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Aircraft Firefighting Capabilities Using Suspended Containers

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Abstract: In the world, the fight against forest and industrial fires is carried out by both ground based equipment and aircraft – airplanes and helicopters. Each of these has its specific advantages and disadvantages. The use of aviation containers for extinguishing fires is an alternative to existing methods at the moment. They are particularly effective in the initial outbreaks of fires in hard-to-reach areas and fires caused by toxic substance, as well as in limiting the growth of their spread. The advantage is that they can be targeted at a specific place and, depending on the type of fire, can be filled with the corresponding fire-fighting substance. These containers can be hung on airplanes and helicopters depending on their load capacity. They are used in the following way, after their targeted drop from the aircraft at a specific effective height, the container is destroyed and a fire-fighting substance is poured onto the burning surface. The moment of release of the aviation fire-fighting container is determined depending on the flight conditions and the targeting system of the aircraft used. For this purpose, mathematical modelling of the process of using the aviation container was carried out, mathematical models for the movement of the aircraft and the aviation fire-fighting container were compiled, and a mathematical model of the targeting system was created.

Keywords: Aircraft, Fires, Aviation containers

Introduction

At present, aerial firefighting is done by fixed-wing aircraft and helicopters. The substances used for extinguishing fires are liquid (water, foam), solid (powdery, bulk) and gaseous (fire extinguishing aerosols, carbon dioxide, etc.). Helicopters and fixed-wing aircraft are used to fight fires from the air. Nearly 1,000 aircraft have been contracted for each fire season in the US in recent years, with an annualized cost of over US$250 million in recent years. Helicopters used to fight fires can be type tankers or carry buckets. Buckets are always filled by dipping into dams, lakes, rivers or artificial reservoirs. The most popular bucket is the flexible Bambi Bucket.

Some of the most popular firefighting helicopters are the Bell 204, Bell 205, Bell 212, Boeing Vertol 107, Boeing Vertol 234, Sikorsky S-70, "Firehawk" and Sikorsky with flexible charging hose. Today, the largest firefighting helicopter in the world is the Mi-26, using the Bambi bucket. Tanker-type firefighting aircraft are divided into the following groups: single-engine air tankers (SEAT) with a capacity of up to 3,000 liters (Air Tractor AT-802; air tankers with a capacity of 7,500 liters to 15,000 (P2V, HC-130H, BAe- 146, MD-87, C-130Q, RJ85, C-130 H & J); air tankers with a capacity of more than 15,000 liters (DC-XNUMX). The use of an aviation container with a capacity of 500 liters (Figure 1) for extinguishing fires is proposed. (Velikov, 2022).

At a height of 100 m, the aviation container is disconnected and the fire extinguishing agent is dispersed. 8 containers with a total volume of 4000 l can be loaded onto a Su 25 type aircraft. Until now, the "Bambi Bucket" type bucket has a capacity of 3000 l, and 6 containers with a total volume of 3000 l can be loaded onto a Mi-17 helicopter. Aviation containers for extinguishing fires are launched from aircraft having targeting systems with an electronic computing machine.

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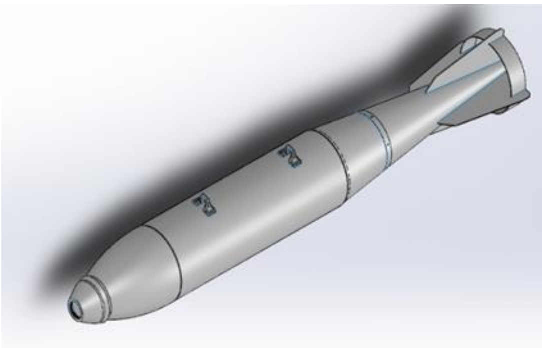

Figure 1. Aviation container type (Velikov, 2022)

Method

With the help of mathematical modelling, the areas of conditions under which aviation containers are launched for fire extinguishing have been determined and the accuracy of reaching the point where the fire-fighting mixture is ejected from the container has been calculated. For this purpose, mathematical models and algorithms have been created: for the movement of the aviation container, for the movement of the aircraft, of the targeting system, of the aiming process, for calculating the accuracy of hitting when using built-in targeting systems and when using suspended targeting containers equipped with a tracking system.

Modelling the Aiming Process of Dropping an Aviation Container for Fire Extinguishing

In many cases, mathematical modelling of complex systems is the only means of studying their effectiveness. This is because it is not possible to analyse and evaluate such systems with laboratory, natural experiments or analytical methods. Modelling makes it possible to study and simulate the functioning of systems in arbitrary conditions. In doing so, numerous variations can be made between system parameters and external conditions to obtain an arbitrary situation. The block principle of mathematical modelling is used to study the aiming process for launching an aviation firefighting container, because it is necessary to model the joint operation of the sight and the aircraft. The studied target system is a dynamic system that is non-linear and non-stationary. In order to make a quantitative assessment of this system, it is necessary to carry out mathematical modelling of the aiming process.

Mode Continuously Computed Impact Point

To solve the task of aiming for the release of an aviation container, it is necessary to bring the aircraft to one of the possible points in which, when the container is released, it falls at the point where the fire-fighting mixture is ejected from it. In modern aviation aiming systems, depending on the flight conditions, the location of the target relative to the aircraft, the type of manoeuvre used for launching, the system for indicating the aiming parameters and the design features of the aircraft, the following mode are used: Continuously Computed Impact Point - CCIP and the Continuously Computed mode Release Point - CCRP (Atanasov, 2014).

When using the CCIP mode, the pilot piloting the aircraft must align the aiming marker with the target and release the container. According to the current flight parameters of the aircraft, the ballistic task is solved, in which the coordinates of the fall of the container are calculated - X_h, Z_h in the HUD coordinate system - $Ox_hy_hz_h$ (Stoĭkov & Atanasov, 2009). The necessary target sighting angles Bh and Eh in the considered coordinate system are determined using the following expressions (Figure 2):

$$B_h = \operatorname{arctg}\frac{Z_h}{X_h}; \qquad E_h = \operatorname{arctg}\left(\frac{H}{X_h}\cos B_h\right). \tag{1}$$

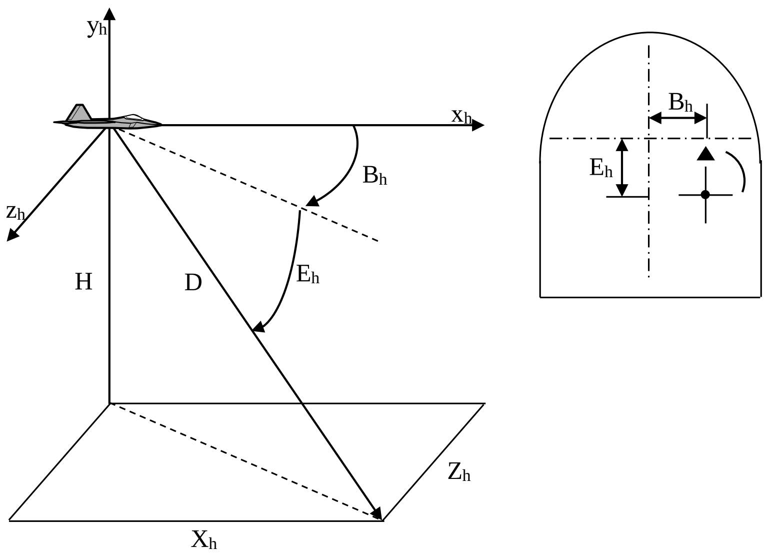

Figure 2. Aiming scheme in CCIP mode

Mode Continuously Computed Release Point

When aligning the reticle with the target, its initial coordinates are calculated. The current coordinates of the target are calculated after integrating the ground speed. Aiming parameters are calculated by the on-board computer. Azimuth aiming is done by automatic or director control of the aircraft, and range aiming is done automatically. When p=x–X=0, the on-board computer sends a signal to automatically launch the aviation container. The accuracy of solving the targeting task depends on the accurate solution of the ballistic task and the accurate calculation of the coordinates of the target relative to the aircraft. The error in determining the current coordinates of the target increases as the path increases, i.e. as the integration time increases.

Mathematical Model of the Targeting Process with the CCIP and CCRP Modes

The block diagram of the aiming process when launching an aviation container using the CCIP and CCRP modes is shown in Figure 3 (Atanasov, 2014). In Figure 3 the following models are shown:

- Aircraft model;
- Ballistic model;
- Mathematical model of a targeting system using the CCIP and CCRP modes.

The structural diagram of the targeting system consists of the blocks for:

- Determination the coordinates of the target x, z;
- Calculation of the X, Z coordinates of the hit of the container;
- Determination of aiming angles E_h and B_h;
- Convertion the target's current coordinates;
- Head-up display (HUD);
- Formation of aiming parameters.

Depending on the input parameters, in the block which determines the current coordinates of the target, the coordinates x, z are determined. In the block for determining the coordinates X and Z, they are functionally connected to: the distance A_0 to the fall point, the time of the fall of the container and the wind speed $\bar{U}$. The block for determining the corners E_h and B_h, converts the X and Z coordinates into angular (E_h and B_h) into a coordinate system of HUD - $Ox_hy_hz_h$. The block for converting the coordinates of the target transforms the coordinates X and Z into angular (βh and εh) into the coordinate system of $Ox_hy_hz_h$. The target parameter indicator shows the angles E_h and B_h. The parameter forming block determines the aiming parameters p and q, depending on the mode used - CCIP and CCRP.

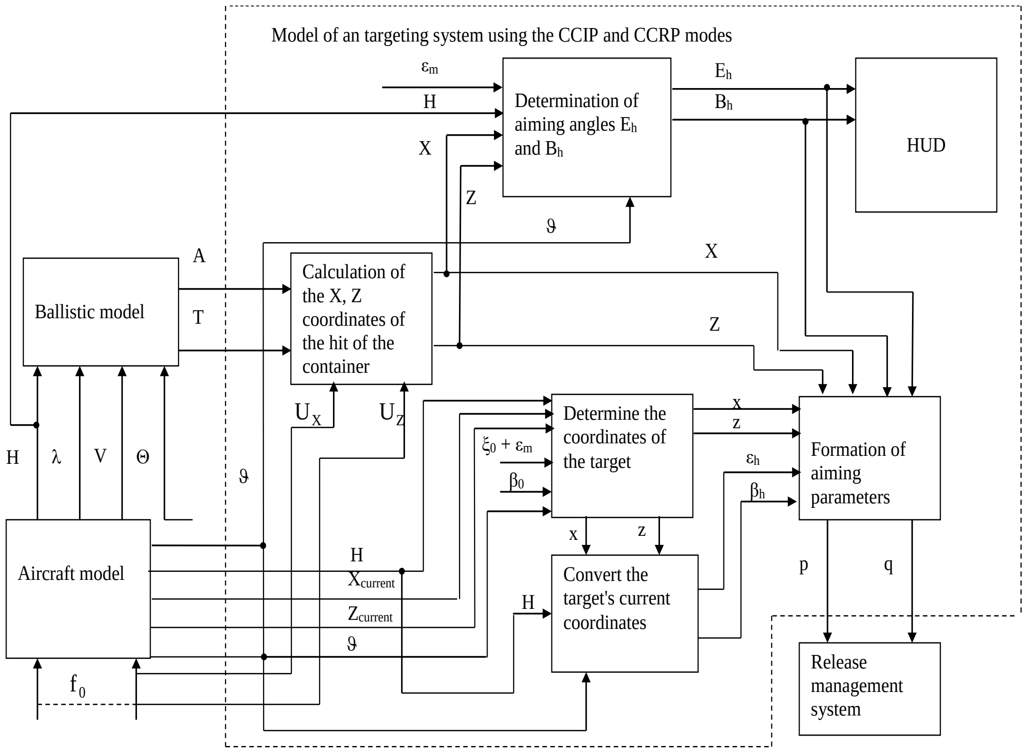

Figure 3. Flowchart of the targeting process when dropping an aviation container using the CCIP and CCRP modes

As a result of solving the targeting task using the CCIP and CCRP modes, the conditions of dropping an aviation container for firefighting are determined $f(t_d)=[V(t_d), H(t_d), E_h(t_d), B_h(t_d), X(t_d), Z(t_d)]$. The algorithm is shown in figure 4 (Atanasov M., 2014).

Mathematical Model for Determining the Accuracy of Dropping an Aviation Container under the CCIP and CCRP Modes

The measured quantity $y^{/}(t)$ is represented as a sum of the true value of the measured quantity y(t) and the error in its measurement ξ_y. The probabilistic characteristics of the error ξ_y of the measured quantity are the mathematical expectation of the error $M[\xi_y]$ and the root mean square deviation $\sigma_{\xi y}$ the error of the measured quantity ξ_y has a random component $\Delta\xi_y$ and a constant component ξ_{yc}:

(2) $$\xi_y = \Delta\xi_y + \xi_{yc}.$$

For the determination of bomb-drop accuracy, it is assumed that the errors of the measured quantities have a normal distribution law. For the measured quantity $y_j(t)$, a random number ξ_{yj} is generated which has a normal distribution law with numerical characteristics $\sigma_{\xi yj}$ and $M[\xi_{yj}]$.

For time t, the measured value $y^{/}_j(t)$ is determined by the equation:

(3) $$y^{/}_j(t) = y_j(t) + \xi_{yj}$$

The current parameters of the flight are determined by the set initial conditions: V, W_x, W_y, W_z, H, ψ, θ, γ, λ, β_{sl}, α. Using a random number generator, normally distributed errors with zero expectation and mean square deviation are generated for each of the measured quantities. By form. (3) the values of each of the measured quantities are determined: $V^{/}$, $W^{/}_x$, $W^{/}_y$, $W^{/}_z$, $H^{/}$, $\psi^{/}$, $\theta^{/}$, $\gamma^{/}$, $\lambda^{/}$, $\beta^{/}_{sl}$.

When using the CCIP mode, the drop parameter is determined by the formula:

(4) $$p^{/}(t)=\varepsilon(t) - E^{/}(t).$$

When the condition $p^{/}(t) \leq 0$ is met, the bomb drop error is determined ΔX:

(5) $$\Delta X=X^{/} - x$$

After N number of realizations, $\sigma_{\Delta x}$ is determined. Provided that the CCRP mode is used, the drop parameter is determined by the formula:

(6) $$p^{/}(t)= x^{/}(t) - X^{/}(t),$$

When the condition $p^{/}(t) \leq 0$ is met, the drop error ΔX is determined.

The algorithm for determining $\sigma_{\Delta x}$ of the hit error when using the CCIP and CCRP modes under specified launch conditions V, H, λ. is shown in Figure 5 (Atanasov, 2014).

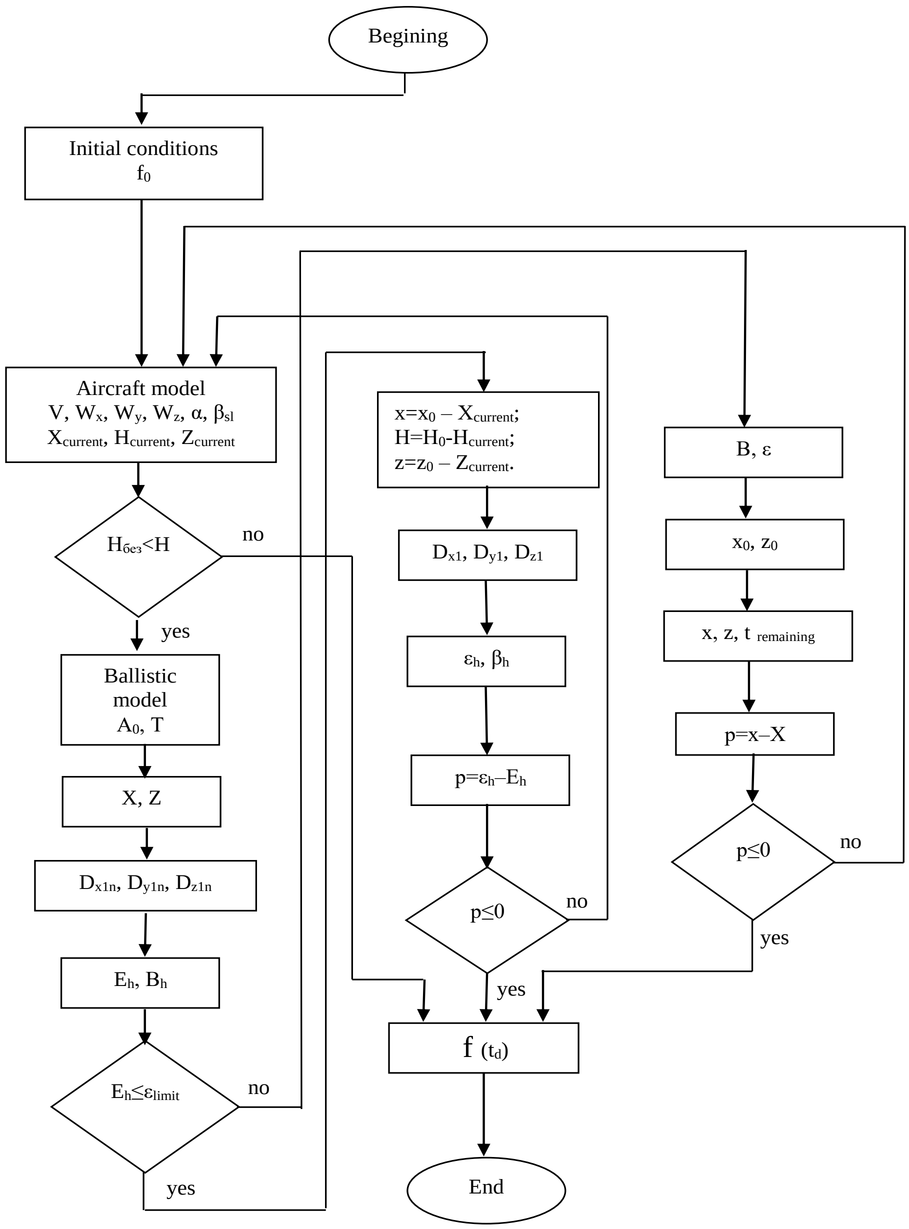

Figure 4. Algorithm of the targeting process when dropping an aviation container using the CCIP and CCRP modes

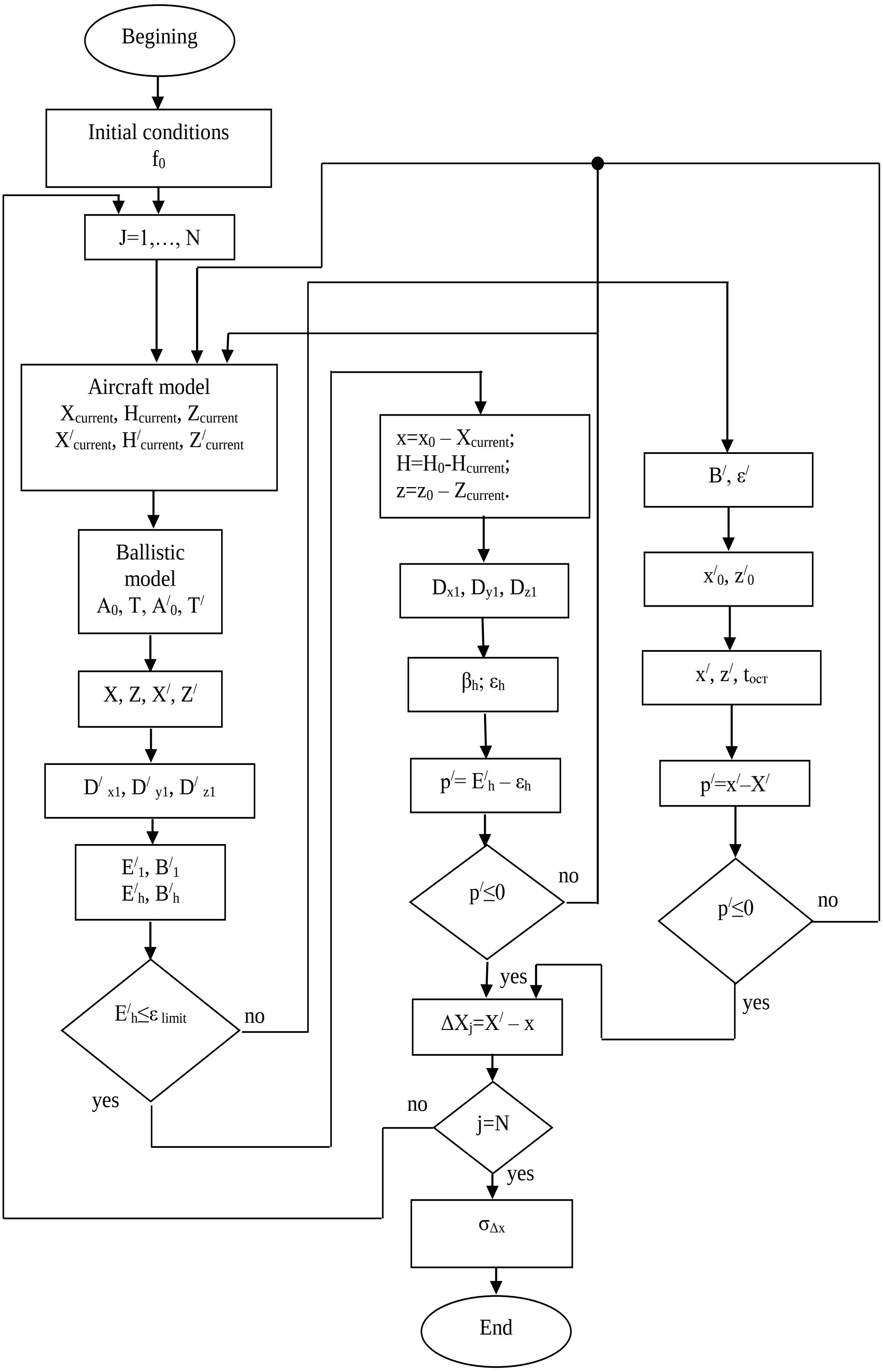

Figure 5. Algorithm for determining $\sigma_{\Delta x}$ using CCIP and CCRP modes

Modern generation 4+, 4++ and 5 aircraft can be fitted with a targeting pod designed to use high-precision weapons against ground targets. Apart from military purposes, these targeting containers can also be used for civilian purposes to accurately deliver various cargoes from the air (Atanasov, 2020; 2022). In Figure 6 an algorithm of the targeting process with a targeting pod is presented (Atanasov, 2014)

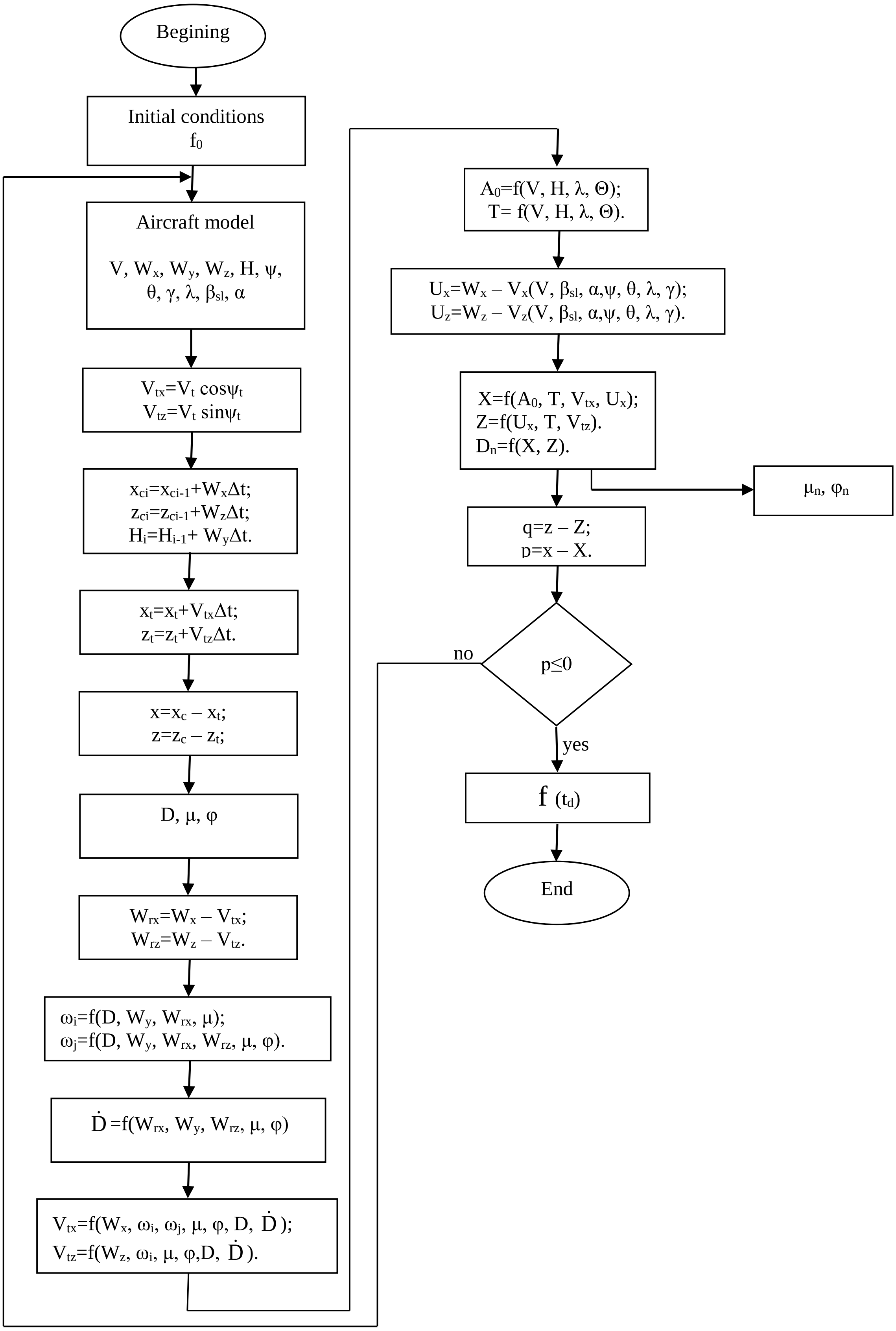

Figure 6. Algorithm of operation of the targeting process with targeting pod

The algorithm for determining $\sigma_{\Delta x}$ when using a targeting container for launching a fire extinguishing container is shown in Figure 7 (Atanasov, 2014).

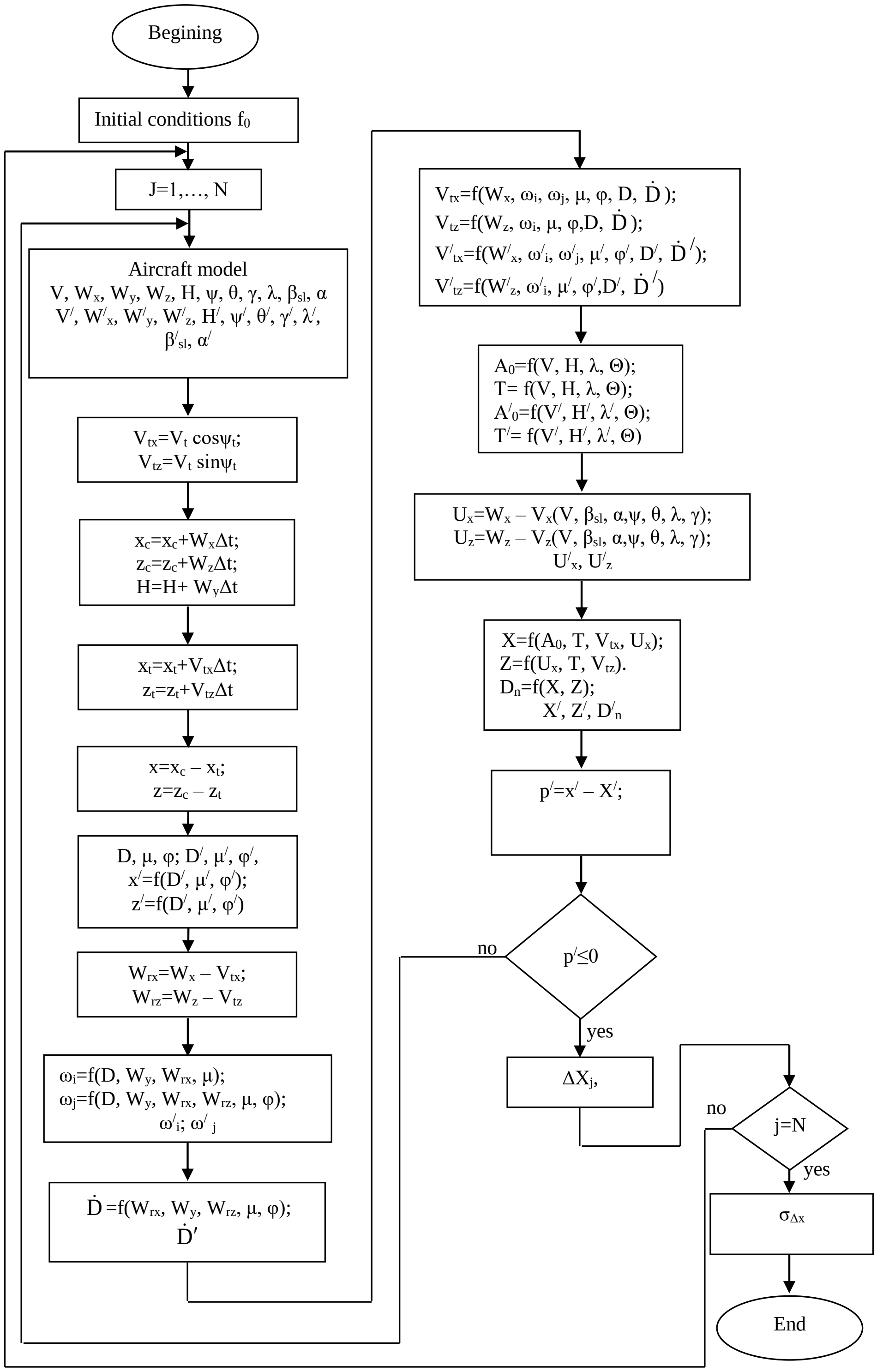

Figure 7. Algorithm for determining $\sigma_{\Delta x}$ using a targeting pod

Results and Discussion

Areas of Use of the CCIP and CCRP Modes When Using a Type Targeting System

The areas of conditions under which an aviation container is launched for firefighting using the CCIP and CCRP modes are defined. The drop is carried out from horizontal flight and diving with an angle of 20^0, from heights H=500 - 2000 m and speeds V=600 - 850 km/h. The research is carried out for launching an aviation container with a volume of 500 l with a characteristic time Ө= 20.38 s using a type targeting system with a limiting aiming angle $\varepsilon_{limit}=|18^0|$.

From Table 1, it can be seen that the range of conditions under which the container is automatically released from horizontal flight using the CCRP mode (angle values are in grey) is greater than that under which the CCIP mode is used (manual drop). The CCIP launch mode is used for the entire range of speeds (V=600 – 850 km/h.) at a height of H=500 m.

Table 1. Aiming angle when dropping an aviation container from horizontal flight

Dropping an aviation container from horizontal flight						
E_d [degr]	V=600 [km/h]	650	700	750	800	850
H=500 [m]	-17.77	-16.57	-15.52	-14.61	-13.80	-13.09
800	-21.94	-20.48	-19.21	-18.00	-17.11	-16.23
1100	-25.22	-23.58	-22.15	-20.89	-19.77	-18.77
1400	-27.96	-26.19	-24.63	-23.26	-22.03	-20.93
1700	-30.32	-28.45	-26.79	-25.33	-24.02	-22.83
2000	-32.39	-30.44	-28.71	-27.16	-25.78	-24.53

Table 2 shows the release angles E_d of the aviation container from a dive angle of 20^0. From the table it can be seen that the range of conditions under which the CCIP method is used is significantly larger than that of the CCRP method. The CCRP method is used at heights H≥1700 m with speeds V≤700 km/h.

Table 2. Aiming angle when dropping an aviation container from a dive

Dropping an aviation container from a 20^0 angle dive						
E_d [degr]	V=600 [km/h]	650	700	750	800	850
H=500 [m]	-9.77	-8.84	-8.05	-7.36	-6.77	-6.26
800	-13.04	-11.87	-10.86	-9.98	-9.21	-8.54
1100	-15.66	-14.34	-13.18	-12.16	-11.27	-10.47
1400	-17.87	-16.43	-15.16	-14.04	-13.05	-12.16
1700	-19.78	-18.25	-16.90	-15.70	-14.63	-13.67
2000	-21.46	-19.86	-18.45	-17.18	-16.05	-15.03

Accuracy of Solving the Aiming Task When Launching an Aviation Container for Firefighting

The accuracy of solving the aiming task when launching a container from a horizontal flight and diving using a type targeting system and a container targeting system for the above conditions was determined. The flight parameters are determined with the errors of the flight information sources specified in table 3 (Atanasov, 2014; Marinov & Ĭordanov, 2019), where V is the airspeed of the aircraft, H is the drop altitude, D is the distance to the point of the fire (hit point), α is the angle of attack, θ is the pitch angle, W aircraft ground speed, γ bank angle, λ pitch angle.

Table 3. Errors of flight information sources

	V, m/s	H, m	D, m	α, degr.	θ, degr.
σ_Δ ±	5	10	6	0,7	0,25
	W_x, m/s	W_y, m/s	W_z, m/s	γ, degr.	λ, degr.
σ_Δ ±	7%(W_x)	1,1	0,1	0,1	1,1

As a result of the mathematical modelling of the aiming process when launching an aviation container for firefighting, the root-mean-square deviation (RMSD) $\sigma_{\Delta x}$ of the container hit error was calculated using a type targeting system and a container targeting system.

It can be seen that when using the CCIP mode, the container hit accuracy is greater than when using the CCRP method. This is explained by the length of the velocity integration time. When the integration time is small, the hit accuracy is similar to that when using the CCIP mode (Table 4, Table 5). From table 4 and Table 5, it can be seen that in a dive, the accuracy of hitting of the air container is greater from a dive than from horizontal flight.

From Tables 4 - 7 it can be seen that when using a type targeting system and a suspended targeting system, provided that 8 containers with a total volume of 4000 litres of fire-fighting mixture can be mounted on the aircraft, will be achieved the desired fire extinguishing efficiency.

Table 4. RMSD of the hit error of the container using a type of targeting system from horizontal flight

$\sigma_{\Delta x}$ [m]	V=600 [km/h]	650	700	750	800	850
H=500 [m]	17.06	17.62	17.96	18.79	21.14	25.04
800	29.16	27.87	27.00	26.08	26.20	26.54
1100	36.11	35.58	35.47	35.18	34.70	34.03
1400	44.97	44.66	44.23	43.88	43.19	42.15
1700	54.52	53.91	53.29	52.64	51.96	51.27
2000	67.22	64.54	63.63	62.49	62.08	61.42

Table 5. RMSD of the hit error of the container using a type of targeting system from 20^0 angle dive

$\sigma_{\Delta x}$ [m]	V=600 [km/h]	650	700	750	800	850
H=500 [m]	10,73	10,78	10,91	11,10	11,34	11,62
800	12,60	13,50	14,33	15,11	15,82	16,49
1100	16,06	17,10	18,10	19,06	19,98	20,87
1400	21,15	21,62	22,22	22,96	23,82	24,80
1700	27,75	27,01	26,70	26,81	27,33	28,26
2000	35,70	33,24	31,54	30,61	30,89	31,21

When dropping an aviation container from horizontal flight and diving using a suspended targeting system, the hit accuracy achieved is greater than when using the CCRP mode with a type targeting system (Tables 4 – 7). This enables accurate dropping of aviation containers from heights above 1500 m. In this way, the accurate and safe use of aircraft in firefighting is ensured.

Table 6. RMSD of the hit error of the container using targeting pod from horizontal flight

$\sigma_{\Delta x}$ [m]	V=600 [km/h]	650	700	750	800	850
H=500 [m]	16.00	18.66	20.41	21.66	22.77	24.13
800	20.37	22.27	2442	26.02	28.02	29.25
1100	24.56	27.33	29.88	32.37	34.97	37.69
1400	28.52	31.34	34.12	36.96	39.94	43.10
1700	31.07	35.26	38.56	41.50	44.65	48.27
2000	27.39	39.36	44.32	45.92	47.77	51.86

Table 7. RMSD of the hit error of the container using targeting pod from 20^0 angle dive

$\sigma_{\Delta x}$ [m]	V=600 [km/h]	650	700	750	800	850
H=500 [m]	14.57	14.73	15.46	16.40	17.18	17.66
800	15.87	17.96	19.14	19.88	20.65	21.69
1100	18.75	20.98	22.43	23.51	24.62	25.96
1400	22.82	24.10	25.49	26.96	28.49	30.08
1700	25.28	27.27	28.88	30.40	32.11	34.13
2000	21.84	30.13	33.45	34.41	35.63	38.46

Conclusion

The following conclusions can be drawn from the research:

- Using containers for extinguishing fires is an alternative to existing means. They are suitable for limiting the spread of fire. They are suitable for use in initial outbreaks. For this purpose, it is necessary to build a national early warning system for the occurrence of fires (Marinov, 2023). This would save considerable effort and money in fighting fires.
- The advantage is that depending on the type of fire, different fire-fighting mixtures can be used to increase efficiency.
- Aviation containers can be placed on different aircraft, making them universal. In this way, more than one aircraft can be used to increase extinguishing efficiency.
- The targeting system of the aircraft allows the precise use of the aviation containers, which increases the extinguishing efficiency.

Recommendations

The research shows that when dropping an aviation fire-fighting container from an aircraft with a type targeting system from altitudes above 1000 m, it would be more effective to drop them from a dive. The use of aircraft with a targeting pod to drop an aviation container from medium altitudes from level flight will increase the accuracy and effectiveness of extinguishing incipient fires.

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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References

Atanasov, M. (2020). Mathematical model and algorithm of operation of a system for release of load from airplane. *Aerospace Research in Bulgaria, 32,* 64-74.

Atanasov, M. (2022). Mathematical model for operation of aviation systems for delivery of special means to air and earth objects*. Aerospace Research in Bulgaria*, *34.* 138-148.

Atanasov, M. (2014). *Tochnost na reshavane na zadachata na pritselvane s neupravlyaemi aviatsionni bombi*. Monografiya, Pleven.

Johnson, R. (2011, September 7). The federal government grounded half its firefighting planes just weeks before the Texas wildfires. Retrieved from https://www.businessinsider.com

Marinov, A. (2023). Hohmann orbit transfer analysis aeronautical research and development. *Bulgarian Air Force Academy*, *2,* 46-51.

Marinov A., & Iordanov, G. (2019). Senzori za otchitane na parametrite na poleta, *Godishna Mezhdunarodna Nauchna Konferentsiya Na Fakultet*, 69-76.

Stoĭkov, O., & Atanasov, M. (2009). Aviatsionni pritselni sistemi – Pŭrva chast. *Disertatsiya Dolna Mitropoliya*

Velikov R., (2022), Izsledvane na efektivnostta na aviatsionnite sredstva za gasene na pozhari. *Disertatsiya, Dolna Mitropoliya.*

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