \\ D_{cy1} \\ D_{cz1} \end{bmatrix} = A_{1,st} \begin{bmatrix} X \\ H \\ Z \end{bmatrix} \tag{6}$$

expression:

$$\begin{bmatrix} D_{нx1} \\ D_{нy1} \\ D_{нz1} \end{bmatrix} = A_{1,ст} \begin{bmatrix} X \\ H \\ Z \end{bmatrix} \tag{9.51}$$

where $A_{1,st}$ is the transition matrix for going from the Oxyz stabilized coordinate system to the $Ox_1y_1z_1$ coordinate system;

$$A_{1,st} = \begin{bmatrix} \cos\vartheta & \sin\vartheta & 0 \\ -\sin\vartheta\cos\gamma & \cos\vartheta\cos\gamma & \sin\gamma \\ \sin\vartheta\sin\gamma & -\cos\vartheta\sin\gamma & \cos\gamma \end{bmatrix}. \tag{7}$$

Angles B_1 и E_1 are determined by the formulas:

$$B_1 = \operatorname{arctg}\left(\frac{D_{cz1}}{D_{cx1}}\right); \quad E_1 = \operatorname{arctg}\left(\frac{D_{cy1}\cos B_1}{D_{cx1}}\right). \tag{8}$$

To determine the calculated angles of the movable grid B_c and E_c, are used the formulas:

$$B_в = B; \quad E_в = E_1 - \alpha_{mount}. \tag{9}$$

Constantly Computed Release Point Modes

CCRP mods is used when $E_s > \varepsilon_{lim}$, i.e. the target in the process of aiming is hidden by the front part of the aircraft body before the moment of drop. In this case, the parameters q and p are determined by the formula (9). The current coordinates of the target η' и ξ' are determined by the formulas:

$$\eta' = \eta'_0 - \eta'_{dist}; \quad \xi' = \xi'_0 - \xi'_{dist}, \tag{10}$$

where η'_{dist} and ξ'_{dist} is the distance traveled by the aircraft for the remaining time $t_{ост}$ from the target attachment to the moment of bomb dropping.

The distance traveled is determined by integrating the ground speed W of the aircraft. The initial coordinates of the target η'_0 and ξ'_0 are determined using the onboard sighting and rangefinder system. The distance traveled is determined by integrating the ground speed W of the aircraft. The initial coordinates of the target η'_0 and ξ'_0 are determined using the onboard sighting and rangefinder system. The calculated coordinates of the target , are determined by the formula:

$$\begin{bmatrix} \eta'_c \\ 0 \\ \xi'_c \end{bmatrix} = A_{\eta'\zeta'\xi',ст} \begin{bmatrix} X \\ 0 \\ Z \end{bmatrix}, \tag{11}$$

where $A_{\eta'\zeta'\xi',st} = \begin{bmatrix} \cos\psi & 0 & -\sin\psi \\ 0 & 1 & 0 \\ \sin\psi & 0 & \cos\psi \end{bmatrix}$

The remaining time t_r is determined by the equation:

$$t_r = \frac{\eta' - \eta'_c}{W_\eta}. \tag{12}$$

Пускането на бомбите се извършва автоматично при q=0, p=0.

Mathematical Model of Bomb Drop by Angular Velocity

Modern aircraft are equipped with new generation optical-electronic systems, which have tracking systems for automatic target designation. When the target is captured by the tracking system, the angular velocity of the target tracking is measured by sensors. This enables the pilot (operator) to continuously monitor the target, both at night and during the day. The angular velocity $\overline{\omega}$ of the target sighting line is a carrier of information about both the coordinates and the speed of the target. They are necessary for solving the aiming task when dropping bombs. Bomb-dropping is carried out when the angular velocity of the target tracking $\overline{\omega}$ is equalized with the calculated angular velocity of the target tracking $\overline{\omega}_c$, i.e. $\overline{\omega} = \overline{\omega}_c$.

The calculated angular velocity $\overline{\omega}_н$ is determined by the calculated coordinates of the target X and Z and the information about the flight parameters received from the radio-electronic equipment. The target and the area around it are shown on a display or the head-up display. If a mismatch is observed between the target and the aiming grid, the pilot makes a correction to eliminate it. When aiming at a moving target, it is necessary for the pilot (operator) to hold the aiming grid on the target when locking onto the target, so that synchronous tracking can be performed by the tracking device. The bomb is released automatically after the aiming parameters are zeroed.

$$\begin{aligned} &q_{\omega i} = \omega_i - \omega_{ic} \text{ - параметър на прицелване по посока;} \\ &p_{\omega j} = \omega_j - \omega_{jc} \text{- distance aiming parameter} \end{aligned} \tag{13}$$

where ω_i is the measured angular velocity of the axis Oi of the tracking device;
ω_j – the measured angular velocity of the axis Oi of the tracking device.

From the calculated calculated target coordinates X and Z and the current aircraft flight parameters, the calculated angular velocities ω_{ic}, ω_{jc} are calculated. The calculated X and Z coordinates are determined by the formula:

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} A_x + U_x T + V_{цx} T \\ -H \\ U_z T + V_{цz} T \end{bmatrix}. \tag{14}$$

To determine the unknown quantities V_{tx} and V_{tz} the following expression is used:

$$\overline{W}_p = \overline{W} - \overline{V}_t .$$

$$\begin{bmatrix} V_{цx} \\ 0 \\ V_{цz} \end{bmatrix} = \begin{bmatrix} W_x \\ W_y \\ W_z \end{bmatrix} - A_{ст,1} A_{1,сл} \begin{bmatrix} W_{прr} \\ W_{прi} \\ W_{прj} \end{bmatrix}, \tag{15}$$

where W_{pr}, W_{pi}, W_{pj} are the projections of $\overline{W}_p$ on the axes of the system Orij.

The projections of $\overline{W}_p$ are determined by the formulas (Atanasov, 2007):

$$W_{pr} = -\omega_{1i} l_j + \omega_{1j} l_i - \dot{D};$$
$$W_{pi} = \omega_{1r} l_j - \omega_{1j} l_r - \omega_j D; \quad (16)$$
$$W_{pj} = -\omega_{1r} l_i + \omega_{1i} l_r + \omega_i D;$$

The calculated angular velocities ω_{ic} и ω_{jc} are determined by formula. (16):

$$\omega_{jc} = -\frac{W_{ic}}{D_н};$$
$$\omega_{ic} = \frac{W_{jc}}{D_c}, \quad (17)$$

$$D_c = \sqrt{X^2 + H^2 + Z^2}\ .$$

From the above it is clear that the use of the method of bomb-dropping by angular velocity allows the velocity of the target to be calculated without prior detection, which makes it easier for the pilot to aim, and it is not necessary to measure the current distance D to the target. The presence of tracking systems (TS) in the TS when using this method allows the use of guided and unguided weapons in one attack.

Determining the Areas of Initial Conditions Under Which Bomb-Dropping Carried out

As a result of the mathematical modeling, are determined the possible ranges of initial conditions V_0, H_0 and λ at which bomb dropping is performed using TS – 1 and TS – 2. When dropping bombs at angular velocity (i.e. when using TS – 2), container-type targeting systems are also used, having thermal imaging electronic-optical sighting systems with multiple image magnification (from 20 to 30 times). This allows detection and recognition from long distances (up to 60 [km]) (Atanasov, 2007). For TS – 1, the ranges of initial conditions at which the CCIP and CCRP bomb dropping methods are used have been determined. The research was carried out at bomb-dropping from horizontal flight using TS – 1 and TS – 2 at speeds V=180 – 280 [m/s] and altitudes H=400 – 1800 [m] (Figure 3.6).

From Figure 2, it is clear that the range of conditions in which the CCRP method is used for bomb-dropping is larger than the range in which the CCIP method is used. When dropping bombs at a higher angular velocity, the range of possible initial conditions increases approximately 1.8 times compared to the same range in the CCIP and CCRP methods (Figure. 2).

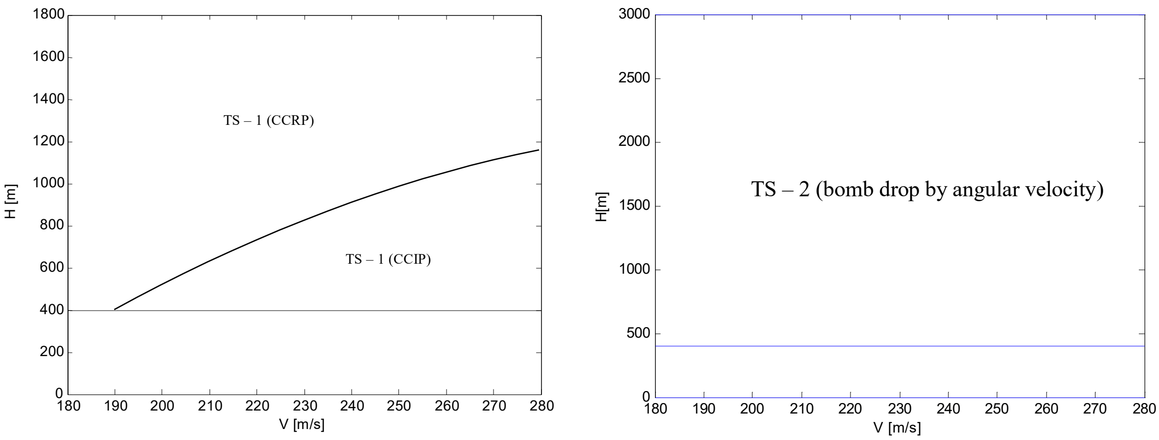

Figure 2 Areas of possible initial conditions for bomb-dropping from horizontal flight

The areas of possible initial conditions (PIC) for a dive bomb-dropping using TS – 1 and TS – 2 have been determined under the following conditions: V_0=180 – 260 [m/s]; H_0=900 – 3000 [m]; ε_0=-6^0, - 10^0, - 14^0; λ= - 20^0.

When dropping bombs with a dive angle of $\lambda = -20^0$, the area of PIC for bomb-dropping using TS – 2 increases approximately from 2.2 to 3 times compared to the same when using ATS – 1 (Figure 3). With an increase in ε_0, the area of PIC when using TS – 2 increases compared to the same when using TS – 1 (Figure 3). From Figure. 3 it is evident that for angles $\varepsilon_0 < -10^0$, bomb-dropping is performed using one of two methods - CCIP or CCRP (when using TS – 1).

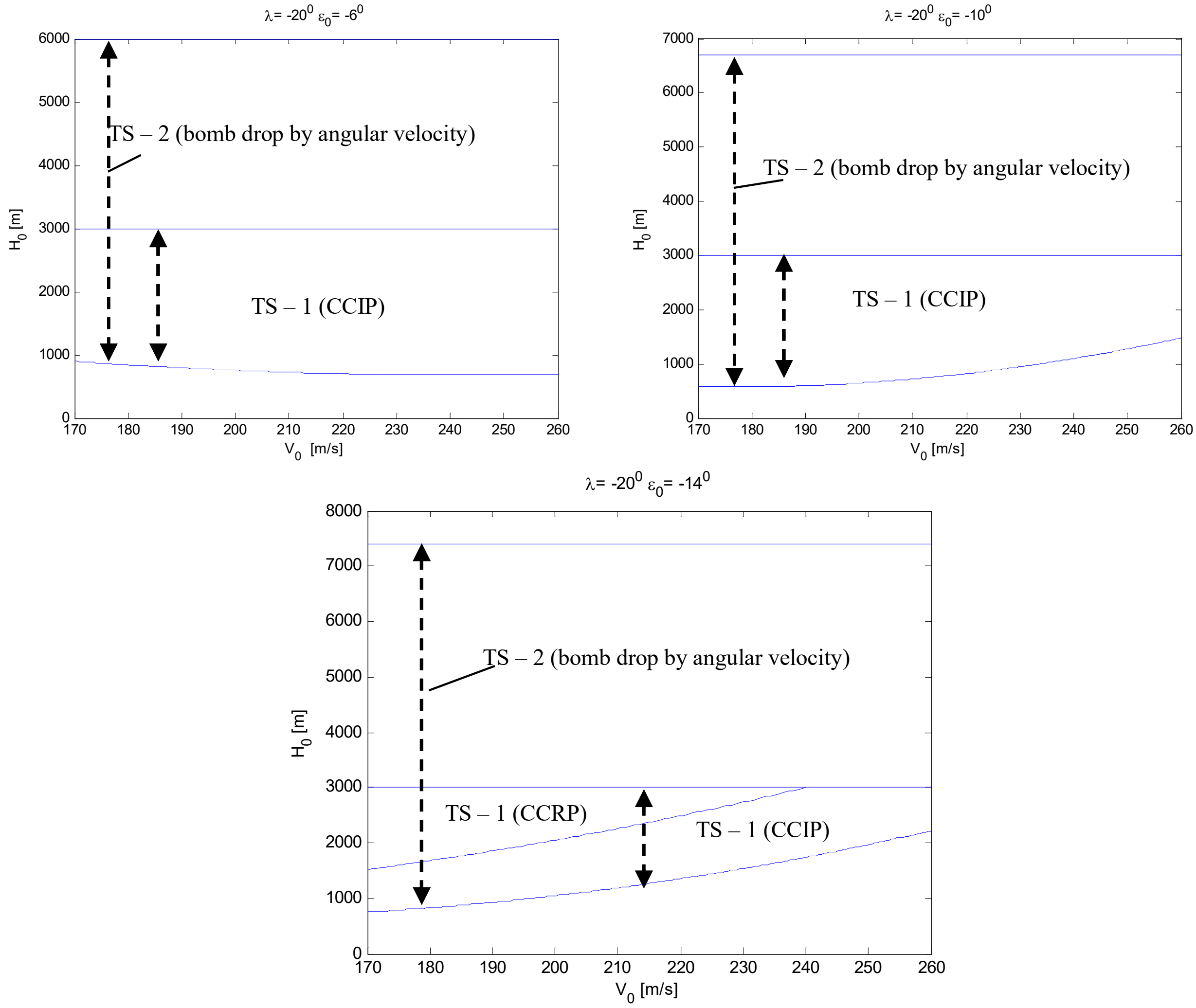

Figure 3. Range of possible initial conditions for a dive bomb drop with an angle of $\lambda=-20^0$

From Figure 2 and 3 the following conclusions can be drawn:

- The range of possible conditions for bomb-dropping from horizontal flight using TS – 2 is approximately 1.8 times larger compared to the same when using TS – 1.

The range of possible conditions for bomb-dropping from a dive using TS – 2 increases between 3.4 – 6.2 times compared to the same when using TS – 1.

- With a decrease in the target sighting angle ε_0, the range of possible initial conditions for bomb-dropping increases for TS – 1, and for TS – 2 it decreases.

- In order to expand the possible ranges of initial conditions for bomb-dropping from a dive using TS – 1, it is necessary for the initial target sighting angle ε_0 to decrease with the increasing of λ.

Determining the Probabilistic Characteristics of the Bomb-Dropping Error

Determining the Probabilistic Characteristics of the Bomb-Dropping Error When Using TS – 1.

When dropping bombs from a horizontal flight from altitudes up to 500 [m] using the CCIP and CCRP methods, the probable deviation E_x of the error Δx is determined by the dependence (Atanasov, 2007):

$$E_x=(20-30)\frac{1}{1000}H\ [m]; \tag{18}$$

When dropping a bomb from a horizontal flight from altitudes H=500 – 5000 [m], the probable deviation E_x is determined by (Atanasov, 2007):

$$E_x=(20-30)\frac{1}{1000}H\ [m]; \tag{19}$$

- during dive bombing and dive recovery bombing[16]:

$$E_x=(20-30)\ (1+\sin\lambda)\frac{1}{1000}H\ [m], \tag{20}$$

where

$$\sigma_{\Delta x}=E_x\ 1.4815. \tag{21}$$

From the empirical formulas (19) – (21) the limits of variation of the root mean square deviation of the bomb-dropping error are determined:

- from horizontal flight:

$$\sigma_{\Delta x\ min}=0.0296\ H\ [m];\ \sigma_{\Delta x\ max}=0.0444\ H\ [m]; \tag{22}$$

- from a dive:

$$\sigma_{\Delta x\ min}=0.0296\ (1+\sin\lambda)\ H\ [m];\ \sigma_{\Delta x\ max}=0.0444\ (1+\sin\lambda)\ H\ [m]; \tag{23}$$

As a result of the mathematical modeling, the probability characteristics of the bomb-dropping error ($\sigma_{\Delta x}$) from horizontal flight and dive using TS – 1 and TS – 2 are determined. The research is conducted for bomb-dropping from horizontal flight using TS – 1 for velocities and altitudes: V= 180 – 260 [m/s]; H=600 – 1800 [m].

As a result of the modeling, the calculated root mean square deviation $\sigma_{\Delta x}$ of the error Δx is shown in Table 1 and Figure 4. With the increase in the velocity V and the height H of the bomb-dropping, $\sigma_{\Delta x}$ changes from 21 to 57 [m]. The influence of the change in the velocity V on the value of $\sigma_{\Delta x}$ is less than the influence of the height H on $\sigma_{\Delta x}$ (Figure 4).

Table 1. Standard root mean square deviation $\sigma_{\Delta x}$ of the bomb-dropping error from horizontal flight

$\sigma_{\Delta x}$ [m] ($\lambda = 0^0$)					
	V=180 [m/s]	**200**	**220**	**240**	**260**
H=600 [m]	23.37	21.095	21.097	23.295	27.77
900	30.36	29.622	29.227	29.178	29.473
1200	38.36	38.286	37.61	36.331	34.45
1500	47.37	47.089	46.218	44.755	42.703
1800	57.39	56.03	55.05	54.45	54.23

Figure 4 shows that at H= 600 [m] and velocity V=200 – 220 [m/s]; H=900 [m] and velocity V=240 – 260 [m/s] the root mean square deviation $\sigma_{\Delta x}$ has minimal significance as the bomb-dropping method changes.

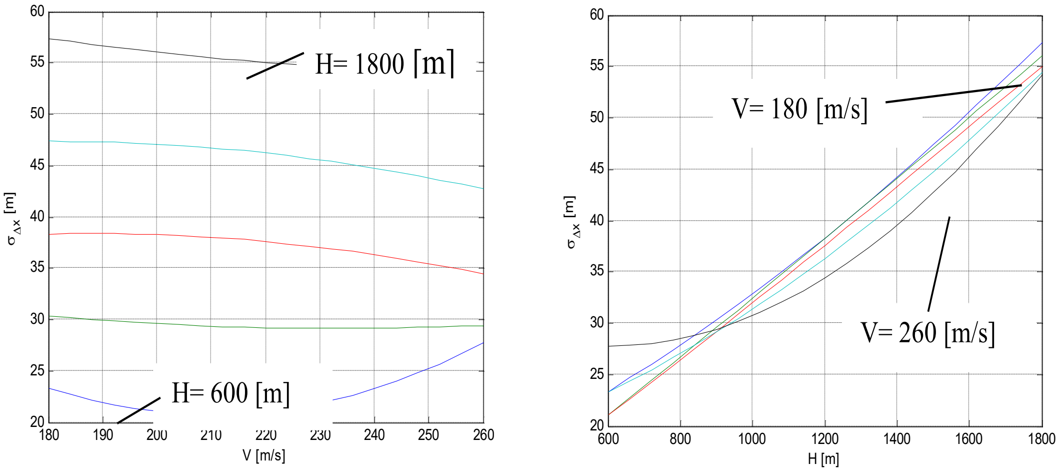

Figure 4. Dependence of $\sigma_{\Delta x}$ on V and H. when bomb-dropping from horizontal flight.

Table 2 gives values for the standard deviation of the error $\sigma_{\Delta xmin}$ and $\sigma_{\Delta xmax}$ obtained using fomula (22). Table 3 gives the standard deviations of the error $\sigma_{\Delta x}$ when bom-dropping with a dive angle of λ= - 20^0 using TS – 1. At a height of H=1500 [m], V=180 – 200 [m/s] and for H=1800 [m], speeds of V=200 – 220 [m/s], the method of bomb-dropping is changed (CCRP with CCIP), as a result of which $\sigma_{\Delta x}$ becomes of minimal significance (Table 3).

Table 2. The limits of variation of $\sigma_{\Delta xmin}$ and $\sigma_{\Delta xmax}$ of the bomb-dropping error from horizontal flight

	$\sigma_{\Delta x\ min}$[m]	**$\sigma_{\Delta x\ max}$[m]**
H=600 [m]	17.7780	26.6670
900	26.6670	40.0005
1200	35.5560	53.3340
1500	44.4450	66.6675
1800	53.3340	80.0010

Table 3. Root mean square deviation $\sigma_{\Delta x}$ of the dive bombing error

$\sigma_{\Delta x}$ [m] (λ= - 20^0)					
	V=180 [m/s]	**200**	**220**	**240**	**260**
H=600 [m]	11.57	12.184	12.8	13.419	14.04
900	14.561	15.909	17.121	18.199	19.141
1200	18.47	19.807	21.15	22.497	23.85
1500	23.296	23.88	24.886	26.315	28.166
1800	29.04	28.126	28.33	29.651	32.09

Determining the Probabilistic Characteristics of the Bomb-Dropping Error When Using TS – 2.

The probabilistic characteristics of the bomb-dropping error when using TS – 2 are determined under the same conditions under which they were determined for TS – 1. The root mean square deviation $\sigma_{\Delta x}$ of the bomb-dropping error from horizontal flight varies in the range from 18.23 to 47.31 [m], with the change in $\sigma_{\Delta x}$ having a steady character (Table 4). It is evident that $\sigma_{\Delta x}$ increases with the increase in the velocity V and the height H of the bomb-dropping, with the latter having a greater impact on the value of $\sigma_{\Delta x}$.

Table 4. Root mean square deviation $\sigma_{\Delta x}$ of the bomb drop error in angular velocity from horizontal flight

$\sigma_{\Delta x}$ [m] (λ= 0^0)					
	V=180 [m/s]	**200**	**220**	**240**	**260**
H=600 [m]	18.23	18.955	19.53	19.955	20.23
900	22.764	24.589	25.813	26.434	26.453
1200	27.02	29.537	31.38	32.547	33.04
1500	30.999	33.8	36.233	38.297	39.993
1800	34.7	37.376	40.37	43.681	47.31

The root mean square deviations $\sigma_{\Delta x}$ of the bomb-dropping error when diving with an angle $\lambda = -20^0$ obtained as a result of the modeling are given in Table 5. The values of $\sigma_{\Delta x}$ vary in the range from 8.93 to 27.49 [m], and they increase with the increasing of the velocity V and height H of bomb-dropping (Table 5). The values of $\sigma_{\Delta x}$ decrease with the increasing of the dive angle λ.

Table 5. Root mean square deviation $\sigma_{\Delta x}$ of the bomb drop error in angular velocity from dive

$\sigma_{\Delta x}$ [m] ($\lambda = -20^0$)					
	V=180 [m/s]	**200**	**220**	**240**	**260**
H=600 [m]	8.9346	9.1808	9.4705	9.8035	10.18
900	12.584	13.446	14.019	14.304	14.301
1200	16.2	17.405	18.2	18.585	18.56
1500	19.782	21.059	22.014	22.646	22.956
1800	23.33	24.407	25.46	26.488	27.49

Comparative Analysis of the Probabilistic Characteristics of the Bomb-Dropping Error from Horizontal Flight

As a result of the mathematical modeling, a comparative analysis of the accuracy of bomb-dropping from horizontal flight using TS-1 and TS-2 is carried out, and for this purpose is determined $\sigma_{\Delta x1}$:

$$\Delta\sigma_{\Delta x} = \sigma_{\Delta x1} - \sigma_{\Delta x2}; \qquad (24)$$

Table 6 shows the differences $\Delta\sigma_{\Delta x}$ for the considered bomb-dropping conditions. For the entire range of bomb-dropping conditions from horizontal flight, the difference $\Delta\sigma_{\Delta x}$ is greater than zero. This shows that the root mean square deviation $\sigma_{\Delta x2}$ of the error when using TS – 2 is smaller than the same when using TS – 1. The difference $\Delta\sigma_{\Delta x}$ varies in the range from 1.41 to 22.69 [m]. For bomb-dropping speeds and heights at which the bomb-dropping method changes (when using TS – 1), $\Delta\sigma_{\Delta x}$ takes minimum values (Figure 6).

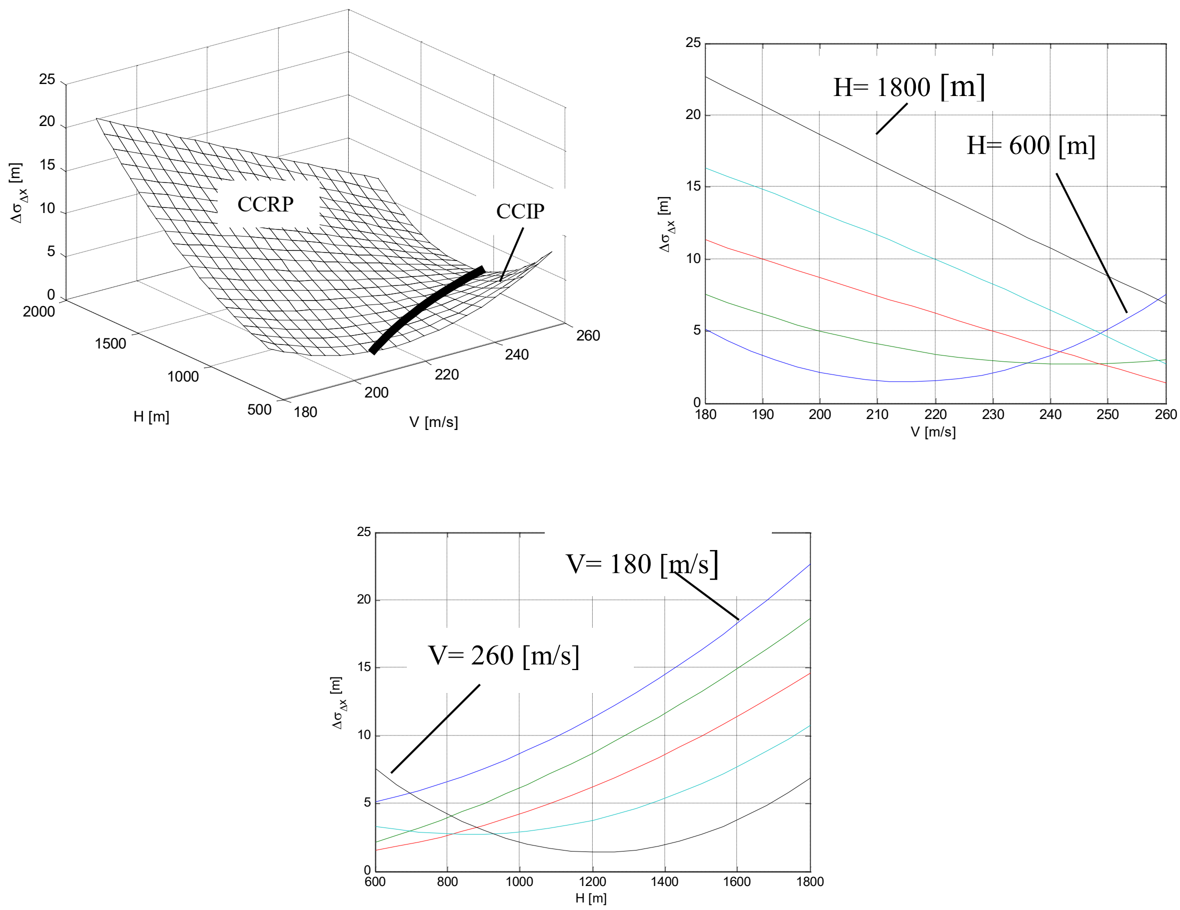

Figure 5. Dependence of $\Delta\sigma_{\Delta x}$ on V and H during bomb-dropping from horizontal flight

Table 6. Comparative analysis of bomb drop accuracy from horizontal flight

$\Delta\sigma_{\Delta x}$ [m] ($\lambda = 0^0$)					
	V=180 [m/s]	**200**	**220**	**240**	**260**
H=600 [m]	5.14	2.14	1.54	3.34	7.54
900	7.596	5.033	3.414	2.744	3.02
1200	11.34	8.749	6.23	3.784	1.41
1500	16.371	13.289	9.985	6.458	2.71
1800	22.69	18.654	14.68	10.769	6.92

A comparative analysis of the probabilistic characteristics of the bomb-dropping error from dives with angles $\lambda = -20^0$ when using TS – 1 and TS – 2 for bomb-dropping velocities and heights: V=180 – 260 [m/s]; H=600 – 1800 [m] is performed.

Table 7. Comparative analysis of dive bombing accuracy

$\Delta\sigma_{\Delta x}$ [m] ($\lambda = -20^0$)					
	V=180 [m/s]	**200**	**220**	**240**	**260**
H=600 [m]	2.64	3.00	3.33	3.62	3.86
900	1.98	2.46	3.10	3.90	4.84
1200	2.27	2.40	2.95	3.91	5.29
1500	3.51	2.82	2.87	3.67	5.21
1800	5.71	3.71	2.87	3.16	4.60

From Tables 7 it can be seen that the bomb-dropping accuracy with the use of TS – 2 is greater than when using TS – 1 with a dive angle $\lambda = -20^0$.

Conclusion

1. The results obtained from the mathematical modeling of the aiming process with the targeting system using the bomb-dropping methods of indicating the point of CCRP and indicating the moment of bomb-dropping are analogous to the results obtained from the objective control system of a fighter-bomber aircraft, the methodological manual for combat use.
2. The range of possible initial conditions for bomb-dropping by angular velocity from horizontal flight increases approximately 1.8 times, and when diving it increases between 1.4 and 6.2 times compared to the same when using existing bomb-dropping methods.
3. With an increase in the dive angle, the range of possible initial conditions decreases when using the currently employed aircraft targeting systems, and with a targeting system using the bomb-dropping by angular velocity method, the same range increases.
4. When using the bomb-dropping by angular velocity method from horizontal flight, the root mean square deviation of the bomb-dropping error decreases by 1.41 – 22.69 [m], and when diving - by 1.64 – 12.72 [m] compared to the same when using existing methods.
5. The method of bomb-dropping by angular velocity allows:

- bomb-dropping with unguided bombs from airplanes, helicopters and unmanned aerial vehicles at any time of the day and in any weather conditions;
- the use of guided and unguided weapons in one attack;
- he delivery of various cargoes to hard-to-reach areas, fire extinguishing, fighting snow

Recommendations

1. When aiming, the pilot, using the control elements of the tracking system, places the marker on the target and performs a target lock.
2. The subsequent flight should be carried out so that the predicted line of the CCRP points passes through the target.
3. When the given conditions are met, the drop will be carried out automatically on the corresponding section of the trajectory.

Scientific Ethics Declaration

* The author declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the author.

Conflict of Interest

* The authors declare that they have no conflicts of interest

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