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FOREIGN TECHNOLOGY DIVISION

MODERN WEAPON-GUIDED MISSILE

by

Liu Shaoqiu, Li Xianlin, et al.

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Book Series in Aer[illegible]ical

and Astronautical Technology

XIANDAI WUQI--DAODAN

MODERN WEAPON--GUIDED MISSILE

Compiled by

Liu Shaoqiu, Li Xianlin,

Chen Mingdi, and Lu Zheng

National Defense Industry Publishing House

Annotation

The series of Brief Guides to Aeronautics and Space Technology was prepared by the Editorial Division of HANGKONG ZHISHI (JOURNAL OF AVIATION SCIENCE) and the National Defense Industry Publishing House in order to meet the requirements of understanding aviation science and technology by workers in general, peasants, soldiers, teenagers, and young adults, to better serve socialism, to serve the national defense buildup, and to make new contributions to carrying out China's Four Modernizations.

The series of brief guides was prepared to make available, in a fresh writing style, relying on plain languages—layman's terms—to highlight complex subjects, as well as present striking diagrams and illustrations to satisfy the reading needs of workers in general, peasants, soldiers, teenagers, and young adults.

Since our technical level is limited, there are bound to be shortcomings and mistakes. We welcome constructive criticism and suggestions from readers in order to promote aviation science and technology.

Foreword

On a number of occasions, China successfully launched artificial earth satellites, several returning to the earth on schedule. Aeronautical and astronautical technology has developed rapidly in China; many people are most eager to learn about rocketry, missilery, aeronautics, and astronautics. Organized by the National Defense Industry Publishing House, we prepared (from publicly available sources) some popular science reading publications in order to introduce basic facts about missiles, aircraft and spacecraft as well as the developmental level and trends at home and abroad. So general readers can be made aware of the progress (of missiles, aircraft and spacecraft), the current state of the art and future trends, characteristics, components, applications, configurations, structures, and functions of major components.

Rocket technology has developed on a foundation of numerous branches of science; this is a solid manifestation of modern achievements in science and technology.

There are many kinds of missiles, and aeronautical and astronautical launch vehicles; so several guides were written about them. This book is one of these guides.

There are many kinds of weapons from ancient archery to modern arms. Rocket missiles are one kind of modern weaponry.

This book introduces missiles as one type of modern weaponry; there are ten chapters. Chapter I is a brief history of rocket developments. Chapters II and III are about the classification and flight principles of guided missiles. Chapters IV through VII outline the functions of major missile sections. Chapter VIII describes winged missiles. Chapter IX tells about the characteristics of cruise missiles, and the last chapter is about developmental trends of ballistic missiles.

By reading this book, a reader can systematically learn about the fundamentals of rockets and missiles.

This book was prepared with group discussion. A popular science writer, Associate Professor Shi Chaoli, and Jiao Yulin of the Editorial Division of HANGKONG ZHISHI reviewed all manuscripts and gave much assistance and guidance. Zhang Shaxin and others also did much work on this book. To them, the authors express their sincere gratitude.

Because of limited technical knowledge and reference materials available to the editors, mistakes and shortcomings will inevitably exist. Reader criticism and corrections are welcomed.

XIANDAI WUQI--DAODAN (MODERN WEAPON--GUIDED MISSILE)

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CHAPTER I

BRIEF HISTORY OF ROCKET DEVELOPMENTS

What Is a Rocket?

A single skyrocket flies off into a moonlit sky, dispalying a colorful sight. We all are familiar with firework; especially, children like them. Firework are often seen at celebrations on special holidays and on New Year's day.

What is a rocket? A skyrocket is the smallest and simplest rocket, often called a flower rocket. The firework unit has an arrowhead, consisting of a paper cylinder packed with gunpowder (flame powder). The exhaust gas pipe is made of clay; a fuse is attached to the pipe end. A stick stabilizes the entire firework unit while ascending, as shown in Fig. 1-1.

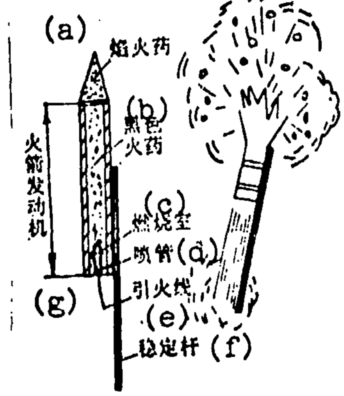

Fig. 1-1. Skyrocket
Key: (a) Flame powder; (b) Black powder; (c) Combustion chamber; (d) Nozzle; (e) Fuse; (f) Guiding stick; (g) Rocket engine.

Why can the skyrocket ascend into the sky? It does so because large volumes of combustion gases quickly escape through a nozzle after the black powder is ignited. The exhaust gases impart a reaction to the firework; when this reaction force has built up to an amount exceeding the weight of the firework unit, it ascends into the sky. Continuous combustion of the black powder provides a continuous gas flow discharging rearward. Thus, the reaction is continuously applied to the firework for its continuous ascent. When the powder has burned up, combustion gases stop being generated and the reaction force disappears. At that time, the flame powder in the top part of firework unit is ignited, releasing colorful flames. The burned-up residue of firework gradually descends as the power is lost. This fact shows that the ascending firework is propelled by the reaction of combustion gases. This reaction is called thrust. The rocket cylinder for combustion of the gunpowder and the nozzle for the exhaust escape make up a rocket engine. The black powder burning in the firework is solid fuel, which is called solid propellant (including oxidizers and combustion agents).

Figure 1-2 shows a short-range rocket (using solid propellant), appearing in the closing stages of World War II. The rocket is composed of a nose cone, a combustion chamber, solid propellant, a nozzle, and fins. After igniting the solid propellant by an ignition device, large volumes of high-temperature, high-pressure combustion gases are liberated in the combustion chamber while the combustion gases quickly escape through the nozzle, a thrust (the reaction of gas flow) is applied to the rocket as it flies forward.

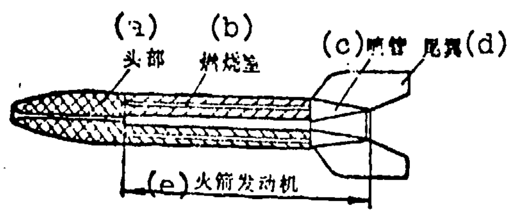

Fig. 1-2. A short-range solid-fuel rocket
Key: (a) Nose cone; (b) Combustion chamber; (c) Nozzle; (d) Fin; (e) Rocket engine.

Although the two examples mentioned previously are a toy and a primitive rocket, yet the concept of producing thrust and the principle of forward flight can be applied to all rockets.

We can see from the above examples that the rocket engine is an engine not requiring atmospheric oxygen but only ignites its self-contained propellant (including solid fuel, liquid fuel, and a solid-liquid mixture fuel), and produces high-temperature, high-pressure combustion gases. The gases quickly form a jet to produce a thrust for the engine. This is a main characteristic of rocket engine and its distinction from other types of engines.

What we usually call a rocket is a flight vehicle powered by thrust provided by a rocket engine. In different usages, a rocket can have different effective payloads. If a warhead is installed, this is a rocket weapon, the so-called military-application rocket. If a rocket has an effective payload other that a warhead, this is the so-called peaceful-application rocket. If a satellite is packed into a rocket, this is a satellite-launch vehicle. Besides, there are high-altitude sounding rockets, hail defense rockets, and others.

The Origin and Development of Rockets

All countries in the world acknowledge that the rocket was invented in China. As early as 683 AD in the early Tang Dynasty, a pill-refining chemist, Sun Simao, summarized a method of compounding gunpowder, drawing from long-established practice of working people. In the final period of the Tang Dynasty, gunpowder was used militarily.

In the early Song Dynasty, approximately 969 AD, Feng Yisheng, Yue Yifang, and others constructed a primitive rocket (gunpowder rocket); it was gradually improved and adopted as a weapon used during battles.

According to historical records, between the 11th and 13th century, rockets were used during battles between Song and Jin forces and between Song and Yuan forces.

In the 13th century, China's rocket and rocket technology were introduced into Arab countries, and then into European countries.

In the late Ming Dynasty, rocket weapons were considerably improved. In the 16th century, flying swords, flying spears, and flying arrows (Fig. 1-3) were constructed and employed for defense against Japanese bandits. Also made were rocket vehicles, shooting off a shower of rockets.

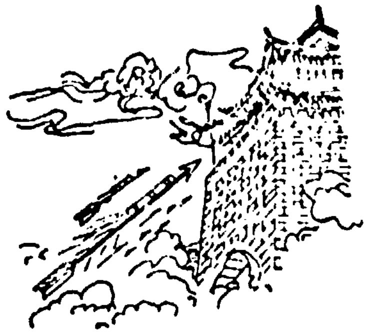

Fig. 1-3. Rocket Weapon

From the 17th to the early 19th century, Russia, India and England also vigorously developed rocket weapons to meet their military needs.

In the mid-19th century, guns and rockets were used side by side. At that time, there were smooth-bore guns with short ranges and poor precision. However, rockets were handy to use, with better performance. In the late 19th century, two new techniques were applied to guns: new gunpowder with nitrocellulose and rifled gun barrels. Thus, ballistic performance was considerably improved with longer ranges and higher precision. Comparatively speaking, there was no new development in rocket with diminishing military applications and stagnant production. At that time, guns were ahead of rockets. In the 1905 Russo-Japanese War and in World War I, rockets were seldom used.

Although rocket development was slow, scientists in many countries consistently conducted research and tests in rocket technology. Among them were Russian scientist Tsiolkovski and Goddard /Robert Hutchings Goddard/ of the United States. Due to slow progress in solid propellants at that time, Tsiolkovski suggested the possible use of liquid propellants with a schematic structure diagram (Fig. 1-4). In addition, he proposed designs for multistage rockets and the concept of interstellar flight.

In the 1930s, new achievements were gained in liquid propellants, new solid propellants, high-temperature materials, and electronic technology. This added new vigor to rocket weaponry. This was a renaissance of rocket technology. After the 1940s, rocket weapons became more and more important in warfare and a new status was [illegible]. In World War II, Germany launched first V-1 and then V-2 rockets to attack London, the British capital. After the 1950s, rocket technology entered a new developmental stage with the emergence of large carrier rockets, such as the intercontinental ballistic missiles, artificial satellites, and cosmos spacecraft. In addition to military applications, rockets are widely employed for peaceful purposes.

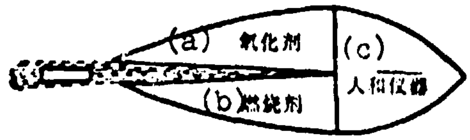

Fig. 1-4. Tsiolkovski's liquid-fuel rocket
Key: (a) Oxidizer; (b) Combustion agent; (c) Crew and instrument.

Although rockets originated in China, in old China rocket technology was not developed for a long time because of the protracted rule of the reactionary ruling class domestically and abroad. After the Liberation, under the leadership of the Party Central Committee and Chairman Mao, and the self-reliance and difficult struggle of the Chinese people, rocket technology rapidly developed within a short period. On 24 April 1970, China successfully launched its first artificial earth satellite. Five and half years later, a recoverable satellite was launched on 26 November 1975. This satellite functioned normally and returned to the earth according to a predetermined plan.

CHAPTER II

GUIDED MISSILES AND THEIR "ORGANS"

Means of Transportation and Weapon

A rocket is a flight vehicle propelled by a rocket engine. There are different types of rockets; some are maneuverable while others are not. Actually, a rocket engine is a jet engine using a self-contained propellent. After its combustion, the combustion gases are expelled rearward at extremely high velocity to produce thrust (reaction force), propelling the rocket forward.

A rocket is an ideal means of transportation in overcoming gravitational force and conquering cosmic space in interplanetary or interstellar flight.

What is a guided missile? What difference is there between a rocket and a guided missile?

Controlled by an internal or external system, a guided missile relies on its own power to deliver a warhead (such as a nuclear weapon) to a predetermined target. Therefore, a maneuverable rocket carrying a warhead is one type of guided missile.

A guided missile may have a rocket engine, or another engine type. This is one difference between a rocket and a guided missile. A guided missile is a pilotless weapon that can be used only once. Again this is one difference between an aircraft and a guided missile.

Guided missiles emerged in late World War II. Germany was the first country to successfully build maneuverable rockets, the V-2 ballistic missiles, a new weapon at the time. In 1944, Germany launched V-2 missiles to attack London of Britain. In all, 1050 missiles were launched; 80 exploded at their launch pads, while 370 failed to reach London. Only 600 missiles reached their targets, but there were considerable flight path deviations.

From World War II to the present time especially in the past two or three decades, developments of guided missile have been rapid with ranges from short to long. Some missiles can even fly over an ocean to cover both continents. There are many types of missiles, which can attack different targets, becoming the most powerful weapon in the modern age. We can say that guided missiles are a solid new achievement of modern science and technology.

Varieties of Guided Missiles

The development of rocket technology fills modern weapon depots with various missile armaments; some are big while others are small. Some missiles resemble aircraft with fuselage and wings; others are long and slender like wooden piles. There are many varieties.

Classified according to fundamental missile applications (by launch point and geographical positions of targets), there are the following major categories:

1. Ground-to-ground missiles (or surface-to-surface missiles) are launched from ground surface or sea surface (or undersea) to destroy targets at the ground surface or sea surface (or undersea).

2. Ground-to-air missiles (or surface-to-air missiles) are air-defense missiles or anti-missile missiles that are launched from the ground surface or sea surface (or undersea) to destroy midair targets at various altitudes (including warheads of ballistic missiles).

3. Air-to-ground missiles (or air-to-surface missiles) are aircraft-carried missiles that are launched from flying aircraft to destroy targets at the ground surface or sea surface (or undersea).

4. Air-to-air missiles are aircraft-carried missiles that are launched from flying aircraft to destroy midair targets.

By ranges, guided missiles can be divided into short range, medium range, long range, and intercontinental varieties.

Short range missiles are missiles with ranges of less than 1000 kilometers.

Medium range missiles are missiles with ranges of 1000 to 5000 kilometers.

Long range missiles are missles with ranges of 5000 to 8000 kilometers.

Intercontinental missiles are missiles with ranges of greater than 8000 kilometers.

By outward appearance and characteristics, guided missiles can be classified into ballistic missiles and winged missiles.

A ballistic missile is a wingless, pilotless flight vehicle carrying a rocket engine. The missile flies along a certain trajectory, mainly attacking stationary targets.

Winged missiles fly within the dense atmosphere, mainly attacking mobile targets.

According to the number of stages, there are single-stage and multistage (two or three stages) missiles.

By stage joining types, one classification includes the tandem type, the cluster type, and the tandem-cluster type missiles, as shown in Figs. 2-1, 2-2, and 2-3.

Additionally, there are other classificatory methods, which will be omitted in this book.

"Organs" and "Systems" of Guided Missiles

The human body includes various organs and systems, like the head, hands, digestive system, and respiratory system. What "organs" and "systems" are included in a missile?

Generally speaking, any type of guided missile has "organs" and "systems", such as the propulsion system, flight control system, missile fuselage, and warhead.

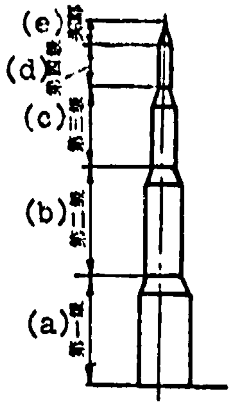

Fig. 2-1. Tandem type multi-stage missile
Key: (a) First stage; (b) second stage; (c) third stage; (d) fourth stage; (e) Nose cone.

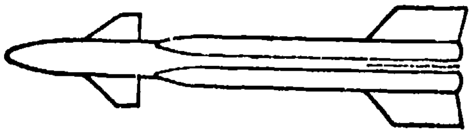

Fig. 2-2. Cluster type missile

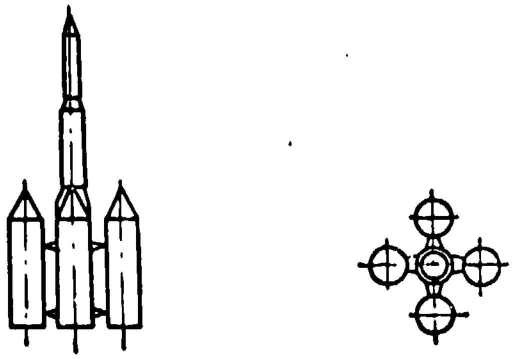

Fig. 2-3. Tandem-cluster type missile

Propulsion System

First, we have to start an engine to drive a motor vehicle forward. Aircraft engines also have to be started for an aircraft to take off from an airfield. So should an engine be started to enable a missile to ascend into the sky? Of course, an engine has to be started.

There is a law of mechanical motion in nature. Relative to the earth, without any external force a body at rest will forever maintain its state of rest. Without any external force, a body at motion will constantly maintain its uniform straight-line motion. This is the well-known Newton's First Law, the Law of Inertia.

The Law of Inertia clearly tells us that a push by an external force is necessary in order to enable a body at rest enter a state of motion. To enable a body in motion to enter a state of rest, an external force must be applied to stop it. A missile follows the Law of Inertia.

Why a missile can fly? This is because there is an engine in the missile; the engine produces a thrust, which propels the missile. Generally, a liquid-fuel rocket engine entails a combustion chamber and nozzle. However, an engine cannot operate by itself and produce a thrust; also required are a propellant (oxidizer and combustion agent), a propellant storage tank, and a transport and supply system for the propellant. The engine, propellant storage tank, and transport and supply system are called power installations, or a propulsion system.

There are two principal categories of engines used in missiles: one is the rocket engine and the other is the air-breathing jet engine. A rocket engine relies on the combustion of the propellant (carried by the missile) to produce a thrust. An air-breathing jet engine takes in air from the atmosphere and burns fuel (or propellant, which is carried by the missile) to produce a thrust. Based on different states of propellants, there are liquid- and solid-fuel rocket engines. The air-breathing jet engines can be divided into turbojet engines and ramjet engines.

Flight Control System

The flight control system (or, in short, the control system) of a missile includes stabilization system and a guidance system.

The stabilization system serves to ensure that the missile travels (by maintaining a certain altitude) along a predetermined trajectory toward a target.

For a flight vehicle (aircraft, guided missile, satellite, or airship) to maintain its flight at a certain attitude, usually a pilot operates the flight vehicle. For a pilotless flight vehicle, its maneuvering is carried out by an attitude stabilizing system. Therefore, the function of the attitude stabilizing system serves to stabilize in-flight attitude of a guided missile, which is prevented from random rolling and turning over during its flight so as to maintain a certain attitude. The attitude indicates the angular position of a missile in space; i.e. its roll angle, yaw angle, and pitch angle.

The guidance system functions to control the motion of a guided missile's center of gravity, so that it can travel by a predetermined guidance pattern toward the target.

Warhead

The guided missile is an advanced modern weapon; its task is to destroy a target. Conventional rifle bullets and cannon rounds destroy targets with their warheads. A missile destroys its target by using a functional part similar to that of rifle bullets or cannon rounds. Sometimes, the functional part is packed in the nose cone of the missile so that the part is also called warhead. Sometimes, the warhead is packed in the midsection of a missile. To settle on a precise term, this part (warhead) is usually called a combat payload for the purpose of final or direct execution of combat.

Because there are varied combat goals and attack targets for missiles, to effectively accomplish a combat mission there are also varied types, structure and appearance of the warhead. As examples, when packed with nuclear warheads we call them nuclear combat payloads and when packed with conventional dynamites, conventional combat payloads.

Missile Fuselage

A warhead is needed for a missile to destroy its target. A propulsion system is required to enable a missile to travel. A flight control system is required for a missile to move along a predetermined route (trajectory) toward the target. These three parts are needed in a missile. Only when these three parts are combined into a functioning entity, is a missile then materialized; it can accomplish the mission of destroying the target. For example, a human body is composed of a head, two hands, two feet, heart, liver, lung and others. So is a missile; the missile fuselage connects the warhead, propulsion system, and flight control system into a complete missile. Thus, all parts and systems can be coordinated to exert their respective functions and finally accomplish the task of destroying the target. Therefore, a missile fuselage acts as the final assembly for all the component parts since all are vital. The missile fuselage not only connects all these parts, but in addition the connection should enable smooth flight with a desirable exterior shape.

Because of different applications, there are different structures and exteriors. For example, a missile usually has no wing, only a fuselage. Some missiles have very small fins. A winged missile has a fuselage and wings.

CHAPTER III

FLIGHT TRAJECTORY OF MISSILE

Discovery of Universal Gravitation by Newton

Newton was a British scientist, living more than 300 years ago. It was said that he returned to the countryside the year he graduated from college. One day, he was sitting beneath an apple tree. Suddenly, an apple fell to the ground. Newton looked around; there was no wind.

"That's strange. What's the reason? Why the apple does not fly to the sky, but drops to the ground," Newton was in deep thought.

The reason is that there are attractive forces among all matter. This force is called universal gravitation. When an apple ripens, it does not fly to the sky because the earth exerts an attractive force on the apple. Similarly, after a jump one has to drop to the ground. Because of universal gravitation, the moon, planets and stars stay in the sky.

Based on the universal gravitation discovered by Newton, we can explain the motion law of cannon rounds and missiles and understand their flight paths.

Trajectory

How does a missile move in space?

People walk on roads; vehicles move on tracks; aircraft and warships have navigation routes; and, of course, a missile also has a "navigation route," which is the so-called flight trajectory (flight locus). More precisely, under the action of various forces a missile follows Nature's law to make a certain motion. The flight trajectory is the moving locus of the missile's center of gravity.

In a general situation, the motion locus (trajectory) of a missile is a three-dimensional curve. Under certain conditions, the lateral motion of a missile is very small, so it can be neglected. Therefore, the three-dimensional trajectory can be simplified into a plane trajectory. Thus, the flight path of a missile becomes a plane curve in the plumb vertical plane.

According to the characteristics of a missile trajectory, generally there are three categories: the first category includes missiles attacking stationary targets. Trajectories of this category of missiles are prespec' ied (predetermined). After launch, the missile cannot change its path but only follows a predetermined curve toward the target. This describes the trajectory of a ballistic missile. The second category includes missiles attacking movable targets. The trajectory cannot be predetermined before launch because this is a random trajectory determined by moving target situation. Trajectories of most winged missiles (such as air-to-air, air-to-ground, and ground-to-air missiles) are of this trajectory category. The third category indicates trajectories of aircraft-type missiles capable of attacking movable targets and also stationary ground targets. Generally, trajectories of this category are divided into two parts: one part is predetermined by a program while the other part is determined by target characteristics at that time.

Varied Forces Acting on a Missile During Flight

The motion of a body is caused by an external force (or forces) acting on it. The kind of external force determines the kind of motion locus. The trajectory of a missile is determined by the external force acting on it. The magnitude and direction of the external force determine the trajectory of a missile.

What forces act on a missile during its flight?

The principal forces acting on a missile during its flight are as follows: engine thrust P, gravitational force G, and aerodynamic force R, as shown in Fig. 3-1.

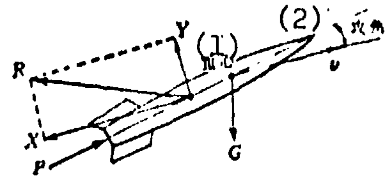

Fig. 3-1. Forces acting on a missile
Key: (1) Center of gravity; 2. Angle of attack.

A railroad train runs fast because a powerful locomotive hauls it. A rocket flies at very high speed due to enormous power of its engine.

Thrust P The thrust is a force acting on a rocket due to its engine's operation. This force is obtained because of propellant combustion to convert chemical energy into kinetic energy. In other words, large volumes of combustion gases after propellant combustion discharge rearward to produce a thrust. This is what Newton's Third Law says: any force produces a reaction force; these two forces are equal in magnitude but opposite in directions. For example, a small boat stops sailing by a windless, tideless lakeside. When a person standing on the boat throws a stone forcefully toward the bank, a force (reaction force) simultaneously acts on the boat. This force pushes the small boat moving away from the bank. This reaction force pushing the moving boat is similar to thrust produced by a rocket engine. The thrust of a rocket engine is always opposite in direction, from that the combustion gases rearward discharge.

Gravitational force G Any two bodies A and B on the earth produce attractive forces between them. The magnitude of the attractive forces is proportional to the masses of these two bodies, and is inversely proportional to the distance between them. However, since the earth has a colossal mass, its attractive force is much greater than any of the attractive forces between A and B. The attractive force exerted by the earth on a body on the ground is called gravitational force. Because of the existence of gravitational force, people cannot fly at will in the sky without a machine to overcome the gravitational force. On the other hand, people can walk and perform activities on earth just because of existence of the gravitational force.

The so-called gravitational force is the attractive force on the ground exerted by the center of gravity of the earth (as shown in Fig. 3-2).

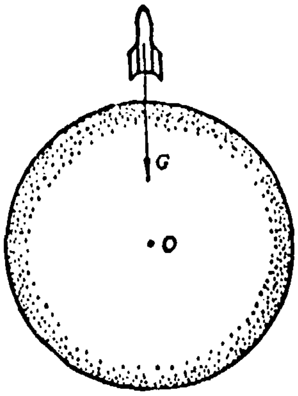

Fig. 3-2. Gravitational force acting on a missile

The gravitational force G of a missile is the result of the attractive force exerted by the earth's center of gravity on the missile. This can be expressed by a formula:

$$G=mg$$

In the formula, m is mass of the missile and g is the gravitational acceleration of the earth. The gravitational acceleration at ground level is $g_0=9.80$ m/sec^2.

The aerodynamic force R When you open an umbrella, you will be aware of a force acting on the umbrella if the wind blows on your face and you hold the umbrella inclining rearward. The wind force pushes the umbrella backward and upward. When you sit in a running car and stretch your hand outside, you feel a force pushing your hand backward. These phenomena indicate that a force is acting on a body if it makes relative motion in the air. This force is called aerodynamic force.

Is a missile acted on by an aerodynamic force when it flies in the air? Of course, there is a force. The missile is acted on by aerodynamic forces distributed on the surface of the missile body.

When a missile flies in air medium, aerodynamic forces are distributed on the surface of the missile body. All these forces can be combined into a resultant (resultant aerodynamic force) acting on the center (focus) of the aerodynamic forces of the missile, and a couple (resultant aerodynamic couple) around the focus.

Presented is a velocity coordinate system Oxyz (Fig. 3-3): the origin of coordinates is located at the aerodynamic center (the intersecting point of the vertical axis of the missile and the resultant force of the aerodynamic forces); the axis Ox points in the velocity direction of the missile; the axis Oy is located in the plane of symmetry of the missile and points upward; and axis Oz is perpendicular to the plane xOy and points to the right (righthand coordinate system).

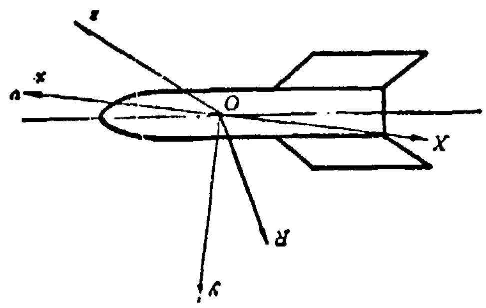

Fig. 3-3. Velocity coordinate system

Project the resultant aerodynamic force R onto the velocity coordinate system. The component X opposite to the direction of the Ox axis is called resistance; the component Y along the Oy axis is lift; and the component Z along the Oz axis is the lateral force. Therefore, the direction of resistance X is opposite to the missile's flight direction. The directions of lift Y and lateral force Z are along the Oy axis and Oz axis, respectively.

The aerodynamic force is closely related to the angle of attack α and the Mach number M.

The Mach number M is expressed by the ratio of missile velocity to the velocity of sound. If M=10, this means that the missile velocity is 10 times the velocity of sound.

The angle of attack α is the included angle between the missile axis and the velocity vector. For ballistic missiles, the angle of attack is small, usually several degrees.

Lift Y Where does the lift come from? The ordinary airfoil type of low velocity aircraft is taken as an example. Figure 3-4 shows an unsymmetrical wing type. The degree of curvature of the upper surface is greater than that of the lower surface. When air passes by this type of wing, streamlines appear like a stream tube with variable cross sections. The cross section of the stream tube near the upper surface is very small, so the stream velocity at these locations is considerably increased with reduced pressure. The cross section of the stream tube near the lower surface is not as much reduced as that of the upper surface, so pressures on the upper and lower surfaces of this airfoil type are not symmetrically distributed, but are as shown in Fig. 3-5. Obviously, the resultant of these pressures is not equal to zero. Therefore, a lift is produced.

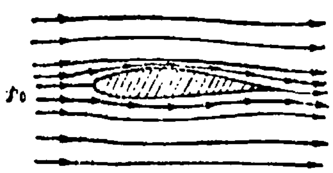

Fig. 3-4. Producing of lift for an airfoil type

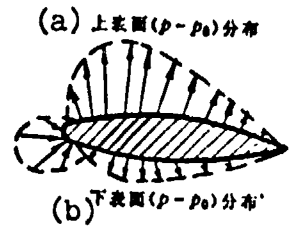

Fig. 3-5. Pressure distribution for an airfoil type
Key: (a) Distribution of ($p-p_o$) at the upper surface; (b) Distribution of ($p-p_o$) at the lower surface.

The principle of producing lift by other parts of a missile fuselage is the same as the production of lift by the profile of an aircraft wing. The lift of the entire missile is the summation of all lifts produced by various parts. However, generally lift is produced by the missile wing. The direction of lift is perpendicular to the direction of relative velocity, the greater the relative velocity, the greater the lift. The lift of the missile fuselage is proportional to its cross-sectional area; the lift is also closely related to the angle of attack. This can be expressed by the following formula:

$$Y = C_y \cdot \frac{1}{2} \rho V^2 S_M$$

In the formula, ρ is density of the atmosphere; V is missile flight velocity; S_M is the maximum cross-sectional area of the missile; and C_y is the lift coefficient, which varies with missile configuration and angle of attack α. The variation of the lift coefficient with airfoil type is shown in Fig. 3-6.

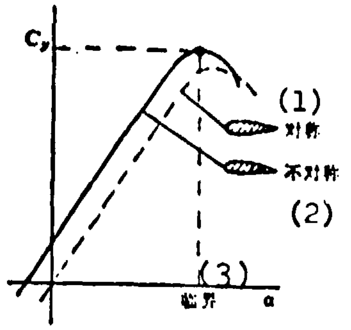

Fig. 3-6. Relationship between C_y and α
Key: (1) Symmetrical cross section; (2) Unsymmetrical cross section; (3) Critical.

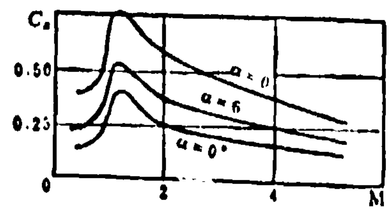

Fig. 3-7. Relationship between resistance coefficient C_X, α, and M

Aerodynamic resistance X during missile flight can be expressed by

$$X = C_x \frac{1}{2} \rho V^2 S_M$$

In the equation, ρ, V and S_M express the same quantities as in the lift formula. C_X is the resistance coefficient, which is related to flight altitude, angle of attack α, and Much number M. Figure 3-7 shows the relationship between the resistance coefficient and Mach number for V-2 ballistic missile.

Lateral force Z The lateral force is also called the lateral-direction force. When a missile makes a side-slip flight or when its rudder (it functions like a ship's stern rudder) makes a deflection angle, a lateral force is produced. The lateral force is always perpendicular to the longitudinal symmetrical plane of the missile.

Principles of producing lateral force and lift are the same. The lateral force coefficient is similar to the lift coefficient.

Additionally, there is a problem of control force. By its characteristics, this force can be considered as an aerodynamic force or an engine thrust. How can this problem be understood?

A ballistic missile has to turn and aim at a target, or a winged missile has to track a target with maneuvering flight. At that time, the missile has to change the original state of motion at every instant. We know from Newton's First Law of Motion; at that time, a force or couple is required. The force maneuvering a missile to turn (or perform a maneuvering flight) is called the control force. The execution mechanism of a missile serves to produce and control signals for proportionally maneuvering forces and couples used in missile flight. The execution mechanism includes a maneuver mechanism and a driving device (used to drive the maneuver mechanism).

The maneuver mechanism is classified into an aerodynamic-force maneuver mechanism and a combustion-gas-powered maneuver mechanism.

The aerodynamic-force maneuver mechanism is an air rudder, which can be installed at different parts of a missile to produce various necessary control forces. The air rudder, which produces a force to activate pitch motion on a missile, is called the elevator. The elevator is installed at a horizontal fin. The air rudder, which produces a force to activate drift motion on a missile, is called the rudder. The rudder is installed at a vertical fin. The air rudder, which produces a force to activate rolling flight for a missile, is called an aileron. The aileron is installed at the trailing edge of a missile wing.

The combustion-gas-powered maneuver mechanism can be classified into the following types:

1. Oscillating combustion chamber or swinging nozzle can completely deflect combustion gas flow discharged from the engine.

2. Mechanisms partially deflecting combustion gas flow include combustion gas rudder, deflector and maneuver mechanism (as shown in Fig. 3-8) for injecting gas or liquid into a nozzle.

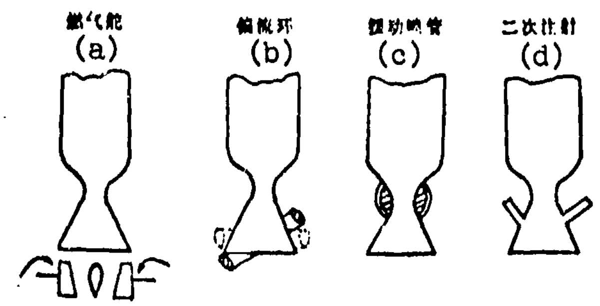

Fig. 3-8. Several types of maneuver plan
Key: (a) Combustion gas rudder; (b) Flow deflecting ring; (c) Oscillating nozzle; (d) Two-time injection.

3. The maneuver mechanism adjusting the thrust of several combustion chambers can lead to a thrust difference in multi-combustion-chambers or multi-nozzles.

Through the execution mechanism, a missile produces a control force. A control torque is formed as the control force is acting on a point other than the center of gravity. Acted on by this couple, the missile rotates around the center of gravity in order to maneuver the missile to turn or perform maneuvering flight.

Flight Trajectory of Ballistic Missile

Let us first take a look at the flight of cannon rounds.

A round continuously accelerates inside a cannon bore under the action of high pressure gas. The round attains a very high velocity at the bore exit and flies at a certain pitch angle (the included angle between warhead axis and the horizon). After leaving the cannon bore, the round flies toward the target along a parabolic trajectory while acted on by the gravitational force and air resistance, as shown in Fig. 3-9.

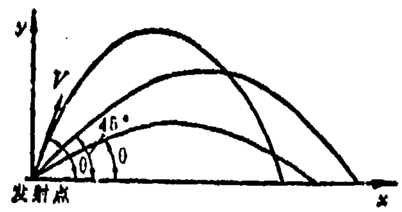

Fig. 3-9. Parabolic trajectory of a cannon round
Key: (*) Point of initial firing.

For rounds with the same pitch angle, the higher the muzzle velocity the farther a round flies and the greater the range (the ground distance from the point of initial firing to the target). However, for rounds with the same muzzle velocity there are different ranges for different pitch angles. Theoretically speaking, the range is the greatest at a 45° pitch angle.

This is to say that the flight trajectory and range of a cannon round are determined by its muzzle velocity and pitch angle.

Ballistic missiles are similar to cannon rounds. When a missile starting flying, it continuously accelerates under the action of the rocket engine thrust. At a certain instant (under predetermined conditions), the engine power is cut off to separate warhead and missile fuselage. The warhead flies toward the target under the action of gravitational force. Therefore, the flight phase of a missile includes the powered phase and the inertia phase. The missile is pushed by the engine and flies under the action of the control system. The trajectory of this sector is called the powered phase. At the instant of engine cutoff, the point corresponding to the trajectory is called the terminal point of the powered phase of the trajectory.

When the engine and control system of a missile are not operating, the missile flies toward the target along a free trajectory by its (missile's) inertia like a round flying out of a cannon bore. This phase of the trajectory is called the inertia phase. The flight path of a missile's inertia phase is mostly outside of the atmosphere; the missile is only acted on by the gravitational force. Therefore, the free trajectory is an elliptic trajectory. In the reentry phase approaching the target, although the air density is gradually greater, the elliptic shape of the trajectory almost does not change. The flight distance of the inertia phase occupies about 90 percent of the entire missile range. We can see that the ballistic missile is similar to a cannon round, traveling along a free trajectory; this is the reason why this term (ballistic missile) is used. The characteristics of a free trajectory are determined by initial conditions (velocity and pitch angle) of the motion. By obtaining the initial conditions, a missile primarily relies on control in its powered phase. In other words, the missile relies on the required (by the powered phase) velocity V_k and trajectory pitch angle ∂_k (the included angle between velocity vector and local horizon) as attained in the powered phase. However, a cannon round only relies on pitch angle and muzzle velocity caused by its motion within the aimed (cannon) bore. Since the range of a cannon round is short, the point of initial firing and impact point can be considered within a plane. Therefore, the best pitch angle of a cannon round is 45°. However, the range of an intercontinental ballistic missile is about 10,000 kilometers; therefore, the best pitch angle is about 20° due to the earth's curvature. Since a cannon round flies within the dense atmosphere at low altitudes, there is considerable aerodynamic force acting on the round. Therefore, a cannon round travels along a parabolic trajectory. However, a missile basically flies along an elliptic trajectory, as shown in Fig. 3-10.

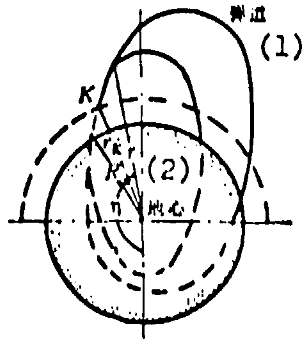

Fig. 3-10. Elliptic trajectory
Key: (1) Trajectory; (2) Earth's center.

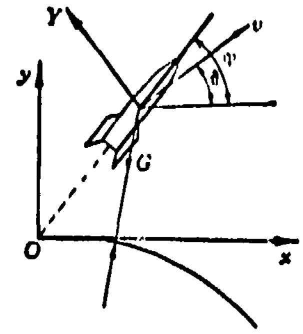

Fig. 3-11. Several angles within flight plane of a missile

When a ballistic missile is designed, the range has been determined (generally decided on by the General Staff). The impact point and the trajectory of the inertia phase are determined by the missile's motion parameters V_k and ∂_k at the terminal point of the powered phase. Therefore, only according to a given range in determining a group of V_k and ∂_k can a flight trajectory of powered phase be designed to enable the missile travel along this trajectory. While arriving at the terminal point of the powered phase, the missile just attains the design values of V_k and ∂_k. This can ensure that the missile is capable of attaining the design range. When designing the flight trajectory of the powered phase, of course except satisfying the range requirement, other requirements have to be satisfied such as small deviation of the impact point, desirable flight stability, convenient maneuverability, and adequate strength for missile fuselage.

In order to enable a missile travel along a powered phase trajectory as designed, first a flight program (or flight plan) of the powered phase has to be designed according to the trajectory of the powered phase. In other words, this serves to prescribe (to design) a law varying with time for a prescribed (design) range angle (or pitch angle) of the missile. The angle ϕ is the included angle between the missile's vertical axis and the horizon at launch, so that $\phi=\partial+\alpha$ (as shown in Fig. 3-11). Then, according to the flight program of the powered phase, a program mechanism can be designed and built. The program mechanism can be mechanically installed or it may be present in other forms. At present, there is a steel belt cam type and a gear cam type with mechanical installation. Other forms of program mechanism include perforated tape memory device and magnetic tape memory device.

Install program mechanism and other instruments in a missile. In flight, according to a selected trajectory program the program mechanism sends instructions for engine cutoff and separation of warhead from missile fuselage. In addition, the program mechanism sends instructions to conduct continuous soundings of exterior interference to sensitive elements (such as accelerometer and gyroscope) and missile motion. Thus, control signals are produced. Through exchange and amplification of intermediate devices and transfer to maneuver mechanisms (oscillating engine or combustion gas rudder), these signals can generate corresponding control forces to maneuver the missile to travel along a predetermined trajectory. If a missile can completely execute the flight program during its flight, parameters at the terminal point of the powered phase can attain the design values. Then the missile can travel along a predetermined trajectory and hit the target accurately.

Generally, the flight program of the powered phase (of a ballistic missile) can be divided into several characteristic phases, such as vertical takeoff phase, turning flight phase, and constant value program phase. The inertia phase trajectory can be divided into free flight phase and reentry phase, as shown in Fig. 3-12.

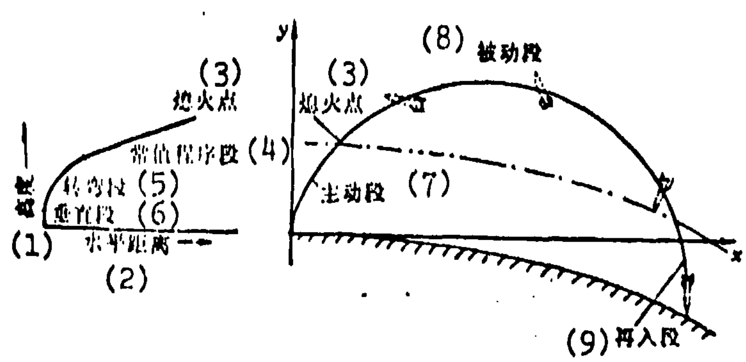

Fig. 3-12. Flight trajectory of ballistic missile
Key: (1) Altitude; (2) Horizontal distance; (3) Point of power cutoff; (4) Constant-value program phase; (5) Turning phase; (6) Vertical phase; (7) Powered phase; (8) Inertia phase; (9) Renetry phase.

Vertical ascent phase Within the first several seconds after launch of a ballistic missile, usually the flight trajectory is designed into a phase of a vertical straight line. The missile is erected on a launch pad. After engine ignition, the thrust increases continuously. When the thrust exceeds the missile weight, it slowly and vertically ascends from the launch pad. As the engine thrust continuously increases and quickly attains its rated value, and the propellant continuously depletes at a rapid pace, the missile weight continuously decreases. Although the missile flies vertically upward in the dense atmosphere, yet the missile velocity still increases quite quickly. After several seconds of vertical flight and the missile velocity attains a certain value, the flight is comparatively steady. The missile begins to turn under the influence of the control system, and enters the turning flight phase.

Why a vertical flight phase is required? Because a ballistic missile is big and its thrust weight ratio (the rate of engine thrust to takeoff weight) is not too high (usually 1.1~1.5). The vertical flight can ensure a steady flight within the first several seconds, not to drop back to ground. Besides, the launch installation is comparatively simple with convenient, initial aiming onto the target. The missile can quickly travel out of the atmosphere to relatively reduce energy loss. Therefore, usually the trajectory of ballistic missile is a vertically ascending flight with a vertical launch.

Turning flight phase   After several seconds of vertical ascending flight, a missile (under the influence of the control system) deviates from the state of vertical flight to slowly incline and turn toward the target in order to transfer into a predetermined elliptic trajectory. The trajectory of the turning flight phase is an arc. The inclining and turning of a missile should be proceeded slowly. A large lateral loading will be induced by a quick turning. Thus, the trajectory is likely to be destabilized and unnecessary troubles will develop in the control systems. In addition, the missile fuselage may be broken.

While designing the turning flight phase, the missile's angle of attack should be limited; usually the absolute value of angle of attack is limited to less than 3°. Selection of turning time should be repeatedly calculated in order to attain a comparatively reasonable figure. Usually, the turning time varies between several seconds to between 10 and 20 seconds. In the case of intercontinental (ballistic) missiles, the turning time is generally between 10 to 20 seconds.

The problem of sound barrier appears in the development process of flight vehicles. The so-called sound barrier can be explained as follows: when the flight velocity of a flight vehicle approaches the sonic barrier, the vehicle develops violent oscillations and becomes difficult to control; even damages may sometimes occur. Since the guided missile is one type of flight vehicle, this problem similarly exists. When the missile flight enters the transonic zone (the flight velocity is 0.8∿1.3 times the velocity of sound; i.e., M=0.8∿1.3), the aerodynamic forces acting on the missile vary widely, lift and resistance force increase considerably. The center of aerodynamic forces (pressure center) moves rapidly black and forth, causing violent oscillations in the missile. The operating conditions of instruments (carried by the missile) deteriorate; it is difficult to control missile flight along a design trajectory. On serious occasions, the missile may be broken. It is necessary to shorten the missile flight time in the transonic zone as much as possible, and the variation range of the gas dynamic center and aerodynamic center should be kept small. In order to achieve this point, the missile should travel with its angle of attack equal to or approaching zero; this is a condition that should be ensured in designing the turning phase flight program. In this phase, the vertical missile axis turns while acted on only by a component of gravitational force until the program angle ϕ attains the predetermined value of ϕ_k.

Constant-value program phase   This is the final segment of the powered phase trajectory. The flight program of this phase should consistently maintain the program angle at the stipulated value ϕ_k (ϕ_k is determined by range requirements) obtained in the previous phase. Under the influence of control system in this phase, the missile maintains a constant ϕ_k value and travels along an inclined straight-line trajectory. The engine thrust incessantly accelerates the missile. When the flight velocity attains the velocity V_k value at the terminal point of the powered phase, the control system sends an instruction to cut off engine power as the powered phase ends. At that time, the control system sends another instruction to separate warhead from missile fuselage. The warhead then begins flight in the inertia phase.

Free flight phase   At the terminal point of the powered phase, the unessential parts (such as missile fuselage and engine) are cast off. The warhead travels alone outside the atmosphere. During this flight phase, the warhead has no thrust and no air resistance (actually, there is still very little air resistance because it is not a perfect vacuum but with thin air). The warhead is acted on only by the gravitational force. Only with a slight disturbance, the missile will turn over without any restraint. This is so-called total "free travel." The flight of missile in this phase does not have a definite direction.

Reentry phase When a missile travels near the target (final phase of trajectory), it (the missile) begins to enter the atmosphere (about 80 km over sea level). As air resistance gradually increases, the warhead with its stabilizer cannot randomly turn over but is braked and stabilized. The result of braking and stabilization generally can ensure the warhead (with stabilizer) rushing downward to the target.

Due to increasing air resistance in the reentry phase, the flight velocity of the missile gradually decreases. At the same time, the missile confronts aerodynamic "heat", which raises the surface temperature of warhead to thousands of degrees. Where does such aerodynamic heat come from?

(1) Because of violent collision between the missile and air molecules, the air is under high pressure and its temperature rapidly increases. The heated air transfers large amounts of heat to the missile, greatly increasing the warhead temperature. (2) The viscous friction between the warhead and the air also produces some heat, which is transferred to the warhead to raise its temperature. Since the relative velocity between the missile and air is quite high and the air is very dense, aerodynamic heating is very serious. This can raise temperatures at missile surface to higher than 1000°C, melting the metal shell. In addition, instruments in the missile may be damaged and the powder package exploded. Therefore, heat shielding during the reentry phase is a very important problem.

There are many types of heat shielding measures. For example, the missile exterior is coated with special materials, such as carbon or magnesium oxide. Low thermal conductivities of these materials and, during their melting and evaporation, considerable heat absorption can prevent the heat from being transformed to the missile in order to protect the warhead. This method is called the ablation method. Moreover, there are other methods.

The flight trajectory of an intercontinental ballistic missile resembles the trajectory of single-stage missiles. Only the powered phase of the flight trajectory of a multi-stage missile is based on the continuous operation of different engine stages. After the operation of an engine stage, it is jettisoned. The instant of power cutoff at the final stage corresponds to the terminal point of the powered phase. The flight trajectory of a multi-stage missile is shown in Fig. 3-13.

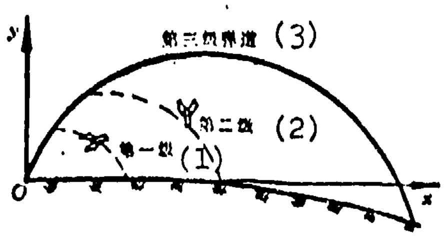

Fig. 3-13. Sketch diagram of trajectory of a multi-stage ballistic missile
Key: (1) First stage; (2) Second stage; (3) Trajectory of third stage.

Flight Trajectory of Winged Missile

A winged missile is maneuverable while attacking a target. The line of missile flight is controlled according to the relationship of relative motion between the missile and the target. Therefore, the motion of target can always directly or indirectly determine the motion of missile (the trajectory). The motion of a target under attack by the winged missile is variable and there are many guidance methods of this category of missiles with complicated combat situations; therefore, the flight trajectory of a winged missile cannot be determined in advance (varieties of possible trajectories). Thus, a winged missile does not follow a trajectory in the form of a typical curve like the trajectory of a ballistic missile. In the following treatment, we explain several guidance methods with examples.

For a convenient explanation, first a relative-position diagram of a missile and a target is shown within any instantaneous attack plane (as shown in Fig. 3-14). In the diagram, the connection line between missile and target is called the target line. The included angle η between missile's velocity vector $\vec{V}_{missile}$ and target line is called the lead angle of the missile.

1. Tracking Guidance Trajectory

The characteristics of tracking guidance enable the missile to travel toward the target at all times. In other words, the velocity vector of the missile consistently points to the target and coincides with the target line (missile lead angle η=0). At the vertical launching of the missile, the tracking guidance trajectory is shown in Fig. 3-15. In the figure, 00', 11' and 22' are target lines at different times. However, the velocity $\vec{V}_{missile}$ at one of the points always trends toward the target. Therefore, at the final point 4 (or 4'), the missile strikes the target. As shown in the figure, curve 01234 is the tracking guidance trajectory under such a situation.

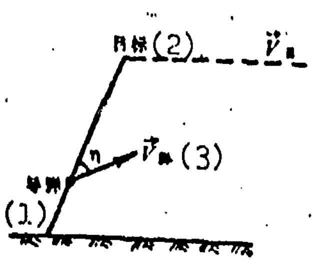

Fig. 3-14. Relative position of missile and target
Key: (1) Missile; (2) Target; (3) $V_{missile}$.

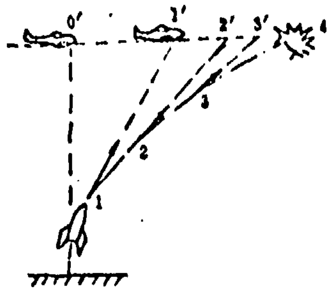

Fig. 3-15. Flight trajectory of tracking guidance

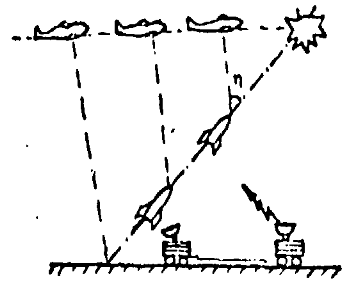

Fig. 3-16. Straight-line trajectory of parallel approach

2. Flight Trajectory of Parallel Approach

The crucial element in a parallel approach is as follows: in the guidance process, the direction of the target line in the air is consistently maintained constant. In this situation, when both the missile and the target engage in constant-velocity straight-line motion, the missile's flight trajectory will be a straight line with a constant direction (lead angle η=constant). This straight line extends to the point of impact (the collision point of missile and target), as shown in Fig. 3-16. If the target engages in maneuvering flight, the missile velocity also varies. In this case, the lead angle of the missile is varied; the flight trajectory of the missile will be a curve.

3. Flight Trajectory of Three-point Coincidence

The crucial element of the three-point coincidence guidance method is to enable the missile to always position itself in the connection line between target and command station. Viewing from the command station toward the target, images of the missile and target always coincide. In other words, the command station missile and target always lie along a straight line. This straight line turns in space along with the target's motion; the flight trajectory of the missile is a curve, as shown in Fig. 3-17.

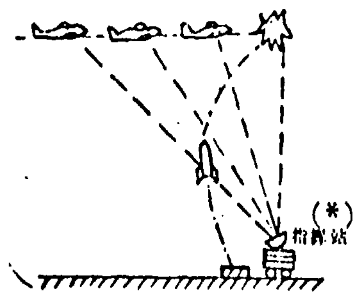

图3-17 三点重合的飞行弹道

Fig. 3-17. Three-point-coincidence flight trajectory
Key: (*) Command station.

Flight Trajectory of Aircraft-type Missile

As shown in Fig. 3-18, the trajectory of an aircraft-type missile is mostly a straight line; the main parts of the trajectory are almost in a horizontal state. The missile flight proceeds according to the predetermined flight program, and only while approaching the target is an automatic homing (seeking target) sometimes added for automatic aiming. Generally, the trajectory of an aircraft-type missile is divided into initial phase, horizontal phase, and dive phase.

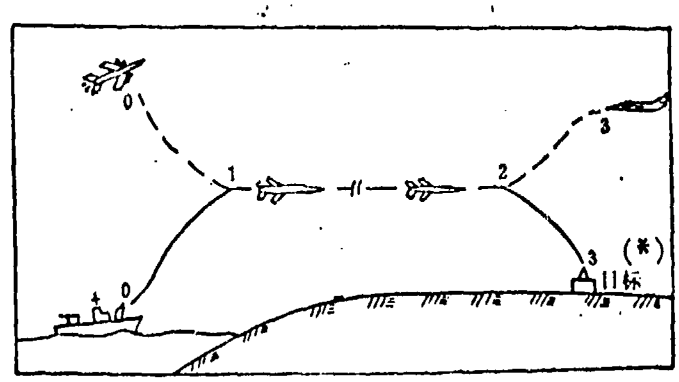

Fig. 3-18. Schematic diagram showing trajectory of aircraft-type guided missile
Key: (*) Target.

Initial phase (0~1) This is a climbing phase for ground-to-air missiles or ground-to-ground missiles; this is a continuously climbing or descending phase for air-to-ground missile after launch from a mother aircraft.

Horizontal phase ($1\sim2$) This includes most parts of the entire trajectory. In this phase, the engine thrust is balanced by air resistance facing the missile, and the missile's lift is balanced by the gravitational force. Therefore, the missile makes a nearly constant-altitude flight on a horizontal line. This kind of flight is called cruise.

Dive phase ($2\sim3$) This is the final phase of the entire trajectory. While still in the air but approaching the target, a ground-to-ground missile or air-to-ground missile is in a transitional stage from horizontal flight to dive. In order to raise the accuracy of the impact point, in this phase a homing system is used for automatic aiming. What the ground-to-air missile attacks is a maneuvering target in air. After completing the horizontal flight, usually the missile uses automatic aiming to hit the target.

CHAPTER IV

MULTISTAGE ROCKET AND INTERCONTINENTAL MISSILE

Can a Single-stage Missile Be Used to Launch an Artificial Earth Satellite?

From the last chapter, we know that the range of ballistic missile is determined by velocity V_k and trajectory pitch angle ∂_k at the terminal point of the powered phase of the trajectory. As we know well, the range of a rifle (or cannon) bullet is determined primarily by muzzle velocity of the bullet and pitch angle of the rifle (or gun) barrel.

For the launch of a launch vehicle of an artificial earth satellite, generally it is the same as the powered phase of a ballistic missile from engine ignition and takeoff to separation of satellite from the rocket (also called the powered phase of the trajectory). The magnitude and direction of rocket velocity (i.e., the velocity and trajectory pitch angle) at the terminal point of the powered phase flight can determine the satellite orbit. Therefore, the magnitude and direction of velocity V_k at the terminal point of the powered phase of the rocket or ballistic missile should be discussed in detail. The magnitude and direction of velocity V_k are characteristic parameters determining the missile range and satellite orbit. The rocket velocity is discussed below.

The velocity V_k at the terminal point of a rocket's powered phase is determined by forces acting on the rocket. Therefore, in order to increase the velocity V_k we have to increase the flow velocity and mass ratio μ_k of the exhaust gases from the engine. This is because: $V_K = C \cdot \ln \mu_K$

In the equation, V_k is the rocket velocity at engine power cutoff; C is the effective flow velocity of combustion gases from the engine; μ_k is mass ratio, the ratio of rocket mass m_0 at takeoff (including the masses of nose cone, rocket structure and propellant) to rocket mass m_k at power cutoff. That is, $\mu_K = \frac{m_0}{m_K}$

Velocity V_k can be also written as $V_K = g_0 I_{sp} \ln \mu_K$. In the equation, g_0 is the gravitational acceleration at the ground surface and I_{sp} is the specific impulse.

The specific impulse I_{sp} represents the thrust produced by a unit weight of propellant consumed per unit of time (equal to mass multiplied with g_0).

Common propellants, the specific impulse in a ground situation, and the effective flow velocity C of combustion gases are listed in the following table.

(a) 推进剂		(b) 比冲 I_{sp} (秒)	(c) C (米/秒)
(d) 固体	(f) 双基药	220	2100
	复合固体推进剂 (g)	245	2400
	(h) 高能固体推进剂	300	2900
(e) 液体	(i) 酒精/液氧	240	2300
	汽油/液氧 (j)	240	2300
	(k) 肼/液氟	334	3270
	偏二甲肼/液氧 (l)	295	2890
	(m) 肼/四氟化二氮	383	3750
	四氢化二氮/四氧化二氮 (n)	250	2450
	(o) 液氢/液氧	388	3800
	液氢/液氟 (p)	400	3900

Key: (a) Propellant; (b) Specific impulse I_{sp} (sec); (c) C (m/sec); (d) Solid; (e) Liquid; (f) Double-radical powder; (g) Compound solid propellant; (h) High-energy solid propellant; (i) Wine/liquid oxygen; (j) Gasoline/liquid oxygen; (k) Hydrazine/liquid fluorine; (l) Metadimethyl hydrazine/liquid oxygen; (m) Hydrazine/tetrahydro-dinitride; (n) Tetrahydrodinitride/tetraoxydinitride; (o) Liquid hydrogen/liquid oxygen; (p) Liquid hydrogen/liquid fluorine.

The flow velocity of engine combustion gases relies on thermodynamic characteristics (heat value) of propellant and design quality of the engine. Since the energy content in chemical propellant is limited, the thermodynamic performance is limited. Therefore, the flow velocity of combustion gases is also limited.

Under a situation of constant mass of the nose cone, one can improve the structural design, reduce the structural mass, and increase the propellant mass; then the value μ_k will be increased and the velocity at the terminal point of the powered phase is also increased because more propellant can be burned to accelerate the rocket. However, as limited by the structural material of the rocket, its shell cannot be made too light. Therefore, it is limited to improving design, reducing structural mass, and packing more propellant for higher μ_k values and higher velocity V_k at the terminal point of the powered phase. Since the mass increment of the propellant storage tank (the main structural part of the rocket) is slower than the increment of the propellant mass, the increase in the takeoff mass can raise values of μ_k and velocity V_k. However, an excessive increase in takeoff mass is disadvantageous to practical applications of rockets. Because of the larger takeoff mass, the launch and surface facilities should be enlarged. In addition, rocket mobility is lowered, causing inconveniences in transportation. Therefore, it is not desirable to raise the takeoff mass in order to produce a higher velocity. Nevertheless, it is limited to increasing the value of μ_k. As a result, the increased velocity of a single-stage rocket is also limited. Generally, the velocity at the terminal point at the powered phase is about 5 km/sec. So, a single-stage rocket cannot be used to launch an artificial earth satellite with a required velocity of 7.9 km/sec.

In the flight process of the entire powered phase for a single-stage rocket, the structural weight (propellant storage tank, accessory equipment, etc.) becomes excessive weight after consumption of the combustion agent and oxidizers; this is dead weight, as commonly termed. This type of rocket not only should allow the effective payload attain the velocity at the terminal point of the powered phase, but the entire rocket structure should also attain the same velocity at the terminal point of the powered phase. Large amounts of energy are consumed to accelerate the useless weight (dead weight). Thus, the attainable velocity of the payload will be considerably reduced at the terminal point of the powered phase. A method of solving this problem is to continuously jettison the "dead weight". A multistage rocket can meet these requirements.

Velocity and Multistage Rocket

What is a multistage rocket?

A multistage rocket joins together several rockets. Like a pagoda, the high-level rocket is small while the lower-level rocket is large (or of the same size). The lowest-stage (called the first stage) rocket fires first. After exhaustion of the propellant in the first stage, it is then separated from the upper stages. Then, it is the turn of second stage (counting upward from the lowest stage). After exhaustion of propellant in the second stage, it is again separated from the upper stages. Thus, one stage at a time is separated until the highest stage is reached. Like a relay race, the joining of a multistage rocket can be tandem connected one by one for a tandem type rocket. Or else several lower-level rockets can be clustered (fastened together) and several upper-level rockets tandem joined to become a hybrid type rocket.

Why can a multistage rocket attain a higher velocity at the terminal point of the powered phase? Because each time a separation occurs in a multistage rocket, the useless accessory weight (dead weight) is jettisoned after the discarded-stage rocket has performed its function. Each separation means some dead weight lost. At the initial operation of a stage, the rocket attains the velocity of the jettisoned stage. The summation of several stages of velocity gives the velocity of the last stage at the power cutoff point. Of course, the velocity thus obtained is much higher than that for a single stage. For clarification, we make a comparison of a single-stage and a two-stage rocket with same takeoff mass m_o.

Assume the total mass of a two-stage rocket is m_o, which includes both stages' propellant mass m_T ($=m_{T1}+m_{T2}$). The mass of propellant for a single-stage rocket is equal to m_T'. Since some joining members have to be added to the two-stage rocket, its structural mass is little heavier. With equal takeoff mass m_o, m_T is a little smaller than m_T' but the difference is not too large. For a single-stage rocket, the situation of the single-stage combustion of propellant m_{T1} to accelerate the rocket is similar to a single-stage rocket; i.e., all propellant m_{T1} is used to accelerate the entire rocket. After the first-stage propulsion unit completes its operation (propulsion), its engine, propellant storage tank, shell and accessory equipment (the so-called "dead-weight") are jettisoned. The propellant m_{T2} of the second stage is only used to accelerate the much smaller residual mass; therefore, a greater velocity can be obtained. In other words, utilization of propellant is more effective.

There is the similar process (as mentioned above) for multistage rockets. When the operation of one (or several) stage of propulsion unit was completed (propellant depleted), it is jettisoned. Thus, the rocket with reduced "dead weight" employs other propulsion units for continuous operation on the basis of the existing velocity. In the flight process the entire rocket attains higher and higher velocity because of the gradual jettisoning of excessive structural mass (called "separation" in this process). Only the last stage and its effective payload can simultaneously attain the required velocity at the terminal point of the powered phase.

If μ_i is used to indicate the mass ratio of the i-th stage rocket; and C_i represents the flow velocity of combustion gases of the i-th stage, when the propellant of the first stage is depleted, the rocket velocity is $V_1 = C_1 \cdot \ln \mu_1$.

When the propellant of the second stage is depleted, an additional velocity is added to V_1; $V_2 = C_2 \cdot \ln \mu_2$

Afterwards, the velocity of each stage is similarly increased. When the propellant of the last stage is depleted, the rocket velocity V_n is

$$V_n = C_1 \cdot \ln \mu_1 + C_2 \cdot \ln \mu_2 + \cdots + C_n \cdot \ln \mu_n$$

If flow velocities (assumed to be C) of each stage combustion gases are the same, then

$$V_K = V_n = C \cdot \ln \mu_1 \mu_2 \cdots \mu_n$$

Some people may think that in a situation of constant takeoff mass, is it possible to use the method of increasing the number of stages to increase without limit the velocity at the terminal point of the powered phase? This is not so. As the number of stages is increased, new contradictions appear. Too many stages will bring new difficulties to the rocket structure for its greater complication and lower reliability. In addition, the velocity does not increase considerably in proportion; therefore, usually the number of stages is three or fewer.

Each stage of a multistage rocket is composed of the following parts: engine, propellant storage tank (for consumption by engine operation of this stage), connectors, instruments, shell sector and load bearing structure. Based on joining methods between stages, rockets can be divided into tandem type multistage rocket (as shown in Fig. 2-1) and tandem-cluster hybrid type multistage rocket (as shown in Fig. 2-3).

There are pros and cons for tandem type multistage rocket and tandem-cluster-type multistage rocket. Therefore, tandem or tandem-cluster hybrid type rockets are adopted.

Although the resistance of a tandem type rocket is small, yet the rocket is slender, of low rigidity, with low resistance against the lateral-direction couple, and easily broken. Therefore, the structural strength of tandem type rockets should be high. The cluster type rocket is short and thick; it can withstand larger acceleration with compact structure.

The tandem rocket is long, so it is inconvenient in transportation and operation. Combat readiness requires more time than other rockets.

During simultaneous operation of several engines of a cluster type rocket, the thrust produced frequently has an eccentric phenomenon; i.e., the resultant of thrust of various engines does not act on the longitudinal axis of a rocket, but deviates from the longitudinal axis to produce a couple turning the rocket from its trajectory. In the case of a tandem type rocket, there is only one engine working. Therefore, only once the engine is properly installed, can the eccentric phenomenon of thrust be avoided.

In the case of a cluster type rocket, the separation mechanism is comparatively complicated with the effect of separation interference. Only one rocket engine has an inconsistent power cutoff time or separation time, a large trajectory error will occur. A propulsion unit of cluster type rocket is joined to the upper stage by apron segment. During separation, it is longitudinal-direction separation with the apron segment; therefore, the separation mechanism is comparatively simple. The effect of separation interference is significantly reduced.

Most multistage ballistic missiles are of the tandem type.

Separation of Multistage Rocket

A multistage rocket can attain high velocities; it can launch an artificial earth satellite or a spacecraft. How can the stages be separated? This is the problem of so-called separation between stages.

We can see from rocket development that the single stage appeared first and then the multistage rockets. Therefore, the joint and separation technique between stages were developed on the basis of joint and separation technique of warheads. In the early period, the joint and separation of warheads used explosive bolts (with springs) or pneumatic device joints and separation system. The warhead and missile body are joined with explosive bolts. On normal occasions, springs are in the compressed state. During separation, the explosive bolts are ignited and exploded to destroy connectors. Springs are stretched to produce a separation force to detach the warhead from the missile body. Later, small solid-fuel reverse-thrust rockets replaced the springs. These reverse-thrust rockets are installed alongside the missile body, which is acted on by the reverse-thrust of solid-fuel rockets to reduce missile velocity. The relative distance between the warhead and missile body is continuously increased and separation occurs.

In principle, the connection or separation between the stages of a multistage carrier rocket is basically the same as the connection and separation of the warhead--application of a separating force to the body being separated. Technically, connection and separation between stages are much more complicated. On one hand, the masses of the two divisions to be separated are relatively large. The upper stage (the effective payload and other stages except for the jettisoned stage) weighs tens or hundreds of tons. On the other hand, during separation between stages not only should the empty lower stage be discarded, but we should also ensure engine ignition in the upper stage during the actual separation. Moreover, problems of controlling carrier rocket and coordination among systems should be solved. Nevertheless, through practice the objective rules of connection and separation between stages have been mastered; new connections and new separation mechanism as well as connection and separation methods have been proposed.

Connection mechanism between stages   At present, in multistage carrier rockets explosive bolts are commonly used to join various stages. The explosive bolts are required to not only join firmly but also to explode quickly and reliably to disconnect the two stages. Earlier, reliability of explosive bolts was low and fragments after the explosion damaged instruments and equipment. Later, redundant elements and parallel circuits were used to augment reliability; backing plates to shield against fragments were installed. Next, developed were explosive bolts, that were free of fragments, and highly reliable igniter squibs (coiled and fixed at the interior surface of the interstage-sector covering). During separation, an electrical impulse detonates the igniter squibs. The exploding gases suddenly expand toward the covering, which is cut as if with a knife (as shown in Fig. 4-1). Recently, a new kind of igniter squib was developed; the powder is packed within a thick plastic tube. Detonation of powder causes the plastic tube to expand and rupture the covering. The plastic tube does not break; therefore, no damage is caused to the instruments and equipment by fragments. Since the combustion rate of the squibs is very rapid (about 7000 m/sec), synchronization is better with explosive bolts. On development of space technology, the carrying capacity is increased because multistage rockets can carry a heavy payload. Many large-diameter explosive bolts should be used; this raises new problems in design. At present, more and more igniter squibs are used in missiles and spacecraft since a trend is developing for these squibs to replace explosive bolts.

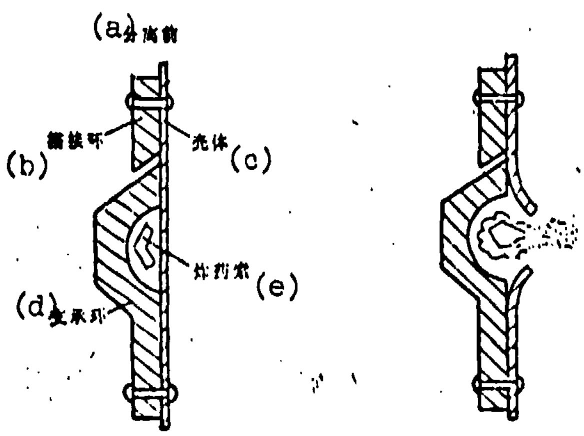

Fig. 4-1. Principle of cutting covering with squibs
Key: (a) Before separation; (b) Adapter ring; (c) Shell; (d) Ring bearing; (e) Squib.

Method of separating stages   Generally, there are two methods of separating stages of carrier rocket: hot separation and cold separation (force-addition separation). Hot separation relies on the upper stage's engine exhaust separating two stages. Refer to Fig. 4-2. The upper-stage engine starts ignition when the two stages are still joined together. Usually, separation proceeds as follows: when the lower stage receives an engine power cutoff command, its thrust decreases.

When the thrust of the lower level drops to a certain value, the upper-stage engine starts igniting. At the same time, an exhaust port of the interstage sector opens to discharge a hot jet stream (in some cases, exhaust discharged from a truss type interstage sector). When the force exerted by the jet stream from the upper-stage engine (acting on the lower stage) attains a certain value, explosive bolts or squibs start an explosion to release the latches and separate the two stages. Then, according to a predetermined program, an attitude control system commences control. Hot separation has the advantages of a large separation force, short lost-control time, and high reliability; however, its interference is correspondingly increased. In addition, many exhuast ports (or the truss type structure employed) should be opened in the interstage sector, and the tank top of the lower stage should have a tough insulation layer to protect against it being damaged by excessively high pressure and heat flow caused by the jet exhaust from the upper stage engine. A sufficient distance should be maintained between the nozzle outlet of the upper-stage engine and the lower-stage tank top, so the positive shock waves on the tank top of the lower stage (caused by the jet stream from the upper-stage engine) must not enter the nozzle in order to avoid impeding normal operation of the upper-stage engine. This will increase the length and weight of rocket structure.

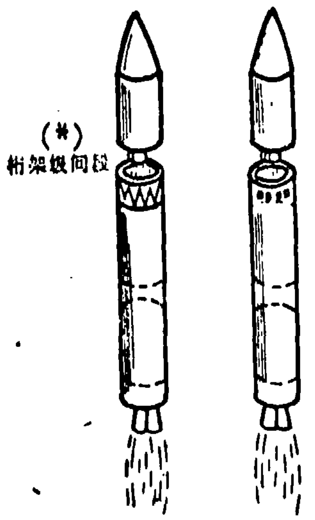

Fig. 4-2. Schematic diagram of hot separation
Key: (*) Trust type interstage sector.

The cold separation method differs from hot separation. This method relies on accessory force addition and a solid-fuel reverse-thrust rocket to effect separation. After separation of the two stages, the upper-stage engine starts ignition. So, this is called cold separation or forced separation (See Fig. 4-3). During separation, the reverse-thrust rocket pushes off the lower stage; in the meantime, the force-application rocket accelerates the upper stage. After these two stages have been separated for a certain distance, the upper-stage engine starts ignition. Among the advantages of this kind of separation is the small acting force required with a comparatively steady operating process and small interference. In addition, no exhaust port is required at the interstage sector and no heat insulation is needed. Of course, cold separation requires very high reliability for the solid-fuel rocket.

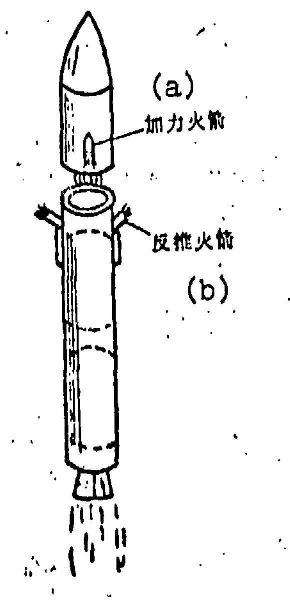

Fig. 4-3. Schematic diagram of cold separation
Key: (a) Force-application rocket; (b) Thrust-reverse rocket.

Now we can see that during separation of stages, at the instant when one stage stops operating and another stage starts operating, many interrelated factors and contradictory requirements should be considered. The coordination problem among systems is conflictingly complicated; otherwise, the flight will fail. Therefore, the problem of reliability merits extraordinary attention.

Intercontinental Guided Missiles

What is an intercontinental guided missile?

An intercontinental guided missile is also called an intercontinental rocket. Some modification is required for assembly into an intercontinental guided missile, such as installing the corresponding flight control system and the payload in the nose cone.

An intercontinental guided missile can fly over an ocean and seas, launched from one continent and arriving at another to attack a strategic target in the enemy's rear. This is the super long-range missile capable of covering more than 8000 kilometers and with a maximum flight velocity of 6.5-7.2 km/sec (23,400 to 25,900 km/hr), corresponding to 20 times the velocity of sound. The peak altitude of the trajectory of an intercontinental ballistic missile is approximately 1500 km. During reentry, the warhead can have an acceleration as high as 50 g. In other words, the force acting on the warhead can be 50 times its weight. Total flight time of an intercontinental missile is about 30 minutes.

Generally, the control system of an intercontinental missile is of the active type. Besides control in the powered phase of the trajectory, the inertia phase of the trajectory is also under control. Usually, guidance during the powered phase is intertia guidance, and the guidance of the last leg of the inertia phase is usually automatic homing guidance. Since guidance during the inertia phase is added, the accuracy of an intercontinental missile is much improved. In addition, adoption of an advanced guidance method like stellar-inertia guidance, and laser or radar homing guidance can further improve the accuracy of intercontinental missiles. Control of intercontinental missile is effected with gimbaled nozzles.

Usually, solid-fuel engines are used in intercontinental missiles, like the Minuteman missile of the United States. However, there are missiles where liquid-fuel rocket engines are employed.

An intercontinental missile uses a silo launch, mobile launch, or underwater submarine launch. The intercontinental missile is gigantic, since tens to one hundred tons of propellant is charged into the missile. Figure 4-4 shows schematic diagrams of four Minuteman missiles.

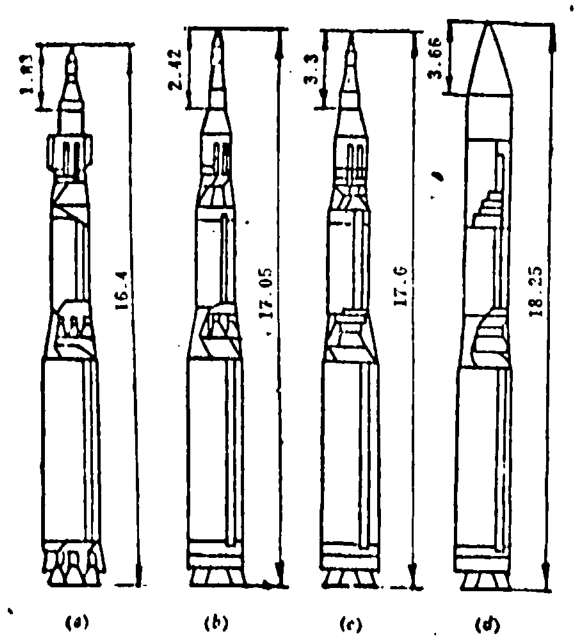

Fig. 4-4. Minuteman intercontinental ballistic missiles: a - Minuteman 1A; b - Minuteman 1B; c - Minuteman 2; d - Minuteman 3.

CHAPTER V

FLIGHT CONTROL SYSTEM OF GUIDED MISSILES

What are the differences between guided missiles on the one hand, and conventional cannon rounds and bombs, on the other.

A guided missile is a weapon that can be controlled. After launch, a guided missile can change its flight direction following signals sent from the ground or by the target (or the missile itself). In addition, errors can be eliminated in order to hit the target accurately. This is the main distinction between a missile and a conventional weapon, like the bomb.

How can a missile fly if it has no controls?

For an intercontinental guided missile, its range is more than 10,000 kilometers and its velocity as high as 6000-7000 m/sec. "A minuscule error could result in a miss of 1000 li [1 li is about 1/3 mile]," says a Chinese proverb. Without missile controls to continuously eliminate interference factors (such as wind and manufacture error), the result can be disastrous. For an intercontinental missile with a range of about 10,000 km, a velocity error of 1 m/sec due to interference (about 1/10,000 of missile velocity) means that the deviation of its impact point can be 80 to 90 km off the target. Then we can see that controls are necessary if a missile is to hit a target accurately.

How can we control a missile? We will talk about this problem below.

Functions of Flight Control System

The flight control system (briefly, the control system) includes two parts: one part is trajectory control; i.e., motion control of the missile's center of gravity. The other part is flight attitude control while moving along the trajectory. In other words, this is control of missile motion around its center of gravity.

Trajectory control involves maneuvering a missile with allowance for its or the target's motion characteristics when determining a target-attack trajectory. In other words, when a missile deviates from the predetermined trajectory, in order to attack the target, corrections are made while maneuvering the missile. The system for executing this control is called a guidance system.

The three-dimensional motion of a missile includes curvilinearity of missile's center of gravity with the missile considered as a particle, and rotational motion (about the center of gravity), such as roll, pitch or yaw motion; motion stabilization about a missile's center of gravity is the premise of controlling the motion of the center of gravity. If the missile cannot maintain its predetermined orientation in space, it is impossible to either control the missile or maintain its flight. The missile will fall to the ground in pancaking motion or break into pieces in space. Therefore, the missile's flight-attitude stabilization should be controlled. The system executing such control is called the attitude stabilization system (or the attitude control system).

So the function of the control system of a missile in flight includes missile guidance and attitude stabilization.

What are the main elements of a missile's flight control system? The main elements of a flight control system are:

Command mechanism It is a unit for control commands. This unit can be placed inside or outside the missile (for example, a ground command station). In addition, some radiation characteristics of a target can be utilized to send a command (instruction) to control the missile.

Sensor It is also called a sounding unit; this is the missile's "sensitive organ." The sensor accepts command or senses deviations caused by interference, thereby forming signals. In other words, when interference from exterior factors (such as wind, missile body, and engine manufacture errors) leads to certain deviations from the missile's predetermined position, a sensor can sense this deviation in order to form signals. Of course, when a command station sends an instruction to the missile, the sensor can also accept this instruction to send signals.

A gyroscope is a sensor we commonly employ; it accepts commands, senses angular deviation, and registers missile velocity and acceleration.

Converter-amplifier: Signals scanned by a sensor cannot be directly sent to an actuator (for explanations of comamnd actuators, see the following text) because: (1) the signal strength is too weak to drive the actuator, and (2) the signals have to be processed. So a converter-amplifier is needed to convert and amplify the signals received in order to provide signals capable of driving the actuator.

Actuator Its function is converting a control signal into a force or couple to maneuver the missile while in motion. The actuator includes a maneuver mechanism and a driving device.

The maneuver mechanism includes a control-surface vane, a (combustion) gas vane, and a gimbaled engine.

The gas vane is installed in the exhaust gas stream at the nozzle inlet of the engine (as shown in Fig. 5-1). When a missile needs a control force, according to instruction (command) from the control system, the gas vane deflects by a certain angle and the gas stream ejected is effected by the inclination of the vane surface. So formulas can be used to express the resistance X_d, lift Y_d and a couple (acting on the gas vane):

$$X_d = C_{xd} \frac{1}{2} \rho W^2 S_d$$

$$Y_d = C_{Yd} \frac{1}{2} \rho W^2 S_d$$

In the formulas, C_{xd} and C_{yd} are coefficients (related to the deflection angle β of the vane in the gas stream); ρ is the density of combustion gas stream; and S_d is the maximum cross-sectional area of the vane.

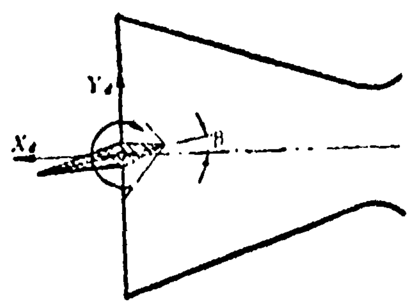

Fig. 5-1. Gas vane

The resistance X_d acting on the gas vane is actually the loss of thrust on the gas vane. However, the lift Y_d of the gas vane can produce a control force to control missile rotation.

By means of a gimbaled engine, a control force is produced. The control force Y_k can be expressed as: $Y_K = P \sin \beta \approx P\beta$

In the equation, P is engine thrust and β is the angle of rotation of the combustion chamber (as shown in Fig. 5-2).

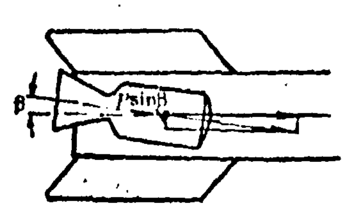

Fig. 5-2. Rotation of engine combustion chamber

Quite a few arrangements can be adopted to take advantage of the rotation of the combustion chamber to control a missile. One arrangement involves the mounting of a gimbaled-engine combustion chamber on a universal frame that can be rotated in either of two directions. Engine deflection can change thrust direction in order to maneuver yaw, pitch or roll motion of the missile (see Fig. 5-3). Based on the magnitude of engine thrust, an adequate control force can be provided by properly controlling the gimbaling angle.

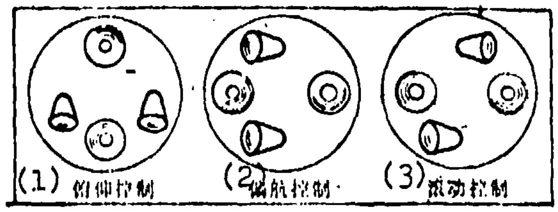

Fig. 5-3. Gimbaling nozzles
Key: (1) Pitch control; (2) Yaw control; (3) Roll control.

For a solid-fuel rocket engine, the propellant is directly charged in the combustion chamber. So the gimbaled nozzles can be utilized to generate the required control force. Or, the technique of double injection can be used to produce the control force. The principle of producing a control force by gimbaling nozzles is similar to a use of hydraulic gimbaling rocket engine. The fundamental principle of the double injection is to inject gas or liquid into the nozzles to deflect the combustion gas stream in order to produce a control force (see Fig. 5-4).

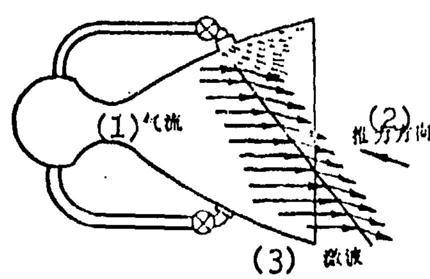

Fig. 5-4. Double injection
Key: (1) Gas stream; (2) Thrust direction; (3) Shock wave.

The function of the driving unit is to drive the maneuver mechanism (according to control signals) and to produce a deflection with the appropriate magnitude and direction. Two examples of driving units are the electro-hydraulic motor and the electro-hydraulic motion unit used at present.

The mutual relationship of the elements of a missile flight control system is shown in Fig. 5-5.

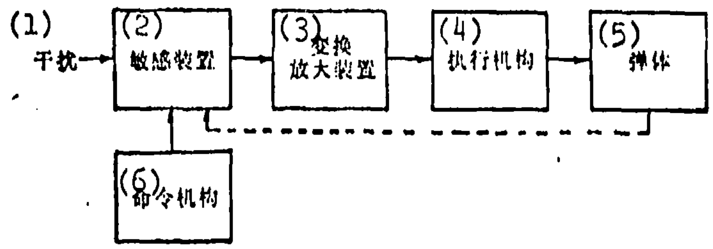

Fig. 5-5. Block diagram of control system
Key: (1) Interference; (2) Sensor; (3) Converter-amplifier; (4) Actuator; (5) Missile body; (6) Command mechanism.

Interference or commands convey different signals to sensors. By means of the converter-amplifier and the actuator, these signals are converted into force or a couple to control missile motion. Thus, the missile is adequately controlled to eliminate deviation caused by interference; or else the missile is maneuvered to be deflected into the required direction.

If part of the actuator (shown in Fig. 5-5) is excluded, the rest is called an attitude stabilization system, which begins sensing interference and maneuvers the missile to eliminate the deviation caused by interference.

Figure 5-6 is a diagram showing the principle of the pitch control circuit of a ballistic missile.

Categories of Control Systems

Generally, a missile control system can be divided into four categories: an independent control system (also called predetermined-guidance system), a homing system (also called as automatic aiming system), a remote control system (also called a command guidance system), and a multiplexed system. Each category can be divided into several programs according to operational principles, as shown in following table:

Independent control systems	Program control
	Inertia navigation
	Astronautical navigation
	Doppler navigation
Homing systems	Active type homing guidance
	Semiactive type homing guidance
	Passive type homing guidance
Remote control systems	Television navigation
	Command navigation
	Radio navigation
	Beam-riding navigation
Multiplexed systems	Independent + homing
	Independent + remote control
	Remote control + homing
	Independent + remote control + homing

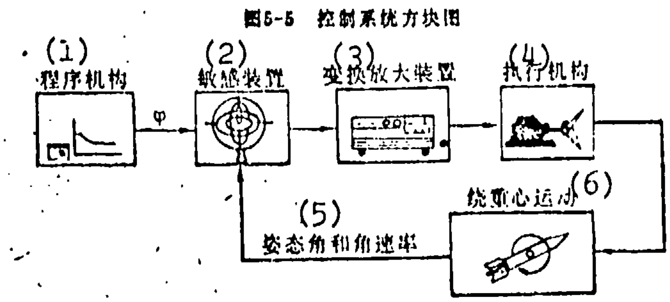

Fig. 5-6. Pitch control circuit
Key: (1) Program mechanism; (2) Sensor; (3) Converter-amplifier; (4) Actuator; (5) Attitude angle and angular velocity; (6) Motion about the center of gravity.

Independent control system Its operational principle applies to the stationary reference systems (inside or outside the missile) as a basic standard to control the missile's flight toward the target. All control systems are placed inside the missile. Once launched, the missile's trajectory cannot be changed. So this is named as independent control system.

Usually, an independent control system is used in missiles (such as ballistic missiles) that can attack fixed targets.

Homing system Its operational principle is as follows: the automatic homing device in the missile can automatically sense (or register) a target's different physical characteristics (such as radio-frequency waves, heat radiation, and photo-radiation), which form control signals for the missile. Thus, the automatic homing device sends control commands to guide the missile heading toward the target, as shown in Fig. 5-7.

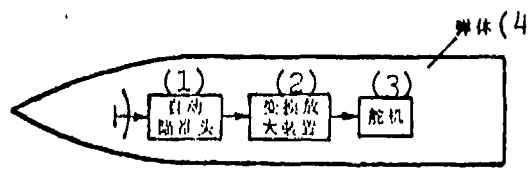

Fig. 5-7. Homing system
Key: (1) Automatic aiming head; (2) Converter-amplifier; (3) Steering machine; (4) Missile body.

Remote control system Its operational principle relies on a command station (outside the missile) to scan the relative positions of target and missile in order to send a command. After the missile accepts the command, which is processed by the internal equipment in the missile body, the missile can be maneuvered to fly toward the target. Or else, after the internal equipment of the missile body senses the missile's deviation, signals are automatically formed inside the missile body to correct the deviation. Then the missile is maneuvered to fly toward the target.

There are advantages and disadvantages in the above-mentioned control systems. A multiplexed control system combines more than two control systems. Thus, advantages of various systems can be adequately exploited. By taking aircraft-type missiles as an example, at the beginning the independent control system is used. Upon approaching the target, the homing system can be used. Apparently, this can improve missile accuracy.

Control System for Attacking Slow-Moving Targets

Slow-moving mobile targets are tanks, warships and aircraft. Problems regarding fast-moving targets, such as artificial satellites and guided missiles will be described in a book, titled FANDAOTAN WUQI (ANTI-MISSILE WEAPONS).

The control system of a missile, which can attack slow-moving mobile targets (briefly, mobile targets), may employ different guidance methods, such as tracking method.

Generally, control systems in missiles attacking mobile targets include homing systems, remote control systems, beam-riding navigation systems, and multiplexed systems.

Classified by the different kinds of radiation energy from a target that a missile intercepts, homing systems include active type, semi-active type, and passive type.

The passive type homing system senses radiation (emitted) energy from the target to determine target position. Then the target is tracked and attacked (see Fig. 5-8).

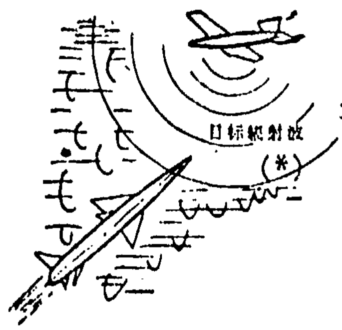

Fig. 5-8. Passive type automatic guidance
Key: (*) Radiation waves from target.

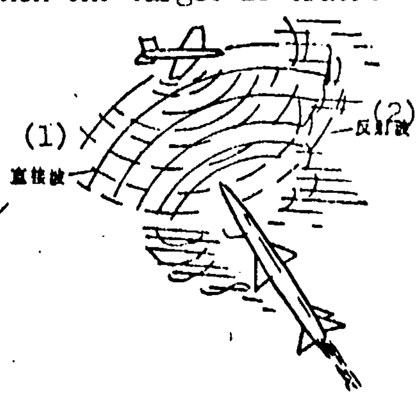

Fig. 5-9. Active type homing guidance
Key: (1) Direct waves; (2) Reference waves.

While adopting the active type homing system, a radar unit in the missile emits electric waves (called direct waves) toward the target. After impinging on the target, the reflection (reflected waves) of electric waves is intercepted by the missile. Guided by the reflected electromagnetic waves, the missile locates the position of target, which is then tracked and attacked (see Fig. 5-9).

When the semi-active-type homing system electromagnetic waves are emitted from the ground surface (or aircraft) toward the target, the reflected electric waves are intercepted by the missile after impinging on the target. Guided by the reflected waves, the missile locates the position of target, which is then tracked. Refer to Fig. 5-10.

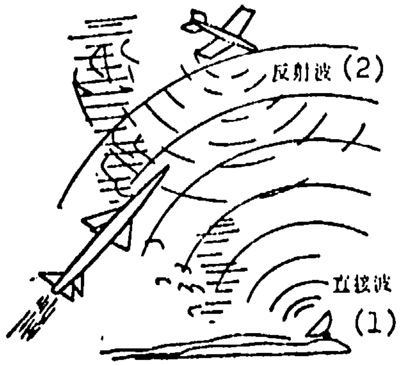

Fig. 5-10. Semi-active-type homing guidance
Key: (1) Direct waves; (2) Reflected waves.

Generally, remote control systems include television remote control systems and radio command remote control systems.

In the television remote control system, it is required to install in the missile nose cone compartment a television transmitter and a pickup tube with an objective lens. A television receiver is installed at the command station. At the station, a missile operator can see everything as scanned by the pickup tube (within the line of sight) of the missile. Based on these pictures, the operator can send appropriate control commands by radio to control the missile heading toward the target.

The operational principle of the radio command control system is as follows: the motion of a missile is under direct control of the command station by instructions (commands). However, instructions from the command station should be determined by the scanned position of targets; the missile is only controlled by the command station. Communication between the missile and targets is provided solely by the command station (on ground or in an aircraft). Figure 5-11 is a block diagram of lead point command type remote control system.

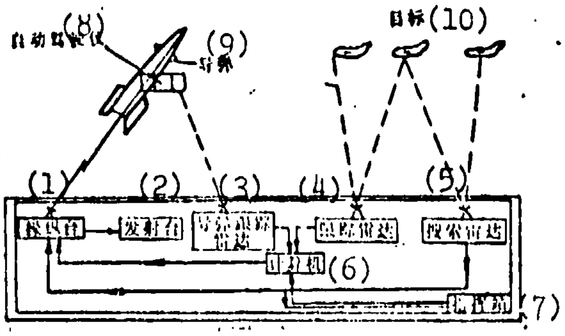

Fig. 5-11. Lead point command remote control system
Key: (1) Maneuver platform; (2) Transmission platform; (3) Missile tracking radar; (4) Tracking radar; (5) Search radar; (6) Computer; (7) Command station; (8) Autopilot; (9) Missile; (10) Targets.

Beaming-riding navigation is a special example of radio navigation. In this case, what is transmitted to the missile are not commands but radar wave beams. In three-dimensional space, the radar set forms a narrow, conical wave beam; the missile automatically flies along the radar wave beam, which guides the missile traveling toward the target (see Fig. 5-12). In the figure, a wide wave beam is used to locate the target. The radar scans with wide wave beams to locate the target.

For improved hit accuracy, two or more guidance systems can be employed. This is a multiplexed guidance system.

Control System of Ballistic Missile

Targets of missile attack can be placed in two prime categories: mobile targets and stationary targets.

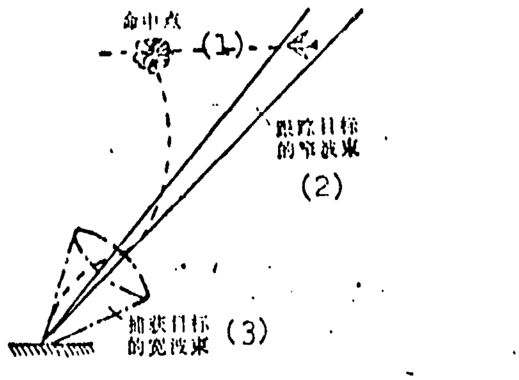

Fig. 5-12. Radar wave beam for missile guidance
Key: (1) Point of impact; (2) Narrow wave beam tracking the target; (3) Wide wave beam locating the target.

What are stationary targets? They are buildings, plants, power stations, cities, bridges, ports, military facilities, airfields, railway centers, missile bases, nuclear power stations, and other buildings and bases of strategic importance.

The trajectory of a missile attacking stationary targets can be predetermined. The control system of the missile is considered as up to standard only by strict maintenance of steady flight along the missile's predetermined trajectory. The independent type control system is widely employed in this missile category.

The control system is described in detail with an example of a ballistic missile.

We know from knowledge of ballistic missile trajectory that the purpose of the program control system of a ballistic missile is to ensure that missile (at the terminal point of the powered phase) accurately attains the required flight velocity V_k and missile pitch angle ∂_k. Then the missile can accurately hit the target.

There are two main subassemblies in this system: the first is the flight program mechanism and the second is the attitude stabilizing device.

The flight program mechanism is a mechanism with a missile's motion program (motion law); briefly, it is called the program mechanism.

The flight program presents the variation law (with time) of the apparent pitch angle (also called the program angle) ϕ as shown in Fig. 5-13.

In Fig. 5-14, angle X_1Ox is the pitch angle; its relation to the trajectory pitch angle ∂ is

$$\varphi = \theta + \alpha$$

In the equation, α is the angle of attack.

The variation law of the missile's pitch angle is predetermined. Thus, the missile can be directed to fly along a predetermined trajectory.

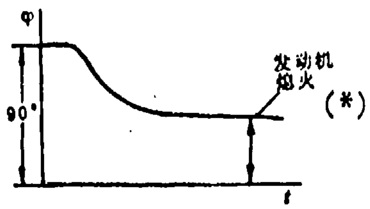

Fig. 5-13. Flight program
Key: (*) Engine-power cutoff.

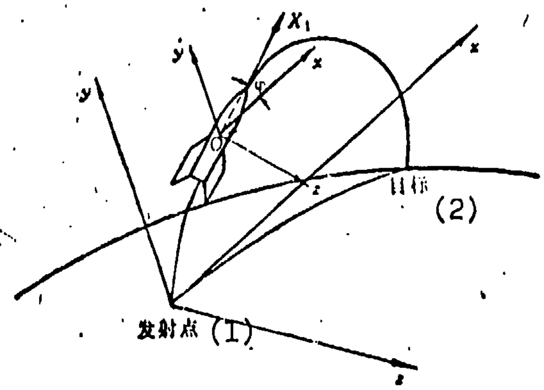

Fig. 5-14. Pitch angle
Key: (1) Launch point; (2) Target.

Operationally, the program control system functions usually as follows: after a missile is launched, at every instant the program mechanism sends a pitch angle ϕ signal. A sensor (a gyroscope, for instance) senses the angle ϕ signal. After conversion and amplification, an actuator is maneuvered so that the position, velocity magnitude and direction (of missile flight) satisfy the predetermined cutoff conditions. Then the control system sends a command for engine-power cutoff (see

Fig. 5-6); the function of the control system is completed at this point. Later, the missile warhead coasts.

CHAPTER VI

CONFIGURATION AND STRUCTURE OF MISSILE

Kinds of Configurations

Some missiles travel within the atmosphere and some penetrate through the atmosphere and travel in outer space. Once launched from the earth, all missiles have a relative airspeed and are acted on by the air. Thus, aerodynamic heat will be converted to heat and damage the missile traveling in the atmosphere. Of course, a missile traveling in the air also produces aerodynamic forces: lift and drag. Aerodynamic heating and drag are related to the missile configuration. For lower aerodynamic heating and drag, the missile should have a good aerodynamic configuration.

There are different kinds of missile configurations: some have a pair of missile wings like an aircraft; some have two pairs of missile wings; some have no wing, or no tail; some have double fins; and some have two sets of canard wings. Therefore are configurations with different characteristics as well as advantages and disadvantages. Study of missile aerodynamic arrangement has the purpose of adequately selecting configurations of different missile sections and appropriate installation of interrelated positions of missile wings, fins, control surfaces, missile body, and engine in order to achieve the required aerodynamic characteristics, as well as the necessary mobility and stability for flight.

Layout of Missile Sections

The missile body in toto is composed of missile body proper, missile wings, fins, control surfaces (rudder surfaces) and others. In addition to the connection of missile wings, fins, and control surfaces, the missile body proper should have installed in it the engine, propellant storage tank, control instruments, warhead and other auxiliary equipment. These subassemblies, component parts, instruments, and equipment units should be rationally installed so that the missile is light-weight and simple in design. Thus, an aerodynamic configuration is desirable; construction and utilization are convenient; and various performance indicators can be attained. This is missile layout. With respect to the relative positions among missile body, missile wings, fins, and control surfaces, generally missile layout can be divided into the following types:

1. Convenient type

In this layout, comparatively large main missile wings (installed near the missile center of gravity) and fins (also called stabilizers, installed at the tail end) are shown in Fig. 6-1. In this conventional layout, some missiles use main missile wings as control surfaces in maneuvering and flight control; and some use fins as control surfaces for this purpose. The former case is frequently seen in air-to-air missiles; the latter case is frequently seen in missiles with comparatively low mobility.

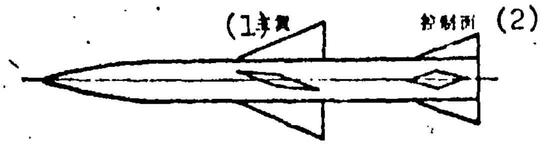

Fig. 6-1. Conventional type missile controlled by main wings
Key: (1) Main wings; (2) Control surfaces.

2. Conard configuration

In this layout, a group of small control surfaces (called canard wings) is installed near the front end of the missile body, and large wing surfaces (main wing surfaces, or fin surfaces) are installed in the mid- or tail-section of the missile body, as shown in Fig. 6-2. Since canard wings are small, the weight of and drag on the missile can be reduced. In a canard-configuration layout, canard wings are used in missile maneuvering and control. Since canard wings are small, roll stabilization is difficult to be maintained.

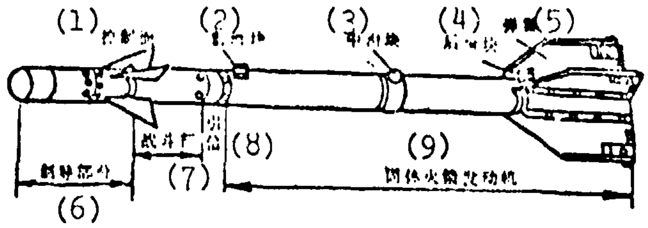

Fig. 6-2. Canard-configuration air-to-air missile
Key: (1) Control surfaces; (2) Front sliding block; (3) Middle sliding block; (4) Rear sliding block; (5) Missile wings; (6) Guidance section; (7) Warhead; (8) Fuse; (9) Solid-fuel rocket engine.

3. Finless type

This type of missiles has no fins, as shown in Fig. 6-3. The control surfaces of the missile are elevator ailerons installed at trailing edges of missile wings. The main advantage of this layout is a smaller number of wing surfaces so that weight, drag, and cost are reduced.

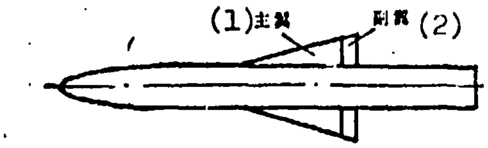

Fig. 6-3. Finless type missile
Key: (1) Main wings; (2) Ailerons.

4. Type of missiles without main wings

In this layout, it is composed of a group of fins, or fins with control ailerons, as shown in Fig. 6-4. Missiles of this layout use a complete fin or aileron for maneuver and control. Although this further reduces the missile weight and drag during its flight, yet the control force is small. Therefore, this type can be used in missiles of low maneuverability requirements.

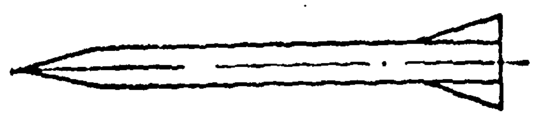

Fig. 6-4. Missile with no main wings

5. Type of missiles without any wings

In the layout of this type, no control surfaces are required for maneuver and control because missiles of this type have only a missile body (shown in Fig. 6-5). Generally, missile maneuver and control (of this type) use a gimbaled combustion chamber and a gimbaled spray nozzle (to eject gas or liquid into the nozzle) to change thrust direction. Usually, this layout is used in large ballistic missiles of low maneuverability and long range.

By the layout of missile wings, the missile layout can be generally divided into three following types:

1. Straight-line wings

In the straight-line wing layout there is only one pair of missile wings, generally instatalled horizontally along both sides of the missile, as shown in Fig. 6-6. This arrangement is generally used for aircraft-type missiles, of which the missile wings serve mainly to produce lift and to balance the gravitational force so that these missiles can continue cruising to attain a greater range.

2. V-shaped wings

There are three V-shaped wings in this case, 120° apart. Since this arrangement does not have outstanding advantages, it is seldom used.

3. Cross-shaped wings

This layout has four missile wings. If viewed from the longitudinal axis of the missile, this arrangement has a "+" shape as shown in Fig. 6-7, or "x" shape as shown in Fig. 6-8.

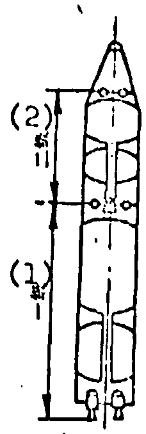

Fig. 6-5. Wingless Missile
Key: (1) First stage; (2) Second stage.

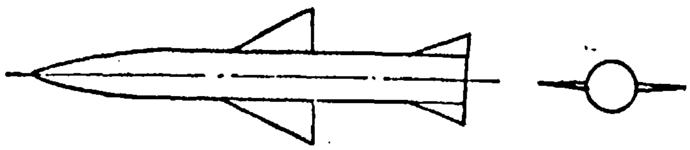

Fig. 6-6. Straight-line-wing missile

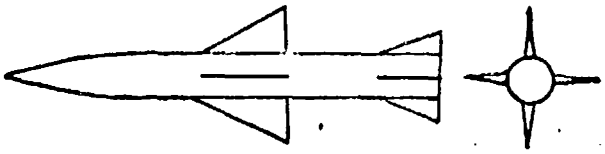

Fig. 6-7. Cross-shaped-wing missile

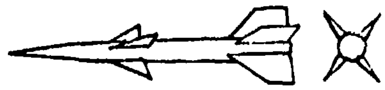

Fig. 6-8. Missile with x-shaped wing surfaces and vane surfaces

For ground-to-air, air-to-air, and air-to-ground missiles, the missile wings are better installed in the "x" shape because of problems in suspension and installation at launching frame.

The missile body can be divided into three main parts: front missile body (or nose), midsection, and rear missile body (or tail section). The layout of the missile body is usually as follows: the warhead is usually placed in the nose section; however, in few cases the warhead is placed in the midsection as shown in Fig. 6-2. The solid-fuel propulsion system occupies almost the entire midsection and tail section. For liquid-propulsion rockets, the combustion chamber (of the engine) is placed in the tail section and the liquid-propellant storage tank is located in the midsection. The layout of the liquid-propellant tank in a missile can be one of three types:

1. The combustion agent and the oxidizer storage tank can be placed in an individual compartment, as shown in Fig. 6-9. Then the agent and tank can have an industrial butt joint surface (Fig. 6-9a); this is one type. Another type is for an individual compartment section but without an industrial butt-joint surface (Fig. 6-9b). In the former type of propellant tank, this is adaptable to an oxidizer, combustion agent or other low-boiling-temperature propellant. It is easy to apply insulation at the tank bottom; it can also better ensure safe operation of hypergolic propellants. Fabrication techniques and industrial testing are relatively simple. Moreover, it is convenient in maintenance and safekeeping. Although the propellant tanks in the latter case do not have the advantages of the former case, yet the length and weight are less than that in the former case. Therefore, structures in the latter case are still utilized in some missiles.

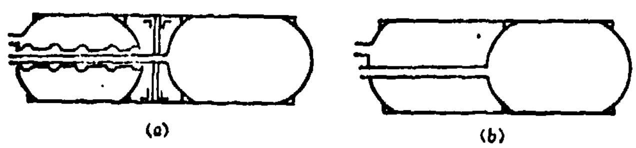

Fig. 6-9. Two types of propellant tanks

2. Combustion agent and oxidizer tank are separated by the instrument compartment, as shown in Fig. 6-10. This layout has the advantage of the propellant tank as shown in Fig. 7-9 (a) [translator's note: "Fig. 7-9 (a)" may be a misprint; it should be "Fig. 6-9 (a)."]. However, because the instruments of the control system are placed between two tanks, the tubular conveyer between the upper tank and the combustion chamber of engine becomes longer so as to add to the structural weight.

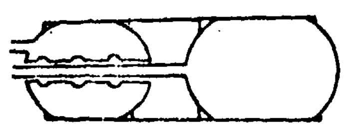

Fig. 6-10. Another type of propellant storage tank

These propellant tanks introduced in previous paragraphs are cylindrical. In order to meet the requirements of the aerodynamic configuration, sometimes the upper tank body of the last stage is made conical in shape or combined conical-cylindrical in shape. Thus, the length and weight of the tank body are greater than that of the cylindrical tank of the same volume. Also, sphere-shaped tanks are adopted, as shown in Fig. 6-11. The tank body is advantageous for low-boiling-point propellant; since the surface area of a spherical tank is smaller than that of a cylinder-shaped tank, the weight of the insulation material can be reduced. In addition, when the same amount of pressure is increased, the weight of spherical tank is less than that of the cylindrical tank.

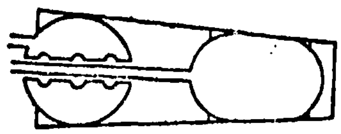

Fig. 6-11. Spherical propellant tank

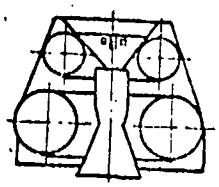

Fig. 6-12. Ring-shaped propellant tank

Sometime, to shorten missile length and to arrange component sections more compactly, a ring-shaped propellant tank is adopted in the last stage as shown in Fig. 6-12.

Flight control instruments can be installed at scattered locations or at a concentrated location. The dispersed installation serves to adequately utilize space in the missile body. For concentrated installation, the flight control instruments are placed in the instrument compartment, which can be placed in the nose section, between the oxidizer tank and combustion tank in the midsection, or between the nose and the midsection. However, whatever the scattered or concentrated installation, instruments should be ensured a good operational environment for normal operation. Therefore, instruments should be placed near the missile's center of gravity, or as far away from sources of heat and oscillation as possible.

An explanation should be made here: whatever the layout of the missile, its center of gravity should be consistently placed in front of the aerodynamic center (focus) during the missile flight. In other words, the missile should be in static stability. Phrased differently, when the external interference is eliminated, the missile should have the capability of restoration to the predetermined dynamic state. Also, the motion range of the center of gravity and the aerodynamic center should be as small as possible. Only in this way, can the missile be conveniently controlled and travel smoothly along the predetermined trajectory. However, it is difficult to control and maneuver this type of missile (of static nonstability) with its center of gravity located behind the aerodynamic center.

Configuration of Missile

The configuration of a missile is composed of the configurations of the missile body and missile wings (main wings and fins). Below we make introductions one by one:

Generally, the missile body is a body of revolution, which is generated by rotating a plane curve (or straight line) around a straight line (called the axis line) for 360° within the same plane. The enclosed body thus generated is a body of revolution.

The above-mentioned missile body can be divided into three sections: front missile body (or warhead), midsection, and rear missile body (or tail section). The front missile body can be in many shapes; most frequently seen are conical, arched, or semi-spherical shapes, as shown in Fig. 6-13.

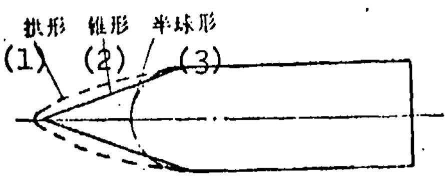

Fig. 6-13. Frequently-seen shapes of warhead cross section
Key: (1) Arched shape; (2) Conical shape; (3) Semi-spherical shape.

In order to ensure good characteristics of the entire missile system, the warhead configurations should be carefully selected. Generally, warhead configurations are selected by considering, from an overall viewpoint, the requirements of aerodynamic force, control, and structure. For example, from an aerodynamic viewpoint the semispherical warhead is inadvantageous because it will encounter greater resistance. However, from viewpoints of structure rigidity and some guidance method (such as infrared guidance), the semi-spherical warhead is excellent. As another example, with the same base area and length, the volume of an arched nose is larger than that for a conical nose. The arched warhead is relatively blunt; considering structure and aerodynamic heating, the arched warhead is better than conical warhead, which is, however, easier to be made.

For ballistic missiles, generally the warhead shapes are combinations of surfaces of conical, cylindrical and/or semi-spherical shapes, as shown in Fig. 6-14.

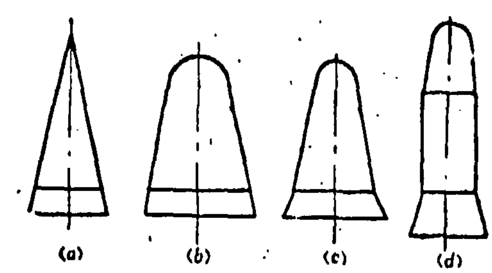

Fig. 6-14. Warhead shape of ballistic missile: a - Cone; b - Combined semi-spherical and conical shape (blunt nose); c - Combined semi-spherical and truncated conical shape; d - Combined semi-spherical and cylindrical shape.

Actually, the combined semi-spherical and cylindrical (or conic) warheads are often used in long-range missiles. The conical warheads are often used in medium-range missiles.

In the layout of many missile configurations, usually the midsection of the body is cylindrical in shape. In addition to adopt the cylindrical shape, the transitional sector for joining various stages or the warhead may use a conical shape, which can reduce drag and increase the bearing capacity, and which is convenient to manufacture.

The frequently-used tail-sector exteriors (of a missile) are cylindrical, contracted, and truncated cone (increasing diameter toward the rear) shapes.

Because of the large base area of the cylindrical tail sector, the drag of the base is high. Due to the reduced base area of the contraction-shaped tail sector, drag at base is reduced.

The configuration of a missile wing is determined by its plane and cross-sectional shapes.

Plane outlines of a missile wing   Usually, three fundamental outlines are used in missile: the prism-shaped wing, triangular wing, and swept-back wing, which has its leading and trailing edges not perpendicular to the longitudinal axis of the missile body, but extending toward the rear of the body. There are many modified versions (as shown in Fig. 6-15) of these three basic plane outlines of missile wings. There are advantages and disadvantages for each type of plane outline. Only under certain situations can the most suitable outline be determined. Therefore, before selection an overall analysis and study should be made (as to a missile wing) of aerodynamic efficiency, structural weight, and manufacturing costs for the most suitable outline.

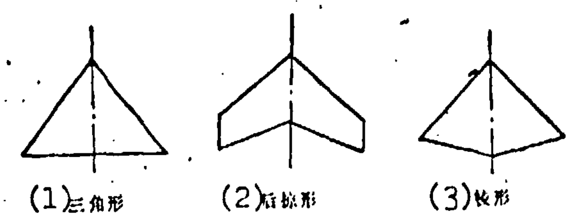

Fig. 6-15. Plane outlines of typical missile wings
Key: (1) Triangular outline; (2) Swept-back outline; (3) Prismatic outline.

Cross-sectional outlines of missile wings   The frequently-used wing cross sections of missiles are double-wedge outline, its modified version, and double-convex outline, as shown in Fig. 6-16. When selecting cross-sectional outlines, an overall consideration (such as selecting the plane outlines of the missile wing) should be made in selecting proper cross-sectional outline. From the viewpoint of aerodynamic efficiency requirements, there is relatively low drag for the double-wedge-form cross section with a certain thickness ratio. From the viewpoint of fabricability, the modified version of double-wedge form (including solid-core wing type) is easily machined. For greater structural strength at local parts and lowered effect of aerodynamic heating, the sharp leading edge (and trailing edge) can be made into rounded corners. Usually, the double-convex form is used for large, non-solid missile wings; the modified version of the double-wedge form is used in small missile wings with a solid core.

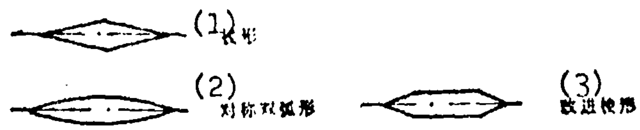

Fig. 6-16. Typical cross-sectional forms of wings
Key: (1) Prismatic form; (2) Symmetrical double-arc form; (3) Improved prismatic form.

Missile Structures

Structures of liquid-propellant missiles are more complicated than structures of solid-propellant missiles. This section mainly introduces structures of liquid-propellant missiles.

The missile body and missile wings are acted on by aerodynamic loading; therefore, a good aerodynamic configuration is required. A good operation environment should be provided for instruments and equipment installed in the missile body. The missiles should be maintained and serviced, and props and suspensions are required during launch; so the missile body should be made sturdy enough. However, to redude weight (Lower structural weight is important for flight vehicles.) the missile body should be made sufficiently light and convenient. These two requirements are contradictory. How can the problem be solved? From practice, solutions can be derived from two aspects: one is the adoption of light but tough structural materials, and the other is the use of optimal structural types.

In considering structural types, a simple rationale is that those parts should be strengthened if acted on by large forces, while the other parts may be structurally weakened if acted on by small forces (usually, it is sufficient to consider just maintaining the structural shapes). The structure thus obtained is generally some type of hollow frame or hollow structure. Therefore, the missile can be sturdy, but light and convenient. There are mainly the four following types of structure used in missiles.

Structural Skins

The earliest adoptions (in large numbers) of structural skins in low-speed aircraft were based on the above-mentioned approaches. Naturally, these structures were used in early missiles. The missile wings of these structures are made by first joining into latticework using some form materials, and then a layer of thin metal plate is used as the skin. Connections between latticework and between latticework and skin are by rivets, welded joints, or cemented joints.

The longitudinal latticework of this type of missile wings includes beams and purlins. The lateral latticework includes the ordinary wing ribs and reinforced wing ribs. Wing beams are the main structural members (acted on by longitudinally directed forces) of missile wings; the wing beams mainly receive aerodynamic loading withstanding the bending of missile wings. Purlins serve mainly to support the skin, to increase its rigidity, and to help wing beams to withstand bending. The cross-sectional outlines of purlins vary, as shown in Fig. 6-17. Which form should be adopted depends on the actual situation and loading conditions.

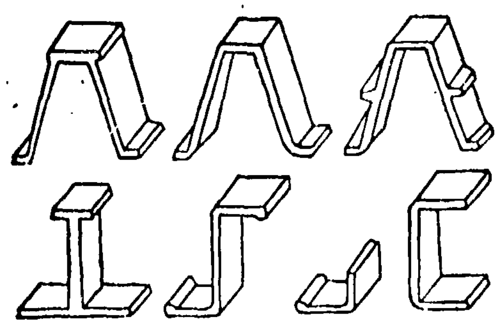

Fig. 6-17. Cross-sectional forms of purlins

The functions of wing ribs serve to maintain the cross-sectional forms of the missile wings, to transmit local aerodynamic loading, and to support the skin and purlins. Except for accomplishing the above-mentioned tasks, the reinforced wing ribs serve mainly to withstand relatively large concentrated loading.

The skin encloses the latticework to give the missile wings a smooth aerodynamic configuration. The skin can also withstand torsion and transmit the aerodynamic forces to the wing ribs, purlins, and wing beams.

The situation of the missile body with latticework-skin-type structure is very similar to that of missile wings. This structural type is mainly used in the instrument compartment, transitional section, tail section, and the part of the missile body with the compartment containing the liquid-propellant storage tank.

Instrument compartment There are different instrument compartment configurations depending on different locations in the missile. When the instrument compartment is placed behind the warhead, the compartment is shaped like a truncated cone. When the compartment is placed between the propellant tanks, it is shaped like a cylinder. There are, in the instrument compartment, frames, which are used for mounting the flght control instruments and automatic adjustment equipment in the missile, and are used for structural members under forces. Several window openings are made in the skin of the instrument compartment in order to install, examine, test, maintain, and service instruments and equipment. In normal times, these window openings are covered.

Transitional section The section joins the various stages and the warhead of a multistage missile into a single entity. Because of different diameters of various stages (or warhead) joined by the transitional section, there are two kinds of transitional sections, conical or cylindrical in shape. Figure 6-18 shows the simplest truncated-cone-shaped transitional section, composed of a shell and two butt-joint frames (without purlins). For the transitional sector (such as the interstage transitional sector) operated under comparatively unfavorable conditions, there are purlins and mid-frames for longitudinal and lateral reinforcements. If hot separation is employed for interstage separation, many windows can be opened in the transitional section joining the front and rear stages in order to ensure smooth passage of high-temperature combustion gases produced by the rear-stage engine. Or, the transitional section can be made into a frame-type transitional section with welded joints of steel tubes, as shown in Fig. 6-19.

Tail section The section protects the engine against collision damage. In the tail section there can be installed the actuators of the flight control system and control surfaces of the missile. The tail section can also join the lower stage, or the missile can be supported on the launch pad. There are different tail-section structures because of different missile types, subassembly arrangements, engine structures, maneuver mechanisms, and methods of erecting a missile on its launch pad. For missiles with solid-fuel brake rocket engines for interstage separation and a gimbaled combustion chamber for maneuvering, the tail section is shown in Fig. 6-20. There are four rectifying cowls along the directions of planes I-III and II-IV. Beneath the rectifying cowls are installed the gimbaled combustion chamber of the gimbaled engine and the solid-fuel brake rocket engine. The engine frame, fixed on the reinforced frame, is used to support the main and gimbaled engines of the missile. There are supports on the lowest-end frame of the tail section in order to erect the missile on its launch pad. On the rectifying cowls, windows are opened to inspect and service the gimbaling mechanism and other parts.

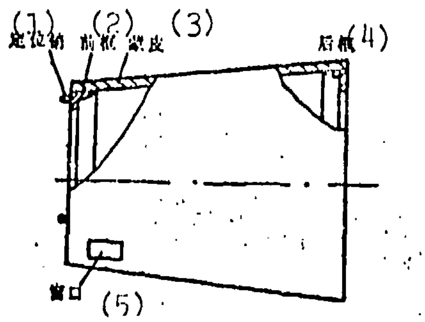

Fig. 6-18. Transitional section
Key: (1) Positioning pins; (2) Front frame; (3) Skin; (4) Rear frame; (5) Window.

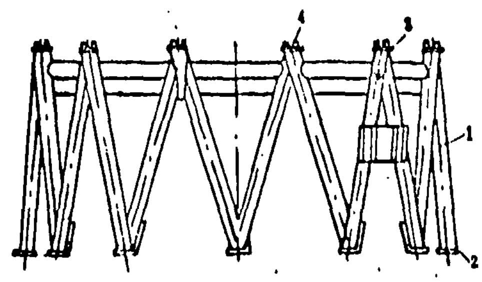

Fig. 6-19. Frame-type transitional section: 1 - Tube; 2 - Bottom plate; 3 - Cushioning seat; 4 - Positioning pin.

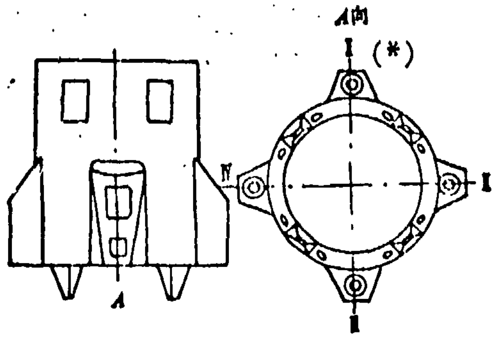

Fig. 6-20. Schematic diagram of one type of tail section
Key: (*) Direction A.

Integral Wall Plat Structure

In the missile development process, flight velocity has become higher and higher. This gradually leads to new problems, such as greater local aerodynamic force. In order to solve these problems, at the beginning the latticework and skin were thickened. Later, the latticework and skin were made into an integral structure. This leads to an integral wall plate type structure with thick walls.

Figure 6-21 shows missile wings of this structural type, which combines the latticework and skin into one whole. So this is called an integral wall plate structure from the viewpoint of the latticework skin. This wall plate can be manufactured by casting, forging, or chemical etching. As shown in Fig. 6-21, after two (upper and lower) plate members are matched at the leading and trailing edges of a missile wing, screws are used to join these two members. For an aerodynamic configuration, a rectifying leading edge is added to the screwed leading edge. In this type of structure, the thickness of the latticework and wall plate can be determined by actual loading at various locations in order to sufficiently exploit the loading capacity of the structure. Moreover, the structural type gives adequate strength (to withstand breakdown) and rigidity (to withstand breakdown) and a smooth configuration to reduce air drag. The weight of the structure is also relatively light.

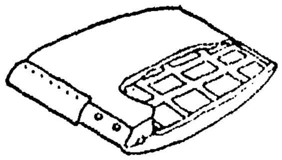

Fig. 6-21. Missile wing of integral wall-plate type structure

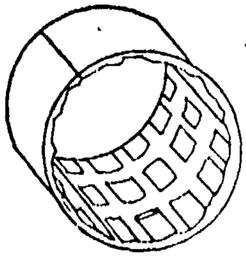

Fig. 6-22. A section of missile body with integral wall-plate type structure

Figure 6-22 shows a section of a missile body with an integral wall-plate type structure; several integral plates are joined (by welding) together.

In some small missiles (such as air-to-air missiles), an integral structure is used for their missile wings, body and vane surface; wings and vane are combined into a single pl·   ·en the missile body is a thin-wall cylinder (generally called as hard-shell-type body).

Since the later stages (· · ballistic missile) fly in a thin atmosphere, there is much less need to protect the engine against aerodynamic drag. The aerodynamic stability of a missile drops sharply; so the later stages of a ballistic missile can use the kind of tail section that can be jettisoned. Jettisoning this kind of tail section can reduce passive weight (dead weight) of later stages to favor a greater range. The tail section (that can be jettisoned) is composed of several thin plates, whose joining can employ quick-release locks (exclusively used for this purpose). By using explosive bolts, the tail section itself can be joined (with butt joint) to the main body of that stage. This tail section (that can be jettisoned) is of the integral wall-plate type structure. During jettisoning of the tail section, the butt-joint bolts are sheared with explosive; latches are released; and the tail section plates are discarded from the missile body.

Sandwich Structure

Further developments in the integral w·ll-plate structure led to sandwich structure, which is composed of two surface plates with a sandwich core between them. This is where the term, sandwich structure, came from. At first, it was noticed that a honeycomb is very thin but it can hold large amount of honey without deformation; it was deduced that the honeycomb bearing capacity is very high. According to this concept, some people used the method of welding or gluing joints of tin foil or stainless steel foil into honeycomb-shaped sandwich cores, both sides of which are covered with facing plates. This structure is used to make bearing parts of missile wings and others. This is the well-known honeycomb sandwich structure, one type of which is shown in Fig. 6-23. Also, bubble plastic or heat insulating material is used as a filler of the sandwich core, which is called filler sandwich structure. Figure 6-24 shows a section of a missile wing using a kind of bubble plastic sandwich structure.

Advantages of sandwich structures are their low weight and high rigidity. So the structure is especially adaptable as a thin wing surface of a high velocity flight vehicle. Since the sandwich honeycomb core or insulating filler has good heat insulating characteristics, this type of structure can serve under relatively high temperatures while heat-insulating material is used for facing plates. The structure can help in solving problems of aerodynamic heating.

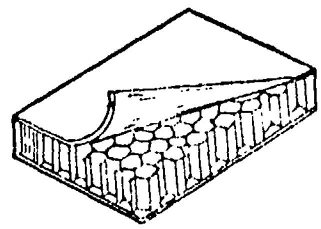

Fig. 6-23. Honeycomb sandwich structure

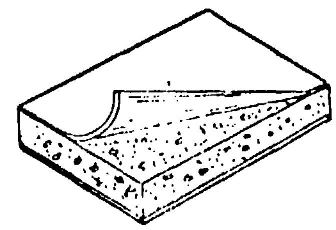

Fig. 6-24. Bubble plastic sandwich structure

Thin-shell S ucture

Some large rockets and missiles have large liquid-propellant storage tanks; some tanks take up a large part of the missile body with diameters as large as 10 or more meters. To reduce the structural weight, a gas-filled thin-shell structure is used for these storage tanks. Most of the storage tank is cylindrical in shape; two terminals of the tank are made into a shape that is semi-ellipsoidal or semi-spherical. The tank is filled with gas at 2 or about 3 atmospheric pressures. Thus the tank shell can be very thin, down to tenths of a millimeter. After being filled with gas, structure rigidity can be increased in order to eliminate the l ngitudinal stress induced by bending and compression of the tank body. In order to avoid lateral deformation in the tank body, some partition frames (for restraining function) can be welded on the tank wall.

Structural Material of Missiles

What kind of material is a missile made of?

Metal is a required structural material of missile bodies. What kind of matals can be used? Light (but strong) materials are best. Here "light" means low specific gravity and "strong" means high strength and high rigidity.

Some other factors should be considered in selecting materials: for examples, the degree of temperature effect on materials, technical characteristics (easily machined or not), cost, and resources. Selection of materials is also a problem requiring overall consideration.

The main structural materials of missile body are aluminum alloys, magnesium alloys, alloy steels, titanium alloys, and composite materials.

Aluminum alloys The specific gravity of this class of alloy is small, about 2.8. At normal temperatures, these alloys have high specific strength (the ratio of tensile strength to specific gravity) and specific rigidity (the ratio of modulus of elasticity to specific gravity). The strength of superhard aluminum is even higher. In other words, for the same strength and rigidity, the structural weight of aluminum alloy is relatively light. There are two categories of aluminum alloys: casting aluminum alloy and deformed aluminum alloy; they are easily machined and formed at low costs. Therefore, aluminum alloys are used to make liquid propellant storage tanks in addition to making of skin and latticework accessories for the missile body. Aluminum alloys have good characteristics in resisting chemical and corrosion reactions; these alloys also have good low-temperature characteristics without being brittle in contact with liquid oxygen (-183°C) and liquid hydrogen (-253°C).

Magnesium alloys This class of alloy has a specific gravity, at 1.8, which is even lower than for aluminum alloys. Although their strength is low, their specific strength is comparatively high and their specific rigidity is not low. However, since the modulus of elasticity is low and their oscillation-reducing characteristics are good, these alloys can withstand relatively high impact vibration loading. These alloys have good machining characteristics. Magnesium alloys can be used to manufacture wing surface and (missile body) cabin sector of various integral wall-plate structures, as well as other latticework accessories. These alloys do have the disadvantage of easy corrosion. There are two types of magnesium alloys: casting magnesium alloy and deformed magnesium alloy.

Alloy steel This includes high-strength structural steel, and stainless steel with high temperature and corrosion resistance. Among various types of alloy steel, the typical high-strength steel includes 30CrMnSi steel. After heat treatment, the ultimate strength is 110 kg/mm^2. The specific gravity of alloy steel is usually used in members in stress (such as beam in stress and reinforced partition frame) and force transmission joint. Stainless steel has good characteristics of cold machining, welding, and low-temperature service, as well as high resistance against corrosion. Thin stainless-steel plate can be used to make skin and large storage tanks for low-temperature propellant.

Titanium alloys This alloy class has characteristics of low specific gravity (about one half of that of alloy steel) and high strength (approaching that of alloy steel); therefore, the alloy class has very high specific strength. Also, the alloy class has good resistance against corrosion and high temperature. Within the temperature range of 150° to about 300°C, the reduction of strength is quite slight. The strength only decreases slightly at high temperatures of about 500°C. Titanium alloys do not become brittle at low temperatures. Most titanium alloys can be welded; therefore, they can be made into missile skin, latticework, high-pressure gas bottles, and low-temperature storage tanks. The shortcomings are inferior characteristics of machining and planing, and comparatively high costs. Moreover, heat needs to be added while forming.

Composite materials Reinforced plastics are a type of composite materials. First of all, glass filaments (glass fibers) are simultaneously wound and glued with resin. Alternatively, glass filaments are first woven into glass fabric and then resin is used to glue the filaments layer by layer. So this is called as glass fiber reinforced plastic (also called reinforced plastics). Since this material is made of two types of materials (glass fiber and resin), it is also called as composite material.

At present, reinforced plastics most frequently used are compounded with epoxy resin (or phenol aldehyde resin) and glass fabric. Although the plastic has a moderate strength, it has low specific gravity, only 1.8 to about 2. So its specific strength can be comparable to that of high-strength aluminum alloy. Also, the forming techniques are simple. So the reinforced plastics are widely used to make missile bodies, missile wings, and high-pressure gas bottles.

Since the rigidity of reinforced plastics is quite low, usually a sandwich structure is formed during application. Bubble plastic or honeycomb is usually made into a sandwich core; this can compensate for the shortcoming of low rigidity. Later, another type of composite materials was made by compounding epoxy resin and graphite fiber (or boron fiber). Another type of composite materials has strength and rigidity much higher than for reinforced fabric. In order to compensate for the inability of resin to withstand high temperatures (Epoxy resin softens at above 200°C.), metals are used to replace resin in making boron-aluminum composite material. Therefore, temperatures as high as 250∿500°C can be tolerated. Also, alloy fibers and alloy materials are made with composite materials. Thus, there are not only better characteristics at high temperatures, but also a significant increase in specific strength and specific rigidity. In short, studies in this area are continuously moving ahead.

After trial manufacture of guided missiles, in order to examine whether or not the structural strength (theoretically calculated) can accommodate actual situations, ground strength tests and repeated test flights should be conducted. Only after ground strength tests and repeated test flights have been smoothly qualified, can serial production of missiles be started before their deployment by troop units.

CHAPTER VII

COMBAT PAYLOAD AND MULTIPLE WARHEADS

Combat Payload of Missiles

The combat payload is the part of the missile involved accomplishing the combat mission at the final instant. When a missile approaches its target, the combat payload executes its mission at a proper attitude according to the predetermined requirements and methods; the mission includes wounding and/or killing enemy human resources as well as destruction of enemy arms, key cities, and military facilities. Therefore, the part of the missile body for the destruction of enemy targets is usually called the combat payload.

If a missile has no combat payload and even though the target is hit directly, the target is not seriously damaged because only the missile's kinetic energy is applied to the target (Fig. 7-1). However, it is quite difficult to directly hit the target because every system in the missile can have some errors. If a missile is equipped with a combat payload, the destructive effect is much greater. Only within the effective range of the combat payload can the target be damaged (or destroyed) without a direct hit, as shown in Fig. 7-2.

Fig. 7-1. Not a direct hit

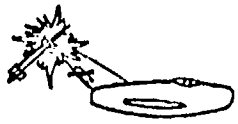

Fig. 7-2. Hitting a target

Usually, the combat payload is composed of three parts: warhead, fuse and safety device. A vast amount of energy is stored in the warhead for destroying the target. A fuse is used to ensure a detonation when the warhead power can be exploited to the fullest. There are many types of fuses; their selection should be based on target types and characteristics of combat payloads. A triggering fuse should be selected if a binding-energy combat payload is used to attack ground armor target. The priming device utilizes the impact force when the missile hits the target; the impact force can ignite a priming device to detonate the combat payload. A proximity fuse is usually selected (such as infrared fuse or radio fuse) if a combat payload is used to attack an air target. The proximity fuses utilize some signals from a target to initiate detonation. An infrared fuse utilizes infrared radiation in the combustion gas stream from an aircraft; a radio fuse utilizes reflected radio waves from a target.

A safety fuse ensures that a warhead does not detonate before the launch of a missile. Before encountering the target, the safety fuse is released on time so that the missile can lead to self-destruct (when it fails to encounter the target). Generally, a safety device utilizes some characteristics (such as acceleration) of missile flight to release the safety to enable the combat payload prepare for detonation. When a missile approaches a target, the fuse receives signals (such as infrared radiation and radar echo) from the target. The closer the missile to the target, the stronger is the signal. The fuse will detonate the combat payload when the signal reaches a predetermined value, which is calculated in advance for a required distance between the target and missile to start its detonation.

Although there are various types of combat payload, generally speaking there are two: nuclear and conventional combat payloads. A nuclear payload can be used to destroy many differing types of target; nuclear payloads include atomic bomb, hydrogen bomb, and neutron bomb. According to the methods of target destruction, there are three categories of conventional combat payloads: detonation, antipersonnel, and binding-energy combat payloads.

Conventional Combat Payload

(1) Detonation Payload

A detonation payload is mainly used to destroy ground surface, water surface, underground, or underwater targets, such as military fortifications, merchant marine, and warships. Therefore, these combat payloads are generally loaded in air-to-air, air-to-ground, ground-to-ship, and ship-to-ship missiles.

A detonation payload is packed with large amounts of dynamite. Generally, the violent impact waves and detonation products (such as large amounts of high-temperature, high-pressure gas) are used to destroy the target after detonation of dynamite in the combat payload. The magnitude of the wave front pressure of the impact waves is related to the characteristics and amounts of dynamite; however, the pressure quickly decreases with increasing distance from the detonation center. Within a certain range, the wave front has a very high pressure that the detonation payload relies on to destroy buildings and to wound and/or kill people.

Figure 7-3 shows the structure of the detonation payload of a ground-to-ground missile. The conical shell is made up of a thin steel plate; high energy dynamite is charged in the shell. A cylindrical detonation-transmitting powder column is placed at the center of the conical shell; fuses are fitted at the front terminal and at the base cavity.

The functioning process of this combat payload is as follows: when the missile approaches or hits a target, fuses at nose and base initiate the detonation, which is transmitted through the powder column to detonate dynamite and destroy the target.

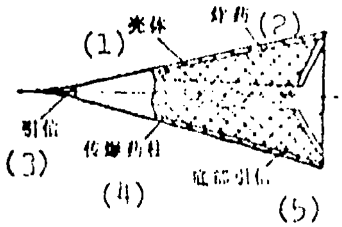

Fig. 7-3. Detonation payload
Key: (1) Shell; (2) Dynamite; (3) Fuse; (4) Powder column for transmitting detonation; (5) Fuse at base.

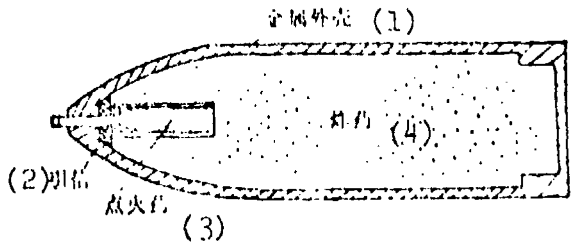

Fig. 7-4. Basic structure of ordinary detonation payload
Key: (1) Metallic shell; (2) Fuse; (3) Igniter; (4) Dynamite.

A structural characteristic of detonation payload is its (relatively) thin shell wall. Thus, more dynamite can be loaded. The basic structure of detonation payload is shown in Fig. 7-4.

An underwater dynamite explosion is basically similar to a midair detonation. The explosion products also form impact waves in the water. Since water density is greater than air density but compressibility is smaller, the pressure and density of explosion products cannot decrease very rapidly. The wave-front pressure of the underwater impact waves is much greater than that in air. If the initial pressure of the wave front of a midair detonation is approximately 1000 atmospheric pressures, the pressure of an underwater detonation can attain 100,000 atmospheric pressures.

Another characteristic of underwater detonations is that the explosion products quickly expand as underwater gas bubbles to expel the surrounding water to move diametrically outward. In the process of motion, when gas bubbles expand with their internal pressure equal to external pressure (the static pressure of surrounding water), expansion should have stopped. However, due to the inertia of the surrounding water current, expansion continuously moves outward. As a result, the excessive expansion of the space inside gas bubbles results in the internal pressure being lower than the external pressure. On disappearance of the inertia function and an increase in the internal and external pressure difference, the surrounding water again shrinks backward to compress gas bubbles smaller. While the gas bubbles are so small that the internal and external pressures are equal, due to the inertia water still continuously compresses the gas bubbles and again the internal pressure is higher than external pressure. When the pressure difference overcomes inertia, gas bubbles again expand. Thus, gas bubbles vary from small to large, and from large to small. The process will be repeated several times before equilibrium is finally reached.

We can see that during the underwater explosion of a detonation payload, there are three types of destruction of merchant marine and warships: the first is the impact waves; the second is the water current; and the third is the explosion products in gas bubbles. However, when detonation occurs at a distance from the target, the main effect is from the impact waves with little effect due to the last two factors.

When dynamite detonates in the soil, it is similar to an underwater explosion. However, since soil contains many spores with scattered particles, no impact waves of apparent wave fronts will appear after detonation.

When a detonation payload explodes at a certain depth beneath the ground surface, a horn flare like detonation hole will be opened in the ground. Generally, this is called a crater, as shown in Fig. 7-5. Based on the extent of destruction and characteristics, a crater can be divided into three areas: destruction area, compression area, and shock area. The detonation power comes in forms of impact waves, fragments, and the overall seismic effect due to detonation. Generally, the crater depth is the standard of evaluating detonation power. If the detonation center is quite deep beneath the surface, detonation cannot penetrate the thick soil layer. Then this is called tunnel detonation, or blind detonation. The shock wave and fragments from this kind of detonation lead to very little damage but the seismic effect due to detonation is the greatest.

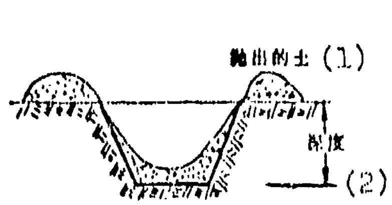

Fig. 7-5. Shape of detonation crater
Key: (1) Soil thrown out; (2) Depth.

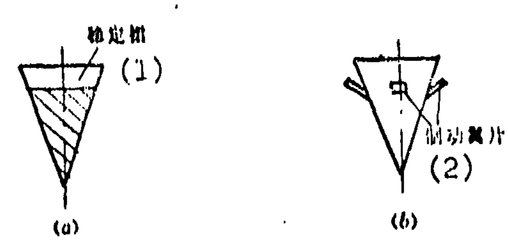

Fig. 7-6. Methods of stabilizing warhead
Key: (1) Stabilizer; (2) Brake impeller.

Generally, a detonation payload is charged into a medium- or long-range ballistic missile. Since the missile velocity is very high, aerodynamic heating is very serious during reentry into the atmosphere. Therefore, methods of heat prevention should be adopted. There are two most common methods of heat prevention: heat absorption type and burn etching type.

Generally, a combat payload of a medium- or long-range ballistic missile can be separated from the missile body. When considering flight stability on return to the atmosphere (reentry into atmosphere), a special stabilizing device should be fitted, such as a stabilizer or brake impeller, as shown in Fig. 7-6.

(2) Antipersonnel Payload

An antipersonnel payload is used to attack enemy air and ground surface (or water surface) arms and human resources, such as aircraft, missiles, ground-arm facilities, and personnel.

Wounding, killing and damage to targets by an antipersonnel payload is due to its enormous kinetic energy and its fragments distributed with a certain density to attack targets. The kinetic energy of fragments comes from the dynamite explosion and the distribution of fragment density is related to the structure and material of the combat payload. The distinction between antipersonnel and detonation payloads is that the former relies on fragments to attack targets while the latter relies on impact waves to damage or destroy targets. Of course, in both cases both kinds can detonate as well as wound and/or kill people, only the emphasis is different. When these two functions are taken care of simultaneously, the payload becomes the so-called antipersonnel-detonation payload.

The antipersonnel payload is composed of the four following parts as shown in Fig. 7-7:

1. Dynamite: this is main source of energy for the antipersonnel payload to destroy the target. 2. Metal shell: after dynamite detonation, the shell body splits into antipersonnel fragments. 3. Detonation attachment: it includes detonator and detonation-transmitting powder. 4. Connecting members: together

with a metal shell, a powder-packing "container" is formed, connecting to the missile-body proper.

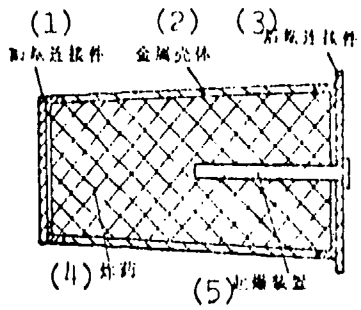

Fig. 7-7. Schematic diagram showing structure of antipersonnel payload
Key: (1) Front end connecting member; (2) Metal shell; (3) Rear end connecting member; (4) Dynamite; (5) Priming device.

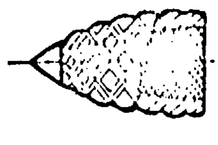

Fig. 7-8. Groove type antipersonnel payload

There are various types of antipersonnel payload structure. On the fragment-forming shell structure, the most frequently seen are the following types:

1. Groove Type

A grooved steel plate is bent into a cylinder or truncated cone, which is joined (by welding) into a shell body, as shown in Fig. 7-8. Grooves divided the steel plate into many cubes, rhombs, or small blocks of other shapes. Grooves can be inscribed on an inner or outer surface of the shell, or both surfaces can be inscribed. The inscribed grooves are weak links. When dynamite explodes, the shell expands and relatively consistent fragments are formed along the grooves. The depth of the inscribed grooves is mainly determined by the thickness of the steel plate. If the inscribed grooves are too deep, the toughness of combat payload will be weakened and the fragment velocity is also low. When the inscribed grooves are too shallow, fragments will not be formed according to the design dimensions. Several or more fragments may be joined together in reducing the number of antipersonnel fragments for lower effects. The diameter of this kind of combat payload is relatively large with a greater antipersonnel radius.

2. Binding-energy Groove Type

Its shell is usually made of a steel tube. Lined closely along the inner wall of the shell is a plastic or celluloid sleeve with special grooves pressed on the groove surface, as shown in Fig. 7-9. The outline of the grooves is determined by the required fragment shape. During the detonation of packaged powder, relatively concentrated energy occurs along grooves to cut the steel shell into small blocks of required shape. The carved grooves on the sleeve should have a proper outline and depth, otherwise an ideal cutting function cannot be ensured. The diameter of this kind of combat payload is relatively small, and likewise for its antipersonnel radius.

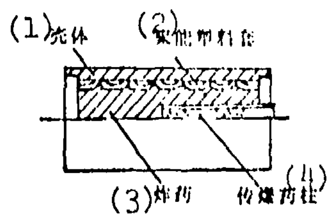

Fig. 7-9. Binding-energy groove type antipersonnel payload
Key: (1) Shell; (2) Binding-energy plastic sleeve; (3) Dynamite; (4) Detonation-transmitting powder column.

3. Prefabricated Type

Although shapes and weights are nearly the same for fragments yielded by two types (groove type and binding-energy groove type) of antipersonnel payload, small fragments or joining fragments can still be formed. Edges of the fragments are indented, with fairly poor aerodynamic characteristics. These shortcomings can be better avoided by using prefabricated antipersonnel payloads. The prefabricated fragments are manufactured in advance according to the predetermined shapes and weights; generally, the fragments are cubes. After the prefabricated fragments are dipped into epoxy resin, they are arranged onto the inner shell made of a thin lead plate or reinforced plastic; after epoxy resin is solidified, it becomes a sturdy outer shell. Alternatively, a layer of thin lead plate or reinforced plastic is added outside the fragment shell. The prefabricated fragments can be arranged into a single layer, double layers, or multiple layers. After the combat payload is detonated, shapes and weights of fragments can basically maintain their original magnitude. This combat payload can be made into diameters of different sizes.

4. Strip Chain Type

Its outer shell is a zigzag welded steel strip with square cross-section and is closed into a cylinder, as shown in Fig. 7-10. Dynamite is charged into the cylinder. After detonation of the dynamite, the outer shell gradually expands due to the force of the explosion. The steel strip is gradually drawn out to form a continuous-strip chain ring for wounding and/or killing human targets. This ring has its diameter gradually expanded to the maximum as the steel strip is completely drawn out. At this point the steel strip breaks into relatively short strips to be continuously flying outward (Fig. 7-11). A quite appreciable antipersonnel effect occurs after the fragments hit a target. This combat payload has a relatively small radius of wounding and/or killing as the antipersonnel ring is almost in the form of a plane.

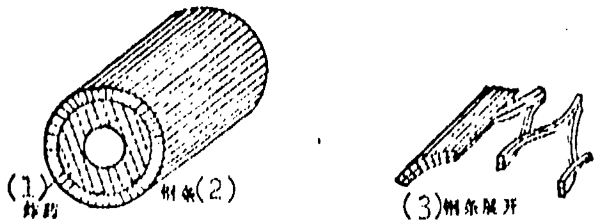

Fig. 7-10. Strip chain type antipersonnel payload
Key: (1) Dynamite; (2) Steel strip; (3) Steel strip drawn out.

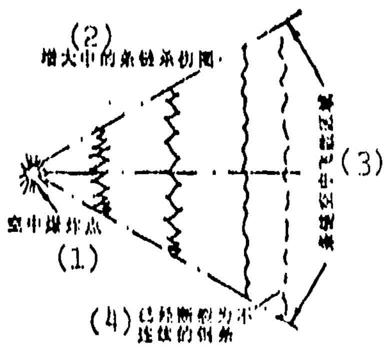

Fig. 7-11. Schematic diagram of strip chain antipersonnel ring
Key: (1) Midair detonation point; (2) Expanding strip chain antipersonnel ring; (3) Midair scattering zone of strip chain; (4) Broken steel strips.

(3) Binding-energy Combat Payload

One end of a cylindrical dynamite is made into a conical groove; when detonation is initiated at the other end, concentration of dynamite energy appears along the axial line of the groove. Users discovered this phenomenon and called it binding-energy phenomenon or effect. The groove on the powder column is called the binding-energy groove. This phenomenon is caused by directional detonation. After detonation of the binding-energy powder column, the explosion products of surface points of the binding-energy groove generally fly out along the direction of normal to the groove surface of these points. Every point on the circle acts in this manner, then along the central axis of the binding-energy groove a binding-energy stream forms with very high velocity, as shown in Fig. 7-12. Thus, the binding-energy combat payload can be considered a combat payload with the dynamite energy concentrated to a fine stream. The velocity of the binding-energy stream can be about 10,000 m/sec, so its kinetic energy is quite enormous, much greater than the ultimate stress of steel. Therefore, the binding-energy stream can penetrate steel armor and concrete fortifications.

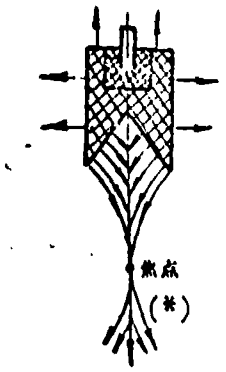

Fig. 7-12. Form of binding-energy stream
Key: (*) Focus.

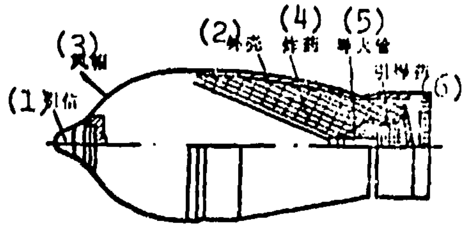

Fig. 7-13. Anti-tank binding-energy payload
Key: (1) Fuse; (2) Outer shell; (3) Cap; (4) Dynamite; (5) Fuse tube; (6) Detonation powder.

If a layer of a metal cover (usually called the powder molding cover) is lined along the surface of binding-energy groove, the armor-piercing effect can be increased (four times greater) over the use of the powder molding cover, which can make the metal binding-energy stream greater in density, longer in distance traveled, and greater in concentration of energy. This can result in a greater armor-piercing effect.

The binding-energy payload can be used to damage armored targets, such as tanks and warships, and is generally installed in anti-tank and ship-to-ship missiles. The payload can be also used to attack air targets.

Figure 7-13 shows a structural diagram of a type of anti-tank binding-energy payload.

At present, a piezoelectric fuse (using piezoquartz in detonation with high-current voltage from impact pressure) is used in binding-energy payloads. While fuses are installed, a desirable form of exterior should be used as far as possible in order to reduce aerodynamic drag. The material, dimensions and shape of powder molding cover have a greater armor-piercing effect. A copper-zinc alloy usually serves for forming into a conical shape. The effect of semi-spherical molding cover is better in penetrating concrete.

For greater destructive power, sometime a more complicated payload should be selected. For ample, when attacking midair targets, a combat payload can be selected as having both functions of antipersonnel and binding-energy. When attacking surface warships, a combat payload can be selected with both the functions of binding-energy and detonation. When attacking ground targets, a combat payload can be selected with both the functions of detonation and antipersonnel attack.

Nuclear Payload

(1) Ordinary Nuclear Weapons

For long-range missiles, if a conventional payload is used the power is too small. Therefore, usually this type of weapon employs a nuclear payload. In addition, in short-range field operations, air combat, and air defense, some missiles are also charged with nuclear payloads for destroying large-area ground targets, attacking aircraft, and intercepting atomic bombers.

The destructive power of a nuclear payload comes from the nuclear-energy release of some elements (such as uranium, plutonium, deuterium, and tritium). However, nuclear energy is released in the conversion process of nuclei. There are two conversion forms of nuclei: one is the fission of heavy nuclei, and the other is the fusion of light nuclei.

The fission of heavy nuclei consists of the nuclear splitting of a heavy element into a lighter element. Tremendous energy is released in this fission process. For example, when neutrons are used to bombard an uranium nucleus, which is split into fragments of almost equal mass and liberates several neutrons as well as release of energy. These neutrons also bombard other uranium nuclei. In this way, the number of fission nuclei will be rapidly increased. This is a chain reaction; its reaction velocity is very high, only several microseconds. Therefore, this is a violent explosion, releasing tremendous amounts of energy. The nuclear energy of 1 kg uranium is equivalent to the energy released in the explosion of 20,000-ton of TNT; this is generally called as a 20,000-ton TNT equivalent weight. The weapon ·tilizing fission of heavy nuclei is called an atomic bomb.

The fusion of light nuclei is a process of light nuclei fused into heavier nuclei. This fusion process also releases tremendous energy. For example, there are three isotopes of hydrogen: hydrogen, heavy hydrogen (deuterium) and superheavy hydrogen (tritium). At superhigh pressures and superhigh temperatures, tens of thousands of degrees, nuclei of heavy and superheavy hydrogen fuse into helium atoms, releasing tremendous energy. This is called a thermonuclear reaction. Fusion can release much more energy (usually ten times) than fission. The weapon made by the principle of fusion of light nuclei is called a hydrogen bomb.

Figure 7-14 shows a structure schematic diagram of atom bomb. In the diagram, each of two lumps of uranium (or plutonium) has a mass less than the critical mass, which is the maximum mass for which no chain reaction will start spontaneously. Thus no chain reaction will start. If a chain reaction should start, a detonator explodes the dynamite to join together the two lumps of uranium. At this time, its combined mass is greater than the critical mass so a chain reaction is started. The (very ‹ κ) bomb shell is made of a heat resistant alloy to prevent the nuclear package from flying apart (during detonation) prematurely; thus, the detonation power is increased. Moreover, the outer shell can also reflect neutrons. At present, the power of an atom bomb may reach millions of tons of TNT equivalent weight.

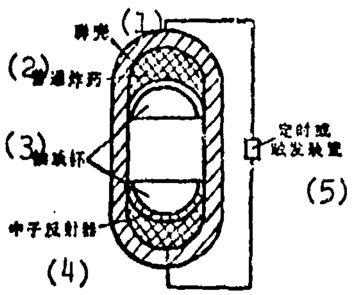

Fig. 7-14. Structure schematic diagram of atom bomb
Key: (1) Bomb shell; (2) Conventional dynamite; (3) Uranium or plutonium; (4) Neutron reflector; (5) Timing or triggering device.

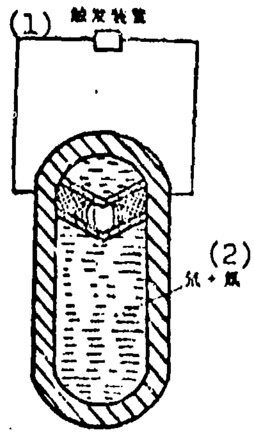

Fig. 7-15. Schematic diagram of hydrogen bomb
Key: (1) Triggering device; (2) Deuterium + tritium.

Figure 7-15 shows a structure schematic diagram of a hydrogen bomb. In order to create a condition of superhigh pressures and temperatures for a hydrogen-bomb reaction, a small atom bomb is charged into the hydrogen bomb. The small atom bomb is the fuse of a hydrogen bomb, which has a relatively thick shell because of its even higher power. At present, the power of hydrogen bomb may reach one half million tons to tens of million tons of TNT equivalent weight.

When a nuclear warhead detonates at the ground surface, the warhead releases shock waves (detonation), photo-radiation (combustion), penetration radiation, and radioactive contamination (wounding and/or killing people). Therefore, a nuclear weapon exerts the combined function of killing and wounding people. The first three forms of destructive energy only exist within a short time while the last form of energy exerts its function of killing and wounding people as well as damaging property for a longer time.

Impact waves during a ground detonation constitute the main damaging factor of a nuclear explosion; this form of energy accounts for about one-half of the total energy released by a nuclear weapon. However, the direct cause of injuries (to people) is mostly due to collapse of buildings. The extent of building damage depends on its building location, terrain and sturdiness. Therefore, nuclear defense is possible only by providing good protection. Actually, the characteristics of shock waves due to a nuclear explosion are basically the same as that from conventional dynamite; only the power intensity of nuclear weapon is much higher.

Photo-radiation is caused by superhigh temperatures from nuclear detonation; this form of energy accounts for about 35 percent of the total energy. Photo-radiation is a form of electromagnetic waves, which exert the function of wounding, killing and damaging through burns. Proper protection against burn is possible; for example, shield protection is very effective. In addition, the exposure time of photo-radiation is very short (only 2~3 seconds); therefore, it is also possible to defend against photo-radiation, which only damages the surface layer of most things, unless the detonation center is very close.

Penetration radiation is invisible radioactive rays, approximately accounting for 5 percent of the total energy; mainly these are gamma rays and neutron fluxes, propagating very far in the atmosphere with intense penetrating power. However, gamma rays weaken with increasing distances and the penetrating power also quickly decreases (shown in Fig. 7-16). The exposure time is short, several seconds to between 10 and 20 seconds. The exposure time of neutron fluxes is even shorter, only tenths of a second. So penetrating radiation can also be protected against. There are similarities between penetrating radiation and X-rays in penetrating the human body. At high intensities, cells will be damaged, causing radiation sickness.

Sources of radioactive contamination come from various radioactive elements after a nuclear detonation; these elements are fission fragments, the part of the nuclear package not involved in the reaction, and radioactive isotopes (also called artificial radioactive isotopes). These isotopes are liberated after atoms (from detonation-area substances, like soil, water, air and buildings) absorb neutrons. Fission fragments are the main source of contamination. Radioactive contamination accounts for about 10 percent of total energy, and the contamination lasts longer, about several hours to several days.

(2) Neutron Bomb

The neutron bomb is a new weapon. Some people call it an enhanced radiation bomb; actually, it is a small hydrogen bomb. This nuclear weapon kills people en masse by using neutron radiation. Neutrons are one kind of fundamental particles, a constituent of nuclei. Neutrons do not carry electric charges; each neuron weighs more than 1800 times the mass of an electron. Neutrons can readily penetrate a nucleus. Upon the detonation of a neutron bomb, large numbers of neutrons are released by nuclear reactions and the blast. Neutron radiation is originally one of the antipersonnel and property-damaging factors after detonation of a nuclear weapon. During detonation of a conventional nuclear weapon, neutrons are sealed in the bomb casing. Thus, most of the neutron energy is transformed into shock waves. Upon detonation of a neutron bomb, large numbers of high-energy neutrons are liberated; the radiation intensity of the bomb is more than 10 times that of a conventional nuclear weapon with the same TNT equivalent weight.

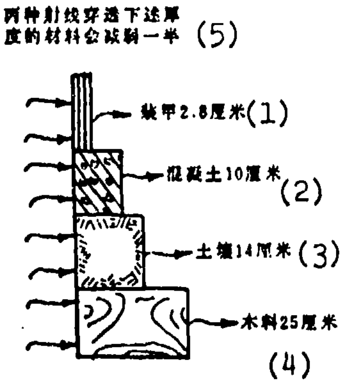

Fig. 7-16. Penetrating power of gamma rays
Key: (1) 2.8 cm of armor; (2) 10 cm of concrete; (3) 14 cm of soil; (4) 25 cm of lumber; (5) Gamma rays weaken by one half after penetrating the following (thickness of) materials.

Neutrons enter a human body whose cell tissues are damaged, causing death. Compared to gamma rays, neutrons possess greater destructive power, especially high penetrating power. A neutron bomb mainly relies on neutron radiation for anti-personnel effect; the bomb releases less powerful shock waves, thermal radiation, and radioactive contamination than conventional nuclear weapons.

Neutrons possess high penetrating power. In the effective range, tank armor and thick walls of reinforced concrete buildings can be penetrated by neutrons to wound and/or kill the people inside. If people linger for five minutes or longer during exposures of 8000 roentgens (units of radiation dosage absorbed by a body), they become immobile. They will die within one or two days if they remain there. Of course, it is possible to defend against neutron bombs. Since the penetrating power of neutrons is still limited, more than 1.5 m of soil layer can withstand neutron radiation. Therefore, tunnels of certain depths can provide effective protection against neutron bombs.

The TNT detonation equivalent weight of a neutron bomb is relatively low, generally in the 1000-ton TNT class (about 1/15 the detonation power of a Hiroshima-type atom bomb) and with small effective radius. At low-altitude detonation (90 m above ground zero) of a small neutron bomb, its destruction radius is limited to only within 180 m of ground zero. Therefore, usually neutron bombs are used as tactical nuclear weapons; they are also called second-generation nuclear weapon.

Multiple Warheads

In the past 10 or more years with the advent of intercontinental ballistic missiles, anti-missile weapons (intercepting ballistic missiles) have also been developed. In order to cope with these defensive weapons, many penetrating (defense) means are used by ballistic missiles in order to avoid interception by anti-missile weapons and to attack the target. Countering the penetrating-technique developments of attacking weapons, a series of anti-penetration means are adopted by defensive weapons, such as an enhanced power of warhead discrimination and early warning, as well as improving and raising the performances of intercepting devices. Thus, the technology of penetration and defense between missiles and anti-missile weapons is continuously developing. As one means of penetration, multiple warheads appeared in this situation.

The concept of multiple warheads originated in the early 1960s. In a mother warhead (also called the mother body or mother compartment), a group (as many as 10 and more) of small subwarheads are loaded. After the mother warhead flies to a certain altitude, the group of subwarheads are released to fly toward the predetermined targets.

The advantages listed below marked the adoption of multiple warheads in a missile: 1. the enemy's anti-missile weapon is not likely to simultaneously intercept all attacking subwarheads because they are so numerous. Thus, the penetration power is increased. 2. In a situation of the same amount of total power, every subwarhead can effectively destroy a target. So the total antipersonnel and damage effect of multiple warheads are greater than for a single warhead. 3. Multiple warheads are more flexible. They can attack one strategic target, or they can attack several military targets.

Multiple warheads can be divided into three types: the first type is called scattered-type multiple warheads; the second type is called individual-guidance type multiple warheads; and the third type is called maneuvering type multiple warheads.

Characteristics of scattered-type multiple warheads include the following: neither the mother warhead nor subwarheads have guidance; neither of them can perform maneuvering flights; and all subwarheads are scattered in a small area near a single impact point. Therefore, all subwarheads can attack only one regional target. Releases of subwarheads proceed as follows: at the terminal point of the powered phase, after the mother warhead separates from its launch vehicle, the warhead will fly to a predetermined altitude and velocity. Then a subwarhead is released after the mother warhead flies a certain distance. All subwarheads are thus released in sequence. By this means, a group of subwarheads are dropped on targets several kilometers or tens of kilometers apart. This type of release is simple but it is less flexible with relatively low accuracy of hitting targets.

A characteristic of individual-guidance type multiple warheads is that the mother warhead has a main engine and a control engine to correct the mother warhead's velocity and direction. At appropriate positions, subwarheads are released one by one or in one group. Every subwarhead can individually attack a single target, or attack the same target by following different trajectories, as shown in Fig. 7-17.

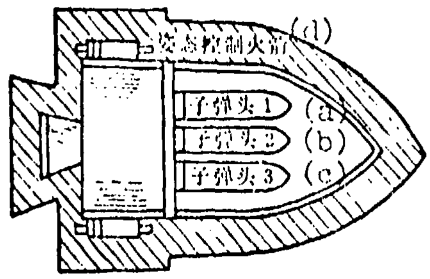

Fig. 7-17. Schematic diagram of a type of individual guidance multiple warheads
Key: (a) Subwarhead 1; (b) Subwarhead 2; (c) Subwarhead 3; (d) Posture control rocket.

The process of relasing individual-guidance type multiple warheads is as follows: after the mother warhead separates from its carrier rocket, a control engine (carried by the mother warhead) starts to operate to correct errors in the powered trajectory phase. According to a predetermined program, accurate corrections are made to velocity and direction of the mother warhead. Then the subwarheads are released in sequence. After all subwarheads have been released, the mother warhead is not under guidance but flies toward the target by inertia. There are a number of guidance methods for the mother warhead during its release of subwarheads. Three guidance methods are listed as follows: 1. change the velocity of the mother warhead. By igniting a power device, the mother warhead can be accelerated to maneuver the subwarheads' drop points at some distances farther from the drop point of the original warhead. The mother warhead can be decelerated to maneuver the subwarheads' drop points nearer to the drop point of the original warhead. 2. Change the direction of the mother warhead. Start the control engine and control the mother warhead to turn flying along a direction perpendicular to the original trajectory plane. Thus, the subwarheads can hit targets at both sides of the original target. 3. Change the attitude of the mother warhead. In the original course, impart to the mother warhead an impulse to change its attitude (angular position in space) and to raise or lower the trajectory altitude to enable a subwarhead to aim at the same target as the previous subwarhead. Although the two subwarheads may hit the same target possibly several seconds apart, the goal of hitting the same target by two subwarheads is accomplished. After all subwarheads are released, the mother warhead reenters the atmosphere along a certain predetermined course to deceive the enemy defense system so that real nuclear warheads can more easily penetrate the enemy missile defense and avoid interception. Figure 7-18 is a schematic diagram showing attacks by individual guidance type multiple warheads.

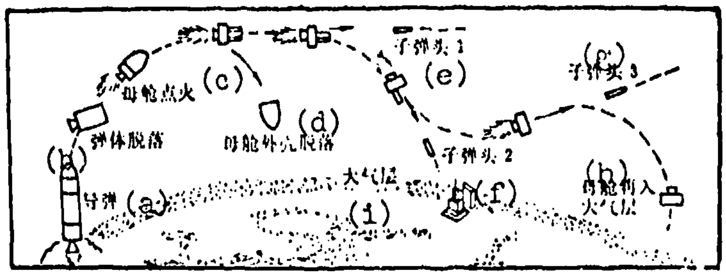

Fig. 7-18. Schematic diagram showing attacks made by individual-guidance type multiple warheads
Key: (a) Missile; (b) Separation of missile body; (c) Ignition of mother cabin; (d) Separation of mother cabin's shell; (e) Subwarhead 1; (f) Subwarhead 2; (g) Subwarhead 3; (h) Mother cabin's reentry into atmosphere; (i) Atmosphere.

Characteristics of maneuvering type multiple warheads are as follows: every subwarhead is equipped with a propulsion and control system to change trajectory during maneuvering flight, and a homing device in the mother warhead can automatically aim at and hit a target.

In order to further enhance penetration capability, raise hitting accuracy of warheads, and increase the distances between subwarheads released by the mother warhead, it is necessary to have every subwarhead equipped with its own guidance system and propulsion device for maneuvering flight. This is the third-stage development of multiple warheads.

In order to enhance penetration capability (by adopting individual-guidance type multiple warheads) and to perform maneuvering flight by subwarheads, the accuracy at the terminal point of the powered trajectory phase is reduced. So it is necessary to continuously guide the warhead after completion of the powered phase. Then guidance is needed in the middle and final trajectory phases (final phase—from 100 km altitude to ground impact). With guidance of the middle and final phases, accuracy requirements can be reduced at the terminal point of the powered phase. So besides continuously increasing the accuracy of the guidance system, adoption of guidance in the middle and final phases is one way of enhancing the accuracy of multiple warheads.

Middle-phase guidance can use the guidance system of the powered phase after enhancing the accuracy of the present guidance system; for example, an inertia guidance system can be used. A kind of middle phase guidance system under development at present utilizes starlight to correct errors of the powered phase and compensate for deviations of warhead flight in its middle phase.

Final-phase guidance is also a main factor of maneuvering type multiple warheads. It is required to more accurately guide subwarheads toward respective targets by using inertia guidance and other automatic homing devices after subwarheads are released.

There are inadvantages in multiple warheads, such as complicated technology, relative difficulty in execution, and lower accuracy. In addition, the nuclear reaction and material utilization are incomplete because the nuclear warheads are relatively small.

CHAPTER VIII

WINGED MISSILES

What are the characteristics and applications (of various types) of winged missiles. We talk about these problems below.

Ground-to-air Missiles

The ground-to-air missile is a type of winged missiles; its development began in the late 1940s and the pace speeded up in the 1950s. At present, more than 50 kinds of ground-to-air missiles have been successfully developed. At the outset, the targets for these missiles were long-range bombers and aircraft-type ground-to-ground missiles, which will be described in the following treatment. Often these targets escaped ground fire and fighter plane interception by flying at high altitudes (10 to 20 km) and high velocities (two to three times the speed of sound). So in this period the ground-to-air missiles had flight velocities of 2 to about 3 times the speed of sound, a launch altitude of 10 to about 20 km, a range of 30 to about 320 km, and a weight of 2 to about 7 tons. The missile's warhead is relatively large. However, nuclear warheads were seldom used. The launch installation was stationary and ground facilities were relatively complicated.

Later aircraft began flying at low altitudes and intercontinental ballistic missiles made their advent. So in the recent decade the development of ground-to-air missiles (as an air-defense weapon) proceeded along two directions: one type was a weapon mainly for intercepting ballistic missiles; this is the so-called anti-missile weapon. The other type was mainly used to intercept low-altitude targets (bombers); this is the so-called air-defense missile. See the book FANDAODAN WUQI (ANTI-MISSILE WEAPONS) for anti-missile information, which is not included in this book.

What does an air-defense missile look like?

The basic component parts of an air-defense missile are shown in Fig. 8-1.

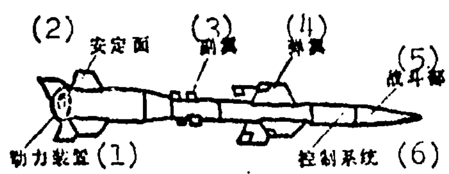

Fig. 8-1. Basic parts of air-defense missile
Key: (1) Propulsion installation; (2) Stabilizer vane; (3) Aileron; (4) Missile wing; (5) Warhead; (6) Control system.

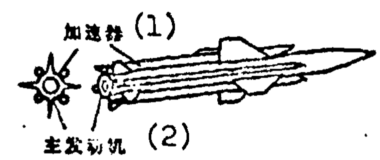

Fig. 8-2. Cluster installation of booster
Key: (1) Booster; (2) Main engine.

Warhead   At present, most air-defense missiles use antipersonnel warheads to destroy targets with exploding fragments. Few of these missiles are fitted with small nuclear warheads.

Power installation   Most air-defense missiles use liquid- or solid-fuel rocket engines. The solid-fuel rocket engine is simple in structure and convenient in operation. However, the operating time is fairly short and a magnitude of impulse not easily adjusted.

Usually, two stages of the propulsion installation are mounted in an air-defense missile. The first stage is called the accelerator (or booster) for the launch and acceleration of a missile. After the missile attains a certain velocity, the booster is automatically jettisoned in order to reduce the missile weight. The second stage of the propulsion installation is called the cruise engine for uninterrupted missile flight in order to cover the full distance. A solid-fuel rocket engine is used for the booster with two possible engine arrangements: one is the tandem installation (as shown in Fig. 8-1) for sleeve fitting of the booster in the rearmost part of the missile body, so the air drag is small for more safety and convenience during separation (unlikely collision with the missile body). The other engine arrangement involves cluster installation (as shown in Fig. 8-2); there are two or four accelerators (or boosters) to be symmetrically arranged around the missile body, so the overall missile length is shortened, resulting in a compact structure. However, larger drag will be the outcome of the relative complexity during separation.

Guidance method There are quite a few guidance types for ground-to-air missiles, such as beam-riding guidance, radio command guidance, automatic guidance during the final phase, infrared homing, and radar semi-active homing.

Missile body It includes three parts: missile body proper, missile wings, and control and stabilizing surfaces.

Generally, the combat procedures of an air-defense missile is shown in Fig. 8-3.

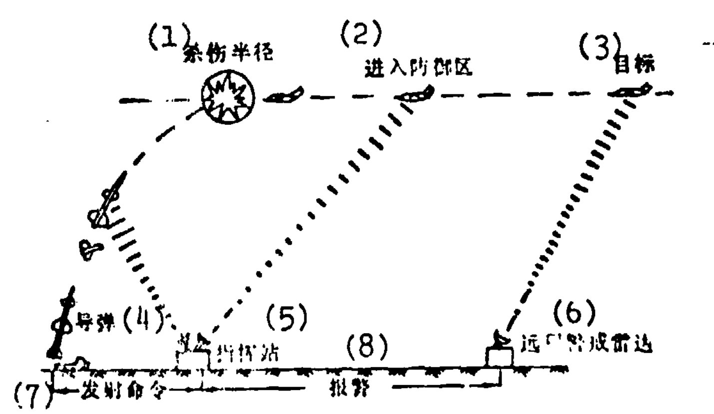

Fig. 8-3. Schematic diagram of combat procedures of an air-defense missile
Key: (1) Radius of wounding and/or killing; (2) Entering defense zone; (3) Target; (4) Guided missile; (5) Long-range early-warning radar; (7) Order to shoot; (8) Alarm.

The early-warning radars guarding the national boundaries search for targets day and night. Once air (invasion) targets are discovered, the radar installation immediately informs the missile launch facilities to enter a state of combat readiness by making all preparations before launching. When one or more targets enter the missile's effective range, one or more missiles are immediately launched. First, a solid-fuel booster is ignited to generate a thrust, which pushes the missile flying upward from the launch pad; the missile climbs rapidly. Several seconds later the operation of the booster is completed with its power cutoff and automatic separation. At this instant, a cruise engine is started to continuously accelerate the climbing missile, which flies toward the target under control of the guidance system. When the missile flies within a certain distance of the target, the fuse safety (of the warhead) is released, to begin warhead operation. When the target enters the radius of the warhead's detonation power, the fuse immediately fires and detonates the warhead, destroying the target.

The efficiency of destroying the target by a single firing of an air-defense missile is not high; usually, several air-defense missiles are required to shoot down an invading aircraft. Therefore, in order to guard a city or a key strategic site, a complete air-defense system should be built; the system includes many ground-to-air missiles.

At present, air-defense missiles are being continuously improved. Improvements include augmented antijamming capability, enhanced capability of low-altitude combat, adoption of more solid-fuel rocket engines, better maneuverability of ground launch, multiple uses of a single missile, and better guidance accuracy.

Air-to-ground Missiles

Air-to-ground missiles are a main weapon for attacking ground targets used by modern bombers, interceptors, and fighter-bombers. There are many kinds of air-to-ground missiles with different applications. From preliminary statistics, there are more than 50 types of such missiles under development and in active service in foreign countries. There are several classification methods of air-to-ground missiles. They can be classified into strategic and tactical air-to-ground missiles based on combat application. They can be classified into decoy missiles, counterradiation missiles, air-to-ship missiles, and airborne anti-tank missiles.

Strategic air-to-ground missiles are a type of modern attack weapon used by a strategic bomber for long-range penetration. Weighing one to ten tons, this kind of missile has a nuclear warhead; the maximum velocity is three times the speed of sound and the maximum range is 1600 km. In foreign countries, the types of deployed strategic air-to-ground missiles include Greyhound, Quail, and Kangaroo.

Tactical air-to-ground guided missiles are attack weapons used by fighter planes. The missiles are mainly used for short-range midair support and medium- and long-range aerial attacks. Generally, these missiles carry short-range conventional (dynamite) warheads of 6 to 60 km. At present, the deployed (and under development) types include Hound Dog, Bullpup and Matador missiles in abroad.

The air-to-ship missiles are attack weapons used by a missile-carrier aircraft to attack warships by midair launch. Weighing about 500 kg, these missiles have a maximum range of 80 km and a maximum velocity of Mach 2. The combat procedures of these missiles are as follows: first, a radar set on the missile-carrier aircraft or nearby shipborne radar set (on friendly warships) discovers a target. While flying at minimum altitude, the aircraft launches a guided missile, which engages in inertial flight over the sea surface at cruising velocity. The missile climbs sharply while approaching the target; in the meantime the missile radar or infrared automatic homing device tracks the target while commencing the final-phase guidance flight. The missile dives into the water just ahead of the enemy vessel and the missile-borne warhead detonates below the ship's water line for maximum damage. If allowed by sea-surface conditions, the missile may not climb abruptly but fly directly to the target. At present, the deployed (and under development) types include Quail and Feiyu (Flying Fish) missiles in foreign countries.

The airborne anti-tank guided missiles are used for short-range midair support in attacking tanks. Usually, the airborne missiles are ground anti-tank guided missiles fitted in helicopter or some light aircraft.

The counterradiation air-to-ground guided missiles are used to attack air-defense radar or radar installation of anti-aircraft gun; these missiles are also called anti-radar missiles. At present, the deployed counterradiation air-to-ground guided missiles include Lark type.

Figure 8-4 shows outlines of some air-to-ground guided missiles.

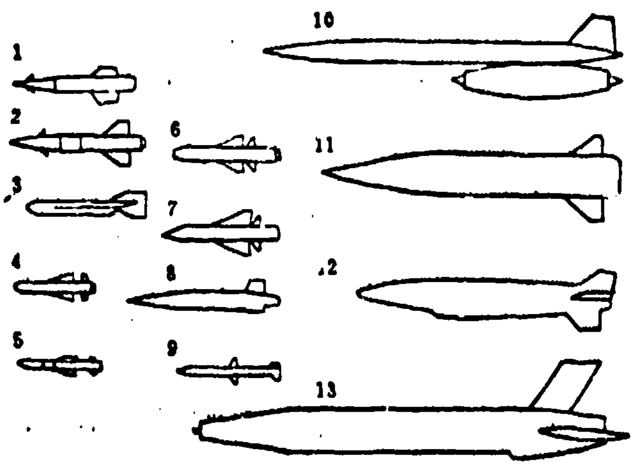

Fig. 8-4. Diagram showing outlines of some air-to-ground guided missiles: 1 - Hound Dog B; 2 - Nuclear Hound Dog; 3 - Quail; 4 - Bullpup; 5 - Cormorant; 6 - Matador (television version); 7 - Matador (radar version); 8 - Short-range attack guided missile; 9 - Lark; 10 - Greyhound; 11 - Lanjian (Blue Sword); 12 - Kitchen; 13 - Kangaroo.

Air-to-ground guided missiles are shown in Fig. 8-5. Different air-to-ground missiles have different requirements in tactical applications, so there are different designs and performance data.

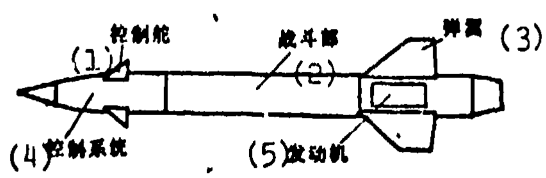

Fig. 8-5. Main component parts of air-to-ground guided missiles
Key: (1) Control vane; (2) Warhead; (3) Missile wing; (4) Control system; (5) Engine.

Aerodynamic configurations of air-to-ground guided missiles   Generally, there are canard configuration and conventional type for the aerodynamic configurations of tactical air-to-ground guided missiles. Most long-range tactical air-to-ground missiles are of the conventional type, such as Bullpup and Matador missiles. Some short-range tactical air-to-ground missiles adopt the canard configuration, such as Hound Dog missiles while others are of the conventional type. Most arrangements are of the "x" shape for missile wings and rudder vane surfaces of the tactical air-to-ground missiles. The plane outlines of missile wings and vane surfaces are triangular and irregular trapezoid. The cross-sectional outlines are level plate and rhomboid, among others.

The aerodynamic configurations of strategic air-to-ground guided missiles include Kangaroo and Kitchen missiles, of the conventional type, and Blue Sword and Greyhound missiles, of the canard configuration.

Structural characteristics of air-to-ground guided missiles   Because of the short flight time and negligible aerodynamic heating, a light alloy structure is usually adopted for the strategic air-to-ground guided missiles.

Owing to the relatively long high-velocity flight time of strategic air-to-ground guided missiles, structural aerodynamic heating should be prevented. In addition, attention should be given to see that the missile can evade interception by enemy air-defense weapons. For the Blue Sword missile, its body is a semi-monocoque type purlin-skin structure and the missile wing has a multispar structure. Most of the monocoque of the Blue Sword missile has a double-layer skin to prevent aerodynamic heating.

Power installation   At present, engines used in air-to-ground missiles are mostly solid-fuel or liquid-fuel rocket engines. Next in frequency of use are turbojet engines and rocket-ramjet hybrid engines.

In the case of strategic air-to-ground guided missiles, they mostly use solid-fuel rocket engines.

Several types of air-to-ship guided missiles under development use turbojet engines.

Guidance method In the early period of short-range tactical air-to-ground guided missiles, visual tracking and radio command guidance were mostly used. Later, television and laser type guidance was used.

For long-range tactical air-to-ground guided missiles, television guidance or inertia guidance with the addition of radar guidance in the final phase are employed.

For the strategic air-to-ground guided missiles, most common is inertia guidance or inertia guidance with the addition of radar guidance in the final phase.

The air-to-ground guided missiles have been developed along with the enhancement of ground defense capabilities. When air-to-ground guided missiles attack ground targets, the defensive fire power will be augmented to cope with the invading aircraft, which can launch missiles only at some distance from the target. Thus the missile range must be increased. So long-range air-to-ground guided missiles were developed with ranges of hundreds of kilometers to 1000 km and more. Some air-to-ground missiles take advantage of electromagnetic-wave radiation during the startup of ground radar to attack radar facilities. Consequently, the ground radar facilities halt operations and generate electronic interference as a counter measure. Then again, a kind of high-velocity counterradiation air-to-ground guided missiles was developed; the missiles can rapidly reach the target and destroy the radar even before its operation shuts down. Several trends in developing air-to-ground guided missiles are enhancement of guidance accuracy, augmented all-weather attack capability, capability of attacking small moving targets, and multiple reuse for a single missile.

Air-to-air Missiles

Air-to-air guided missiles are mainly launched by interceptor planes to attack enemy aircraft. Since the missiles can intercept enemy aircraft at a distance from the key defense region, these missiles can form a unified air-defense system together with ground-to-air missiles.

When enemy aircraft enter the missile attack zone, our pilot can launch air-to-air guided missiles. A launched missile accelerates by using its engine power while the missile rapidly leaves its carrier plane and approaches the enemy aircraft. During missile flight, the on-board guidance system guides the missile to the vicinity of enemy aircraft. When enemy aircraft enters the radius of wounding and/or killing, the missile detonates the warhead, destroying the enemy aircraft. The combat procedure of an air-to-air guided missile against an enemy aircraft is shown in Fig. 8-6.

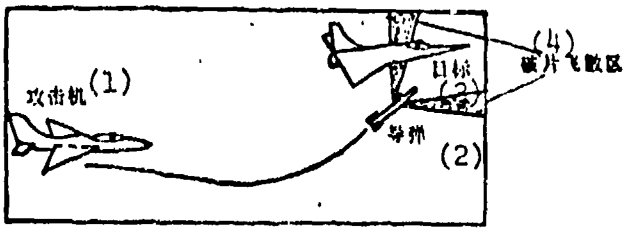

Fig. 8-6. Schematic diagram of air-to-air guided missile attacking enemy aircraft
Key: (1) Attacking aircraft; (2) Guided missile; (3) Target; (4) Scattering zone of fragments.

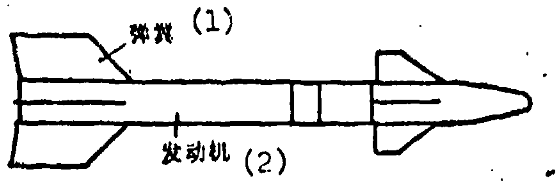

Fig. 8-7. Schematic structure diagram of air-to-air guided missile
Key: (1) Missile wing; (2) Engine.

The structure of an air-to-air guided missile is shown in Fig. 8-7.

Since air-to-air guided missiles are fitted into an aircraft, missile weight and dimensions are somewhat limited. Usually, the weight is between 50 to 200 kg, and the missile length is 2 to 4 m; its diameter is also small, from 0.12 to 0.4 m.

Air-to-air guided missiles are mostly of a winged structure. Generally, the missile body is long and slender while its nose is conical or egg-shaped. Generally, the missile wing and vane surfaces use the typical "x" or "+" shape in arrangement; in other words, there are two pairs of wings and two pairs of vane surfaces. The arrangements of movable vane surfaces and stationary missile wings are in a canard configuration or of the conventional type. The sidewinder missiles are arranged as in the former case, and the Fire Beetle missiles are as in the latter case, as shown in Fig. 8-8.

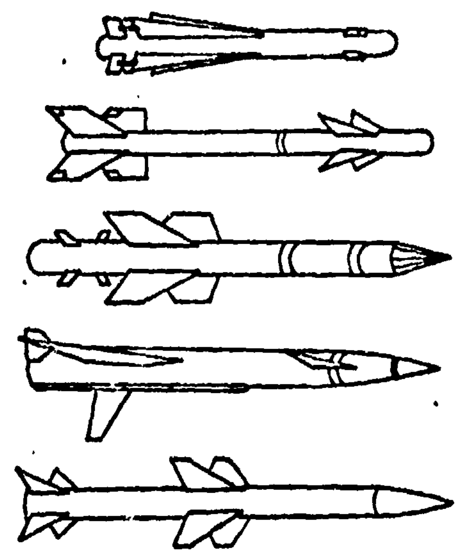

Fig. 8-8. Several types of air-to-air guided missiles

In Fig. 8-8, the missile outlines from the top downward are those of Hawk, Sidewinder, Fire Beetle, Matador R-511, and Sparrow 1.

Layouts of aerodynamic configurations of some air-to-air guided missiles are quite diverse. For examples, canard configuration vane surfaces and single missile wing are used for Matador R-511 air-to-air missiles; Sparrow missiles have rotary wings but stationary stabilizer vanes for the missile tail section; and a tail-less type is used for the Hawk air-to-air missiles.

Aerodynamic heating is not serious because air-to-air missiles fly at high-speed only for a short time. Basically, present-day air-to-air missiles use a light alloy structure.

The velocity of air-to-air missiles is approximately Mach 2 to Mach 3 and the ranges vary from several to tens of kilometers. The range of a long-range air-to-air guided missile may be 100 kilometers or more.

It is required that air-to-air missiles should have greater velocity than that of the carrier aircraft. Since the period of air combat is very short for modern interceptors, launch preparedness of these missiles should be very short, enabling them to rapidly attain combat readiness. At present, solid-fuel rocket engines are generally used for propulsion installations of air-to-air missiles because these solid-fuel rockets have high specific impulse with convenience in storage and operation. Under most situations, an air-to-air missile is equipped only with one engine, which can rapidly accelerate the missile to maximum velocity. After the engine completes its operation, the missile flies forward by its inertia. Because of aerodynamic drag, the missile velocity gradually decreases. Some missiles are equipped with two engines; during launch, a booster engine accelerates the missile, and a cruise engine follows up to maintain and approach constant velocity as in the case of Fire Beetle air-to-air missiles.

Ship-based Missiles

Since World War II, as missile technology developed rapidly, increasingly guided missiles have been installed on naval warships with the advent of guided missile cruisers, guided missile destroyers, guided missile escort warships, and guided missile patrol boats. These guided missiles are called ship-based missiles, which are launched from warships (as tactical weapons) to attack targets on the water surface and ground surface and in the air. Thus far, more than 50 models of these missiles have been developed abroad.

A typical flight trajectory of a ship-to-ship guided missile is shown in Fig. 8-9.

The range of a ship-to-ship missile is several kilometers to hundreds of kilometers with velocities from Mach 0.5 to 2.4 and with a weight of tens of kilograms to several tons. Missiles of longer range (heavier weight and higher velocity) are installed on cruisers, destroyers and submarines of higher tonnages. Missiles of shorter range and lower weight are installed on missile patrol boats, torpedo boats, and gunboats. Figure 8-10 shows the outlines of several types of ship-to-ship missiles.

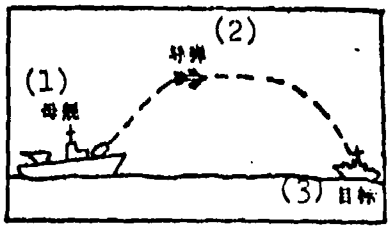

Fig. 8-9. Flight trajectory of a ship-to-ship missile
Key: (1) Mother ship; (2) Guided missile; (3) Target.

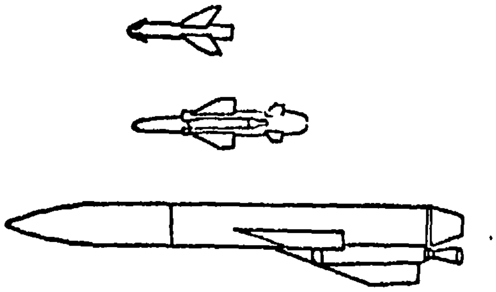

Fig. 8-10. Configurations of several types of ship-to-ship missiles

Ship-to-air missiles are launched from a warship to attack midair targets (such as aircraft or ship-to-ship missiles); these missiles are defensive weapons with flight trajectory as shown in Fig. 8-11.

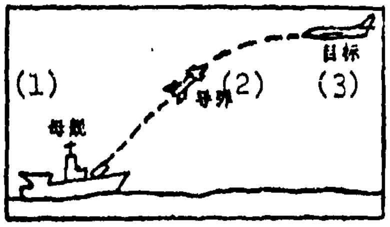

Fig. 8-11. Flight trajectory of a ship-to-ship missile
Key: (1) Mother warship; (2) Guided missile; (3) Target.

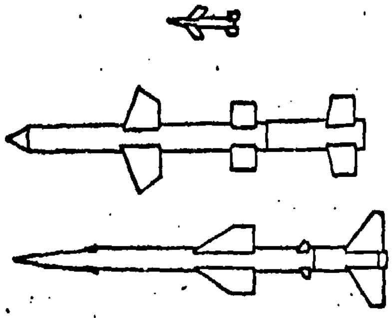

Fig. 8-12. Configurations of several types of ship-to-air guided missiles

Since ship-to-air missiles serve in attacking fast-moving midair targets, these missiles have relatively high velocities, usually about Mach 2.5, or even as high as Mach 3.5. The range is relatively short, generally not exceeding 60 km.

The altitude reached by a missile is quite high, generally between 3000 to 20,000 m. Usually, ship-to-air missiles are installed in relatively large warships, such as aircraft carriers, cruisers, destroyers, and submarines. Figure 8-12 shows outlines of several types of ship-to-air guided missiles.

At present, warheads of ship-based guided missiles are mostly dynamite warheads; sometime, small nuclear warships are used.

The bodies of ship-based missiles are mostly cylindrical in shape. The layouts of missile wings and fin surfaces are of the conventional type and the canard configuration. In order to reduce the floor space occupied by missiles on ships, often the missile wings are capable of folding. Arrangements of wings and fin surfaces of ship-to-air guided missiles are similar to those on air-defense missiles.

Most ship-based missiles use two-stage power installations. The first stage is called the booster for the launch phase; the booster enables the missile to attain a certain initial velocity and to fly from the ship and reach a certain flight altitude. The booster is separated after the missile launch is completed. The second stage is called the main engine to continuously push the missile in powered flight (after the booster power is cut off) until the entire flight course is completed.

To sufficiently exploit combat power of ship-based missiles in meeting requirements of modern naval warfare, there are the following development trends for ship-based guided missiles.

Minimum altitude The flight altitude of a guided missile is reduced for flights at a minimum altitude.

Solidification Solid-fuel rocket engines are used as booster and main engine of a ship-based guided missile.

Multiple applications A missile can be used in several ways.

Smaller and smaller missiles   Small ship-to-ship guided missiles have been developed.

In addition, guidance accuracy can be enhanced by augmenting the antijamming capability of ship-based missiles, and utilizing laser technology.

CHAPTER IX

CRUISE GUIDED MISSILES

What Are Cruise Guided Missiles?

Cruise missiles are actually a type of pilotless aircraft with jet propulsion.

What kind of flight state is cruise? This is a flight state when the weight and lift of a flight vehicle is balanced; also balanced is the engine thrust and the flight-vehicle drag. The vehicle can fly under these conditions; it is a kind of long-range aircraft-type guided missiles, which have wings and jet power like an aircraft. Therefore, cruise missiles are a type of winged missile.

The range of a cruise missile is from 2000 to 8000 kilometers; the missile flies along a low trajectory (in the atmosphere) toward a target.

Applications of cruise missiles are quite varied. Only by fitting appropriate warheads as well as the corresponding control and propulsion systems, can cruise missiles be fitted into short-range missiles or long-range missiles. The same type of cruise missiles can be equipped with either conventional warheads or nuclear warheads. Cruise missiles can be launched either from a submarine or from an aircraft. Under development are cruise missiles capable of launching from surface warships or motor vehicles on the ground.

The guidance system of a cruise missile applies terrain-matching technology as well as inertia guidance or final-phase guidance. These techniques are properly combined to enable a guided missile attain a guidance accuracy of within tens of meters from the intended target. It is also allowed to permit extensive selection of attack methods; therefore, its rate of hitting the target is high.

The cruise missile is small in volume and light in weight; therefore, a single aircraft or ship can carry a considerable number of these missiles to strengthen its attack capabilities.

Construction costs of a cruise missile are quite low because the missile travels within the atmosphere with only the consumption of a combustion agent but no oxidizers. Especially in the case of cruise missiles capable of midair launch, the launch mother-aircraft acts like a booster (with multiple reuse) so the missile costs can be further reduced. A long-range cruise missile is much cheaper than an intercontinental ballistic missile.

The cruise missile is a low-altitude penetration weapons; it has the following advantages in penetration technique.

Surprise attack   A cruise missile is launched outside of the enemy air defense ring and travels in the blind zone of the early warning radar. The missile engages in a low-altitude attack at supersonic velocity. Therefore, even though the defense system is highly automated, it is difficult to halt penetration by cruise missiles. For example, a cruise missile flies at a 400-m altitude. If the missile flies at Mach 2 and at some distance it is discovered, the defense system can only have about six seconds to shoot it down. As shown in Fig. 9-1, there are different flight altitudes of a ballistic missile compared to a cruise missile and so there are different distances for a ground radar installation to detect eack kind of missile. The detection distance for cruise missiles is short while that for a ballistic missile is long. So it is relatively difficult to counterattack cruise missiles.

Hedgehopping and rapid pass   For a cruise missile flying at low altitude, its angular velocity is higher than for a high-altitude weapon. For example, if an aircraft flies at 200 m/sec at 400-m altitude, the angular velocity for a ground anti-aircraft gun (to attack the aircraft) is about 45°/sec. The time period within the effective shooting range of the gun is only about two seconds. Therefore, for a cruise missile flying at high velocity, it passes by quickly. This considerably reduces the probability of being hit with anti-aircraft weapons.

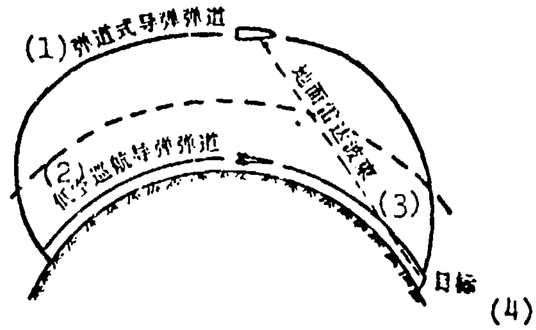

Fig. 9-1. Trajectories of ballistic missile and cruise missile
Key: (1) Trajectory of ballistic missile; (2) Trajectory of low-altitude cruise missile; (3) Wave beam of ground radar; (4) Target.

Flexible maneuverability A cruise missile can be launched from a readily maneuverable large bomber or a submarine. In addition, the missile itself can perform a maneuvering flight. For example, a cruise missile Shillelagh of the United States can be launched from a Trident submarine. Other cruise missiles, the AGM-86 A and B, can be launched from a B-52 bomber. The combination of piloted aircraft and pilotless flight vehicle, as well as the combination of a bomber (or a submarine) and air-to-ground (or underwater-to-ground) guided missile, can considerably expand the attack region without risk to the carrier aircraft (or submarine); this can reduce pilot casualties.

Like any other weapons, a cruise missile also has some vulnerabilities. Although the cruise missile's low-altitude flight can cause considerable difficulties to radar detection, yet the advanced downward scanning radar can still detect this kind of missile. Since the air density at low altitudes is high, the velocity pressure (its value being one-half of the product of the missile velocity squared and the atmospheric density) is also high; so aerodynamic heating is serious. As a result, cruise missile velocity is limited. Moreover, the guidance system of cruise missiles is also relatively complicated.

Makeup of Cruise Missile

As a long-range aircraft-type missile, the cruise missile is a type of guided missile. Therefore, like other missiles the cruise missile is made up of a warhead, a propulsion system, a flight control system, and a missile body.

The cruise missile is required to have good maneuverability and limited volume. Therefore, its warhead should have high power with small volume. Thus, usually the warhead of a cruise missile is a nuclear or high-energy explosive warhead.

For the propulsion system of a cruise missile, the specific impulse is high and the missile configuration is small in dimensions. The thrust-to-weight ratio of the engine is high.

One engine type used in cruise missiles currently developed is the integrated type rocket-ramjet engine. This propulsion installation is integrated with the missile body; the solid-fuel booster and the ramjet engine share the same combustion chamber, so the rate of space utilization is quite high. The specific impulse of a ramjet engine using liquid propellant is as high as 1200 seconds, which is five times that for a solid-fuel rocket engine. Another propulsion installation is the turbojet engine.

Cruise missiles fly at low altitudes in the atmosphere, at subsonic or supersonic velocities. Their configurations are like aircraft-type guided missiles with control surfaces and relying on aerodynamic force for maneuvering. Since the air density at low altitudes is high, missiles face with high drag. For example, for missiles with the same configuration, weight and velocity, a missile flying at sea level is faced with 20 times the air drag compared with flying at 20-km altitude. Therefore, the design of the aerodynamic configuration of the missile body is given particular attention. As for lift, cruise missiles only demand an equilibrium between lift and weight. As indicated by testing, wings of cruise missile flying at Mach 2 can be made smaller, or even done away with entirely. The top portion of Fig. 9-2 shows an outline of a wingless cruise missile under development. The lune-shaped air intake of the integrated type ramjet is placed in the lower part of the missile body. The bottom portion of Fig. 9-2 shows an outline of a cruise missile (under development) with small-aspect-ratio missile wings, whose area is very small with a streamlined compact structure.

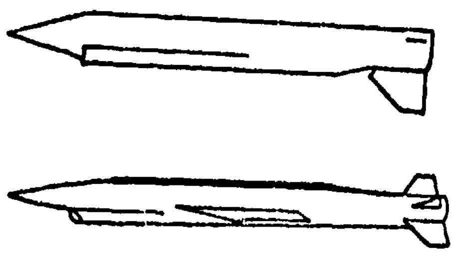

Fig. 9-2. Outlines of two types of cruise missiles

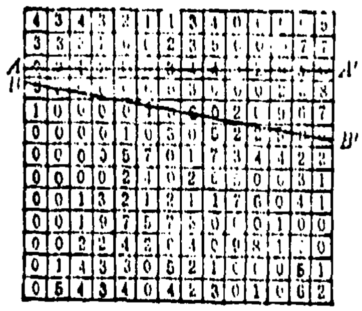

Fig. 9-3. Digital map

Cruise missiles are a type of attack strategic weapon; their warheads should have high power and very high firing accuracy. So a highly accurate guidance system should be required. For example, cruise missiles under development in the United States use inertia guidance and terrain matching. In Soviet Union, the cruise missiles under development use inertia guidance and active radar homing guidance system

Guidance System of Terrain Matching

Are the guidance systems of cruise missiles and aircraft-type missiles identical?

They are not identical. The guidance system of cruise missiles is relatively complicated with high-quality requirements. Generally, there are terrain-matching guidance, area correlation guidance, or global navigation satellite guidance system.

Terrain-matching guidance   Terrain matching is a guidance system for locating the cruise missile based on the characteristic that there are different elevations above sea level at different points of the ground surface. First, we have to comprehend in detail the terrain that cruise missiles will fly over. Then the terrain of these areas is depicted as dital map, as shown in Fig. 9-3.

How can a digital map be drawn?

Assume that an area digital map (10 km long and 2 km wide) has to be drawn up. It is then required to have a reconnaissance satellite (or other means of reconnaissance) flying over the area to survey a regional topographic map (10 km long and 2 km wide) with sufficient resolving power. Many small squares (for example, 2000) are drawn with a side of definite length (such as 100 m). Each small square has an average value of ground elevation above the sea level. A map based on these features (the average values of ground elevation of these small squares) is called a digital map. In other words, only grids are divided small enough and the resolving power in surveying is sufficiently accurate, targets such as houses, small towers and highway can be distinguished.

Terrain matching means that the digital maps (that the cruise missile will fly over) are stored in the memory device of the missile onboard computer. When the missile travels in air, its altimeter of the downward scanning radar can read a series of ground-elevation data, such as 33000156022500.... In the meantime, the computer quickly scans all possible digital sequences on the digital map. This digital sequence is matched (compared) with the digital sequence taken by the missile's altimeter. The computer can recognize a line B-B' corresponding to an altimeter reading. This means that the missile is flying over the line B-B'. If this is the flight trajectory required by the missile's stored-program, the computer sends a comand to the autopilot to maintain the flight course.

If in the missile's stored-program, the correct course is line A-A' while flying over such an area, this is a mismatch between the altimeter readings and the digital sequence stored for the correct course. At that time, after its scanning of the digital sequence in the vicinity of line B-B' the computer discovers that the digital sequence (of the missile's correct course) is

2210003440?930...., and then the distance between lines B-B' and A-A' is calculated. At the same time, the computer sends an instruction to the autopilot for a S-shaped maneuvering flight until the altimeter readings are matched with the digital sequence of line A-A'.

Of course, it is not necessary to use terrain-matching guidance for the entire course from beginning of launch to the target. This would be quite complicated and would require a large memory storage capacity. The terrain-matching system can periodically correct the course error of inertia guidance. The entire missile trajectory is composed of several sections. The missile is under inertia guidance during flight along the various sections. Terrain matching is used only in several appropriate areas to check the position signals of inertia guidance and to correct the errors of the guidance system during flight along the previous sector, as shown in Fig. 9-4. If the selected terrain discrimination has apparent features, satisfactory accuracy can be attained.

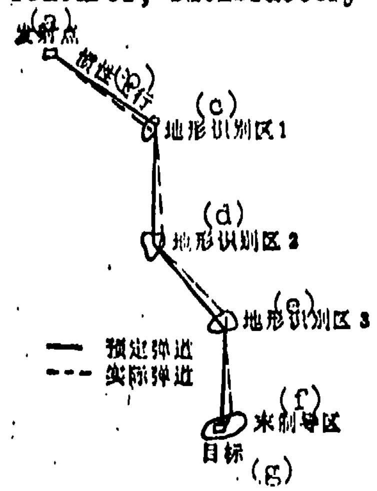

Fig. 9-4. Terrain matching: —— the prescribed trajectory; --- the actual trajectory.
Key: (a) Launch point; (b) Inertia flight; (c) Terrain discrimination area 1; (d) Terrain discrimination area 2; (e) Terrain discrimination area 3; (f) Final-phase guidance areas; (g) Target.

Area correlation guidance system This system is similar to terrain-matching guidance system. The main distinction between them is as follows: the map used for the area correlation guidance system is not drawn according to ground elevations above sea level. Differences in microwaves reflected by different features of ground surface serve as the basis for drawing the digital map. In other words, the map is drawn by using the electromagnetic spectrum.

The sensor used in the area correlation guidance system is a localizer, not an altimeter. So in adopting the area correlation guidance system, it is necessary also first of all to store the signals (of the prepared map) in the memory storage device of the onboard missile computer.

When the missile travels in air, its localizer surveys the area (such as rivers, roads, and houses) it passes by. Different reflections of microwave signals are fed into the computer, which compares the received signals with the map (electromagnetic spectrum) signals in the memory unit; error signals are then sent out. Based on the error signals, the computer sends a command to the autopilot for necessary actions in order to restore the missile to its predetermined course.

Global navigation satellite guidance system This system requires 24 satellites in earth orbit; their positions are so arranged that at any time on the ground at least four satellites can be seen. During operation, every ten-millionth of a second an accurate synchronous encoded signal is transmitted by a satellite. A receiver in the missile sends the signal at the right time to missile's computer, which calculates the distance between the missile and each satellite based on time differences of the four signals received. Then from the satellite data of the earth orbit, the actual position of the missile can be determined. The location is accurate to within 10 m.

Combat Procedure of Cruise Missile

(1) Combat Procedures of Cruise Missile Launched From Sea Surface

Let us assume that the cruise missile is launched from a submarine. At the beginning of combat, the missile (with its protective cylinder) is placed in a torpedo tube. The submarine's launch control system is used to test the missile then the inertia guidance system executes the aiming of the missile. The operation takes approximately 20 minutes. Then the hydraulic catapult system of the submarine pushes the missile out of the torpedo tube. The missile is connected with a guy wire (about 12 m long), which pulls out the missile and actuates the safety lock device. The booster is ignited; the protective cylinder sinks into the sea after the missile is catapulted from the torpedo tube. The launch depth is about 15 meters below the sea surface. After the missile emerges from the sea, the air intake is opened and fins are extended. When the missile is boosted to about 300 m from the sea surface, the booster is separated; the turbofan engine is started, the missile wings are extended, and the guidance system begins operating. As the missile attains its maximum altitude, the thrust also reaches its rated value. Then the missile descends to its normal cruising altitude. From launch to the normal cruise altitude lasts about one minute. For a typical launch, the booster operating time is approximately 10 seconds; the first five seconds are used for booster flight underwater while the second five seconds used to push the missile to an altitude of 100 m. Figure 9-5 shows the flight course of a cruise missile launched from a submarine.

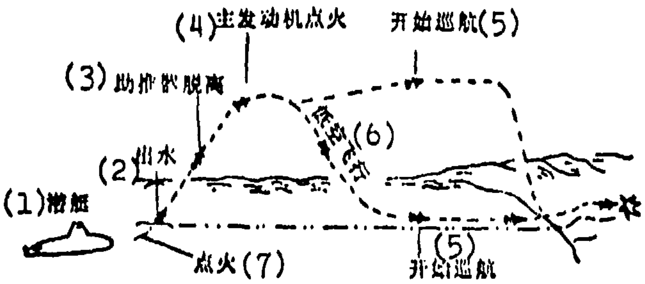

Fig. 9-5. Trajectory of a cruise missile launched from a submarine
Key: (1) Submarine; (2) Missile emerging from water; (3) Separation of booster; (4) Firing of main engine; (5) Beginning of cruise; (6) low-altitude flight; (7) Ignition.

The guidance system of this type of cruise missile is mostly inertia guidance with the addition of terrain matching. During the flight, the on-board computer compares the terrain signals as the missile flies by with the course topographic map stored in computer's memory device to derive error data from. The computer then sends an instruction (based on the error data) to the autopilot to restore the missile to the predetermined course. During the flight, the missile's course is continuously corrected until the target is hit.

(2) Combat Procedures of Cruise Missile Launched in Air

How does a cruise missile engage in combat after it is launched in air?

The combat procedures of air-launched cruise missiles are generally the same as the submarine-launched missiles. The air-launched cruise missiles are loaded in a mother aircraft, which launches these missiles. A bomber usually can carry several cruise missiles within the fuselage or suspended below the wings. The launch altitudes can be flexibly controlled. Before launch, the mother aircraft performs positioning and aiming as well as providing electric power and cooling air. During launch, the electric power supply system feeds electricity to autopilot and computer; the power is used for extension of control surfaces, starting of engine, and maneuvering of elevons. During cruise, a direct-current generator (engine-driven and air-cooled) supplies electric power. After the missile is launched from the mother aircraft, the air intake opens 0.1 sec later. The fins and wings extend successively in about 0.5 to 2 sec, and the engine starts in about 0.5 sec. Usually, the rated thrust is attained in about 10 sec. The guidance method is the same as for submarine-launched cruise missiles.

When an air-launched cruise missile flies over undulating terrain, the missile can perform terrain tracking at an altitude lower than for the submarine-launched missile. While approaching a traget, the closely-guarded defensive area is evaded according to the on-board program. At about 25 km from the target, the engine delivers its rated thrust so the missile can penetrate the defense at subsonic velocity until the target is hit, as shown in Fig. 9-6.

Cruise Missiles: Past and Present

Several decades have elapsed since the advent of cruise missiles, which were developed sporadically.

Initial development stage Cruise missiles were developed on the basis of V-1 aircraft-type missiles. As early as World War II, the German fascists first developed and deployed the V-1 aircraft-type missiles, which were equipped with a not-too-complicated rocket engine. These V-1 missiles were small pilotless aircraft controlled by autopilot.

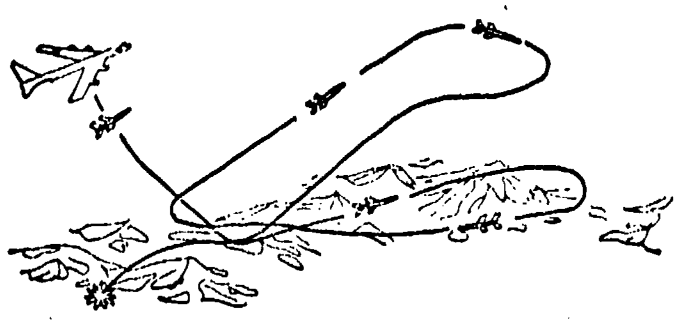

Fig. 9-6. Diagram showing an air-launched cruise missile in flight

Following World War II up to the late 1950s, this was a period mainly of the trial manufacture of these missiles, which were crude and bulky with low accuracy and low velocity.

Suspension stage Before and after the 1960s, advanced ballistic missiles were developed; so missiles improved from the V-1 phase were gradually retired because of their vulnerability under enemy fire owing to low velocity and low accuracy.

The restoration and development stage covers the period from the early 1970s to the present. Because of advancements in electronic technology, highly accurate guidance systems emerged. In addition, developments in small turbofan jet engines and small warheads considerably reduce the volume and production cost of cruise missiles, which can fly at minimum altitudes for a greatly enhanced penetration capability. These developments not only resurrect the cruise missile but also account for its fast-paced development. In June 1972, a decision was made in the United States to develop two types (submarine- and aircraft-launched) of cruise missiles. Sea-launched cruise missiles are launched from submarine torpedo tubes; air-launched missiles are launched from bombers or other aircraft (such as the Boeing 747). These cruise missiles can be launched outside the enemy defensive ring.

CHAPTER X

BALLISTIC MISSILES ARE STILL UNDER DEVELOPMENT

Developments of ballistic guided missiles have been covered more than three decades from the emergence of the German V-2 to the present; these developments can be generally divided into three periods as three generations of missiles were developed and built.

The first period is from the early 1940s to the late 1950s for building the first-generation missiles, such as the Thor and Atlas in the United States, and SS-4 and SS-6 missiles in the Soviet Union. The first-generation missiles had the following characteristics:

1. Missile performance was still low. The warhead was bulky; the specific power (the ratio between warhead detonation power and its weight) was low and likewise for its accuracy.

2. Liquid propellant was used, mainly low-temperature propellants (like liquid oxygen). The launch preparation required a long period.

3. A single warhead was used per missile. Every missile could be aimed at only one predetermined target without the capability of changing its aim toward other targets.

4. Missiles were stored and launched on ground surface so they could be easily spotted by aerial or space reconnaissance. Survivability was low so these missiles could be easily destroyed.

The second period is from the late 1950s to early 1960s. In this period, the main development requirement was survival after a nuclear strike against missiles. The principal characteristics of the second-generation ballistic missiles (under development in this period) are as follows:

1. Compared to the first generation, there was better missile performance, such as better accuracy, range and specific power.

2. These missiles used solid propellant or storable liquid propellant, so the launch preparation time was shortened.

3. The launch mode was converted from ground launch to underground or underwater launch; the deployment was converted from relatively concentrated siting to dispersal siting. So the survivability was improved.

4. Multiple warheads with a certain degree of maneuverability, since a missile could be aimed at several targets, made their advent.

5. The development pace was rapid in building solid-fuel ground-to-ground as well as submarine-to-ground guided missiles.

The third period is from the mid-1960s to the present. Following missile developments of the first two periods, accuracies in guidance and target strike have been much enhanced. In the development of ballistic guided missiles, anti-missile missiles came on the scene. So in this period, ballistic missiles should evade attack by enemy missiles and interception by enemy anti-missile missiles. Therefore, the characteristics of the third-generation ballistic missiles are the development of guided missiles with multiple warheads to enhance the penetration capability. In addition, survivability should be increased by hardening the silos or extending the range of submarine-to-ground guided missiles.

How will strategic ballistic missiles develop in the future? "Self-preservation and elimination of enemy" is a basic military principle. Developments of strategic ballistic missiles also conform to this principle. Self-preservation means enhancement of missile survivability while elimination of enemy means improvements in missile's penetration capability and target strike accuracy.

Enhancement of Survivability

Below are described methods for enhancing survivability of ballistic guided missiles: (1) the missiles are concealed so detection by enemy forces will not be easy. (2) Launch sites are hardened, so the missiles can withstand nuclear strike to a certain extent. (3) Missiles can be moved from site to site for launching, so enemy will find too difficult to detect the missiles' storage and launch sites. As the reconnaissance techniques are more and more perfected, and the continuous enhancement of target strike accuracy and warhead power advances, it is possible for a subwarhead to destroy a silo. Even if the ballistic missiles are concealed in hardened silos, it is still difficult to evade destruction by enemy nuclear strikes. Since either concealment or hardening of launch sites means limited improvement in raising missile survivability, only mobile storage and launch can enhance survivability more productively. So at present the development of mobile missiles is an active concern.

There are three directions in developing mobile missiles: underwater, in the atmosphere, and by surface transport. The development of submarine-to-ground missiles provides fairly high survivability. However, there are certain shortcomings, such as high construction costs, low accuracy, and vulnerable submarine bases. Therefore, it is feasible to increase the number of submarine-to-ground missiles, but not all nuclear missiles will be placed in submarines. Airborne launching involves missiles on aircraft. In developing these missiles, there are more technical difficulties and higher costs as well as relatively low accuracy. Missiles capable of surface transport involves missiles moved on or under the ground. Development of these missiles is technically not as difficult as other methods, with low costs. However, transportability is limited and so the survivability is relatively low.

At present, under research abroad are missiles in the airborne launch mode and surface transport launch mode. Although technical difficulties are fairly high in the former case, the survivability is also higher. So the United States Air Force is inclined to engage in airborne transport launch mode. There are many versions of mother planes carrying guided missiles, including widebody jet liners, giant transport craft, medium-size aircraft, vertical takeoff and landing aircraft, helicopters, and amphibious aircraft.

The survivability of the surface transport launch mode is not as high as for the airborne transport launch mode. In addition, the transport distance in the surface mode is quite limited but it is easier to carry out the mode. There are several schemes of surface transport launching, such as by railway, by highway, by inland river, by hovercraft, by cross country, and by moving from several ground shelters. In the mobile mode involving several ground shelters, a series of shelters are excavated. A guided missile is stored in turn among several shelters, so that the enemy is not likely to know which shelter houses a missile. At present, more research is underway on the surface launch mode with underground transport; in general there are the three following types: (1) a series of hardened shelters are excavated for launching the missile, with an underground road connecting different shelters. The missile is moved from shelter to shelter via the underground road. (2) A trench is excavated; the trench is covered so that it provides some anti-pressure capability. The missile is moved on rails inside the trench so that the enemy does not know the exact location of the missile. (3) Passages are dug under lakes, ponds or riverbeds so that missiles can move freely from shelter to shelter undetected.

A missile in the mobile launch mode requires solid fuel as propellant. The transport vehicle can be used either as a means of transportation or as a launch pad. It is intended to place a missile into a container, which is insulated and can withstand shocks. The container can be also used as a launch tube, and it is integrated with the transport vehicle into a single entity. In peacetime, the container is placed horizontally. During launching, the container can be erected to launch the missile vertically.

Enhancement of Penetration Capability

With never-ending improvements and developments in anti-missile weapons, a ballistic missile should have relatively high penetration capability. As the capability of discriminating real missiles from decoys is continuously improved, it is difficult to conceal the real warhead by releasing light and heavy decoys. Therefore, active penetration measures should be used. At present, the mother warhead can be guided and maneuvered, but not subwarheads; missiles in deployment at present with separate-guidance-type multiple warheads are of this type. Under priority development are maneuverable multiple warheads while both the mother warhead and subwarheads can be guided and maneuvered. Thus, anti-missile missiles are relatively difficult to intercept. In addition, multiple warheads can attack several targets because each subwarhead can attack a separate target. So the maneuverable multiple warheads have a relatively high capability of penetration as well as a damaging effect with the wounding and/or killing of people.

Additionally, there are partial orbit weapons for penetration. A warhead is first launched to enter an orbit hundreds of kilometers high; the warhead then reenters the atmosphere over the target area. Since the descent velocity is high (only requiring about two minutes to reach the ground surface), defense against the warhead is not easy. However, the accuracy of this weapon still remains a problem so relatively complicated procedures of final-phase guidance are required. The partial orbit weapon is still in the exploratory stage.

Enhancement of Missile Accuracy

In order to augment missile accuracy, generally speaking the guidance accuracy must be improved to lower missile errors not related to guidance (such as the asphericity of the earth), and to adopt medium- and final-phase guidance.

At present, the accuracy of the inertial element of the guidance system has been much improved. For example, the accuracy of the acceleration chart has been raised from several thousandths for V-2 missiles to several hundred-thousandths for present-day missiles. Gyroscope accuracy has been raised from several degrees (of drift) per hour to several hundredths or thousandths of a degree per hour, a gain of more than a hundredfold. Already developed are highly accurate elements, such as the laser gyroscope (with no spinning rotor) and the sine cu e acceleration chart.

Missile errors not related to guidance (inherent errors and environmental errors) must be reduced. Inherent errors include the warhead atmospheric reentry error and engine aftereffect deviations, because the engine thrust cannot be brought instantly to zero. Environmental errors include the positional errors of target coordinates, calculation errors of the geodetic range, and gravity anomalies due to differences between the calculated reference gravity and the actual gravity on the earth's surface. When the requirements on missile accuracy are low, the non-guidance-related errors are minor. However, when there are high requirements on missile accuracy, the non-guidance-related errors should be reduced or even eliminated.

Later, the guidance system may require an advanced intertial reference sphere to replace the currently-used gyroscope and gimbal system. The reference sphere can directly sense missile pitch, yaw, roll and velocity with errors much smaller than the current system error; accuracy can be held to less than 100 m from the intended target.