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The Structural Design of a Mother-Bomb Carrier for Naval Information Ammunition

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Abstract: An innovative design of cluster bomb retrofitted from standard ammunition is proposed in this paper. After analyzing the stress at key positions, the requirements for material selection, fabrication and design of retrofitting parts are determined to ensure the necessary launching and in-air explosion strengths based on such features of gun-launched cluster bomb as high overload, high rotational speed, and thin shell wall. As verified in tests, the retrofitted cluster bomb can open the cabin reliably, which satisfies the required launching and in-air explosion strengths. Additionally, it is highly consistent with the original standard ammunition in terms of external ballistics. The proposed design of retrofitted cluster bomb can be applied in the dispenser design of information ammunition, and even can be used in the active cannon straightway. Therefore, it offers a new approach in the research and development of information ammunition with a cluster bomb structure for in-service naval guns.

1. Introduction

Since the 1970s, more and more developed countries started the research of information ammunition. As more and more developed countries invest in the research of information ammunition, the technology of information ammunition has been developed rapidly, at present a variety of information ammunition has been developed and supplied to forces. Based on its relationship with information, information ammunition can be classified into information gathering ammunition (recon bomb and assessment bomb, etc.), information utilizing ammunition (guided bomb[1], terminal sensitive sub-ammunition and trajectory correction projectile, etc.), and information jamming ammunition (gun-launched chaff jammer, communication jammer and decoy jammer, etc.).

Information ammunition generally refers to the ammunition that uses a projectile to carry and deliver core load to a designated space for the desired purpose [2]. The design of projectile for information ammunition often adopts the cluster bomb structure, e.g. communication jammer, chaff jammer, radar decoy jammer. Etc.

In the research and development of ship information ammunition, higher requirements are often imposed to make them applicable to in-service naval guns and meet the needs in the hoisting, feeding, and loading process, and the firing computation of naval guns.

Four parameters including shape, mass, centroid and inertia moment of projectile are crucial to the development of information ammunition with a cluster bomb structure for in-service naval guns. The newly developed information ammunition with a cluster bomb structure must be suitable for the hoisting, supplying, and ramming system of in-service naval guns, and applicable to their launching system and fire control computation system. Meanwhile, these systems have been structurally fixed, so that they are not easily altered. For this purpose, the simplest way is to retrofit the standard ammunition projectile into the cluster bomb for specific functionality but keep the consistency in the above four parameters (that is, “four consistencies”). In this way, the newly developed information ammunition can be directly used by in-service naval guns, and can use the the original firing table [3, 4].

Naval guns experience high overload and high rotational speed in launching cluster bomb projectiles. Hence, the cluster bomb retrofitted from standard ammunition must satisfy the requirements for firing strength, so as to prevent deformation of projectile, rupture or come-off of parts, or other accidents [5-7]. When the cluster bomb explodes in the air to open the cabin and eject the core payload, its internal parts are under the gunpowder combustion gas pressure of ejecting explosive. Affected by the pressure inside projectile body, these parts are subject to the inertial force and compressive force in the opposite direction of launching. When ejecting in the air, some parts may be even exposed to the force much greater than that at the time of launching [8-11]. Retrofitting standard ammunition into cluster bomb must also meet the requirements for explosion strength in the air. Therefore, it is necessary to work hard on the general design, material and technology of refitted parts in the design of the mother bomb, so as to make it keep "four consistencies" with the original standard ammunition, and to meet the requirements of launching and air explosion intensity.

For the research and development of information ammunition, a cluster bomb retrofitted from standard ammunition is proposed in this paper. A general design is outlined as well. After analyzing the forces applied at key positions and the strength, the requirements for material selection, fabrication and design of retrofitted cluster bomb are detailed to offer a new approach to the research and development of information ammunition with a cluster bomb structure for in-service naval guns.

2. General Design of Retrofitted Cluster Bomb

A retrofitted cluster bomb has a cluster bomb structure with the cabin at its bottom. The cabin at its bottom can be opened backwards by the piston ejecting mechanism of single chamber combustion. As shown in Figure 1, it consists of a detonator, a dispenser case, a head nut, a bottom nut, bullets, a ejecting box, a pusher, and a strut. Among these parts, the dispenser case is made of the original projectile body by removing a portion of its head and tail, and properly thinning the wall of projectile from inside. The head nut is put in place of the removed head of projectile, and threaded onto the dispenser case. The ejecting box is mounted inside the head nut for opening the cabin. The removed tail of projectile is replaced by the bottom nut threaded onto the dispenser case. The threads of the bottom nut may be sheared off at the time of ejecting backwards, so as to open the cabin. The piston ejecting mechanism also contains a pusher and a strut inside the dispenser case of cluster bomb. The dispenser is a piston ejecting structure. The hollow and cylindrical strut is filled with bullets for the purpose of central load.

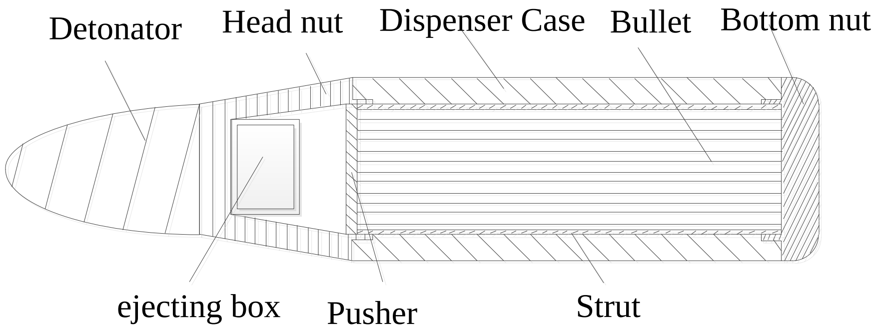

Figure 1: Formation of cluster bomb retrofitted from standard ammunition

The cabin is opened in the following process: after the retrofitted cluster bomb is launched, the detonator controls the point where the cabin is opened for external ballistics. After the detonator is triggered, the ejecting explosive is ignited to generate high-temperature and high-pressure powder gas through combustion. When the powder gas pressure increases to a certain level, it drives the pusher and strut (containing bullets) to shear off the threads of the bottom nut, and further move towards the end of projectile until the bullets are pushed out of the dispenser together with the strut.

The general design must fully take into account “four consistencies”. First, if the size is changed dramatically, the retrofitted ammunition will be unable to satisfy the needs of hoisting, supplying, and ramming system [12]. Second, if the mass is changed significantly (the central load of information ammunition is normally lighter than the fillings of standard ammunition), the launching system will be unable to automatically remove the case for continuous firing. Third, if the above two parameters remain unchanged, but the centroid and inertia moment of retrofitted ammunition are changed, external ballistics will be different. In other words, if any of these four parameters is changed, the external ballistics of projectile will be modified, so that the original firing table will not be applicable anymore. In the worst scenario, the retrofitted ammunition will not be normally launched or used [13]. Consequently, it is very crucial to keep “four consistencies” between the retrofitted cluster bomb and the standard ammunition, which causes new requirements for the cluster bomb design. For instance, additional weight must be used to guarantee the consistent mass of projectile if bullets are lighter; centroid adjusting mechanism is added inside to keep the consistent centroid; the head nut must be made of low-density aluminum, and the bottom nut should be made of high-density steel, in order to ensure the consistent inertia moment. Meanwhile, the wall of standard ammunition must be thinned with the reduced thickness of projectile bottom to make more room for loading bullets.

With the general plan, further improvements are made to realize the consistency between the retrofitted cluster bomb and the original standard ammunition in four parameters. However, the retrofitted gun-launched cluster bomb features high overload, high rotational speed, and thin shell wall. Theoretical calculation and field tests must be therefore carried out to determine whether the material selection, fabrication, and design of its projectile body and parts satisfy the requirements for launching and in-air explosion ejecting strength.

3. Strength Analysis and Design of Retrofitted Cluster Bomb

The strength of cluster bomb is reflected in two aspects, that is, launching strength and in-air explosion strength. At the time of launching, the projectile of the retrofitted cluster bomb is mainly exposed to the following loads inside the chamber: powder gas pressure, inertial force, filling pressure, guidance lateral force, band pressure, unbalanced force, and friction, etc. [13]. Among them, powder gas pressure is the main load acting on the projectile body of cluster bomb. The other forces must be originated from its mutual effect with cluster bomb and gun. Hence, powder gas pressure is primarily considered in the calculation of launching strength. When launching the retrofitted cluster bomb designed in this paper, the maximum powder gas pressure is measured and used to calculate the pressure in chamber[14, 15], that is, P_m = 294.19 Mpa. At the time of in-air explosion, the internal parts are affected by the ejecting powder gas pressure and the pressure inside projectile, and also subject to the inertial force and compressive force in the opposite direction of launching. For this reason, some internal parts may, at the time of ejecting in the air, bear the force much greater than that when launching. Based on the volume of ejecting box and the type of ejecting explosive available, a quantity of ejecting explosive is preliminarily determined (and slightly adjusted in the subsequent improvement of design). The measured maximum pressure of ejecting is P_p = 75.23 Mpa.

Considering the stress analysis and required strength at the key positions of the retrofitted cluster bomb, the requirements for material selection, fabrication and design are put forward. Moreover, it is theoretically verified that the strength of the cluster bomb retrofitted from standard ammunition meets the requirements.

3.1 Case Strength Analysis and Design of Cluster Bomb Retrofitted from Standard Ammunition

The case of the cluster bomb retrofitted from standard ammunition is made by adding a head nut outside the projectile body of the original standard ammunition. In order to comprehensively verify the strength of the cluster bomb case, five key profiles are selected as shown in Figure 2, that is, 1-1, 2-2, 3-3, 4-4 and 5-5.

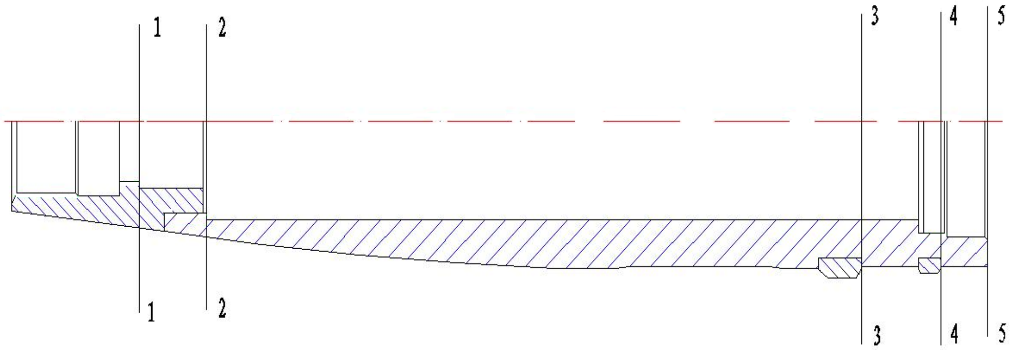

Figure 2: Key profiles for calculation of case strength

We first analyze the launching strength of the retrofitted cluster bomb case. The powder gas pressure used in this calculation is called calculated pressure, which is normally 1.1 times of the average maximum chamber pressure under normal temperature, that is, $P = 1.1P_m = 323.6$ Mpa.

When calculating its launching strength, the cluster bomb case is assumed to bear the axial inertial force. Under the effect of such force, the stress in the case profile n-n is as follows:

$$\sigma_n = -P\frac{R^2}{R_n^2 - r_n^2}\frac{q_{Bn}}{q} \tag{1}$$

Where the negative value indicates the compressive stress; P is the calculated powder gas pressure; R is the projectile radius; q is the weight of projectile; r_n and R_n are the inside and outside radius of a calculated profile, respectively; q_{Bn} is the weight of connection between projectile and case above the calculated profile (including weight of detonator).

Under normal circumstances, the connection between the bottom and the wall (in the vicinity of projectile band) is a vulnerable part of the cluster bomb case launching strength [16]. The cluster bomb case launching strength satisfies:

$$\frac{\sigma_n}{K_m} \le \sigma_s \tag{2}$$

Where σ_s is the yield point of case metal; K_m is the coefficient of coincidence, $K_m = 1.2 – 1.4$.

The parameters of the cluster bomb retrofitted from standard ammunition in this paper are submitted into Eq. (1) to obtain $\sigma_{n1} = -P\frac{R^2}{R_1^2 - r_1^2}\frac{q_{B1}}{q} = -111.8Mpa$. Similarly, we can get $\sigma_{n2} = -139.47$ Mpa, $\sigma_{n3} = -411.78$ Mpa, $\sigma_{n4} = -646.64$ Mpa, and $\sigma_{n5} = -597.4$ Mpa.

Taking $K_m = 1.3$, we can get $\sigma_{n3} / K_m = 316.75$ Mpa, $\sigma_{n4} / K_m = 497.41$ Mpa, and $\sigma_{n5} / K_m = 459.54$ Mpa, which satisfy the conditions defined in Eq. (2). These values are all below the yield limit of projectile metal of the standard ammunition, that is, $\sigma_s = 588.2$ Mpa. It is therefore proved that the thinned projectile body can still meet the requirements for launching strength. Meanwhile, it is evident that the profiles 1-1 and 2-2 bear low stresses at the time of launching. In the general design of retrofitting standard ammunition into cluster bomb, it is consequently feasible to use the head nut made of aluminum that has low density and poor tensile capacity for the purpose of guaranteeing unchanged inertia moment of the cluster bomb.

Second, the in-air explosion ejecting strength of the cluster bomb case is analyzed. At the time of in-air explosion ejecting, the cluster bomb case is under the effect of powder gas pressure generated by ejecting explosive. The strength is vulnerable around the combustion chamber indicated by profiles 1-1 and 2-2. The stress is defined by:

$$\sigma_{pn} = \frac{\sqrt{3}R_n{}^2}{R_n{}^2 - r_n{}^2}P_p \tag{3}$$

Where P_p is the powder gas pressure generated by ejecting explosive.

The in-air explosion ejecting strength satisfies:

$$\sigma_{pn} \leq \sigma_s \tag{4}$$

The parameters of the cluster bomb retrofitted from standard ammunition are submitted into Eq. (3) to obtain:

$$\sigma_{pn1} = \frac{\sqrt{3}R_1^{\ 2}}{R_1^{\ 2} - r_1^{\ 2}} P_p = 352.1Mpa \tag{5}$$

$$\sigma_{pn2} = \frac{\sqrt{3}R_2^{\ 2}}{R_2^{\ 2} - r_2^{\ 2}} P_p = 464.16Mpa \tag{6}$$

After comparing it with the stresses at the time of launching, it is found that the stress at the profiles 1-1 and 2-2 at the time of in-air explosion is greater than that at the time of launching. Meanwhile, the original standard ammunition has steel at the profile 2-2, whose yield limit is σ_s = 588.2 Mpa, satisfying Eq. (4), so that its in-air explosion strength is sufficient. Nevertheless, it has aluminum at the profile 1-1, whose yield limit is normally low (σ_s < 220 Mpa), not ensuring the in-air explosion ejecting strength. For this reason, the head nut made of aluminum must be heat treated to make its yield limit exceed 352.1 Mpa. Considering strength margin and heat treatment cost, the yield limit of the head nut after heat treatment is selected to be 400 Mpa, which can satisfy the requirements for strength at the time of launching and in-air explosion.

3.2 Bottom Nut Strength Analysis and Design of Cluster Bomb Retrofitted from Standard Ammunition

First, the strength at the projectile bottom is calculated. According to Reference [13,17], a projectile bears the highest stress at the center of its bottom, that is, the center of bottom nut in the cluster bomb (also known as projectile bottom) at the time of launching. Driven by the powder gas pressure and the axial inertial force of internal fillings, the maximum flexural stress σ_w occurs at the center of projectile bottom at the time of launching, which is given by:

$$\sigma_w = \frac{5\overline{p_z} r_{pj}^2}{4h^2} + P_c \tag{7}$$

The flexural strength at the projectile bottom satisfies $\frac{\sigma_w}{K_m} \leq \sigma_s$.

In the meantime, the shear stress σ_τ is generated at the circumferential profile of projectile bottom, while the compressive stress σ_j is generated at the annular end of flange (A). These stresses and strengths respectively satisfy [9]:

$$\sigma_\tau = \frac{\overline{p_z} r_{pj}}{h_e + 2h_D} \leq [\tau] \tag{8}$$

$$\sigma_j = \frac{p r_D^{\ 2} - p_c r_{pj}^{\ 2}}{r_D^{\ 2} - r_{pj}^{\ 2}} \leq [\sigma_j] \tag{9}$$

where r_D is the outside radius of the flange of projectile bottom; r_{pj} is the inside radius of the flange of projectile bottom (approximate to the average radius of fitting threads); h_D is the thickness of flange; h_e is the length of threads at the projectile bottom; h is the thickness of projectile bottom; q_n is the weight of projectile bottom; q_c is the weight of internal fillings; P_c is the pressure of internal fillings, $P_c = P\frac{R^2}{r_{pj}^2} \times \frac{q_c}{q}$; $\overline{P_z}$ is the axial equivalent stress, $\overline{P_z} = P[1 - \frac{R^2}{r_{pj}^2} \times \frac{(q_n + q_c)}{q}]$; K_S is the coefficient of coincidence, $K_S \approx 1.5$; σ_S is the yield point of metal at the projectile bottom[18]; $[\tau]$ is the allowable shear stress, $[\tau] \approx \sigma_s / 2$ for metal; $[\sigma_j]$ is the allowable compressive stress, $[\sigma_j] \approx 2\sigma_s$ for metal.

The parameters of the cluster bomb retrofitted from standard ammunition are submitted into Eqs. (7), (8) and (9) and the expressions of P_c and $\overline{P_z}$ to obtain:

$$P_c = P\frac{R^2}{r_{pj}^2}\times\frac{q_c}{q} = 130.58MPa \tag{10}$$

$$\overline{P_z} = P[1-\frac{R^2}{r_{pj}^2}\times\frac{(q_n+q_c)}{q}] = 105.21MPa \tag{11}$$

$$\sigma_w = \frac{5\overline{p_z}r_{pj}^2}{4h^2} + P_c = 512.69Mpa \tag{12}$$

$$\sigma_\tau = \frac{\overline{p_z}r_{pj}}{h_e+2h_D} = 109.59MPa \tag{13}$$

$$\sigma_j = \frac{pr_D{}^2 - p_c r_{pj}{}^2}{r_D{}^2 - r_{pj}{}^2} = 589.89MPa \tag{14}$$

The projectile bottom of the cluster bomb proposed in this paper is made of heat treated steel [19] with the yield limit of 560 MPa. Thus we have:

$$\frac{\sigma_w}{K_m} = \frac{512.69}{1.5} = 341.78Mpa < \sigma_s = 560Mpa \tag{15}$$

$$\sigma_\tau = 109.59MPa < \frac{\sigma_s}{2} = 280MPa \tag{16}$$

$$\sigma_j = 589.89MPa < 2\sigma_s = 1120MPa \tag{17}$$

It is proved that the launching strength of the projectile bottom is guaranteed.

Second, the strength of threads connecting the bottom nut of cluster bomb with the case is analyzed[20]. At the time of launching, the maximum chamber pressure is generated, and causes the maximum inertia moment at the projectile bottom. Under the effect of such maximum inertia moment, the projectile bottom does not rotate relative to the projectile body, so that the connecting threads are not sheared off. Hence, the maximum strength of connecting threads at the projectile bottom is sufficient.

The maximum inertia moment at the projectile bottom is expressed by:

$$M_G = A_n a_j\,, \tag{18}$$

Where A_n is the pole inertia moment at the projectile bottom; a_j is the acceleration at the projectile bottom at the moment when the maximum chamber pressure is generated, $a_j = \frac{P\pi^2 Rg}{q\eta}$. After the projectile bottom is tightened onto the case, the friction torque generated between the projectile bottom and the case at the moment when the maximum chamber pressure is generated at the time of launching is given by:

$$M_m = \frac{2}{3} f_D \pi P \frac{(r_D{}^3 - r_{pj}{}^3)}{(1-\frac{r_{pj}{}^2}{r_D{}^2})} \tag{19}$$

Where f_D is the friction coefficient, $f_D \approx 0.1$.

After comparing M_m and M_G, it is found that the projectile bottom does not rotate relative to the case at the time of launching if $M_m > M_G$.

Meanwhile, the threads connecting the projectile bottom with the case have the resistance to breaking as follows:

$$\theta = \pi r_{pj} h_e \tau_b \tag{20}$$

Where τ_b is the limit of shear strength, and $\tau_b = \sigma_s$ for general metal.

Hence, there is $\theta = \pi r_{pj} h_e \sigma_s$.

The connecting threads can be broken by the torque given by:

$$M_H = \theta f_e \frac{r_D + r_{pj}}{2} + \theta r_{pj} \left(\frac{t + 2 f_e \pi r_{pj} / \cos\beta}{2\pi r_{pj} - f_e t / \cos\beta} \right) \tag{21}$$

Where t is the pitch; β is the friction angle of threads, and β = 30° for metric threads; f_e is the friction coefficient, and $f_e \approx 0.1$.

After comparing M_H and M_G, it is found that the threads connecting the projectile bottom with the case are not broken at the time of launching if $M_H > M_G$. It is therefore guaranteed that the projectile bottom does not come off when the cluster bomb is launched or during its flight.

The parameters of the cluster bomb retrofitted from standard ammunition are submitted into Eqs. (18), (19) and (21) to obtain:

$$M_G = A_n a_j = A \frac{P\pi^2 Rg}{q\eta} = 3165.7 N \cdot m \tag{22}$$

$$M_m = \frac{2}{3} f_D \pi P \frac{(r_D{}^3 - r_{pj}{}^3)}{(1 - \frac{r_{pj}{}^2}{r_D{}^2})} = 10756 Nm \tag{23}$$

$$M_H = \theta f_e \frac{r_D + r_{pj}}{2} + \theta r_{pj} \left(\frac{t + 2 f_e \pi r_{pj} / \cos\beta}{2\pi r_{pj} - f_e t / \cos\beta} \right) = 0.0343\theta \tag{24}$$

Since M_m = 10873.2 N·m, it is greater than M_G = 3165.7 N·m, and not affected by the material of the projectile bottom. Hence, the projectile bottom does not rotate relative to the case. Meanwhile, if M_H is larger than M_G = 3165.7 N·m, the threads at the projectile bottom must be able to resist the torque no less than 92294 N. When the projectile bottom is made of steel with the yield limit of 560 Mpa, the length of threads should not be less than 0.0014 m.

At last, the shear reliability of threads at the projectile bottom is analyzed. The threads connecting the projectile bottom with the case must be reliably sheared off at the time of in-air ejecting. Hence, the shear force generated by the powder gas of ejecting explosive should be greater than the shear strength of such connecting threads. Under the effect of in-air ejecting, the shear force generated by such powder gas is defined by:

$$F = P_p \pi r_T^2 \tag{25}$$

The shear strength of connecting threads is determined by:

$$\theta = \pi r_{pj} h_e \sigma_s \tag{26}$$

In order to reliably shear off the threads connecting the projectile bottom with the case, their strength must satisfy:

$$F > f_{id}\theta \tag{27}$$

Where f_{id} is the safety factor for reliably shearing off threads, and $f_{id} = 1.5$.

The parameters of the cluster bomb retrofitted from standard ammunition are submitted into Eqs. (25), (26), and (27) to obtain:

$$F = P_p \pi r_T^2 = 265100N \tag{28}$$

$$f_{id}\theta = f_{id} \pi r_{pj} h_s \sigma_s = 98.9 \times 10^6 h_s \tag{29}$$

It is required that, if $F > f_{id}\theta$, the length of threads at the projectile bottom must not be greater than 0.0027 m. Therefore, attention should be paid to the thread length of bottom nut in the design of projectile bottom. Based on actual condition, the proposed design has the thread length of 0.0020 m for the projectile bottom.

Moreover, it is necessary to verify whether the threads of head nut are reliably connected in the similar way, but it is omitted in this paper.

4. Field Tests with Live Fire

Based on the proposed design, bullets were loaded into the cluster bomb retrofitted from standard ammunition. The cluster bomb was first checked for static parameters, and then field tested with live fire for launching strength and opening the cabin through in-air explosion.

(1) As revealed in the check of static parameters, the retrofitted cluster bomb kept practically consistent with the original standard ammunition in terms of shape, mass, centroid, and inertia moment, which satisfied the requirements of military standards.

(2) After the strength test was completed, the recovered bomb was checked, and it was found that the cluster bomb had intact appearance, and its connections of head nut and bottom nut with the case were not damaged. Moreover, only very tiny deformations were detected at five positions of the projectile, that is, upper center, lower center, cylinder, below projectile band, and center of projectile bottom, but such deformations did not exceed 0.06 mm. It is proved that the proposed design of cluster bomb retrofitted from standard ammunition meets the requirements for launching strength.

(3) During the in-air explosion test for opening the cabin with small angle of fire, the sound of opening the cabin in the air was heard. After the test, bullets were found on the ground near where the cabin was opened. Moreover, the recovered dispenser had its bottom sheared off, but the case was intact and free of crack or deformation. The connection of head nut with the projectile body was well preserved as well. It is proved that the design of cluster bomb retrofitted from standard ammunition satisfies the requirements for strength of opening the cabin through in-air explosion and ejecting central load.

(4) In both of the above tests, the cluster bomb was successfully hoisted, supplied, rammed, and launched. In the strength test, the density of landing points of the cluster bomb without opening the cabin satisfied the requirements for such density of standard ammunition. Meanwhile, in the in-air explosion test for opening the cabin with small angle of fire, ballistic radar was used for projectile tracking to measure the movement parameters 15 s before the cluster bomb left the gun muzzle. The measured parameters were consistent with those of the original standard ammunition.

5. Conclusions

Based on o the requirements of the application background, a design of retrofitting standard ammunition into cluster bomb is put forward together with its general plan. After analyzing the stress at key positions, it is theoretically verified that the strength of the proposed design satisfies the requirements. The requirements for material selection and fabrication process are also given. Field tests are carried out with live fire of the retrofitted cluster bomb. The test results reveal that the proposed design is reasonable and feasible, and satisfies the requirements for strength and “four consistencies”.The retrofitted cluster bomb in the proposed design can be better used for in-service naval guns. It presents a new approach in the research and development of information ammunition with a cluster bomb structure for in-service naval guns. Therefore, it is of great significance to military applications and can be further promoted.

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