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A Systematic Research on Ballistic Characteristics of Aerial Ammunitions

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Abstract

Aviation has come a long way since its early days, and as technology has advanced, air vehicles have become even more advanced and effective, especially on the battlefield. In addition, in-depth research and discoveries in the field of aviation have a significant impact on the aviation industry, especially in the field of munitions. In this context, aerial ammunition is an important component of aviation and is widely used in combat. Because a malfunction that may occur during separation or premature detonation during separation from the aircraft may cause fatal effects on the crew. That's why the bomb must be safely separated from the air vehicles. Modern bombs are therefore equipped with advanced safety features that guarantee a precise and safe separation from the aircraft before explosion. In addition, the determination of the ballistic coefficient according to the size of the desired effect reveals the importance of the choice of munition types. Otherwise, it will not be possible to achieve the desired level of target destruction. This study aims to provide a comprehensive understanding of the basic characteristics of aerial munitions, including the composition and operation of generic aircraft bombs.

Keywords: Aerial Ammunition, Generic Bomb Types, Air-to-Ground Bombs, Safe Separation, Tactical Ammunition

JEL Classification: L93.

Havacılık Mühimmatlarının Balistik Karakterizasyonuna Yönelik Bir Sistematik Araştırma

Öz

Havacılık ilk günlerinden bu tarafa çok yol kat etmiştir ve teknoloji ilerledikçe uçaklar daha da gelişerek özellikle harp sahasında çok etkili hale gelmiştir. Ayrıca havacılık alanında derinlemesine gerçekleştirilen araştırma çalışmaları ile ortaya konan buluşlar özellikle mühimmat konusunda havacılık sektörünü büyük ölçüde etkilemektedir. Bu bağlamda, havacılık mühimmatları havacılığın önemli bir bileşenidir ve muharebede yaygın olarak kullanılmaktadır. Havacılık mühimmatının, uçağa konuşlanma sırasında meydana gelebilen bir arıza veya uçaktan ayrılırken meydana gelen erken patlamanın mürettebat üzerinde ölümcül etkilere neden olmasından dolayı bombanın emniyetli bir şekilde ayrılması gerekmektedir. Bu nedenle çağdaş bombalar, patlamadan önce uçaktan kesin ve güvenli bir şekilde ayrılmayı garanti eden gelişmiş güvenlik özellikleriyle donatılmaktadır. İlave olarak, istenen etkinin boyutuna göre balistik katsayının belirlenmesi, mühimmat

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tiplerine yönelik seçimin önemini ortaya koymaktadır. Aksi takdirde hedefteki tahribatın istenilen ölçüde gerçekleşmesi mümkün olmayacaktır. Bu çalışmanın amacı, hava mühimmatlarının temel özellikleri ve jenerik uçak bombalarının bileşimi ile işleyişi hakkında kapsamlı bir kavrayış sunmaktır.

Anahtar Kelimeler: Havacılık Mühimmatları, Jenerik Bomba Türleri, Havadan Yere Bombalar, Emniyetli Ayrılma, Taktik Mühimmatlar

JEL Sınıflandırma: L93.

INTRODUCTION

Aerial bombs, versatile munitions that can be released from airplanes or other flying machines, are designed to perform a wide range of combat tasks in modern aviation. Their classification is based on various principles, including the combat task they are designed to solve, the appearance of the effect or destruction factors they create, and the type of target they are intended to destroy.

Airborne bombs are divided depending on the combat task they are designed to solve. These include primary-purpose aerial ammunition, auxiliary aerial ammunition, and particular-purpose aerial ammunition. Aerial ammunition for the primary purpose is designed to destroy various ground (underground) and sea (surface, underwater) targets of the enemy. As a result of their direct impact on various targets, it is accepted to destroy or disable the target due to the destructive effect of the impact, the explosion of the explosive discharge (explosive products, impact wave, and shrapnel), and the effect of the high temperature and flame of the combustion of incendiary substances.

Different types of primary-purpose bombs are used to damage or destroy targets, and these bombs are classified based on their destruction effect and the type of target to be destroyed. The following are the main types of primary-purpose bombs, as shown in Figure 1:

- *High-explosive aerial bombs:* These bombs use the gas-like products of the explosion and the shock wave as the main factors of destruction (e.g., Mk 82, Mk 84).
- *Shrapnel-effective aerial bombs:* These bombs use shrapnel formed during the fragmentation of the body as the main factor of destruction (e.g., 9N123K)
- *Cumulative effective aerial bombs:* These bombs use the powerful armoring effect of the molten metal stream formed during the compression of the metal coating of the specially shaped projectile by the explosive products as the main factor of destruction (e.g., JDAM).
- *Armor-piercing and concrete-piercing aerial bombs:* These bombs use the impact of kinetic energy and other factors of destruction on the target as the main factor of destruction (e.g., Brab500).
- *Incendiary aerial bombs:* These bombs use fire, flame, and separate sources of fire caused by the burning of combustible material as the main factors of destruction (e.g., Mk 77).

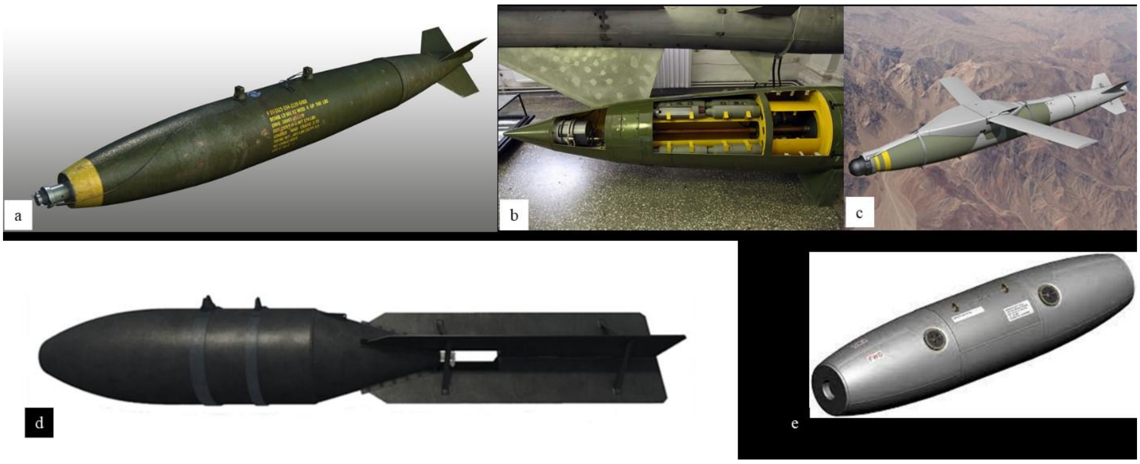

Figure 1.a. High-Explosive Bomb, **1.b.** Shrapnel Effective Bomb, **1.c.** Cumulative Effective Bomb, **1.d.** Armor-Piercing (Concrete-Piercing) Bomb, **1.e.** Incendiary Bomb (The Figure was Collected Based on the information) (Balagansky, 2022).

Depending on the target type, there may be anti-tank (cumulative) or anti-submarine (explosive) aerial bombs. However, many primary-purpose aerial bombs have a combined destruction effect, such as cluster-explosive, cluster-incendiary, cumulative-cluster, etc.

Cluster munitions with a fougasse effect are versatile aerial ammunition that can destroy a variety of targets, including enemy personnel on the battlefield or in concentration areas, aircraft parked in open areas or behind trenches, guided anti-aircraft missile positions, operational-tactical missiles, RLS, brick and reinforced concrete buildings, warehouse buildings, underwater and underground targets.

The effectiveness of cluster munitions is evaluated based on their general and unique characteristics of destruction. For example, the fougasse effect is assessed using criteria such as overpressure, the impulse of the explosion products, shock wave during the explosion in the air, as well as the radius of destruction and the dimensions of the hole created during the explosion on the ground. Shrapnel-effect munitions are evaluated based on the total number of shrapnel, their initial velocity, the fragmentation pattern of the body into shrapnel, and the laws of their flight in different directions.

Additional characteristics of shrapnel munitions include their ability to penetrate obstacles and ignite fuel, as well as the characteristics of the explosion of explosives or solid-fuel rocket engines. Cumulative-effect munitions are evaluated based on the armor-piercing thickness and the armor-back characteristics of the cumulative warhead, including the number of shrapnel produced after armor-piercing, their weight, velocity, and flight angles.

The unique characteristics of incendiary ammunition are the number of parts of the flame mixture (flame sources), their weight, temperature, and burning time, as well as their ability to ignite flammable materials, stickiness, incendiary effects, and the activation and destruction of burns.

Impact munitions have special characteristics related to their depth of penetration into various media (soil, concrete, etc.) and the thickness of the barrier being penetrated.

Aviation ammunition manuals and official reference books provide more comprehensive information on ammunition's special characteristics and appropriate formulas for calculating them.

This chapter discusses physical processes that lead to the formation of different types of destruction effects and provides numerical values for some unique characteristics, such as visibility.

The special characteristics of the destruction effect of aviation and its means of destruction form the basis for calculating their general characteristics. The extermination zone is used as a general characteristic. The target destruction zone is a particular conditional area of the target that, when hit, causes one unit of damage. The induced destruction zone is much larger than the target's ground frontal area for ranged munitions that can destroy a target upon detonation at some distance from the target (fougasse, shrapnel, and incendiary). For impact munitions capable of destroying the target by direct impact (cumulative bombs, anti-aircraft shells), the induced destruction zone is usually smaller than the actual area of the target.

In some cases, the average number of hits required is used as a generalized characteristic of impact munitions, which is equal to the ratio of the area of the target to the area of destruction delivered, which is equal to the sum of the areas of the easily defeated units of the target. Particular calculations determine the price of the generalized characteristics of impact ammunition. The main content of these calculations consists of assessing the dependence of the probability of destroying the target on the coordinates of the bomb's explosion point and, as a result, determining the average value of this probability (Ghose, 2004).

The numerical value of the characteristics of the field of destruction depends on several factors. These include the ease with which targets can be defeated, the degree of destruction required, and the conditions of combat training that determine the speed and angle of meeting the target. Additionally, the effectiveness of this or that type of destruction effect is also determined by the characteristics of ammunition.

The target's defeat characteristics include the various units that are easily defeated, the destruction of which would cause the target to be disabled. The degree of protection of each vital unit and their areas, as well as their location in the target area, are also important factors.

The degree of target destruction required is characterized by the time it takes for the target to lose its function as a combat unit. This time is determined by the tactical and strategic tasks set before the aviation that uses the given means of destruction.

The numerical value of the generalized characteristics of the field of destruction is based on several factors. These factors include the ease of defeating targets, the required degree of destruction, and the conditions of combat training. The conditions of combat training determine the conditions for meeting the target, such as the speed and angle of meeting ammunition. The characteristics of ammunition also play a role in determining the effectiveness of this or that type of destruction effect.

The target's defeat characteristics include the various units that can be easily defeated and whose destruction would cause the target to be disabled. The degree of protection of each vital unit, as well as their areas and location in the target's area, also contribute to the target's defeat characteristics.

The degree of target destruction required is characterized by the time the target loses its function as a combat unit. This time is determined by the tactical and strategic tasks set before the aviation that uses the given means of destruction.

The placement of guided missile units on and inside the body of a missile is called a missile assembly. It is divided into two parts, namely, the aerodynamic assembly and the structural assembly. The placement of control units, war supplies, engine units, power supply systems, and electrical systems inside the body of guided missiles is called constructive assembly.

The mutual placement of elements of systems that create aerodynamic control forces in the body is called aerodynamic assembly.

The constructive assembly should ensure the reliability of systems and units of guided missiles and bombs, convenient and safe operation, high production accuracy, and small weight and volume dimensions. The aerodynamic assembly should ensure proper control of guided missiles and bombs, which is characterized by balancing the missile at the maximum angle of attack and the static stability of the missile at all speed and height limits of the flight.

From a closer look at the assembly characteristics of a small-caliber missile in Figure 2 to a short-range air-to-air missile, a typical rocket of this class can be seen. It has a passive infra-red self-guided warhead and is designed with an axisymmetric "duck" aerodynamic scheme with stabilizer spoilers.

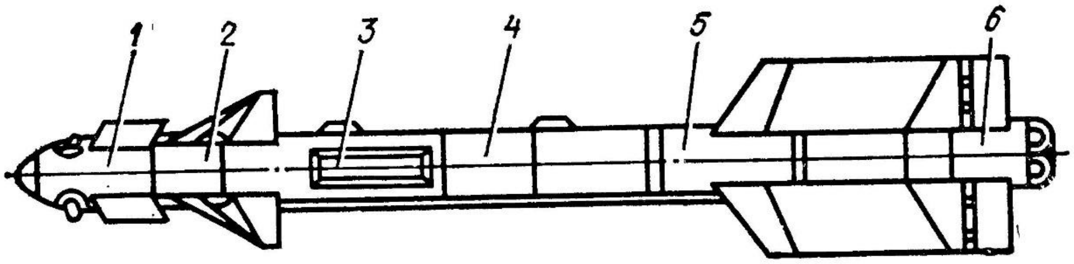

Figure 2. Small range "air-to-air" guided aviation missile (duck pattern) (The Figure was re-illustrated based on the information) (Shiyao, 2019)

1-infrared self-guided warhead; 2-rudder transmission, contact explosive device; 3-blocks of the autopilot, non-contact detonator, automation and switching block; 4-combat part and protective-executive mechanism; 5-solid fuel rocket engine; 6-rudder transmissions of ailerons, gas transmissions.

Structurally, these missiles consist of six sections. The first section is a passive-infrared homing warhead with an angle-of-attack transmitter and stabilizer disruptors mounted on the fuselage. The second compartment is a rudder on which a contact detonator is installed. In the third compartment, you'll find the blocks of the autopilot, contactless detonator, automation, and switching unit. The fourth section contains the fighting part and the protective-executive mechanism. The fifth section is a solid propellant rocket engine, and the sixth section is the steering gear of the autopilot.

Medium-range "air-to-air" guided missiles are also made in the "duck" aerodynamic scheme with axisymmetric and stabilizing spoilers. A typical assembly scheme of modern medium-range air-to-air guided missiles is shown in Figure 3.

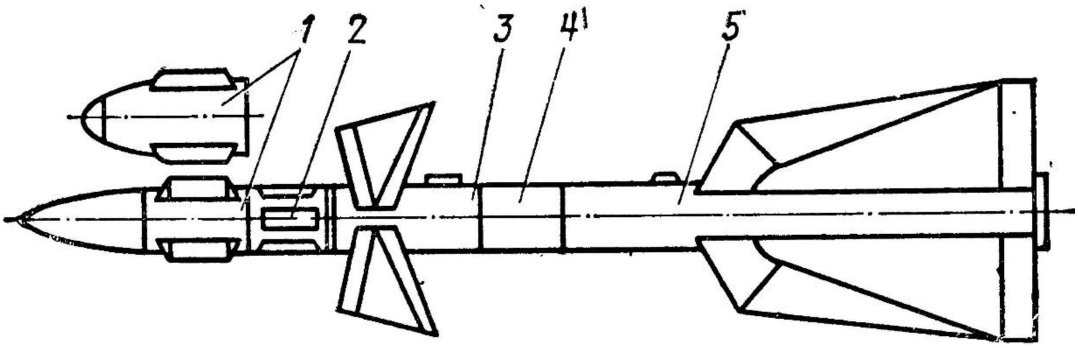

Figure 3. Medium-range air-to-air guided missile

1-Infrared or Radiolocation Self-Directing Head, 2-Equipment Section; 3-Steering Transmission and Feeding Unit, 4-Fighting Part, 5-Solid Propellant Rocket Motor (The Figure was re-illustrated based on the information) (Chadha et al., 2018).

This rocket is made up of six parts that are joined in an aerodynamic "duck" configuration. Stabilizers are put on an optical or radio-technical coordinator, which is the first section. The missile control units and radio detonator are in the equipment portion, which makes up the second section. The rocket's electrical power source and steering gear are located in the third portion. The battle section is the fourth division. An engine that uses solid propellants makes up the fifth part. The blaster's body has attached wings.

Figure 4 depicts a typical long-range air-to-air guided missile assembly system. There are four pieces to this missile. A multifunction control unit, autopilot hardware, a radio detonator, and a contact detonator are all included in the first segment. The missile's onboard digital computer (BRHM), semi-active radio technical target coordinator, and inertial unit comprise the control unit, which communicates digitally with the aircraft carrier. The combat portion and the protective-executive mechanism make up the second division. A solid propellant rocket motor (BYRM) makes up the third unit. The fourth section has a power supply system, a battery pack, and a steering gear and is covered with a nozzle extension. High tactical-technical features can be achieved with such an internal and external assembly.

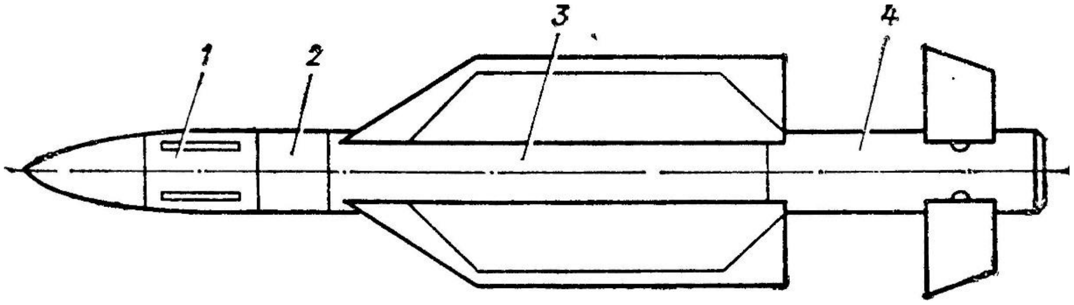

Figure 4. Long-range air-to-air guided missile

1-Multifunction Control Unit, 2-Fighting Part and Protective-Executive Mechanism, 3-Solid Fuel Rocket Engine (Byrm), 4-Steering Gear and Feed Unit. (The Figure was re-illustrated based on the information) (Jones, 2018; Altmann & Suter, 2022).

In tactical "air-to-ground" guided aviation missiles, they also differentiate between aerodynamic (external) and structural (interior) assembly. The items given below are all guaranteed by the constructive collection of such means of destruction.

- The effective destruction of the target due to the specific type, shape, and location of the combat element;
- The maximum reliability and survivability;

- The maximum simplicity and high technology of construction;
- The minimum weight with maximum compactness and slight displacements of the center of gravity during flight; the favorable working conditions of various units;
- The technicality of operation and access to aggregates;
- The modularity of the construction and the uniformity of the connections;
- The ability to be repaired;
- The application of modern materials adopted in the industry

The aerodynamic assembly of "air-to-ground" guided destruction vehicles should do the following: locate the rocket or bomb's wing; locate the areas and locations of the feathers within the rocket or bomb; The internal assembly, which is dependent on the aerodynamic scheme and depends on the fuel burning process breaking centrality (balancing), is closely related to the resolution of these problems. This is a look at some of the standard assembly procedures for modern "air-to-ground" tactical manned aircraft destroyers. Figure 5 shows a missile with a "duck" aerodynamic scheme that is controlled remotely via a radio command system.

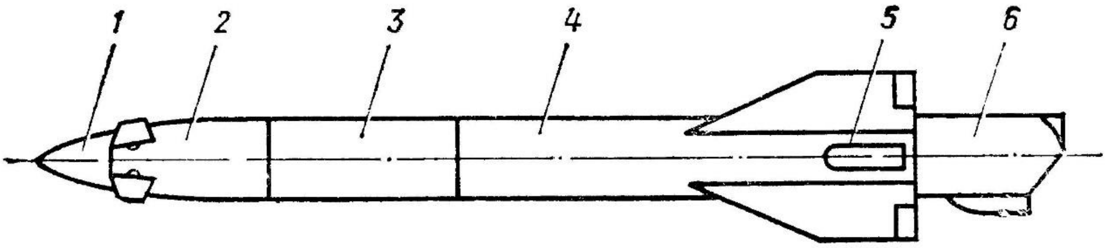

Figure 5. Tactical "air-to-ground" guided aviation missile

1-Ballistic Cone, 2-Steering Gears and Additional Measuring Devices, 3-Fighting Part; 4-Solid Fuel Rocket Motor, 5-Energy Department, 6-Management Unit (The Figure was re-illustrated based on the information) (Michal, 2021).

This rocket has a crisscrossed arrangement of its rudders and wings. The rocket's body has a cylindrical shape. There are six sections to the rocket. The ballistic cone is the initial portion. Additional gauges and the steering gear of the second portion. With fougasse and shrapnel, the third unit proves to be a potent combat force. An engine that uses solid propellants makes up the fourth part. The section on energy is the fifth one. The antenna and control signal generation equipment are located in the sixth portion, which is called the control section.

Figure 6 shows an air-to-ground guided missile with a special solid warhead. The thick-walled body of a conventional aviation bomb is used as a particularly robust warhead. Such missiles, as a rule, have a television or laser self-guidance system and are designed for the destruction of small, specially fortified targets.

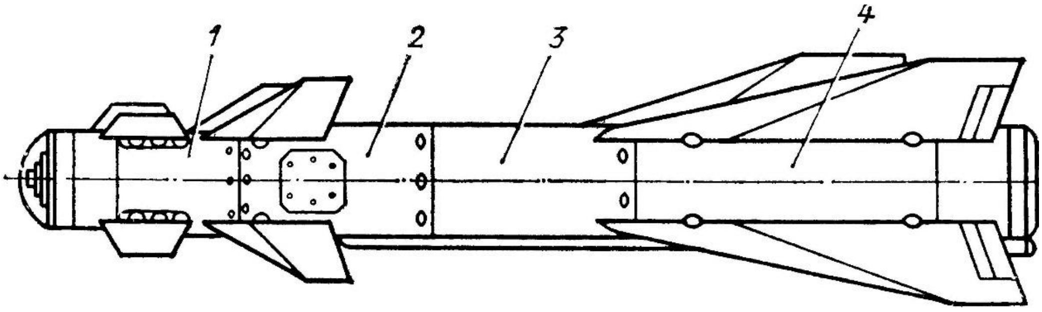

Figure 6. An air-to-ground guided missile with a special solid warhead

1-Television Coordinator; 2-Autopilot and Blasting and Feeding System; 3-Fighting Part; 4-Solid Propellant Rocket Engine and Aileron Block (The Figure was re-illustrated based on the information) (Roberts & Capezznto, 1999).

Figure 7 shows an illustration of a guided aviation bomb in assembly. The bomb consists of several parts that are put together in an aerodynamic scheme with stabilizers. These parts include the target's laser coordinator, the main conical shield that houses the electronic computing equipment, and the stabilizers. The tail section of the bomb contains a completed warhead, explosives, control units, a gas generator, a turbo generator, and steering gears.

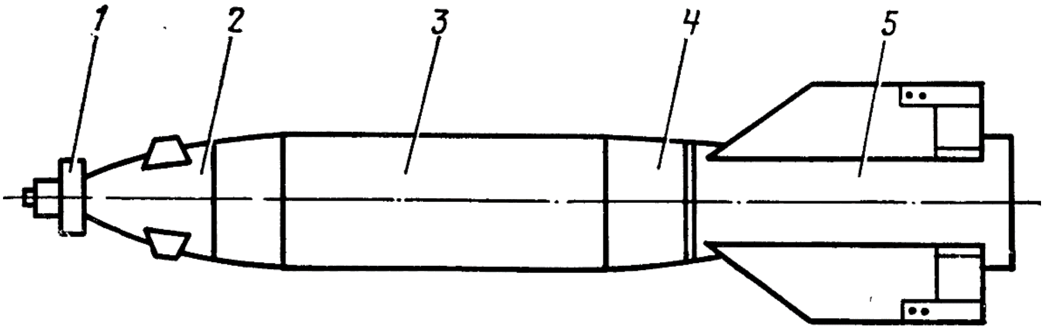

Figure 7. Controlled aviation bomb.

1-Target Laser Coordinator, 2-Conical Shield, 3-Fighting Part, 4-Contact Detonator and Control Unit, 5-Tail Part (The Figure was re-illustrated based on the information) (Kravchuk et al., 2021).

The weapon systems of strategic aviation aircraft include the Tomahawk-type missile, which is designed to destroy strategic targets located far from state borders. This missile is constructed using a conventional design and consists of missile wings and stabilizers, a power plant, a cooling system, an onboard control system, a static pressure receiving system, a warhead, and electrical equipment. The missile is powered by a turbojet two-stroke engine (TRIKM) and is equipped with a special warhead. The fuel supply, engine start, and regulation system includes a compact electronic regulator for controlling and adjusting engine modes. The electrical equipment comprises a power supply system with a turbo-generator and a control unit installed inside the engine.

The glider of the rocket consists of a body, a wing assembled (folded) with blocks and mechanisms, and a tail part. The body is divided into three parts:

- The front flow (shield).
- The middle part of the body (where the tank is located).
- The tail section.

The power plant includes a turbojet two-stroke engine, an engine starting system, and a fuel system.

It should be noted that the "air-to-ground" guided aviation missile is more complex, has many elements, and requires a lot of time to prepare for combat use. The diversity of such means of destruction is related to the large number of land and sea targets (Cressman, 1990).

The energy supply system of guided missiles (guided bombs) is designed to power the control system units and explosive devices after the missile is launched. The power supply system consists of a system for ensuring the operation of steering gears and a power supply system combined in a single power unit of the rocket.

Power units of short-range "air-to-air" guided missiles are designed to process stable voltage in terms of price and frequency and to supply working gas to steering gears. They consist of a gas generator, a turbo-generator, and a stabilization unit. Recently, heating-type disposable chemical current sources (batteries) activated using pyrotechnics are used as a power source. The batteries use a calcium-acid-tungsten electrochemical system with a solid electrolyte. Such a power source does not require voltage stabilization.

The power units of medium- and long-range air-to-air guided missiles are similar and integrated into the power unit. The following units are placed inside the power unit: gas distribution furnace with a power source, Stabilizers, and gyro motor power source assembled block. In the rear part of the gasification furnace, a heat-insulating cover is attached, which protects the engine igniter from overheating at the start of the gas generator. The primary energy source is the gasification furnace, equipped with a gas generator and a turbo-generator with an electro-gas valve. Stabilizers include an assembled block charge choke, a diode rectifier, and a circuit board.

The working principle of the stabilizers is that with the change in the voltage of the turbo-generator (or with the change in the current in the load), the inductive resistance of the working windings changes. As a result, the stability of the voltage of the load (energy consumers) is ensured. It is set to convert to two-phase voltage, which is essential for

"Air-to-ground" controlled means of destruction use power units with a concentration of electrical power sources and gas systems, which use air (pneumatic system), and gas produced by burning gunpowder cartridges (hot gas system) as a working source. Electric batteries are often used as electricity. The battery is assembled in a stainless-steel body and closed with a lid made of this material. The lid has five hermetic outlets. As an alternating current source, the rocket uses a power source that converts direct current into alternating current, which is vital for powering the gyro-motors of the autopilot and the target coordinators. Pneumatic systems are widely used to provide compressed air for rudder drives and aileron drives in "air-ground" controlled destruction vehicles, to maintain the angular speed of rotation of gyroscopes' rotors, as well as for locking gyroscopes, accelerometers, and rocket rudders. The pneumatic system of the missile consists of a pneumatic block, three-mouthed pipes, conductors, a collector (a channel that collects and transports liquids or gases), a discharger, arresters, and pipelines as shown in Figure 8. The cylinder of the pneumatic block is filled with compressed air at the factory. When voltage is applied from the carrier to launch the rocket, air is injected from the balloon into the pneumatic system. The air system can also be set to maintain the bulb battery's operating mode and cool the target conductor.

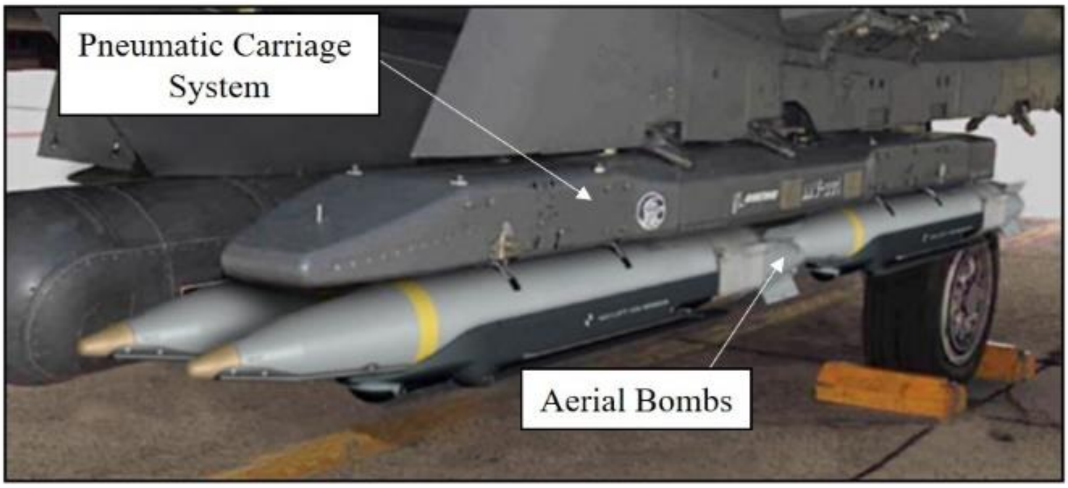

Figure 8. A Pneumatic Multi-Stores Carriage System Installed on Aircraft (The Figure was re-illustrated based on the information) (Nadar, 2014).

Packing, marking, and coloring of guided missiles and guided bombs are very important activities. Controlled aviation destroyers and their components are delivered to military units from crates and cemented metal containers from the manufacturing plants. Removable wings and rudders can be assembled in these containers or separate boxes. Destroyer components, manufactured separately in the industry, are collected in the designated boxes. Protection-executive mechanisms, detonators, igniters, tracers, pyrotechnic means, and other elements for controlled aviation destruction can be sent in single-use metal boxes or multi-use hermetic jars (Chesneau, 1980).

Containers are intended for long-term storage of missiles equipped or unequipped and for transporting missiles in them. They allow rockets to be used multiple times in dry and wet climates, in various unsuitable conditions, etc. they provide. Inside the hermetically sealed container, an air environment is created and maintained, depending on the ambient temperature, under excess pressure conditions, and dried up to the specified boiling point. Airtight shipping containers and crates can be bundled with unique packing materials.

Marking of guided missiles is usually carried out in the following order: factory code, type of product, quarter and year of release, serial number of the product in the series or batch.

1. MATERIAL AND METHODS

The main characteristics of aerial ammunition include the size of the bomb, the filling factor, ballistic characteristics, the characteristics of the destruction effect or the effect created, and the range of conditions of combat application.

The caliber of aerial ammunition is the nominal weight of an aviation bomb expressed in kilograms, for which the limits of the main volume-weight characteristics (mass, diameter, length, and size of the stabilizer when open) are set.

The bomb pattern mainly determines the degree of damage inflicted on the target or the effectiveness of the task being solved. Several standard prints are used for modern aerial bombs. 0.5, 1.0, 2.5, 5.0, 10, 25, 50, 100, 250, 500, and 1,500 kg and older bombs are available in 3,000, 5,000, and 9,000 kg.

The caliber of an aviation bomb is indicated by its conventional name, for example, OAB-10 (10 kg caliber). If the actual mass of the air bomb differs from its print by 10-15%, this difference is indicated in its conventional name: for example, OFAB-100-120-shell fuze air bomb print 100 kg weight 120 kg.

Suppose there are different types of aerial bombs of the same type and caliber, which differ in their structural or other features. This is also indicated in the conventional name, for example, FAB-500T 500 kg thick-walled fuga bomb.

The loading factor is the ratio of the mass of the combat supply (significantly the explosive charge) to the total mass of the aerial bomb. The value of the filling factor for air bombs can be in the range of 0.1-0.7 and mainly depends on the type of air bomb. For example, the filling coefficient of concrete-piercing aerial ammunition is 0.1-0.15, and that of fougasse aerial ammunition is 0.4-0.5.

The filling factor mainly determines the destructive effect and effectiveness of a given type of aviation bomb.

The ballistic characteristics of aerial ammunition determine the ballistic characteristics (aerodynamic characteristics) of an aviation bomb. Ballistic characteristics strongly influence bomb trajectory quantities, and these characteristics are factored into sighting devices when determining aiming angles.

Assault bombs differ from other bombs (explosive, shrapnel-explosive) by the presence of a braking device, which uses a parachute as a braking device. This is explained by the fact that when bombs of a conventional design are dropped from low altitudes, they lag behind the plane at a very small distance and approach the earth's surface at a very small angle. Therefore, when using air bombs with instantaneous action explosives, the shrapnel separated from the explosion can fly to the front of the aircraft and damage the aircraft, which means that the safety of the aircraft is not ensured during combat use. For this reason, the firing of conventional bombs from low altitudes is possible with explosives with an attack delay of 10-240 seconds. However, in this case, accurate bomb shooting is not obtained because the bomb misses the target; the bomb moves several hundred meters away until the detonator is detonated.

In addition, considering evasion in aiming does not ensure accurate bombing because the deviation in the evasion time depends on many external influences; that is, the deviation itself is a random quantity. In addition, when the aerial bomb approaches the earth's surface at a small angle and when it is deflected, the effect of the bomb on the shrapnel decreases to some extent. This result is explained by the fact that the main part of the shrapnel of the body of the cylindrical bomb flies in a narrow-angle area (Figure 8.) with a width of ψ=15-200, which forms an angle of about 900 with the longitudinal axis of the bomb. Therefore, when an aviation bomb explodes vertically, the destruction of ground targets can be shown as a circle with a large radius Rn. Still, when approaching the earth's surface at a small angle or when an aviation bomb explodes during a roll, in which the bomb is still in a horizontal position or close to it, the indicated destruction area drops suddenly. It is limited by two circumscribed circular regions, as shown in Figure 9, whose angular width is approximately equal to the width of the shrapnel flight region.

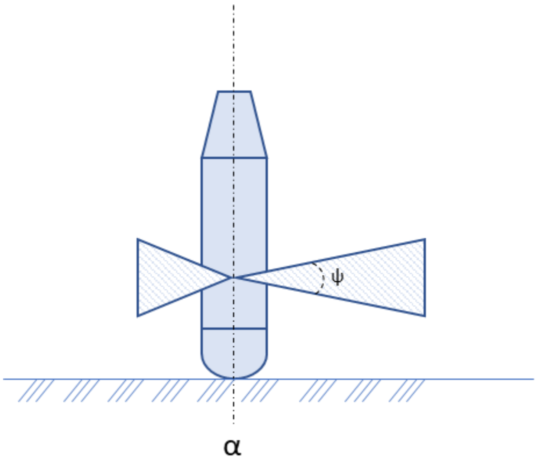

Figure 9. The destruction zone of an air-locked fuga bomb

a-Large Approach Angle; b-Small Approach Angle (The Figure was re-illustrated based on the information) (Krawczyk & Tomala, 2014).

The braking device reduces the speed of the aerial bomb due to some additional friction (braking) created, which ensures that the bomb lags behind the aircraft and allows the aircraft to move away from the point of impact of the bomb. The braking device increases the angle of the bomb falling on the surface and ensures effective destruction of the target with shrapnel.

Braking devices can be of different constructions or have different working principles, but attack bombs mainly use a parachute. The parachute is placed in a metal container together with the device that moves it, which is installed in the tail part of the bomb at the factory (Fig. 6a) and is considered an integral part of the bomb. The cords of the parachute are connected to the fuse mechanism of the detonator, which prevents the sudden detonation of the bomb and the activation of the detonator if the braking mechanism fails.

During normal operation, the parachute bomb is released into the air stream after 1-2 s by the team of the detonator after it is ejected from the aircraft. To ensure the safe and effective firing of conventional bombs of the old design at low altitudes, installed braking devices are used, which are installed on the bomb immediately before combat use. Installation braking devices is a thin-walled cylindrical container 4, which is connected to a parachute 5 to the bottom eye of the bomb with a cardan 1, flat washers 2 and a nut 3. Release mechanism 6 serves to move the device, which is connected to the launch of the detonator from the flying machine (Deng & Wang, 2005).

Volume detonation aviation bomb ODAB-500 destruction of manpower and lightly armored equipment (aircraft and helicopters in open stands, various types of radio location stations, automobile equipment, etc.) as well as manpower and equipment in open storage (trenches, defensive positions, etc., ensures high quality in the making.

ODAB-500 consists of a thin-walled body 1, a combat supply 2, which uses high-calorie liquid fuel with several auxiliary dispersing explosives 3 added as a supply, a brake parachute container 5, and a second detonating explosives.

Upon encountering an obstacle, the dispersive explosive substance is first activated by the command of the detonator; the body disintegrates, disintegrates, and the liquid fuel is dispersed due to the effects of the components obtained as a result of the explosion.

During dispersal, liquid droplets vaporize and, when mixed with air, form an explosive cloud of air-fuel mixture, the size of which depends on the pressure of the bomb. When the size of the cloud reaches a certain size, there is a second detonating explosive charge, which detonates and creates a detonation of the air-heat mixture throughout the entire volume of the cloud.

Classification and components of aviation artillery installations. The set of devices placed in flying machines and serving the effective use of artillery weapons are called aviation artillery devices. These devices ensure the attachment of the weapon to the flying machine, supply cartridges, direct the weapon to the target, remove the case and sleeves, and perform other operations related to the movement of the weapon.

The classification of devices is done primarily according to the degree of displacement of the weapon relative to the aircraft, the location of the device, and the method of attachment to the aircraft.

They are divided according to the degree of displacement of the weapon relative to the aircraft;

- Moving devices
- Fixed devices.

Fixed devices are called devices that maintain the weapon's position when installed and reset. Aiming the gun at the target is performed by maneuvering the flying machine. Due to their combat application characteristics, fixed devices are offensive. Fixed devices are used in the armament of fighters, fighter-bombers, and, in some cases, bombers (Dodson, 2005).

Movable devices are those in which it is possible to shoot from the weapons installed in them in a direction other than the direction of the shooting devices. Movable devices make it possible to complete or replace the maneuver of the aircraft with the firing maneuver. Aiming the weapon is performed by a crew member (shooter) not involved in the flight. Steep mounts are the only type of mount for heavy bombers and military cargo aircraft, as these aircraft have low agility. Front-line bombers can have both movable and fixed mounts.

It should be noted that the structure of both devices are significantly different and are determined by specific characteristics: the type of aircraft, the number and type of weapons, the location of the device on the plane, and the degree of mobility of the device, as well as from the kind of control system.

According to the device's location in the aircraft, it is divided into two parts: artillery mounted on the body and on the wing. The fuselage-mounted devices are mainly placed under the nose of the fuselage. It is one of the main types of equipment for fighter planes. However, due to the limited number of installations in the aircraft's body, the cannons can also be placed in the wing base of the flying machines. It should be noted that wing devices are used in individual cases in fighter and fighter-bombers, and in bombers, only body-mounted devices are used.

According to the attachment method of flying machines, they are divided into mounted and suspended devices. Mounted devices are permanently attached to aircraft.

Suspension devices are temporarily attached to the aircraft, which directly reinforces the artillery weapon system of the aircraft during the designated combat flight.

Hanging artillery installations further expand the combat capabilities of the flying machine, making them more applicable. Containers with cannons are attached to airplanes, along with bombs and missiles.

The main components of the equipment are the following: the carriage, the system of supplying the cartridges with electric current, the reloading system, and the power transmission.

The above components apply to all installations, i.e., fixed and movable installations. Power transmissions are additionally available in moving units. Power transmissions are designed to drive the weapon relative to the aircraft. Electric and hydraulic power transmissions are primarily used in operation.

Main units and systems of artillery installations. A mount is a power structure designed to attach a weapon to an aircraft and transfer all forces acting on the weapon to the aircraft structure. The carriage of the stationary unit keeps the weapon in a given position during assembly and reset. The carriage of the mobile device must ensure that the weapon can be turned in any direction within the firing zone.

The carriage consists of a body and joints that ensure rotation and fastening of the weapon. The body of the carriage is considered the main power element of the carriage. It is intended for connecting the device to the flying machine. The rest of the elements of the carriage are placed in the body - the power transmission device, the system of supplying the cartridges with electric current, and other devices that ensure the regular operation of the device.

The swivel joint only applies to the movable unit and allows the weapon to rotate in any direction during firing in the firing zone. The connection of the turning joint elements with each other and the chassis is carried out directly with different types of bearings and on the power transmission.

The core of the carriage and the rotary joint form a structure that is determined by the degree of movement of the device, the type of weapon mounted on the aircraft, and the device's location on the air vehicle.

The working principle of the turret top assembly is as follows. The weapon is held in the "kachalka" 4 with front 2 and rear 3 fastening nodes, as provided in Figure 10. Through the Kachalka transmission 7, the moving ring 8 is set to rotate around the O-O the axis of the transmission motor 5. The movable ring is rotated by the motor 6 in the fixed ring 9. A fixed ring secures the device to the aircraft (Evans & Peattie, 1997).

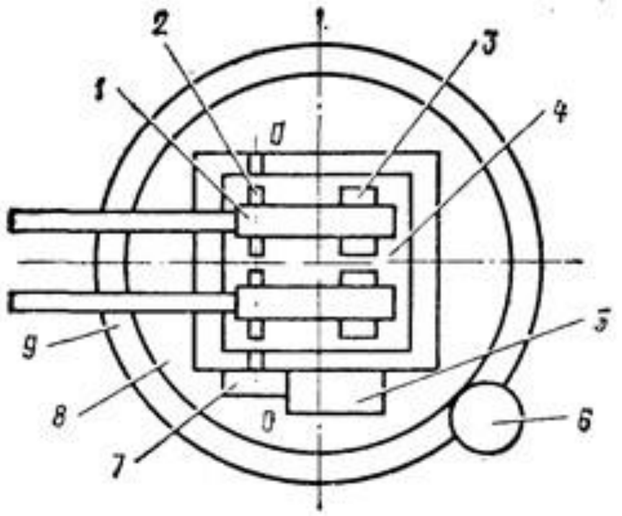

Figure 10. The top device of the circular rotation

1-Gun, 2-Front Mounting Assembly, 3-Rear Mounting Assembly, 4-Carrier, 5-Vertical Aiming Motor, 6-Horizontal Aiming Motor, 7-Gear (Reducer), 8-Moving Ring, 9-Fixed Ring

The basis of the "Lafetinarcha" device is post 1, as seen in Figure 11, in which the front fastening joint 2 rotates on the pads. A movable ring 3 rotates inside the pole on which the weapon is mounted. Weapon mounting joints ensure that the weapon is fixed to the carriage and directly receives all the forces from the side of the weapon, as well as ensure the adjustment of the position of the weapon in the installation. The device has two attachment joints for each weapon, one of which is the base and the other is the retainer. The main joint holds the gun in the shock absorber and the keeper directly behind the gun body. The main joint receives forces in three directions: longitudinal and two transverse directions. During firing, the weapon changes its position in the longitudinal direction, so the retaining device is installed in such a way that it prevents the weapon from changing its position in this direction. In addition, in order to ensure the angular displacement of the weapon in necessary situations, the holding device is made in an adjustable structure.

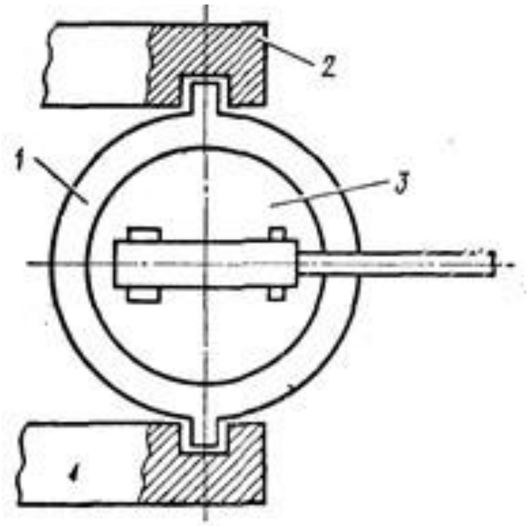

Figure 11. Lafetinarcha (branch) device

1-Pole, 2-Upper Fixed Bracket; 3-Moving Ring, 4-Bottom Fixed Bracket

The device for supplying cartridges to the weapon is designed to supply cartridges to the receiver of the weapon, as well as to remove spent casings and cartridges. Modern supply systems are divided into tape and comb.

In the tape supply system, cartridges are loaded onto tapes with the help of cartridges. In general, a belt system consists of a cartridge case, transfer arms, case and cartridge pullers, case and cartridge accumulators, and cartridge pull mechanisms.

The complexity of the tape supply system depends on the degree of mobility of the weapon, the assembly scheme of the device, and the ability to safely eject the cartridges and cartridges from the aircraft. Simpler systems are systems for securing fixed installations (Ewing, 2004).

If the weapon has two degrees of freedom, then the securing system is considered the most complex. Such systems have rigid and flexible drive arms and a motor for pulling the cartridge tape.

The traction motor is designed to facilitate the operation of the transmission mechanism, which fulfills the working conditions that are motivated by the large friction of the transmission arms during the movement of the cartridge tapes. They engage when the shooter presses the battle button.

The operation of the ball feeding system, for example, in the upper unit is as follows. Cartridge tape 1 is transferred to ball 2 from cartridge box 6, which is firmly fixed on the movable ring 7 of the frame of device 3 with a solid sleeve 4. A hammer motor 5, which moves the cartridge tape, is attached to the solid arm.

Cartridges are fed into the device by means of a cartridge hammer 9, and shells are fed into the device by means of a cartridge hammer 10, from where they are dispersed into a stationary hopper 8, which serves as a shell stacker and a cartridge stacker.

The external drum 2 of the comb system is shown in Figure 12. stores cartridges and spent shells. Cartridges and shells are held by longitudinal guides from the rear of the outer drum and from the rear side of the cylindrical part by three spiral protrusions of the inner drum. When firing, the inner drum rotates and transfers the cartridges to the output joint 1, which is collected in the transporter. Cartridges are transferred to the ball 7 with the transmission lever 8 of the conveyor. The fired shells' transportation and placement in the drum is performed by the hammer arms 5 and the output connection 4 of the transporter.

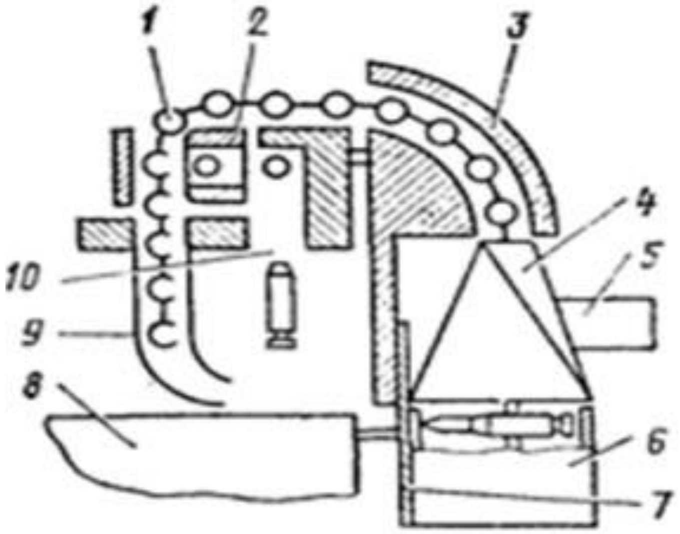

Figure 12. Grill system of nutrition

1-Cartridge Tape, 2-Ball, 3-Moving Ring, 4-Arm, 5-Traction Engine, 5-Box, 7-Rama, 8-Bunker, 9-Manga Hammer, 10-Shell Hammer.

The conveyor is moved from the input device to the output device by the drive arm 6. The transmission of the carrier and the internal drum is carried out from the motor of the ball, which is essential to ensure the coordinated (joint) operation of the gun feeding system].

During the take-off of the aircraft to eliminate accidental shots, the final preparation of the weapon for the first shot is performed by the reloading system in the air, which eliminates delays during the shot and activates the cannon's mechanisms.

Reloading is the process of performing a series of operations of the mechanisms of gunpowder-gas-powered conventional and drum-type weapons using energy from an external source. During reloading, the unfired cartridge in the ball cartridge is discarded and replaced by the next cartridge.

The reloading system includes a reloading mechanism and a power source, which is considered the structural mechanism of the ball. Recharging systems differ according to the type of energy used. Two types of reloading mechanisms are most commonly employed: pneumatic and pyrotechnic. The type of system is selected depending on the weapon's characteristics.

The pneumatic recharging system receives compressed air from the onboard source of the aircraft through reducer 1, rotary joint 2, and counter valve 3, as shown in Figure 13.

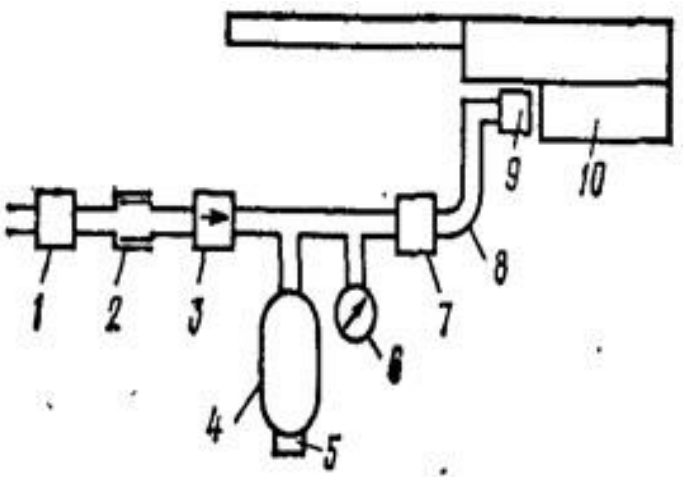

Figure 13. Pneumatic refill system

1-Reductor, 2- Turning Joint, 3-Reverse Valve, 4-Balloon, 5-Protective Valve, 6-Manometer, 7-Electropneumoklapana, 8-Pipe Transmitter, 9-Switch Valve, 10-Refill Cylinder.

The reducer reduces the pressure of the onboard air source to the working pressure of the mechanisms of the pneumatic recharging system. The rotary joint supplies the air pressure to the moving elements of the unit. The check valve ensures that the air supply in cylinder 4 is maintained when the pressure in the onboard source decreases. In the balloon unit, the reserve is important for air generation and use during refilling.

The pressure in the system is measured by manometer 6. Safety valve 5 releases excess air when the pressure in the cylinder exceeds the norm.

Opening and closing the air supply to the refill cylinder 10 is performed by an electro-pneumo-valve, which is actuated by the refill control system by a switch valve 9. When air is supplied for refilling, the bypass valve securely connects the refill cylinder and the tube actuator 8. When the air supply stops, the bypass valve opens wide, accelerating air release from the refill cylinder and reducing the refill time.

In the pyrotechnic reloading system, the energy of the gunpowder gases of the pyro cartridges activated by the reloading control system is used for reloading.

The advantages of the pyrotechnic reloading system are as follows: -lightweight, simple structure, and high reliability.

The main disadvantage is the limitation of the number of reloads performed during one flight in the air (which is determined by the number of pyro-cartridges).

Power transmission of moving devices. The power transmission of mobile artillery units performs the rotation of the weapon relative to the flying machine in flight. It should provide tracking of the target under conditions of non-constant external influences (aerodynamic, kick and inertia, continuous and large changes in the angular velocity of the target line).

The power transmission must work reliably under strong vibrations associated with shooting; it must have great strength so that the affected parts of the device do not lead to more scattering of projectiles during shooting. High-altitude and high-speed flights of modern flying machines create unfavorable conditions for cooling transports. To those listed above, adding the requirements of small weight and volume dimensions is necessary.

Two types of transmission mostly meet the requirements listed above:

- Electric power transmission with an electric machine amplifier;
- Hydraulic power transmission with wide adjustment.

Electric power transmission with an electric machine amplifier is built into a generator-engine system. The motor armature is fed only from a separate direct current generator - an electromechanical amplifier (EMG). The signal to the excitation loop of the amplifier of the electric machine is given in the form of voltage. The core of the generator of the electric machine amplifier rotates with the engine of the generator at a constant speed. In the loop of the armature, an electric motive force corresponding to the magnetic flux of the control loop is generated. As a result, a voltage is generated at the generator's output, which is supplied to the propulsion engine and rotates the weapon.

DC motors are widely used as transfer motors. The main requirement for direct current propulsion motors of artillery installations is that the rotation speed does not depend on external influence.

2. BALLISTIC CHARACTERISTICS OF AERIAL AMMUNITION

In general, the ballistic characteristics of aerial ammunition are determined by their mass m and characteristic area S. The dependence of the S-like cross-sectional area and the frontal resistance on the number M=cx(M) is taken. However, for convenience in practice, instead of these indicators, any generalized quantity is used, which is the ballistic characteristic of an aviation bomb. With this in mind, one of the following quantities is currently used as the ballistic characteristics of aerial ammunition.

Ballistic coefficient is given in Equation 2.

$$c = \frac{\dot{I}d^2}{m}10^3 \tag{1}$$

where d is the maximum diameter of the aviation bomb; $\dot{I} = \frac{C_x(M)}{{C_x}^e(M)}$ is the form factor of the aerial bomb;$C_x(M) = \frac{v}{a}$, is the dependence of the given aerial bomb impact on the number M; $C_x(M)$-M is the standard of cx from the number is dependent, the group is the same for aerial bombs and is also called the law of friction; v is the speed of the air bomb in its trajectory; a is the speed of sound.

An example views of dependences cx (M), C_x e (M), and i (M) is shown in Figure 14. It can be seen from here that it depends on the number M in i, but always the average value of the intervals (ranges) of changes in the air of the given aerial bomb M is taken.

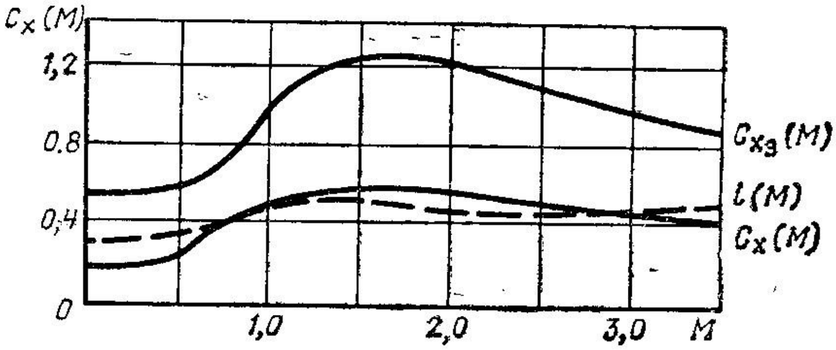

Figure 14. View of dependencies of cx (M), C_x e (M) and i (M)

The characteristic time is defined as the time of fall of a bomb dropped from an airplane flying horizontally at a speed of 144 km/h (40 m/s) at an altitude of 2000 m under normal atmospheric conditions.

Characteristic speed - the value of which is determined as given in Equation 2.

$$v_A = \sqrt{\frac{2mg_0}{S\rho N_0 C_{x0}(M=0.4)}} \tag{2}$$

Where g_0 is the acceleration of gravity at sea level, No is the normal density of air at sea level.

There is a certain functional dependence between all these quantities; when one of them is known, the rest can be calculated. It can be said that the smaller the diameter of the air bomb and the larger its mass, or if its head is designed to reduce air resistance during movement, the value of the ballistic coefficient will be smaller, as depicted in Figure 15.

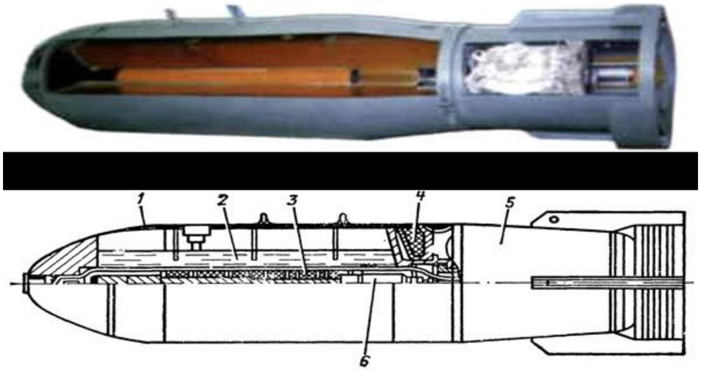

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Figure 15. Typical scheme of volume detonation aviation bomb ODAB-500) (Krishnamoorthy et al., 1997).

1-Trunk, 2-Supply, 3-Dispersive Load, 4-Second Cargo (Landing), 5-Parachute Container, 6-Explosive.

The difference between ODAB-500 with the same cap and the usual FAB is explained by the fact that in ODAB-500, the supply's energy is used more efficiently. Indeed, when ordinary solid explosives detonate near the detonation point, a high-energy mixture (the pressure of the explosion products is 150-200 thousand atmospheres) is formed, rapidly decreasing as the shock waves at the detonation point move away.

As a result of the explosion of the fuel-air mixture, less pressure (20-30 atmospheres) is created, but it covers an area equal to the radius of the created cloud, thereby increasing the ability to destroy practically any target (airplanes and helicopters in open stands have a pressure of 0.3-0.4 atmospheres they take average damage from shockwaves). Thus, a sufficiently high pressure is created within the dimensions of the fuel-air mixture cloud, outside of which shock airwaves are produced, which can destroy targets.

In addition, the fuel-air mixture in the process of cloud formation leaks into trenches and covered spaces and fills areas under trees, which increases the destruction capability of ODAB.

The latest advancements in bomb technology exemplify a strategic shift from conventional large-yield munitions to compact, precision-guided bombs with sophisticated capabilities. A key breakthrough is the development of Small Diameter Bombs (SDBs), which can strike targets with unparalleled accuracy from considerable distances, thus significantly minimizing collateral damage. These bombs leverage GPS, inertial navigation, and laser guidance systems for pinpoint precision. Moreover, their programmable fuzes facilitate airburst, delayed, or ground-penetrating detonations, offering adaptability to engage various targets effectively. Going beyond precision, integrating networked capabilities in munitions signifies a groundbreaking advancement. Weapons like the Small Diameter Bombs are equipped with datalinks, enabling mid-flight targeting updates and mission adjustments, substantially reducing the risk of unintended casualties (Elert & Sokołowski, 2018).

Furthermore, the future of aerial bombs revolves around modularity, aiming to create bombs with interchangeable seeker heads and warhead sections. This innovative approach allows a single aircraft to engage a diverse range of targets by interchanging components easily, from armored vehicles to fortified bunkers. Ultimately, these technological advancements underscore a departure from sheer destructive capabilities and a deliberate focus on enhancing precision, versatility, and discrimination- a definitive testament to the evolving landscape of modern warfare.

3. DISCUSSIONS

Although there are many different types of aerial ammunition, most of them have a similar structure, as shown in Figure 16. A typical aviation bomb consists of body 1, combat equipment 2, suspension lugs 3, and stabilizing device 4.

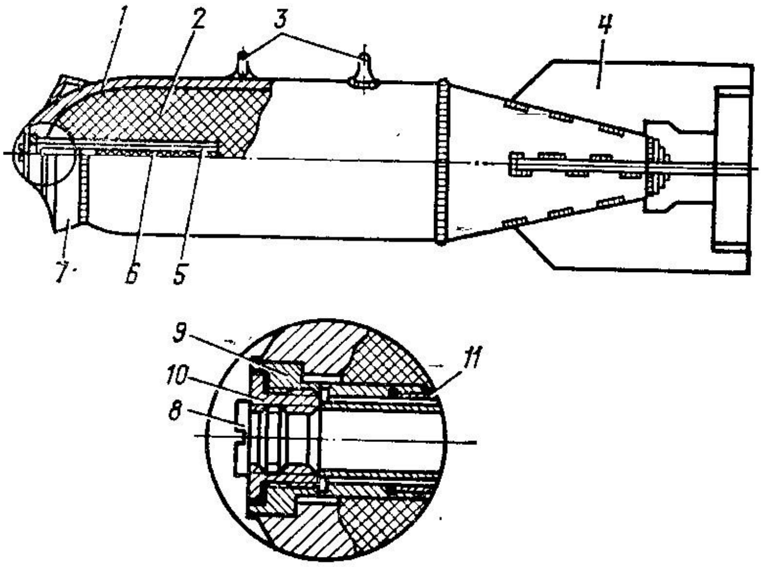

Figure 16. Structure of a typical aviation bomb:

1-Trunk, 2-Combat Supplies, 3-Hanging Headphones, 4-Stabilizing Device, 5-Wick (Detonator) Cup, 6-Additional Detonator, 7-Ballistic Circle, 8-Cover, 9-Head Carving, 10-Transient Carving, 11-Wick Cup Tube) (Momcilo, 2015).

The body is designed to combine all the elements of the aviation bomb in one unit and to accommodate combat supplies. The strength of the body should ensure the ability to combat the application, storage, and maintenance of the bomb. Usually, according to the body's structure, it consists of head, middle, and tail parts, and they are connected to each other by welding. The head part is made in two intersecting cones in half space. The shape and dimensions of the warhead strongly influence the aerodynamic characteristics of the bomb, especially against drag. The warheads of aerial ammunition designed to penetrate solid obstacles are made of significantly stronger material. Most small-caliber aerial ammunition has a threaded hole in the head corresponding to the detonator groove's diameter (the groove's diameter is 26mm). In large-caliber aerial ammunition, a fuse (detonator) cup 5 is installed on the head, which consists of a head recess 9, a transient recess 10, and a fuse cup tube 11. The diameter of the head and transitional recesses ensures the connection of detonators with a groove of 36 and 52 mm to the bomb. An additional detonator (incendiary bullet) 6 is placed in the fuse cup, which causes the explosion (fire) impulse to increase (Holmes, 1979).

The middle part of an aviation bomb is cylindrical. The thickness of the wall may vary depending on the purpose (type) and print of the bomb.

In the middle part of the body, the ears of the suspension system 3 are fixed.

The tail part of the fuselage is made in the form of a cone, which improves the ability of the bomb to break the airflow and the reliable operation of the stabilizers.

Most large-caliber bombs have one or two threaded fuse cups installed in the tail section for detonators. Sometimes, the wick cup is also installed on the side.

A metal or plasma cover 8 is attached to each threaded eyelet to protect detonators and explosives so that the threaded eyelets are not damaged and moisture and foreign elements do not fall into the detonator cups (Hakim, 1995).

The body of most bombs is made of steel plate by welding. The body of most bombs is typically constructed using steel plates that are welded together. In some cases, to ensure high strength, the body of aerial ammunition is made using cast (steel, steel cast iron) or seamless sections of steel tubing.

The stabilizing device (stabilizer) gives the bomb the necessary stable motion in the air after launching it. An aviation bomb is considered stable when, during the fall, its axis tries to coincide with the velocity vector, which continuously changes its position in space due to the free fall momentum.

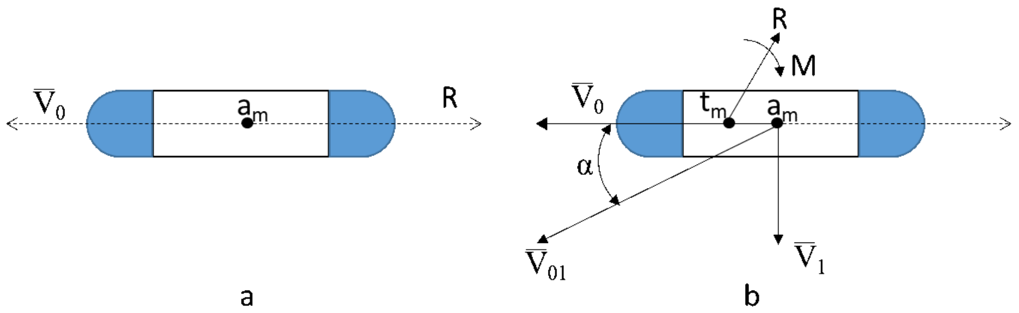

Figure 17.a. Initial Moment After the Launch of an Aerial Bomb Without a Stabilizer, **17.b.** The Vertical Velocity Component

Figure 17.a is the initial moment after the launch of an aerial bomb without a stabilizer during the horizontal flight of the aircraft. In this case, the velocity vector of the bomb, which is equal to the speed of the plane, $\overline{V}0$, is directed in the direction of the axis of the bomb, and the frictional force of the air acting on the bomb is directed in the opposite direction. After some time has passed, the vertical velocity component $\overline{V}1$ as shown in Figure 17.b is added to the initial velocity vector of the air bomb due to the release acceleration, and the velocity vector of the bomb relative to the air $\overline{V}01=\overline{V}0+\overline{V}1$ will deviate from the axis of the bomb by several angles of attack α.

When the angle of attack is formed, the aviation bomb is not located symmetrically concerning the air stream flowing along the vector $\overline{V}01$. Therefore, the air resistance in $\overline{R}$ will no longer be directed along the axis of the bomb but will form an angle of several degrees with it. The point of action of this force, i.e., the center of pressure for an axisymmetric oblong bomb, is located in front of the center of mass of the aerial bomb, and the force R will create a pitching moment M relative to it, which will try to increase its angle of attack. Under the influence of this moment, the bomb will start to spin as it falls. A spinning aerial bomb does not allow out an aiming bomb, as its trajectory and the point of final drop depend on many factors that cannot be taken into account when aiming. When the bomb is dropped from the plane, it already has an initial angle, which makes it even more challenging to aim.

3.1. Safety Rules During the Operation of Aerial Ammunition

1. Working with aerial ammunition is dangerous; therefore, during these works, essential conditions must be created that comply with technical safety rules, fire safety, and labor protection rules. Technical safety regulations must be followed in all cases.

2. Persons who know the structure and working principle of aerial ammunition, the rules of preparation for their combat application, who have studied the management of storage and protection of aviation ammunition, the relevant technical and safety regulations, who have passed special training and passed the approval, are allowed to work in aerial ammunition.

3. It is prohibited during the operation of aerial ammunition:

- To drop, press, or hit aerial bombs on tarred or untarred, as well as to drag or roll them on untarred soil or concrete
- Loading bombs without a lift by sliding
- Slide the aerial bomb onto the tarred soil or concrete
- Placement of bombs under power lines
- Carrying out the loading of aerial ammunition in faulty tanks, repairing the tank when there is a bomb inside the tank
- Overloading of transport equipment intended for the transportation of aerial ammunition
- Dismantling of aerial ammunition
- Sliding of the ball hook of the electric release device of the software switching mechanisms on the rack of the impulse transmitter mechanism of the bomb handle during the hanging or removal of the bomb
- Use of bombs with electric release devices with damaged wires
- Standing on the stabilizer side of the bomb when the ball hook of the electric release device is transferred to or removed from the impulse mechanism of the bomb handle
- To drop a bomb without making sure that the plane's bombing system is completely disconnected from the electrical network when the bomb is dropped
- To connect the electrical circuit of the bombing system after the bomb is hung until combat application.

Safety rules during the operation of aerial ammunition differ for different bombs, and this information is indicated in their technical explanations for different aerial ammunition.

3.2. Safe Separation

Safe separation of aerial bombs from fighter aircraft is a critical process that involves meticulous planning and execution. This procedure ensures the safe deployment of bombs from a fighter aircraft, minimizing the risk of accidental detonation and ensuring the safety of both the aircraft and the ground personnel (Pan et al., 2023).

Throughout the history of aviation, engineers have consistently made efforts to enhance their capacity to deliver weapons with precision, reliability, and safety. In contemporary times, the successful engagement of a target necessitates seamless integration between the aircraft and the weapon, enabling the full exploitation of the weapon's capabilities. However, this integration process presents challenges, including ensuring safe separation and assessing the structural integrity of the aircraft when a weapon is released. Furthermore, the complexity of integrating weapons onto aircraft is compounded when considering the intricate requirements for priming and aiming. Thus, the effective integration of weapons onto aircraft requires a multi-disciplinary approach within the integration organization (Daso, 2008). Ensuring the safe separation of these weapons from the aircraft is paramount to the success of any mission. The potential consequences of improper separation are dire, ranging from inadvertent detonation to compromising the structural integrity of the aircraft. Therefore, meticulous planning and execution are essential components of the process, underscoring the critical importance of safe bomb deployment from fighter aircraft.

The first step in safely separating aerial bombs is a thorough pre-flight inspection. This critical phase ensures that every aspect of the bomb deployment process is meticulously scrutinized before takeoff. During the pre-flight inspection, highly trained personnel meticulously visualize the bombs and their supporting equipment, such as bomb racks and release mechanisms, to ensure they are securely attached and free from any visible defects or anomalies. Additionally, technicians meticulously verify that the bombs are properly armed and fused according to operational requirements, minimizing the risk of accidental detonation during deployment. Furthermore, compatibility checks are conducted to ensure that the bombs are suitable for the specific aircraft and mission parameters. Any identified defects or malfunctions are promptly addressed and rectified to maintain the highest standards of safety and operational readiness. This comprehensive pre-flight inspection process plays a crucial role in mitigating risks and ensuring the safe and successful separation of aerial bombs from fighter aircraft.

To gain a comprehensive understanding of the complexities involved in aerial bomb deployment, it's imperative to first grasp the fundamental technical requirements that govern this process. Recognizing the critical role of suspension and positioning requirements sets the stage for a deeper exploration of the intricacies involved. Additionally, understanding the significance of front lug shifting for stability and aerodynamics, along with the necessity of increasing suspension lug base for large bombs, provides essential insights into the challenges and considerations at play. These technical factors not only ensure the secure attachment of bombs to the aircraft but also optimize their positioning for deployment, thereby laying the groundwork for safe and efficient separation. By delving into each of these components, we can develop a nuanced understanding of their collective importance in facilitating the successful deployment of aerial bombs, ultimately contributing to the enhanced performance of aerial operations.

3.2.1. Suspension and Positioning Requirements

3.2.1.1.Determining the Point of Bomb Suspension

Determining the point of bomb suspension is a critical step that requires meticulous planning and engineering precision. This process entails considering a range of factors and accurately identifying the point where the bomb will be suspended, ensuring its safe deployment and movement towards the intended target during flight. It's imperative to recognize that this determination is not solely based on engineering parameters; rather, it's intricately tied to operational objectives that define the mission's success.

Operational objectives play a pivotal role in determining the point of bomb suspension. These objectives encompass a spectrum of goals, from directing the bomb accurately towards its target to ensuring optimal detonation and damage potential. Engineers leverage mathematical models and simulations not only to calculate the physical parameters but also to align the suspension point with these operational objectives. By integrating these factors seamlessly, engineers can pinpoint the optimal suspension point that maximizes mission effectiveness and safety.

Additionally, the point of bomb suspension should be selected considering the aircraft's aerodynamic structure and flight characteristics. Specifically, the most suitable position for the bomb should be calculated, taking into account factors such as the aircraft's center of gravity balance, interaction with airflow, and other aerodynamic considerations. This is a crucial factor that can affect the aircraft's stability and maneuverability. These aerodynamic factors, intertwined with the structural and safety considerations, form the cornerstone of the bomb suspension process.

Furthermore, safety and risk factors must be considered when determining the point of bomb suspension. It is particularly important that the point of bomb suspension does not compromise the structural integrity of the aircraft or jeopardize flight safety. Therefore, engineers must also consider factors such as the aircraft's carrying capacity and structural durability when identifying the point of bomb suspension. By harmonizing aerodynamic precision with structural robustness, engineers ensure not only optimal flight performance but also the safety and integrity of the aircraft throughout its mission.

Finally, collaboration and communication are essential during the process of determining the point of bomb suspension. Engineers must maintain constant communication with the aircraft's design team and operational personnel, working together to meet the requirements of all stakeholders. This collaboration ensures the identification of the correct and safe point of suspension and can be key to operational success.

3.2.1.2.Design and Features of the Suspension Lug

Designing the suspension lug and specifying its features is a fundamental aspect of ensuring the safe deployment and stable positioning of aerial bombs on fighter aircraft. This process involves a comprehensive understanding of the bomb's characteristics, the aircraft's structural dynamics, and the aerodynamic forces experienced during flight.

To begin with, engineers must consider the structural integrity and load-bearing capacity of the suspension lug. The design should be robust enough to withstand the forces exerted during acceleration, deceleration, and maneuvering while ensuring the bomb remains securely attached to the aircraft.

Moreover, the design of the suspension lug must take into account compatibility with the aircraft's bomb racks and release mechanisms. This requires precise engineering to ensure seamless integration and operation within the aircraft's existing infrastructure.

Additionally, aerodynamic considerations play a crucial role in the design of the suspension lug. Engineers must optimize the lug's shape and placement to minimize drag and airflow disruption, thereby enhancing the aircraft's overall performance and stability during flight.

Furthermore, the materials used in the construction of the suspension lug are critical to its performance and longevity. High-strength alloys or composite materials are typically employed to withstand the harsh operating conditions experienced during aerial missions while minimizing weight to optimize the aircraft's payload capacity.

Finally, rigorous testing and evaluation are essential to validate the design and ensure its compliance with safety standards and regulatory requirements. This may involve simulated flight testing, structural analysis, and real-world field trials to verify the suspension lug's performance under various operating conditions.

3.2.1.3.Adapting the Suspension Lug According to the Size and Weight of the Bomb

Adapting suspension lugs according to the size and weight of the bomb is a critical aspect of ensuring optimal performance and safety during deployment. Engineers must meticulously tailor the design and specifications of the suspension lugs to accommodate variations in bomb dimensions and masses, considering factors such as aerodynamic stability, structural integrity, and load-bearing capacity.

Firstly, engineers analyze the specific dimensions and weight distribution of the bomb to determine the optimal configuration for attachment to the aircraft. This analysis involves assessing the center of gravity, moments of inertia, and aerodynamic characteristics to ensure proper balance and stability during flight.

Next, engineers modify the suspension lug design to accommodate the unique requirements of different bomb sizes and weights. This may involve adjusting the lug's geometry, dimensions, or materials to provide adequate support and secure attachment while minimizing added weight and aerodynamic drag.

Furthermore, engineers consider the dynamic behavior of the aircraft-bomb system during maneuvers and operational scenarios. They optimize the suspension lug design to mitigate any potential issues related to vibration, oscillation, or dynamic loading, ensuring smooth and stable deployment under all conditions.

Moreover, the adaptation of suspension lugs may involve incorporating features such as adjustable mounting points or modular components to facilitate versatility and compatibility with a range of bomb configurations. This flexibility allows for streamlined logistics and maintenance while ensuring optimal performance across diverse mission requirements.

Finally, comprehensive testing and validation procedures are conducted to verify the effectiveness and safety of the adapted suspension lug designs. This may include simulated flight tests, structural analysis, and field trials to assess performance under real-world conditions and ensure compliance with stringent safety standards.

Following the meticulous pre-flight inspection detailed above, the loading and securing of bombs onto the aircraft demand utmost precision and attention to detail. Every step in this complex process is critical, from attaching the bombs securely to the bomb racks to ensuring the placement of all safety pins and locks. Moreover, meticulous calculations regarding the weight and balance of the aircraft are imperative to guarantee stability during flight. A thorough understanding and execution of proper loading and securing procedures are essential to mitigate any risks of unintended release during flight.

The actual separation of the bombs from the aircraft is a critical moment that requires careful coordination between the pilot and the ground control team. Building upon the meticulous preparations, detailed procedures guide the pilot in executing the release of the bombs with precision and safety in mind. The pilot's adherence to specific protocols minimizes the risk of unintended detonation and ensures the safe separation of each bomb. Simultaneously, the ground control team plays a crucial role, closely monitoring the release process and confirming the safe detachment of each bomb from the aircraft before signaling the all-clear. This coordinated effort between the pilot and ground control team is essential to ensure the success and safety of the bomb separation process. Simulating the bombing activity is also of vital importance (Sabatini et al., 2000).

3.2.1.4.Assembly Process and Correct Assembly Methods

The first step in safely separating aerial bombs is a thorough pre-flight inspection. This involves visualizing the bombs and their supporting equipment, such as bomb racks and release mechanisms. The inspection also includes properly arming and fusing the bombs and verifying that they are compatible with the aircraft. Any defects or malfunctions must be identified before the aircraft takes off.

The assembly process and proper mounting techniques are crucial aspects of ensuring the safe and effective attachment of bombs to fighter aircraft. Engineers and technicians follow meticulous procedures to guarantee secure installation and minimize the risk of detachment or malfunction during flight.

Firstly, the assembly process begins with preparing the aircraft and bomb racks for mounting. This involves inspecting the mounting points, ensuring they are free of debris or damage, and verifying the integrity of associated hardware such as bolts, nuts, and locking mechanisms.

Next, technicians carefully position the bombs on the designated racks, aligning them according to precise specifications provided by engineering guidelines. Attention to detail is paramount during this step to ensure proper weight distribution, balance, and clearance with surrounding components.

During the mounting process, technicians use specialized tools and equipment to secure the bombs to the aircraft securely. Torque wrenches, fasteners, and locking pins are employed to achieve the required tightness and prevent loosening or shifting during flight.

Moreover, technicians follow specific torque values and tightening sequences prescribed by aircraft manufacturers and regulatory standards to ensure consistent and uniform attachment across all mounting points. This standardized approach minimizes the risk of over-tightening, which could compromise structural integrity, or under-tightening, which could lead to loosening or detachment.

Additionally, technicians may employ additional measures such as safety wire or adhesive bonding to provide extra reinforcement and prevent accidental release or separation of the bombs. These supplementary techniques enhance the overall reliability and security of the mounting assembly.

Finally, thorough inspection and quality control procedures are conducted following the mounting process to verify compliance with safety standards and technical specifications. This may involve visual checks, functional tests, and structural integrity assessments to confirm that the bombs are securely mounted and ready for operational deployment.

3.2.2. Front Lug Shifting for Stability and Aerodynamics

3.2.2.1. Shifting the Front Lug Forward 220 mm from the Center of Gravity of the Bomb: Reasons and Importance

The forward shifting of the front lug by 220 mm beyond the bomb's center of gravity is a critical adjustment in bomb suspension systems, with specific reasons and importance underlying this positioning. Firstly, this displacement aims to optimize the aerodynamic characteristics of the bomb during flight. By positioning the lug forward of the center of gravity, it facilitates a more stable and streamlined airflow around the bomb, reducing aerodynamic drag and enhancing overall stability. This adjustment is particularly crucial during high-speed maneuvers and adverse weather conditions, where precise aerodynamic performance is essential for safe and accurate bomb delivery. Moreover, the forward displacement of the front lug plays a significant role in mitigating the risk of inadvertent bomb release or separation during flight. By positioning the lug ahead of the center of gravity, any forces acting on the bomb tend to push it toward the aircraft rather than away from it. This inherent stability minimizes the likelihood of premature bomb release due to aircraft vibrations, turbulence, or sudden maneuvers, ensuring the safety of both the aircraft and ground personnel.

Furthermore, the forward shifting of the front lug contributes to the overall balance and handling characteristics of the aircraft-bomb combination. By strategically positioning the lug in relation to the bomb's center of gravity, engineers can optimize the weight distribution and moment of inertia, thereby improving the aircraft's maneuverability and responsiveness during bomb delivery missions.

Overall, the forward displacement of the front lug by 220 mm represents a carefully calculated adjustment that balances aerodynamic performance, stability, and safety considerations in bomb suspension systems. This positioning not only enhances the bomb's flight characteristics but also reduces the risk of accidental release, ensuring the effective and secure delivery of ordnance in diverse operational scenarios.

3.2.2.2.The Effect of Shifting on Aerodynamic Stability

The effect of the shifting process on aerodynamic stability is paramount in bomb deployment systems, influencing various aspects of flight performance. By shifting the front lug forward of the bomb's center of gravity, the overall aerodynamic profile of the bomb-aircraft system is optimized, minimizing aerodynamic drag and improving stability, particularly during high-speed flight regimes and dynamic maneuvers. This streamlined airflow around the bomb reduces turbulent airflow separation, ensuring smoother, more predictable aerodynamic behavior and enhancing overall flight stability. Moreover, this shifting process directly impacts the dynamic response of the bomb to external forces and disturbances. Positioning the lug ahead of the center of gravity provides the bomb with greater resistance to destabilizing influences such as gusts, turbulence, and aircraft vibrations. This increased stability mitigates the risk of unwanted deviations in flight path or orientation, ensuring precise and predictable bomb delivery under diverse operational conditions.

Furthermore, the shifting process contributes to the overall controllability and maneuverability of the aircraft-bomb system. By optimizing the aerodynamic stability of the bomb, pilots can achieve greater control authority and responsiveness during bomb delivery missions. This enhances their ability to accurately place ordnance on target, even in challenging environments or high-threat scenarios.

Aerodynamic stability stands as a cornerstone in the successful deployment of aerial bombs from fighter aircraft. By optimizing the bomb's airflow characteristics, the shifting process significantly enhances aerodynamic stability. This optimization not only improves the bomb's resistance to external disturbances but also enhances its overall controllability. In essence, aerodynamic stability plays a critical role in ensuring the safe, precise, and effective delivery of ordnance from fighter aircraft across diverse operational scenarios. Besides, the assessment of missile stability encompasses both static stability and dynamic stability. A statically stable missile has the capability to counteract an increasing angle of attack with a certain degree of pitching moment (Fleeman, 2001). In practical terms, statically stable missiles demonstrate weathercocking tendencies, resulting in shifts in orientation in response to changes in flight conditions. In order to hold this aerodynamic characteristic, a sign of the Cmα (pitch stiffness derivative) must be negative, as given in Equation 3.

$$C_{m\propto} = \frac{\Delta C_m}{\Delta\propto} < 0 \tag{3}$$

The aerodynamic stability of aerial bombs is greatly influenced by the control alternatives, as illustrated in Figure 18.

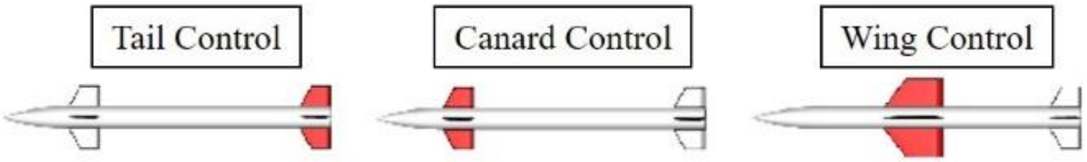

Figure 18. Control Variations of Aerial Ammunitions (The Figure was re-illustrated based on the information (Arslan, 2014).

3.2.2.3.The Importance of Front Lug Position for Safe Aircraft Separation

The positioning of the front lug plays a crucial role in ensuring the safe separation of bombs from the aircraft, directly influencing the dynamics and outcome of the separation process. By strategically placing the front lug at an optimal position relative to the aircraft's center of gravity, engineers aim to achieve controlled and predictable separation behavior, critical for minimizing the risk of interference between the bomb and the aircraft structure during release, which could lead to unintended collisions or disturbances. Moreover, the precise positioning of the front lug is essential for maintaining the stability and integrity of the aircraft-bomb system throughout the separation event. Placing the lug at the correct location ensures that the bomb's release does not induce excessive pitching, rolling, or yawing moments on the aircraft, which could compromise flight safety, instead facilitating a smooth and stable separation trajectory, allowing the bomb to clear the aircraft's wake without endangering its structural integrity or aerodynamic stability.

Additionally, the front lug's positioning significantly influences the trajectory and behavior of the released bomb, directly impacting its accuracy and effectiveness in reaching the designated target. By meticulously adjusting the lug's position, engineers aim to ensure that the bomb follows a predictable flight path and maintains proper orientation during separation, thereby improving overall delivery accuracy and mission success rates.

To summarize, the precise placement of the front lug is paramount for ensuring the safe and efficient separation of bombs from aircraft, thereby minimizing the risk of interference, preserving flight stability, and optimizing delivery precision. Through rigorous engineering analysis and testing, engineers strive to identify the optimal lug position that strikes a balance between these factors, facilitating reliable and consistent bomb deployment in operational settings.

3.2.3. Increasing Suspension Lug Base and Front Lug Shifting for Large Bombs

3.2.3.1.Increasing Suspension Lug Base for Mounting Large Bombs: Rationale and Importance

The decision to increase the suspension lug base for the mounting of large bombs stems from a combination of engineering considerations and operational requirements, all aimed at enhancing the safety and effectiveness of bomb deployment from aircraft. Large bombs, due to their size and weight, pose unique challenges during the suspension and release process, necessitating modifications to existing suspension lug configurations.

Primarily, the rationale behind enlarging the suspension lug base lies in improving the structural integrity and load-bearing capacity of the mounting system to accommodate the increased weight and size of large bombs. By widening the base, engineers aim to distribute the load more evenly across the aircraft's structure, reducing stress concentrations and minimizing the risk of structural deformation or failure during bomb deployment.

Moreover, enlarging the suspension lug base enhances the system's stability and resistance to dynamic forces encountered during flight maneuvers or turbulent conditions. Large bombs inherently introduce additional aerodynamic loads and moments on the mounting system, which must be adequately countered to maintain flight safety and stability. By expanding the lug base, engineers increase the system's resistance to lateral and torsional forces, thereby reducing the likelihood of sway or oscillations that could compromise the bomb's release accuracy or the aircraft's controllability.

Furthermore, the larger lug base provides a more secure and robust attachment point for large bombs, reducing the risk of detachment or displacement during high-stress flight scenarios such as combat maneuvers or evasive actions. This enhanced attachment stability is crucial for ensuring reliable bomb delivery and minimizing the potential for unintended releases or malfunctions that could jeopardize mission success or pose safety risks to the aircraft and its crew.

In summary, increasing the suspension lug base for mounting large bombs is driven by the need to enhance structural integrity, stability, and attachment security, thereby ensuring the safe and effective deployment of heavy ordnance from aircraft. Through careful engineering analysis and validation, engineers strive to optimize the lug configuration to meet the demanding requirements of modern aerial warfare while maintaining the highest standards of safety and reliability.

3.2.3.2. Forward Shifting of Front Lug by 440 mm from the Center of Gravity for Large Bombs: Reasons and Importance

Furthermore, continuous training and periodic inspections are essential to maintain the safety of the aerial bomb separation process. Pilots and ground personnel must undergo regular training and evaluation to ensure they are up-to-date with the latest procedures and protocols. The equipment and systems used in the separation process must also be regularly inspected and maintained to ensure reliability and functionality.

The decision to shift the front lug forward by 440 mm from the center of gravity for the mounting of large bombs is grounded in a thorough analysis of aerodynamic principles, structural requirements, and operational considerations. This adjustment aims to optimize the positioning of the front lug to ensure stability, control, and safety during the release of large bombs from aircraft.

The primary reason for moving the front lug forward is to improve the aerodynamic performance of the bomb-aircraft system during release maneuvers. Large bombs, due to their size and weight, exert significant aerodynamic forces on the aircraft when suspended beneath it. By shifting the front lug forward, engineers seek to mitigate potential aerodynamic disturbances and moments that could affect the aircraft's stability and controllability during bomb release.

Furthermore, relocating the front lug enhances the overall balance and weight distribution of the bomb-aircraft configuration, minimizing trim changes and control surface deflections required to maintain stable flight conditions. This optimized weight distribution is particularly crucial for high-performance aircraft operating at varying speeds and altitudes, where minor deviations in aerodynamic balance can have significant impacts on flight characteristics and handling qualities.

Moreover, moving the front lug forward improves the system's mechanical advantage during bomb release, reducing the required release force and ensuring smoother and more predictable bomb separation dynamics. This enhanced mechanical efficiency not only reduces the risk of unintended bomb hang-ups or partial releases but also minimizes stress on the release mechanisms and associated components, enhancing their reliability and longevity.

In summary, shifting the front lug forward by 440 mm for the mounting of large bombs is motivated by the need to optimize aerodynamic performance, weight distribution, and mechanical efficiency during bomb release from aircraft. Through careful analysis and testing, engineers aim to maximize the safety, effectiveness, and reliability of bomb deployment operations, ensuring mission success and the protection of aircraft and personnel.

3.2.3.3. The Role of Front Lug Position in Aerodynamic Stability and Safe Separation

The role of the front lug position in aerodynamic stability and safe bomb separation is fundamental to the overall design and operation of aircraft-bomb systems. The precise location of the front lug plays a crucial role in maintaining aerodynamic stability during various flight phases, particularly during the critical moment of bomb release.

First and foremost, the position of the front lug directly influences the aerodynamic forces that act on the aircraft-bomb configuration. The optimal placement of the front lug helps to minimize disturbances to the airflow around the aircraft, reducing the risk of aerodynamic instability and control issues during bomb release maneuvers. By carefully positioning the front lug, engineers can mitigate undesirable effects such as pitch, yaw, or roll moments that could compromise the aircraft's flight characteristics and handling qualities.

Furthermore, the front lug's position significantly affects the dynamic behavior of the aircraft-bomb system during bomb release events. The front lug serves as a pivotal point for the release mechanism, determining the trajectory and separation dynamics of the bomb. An accurately positioned front lug ensures smooth and predictable bomb separation, minimizing the likelihood of hang-ups, swings, or other undesirable behaviors that could jeopardize safety or mission success.

Moreover, the front lug position is intricately linked to the overall structural integrity and load distribution of the aircraft-bomb system. A properly positioned front lug helps to distribute the load evenly across the aircraft's structure, reducing stress concentrations and potential points of failure. This balanced load distribution is essential for maintaining structural stability and preventing structural damage, particularly under high-stress conditions during bomb release and subsequent flight maneuvers.

In summary, the front lug's position is paramount for ensuring aerodynamic stability, predictable separation dynamics, and structural integrity during bomb deployment from aircraft. By carefully considering and optimizing the front lug's location, engineers can enhance the safety, effectiveness, and reliability of aerial bomb separation operations, contributing to overall mission success and the protection of aircraft and personnel.

Finally, the safe separation of aerial bombs from a fighter aircraft is a complex and highly regulated procedure that involves multiple steps, from pre-flight inspection to post-flight evaluation. It requires high coordination, precision, and attention to detail to ensure that the bombs are deployed safely and accurately. Strict adherence to established protocols and continuous training and evaluation are crucial for this process's success and everyone's safety.

4. CONCLUSIONS

The following information pertains to the deployment of aerial bombs. When it comes to bombs, their size and displacement are critical factors that require careful consideration. For instance, more giant bombs with displacements between 1500 and 5000 kg demand a thoughtful approach in terms of suspension and detonation mechanisms. To ensure safe and effective deployment, the base of the suspension lugs for these bombs should be 480 mm. This distance is crucial as it allows the bomb to hang properly and maintain balance during transport. Additionally, the front lug of the bomb must be shifted 220mm towards the head from the center of gravity. This shift in position is crucial in providing the necessary stability and aerodynamics during flight.

For even larger bombs with a displacement of 9000 kg, the base of the suspension lugs must be increased to 1000mm. This is necessary due to the weight and size of the bomb, as a larger base is needed to support its mass. Similarly, the front lug must be shifted forward 440 mm from the center of gravity. This shift is essential in maintaining the balance and stability of the bomb during flight, ensuring it reaches its intended target accurately.

In addition to proper suspension, aerial bombs must be equipped with different detonators to set them off immediately upon impact. These detonators serve a crucial role in ensuring the mission's success, whether for strategic or tactical purposes. Aerial bombs are designed to create a maximum impact upon detonation, and a delay in the explosion could harm the mission's success.

Different detonators are used for different types of aerial bombs based on their intended use. For example, incendiary bombs require a different detonator than high-explosive ones, aiming to start fires rather than cause maximum destruction. The detonators must also be calibrated to the size and weight of the bomb, ensuring a precise and instantaneous explosion upon impact.

In conclusion, it is vital to adhere to the specifications mentioned above when handling aerial ammunition. The size and displacement of aerial bombs play a significant role in determining the necessary specifications for their proper deployment. Any miscalculation or error in these areas could have severe consequences, making it imperative to adhere to these guidelines when handling aerial bombs.

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Data Availability Statements

The datasets used or analyzed during the current study are available from the corresponding author upon reasonable request.

Competing Interests

The authors state that no known competing financial interests or personal relationships could have appeared to influence this proceeding paper.

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