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Possibilities for Improving Algorithms for Combat Use of Aircraft Using Unguided Weapons

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Abstract: Combat actions in recent local conflicts make us consider and re-evaluate some of the concepts concerning the development of combat aviation. As it turns out, conducting combat operations at high intensity for a long period of time using all components of the armed forces shows that the use of high-tech aircraft is extremely expensive and requires a large period of time to bring them back to full operational readiness when damage has been inflicted on them during hostilities. This is evidenced by the limited use of 5th generation aircraft in local conflicts. They are mainly used at long distances and with a tangible technological superiority over the enemy. Also, the sustained use of high precision guided weapons proves to be extremely expensive. All this makes us think and apply a creative approach to finding a solution to these problems. One of these approaches is through the improvement or rather the modernization of existing combat platforms through the implementation of advanced mathematical models and algorithms for combat use, which will increase the accuracy and efficiency of the use of unguided weapons, which are significantly cheaper compared to using guided ones. As the accuracy of using unguided weapons increases, it approaches that of guided ones. This is very important in the conduct of prolonged intensive combat operations in the conditions of limited resources. On the other hand, the use of advanced algorithms for combat use will simplify and facilitate the pilot's work with the controls of the aviation armament during the execution of combat tasks.A general mathematical model and a general algorithm for the combat use of aircraft weapons are proposed. A general mathematical model was developed for solving the ballistic task for large groups of guided and unguided weapons, which is a component of the general algorithm for combat use.

Keywords: Aircraft, Algorithm, Weapons

Introduction

The development of technologies and their implementation in combat aviation requires a rethinking of the concepts for the development of strike avionics responsible for solving combat tasks. New understandings of the strategy of conducting combat actions, to a large extent, determine the development of combat aircraft. One of the views on the development of combat aircraft i.e. for the creation of 6th generation aircraft, is that the aircraft themselves, with the help of the pilot and artificial intelligence, can control unmanned aerial vehicles in missions to strike air and ground targets. They should also be used as unmanned aerial vehicles (Mitov et al., 2019). This makes it possible to expand the spectrum of solved combat tasks, and from here to change and improve the tactics of using such aircraft.

Conducting high intensity combat operations over a long period of time shows that the use of high-tech aircraft is extremely expensive. Local conflicts show that the use of high precision guided weapons is extremely expensive as well. One of the possible solutions improving the mathematical models and algorithms for the combat use of unguided weapons, which will increase the accuracy and efficiency of their use. Combat use of aircraft is characterized by the following stages:

• Target identification.

• Decision to use a specific type of weapon.
• Decision to select a specific target attack type.
• Solving the task of guiding the weapon to a contact with the target.
• Determining the moment to fire, launch or drop.
• Exiting the attack.

All that demonstrates the great psycho-physical load on the part of the pilot during the execution of the combat task in a shortage of time. This necessitates the implementation of expert systems and advanced combat algorithms in combat aircraft in order to facilitate the work of the pilot.

Method

On the basis of mathematical modelling, the ultimate task of the aircraft hitting the target was solved, and the accuracy of the combat use of unguided weapons was determined. A comparative analysis was carried out, which showed how much the hit accuracy increases when using a general algorithm of work for the combat use of unguided weapons. A general mathematical model and a general algorithm for the combat use of aircraft weapons are proposed. A general mathematical model was developed for solving the ballistic task for large groups of guided and unguided weapons, which is a component of the general algorithm for combat use.

General Mathematical Model and General Algorithm for Combat Use with Unguided Weapons

To compile a general mathematical model for the combat use of unguided weapons (UW), the general vector scheme determining the contact of the UW with the target - air or ground (Figure 1) is used (Atanasov M., 2014).

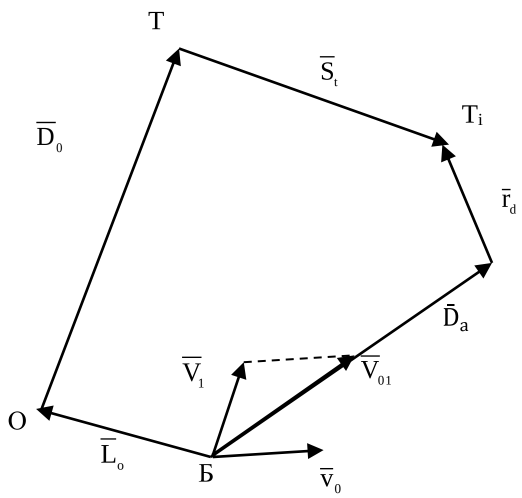


Figure 1. The aiming vector scheme

(1) $$\overline{D}_0 = \overline{D}_{ov} + \overline{r}_d - \overline{L}_0 - \overline{S}_t,$$

where

$\overline{L}_0$ is the base vector of the weapon;

$\overline{D}_0$ - the target distance vector at the time of the shot;

$\overline{D}_a$ - the vector of the advance distance to the target at the time of the shot;

$\overline{S}_t$ - the vector defining the target's motion;

$\overline{r}_d$ – the vector determining the deflection of the projectile for a mobile aircraft gun.

In the general case, at the time of firing and dumb bomb (DB)-dropping, angles $\beta_{t1,0}$ and $\varepsilon_{t1,0}$ of aiming at the target relative to the associated coordinate grid $Ox_1y_1z_1$ are determined by the formulas (Figure 2):

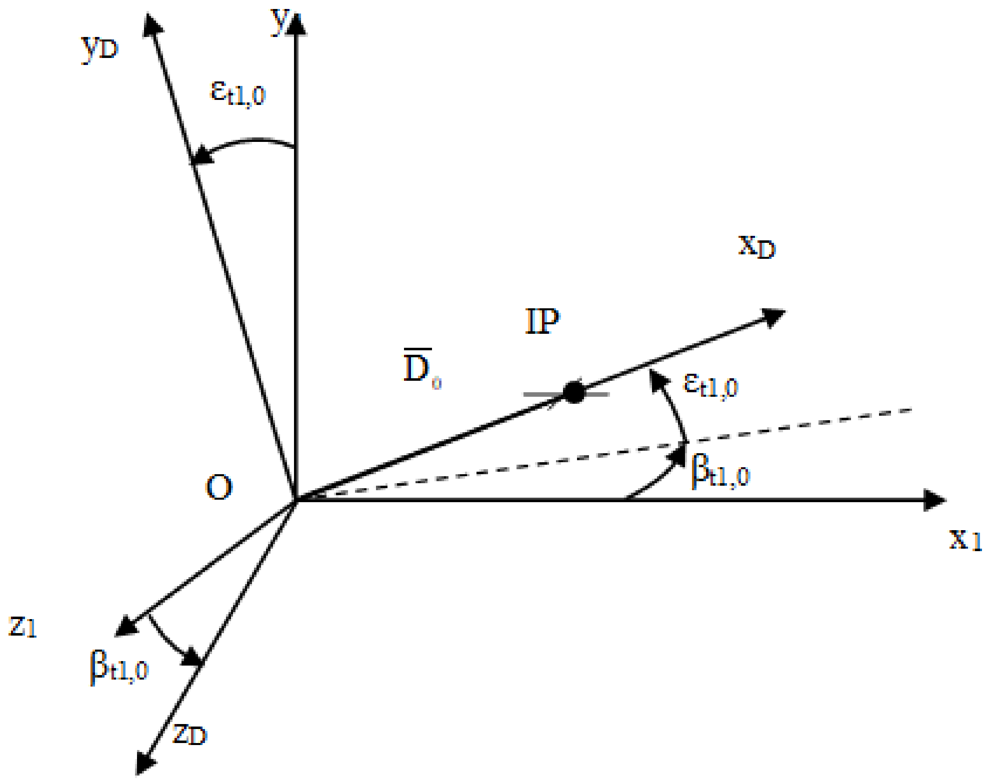


Figure 2. Impact point (IP) and target aiming angles βt1,0, εt1,0 at the time of firing and bomb drop

(2) $$\beta_{t1,0} = \operatorname{arctg}\left(\frac{D_{0z1}}{D_{0x1}}\right); \qquad \varepsilon_{t1,0} = \arcsin\left(\frac{D_{0y1}}{D_0}\right).$$

where:

(3) $$\begin{bmatrix} D_{0x1} \\ D_{0y1} \\ D_{0z1} \end{bmatrix} = \begin{bmatrix} X_1 \\ Y_1 \\ Z_1 \end{bmatrix} + C_r \begin{bmatrix} \cos\beta \sin\alpha \sin\beta' \cos\varepsilon' - \sin\beta \sin\varepsilon' \\ \sin\beta \cos\beta' \cos\varepsilon' + \cos\beta \cos\alpha \sin\beta' \cos\varepsilon' \\ \cos\beta \cos\alpha \sin\beta' \sin\varepsilon' + \cos\beta \sin\alpha \cos\beta' \cos\varepsilon' \end{bmatrix} - \begin{bmatrix} L_{0x1} \\ L_{0y1} \\ L_{0z1} \end{bmatrix} -$$
$$- \left[\left[A_v^{(1)}\right]^T \begin{bmatrix} V_1 \\ 0 \\ 0 \end{bmatrix} + A_1^{(xDyDzD)} \begin{bmatrix} \dot{D} \\ \omega_{zD} D \\ -\omega_{yD} D \end{bmatrix} \right] T - \frac{1}{2} \begin{bmatrix} a_{vx1} \\ a_{yx1} \\ a_{vz1} \end{bmatrix} T^2 +$$
$$- \frac{1}{2} A_1^{(xDyDzD)} \begin{bmatrix} \ddot{D} - D\left(\omega^2{}_{yD} + \omega^2{}_{zD}\right) \\ \omega_{xD}\omega_{yD} D + \dot{\omega}_{zD} D + 2\omega_{zD} \dot{D} \\ \omega_{xD}\omega_{zD} D - \dot{\omega}_{yD} D - 2\omega_{yD} \dot{D} \end{bmatrix} T^2.$$

General Structural Diagram of a System for Combat Use with Unguided Weapons

On the basis of the abovementioned general mathematical model for the combat use of unguided weapons, a general structural diagram of a system for combat use of unguided weapons (Figure 3) is proposed. The general structural scheme consists of:

- Targeting Block;
- Radar and Electro-Optical Tracking System (EOTS)
- Block For Determining the Target Motion Vector $\overline{S}_t$;
- Block for Determining the Advance Distance Vectors $\overline{D}_a$ to the Target and the Deviation $\bar{r}_d$ of the Projectile;

- Block for Determining the Distance to the Target at the Time of the Shot $\overline{D}_0$;
- Ballistic Block;
- Block with Input Parameters;
- Block for Determining Angles $\beta_{t1,0}$ and $\varepsilon_{t1,0}$;
- Block for Determining η_c, ξ_c of the Current Coordinates of the Target Relative to the Aircraft;
- Heads-up Display (HUD).

The azimuth angle β_{t1} and the angle ε_{t1} of the target location are fed from the target designation unit to the Radar/EOTS.

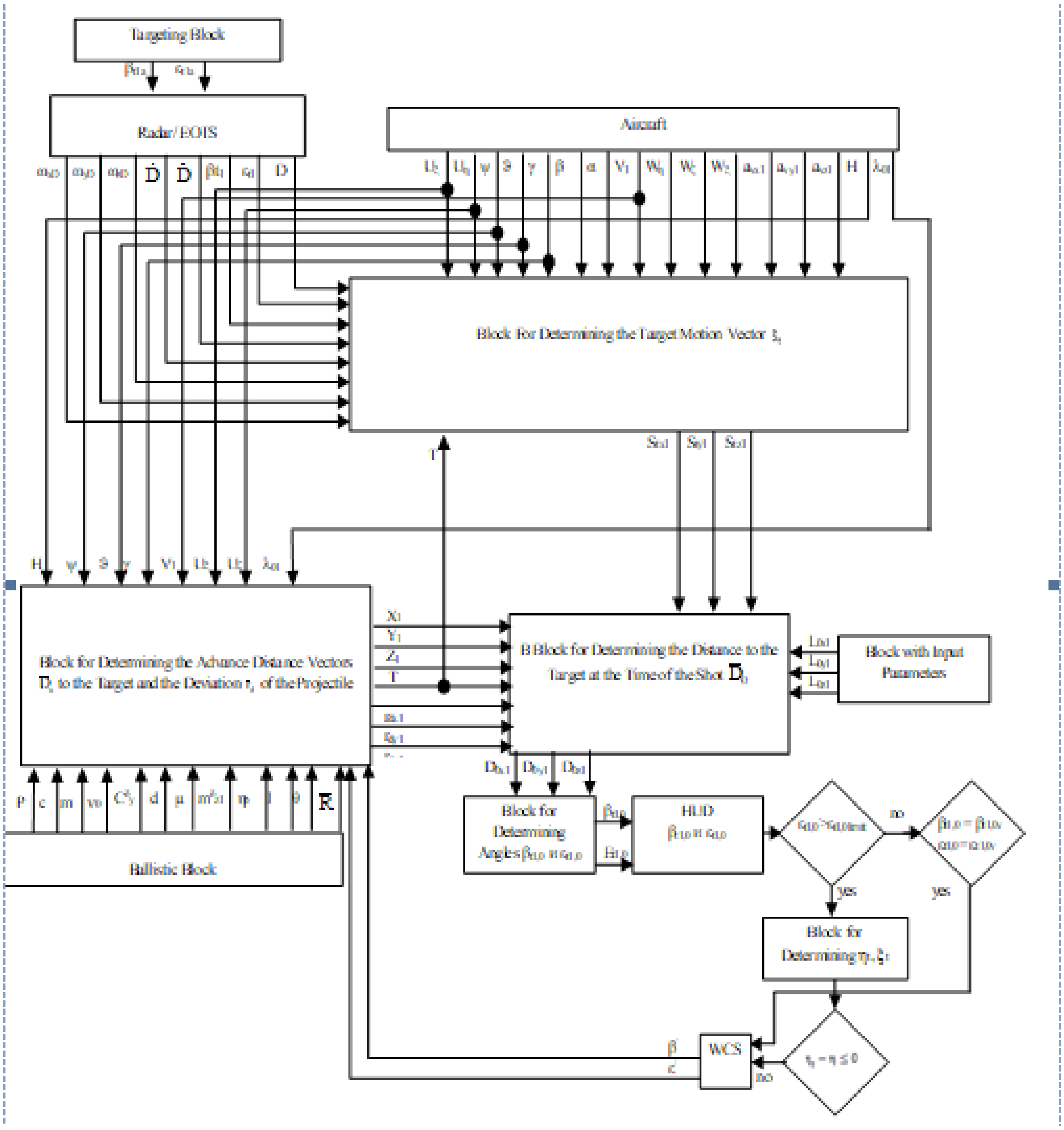


Figure 3. General structural diagram of a system for combat use with UW

The vector determining the movement of the target $\overline{S}_t$ is calculated after solving the ballistic task, depending on whether the target is air or ground. Provided that the aircraft artillery weapon is stationary, the vector $\overline{r}_d$ is not calculated. Using the derived formulas from (3), the distance to the target for the time of the shot is determined in the corresponding block. From the ballistic block, depending on the UW used, the values of P, c, m, v_0, C^δ_y, d, μ, m^δ_{z1}, η_b, l, θ and the coordinates of the explosion point - R_η, R_ζ, R_ξ are supplied (Stoĭkov & Atanasov, 2009). From the block with input parameters, the base $\left(\overline{L}_0\right)_1$ of the aviation artillery weapon is supplied. The angles β'

and $\varepsilon^{/}$ at which the aircraft gun (AG) is rotated relative to the $Ox_1y_1z_1$ system are supplied from the weapon control system (WCS).

The target sighting angles $\beta_{t1.0}$ and $\varepsilon_{t1.0}$ are calculated with the form. (2) in the corresponding block. When firing and bomb drop is carried out in CCIP mode, the calculated angles $\beta_{t1.0}$ and $\varepsilon_{t1.0}$ are displayed on the HUD. This is the reticle position. When the reticle aligns with the target, the pilot presses the combat button, which sends a signal to the WCS. When bomb drop is carried out in the invisible zone (CCRP mode), after aligning the reticle with the target, the current coordinates η_c, ξ_c of the target relative to the aircraft in the corresponding block are calculated. When the condition $\eta_т - \eta \le 0$ is met, a signal is sent to the WCS.

Solving the Ballistic Task

Unguided weapons are used in a large range of aircraft speeds and altitudes, angles and distances to the target, presence of an angle between the vectors of the speed of the aircraft and the initial speed of the UW. In different aviation aiming systems (AAS), fundamentally different ballistic schemes are used, requiring specific methods of solving ballistic tasks and forms of presentation of the results of the decisions. Therefore, it is necessary to compile a common ballistic model for all types of unguided UW, and the type of UW used is entered on board the aircraft. For the synthesis of the ballistic model, a system of differential equations describing the spatial movement of the UW in the navigation base $O\eta\zeta\xi$ is proposed. The $O\eta$ axis of the navigation base is oriented along the north meridian, the $O\zeta$ axis is oriented along the local vertical, and the $O\xi$ axis is oriented to form a right coordinate system. The movement of the unguided UW is described by the system of differential equations (Atanasov, 2014):

$$\dot{y} = f_w(y_w, t),$$

where y_w is the vector of phase coordinates of the UW, which depends on: the composition of forces and moments in the mathematical model; the coordinate system in which the vector equations are projected; the different assumptions and the type of UW.

General Work Algorithm for Combat use With Unguided Weapons

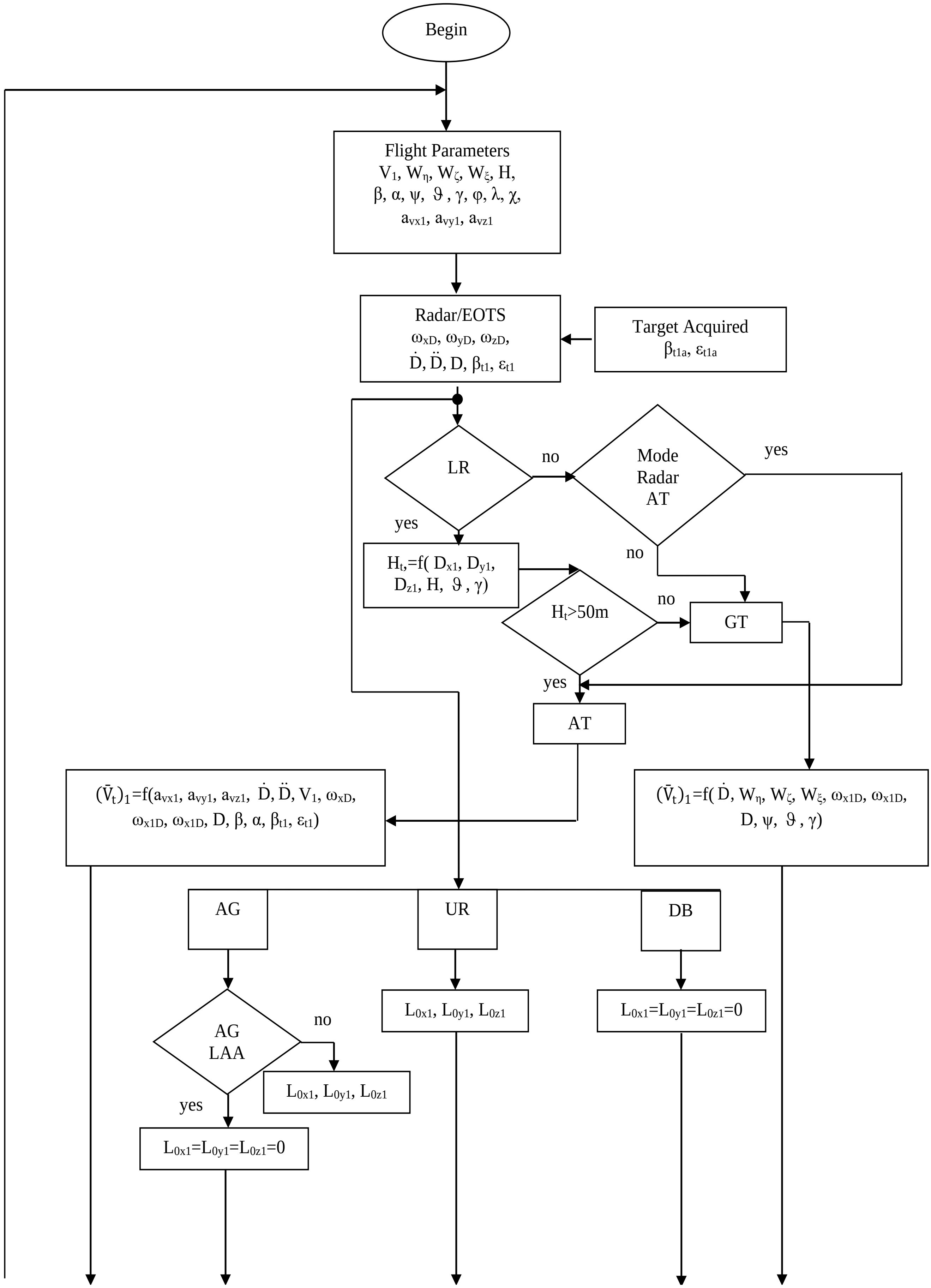
On the basis of the developed general mathematical model and general structural diagram of a firing and bomb-dropping system, a general work algorithm for combat use with unguided weapons was developed (Figure 4). After the target is acquired by the radar or the EOTS, it is automatically determined whether it is an air or ground target. In the event that the acquisition is carried out by the EOTS using the laser rangefinder (LR), the distance D to the target is measured and its altitude H_t is determined using the formulas:

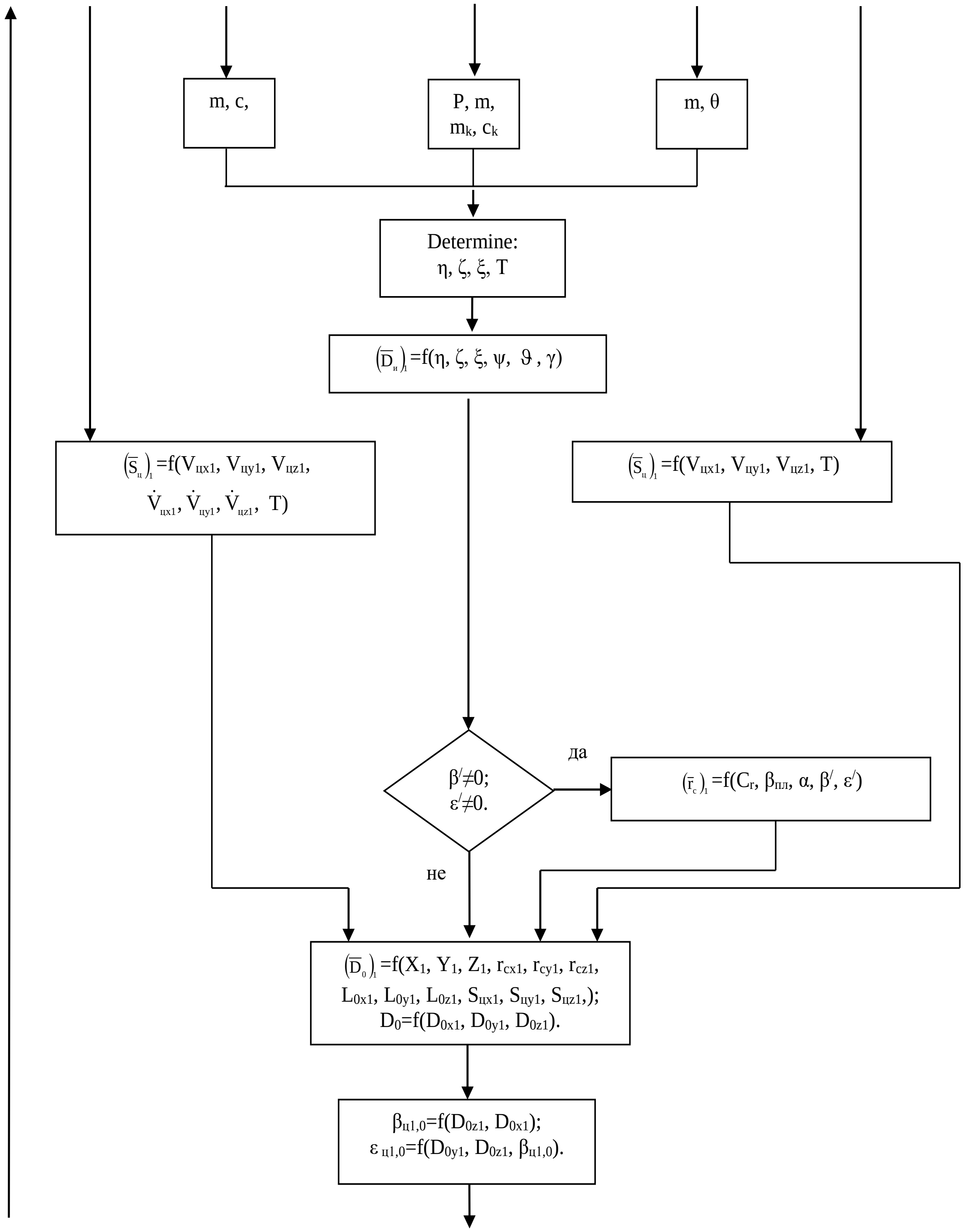
(4) $$\begin{bmatrix} D_{x1} \\ D_{y1} \\ D_{z1} \end{bmatrix} = A_1^{(xDyDzD)} \begin{bmatrix} D \\ 0 \\ 0 \end{bmatrix};$$

(5) $$\begin{bmatrix} D_{\eta} \\ D_{\zeta} \\ D_{\xi} \end{bmatrix} = \left[A_{\eta\zeta\xi}^{(x_1y_1z_1)}\right] \begin{bmatrix} D_{x1} \\ D_{y1} \\ D_{z1} \end{bmatrix};$$

(6) $$H_t = H - D_{x1}\sin\vartheta - D_{y1}\cos\vartheta\cos\gamma + D_{z1}\cos\vartheta\sin\gamma.$$

Provided that $H_t > 50$ m, a decision is made – it is an air target (AT) . If the condition is not fulfilled – it is a ground target (GT). When using the radar, the pilot manually selects the "air target" or "ground target" mode. Depending on the type of target, the velocity V_t of the target is calculated. Depending on the target, the pilot chooses the type of weapon to use. Afterwards, the relevant parameters that are to be entered in the system of differential equations for the motion of the UW are selected.


Begin
Flight Parameters
V1, Wη, Wζ, Wξ, H,
β, α, ψ, ϑ, γ, φ, λ, χ,
avx1, avy1, avz1
Radar/EOTS
ωxD, ωyD, ωzD,
Ḋ, D̈, D, βt1, εt1
Target Acquired
βt1a, εt1a
LR
no
yes
Mode
Radar
AT
yes
no
Ht=f(Dx1, Dy1,
Dz1, H, ϑ, γ)
Ht>50m
no
GT
yes
AT
(V̄t)1=f(avx1, avy1, avz1, Ḋ, D̈, V1, ωxD,
ωx1D, ωx1D, D, β, α, βt1, εt1)
(V̄t)1=f(Ḋ, Wη, Wζ, Wξ, ωx1D, ωx1D,
D, ψ, ϑ, γ)
AG
UR
DB
AG
LAA
no
yes
L0x1, L0y1, L0z1
L0x1=L0y1=L0z1=0
L0x1, L0y1, L0z1
L0x1=L0y1=L0z1=0


m, c,
P, m,
mk, ck
m, θ
Determine:
η, ζ, ξ, T
(D̄и)1 =f(η, ζ, ξ, ψ, ϑ, γ)
(S̄ц)1 =f(Vцx1, Vцy1, Vцz1,
V̇цx1, V̇цy1, V̇цz1, T)
(S̄ц)1 =f(Vцx1, Vцy1, Vцz1, T)
β/≠0;
ε/≠0.
да
не
(r̄c)1 =f(Cr, βпл, α, β/, ε/)
(D̄0)1 =f(X1, Y1, Z1, rcx1, rcy1, rcz1,
L0x1, L0y1, L0z1, Sцx1, Sцy1, Sцz1,);
D0=f(D0x1, D0y1, D0z1).
βц1,0=f(D0z1, D0x1);
ε ц1,0=f(D0y1, D0z1, βц1,0).

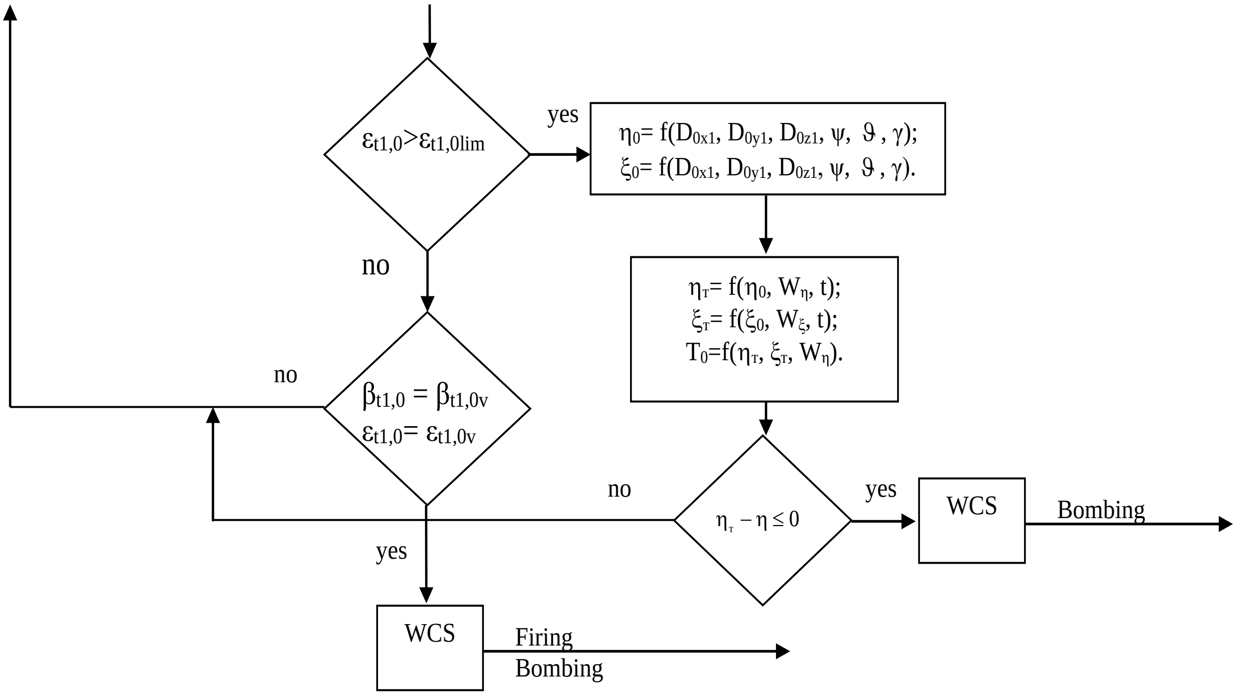


Figure 4. General algorithm of work for combat use with UW

When shooting at an air target, the system of differential equations is solved for the distance $\bar{D}_a$.

When firing at a ground target and dropping a bomb, the system of equations is solved for the altitude at which the combat use takes place. After solving the system, the vector of the advance distance $\bar{D}_a$ to the target is calculated for the moment of the shot and the time T of the UW flight. When bombing and firing with an AG located along the axis of the aircraft (LAA), it is assumed that the vector of the base on the weapon is $\bar{L}_0 = 0$. When firing with unguided rocket (UR) and an AG located in a container attached to the aircraft, it is assumed that $\bar{L}_0 \neq 0$. Depending on what the target is (air or ground), the vector $\bar{S}_t$ defining the target's movement is calculated. Provided the target is stationary $\bar{S}_t = 0$. On the condition that the weapon is mobile ($\beta' \neq 0$; $\varepsilon' \neq 0$), the vector $\bar{r}_d$ determining the deflection of the projectile is determined.

The next step is to calculate the vector of distance $\bar{D}_0$ to the target at the moment of the shot, from which the angles βt1,0 and εt1,0 of aiming the target relative to the associated coordinate $Ox_1y_1z_1$ are determined. Provided that firing or bombing is carried out in the visible area ($\varepsilon_{t1,0} < \varepsilon_{t1,0limit}$) and when the reticle is aligned with the target $\beta_{t1,0} = \beta_{t1,0v}$, $\varepsilon_{t1,0} > \varepsilon_{tt1,0limit}$ is signaled to the WCS, after which firing or bomb-dropping begins. Provided that the bomb drop takes place in the invisible zone ($\varepsilon_{t1,0} > \varepsilon_{tt1,0limit}$), the initial η_0, ξ_0 and the current coordinates η_t, ξ_t of the target relative to the aircraft are determined. When the condition $\eta_t - \eta \leq 0$ is met, the bomb drop is carried out automatically. Provided that $\eta_t - \eta > 0$ or $\beta_{t1,0} \neq \beta_{t1,0v}$; $\varepsilon_{t1,0} \neq \varepsilon_{t1,0v}$ then the process continues and returns to the starting position.

Results and Discussion

Comparative Analysis of the Accuracy of Combat use of Unguided Weapons

Bomb drop error is a sum of random and systematic error. Therefore, it is necessary to take some mean value of it. Considering that in most cases its sign is not of interest, the square root of the second starting moment of the error is taken as a criterium for evaluating the accuracy of firing and bomb dropping (Atanasov, 2014):

(7) $$\sqrt{\alpha_{2\Delta x}} = \sqrt{M^2[\Delta x] + D[\Delta x]} \,,$$

where M[Δx] is the mathematical expectation of the hit error;
- D[Δx] is error variance.

The accuracy of launching an unguided rocket and the accuracy of dropping a conventional bomb from a 4+ generation aircraft using type targeting system are calculated. The accuracy of firing and bomb drop under the same conditions with a targeting system using the proposed general algorithm for combat use is calculated and a comparative analysis is carried out. The test is carried out for launching an unguided C-25 rocket for the following launch conditions:

- dive angle $\lambda = -30^0$;
- speeds - V=56.56; 111.11; 166.67; 222.22; 277.78 m/s;
- altitudes H= 200; 500; 800; 1100; 1400 m.

When shooting with a dive angle $\lambda = -30^0$, Table 1 presents the calculated allowed shooting distances D, with the allowed distances D ranging from 1504.23 m to 2609.50 m. For the allowed launching distances D (Table 1), the relative percentage increase in accuracy when using the general algorithm for combat use $\Delta\alpha_{2x}$ % is in the range of 31.34 % to 35.23 % (Table 2).

Table 1. Allowed launching distance with an unguided rocket

Launching an unguided rocket with a dive angle $\lambda = -30^0$					
D, [m]	V= 55.56 [m/s]	111.11	166.67	222.22	277.78
H=200 [m]	-	-	-	-	-
500	-	-	-	-	-
800	-	-	-	1504.23	1516.10
1100	1914.56	1972.82	2017.66	2049.10	2067.14
1400	2408.90	2484.18	2542.70	2584.48	2609.50

Table 2. The relative percentage increase in accuracy when launching an unguided rocket $\Delta\alpha_{2x}$ %

Firing an unguided rocket with a dive angle $\lambda = -30^0$					
$\Delta\alpha_{2x}$ [%]	V= 55.56 [m/s]	111.11	166.67	222.22	277.78
H=200 [m]	-	-	-	-	-
500	-	-	-	-	-
800	-	-	-	31.60	34.50
1100	31.34	31.46	32.11	33.01	34.67
1400	31.68	32.40	32.65	33.83	35.23

A comparative analysis of the accuracy of a bomb drop from a horizontal flight with an aviation bomb having a characteristic time of fall Θ=21.1 s is performed. The test is carried out for the following bomb drop conditions:
- horizontal flight and diving;
- speeds - V=180; 200; 220; 240; 260 m/s;
- altitudes H= 600; 900; 1200; 1500; 1800 m.

The relative percentage increase in bomb drop accuracy when using the general algorithm for combat use ranges from 15.07% to 61.15% (Table 3). A greater relative percentage increase in accuracy when using the general combat algorithm is achieved in the area of conditions for the CCRP method for an aircraft with a type targeting system (shaded in grey - Table 3).

Table 3. The relative percentage increase in bomb drop accuracy $\Delta\alpha_{2x}$ %

Dropping an dumb bomb from horizontal flight					
$\Delta\alpha_{2x}$ [%]	V=180 [m/s]	200	220	240	260
H=600 [m]	36.37	27.36	24.12	23.76	26.21
900	45.81	36.93	27.60	20.08	15.07
1200	52.46	42.99	33.95	24.41	15.91
1500	56.64	49.33	39.59	30.31	21.20
1800	61.15	53.07	45.86	38.45	29.11

Conclusion

1. The proposed structural scheme and developed general algorithm for the combat use of unguided munitions ensures the expansion of the range of combat conditions for firing and bomb drop and increases their effectiveness.

2. When dropping a bomb from a horizontal flight on a stationary target, the relative percentage increase in accuracy for a targeting system working with the proposed general algorithm is between 15.07% and 61.15%, and when firing an unguided rocket it is in the range of 31.34% to 35.23%.
3. The conducted research shows that for an targeting system working with the proposed algorithm, the criterion for effectiveness of the combat use of unguided weapons - "price-accuracy" is fulfilled.

Recommendations

With the help of the proposed mathematical model and general algorithm, it is possible to determine the areas of conditions for the combat use of weapons from a multi-purpose aircraft on air and ground targets. On the other hand, the use of advanced algorithms for combat use will simplify and facilitate the pilot's work with the controls of the aviation armament during the execution of combat tasks.

Scientific Ethics Declaration

The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

Acknowledgements or Notes

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