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Conceptual Design of a Reusable Submunition Dispenser for Unmanned Aerial Vehicles

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Abstract. The paper describes a concept for developing a dedicated combat asset for performing effective fragmentation attack on surface targets and having dimensions and weight suited to being carried by an unmanned aerial vehicle (UAV) with a maximum payload of 150 kg. The designed combat asset, i.e. cluster bomblets ejected from a reusable submunition dispenser, will be intended for destroying enemy personnel, unarmoured ground targets, lightly armoured equipment, ground support equipment, and aircraft and field ammunition depots. The introduction of the paper analyzed the existing submunition dispenser and cluster bomblet solutions. The key aspects of the paper include the calculation of the effective blast radius of the designed cluster bomblet and the analysis of the trajectory of a bomb dropped from horizontal flight. A bombing analysis was carried out, taking into account the influence of the atmosphere and drop control conditions on bombing accuracy and proper fragment coverage of the bombed area.

A preliminary concept of the airdrop control system was developed, which could enable effective bombing with a series of cluster bomblets. As part of the work, element models and CAD assembly models of the dispenser and cluster bomblet structures were fabricated.
Keywords: unmanned aerial vehicle, submunition dispenser, cluster bomblet, bombing ballistics, effective blast radius

1. INTRODUCTION

With the emergence of combat unmanned aerial vehicles (UAVs) that carry weaponry, there has been a need to design specific instruments of war and weapon stations that enable them to be suspended and dropped in a controlled manner at the appropriate variant, location and time. The use of single aerial bombs suspended from a UAV significantly reduces the ability to combat surface targets, necessitating the use of multiple aircraft for a single mission. Hence, efforts have been made to develop a dedicated combat asset for performing an effective fragmentation attack on surface targets and having dimensions and weight suited to being carried by a UAV with a maximum payload of 150 kg. An example of such a UAV is the Skorpion, a UAV designed at the Institute of Aviation Technology of the Faculty of Mechatronics, Armament and Aviation of the Military University of Technology in Warsaw, Poland. Cluster bomblets ejected from submunition dispensers are designed for destroying enemy personnel, unarmoured ground targets, lightly armoured equipment, ground support equipment, and aircraft and field ammunition depots.

In developing the concept of a new combat asset, the authors decided to analyze existing solutions in this field.

Polish bombing weaponry designs in recent years have included the ZK-300 aerial cluster bomb. When dropped, the bomb releases 315 LBOk-1 fragmentation bomblets with a total weight of 252 kg, whose blast area forms a 200 × 1500 m rectangle [1, 2]. It is dropped from a Su-22 aircraft from level or ascending flight at speeds up to 900 km/h. The program of dispersing cluster bomblets along the flight trajectory is carried out with the use of the Ucz-1B timing device, which generates electric impulses that activate pyropistols that serve first to deflect the front parts of the fairings and to drive them away from the body of the bomb. Then, submunition is ejected from the packets in a sequence that ensures that the center of mass of the entire bomb moves forward, increasing its flight stability. After the drop, the bomb body follows a ballistic trajectory until it hits the ground. Another such design solution is the 250 kg LBKas-250, a Polish aerial cluster bomb loaded with 120 LBOk-1 fragmentation bombs with a total weight of 96 kg.

The Polish Air Force also uses the ZR-8 tube bomb dispenser used to drop LBOk-1 bomblets from Su-22 aircraft and W-3W and W-3PL helicopters. In the ZR-8 dispenser (which remains suspended on the aircraft during use), the bombs are placed in PLBOk-1-15 packets forming a tubular container holding 15 LBOk-1 bombs together with a WPR-1-15 ejector.

The bombs leave the packet when the ejector is triggered, which causes the piston to move with the bombs as a result of the produced gunpowder gases. The ejection time for a set of 15 bombs is 1–3 seconds [3]. After the bombs are ejected, the empty packets remain in the dispenser. The Polish designs presented above use domestically produced small-size LBOk-1 bombs, in which steel balls embedded in the aluminium body of the bomb, propelled by explosive material, are the main striking agent. The bomb's yield is approximately 50% higher than that of infantry hand grenades.

An American example of a cluster bomb dispenser design is the CBU-2/A (Cluster Bomb Unit), which consists of two components: the SUU-7A/A aircraft dispenser and the BLU-3/B submunition. The dispenser has a thin sheet metal body containing 19 aluminium tubes, 17 of which are loaded with BLU-3/B bombs (it holds up to 360 in total). When the bomb is ejected from the dispenser, the air pressure releases the clamp securing the vanes, which are spread out by springs to stabilize the bomb's flight during its free fall. Contact with the target detonates a demolition load that ruptures the bomb body and hurls steel balls [4]. This type of cluster bomb was widely used by the United States Air Force during the Vietnam War.

It has often been called the 'pineapple bomblet' because of its distinctive appearance with the outstretched vanes. A single bomb weighs 785 grams and contains 165 grams of RDX explosive.

A different design in terms of the ability to carry submunition is the AGM-154A JSOW glide dispenser, which is fitted to F-16 aircraft, for example. It features a seeker head that uses two navigation systems: an inertial navigation system (INS) and a satellite GPS [5]. With its modular design, it is possible to use different variants of warheads while maintaining the same external dimensions of the dispenser. The AGM-154A is a standard JSOW variant that carries 145 BLU-97A/B bomblets weighing 1.54 kg each in its warhead. The submunition is designed to attack infantry and artillery groupings, armoured and unarmoured vehicles, and ground targets, especially ammunition and fuel depots. The bomb used a combination warhead: a cumulative warhead against armoured targets, a shielded fragmentation warhead to destroy unarmoured targets, and an additional incendiary zirconium ring.

An example of Soviet military technology in the field of bomb dispensers is the KMGU-2, also used in the Polish military aviation on MiG-29 aircraft. The dispenser has a cylindrical body with front and rear streamlining, eight lids opened by a pneumatic-electric mechanism and a pyrotechnic submunition ejection system.

The central part of the body contains a chamber housing the fixing points for bomblets packets. Bombs are fixed in special sockets in so-called BKF blocks [6]. The dispenser remains on the aircraft's fuselage during use and allows bombs to be dropped from an altitude of 50÷1500 m at a carrier speed of 700÷1200 km/h. It holds a simultaneous load of eight packets, each of which can be filled with one of three types of submunitions: 12 × PTAB – 2.5 bombs, 12 × AO – 2.5RT bombs, or 250 × PTAB – 1M bombs.

None of the submunition dispenser analyzed meet the UAV requirements due to excessive dead weight, geometric dimensions and specialized carrier-specific adjustment. The concept of a reusable submunition dispenser presented in this paper fills a gap in the development of a combat asset suitable for delivery by unmanned aerial vehicles. The use of a cluster bomblet dispenser in UAVs is a novel idea – the authors have not yet encountered the use of such a combat asset in this type of aircraft. However, based on the analysis of existing dispenser and cluster bomblet designs, a decision was made to use some of the solutions (e.g. LBOk-1) and propose a concept for the design and mechanisms of a cluster bomblet and an entire dispenser.

2. CLUSTER BOMB CONCEPT

The concept of the newly-designed submunition is based on the design of a cluster bomblet with 6.5 mm steel balls embedded in the body of the bomb as the main offensive element. Bombs will be placed in packets forming one integrated load, with seven bombs per packet. The designed bomblet will consist of four basic elements: bomb body with ball fragments and blasting material (a – Fig. 1), stabilizing and braking device (b – Fig. 1), blasting cap safety mechanism (c – Fig. 1), firing pin holder with spring (d – Fig. 1).

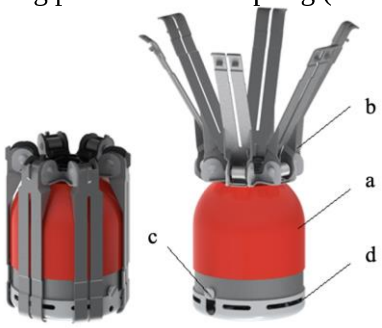

Fig. 1. View of the bomb with the folded and unfolded stabilizing vanes and the basic elements of the bomb marked: a – bomb body with fragmentation balls and blasting material; b – stabilizing and braking device; c – blasting cap safety mechanism; d – firing pin holder with spring

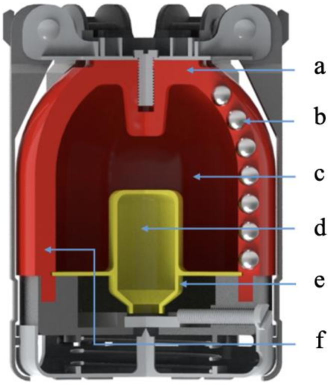

Fig. 2. Cross-section of bomb body with description of construction elements: a – bomb body; b – steel ball; c – blasting material; d – detonating charge; e – cardboard insert; f – filling material

The internal structure concept is shown in the cross section of the developed CAD model of the designed bomb (Fig. 2).

The blasting cap safety mechanism is designed to prevent premature firing pin impact during transportation and bomb storage. The structure of the mechanism is shown in Figure 3, together with its basic components: annular opening (interacting with the bomb body mounting projection) (a – Fig. 3); threaded safety hole (b – Fig. 3); screw (c – Fig. 3); safety insert (d – Fig. 3); blasting cap safety mechanism body (e – Fig. 3); threaded safety hole (f – Fig. 3). The safety device moves the adjustable insert placed in the body by screwing a screw into the appropriate (right or left) threaded hole.

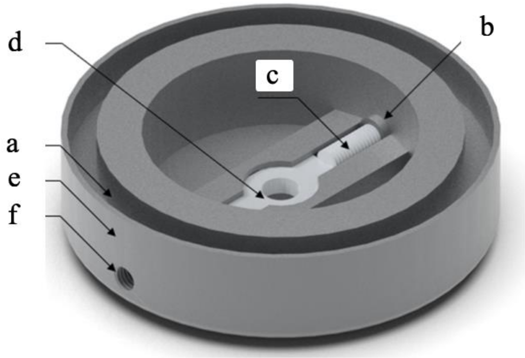

Fig. 3. Structure of the blasting cap safety mechanism: a – annular opening ; b – threaded safety hole; c – screw; d – safety insert; e – blasting cap safety mechanism body; f – threaded safety hole

The next step was to select the bomb's blasting material. For this purpose, blasting explosives used in the submunition of cluster bombs were analyzed. It was observed that in low-weight fragmentation bomblets (e.g. BLU-3/B; BLU-26/B; BLU-24/B; BLU-36/B; BLU-49/B; BLU-66/B; BLU-97/B), the most commonly used blasting materials are those of the CYCLOTOLI family, i.e. mixtures of hexogen (RDX) with TNT. Various CYCOLTOL compositions used for this purpose contain from 50 to 80% RDX.

Based on lists of maximum detonation pressures (Table 1) of various CYCLOTOL compositions, a decision was made to use 140 g of CYCLOTOL-78/22 explosive, which is a mixture of 78% RDX and 22% TNT. The detonation parameters and the heat of explosion of the selected mixture were determined in the study. Next, the weight of TNT producing a blast wave with the same characteristics as 140 g of CYCLOTOL-78/22 was determined using the TNT equivalence relationship.

Table 1. Summary of maximum detonation pressure values determined experimentally and analytically [7]

Explosive[a]	ρ (g mL^{-1})	P(kbar)$_{exp}$	P(kbar)$_{K\text{-}P}$	P(kbar)$_{Eq.(2)}$	%Dev
Composition B	1.713	294[1]	287	344	16.9
EDC-24	1.776	342[1]	331	361	5.5
95/5 NQ/Estane	1.705	268[1]	225	303	12.9
COM B	1.72	295[16]	288	255	-13.7
COM B-3	1.72	287[16]	287	254	-11.5
CYCLOTOL-78/22	1.76	317[16]	316	265	-16.4
CYCLOTOL-77/23	1.743	313[1]	309	345	10.3
CYCLOTOL-75/25	1.76	316[16]	314	263	-16.6
CYCLOTOL-65/35	1.72	292[16]	291	257	-11.9
CYCLOTOL-50/50	1.63	231[16]	248	248	7.5
PBX-9007	1.64		264	255	
PBX-9205	1.67		280	260	

To calculate the effective blast radius, a method based on the proposal of the air drag law for spherical debris [8] was used, based on a constant value of aerodynamic drag force coefficient C_x. To determine the blast radius, the minimum surface effective energy density of a spherical fragment was assumed to be E_{jksk} = 150 J/cm^2, corresponding to the impact on a standard uniformed soldier. The calculations also needed to assume that each bomb would be a source of fragments in the form of 250 × 6.5 mm balls made of steel with a density of 7850 kg/m^3. As a result of the calculations, an effective distance of 98.8 m for a fragmentation attack by a single bomblet was obtained. Table 2 shows the basic tactical and technical data of the designed cluster bomblet.

Table 2. Tactical and technical data of the designed cluster bomblet

Basic dimensions	
Body diameter	70 mm
Diameter with folded vanes	77 mm
Body length with fuse	85.5 mm
Length with folded vanes	101 mm
Length with unfolded vanes	179 mm
Diameter of unfolded vanes	138 mm
Bomb weight	0.8 kg
Tactical data	
Explosive weight	0.14 kg
Explosive	CYCLOTOL-78/22
Projectiles	6.5 mm steel ball
Fragmentation ball weight	1.12 g
Detonating charge weight	0.01 kg
Number of fragmentation balls	250

3. ANALYSIS OF THE TRAJECTORY OF A BOMB DROPPED DURING HORIZONTAL FLIGHT IN VACUUM AND IN SILENCE

The primary tasks of the ballistics of bombing include describing the motion of the bomb's center of gravity. This is accomplished by determining the trajectory of the bomb's center of gravity or the main bomb trajectory elements (BTEs) that characterize it, i.e., time of fall – T, range – A, initial velocity – V_b, terminal velocity – V_k, and angle of fall – β_k.

The theory of the motion of the center of gravity of a bomb dropped from an aircraft without regard to the force of air resistance is called the theory of parabolic bomb motion. The simplest 3-degree model treating the bomb as a material point moving in the atmosphere under the influence of gravity and aerodynamic resistance was used for the calculations. This model assumes perfect stabilization of the bomb along the trajectory (the bomb axis always coincides with the bomb velocity vector). Despite the fact that studying bomb motion in a vacuum has only theoretical significance (in reality, the bomb encounters resistance related to the medium, e.g. air resistance), the principles of the parabolic theory of bomb motion are used during the execution of a bombing from a low-level flight and during the analysis of the BTEs during the change of drop parameters. The bomb trajectories presented in Figure 4 were determined analytically using the bomb trajectory equation for assumed bombing velocities of unmanned aerial vehicles of 150–800 km/h and bombing altitudes of 800 m.

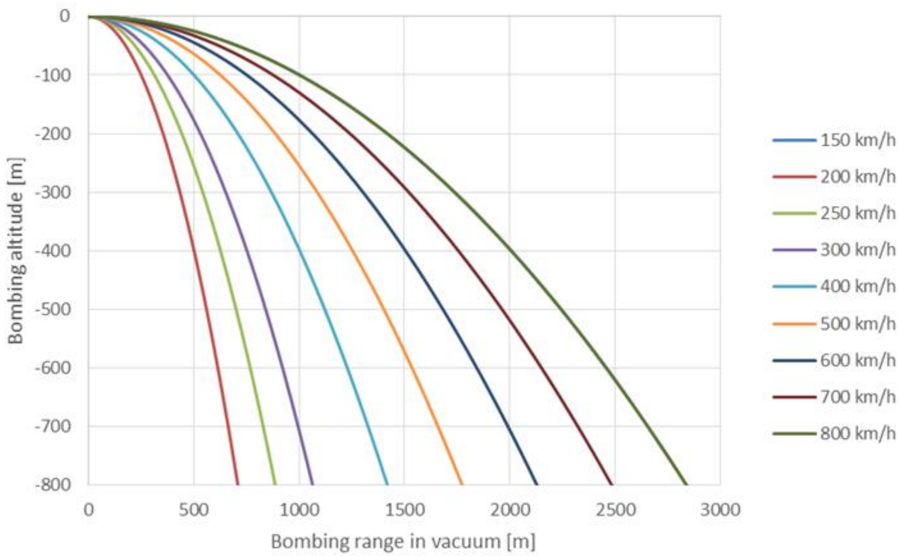

Fig. 4. Trajectories of the bomb dropped in vacuum during horizontal flight for a range of bombing velocities (150–800 km/h) at a bombing altitude of 800 m

Bombing in silence is obtained by taking into account the frontal drag force and employing the parameters of the reference atmosphere for the calculations (without considering the impact of steady wind). The trajectory of a bomb through the air when the frontal drag force is taken into account is called a ballistic curve and is steeper than the parabolic curve. Because of the similarity in terms of weight and aerodynamics of the designed submunition and the LBOk-1 bomb, ballistic tables [9] for horizontal flight bombing with bombs of this type were used to determine the basic BTEs. The dashed line in Figure 5 shows the trajectory of a bomb dropped during a horizontal flight in silence, taking into account the effect of air resistance force R, while the solid line indicates the trajectory of a bomb dropped in vacuum. When air resistance is present, a decrease in range A_0 and the angle of sighting φ_0 is observed, whereas the lead angle increases ψ_0. This is achieved through a decrease in the horizontal component of velocity V_x under the influence of the horizontal component of air resistance R_x. The bomb is pushed off the parabolic trajectory and falls down the steeper trajectory without reaching the sighting point P_c. Owing to the braking and stabilizing system used, it falls at a greater angle β_k, i.e. perpendicularly to the ground plane at the end point P_k. Under the influence of the vertical component of the air resistance force R_y, the vertical component of the velocity V_y decreases, which results in an increase in the bomb drop time T and the aircraft path S_s.

The air resistance force *R* causes a difference in bomb position from that of the aircraft, resulting in a backward shift of the bomb drop point P_k by the value of the line inclination *Δ* (Fig. 5).

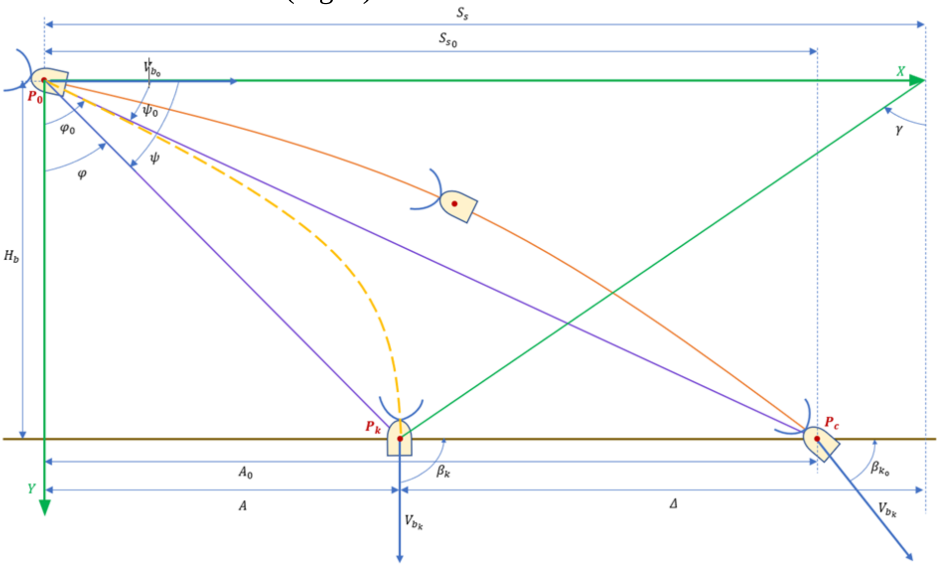

Fig. 5. Change in BTE during horizontal-flight bombing in silence under air resistance *R* based on [9]

For the cluster bomblet concept under consideration, calculations were made for the aiming data required for horizontal-flight bombing. Meanwhile, Table 3 presents sample results of these calculations presented as the sighting angles, lead angles and line inclinations for a bombing altitude of 100÷250 m and a bombing speed of 150÷300 km/h.

Table 3. Summary of sighting angles, lead angles and line inclinations for a bombing altitude of 100÷250 m and a bombing speed of 150÷300 km/h.

Altitude H_b	*Bombing speed* v_b [km/h]														
	150			180			200			250			300		
	φ	ψ	γ	φ	ψ	γ	φ	ψ	γ	φ	ψ	γ	φ	ψ	γ
100	38°40′	51°20′	61°45′	43°40′	46°20′	64°27′	46°40′	43°20′	68°13′	52°27′	3733′	72°43′	57°01′	32°59′	75°32′
150	29°33′	60°27′	60°02′	34°13′	55°47′	64°25′	36°45′	53°15′	65°10′	42°25′	4735′	71°42′	47°02′	42°58′	74°10′
200	23°16′	66°44′	59°28′	27°01′	62°59′	63°54′	29°15′	60°45′	66°15′	34°37′	5523′	70°54′	39°01′	50°59′	74°
250	18°59′	71°01′	59°22′	22°01′	67°59′	63°49′	24°08′	65°52′	66°09′	27°27′	6233′	70°46′	32°57′	57°03′	74°10′

To correctly determine the basic elements of the bomb trajectory for horizontal-flight bombing, we must also consider the effect of steady wind. Depending on the wind angle, there are two basic types of downwind bombing: upwind and crosswind. However, due to the length limitations of this article, the results of these calculations will not be presented.

4. DESIGN CONCEPT OF A REUSABLE SUBMUNITION DISPENSER

The designed submunition dispenser is a tubular container intended for carrying and releasing cluster bomblets in the direction opposite to the carrier's flight. The dispenser remains on the carrier after the bombs are ejected from the packet. The bombs are ejected from the packet using a pyrotechnic ejector mechanism. The designed dispenser consists of six basic elements: the body of the dispenser (a – Fig. 6), eighteen tubes to accommodate the bomb packets (b – Fig. 6), the pyrotechnic ejector mechanism (c – Fig. 6), the electrical connector and firing control system (d – Fig. 6), the front fairing (e – Fig. 6), the suspension lug (f – Fig. 6).

The packet launch control system is designed for the controlled release of bombs from the eighteen packets (each packet contains seven bomblets) in the following variants: individually (a series of single packets), in a series of two packets, in a series of six packets, as a whole (a series of eighteen packets). The time intervals t_p between the launches of the packets in a series will be determined by a programmer included in the packet launch control system and will be as follows: 0.2; 0.5; 1.0; 1.5; 2; 2.5 s.

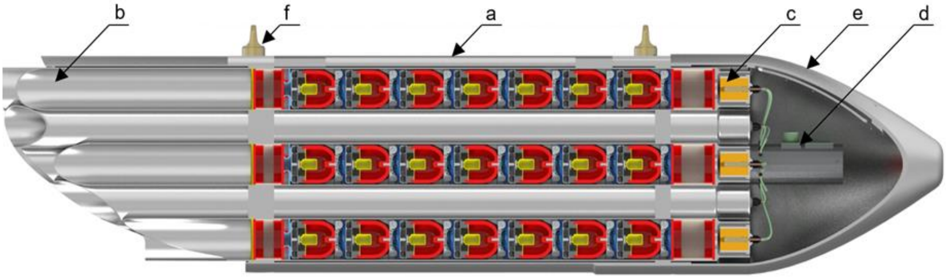

Fig. 6. Cross-section of a reusable submunition dispenser – basic structural elements: a – body of the dispenser; b – eighteen tubes to accommodate the bomb packets; c – pyrotechnic ejector mechanism; d – electrical connector and firing control system; e – front fairing; f – suspension lug

The ejection time T_w for releasing seven bombs from the packet is 1 to 2 seconds. The time intervals and the ejection time for the bomb packets are illustrative and have been assumed on the basis of an analysis of existing solutions [4]. A CAD model of the submunition dispenser in isometric view is shown in Figure 7.

Fig. 7. CAD model of the reusable submunition dispenser in isometric view

The locations of the bomb-releasing components are shown in Figure 8. The bombs are ejected from the packet using a pyrotechnic ejector mechanism. When the pyrotechnic charge is triggered, the gunpowder gases produce a region of high pressure that acts on the front plane of the gas piston. This results in the displacement of the gas piston along with the bombs, which by pressing on the protective rubber membrane cause it to break through and open the packet of cluster bomblets. Due to the continuous supply of gunpowder gases, all of the bomblets in the tube are displaced and subsequently released in the direction opposite to the carrier's flight.

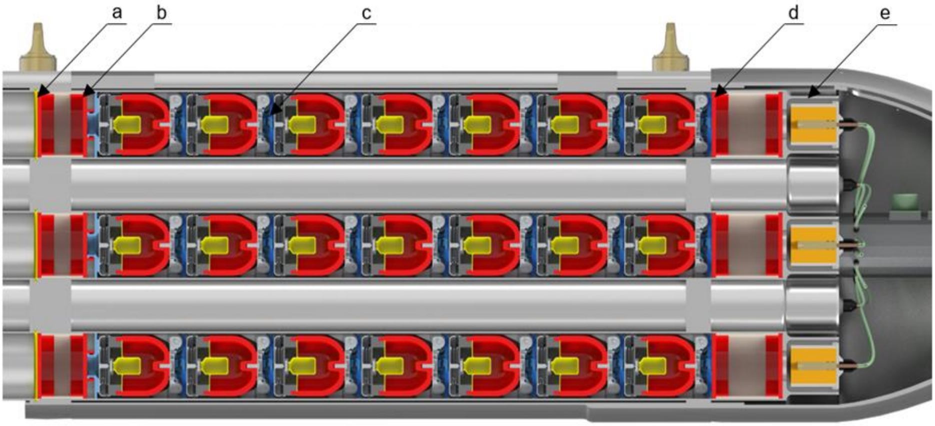

Fig. 8. Location of components responsible for ejecting bombs from the packet:
a – protective rubber membrane; b – discharge piston; c – plastic spacer;
d – gas piston; e – pyrotechnic ejector assembly

The body of the dispenser is equipped with two suspension lugs enabling its attachment to the lifting hooks of the MAU-12 ejector rack. The designed dispenser is planned to be mounted on a sub-fuselage suspension using a Centerline Pylon beam with the MAU-12 ejector rack used on the F-16 aircraft. Basic dispenser information is shown in Table 4.

Table 4. Basic dispenser information

Length	1830 mm
Diameter	407 mm
Number of bombs held	126
Empty dispenser weight	approximately 45 kg
Weight of dispenser with 18 packets	approximately 150 kg

5. CONTROL SYSTEM CONCEPT FOR A SUBMUNITION DISPENSER

Series bombing is a type of bombing that involves dropping bombs in a single raid at predetermined intervals t_b. Timing intervals can be adjusted manually, by pressing the combat button for a specified period of time, or automatically, by using an appropriately programmed discharge control system. The diagram shown (Fig. 9) contains the basic elements of the bomb trajectory during bombing with a series of seven bomblets, where: L_s – horizontal spread of bombing series, l_b – distance between bombs in a series, t_b – time interval between bombs in a series.

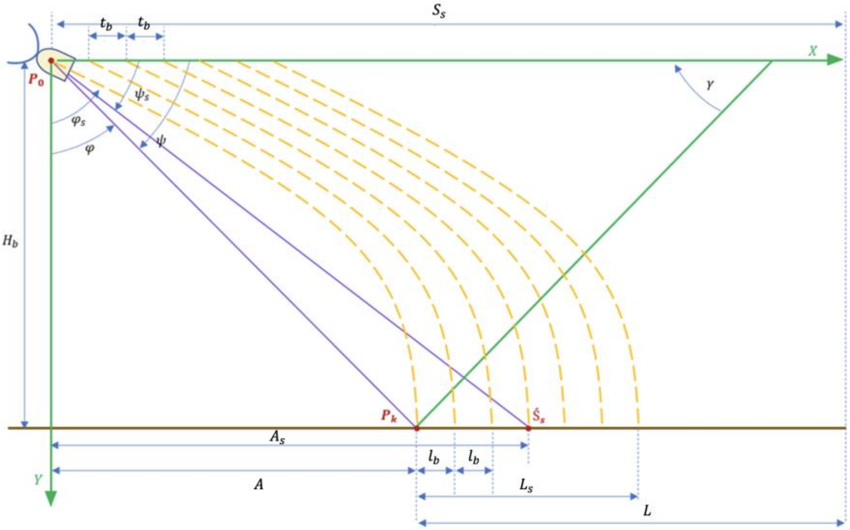

Fig. 9. Trajectory of one bomb packet dropped during bombing

The linear distance between bombs in a series is determined from the relationship between the bomb speed V_b and the time interval between bombs:

$$l_b = V_b * t_b, \quad (1)$$

where: V_b – bombing speed,

t_b – time interval between bombs in a series.

The horizontal spread of bombing series is calculated using the following formula:

$$L_s = V_b * t_b * (n - 1), \quad (2)$$

where: n – number of bombs in a series.

From the series bombing diagram (Fig. 9) it can be seen that in order to perform correct bombing with a packet of cluster bomblets, the center of the bombing series $\acute{S}_s$ must overlap with the centre of the target. This means that the sighting point must be elevated ahead of the center of the target by a value equal to half the length of the horizontal spread of the bombing series. The series center range A_s will therefore be greater than the bomb range A, and, consequently, the series sighting angle φ_s will be greater than the sighting angle φ for ordinary horizontal-flight bombing. It is also necessary to determine the lead angle for the series ψ_s (the angle between the sighting line for the series and the horizontal drop plane). Where the series lead angle ψ_s is greater than the maximum lead angle that can be set on the sight, the bombing follows the so-called hold time t_w, calculated with an appropriate formula. Due to the use of a stabilisation and braking device, the trajectory of the bomb is mainly affected by the speed of the aircraft and the wind speed and direction, while the speed of ejection from the packet can be ignored. When bombing with cluster bomblets, the bomb spread has the greatest effect on the accuracy of the drop.

In order to determine the recommended drop variants and sighting parameters, a decision has been made to propose the values of the basic operational data for the proposed carrier – UAV (bombing speed 150–800 km/h, bombing altitude 100–250 m, maximum sighting angle 15 degrees) and for the designed submunition dispenser (time interval between the launches of the bomblet packets t_p = 0.2; 0.5; 1.0; 1.5; 2; 2.5 s; number of packets in the dispenser p = 18; average bomb release time 1.5 s). The design specifies a scheme for calculating sighting parameters for horizontal flight bombing. The range A and bomb drop time are then read from the ballistic tables T. Then the horizontal spread L_s and the series center range A_s are calculated, and the lead angle ψ_s and sighting angle φ_s are determined for the series. This diagram was used as a basis for the calculations necessary to carry out accurate bombing using the designed submunition dispenser. An important parameter necessary to take into account in the process of preparing the targeting for the performance of a specific combat task is the fragmentation blast radius.

Assuming an ideal bomb spread (equal spacing between individual bombs), we can observe that as the number of packets fired increases, the spacing between the bombs decreases. As a result of the analysis, it was concluded that the most favorable variant of using the dispenser is when the distances between bombs are about half of the effective blast radius of a single bomb.

6. CONCLUSIONS

The article describes elements of the conceptual design for a cluster bomb unit for unmanned aerial vehicles. The project was motivated by needs identified by the authors related to the development of new types of combat assets adapted for use by UAVs. Using the information on cluster munitions used in the aviation of the Polish Armed Forces and the Air Forces of other countries, an analysis was carried out to examine the details of the design solutions used. Taking into account the characteristics of the proposed carrier, and the concept adopted, a structural design was developed and a CAD assembly model of the dispenser and cluster bomblet was fabricated. All components of the bomb dispenser were also modelled. An important part of the work was to perform the calculations necessary to determine the effective blast radius of the designed bomblet and to present calculations of the ballistics of horizontal-flight bombing using the designed dispenser. The project discussed problems associated with bombing using cluster bomblets resulting from the influence of the atmosphere and drop control conditions on bombing accuracy and proper fragment coverage of the bombed area. On the basis of the obtained results, a preliminary concept of the airdrop control system was developed, which would enable effective bombing with a series of cluster bomblets.

With the extensive calculations performed in this work, concerning the cluster bomblets, the bombing conditions, and the developed dispenser model with all of its components, this work represents a comprehensive and well-documented submunition dispenser concept. However, it should be noted that practical implementation of the dispenser will require some additional research and calculation relating to aerodynamics, balancing, structural strength and implementation of the drop control system.

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Projekt koncepcyjny zasobnika bomb małego wagomiaru dla bezzałogowego statku powietrznego

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Streszczenie. Praca zawiera koncepcję opracowania dedykowanego środka bojowego do efektywnego rażenia odłamkami celi powierzchniowych, posiadającego wymiary i masę dostosowaną do przenoszenia przez BSP o maksymalnym udźwigu 150 kg. Projektowany środek bojowy w postaci bomb małego wagomiaru wyrzucanych z zasobnika bombardierskiego będzie przeznaczony do rażenia: siły żywej przeciwnika, nieopancerzonych celów naziemnych, sprzętu lekko opancerzonego, sprzętu naziemnej obsługi i statków powietrznych oraz polowych składów amunicji. We wstępnej części pracy, dokonano analizy istniejących rozwiązań w zakresie zasobników oraz bomb małego wagomiaru. Kluczowym elementem pracy są obliczenia skutecznego promienia rażenia odłamkami projektowanej bomby oraz analiza toru ruchu bomby zrzuconej z lotu poziomego. Dokonano analizy bombardowania z uwzględnieniem wpływu atmosfery oraz warunków sterowania zrzutem na celność bombardowania i właściwe pokrycie odłamkami bombardowanego obszaru. Opracowano wstępną koncepcję systemu sterowania zrzutem umożliwiającą wykonanie skutecznego bombardowania serią bomb małego wagomiaru. W ramach pracy wykonano modele elementów oraz modele złożeniowe CAD konstrukcji zasobnika oraz bomby małego wagomiaru.

Słowa kluczowe: bezzałogowy statek powietrzny, zasobnik bombardierski, bomba małego wagomiaru, balistyka bombardowania, skuteczny promień rażenia