CHAPTER 4

MISSILE GUIDANCE AND CONTROL

INTRODUCTION

In the preceding chapters you learned that the essential parts a guided missile needs to perform properly are:

1. Airframe and control surfaces.
2. Propulsion system.
3. Warhead system.
4. Guidance and control system.

In addition, in chapter 2 you studied the basic fire control problem, and learned how some of the forces of nature affect the trajectory of a guided missile as it flies to its intended target. In chapter 3 you learned how wings and fins steer a missile and keep it pointed along its flight path. The use of interior control devices by missiles without exterior control surfaces (or limited ones) was described briefly. The different types of guidance systems used in missiles are inertial, command, beam-rider, and homing guidance.

In this chapter we will show you the basic functional components of a guidance system. Some of them are within the missile, and some are on the launching ship. Then we will discuss briefly some of the parts in the missile's guidance and control equipment and how they work. Finally, we will cover the way specific missiles (the ones you will work with) are divided into sections or compartments.

GUIDANCE AND CONTROL

Before we go on to discuss any particular type of guidance system, it is necessary to consider first the overall operation of an entire missile guidance and control system; to divide it into convenient groups of units; and to indicate the general function of each major group so that the operation of the particular units may be understood in relation to the operation of the guidance and control system as a whole. Also, in the interest of terminology standardization and to assist common understanding, we shall call the complete system within a missile that steers and stabilizes it a guidance and control system. Depending on your experience with missiles, you may take exception to this designation. And if you do, there is good reason for it. The reason is shown in figure 4-1. For example, if you have worked on the Tartar or Terrier missiles you will consider the system that guides and controls a missile to be its steering system. On the other hand, a Talos GMM would call it a guidance and control system. We will stick with the latter designation - not because we favor Talos but because most manuals, and many Navy publications, use this term.

SUBSYSTEMS AND COMPONENTS

In figure 4-2 we show that the complete system for steering and stabilizing a surface- to-air missile may be considered as consisting of two major divisions or systems: (1) the guidance system and (2) the control system, which functions similarly to an automatic pilot in an aircraft. For convenience, we will include the control surfaces (wings and fins) and interior control devices as part of the control system.

In many ways a guidance and control system is simply a flying servomechanism. At first thought this idea may not be clear to you. So to make it clearer, let's review the definition of a servomechanism and see if the definition fits a missile guidance and control system. You learned in Basic Electricity. NavPers 10086-B, that, and we quote the text - "A servomechanism is an electromechanical device that positions an object in accordance with a variable signal. The signal source may be capable of supplying only a small amount of power. A servomechanism operates to reduce the difference (error) between two quantities."

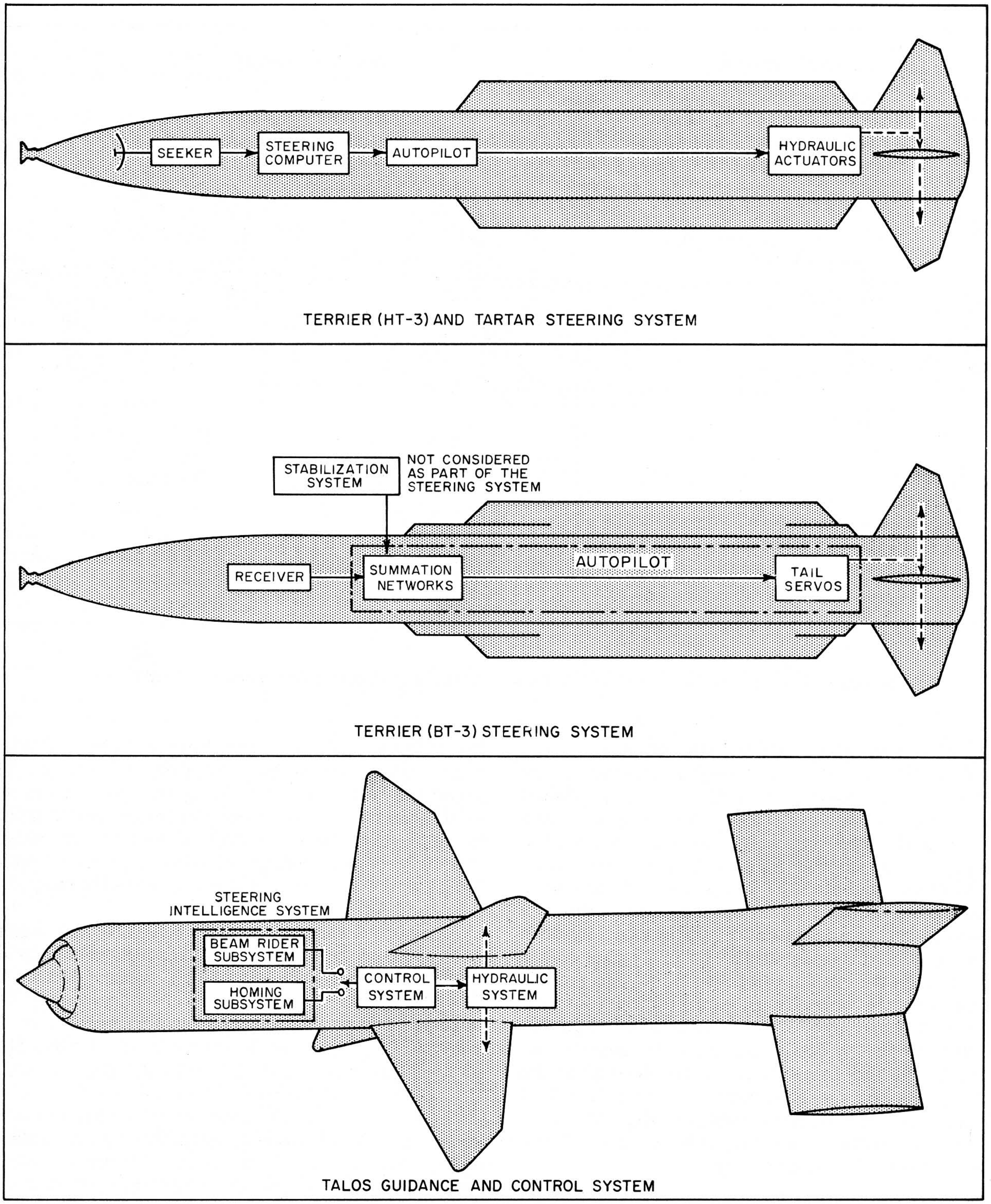

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Figure 4-1.—Names for guidance and control systems and system components.

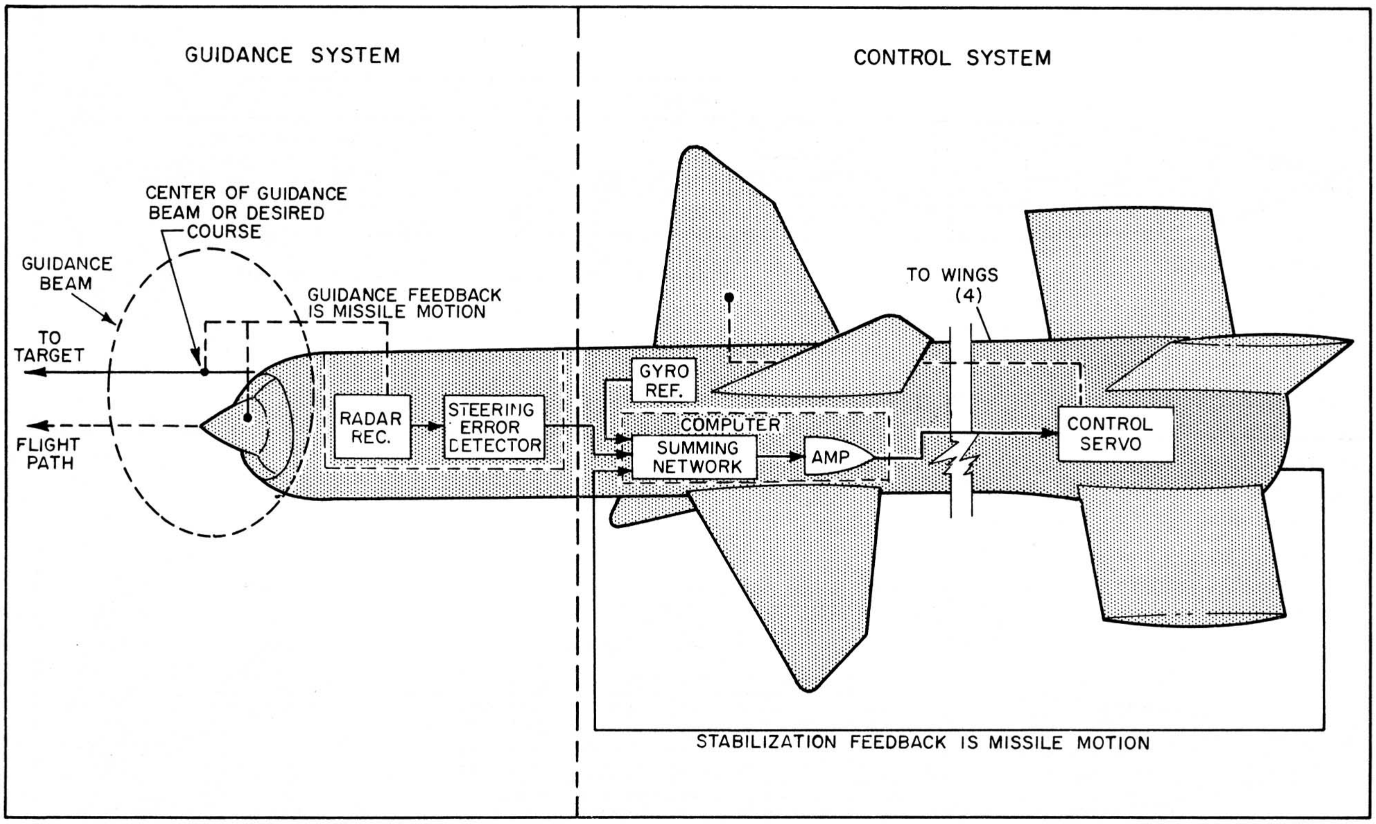

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Figure 4-2.— Essential parts of a basic missile guidance and control system.

A guidance and control system meets the requirements of a servomechanism as it is implied in the above definition. The guidance portion of the system develops the variable input signal. The input signal represents the desired course to the target. The missile control system operates to bring the missile onto the desired course. Therefore, you can say that the output of the guidance and control system is the actual missile flight path. If there is a difference between the desired flight path (input) and the one the missile is actually on (output), then the control system operates to change the position of the missile in space to reduce the error. When the missile has been steered to the desired course, the guidance system will detect no error and the control system will not move the control surfaces in response to a guidance error, because there isn't any.

The units of the guidance system may be carried in the missile (as in active and passive homing), or they may be distributed between the missile and the launching ship (as in beam-rider and semi active homing missiles). The principal functions of the guidance system are to detect the presence of the target and track it; to determine the desired course to the target; and to produce electrical steering signals which indicate the position of the missile with respect to the required course.

The units that respond to the guidance signals and actuate the control surfaces make up the major division referred to in figure 4-2 as the CONTROL SYSTEM. For convenience we will include gyros in this system. The units in the control system may be considered as consisting of two groups: the COMPUTER, and the CONTROL-SURFACE SERVOSYSTEM.

Specific computer units vary widely in design because of basic differences in the type of guidance used. But in most cases this section contains damping instruments (accelerometers and rate gyros), summing networks (electrical circuits that add and subtract voltages), and servoamplifiers as principal components. In general, these units originate information about missile motion and flight attitude, add this data to incoming guidance signals, and produce output voltages suitable for operating the control-surface servo.

A typical control-surface servosection is made up of hydraulic units. This section serves as a power stage of the control system; it releases large amounts of energy under accurate control. The principal parts of this section are electrically operated servovalves and the wing or tail hydraulic actuator units which make the adjustments to guide and stabilize the missile. In the newest missiles, hydraulic actuators are replaced by electric systems. This saves considerable weight and space in the missile.

TYPES OF FEEDBACK LOOPS

As indicated by the feedback loops shown in figure 4-2, the basic operation of the guidance and control system is based on the closed-loop or servo principle. The control units make corrective adjustments of the missile control surfaces when a guidance error is present, in other words, when the missile is not on the correct course to the target. The control units will also adjust the control surfaces to stabilize the missile in roll, pitch, and yaw. You must keep in mind that guidance and stabilization are two separate processes, even though they occur simultaneously. To make this idea clearer, think of yourself throwing a dart with its tails removed. It is possible for you to hit the bulls-eye of a target because your arm and brain guide the dart onto the proper trajectory to score a hit. But without its tail surfaces to stabilize it, it is very possible that the dart will land on the target in some position (attitude) other than point first. Well, missiles are like darts or arrows in this respect, and must be stabilized about the three (roll, pitch, and yaw) axes we talked about in chapter 3, so that the missile will fly nose first and will not oscillate about its direction of flight. So in summary we can say that, if there is an error in missile heading due to guidance or stabilization, the corrective actions taken by the control system are such that any error present in the system is reduced to zero. This is true servo action, as you have learned in previous Navy courses on basic electricity and electronics.

Now that you have a general picture of the overall operation of a missile guidance and control system, let's turn our attention to the feedback loops in our flying servo.

Guidance Feedback Loop

Consider first the guidance feedback loop, which is indicated by the broken line between the desired course line and missile flight path (fig. 4-2). The loop is not a physical circuit, but rather a method of operation that is built into the system. By means of this operation, the position of the airframe, as well as the guidance signals, determines the amplitudes and polarities of the guidance signals that actuate the control units.

For example, in the beam-rider system, steering (guidance) error voltages are produced in the radar receiver in the guidance section by comparing the position of the missile with the center of the guidance beam (fig. 2-17) or to be more exact, with the nutation axis (fig. 4-3) of the beam. If the missile is not flying along the nutation axis, then the guidance system produces error voltages and sends them to the control section. The control section makes corrective adjustments of the control surfaces in response to the error signals. As the missile approaches the nutation axis of the radar beam (which defines the course to the target), the error voltages get smaller, and become zero when the missile flies along the nutation axis.

Before proceeding further, let's stop to define "nutation axis," mentioned above. Nutation is difficult to describe in words but easy to demonstrate. Hold a pencil in both hands; while holding the eraser end as still as possible, swing the point through a circle. This motion

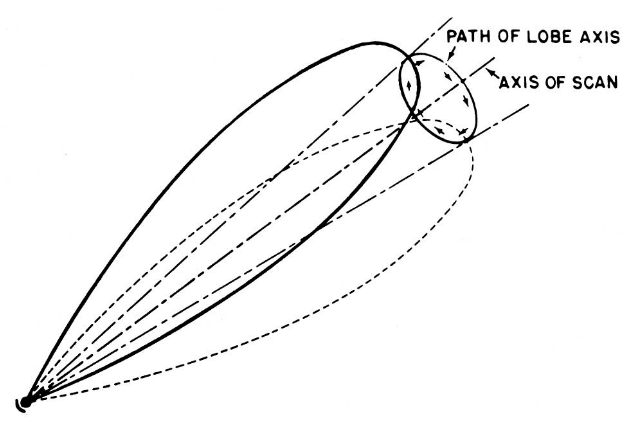

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Figure 4-3. —Nutating lobe of radar beam, conical scanning

of the pencil is nutation. The pencil point corresponds to the open or transmitting end of the radar waveguide antenna. The radar beam moves in a similar manner when scanning, moving in a conical pattern without changing the vertical or horizontal orientation. Figure 4-3 illustrates a conical scanning pattern and the axis of scan. When a conically scanned radar beam is used for missile guidance, the desired path of the missile is not along the axis of the beam but along the axis of scan.

In the operation of most homing missiles, error signals are produced by measuring the position of the target with respect to the line of sight of a gyro stabilized radar antenna called the seeker head. It is located in the nose of the missile and points at the target. A line drawn through the fore-and-aft axis of the antenna to the target describes the desired course for the missile. Any deviations of the missile that throw the antenna off course result in guidance signals which are sent to the control system. The control system reacts by correcting the missile heading, and the error signals progressively decrease and approach zero as the missile comes on course. Thus, in either beam riding or homing systems, feedback action is a fundamental process of guidance, and consists of altering the position of the airframe. Thus the missile acts like a position servo as it responds to guidance signals. 14W

Stabilization Feedback Loop

The stabilization feedback loop shown in figure 4-2 indicates in a general way the basic method used in most missile control systems for stabilizing the missile. The stabilization loop is completed by the inputs and outputs of DAMPING devices, which in most systems are rate gyros and accelerometers. The input to each of these instruments is some motion of the missile. The rate gyros measure angular velocity about a missile axis and the accelerometers measure the linear acceleration along an axis. Thus the control system receives stabilization signals that are proportional to the particular component of motion to which a damping instrument is sensitive.

The damping voltages are applied to the input of the summing circuits in the computer Another input to the summing network is the guidance signals. The two sets of signals art added in the summing network and product control signals which ultimately keep the missile on course and in the proper flight attitude. The general effects of damping are:

1. To oppose any tendency of the missile to move from the desired course or heading once it is established.
2. To prevent or minimize overshooting and oscillation when the missile is maneuvering in response to guidance command signals.

The stabilization loop in a missile does the same thing for it as the stabilization loop in the launcher power drive does for a launcher. In both applications the stabilizing loop prevents overshooting and hunting about the desired position.

In chapter 7 of this book we will cover the fundamental principles of servo operation in detail. What you learn there about controlling the position and movements of launching system equipment can be applied directly to automatic control of missiles. We suggest that after you read chapter 7, you return to this chapter and reread it. Then you will see for yourself that there are many parallels between the two applied fields of servomechanism theory. For example, launcher power drive servos use tachometer generators to measure the angular velocity of a launcher. The output of the generator is a voltage proportional to the angular velocity (rate) of the launcher. This voltage is sent to a servoamplifier to aid in stabilizing the launcher. Missiles use a similar technique. But in a missile, a rate gyro is used instead of a tachometer generator. The gyro measures the missile's angular velocity about a particular axis (yaw, pitch, or roll). The output of the gyro is a voltage that is proportional to missile angular velocity (rate) about an axis. This rate voltage is sent to a servoamplifier to help stabilize the missile motion about the selected axis. You will a find other parallels after you study chapters 7 and 8, and read a missile OP.

COMPONENTS AND INSTRUMENTS

In the last few pages several components of guidance and control systems have been mentioned without explanation of what the) are, or how they operate. The following pages will contain these explanations.

Earlier, we talked about the overall operation of the guidance and control system of a missile. For convenience and standardization, we divided the system into two parts: the guidance system and the control system. We indicated the general function of each major system so that its operation could be understood in relation to the operation of the overall system as a whole. With this background, we are ready to take up some of the particular instruments and electronic components in guidance and control systems.

Gyroscopes

One of the most important instruments in a missile control system is the gyroscope, or gyro for short. Any spinning object - a top, a wheel, a planet, or a spinning projectile - is fundamentally a gyro. But strictly speaking, a gyro may be defined as a mechanical device

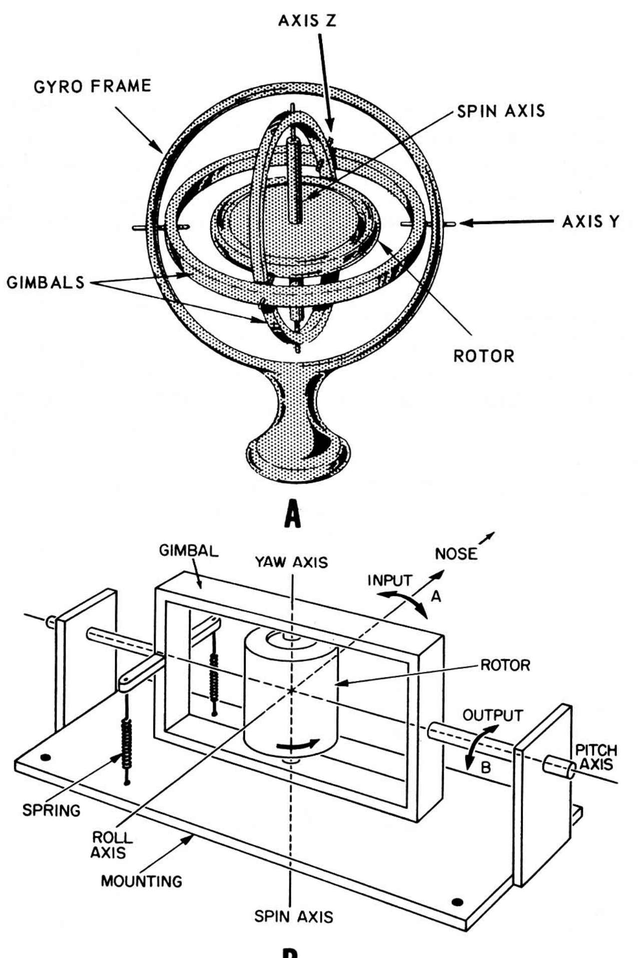

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Figure 4-4.—Gyroscopes: A. Free gyro has two degrees of freedom; B. A rate gyro has one degree of freedom.

containing a spinning mass mounted in such a manner as to have either one or two degrees (directions) or freedom.

A gyro that has two degrees of freedom is sometimes called a universally mounted gyro or a free gyro. In a free gyro the rotor is mounted in gimbals so that it can assume any position. Notice in figure 4-4A which shows a drawing of a free gyro, that the rotor can turn about axes Y or Z, or you can say the rotor has two degrees of freedom. Figure 4-4B shows a rate gyro, also called a single degree of freedom gyro. Its rotor can move about only one axis. Incidentally, when you are counting degrees of freedom of a gyro rotor you never count the freedom of a rotor to move about its axis.

The two characteristics of gyros that are most useful in missile control systems are:

1. The gyro rotor tends to remain fixed in space, if no force is applied to it. For example, if you started the rotor of a free gyro spinning, and pointed the gyro rotor spin axis at a star, the spin axis would remain pointed in that direction unless some force moved it off.

2. The spin axis has a tendency to turn at a right angle to the direction of an applied force.

The idea of maintaining a fixed plane in space is easy to show. When any object is spinning rapidly, it tends to keep its axis pointed in the same direction. A toy top is a good example. As long as it is spinning fast, it stays balanced on its point. It resists the tendency of gravity to change the direction of its spin axis.

The resistance of the gyro against any force which tends to displace the rotor from its plane of rotation is called rigidity in space.

Precession

As previously mentioned, the second property of the gyro is that its spin axis has a tendency to turn at a right angle to the direction of a force applied to it. Take a look at figure 4-5. When a downward force is applied at point A, the force is transferred through pivot B. This force causes downward movement at C. This movement at a right angle to the direction of the applied force is called precession. The force associated with this movement (also at right angles to the direction of the applied force) is called the force of precession. Other spinning objects, such as a spinning projectile, show the same tendency to deviate from the direction of the force applied.

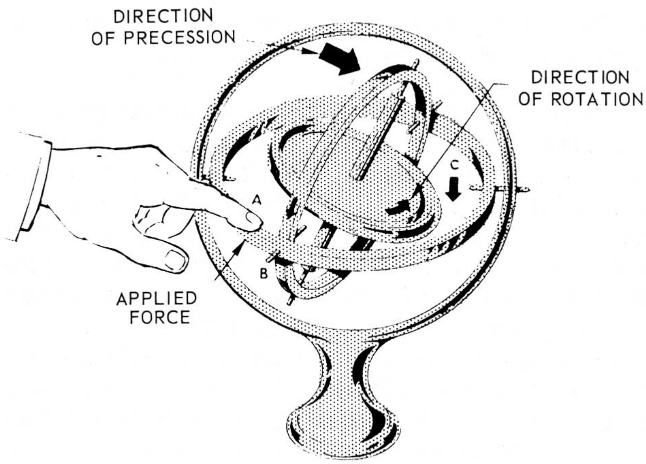

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Figure 4-5.—Precessing a gyro.

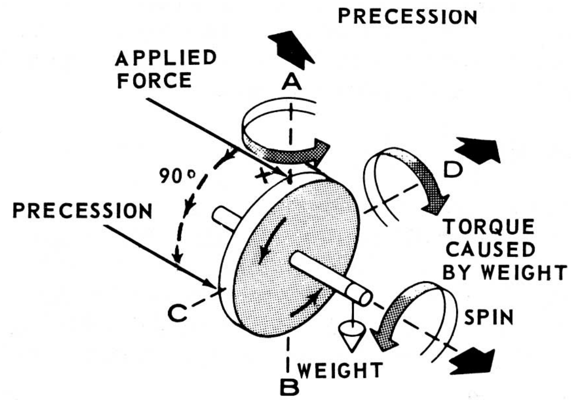

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Figure 4-6.—Direction of gyroscopic precession.

The earth precesses as it spins on its axis. A spinning bicycle wheel acts as a gyroscope and so do airplane propellers. You can probably think of other examples.

DIRECTION OF GYROSCOPIC PRECESSION. - Let us now see how we can determine the direction of precession caused by the application of a force tending to turn the rotor out of its plane of rotation. In figure 4-6, a weight is attached to the spin axis. This is in effect the same as applying a force at point X. The resulting torque tends to turn the rotor around axis CD. But due to the property of precession, the applied force will be transferred 90° in the direction of rotor spin, causing the rotor to precess around axis AB.

Free Gyros In Guided Missiles

To illustrate how free gyros are used in detecting missile attitude, let us first refer to figure 4-7. Suppose that the design attitude of the missile is horizontal as shown in the figure The gyro within the missile has its spin axis in the vertical plane, and is mounted in gimbals in such a manner that a deviation in the horizontal attitude of the missile would not physically affect the gyro. In other words, the missile body can roll around the gyro and the gyro will still maintain its same position in space. Figure 4-8 shows this occurrence. Note that the missile has rolled approximately 30°, but the gyro has remained stable in space. If we could measure the angle between the rotor and a point on the missile body we would know exactly how far the missile deviated from the horizontal attitude Having determined this, the control surface could then be positioned to return the missile to the horizontal.

Actually, a minimum of two free gyros s required to keep track of pitch, roll, and yaw. The vertical gyro just described can also be used to detect missile pitch as shown in figure 4-9. To detect yaw, a second gyro is used with its spin axis in the horizontal plane and its rotor in the vertical plane. Yaw will then be detected as shown in figure 4-10.

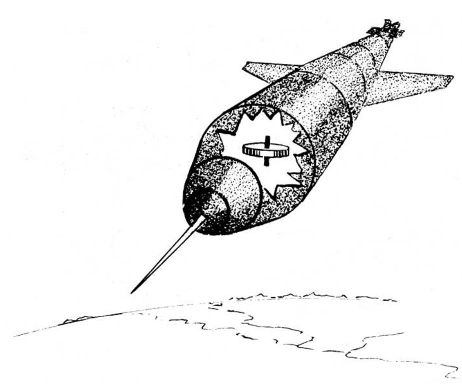

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Figure 4-7.—Missile horizontal—gyro remains fixed in space.

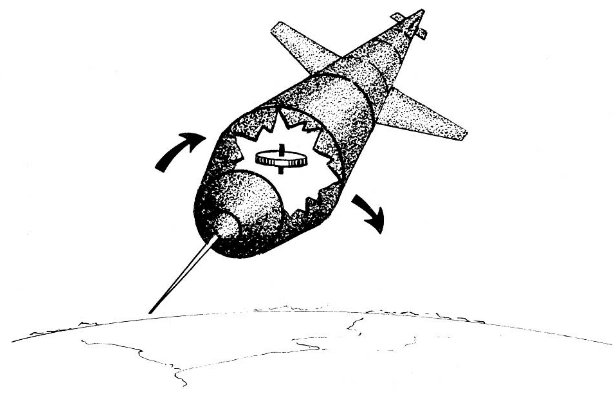

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Figure 4-8. — Missile rolls — gyro stays fixed in space.

Rate Gyros

The free gyros just described provide a means of measuring the amount of roll, pitch, and yaw. The free gyros therefore can be used to develop signals, which are proportional to the amount of roll, pitch, and yaw. Due to the momentum of a missile in responding to free gyro signals, large overcorrections would result unless there were some means of determining how fast the angular movement is occurring. For example, suppose that a correction signal is generated which is proportional to an error of 10° to the left of the proper heading. The control surfaces are automatically positioned to bring the missile to the right. The missile responds by coming right. But because of its momentum it will pass the correct heading and introduce an error to the right. To provide correction signals that take momentum of the missile into account, rate gyros are used. These gyros continuously determine angular accelerations about the missile axes. By combining free gyro signals with rate signals from the rate gyros, the tendency to overcorrect is minimized and a better degree of stability is obtained. The rate gyro actually provides a refinement or damping effect to the correcting process. Without rate gyros, a missile would over-correct constantly.

The basic difference between the free gyro and the rate gyro is in the way they are mounted. Figure 4-4 shows a simplified view of a roll rate gyro. Notice that the rotor is mounted in single gimbals rather than the two sets of gimbals which supported the free gyro. This

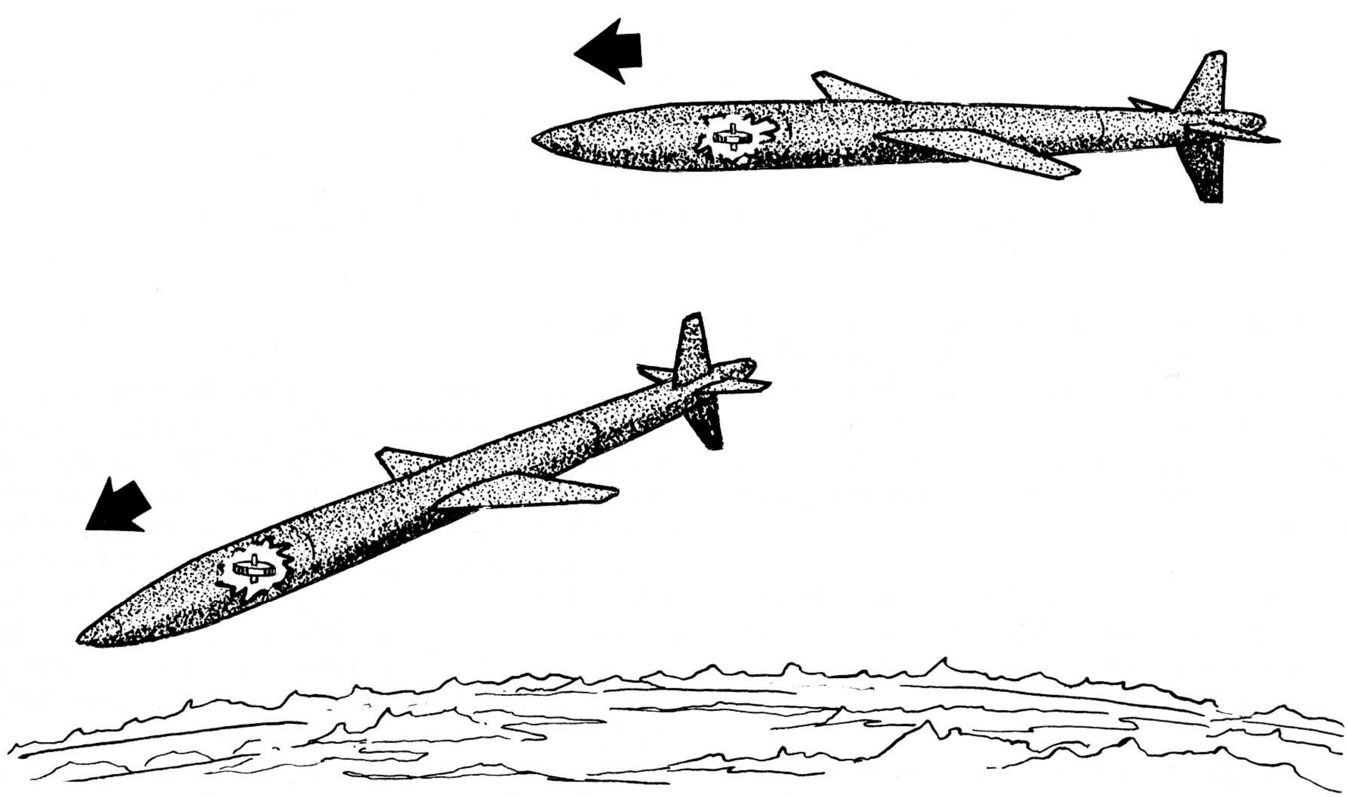

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Figure 4-9. — Missile pitches — gyro stays fixed in space.

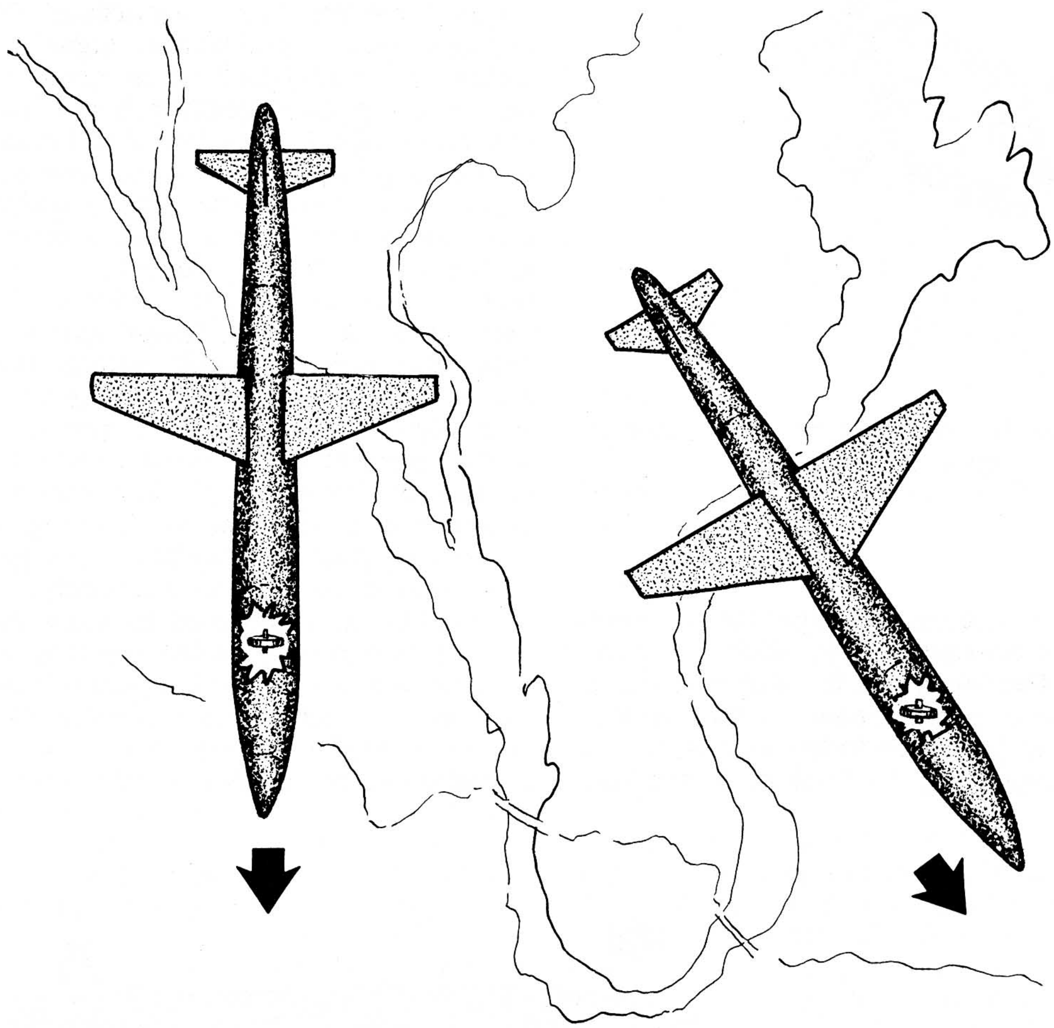

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Figure 4-10.—Missile yaws—gyro remains fixed in space.

arrangement restricts the freedom of the gyro rotor. When the missile rolls, the gyro mounting turns about the roll axis (arrow A) carrying the gyro rotor with it. This causes a force of precession at a right angle to the roll axis, which causes the rotor to turn about the pitch axis (arrow B).

Restraining springs may be attached to the gimbals as shown. The force on the springs would then be proportional to angular acceleration about the roll axis.

Three rate gyros are normally installed in a missile to measure the accelerations about the three mutually perpendicular missile axes (fig. 3-3A).

Accelerometers

An accelerometer is an inertia device. A simple illustration of the principles involved in accelerometer operation is the action of the human body in an automobile. You know that if an automobile is subjected to acceleration in a forward direction you are forced back in the seat. If the auto comes to a sudden stop, you are thrown forward. When the auto goes into a turn you tend to be forced away from the direction of the turn-that is, if the auto turns left, you are forced to the right, and vice versa.

In figure 4-11 we replace the human in an auto with a mass suspended in an elastic mounting system. Any accelerations of the auto will cause movements of the mass relative to the car.

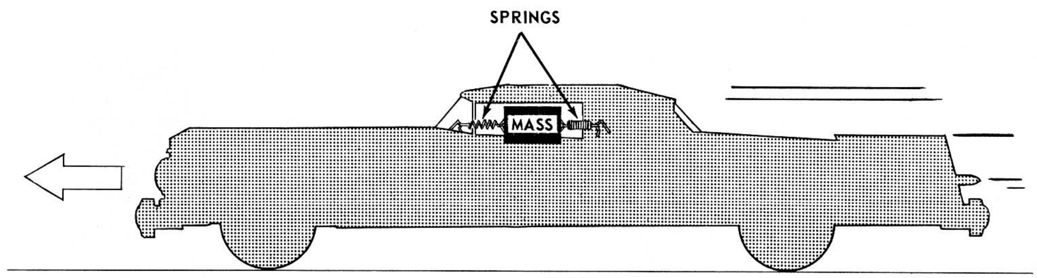

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Figure 4-11.—Spring-suspended mass reacts to acceleration of car, proportional to the force and opposite in direction.

The amount of displacement will be proportional to the force causing the acceleration. The direction in which the mass moves in relation to the auto will be opposite to the direction of the acceleration.

The movement of the mass is in accordance with Newton's second law of motion which states that when a body is acted on by a force, its resulting acceleration is proportional to the force and inversely proportional to the mass of the body. In mathematical terms this may be expressed as $a = F/M$, or by transposition $F = Ma$, where F equals force, M equals mass, and a equals acceleration.

When the auto in figure 4-11 is standing still, the mass will be at its rest point. When the car starts off in the forward direction the mass will lag in proportion to the acceleration force. It will also tend to oscillate about its rest point due to the spring tension. If permitted to oscillate, the movement of the mass would not represent the true accelerations of the auto. To eliminate the unwanted oscillations, a damper is included in the accelerometer unit. The damping effect should be just great enough to prevent any oscillations from occurring but still permit a significant displacement of the mass. When this condition exists, the movement of the mass will be exactly proportional to the accelerations of the auto.

Figure 4-12 shows a mass suspended by one spring in a liquid-damping system. If the case experiences an acceleration in the direction indicated by the arrow, the spring will offer a restraining force proportional to the downward displacement of the mass. The viscous fluid tends to oppose the movement of the mass, and therefore damps its action and prevents its oscillation. By including an electrical pickoff in the system, we can measure the displacement of the mass which is proportional to force and acceleration.

SENSORS AND PICKOFFS

Most guided missiles contain a variety of sensors. A sensor is a device which can detect energy. There are many sensors found in nature. The ear is a sensor which detects sound energy. The eye detects the presence of light energy.

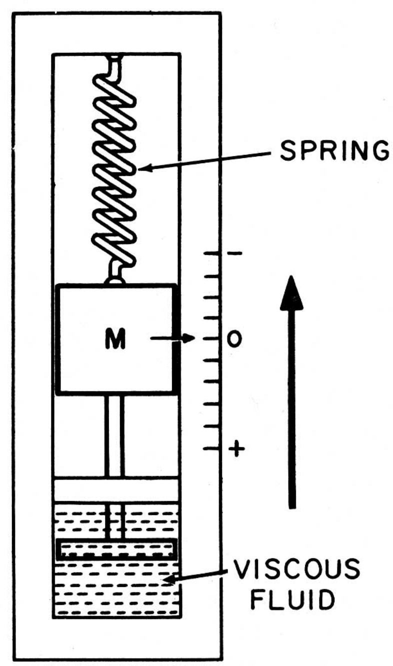

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Figure 4-12.—Liquid-damping system.

In addition to the sensors found in nature, man has been able to devise a large number of energy detectors which have industrial and military applications.

Types of Sensors in Missiles

A simple example of a man-made sensor is the photoelectric cell in a light meter. The photoelectric cell can detect the presence of light in much the same manner as the eye. Various types of photoelectric cells are used for different purposes. Figure 4-13 shows a vacuum-type photoelectric cell. When no light enters the tube, no electrons are released and none move from cathode to anode. When light enters the cell, electrons are released and can move to the anode and cause current to flow in the circuit. The small current from the photocell can be amplified so it can operate a relay and open or close a switch. This is popularly called an electric eye and has countless uses in industry. An electrical pickoff attached to the photocell can detect the direction of the light source. Many different types of light cells are made for different purposes, but all are dependent on light and therefore are ineffective when the light is obscured or absent.

Another simple example of a sensor is the aneroid barometer which detects atmospheric pressure. Devices which can sense radiated heat energy (all objects on earth radiate some heat energy in the form of electromagnetic waves) are infrared (heat) sensors. Radio receivers, although not commonly thought of as sensors, actually perform the same basic function as a sensor that is, they detect energy. Radar sensors have been developed since World War II.

Energy detection in itself is of no practical value. For a control system - whether it be associated with the human body or a guided missile - to respond to detected energy, there must be some type of mechanism associated with the sensor which will convert its intelligence into usable form. In the case of the vibrating eardrum, a nerve must be connected between it and the brain if the brain is to respond to noise. In response to the mechanical vibrations of the eardrum, the nerve produces signals which are transmitted to the brain. Without the nerve, the eardrum could vibrate continuously, yet no indication of sound would reach the brain. The same is true of the photoelectric cell (or the eye) which generates an electric current proportional to the intensity of light. Unless the electric current produces a meaningful effect, the cell has no useful application.

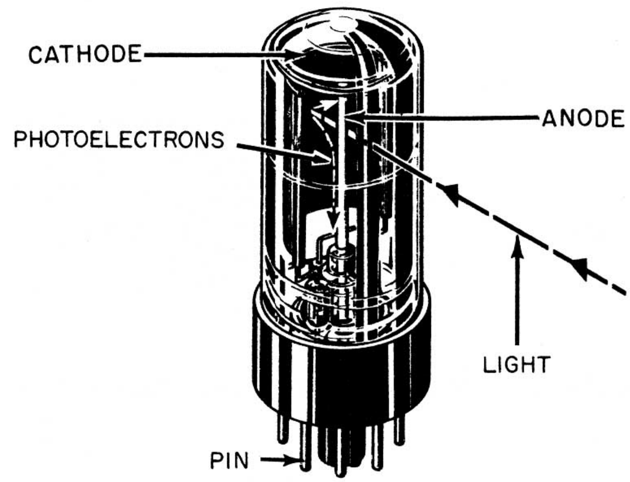

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Figure 4-13.— Photoelectric cell.

In most light meters the current is accepted by an electrical circuit and then converted to mechanical motion of an indicating needle. In the aneroid barometer, mechanical motion may be transmitted through a mechanical linkage to an indicator, or an electrical device may be associated with the bellows to cause indicator movement.

The devices which receive energy from sensors and transmit this energy-either in the same form or another form - to a point where it is put into practical use are generally referred to as pickoffs. In the case of the ear, the nerve was the pickoff. An electrical circuit acted as the pickoff in the light meter. An electrical circuit or mechanical linkage served as the pickoff in the barometer.

Pickoffs Used In Missiles

Most of the pickoffs used in guided missiles are electrical devices. In addition to transmitting energy from sensors, they are also used to measure outputs of physical references such as gyros. In this second respect, the pickoffs themselves act as sensors. (The gyro rotor in itself cannot determine missile attitude information. For this reason the gyro has been classed as a physical reference rather than a sensor.) Pickoffs must be used in conjunction with free and rate gyros to determine missile attitude and motion information.

Electrical pickoffs are extremely sensitive and reflect little torque back to the sensor or reference unit. It is primarily these qualities which make them useful in guided missiles. The most common types of electrical pickoffs are:

1. Potentiometer pickoffs
2. Synchro pickoffs

Potentiometers and synchros are covered in chapter 7 of this course. Also, the fundamental types of synchro units and their basic principles of operation are discussed in Basic Electricity, NavPers 10086-B so we won't cover these units here.

MISSILE GUIDANCE PHASES

Missile guidance is generally divided into three phases - boost, midcourse, and terminal. Figure 4-14 illustrates these three phases of guidance for Tartar, Terrier, and Talos (the three T's) missiles.

As you learned in the preceding chapter, Navy surface-to-air missiles are boosted to flight speed. This boosted period lasts from the time a missile leaves the launcher until the booster burns up its fuel. In the case of missiles with separate boosters, the booster drops away from the missile at burnout.

Boost is a very important phase of a missile's flight. The missile must get off to a good start or it will not hit its target. Before launch the missile is aimed in a specific direction on orders from afire control computer. Movement of the launcher in response to the computer orders establishes a line of flight (called a trajectory or a flight path) along which the missile must fly during the boosted portion of its flight. The flight path extends from the launcher to a point in space. And at the end of its boost period the missile should be at this point.

There are several reasons why this is important. First, if the missile is a homing missile, it must "look" in a predetermined direction for the target. The fire control computer calculates this predicted target position, based on where the missile should be at the end of boost phase. Before launch, this information is fed into the missile.

Finally, when a beam-riding missile reaches the end of its boosted period, it must be in a position where it can be captured by a radar guidance beam. Therefore, it is absolutely necessary that all missiles fly along the prescribed launching trajectory as accurately as possible. If they don't, then a homing missile will not see its target, nor will a beam rider be captured by its guidance beam (fig. 2-17). To assure that missiles will fly along the launching trajectory, special guidance systems are added to them, as in the Tartar and Talos. Or, like Terrier, each missile is made with such built-in stability that it can fly as straight as an arrow. But regardless of which technique is used, the boost phase guidance system keeps the missile heading exactly as it was at launch.

The MIDCOURSE phase begins where the boost phase ends, and ends where the terminal or last phase begins. It is during the midcourse phase that most of the major corrections to the missile's flight path are made.

The TERMINAL phase occurs as the missile approaches the target. This phase requires very high accuracy from the guidance system since the missile may have to make sharp turns and undergo high accelerations, especially against fast-moving and maneuvering targets.

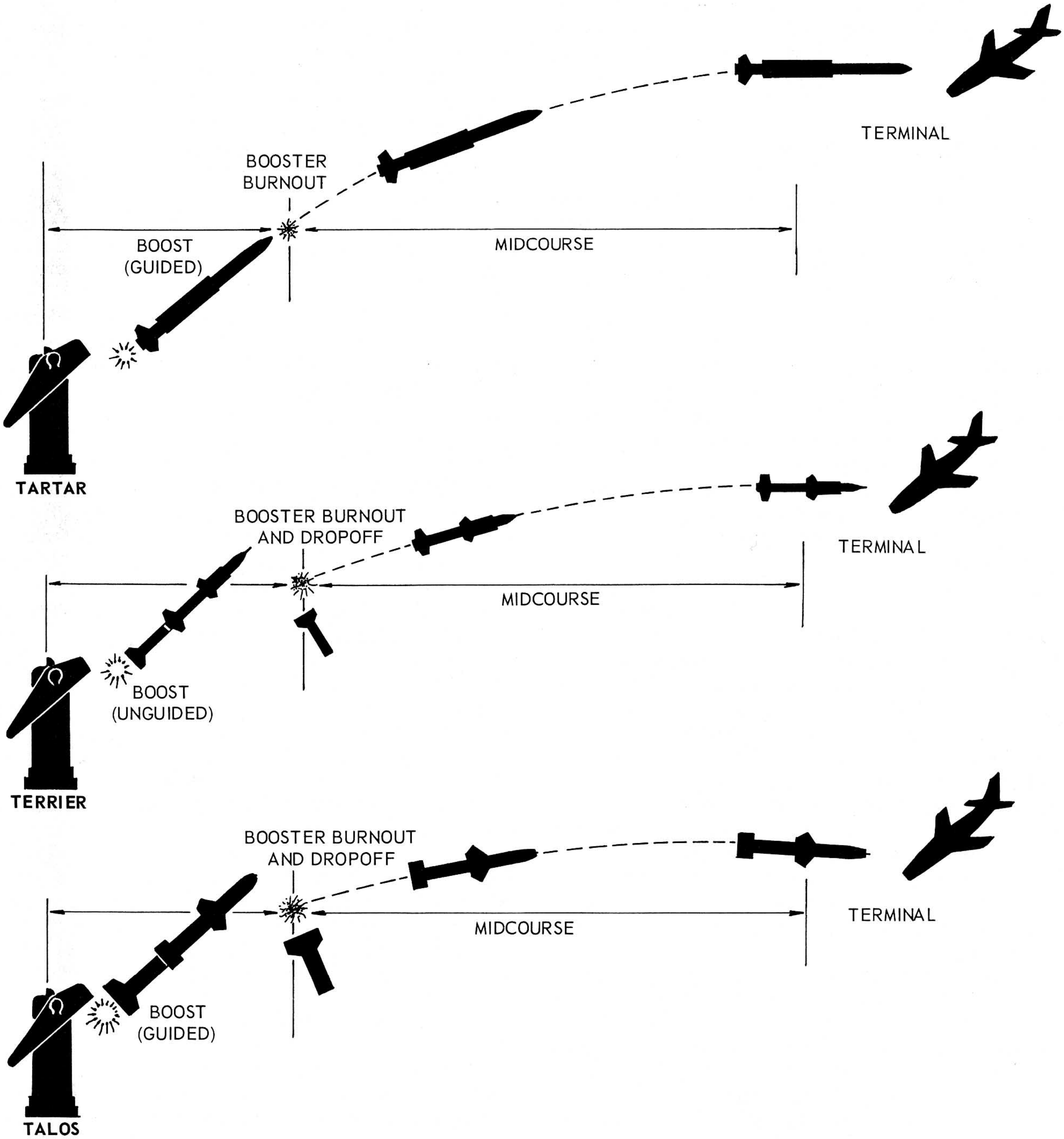
In some missiles a single guidance system may be used for all three guidance phases. Other missiles may have a different guidance system for each phase, and this is usually the case with Navy surface-to-air missile systems.

TYPES OF GUIDANCE SYSTEMS

So far, we have looked at missile guidance and control from the missile's viewpoint. Now let's consider the overall guidance and control picture in terms of shipboard and missile guidance systems. Guidance systems for missiles launched from ships can be divided into four groups: (1) self-contained, (2) command, (3) beam-rider, and (4) homing. No one system is best suited for all phases of guidance. It is logical then to combine a system that is excellent for midcourse guidance with one that is excellent for terminal guidance. Combined systems are known as composite guidance systems or combination systems. A particular combination of command guidance and semiactive homing guidance is called hybrid guidance. When a missile changes from one type of guidance to another while in flight, it must also contain some type of switching device to make the change. This device is called a control matrix, a highly sophisticated equipment found in modern missiles.

Self-Contained Guidance Systems

The self-contained group consists of the guidance systems in which all the guidance and control equipment is inside the missile. Some of the systems of this type are: PRESET, TERRESTRIAL, INERTIAL, and CELESTIAL-NAVIGATION. These systems are most commonly



83.18
Figure 4-14.—Guidance phases of flight for the 3 T's.

applicable to surface-to-surface missiles, and countermeasures are ineffective against them. Such systems neither transmit nor receive signals that can be jammed.

PRESET GUIDANCE. - The term "preset" completely describes this guidance method. All the control equipment is inside the missile, and all the information relative to the target location and the trajectory the missile must follow are calculated and set into the missile before it is launched. One disadvantage is that the trajectory cannot be changed once the missile is launched. For this reason it is used against stationary targets and large land masses; it cannot be used against a moving target. It is a relatively simple type of guidance system. The German V-2 is an early example of a guided missile with preset guidance. A completely preset system probably will not be used in missiles of the future, but some features of the preset system will be combined with other systems.

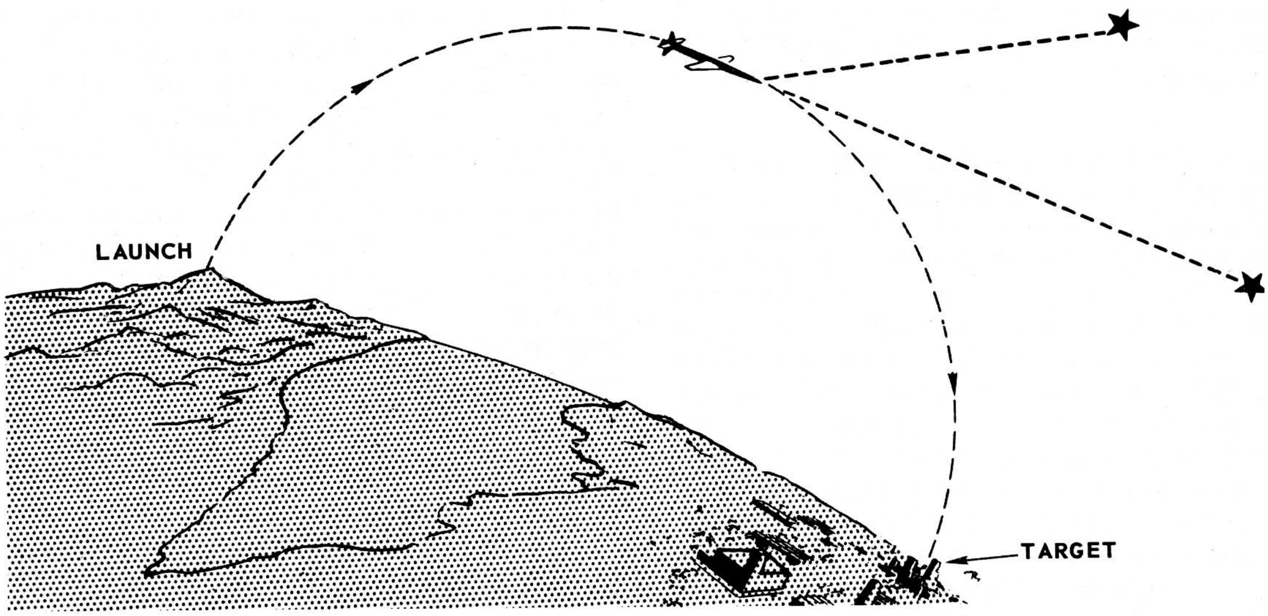
INERTIAL GUIDANCE. - The inertial guidance method is used for the same purpose as the preset method and is actually a refinement of the preset method. The inertially guided missile also receives programmed information prior to launch, Although there is no electromagnetic contact between the launching site and the missile after launch, the missile is able to make corrections to its flight path with amazing precision. The method of controlling the flight path is based on the use of accelerometers which are mounted on a gyro-stabilized platform. An accelerometer is an inertia device. (Inertial guidance gets its name from this property of matter.) A simple illustration of the principle involved in accelerometer operation is the human body in an automobile. If the automobile is subjected to sudden acceleration, the body is forced back into the seat, and it does the same thing for the missile. All in-flight accelerations are continuously measured by this arrangement; and the missile generates corresponding correction signals to maintain the proper trajectory. The use of inertial guidance takes much of the guess work out of long-range missile delivery. The unpredictable outside forces working on the missile are continuously sensed by the accelerometers. The generated solution enables the missile to continuously correct its flight path. The inertial guidance method has proved far more reliable than other long-range guidance method developed to date.

CELESTIAL-INERTIAL SYSTEM. - Navigation by the stars has been used for many centuries. The navigator measures the angular elevation of two or more known stars or planets, using a sextant. From these measurements, the ship's position can be plotted. The adaptation for missiles uses an inertial system that is supervised by an series of fixes on celestial bodies (fig. 4-15). Since a missile does not carry a human navigator, checking of the position must be done by a mechanical substitute. One of the systems is known as Stellar Supervised Inertial Autonavigator; another is called Automatic Celestial Navigation.

TERRESTRIAL GUIDANCE METHOD.- Several picture and mapmatching guidance systems have been suggested and tried. Terrestrial reference navigation relies on comparisons of photos or maps carried in the missile with an image of the terrain over which the missile is flying at that time. The basic idea can be shown by using the common photograph as an example. If a photographic negative is placed over its coinciding, positive, the entire area will be black. If the positive were a transparency, the entire area would be opaque and no light would get through. If either the negative or positive is moved slightly with respect to the other, light will show through where the prints are not matched. This is the theory on which a radar-mapmatching system works. Instead of a transparency for the positive image, the projected image of the terrain from a lens or a radarscope is used. Such a system is usable only against large land targets. Since landscape features can change over a period of time (buildings can be demolished or whole new complexes of buildings can be erected and roads changed), the "negative" to be used for comparison by the missile radar must be a recent one.

Development of Surface-to-Air Guidance Systems

Once an inertially guided missile is launched, it loses contact with any manmade devices located on the earth. The principal link, however, between an inertially guided missile and earth is the force of gravity. But Navy surface- to-air missiles, while in flight, normally have some manmade link between them and their launching platform (ship). The link is always in the form of electromagnetic energy from a shipboard radar. Depending on the type of guidance system used, the link is either a direct one

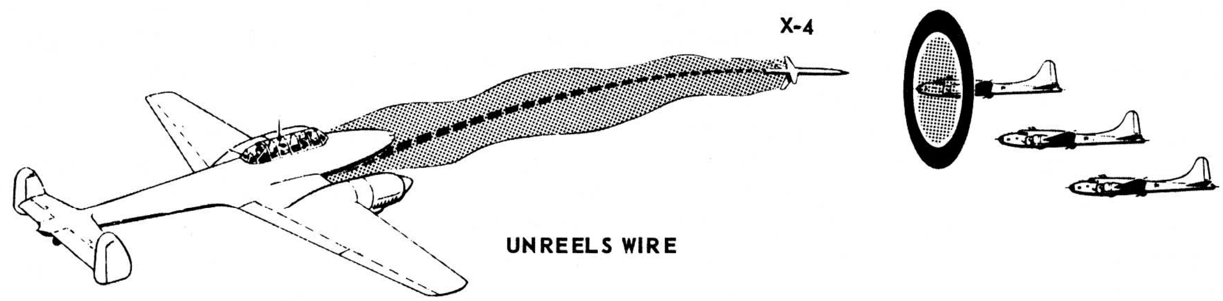


33.94
Figure 4-15.—Celestial guidance.

between the radar and missile, or it takes a roundabout path from its source to the missile. But regardless of the guidance method used, the missile and ship, under normal operating conditions, are linked by radar waves. However, under unusual circumstances such as a jamming target, the radar string between ship and missile is broken, and the missile is then linked by electromagnetic energy with the target.

When you consider the size of the earth, the distance covered by a Navy surface-to-air missile is very short. Range of the Tartar missile is in excess of 10 miles, and Talos a range in excess of 65 miles. Therefore, the targets that these missiles are used against must be kept under constant observation. Also, SAM (RIM) targets are usually moving. So, some means must be used to bring the missiles on target rapidly. Radar meets these two basic requirements perfectly. It can "see" in the dark and in bad weather, and it sends out beams of electromagnetic energy which can provide a control link between a missile and its launching platform (ship). Then, if guidance information is sent over this link, the missile can be directed onto the proper course to the target. When this guidance technique is used the missile is, in a sense, a puppet on the end of a string - an electromagnetic string. The radar tells the missile where to go and remotely controls its flight. The missile acts on this guidance information through control equipment inside the missile. The control equipment actuates the missile's wings or tails to bring the missile heading to the course prescribed by the radar. In this view of a guidance system, again notice that some of the overall guidance equipment is in the missile and some is on the ship.

The history of missile guidance systems is short. All of the significant developments are recent, principally because the state of electronics before the nineteen forties was relatively primitive. One of the first guided missiles was the German X-4. It was an air-to-air missile designed for launching from fighter aircraft as shown in figure 4-16. It was propelled by a liquid-fuel rocket, and roll-stabilized by four fins placed symmetrically. The X-4 was guided by electrical control signals sent from the launching aircraft, through a. pair of fine wires that unrolled from two coils mounted on the tips of the missile fins. The pilot observed the target, and measured its position relative to the missile. He compared their relative positions and computed the guidance commands necessary to bring the missile onto the right flight path. Then he sent these steering commands over the two wires to the missile control system which moved the control surfaces. This was a crude guidance system, but the point is that it contained all of the essential functional parts of present



83.20
Figure 4-16.—Wire guidance.

day guidance systems - (l) units to detect the presence of targets, (2) to track them, (3) compute guidance commands, (4) direct, and (5) control missile motions. Also note especially that the link with the launching platform (plane in this case) was a pair of wires. The wire link is analogous to the radar link of today's SAM (RIM) guidance systems.

One obvious disadvantage of a wire guidance link is that it shortens the range of a missile. So the next step in the development of guidance systems was to replace the wire link with one that could be stretched.

However, wire guidance is not obsolete. The Navy has a wire-guided torpedo (Astor), and several of the newest anti-tank missiles use wire guidance. Among these are Entac, SS-10, SS-11, TOW, and MAW. Since anti-tank missiles are necessarily short-range, wire guidance is well-suited to them.

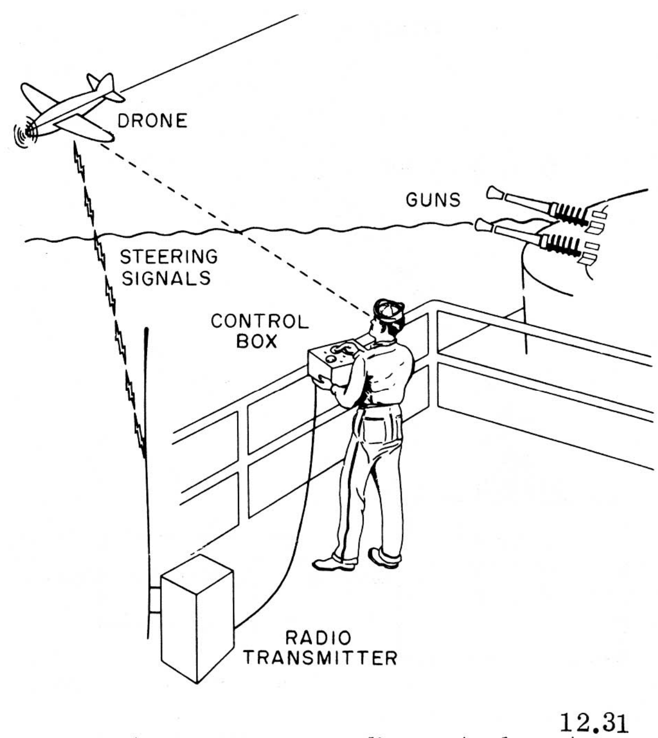
Command Guidance

The wire-link guidance system is obviously a command system, with the missile receiving commands from the ship's radar via the wires unreeled as it flies. Other command systems are by radio and radar without wire connections. A possible reason for the name of this guidance system category is that the shipboard portion of the overall guidance system sends directly to the missile specific commands such as turn right, go up, turn left, reverse throttle, and detonate warhead.

Remote Control by Radio

A guidance system based on remote control of the missile by radio was a natural step in the development of missile guidance systems. Using this technique, the control link could be stretched many miles, and any physical contact between launching platform and the missile eliminated.

A simple radio remote control system is shown in figure 4-17. In this system the operator visually observes the drone (tracking) and mentally decides the changes necessary in course, speed, and altitude (computing). Guidance commands such as up - down, right - left, and slow down - speed up are then sent to the drone by



12.31
Figure 4-17.—Drone radio control system.

radio (directing) where a receiver in the missile picks them up. The guidance commands are then sent to the missile's flight control system to execute the desired maneuver (steering). This method was used in World War II to direct obsolete, wornout airplanes (nicknamed "Weary Willies"), loaded with explosives, to enemy targets, such as factories and bridges; then explode them. In this radio guidance system the guidance commands originate from a source outside the missile. Later on we will show how more sophisticated missiles develop their own guidance signals. But first, let's talk about a further step in the development of missile guidance systems.

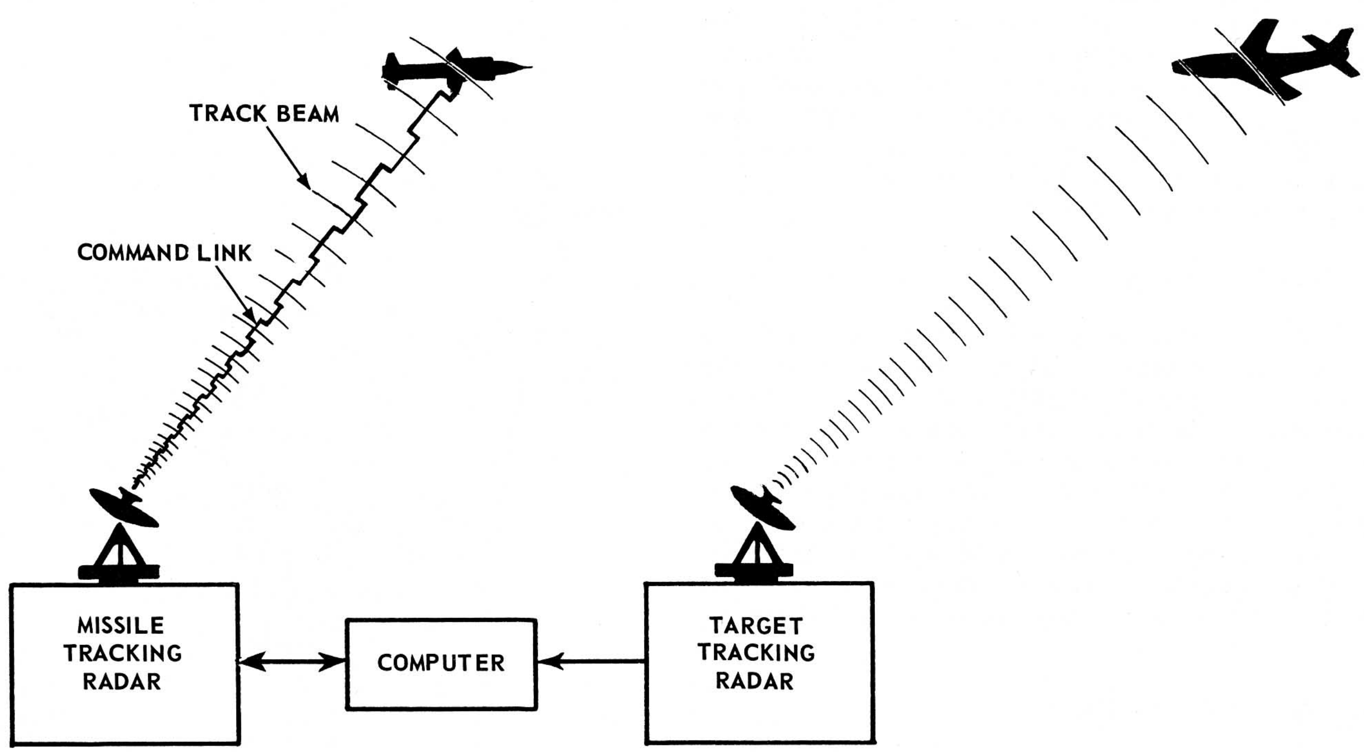
Missile Remote Control by Radar

The basic missile guidance system shown in figure 4-18 contains two radars and a computer. These three units replace the human operator we needed in the radio remote control system we talked about a moment ago. One radar tracks the target, the other tracks the missile. Both radars are located at the launching platform. And so is the computer which takes the two sets of tracking data and issues commands so that the missile will either collide with the target or pass within lethal range of it. The command signals are sent to the missile by the missile tracking radar beam. Notice that here, as in the radio remote control system, guidance signals are developed in a source outside the missile. The two systems we have just talked about come under the broad category of command guidance.

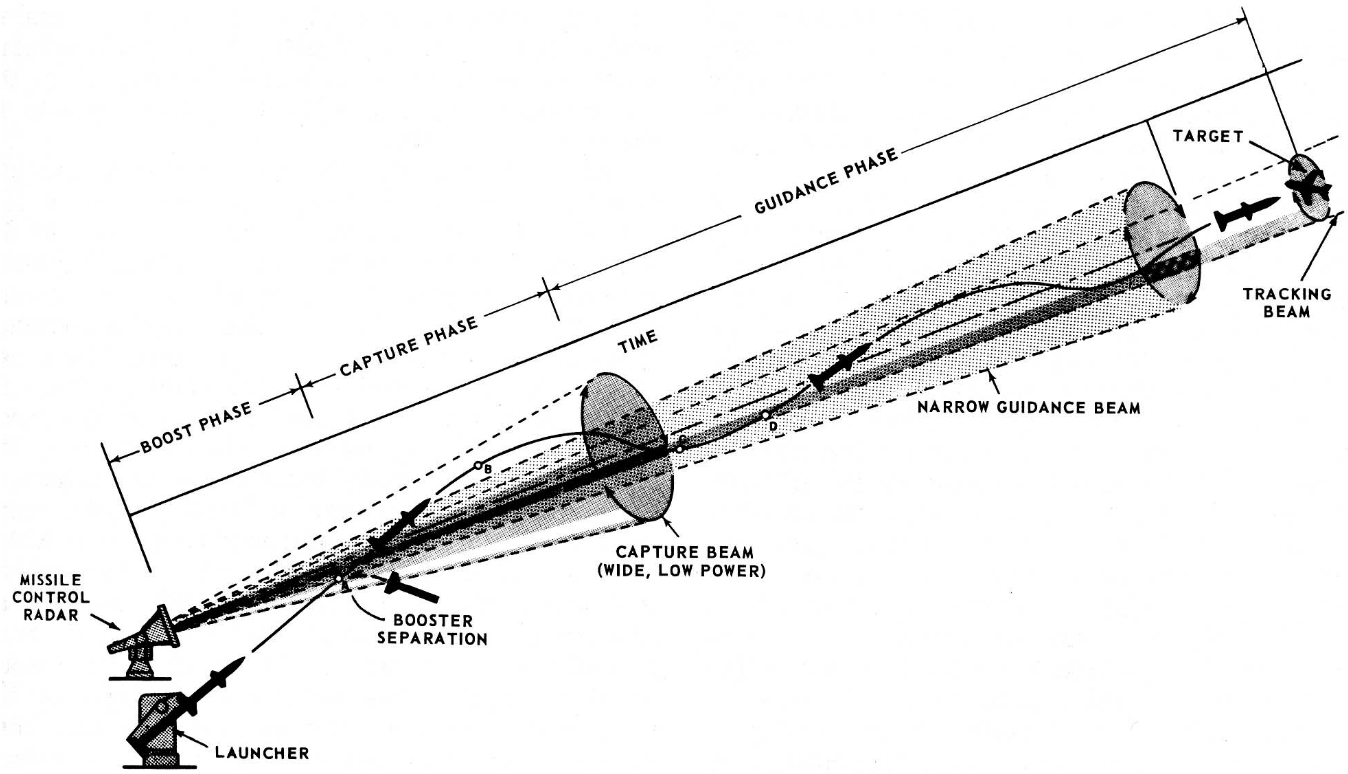
But in the systems that we will study next, only information is sent over the radar beams- not guidance signals. It is the missile's guidance system that acts on the information and develops guidance signals to direct the missile to the desired flight path.

BEAM-RIDER METHODS

In the beam-rider guidance system, shown in figure 4-19 a device in the missile keeps it centered in the beam. (The basic principles of radar and the general characteristics of a radar beam are discussed in Basic Electronics, NavPers 10087-B.)



83.22
Figure 4-18.—Radar command system.



12.38
Figure 4-19.—Beam-rider guidance system.

The basic beam-rider system resembles the method for controlling rockets first proposed in 1925. At that time, it was suggested that a rocket could be made to follow a searchlight beam using a simple control system containing four light sensitive, selenium cells. The cells were to be attached to the tail assembly of the rocket in a cross-shaped arrangement. After launching, the rays of the guiding searchlight would fall equally on the four cells as long as the rocket stayed in the center of the beam.

If the rocket strayed from the desired track, the four cells would then pick up different amounts of light. Since the electrical resistance of a cell is proportional to the amount of light that falls on its sensitive surface, the unequal responses of the four units could be converted into corresponding electrical signals. The signals were to be amplified, and then sent to a control system which would turn the rudders to bring the rocket back to the center of the beam.

Missile engineers never developed this system in the form proposed. But it is nevertheless interesting and noteworthy since the modern beam-rider missile works on the same general principle. Of course, there are many refinements in the present systems. For example, instead of a light beam, the beam of a fire control radar is used for guidance.

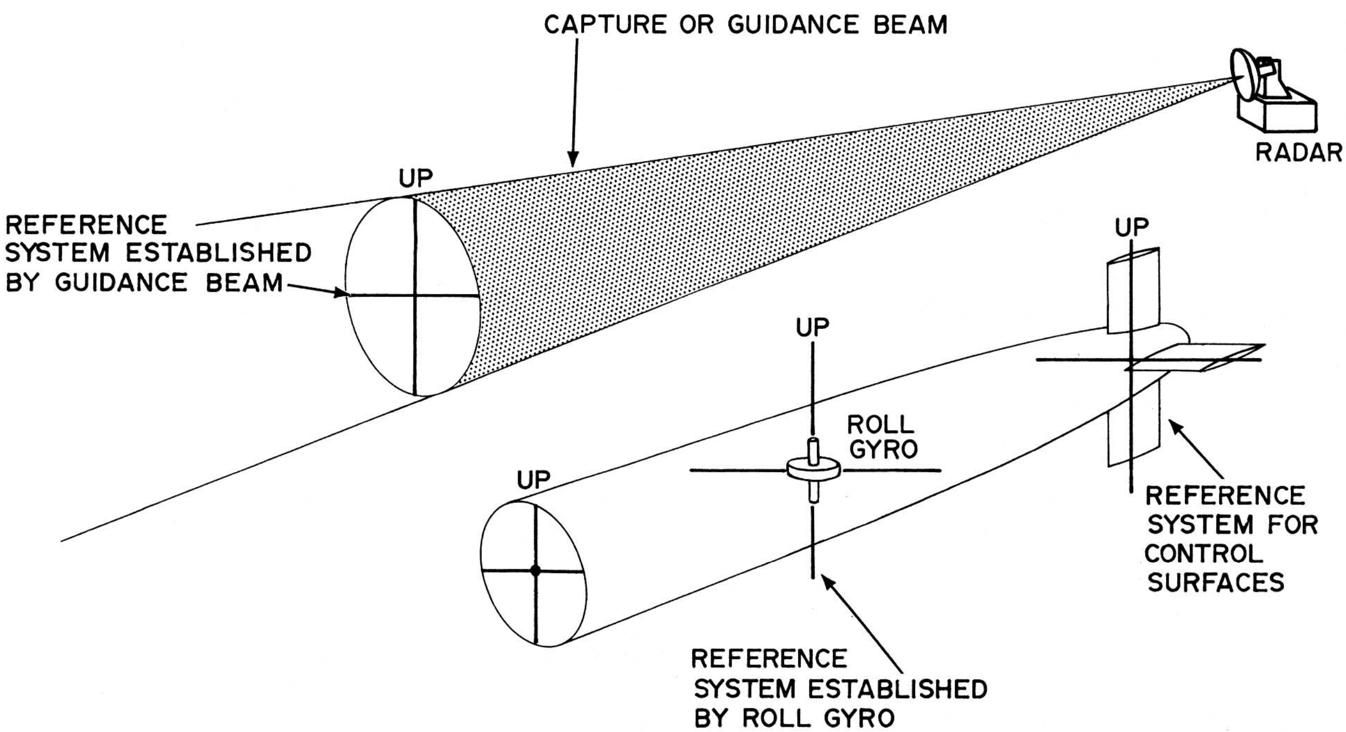
In place of selenium cells, the missile has a radar antenna-receiver system which senses the missile direction and distance from the center of the guidance beam. The missile control system then corrects the missile's flight to place the missile in the center of the guidance beam.

So far in this book, we have assumed that there is one beam, the guidance beam. There are actually two- a capture beam and a guidance beam. (See fig. 4-19.) The capture beam is a wide-angle low power beam used during the early part of missile flight to capture the missile. The guidance beam is a very narrow, high power beam used for guidance over the major part of the missile's flight. A wide capture beam is needed because missiles with external boosters have dispersion.

When the booster is ignited, the missile- booster combination is launched in such a direction that it will intersect the capture beam, as we explained in chapter 2. The booster burns out after about 4 seconds of flight, and aerodynamic drag causes it to separate from the missile.

When the booster separates, the missile should be in the capture beam. The capture and guidance beam contain the same kind of guidance information, and both nutate about the radar line of sight to the target. The guidance beams are kept on the target by the tracking radar and its associated director controls. Depending on the missile, the missile is roll stabilized somewhere between the time it is launched and after it enters the capture beam. The missile must be roll stabilized so that it can properly determine which way it must deflect the control surface in response to the guidance information in the beams. Proper operation of the missile guidance and control system depends on correct missile roll attitude relative to the guidance beams. In figure 4-20 you can see that the guidance beams contain a reference system. It is enough to say here that the beam reference is established by frequency-modulating the pulse repetition rate of the shipboard radar. What is important to you as a GMM is the roll gyro in the missile. Radar guidance information may be properly received and processed regardless of roll attitude, but when the missile makes corrections to its flight path, the control surfaces must be properly positioned in respect to the radar beam reference to turn the missile in the proper direction.

After the missile is captured (by the capture beam), it rides the capture beam for a few seconds. During this time it gets closer to the scan axis of the radar beam. Then, capture-guidance change-over takes place. This means that the radar receiver in the missile switches from the capture beam to the guidance beam, and starts receiving guidance information from it. As we said a moment ago, at capture-guidance change-over the missile should be close to the axes of the two radar beams, and the change to the guidance beam should be fairly smooth. Since the missile follows the guidance radar axis, which in turn follows the target, the missile approaches the target on an arc until intercept is attained as illustrated in figure 4-21. The missile may have to make a sharp turn to follow the radar beam to the target. This is a disadvantage of the beam-rider method, for the angle of turn may be too great for the missile to make safely.



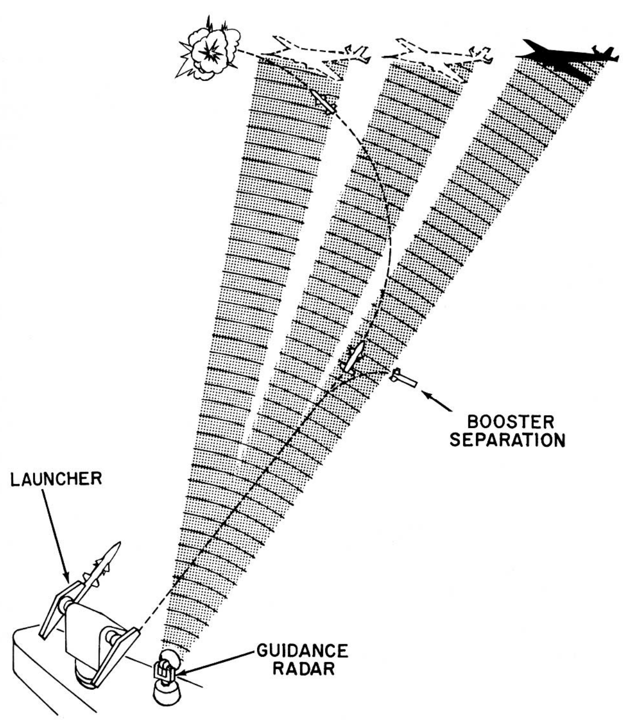
83.23
Figure 4-20.—Radar reference system and missile roll reference system.

Homing Systems

The types of homing systems are active, passive, and semiactive. They may also be named according to the type of signal followed, such as infrared homing, acoustic homing, or optical homing. Still another method of naming may be according to the flight path or trajectory followed, as pursuit homing, lead homing, or zero-bearing.

Active Homing

In active homing (fig. 4-22) the missile contains both a radar transmitter and receiver. The transmitter sends out radar signals. They strike the target and are reflected. The returned echoes are picked up by the missile's antenna and passed into the receiver. Here the information locating the target with respect to the missile is extracted. The output of the receiver is guidance information; it is sent to the computer, where steering corrections are computed. The output of the computer is sent to the control section, which in turn corrects the missile flight path to cause collision of the missile and target.



83.24
Figure 4-21.—Beam-rider track.

Passive Homing

Passive homing guidance equipment in a missile consists basically of an antenna and a receiver. The receiver-antenna combination detects the presence of a target and tracks it by sensing some type of radiation that the target emits. A passive homing system, like an active system, is completely independent of the launching ship. Unlike the active method, however, the operation of the passive homing system cannot be detected by the enemy since there is no electromagnetic radiation from the missile. A passive homing system is illustrated in figure 4-23.

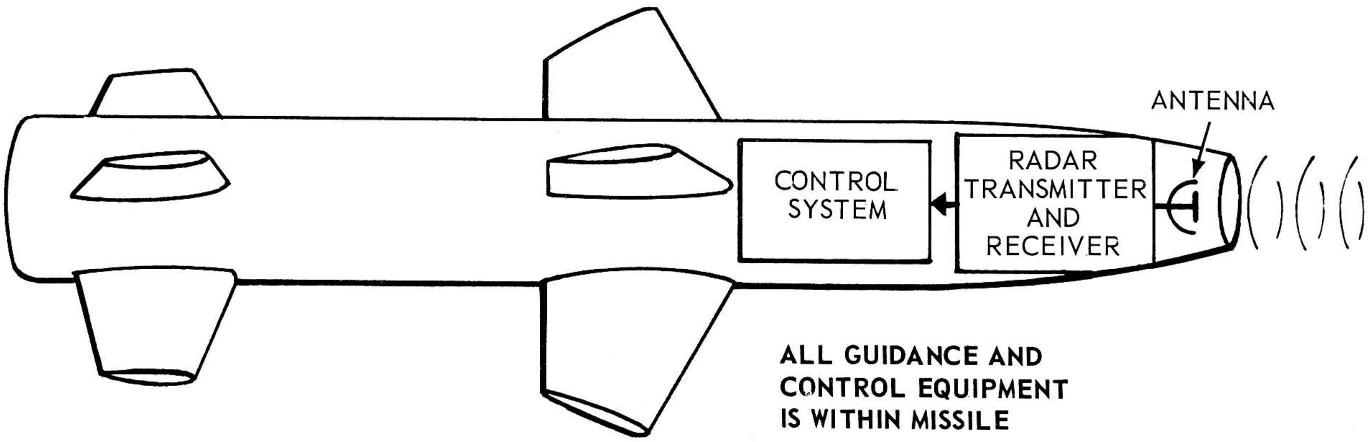
Some surface-to-air missiles use passive homing when their normal guidance system is jammed. Then the target is the source of electromagnetic energy used by the passive homing system to develop guidance signals. The energy source within the target may be an electronic jammer. The jammer is used to mix up the guidance information in the radar beams that are transmitted from the launching ship's equipment.

Other sources of energy located at the target are light, heat from the propulsion system, and sound, to name a few. No ship-launched surface-to-air missiles (RIMs) in current use depend on passive homing guidance all the way.

Several air-launched missiles use the homing method of guidance. The Navy's Shrike uses passive radar homing, Sidewinder used infrared homing, and Sparrow III uses semiactive continuous wave (CW) radar homing.

SEMIACTIVE LEAD HOMING GUIDANCE

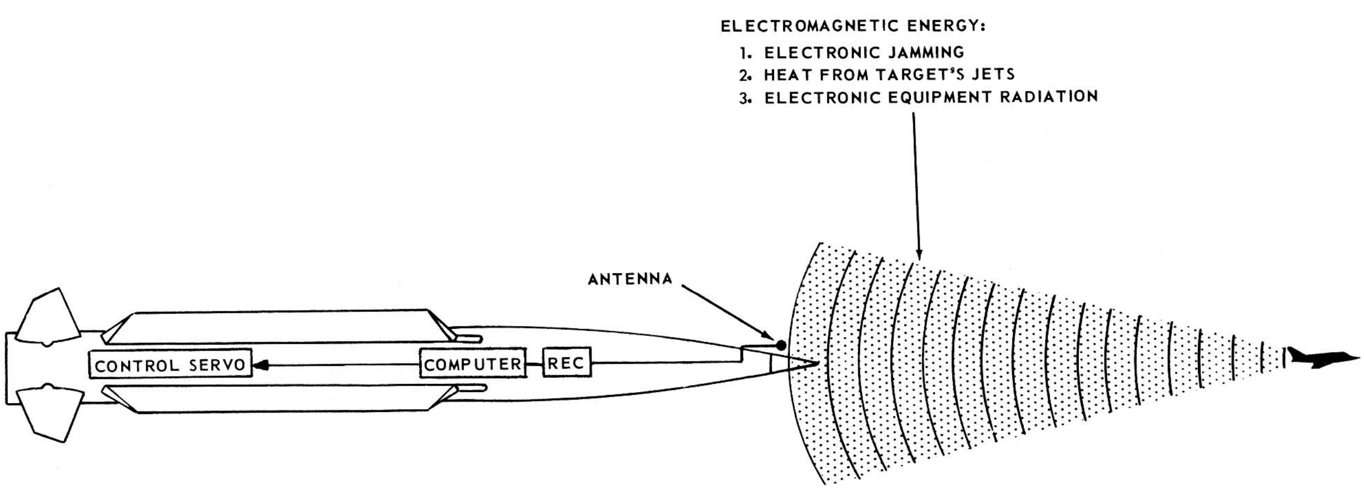
A missile using semiactive homing guidance receives radar energy along an indirect path. Radar waves are sent out from a fire control radar to a target. The transmitted waves strike the target and bounce off it. Some of the reflected waves of radar energy travel toward the semiactive homing missile sent out from your ship to intercept the target. Figure 4-24 shows the paths of the homing signals. A radar receiving antenna, called the seeker, or seeker head, in the nose of the weapon picks up the reflected energy. Then the rest of the missile guidance system causes the missile to home on the target.



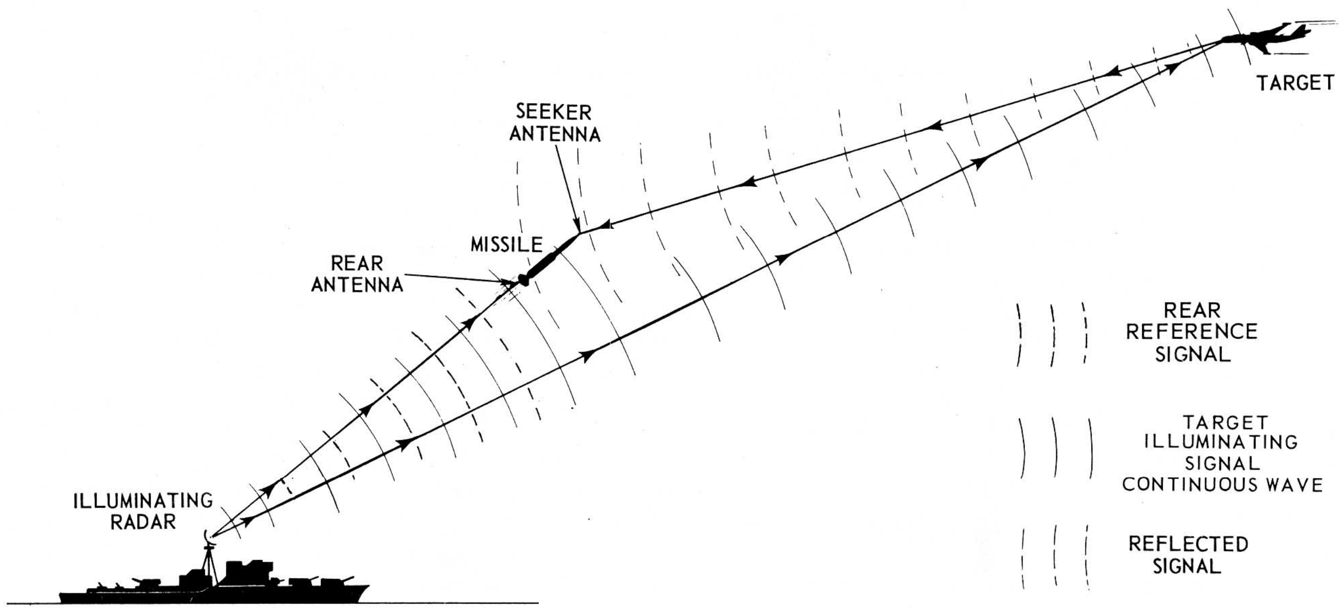
83.25
Figure 4-22.— Active homing guidance system.

Semiactive homing is more accurate than beam-rider guidance because the closer a semiactive guidance system gets to a target the more accurate the system becomes. On the other side of the guidance coin, the beam rider becomes less accurate as it approaches the target because the guidance beam spreads out from its source. The farther the target is from the ship, the wider the beam is in the target area. Thus the beam rider missile must maneuver more to stay in the center of the beam. But the semiactive homing missile receives stronger radar echoes as it approaches the target, and gets tighter control over its movements. We're not implying that the beam rider is not effective, because it is. We just want to point out that the beam rider technique has decreased accuracy at extended range.

The radar receiver in a semi active homing missile acts similarly to the beam-rider receiver, but with one exception. Instead of receiving target position information from a beam the semi active missile receives echoes from a target. You will recall that the fire control radar determines the direction to the target for the beam rider. The semi active homer itself must determine its course to the target. Briefly, this is the way it does it. The missile's homing antenna system



83.26
Figure 4-23.— Passive homing guidance system.



83.27

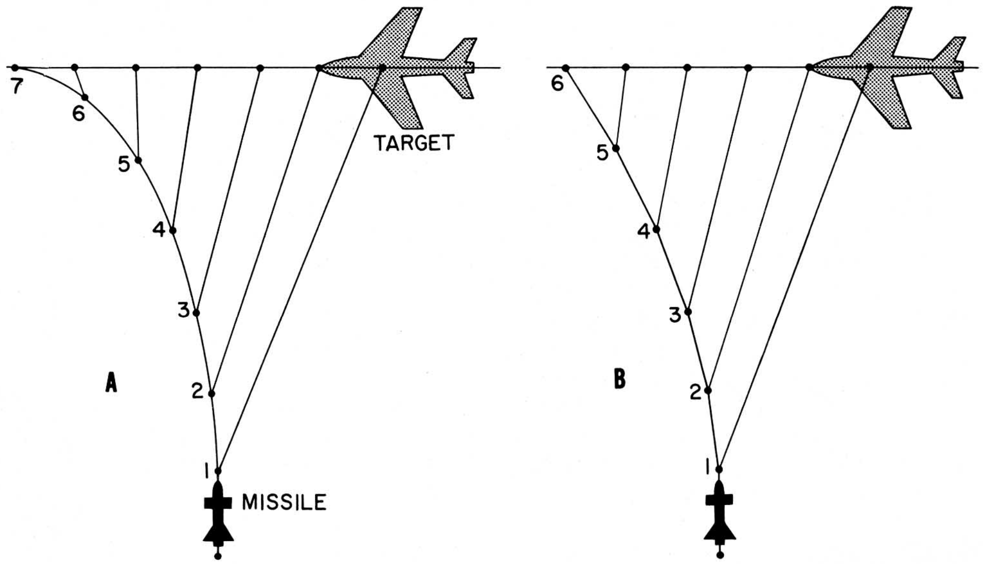
Figure 4-24.—Semiactive homing guidance system.

locates the target, and automatically tracks it. The tracking process established the line of sight between the missile and target. A computer in the guidance system uses this tracking information to produce steering signals.

You might think that the missile flies along the line of sight, but this is not the case. The missile is made to fly a collision course. If you have ever stood a wheel watch on board ship, you know what a collision course is. It's the one that causes a lot of excitement when steering unintentionally. But to illustrate a point, let's say you are the helmsman and the officer of the deck gives you a course to intercept a ship. Say the ship bears 045° relative. If the intercept course is correct, this bearing will not change as your ship steams along its track. As you shall soon see, the semi active homing missile uses a similar navigational technique to intercept a target. The guidance system uses a refined collision course, and it is the refinement to the course that interests you. The missile receives this refinement before it is launched. And how does it get it? Like the other preflight information we have talked about, the missile receives navigational information through the warmup contactor on the launcher.

Now back to semi active homing navigation. Figure 4-25 shows a situation similar to the one on board ship that we talked about a moment ago. But in this case the missile contains the helmsman in the form of the guidance system. Now the target is a supersonic bomber instead of a ship. To intercept high-speed targets like aircraft and missiles, a semi active homing missile must follow a lead (collision) course. The intercept point is at the intersection of the missile and target flight paths. The best collision or lead course happens when the missile heading keeps a constant angle with the line of sight to the target. This course requires missile accelerations to be only as great as target accelerations. Specifically, if the target flies a straight-line, constant-velocity course, the missile can also follow a straight-line collision course if its velocity does not change. But in practice, this ideal situation does not exist. Missile velocity seldom stays constant. Irregular sustainer propellant burning changes thrust, and therefore affects speed. Outside disturbances such as wind gusts change the speed and path of the missile. So the missile will often have to adjust its direction to maintain a constant bearing with the target.

If the missile path is changed at the same rate as the changes in target bearing (see part A of figure 4-25), the missile will have to turn at an increasing rate (positions 1 to 6), and will end up chasing the target (positions 6 to 7). This flight path follows a pursuit curve and the



83.28
Figure 4-25.— Proportional navigation.

missile cannot maintain a constant bearing with the target. The missile is just keeping up with changes in target bearing and may not be able to catch up with the target. At the same time, it is burning up a lot of needed fuel.

So, to achieve the desired straight-line course during the final and critical portion of the attack, the missile must turn at a rate greater than the rate at which the line of sight is turning. By overcorrecting the missile path in this way, a new collision heading is reached; and the bearing angle will remain almost constant, especially near intercept. This type of control is depicted in part B of figure 4-25. The ratio of rate of turn of the missile to the rate of turn of the line of sight (rate of change of target bearing) is called the navigation ratio, and is usually between three to one and four to one.

This technique of overcorrection results in a course called proportional navigation or, as you will sometimes see it written in OPs, N factor. Regardless of name, the shipboard missile fire control computer calculates the ratio and transmits it to the missile launching system for transfer to the missile's guidance and control system before launch.

DOPPLER PRINCIPLE

This principle, which bears the name of its discoverer, Christian Doppler (1803-53), pertains to the shift or change in frequency of a series of waves that occurs when there is relative motion along the line of transmission of energy between the source and the receiver of these waves. Some examples of waves that can be frequency shifted are sound, light, infrared, radio, and radar. A simple illustration of the Doppler effect in terms of sound waves is familiar to everyone who has observed the change in pitch of a train whistle as it approaches or recedes rapidly. When approaching, the sound-producing whistle comes a little nearer between each two successive sound waves it emits, and the waves strike the ear in more rapid succession, so that the frequency becomes greater and the pitch rises. If the train is moving away from the observer, the interval between successive sound waves is slightly increased, the frequency received by the ear is slightly decreased, and as a result, the pitch is lowered. The difference between the frequency of the sound waves when the train is standing still and when it is in motion is called the Doppler shift. This frequency difference could be used to measure the speed of the train with respect to the observer. The acoustical Doppler effect varies with the relative motion of the listener and the source, and the medium through which the sound passes. In the familiar example given, the sound waves were passing through normal atmosphere. By applying the principle to light waves, scientists are able to estimate the velocity of luminous bodies, such as stars.

The laws applying to light and other electromagnetic waves, applied to radar, gave us the Doppler radar system to measure the relative velocity of the system and the target. A radar set radiates waves of r-f energy. When these waves strike an object, some of the r-f energy is reflected back as an echo. When the echo returns to the radar set, the radar detects or "sees" the target. A continuous-wave (CW) radar set beams uninterrupted energy of a constant frequency toward the target. The target, in reflecting the waves, is in effect a second transmitter. The difference in frequency between the reflected waves and the original is the Doppler shift, and mixing the reference and the echo voltages gives the Doppler signal. The presence of this signal indicates a moving target. To eliminate the possibility of homing on objects other than the target, a band-pass filter is inserted in the control circuit to eliminate interfering signals. A band-pass filter will pass only a narrow band of frequencies.

The Doppler principle is illustrated in figure 4-26. Note that the received wave from a distant moving object is shifted both to the right and upward with respect to the original transmission. Consequently, the beat frequency (the signal resulting from mixing the two signals in the receiver) will be alternately very small and very large on succeeding half cycles. Thus the frequency-modulated radar determines the distance to a reflecting surface by measuring the frequency shift between the transmitted and the reflected waves.

Pulse Doppler Radar

Theoretically, continuous-wave systems are the most efficient in use. The chief difficulty is leakage of spurious signals from the transmitter to the receiver. Pulsing enables the receiver to be rendered insensitive during transmission, thereby avoiding leakage signals. The pulse- Doppler method uses high frequency c-w in the form of short bursts or pulses. The pulse repetition rate (PRR) is much higher than that of a conventional pulse radar, and the pulse length is longer. The pulse radar radiates energy at a selected time interval; this permits very accurate measurement of range.

CLASSIFICATION OF NAVY MISSILES

Although missiles are often known by their popular names (for instance, TERRIER, TARTAR, TALOS, or STANDARD), every missile is also assigned a military designation. This designation indicated the launch environment (where launched and from what type of launching device), mission, delivery vehicle type, design number, and series symbol of the missile.

The following letters are used to indicate the launch environment:

A - air launched.

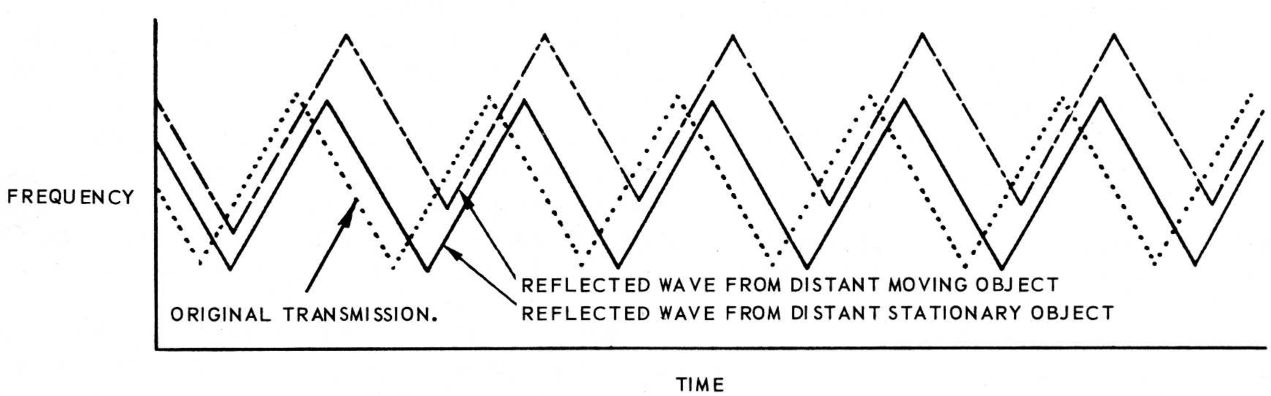
B - capable of being launched from more than one environment.

C - horizontally stored in a protective enclosure (coffin type structure) and launched from above ground level.

H - vertically stored below ground (silo stored) and launched from above ground.

L - vertically stored and launched from below ground level (silo launched).

M - launched from a ground vehicle or movable platform (mobile).



144.35

Figure 4-26.—Doppler effect on frequency modulation (sawtooth wave) of radar.

P - partially protected or nonprotected in storage (soft pad) and launched from above ground level.

R - launched from a surface vessel, such as a ship, barge, or other surface craft. (TERRIER, TARTAR, TALOS, and STANDARD have "R" designation.)

U - launched from a submarine or other underwater device.

The following letters are used to indicate the mission:

D - decoy (confuse, deceive, or divert enemy defenses).

E - special electronics (communications, countermeasures, etc.).

G - surface attack (enemy land and sea targets).

I - intercept-aerial (TERRIER, TARTAR, TALOS and STANDARD fall into this category.)

Q - drone.

T - training.

U - underwater attack.

W - weather.

The following letters are used to indicate the vehicle type:

M - guided missile (the 3 Ts and Standard).

N - probe.

R - rocket.

The design number is a number assigned to each type of missile with the number "1" assigned to the first missile developed. For example, all five modifications of the TERRIER missile (BW-0, BW-l, BT-3, BT-3A and HT-3) have the design number "2." TARTAR missile modifications (Basic and Improved TARTAR) have the design number" 24."

To distinguish between modifications of a missile type, series symbol letters beginning with "A" are assigned. Therefore, the TERRIER BW-0 has been assigned the symbol letter "A" and the TERRIER BW1 has been assigned the symbol letter "B." The series symbol letter follows the design number. Incidentally, to avoid confusion between letters and numbers, the letters "I" and "O" will not be used for series symbol letters.

If necessary, a prefix letter is included before the military designation. A list of applicable prefix letters follow:

J - special test, temporary.

N - special test, permanent.

X - experimental.

Y -prototype.

Z - planning.

The following list of Navy shipboard missile and rocket designations is included for reference:

TERRIER (BW-0) - RIM-2A
TERRIER (BW-1) - RIM-2B
TERRIER (BT-3) - RIM-2C
TERRIER (BT-3A) - RIM-2D
TERRIER (HT-3) - RIM-2E
TALOS (6b) - RIM8A
TALOS (6b1) - RIM-8C
TALOS (6bW) - RIM-8B
TALOS (6bW1) - RIM-8D
TALOS (6c1) - RIM-8E
TALOS (6b1/CW) - RIM-8F
TARTAR (Basic) - RIM-24A
TARTAR (Improved) - RIM-24B
STANDARD (MR) - RIM-66A
STANDARD (ER) - RIM-67A
POLARIS (A-1) - UGM-27 A
POLARIS (A-2) - UGM-27B
POLARIS (A-3) - UGM-27C
SUBROC - UUM-44A
WEAPON ALPHA - RUR-4A
ASROC-RUR-5A J

All Navy missiles are assigned mark (Mk) and modification (Mod) numbers. These numbers and the name of the missile constitute the official nomenclature approved by Ordnance Systems Command. Missiles having two stage propulsion systems (separate boosters), for instance, the TERRIER, TALOS, and STANDARD (ER), have one Mk and Mod number for the complete round. However, the individual missile and booster sections have their own mark and modification numbers. A chart of all Navy missile designations, including the former designations is published periodically by Ordnance Systems Command and for all the Services by the Department of Defense.

SURFACE-TO-AIR MISSILES

Long known as SAMs, the ship-launched missiles you will handle are now designated RIMs. Shore-launched surface-to-air missiles are still called SAMs.

So far in this text, we have emphasized the principles which underlie the operation of guided missiles in general. Very little mention has been made of specific Navy missiles. This has been done intentionally with several reasons in mind,

First, many of the principles Which have been discussed are common to all missiles To discuss each principle with relation to each operational missile is beyond the scope of this course.

Second, a given principle might be related to one model of a missile family and unrelated to another model of the same family. Thus, confusion would arise.

Finally, your duties aboard ship in regard to missiles require that you have only a general knowledge of how missiles work.

TERRIER MISSILE CHARACTERISTICS

Terrier missiles (fig. 4-27), come in three different varieties - beam-rider, wing-controlled (BW); beam-rider, tail-controlled (BT); and semiactive-homing, tail-controlled (HT). The beam-rider, wing-controlled missiles have the popular designation of BW-0 and BW-1. These missiles are being phased out of operation so we won't cover them here.

The beam-rider, tail-controlled (BT) missiles are of two major types, BT-3 and BT-3A. The BT-3A is similar to the BT-3. The principal difference between the two is that the BT-3A can carry a conventional or a nuclear warhead. When a nuclear warhead is installed in the BT-3A, the missile is designated BT-3A (N). A fragmentation warhead can also be used. In this case the missile is called a BT-3A (F). The range of the BT-3B is much greater than that of the BT-3A.

In outward appearance and size, the HT-type Terrier missiles are similar to the BTs, though somewhat longer. Figure 4-27D shows the general appearance and the location of the four major units. You can see a difference in the appearance of the nose section, but the chief difference is in the method of guidance, which will be explained later.

BT Terrier Missiles

Figure 4-28 shows the general outline of the components of the BT-3 and BT-3A (F) Terrier missile. Note that this is the Terrier missile, not the Terrier round - the booster rocket is not included here. We covered the external features of the Terrier in the previous chapter. Now we will discuss the various sections in the BT type missiles. BTs are composed of six sections:

1. Mounted on the front of the missile is the nose section. This section contains an air pressure measuring instrument called a nose probe. It has an electrical output which is proportional to missile speed and to air density. This signal changes the gain of the tail steering control amplifiers. This variable gain is needed because the higher a missile flies, or the lower its speed, the more tail deflection is needed to produce a given movement of the missile body.

A dust cover is placed over the pressure probe to prevent dirt and other foreign material from entering the nose probe. The dust cover is torn away or split apart at launch.

2. Just aft of the nose section is the fuze section. It contains the target detection device (TDD) and the warhead safety and arming device (S&A). The TDD senses the presence of a target and sends a signal through the S&A device to detonate the fragmentation warhead. The primary purpose of the S&A device is to delay arming the warhead until the missile is clear of your ship. (There is more about the TDD and the S&A device in chapter 10.)

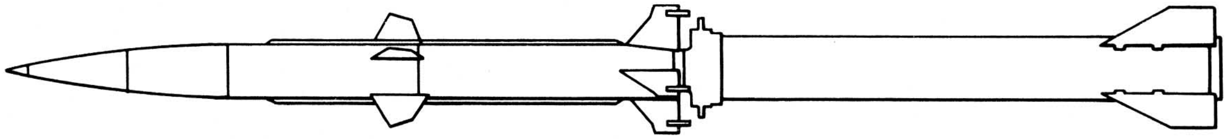
3. Aft of the fuze section is the warhead. This is the' 'reason for being" of the entire missile, as well as the weapon system itself. The main idea behind the millions of dollars worth of equipment on your ship is to put the warhead section where it will do the most damage to the target.

When the missile approaches close to or collides with the target, this is the "moment of truth." The kill is made with small metal fragments ejected from the exploding warhead (fragmentation type).

4. Next to the warhead section is the electronic section. This section contains the guidance equipment and electrical power supplies. The major unit in the electronic section is the radar receiver. It picks up radar information from the guidance beam and converts it into steering signals. You might say that the receiver compares the missile's position with that of the guidance beam's center. For illustration, if the missile is to the right and up from beam center, the receiver circuitry generated tail control signals to bring the missile down and to the left. When the missile is flying in the exact center of the beam, no steering signals are produced. But this seldom happens. Wind gusts blow the missile off course, and gravity is always at work tending to push it down. The missile fights both forces by constantly correcting its flight path. In practice, the missile's flight is often a spiral around the axis of the guidance beam.

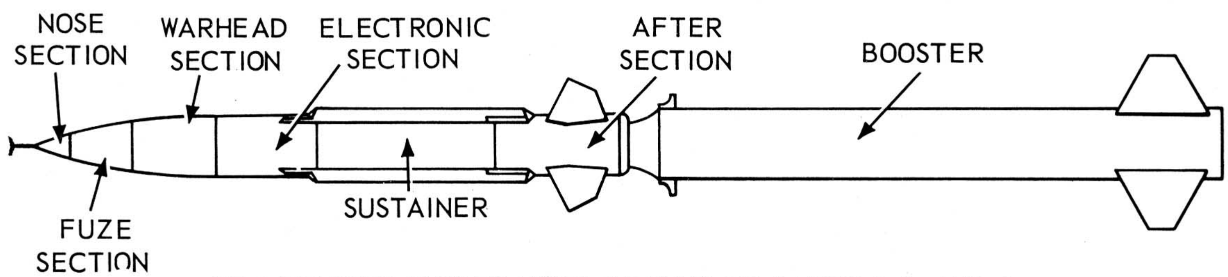
The electronic section contains vacuum tubes. As you know, vacuum tubes control the flow of electrons that are emitted from heated cathodes. For stable operation of vacuum tube circuits the flow of electrons from the cathode surface must be even, steady cathode emission

A



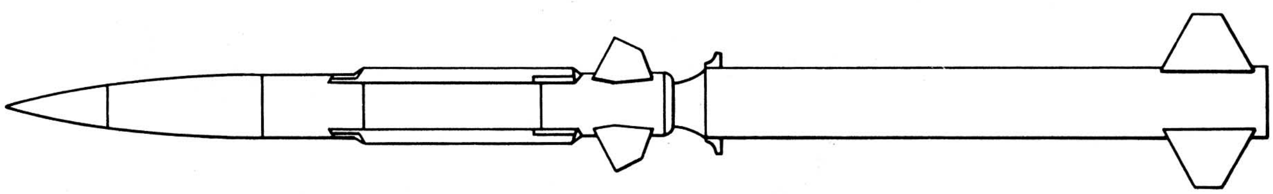
BW-1 TERRIER GUIDED MISSILE ROUND MK 6 MOD 0

B



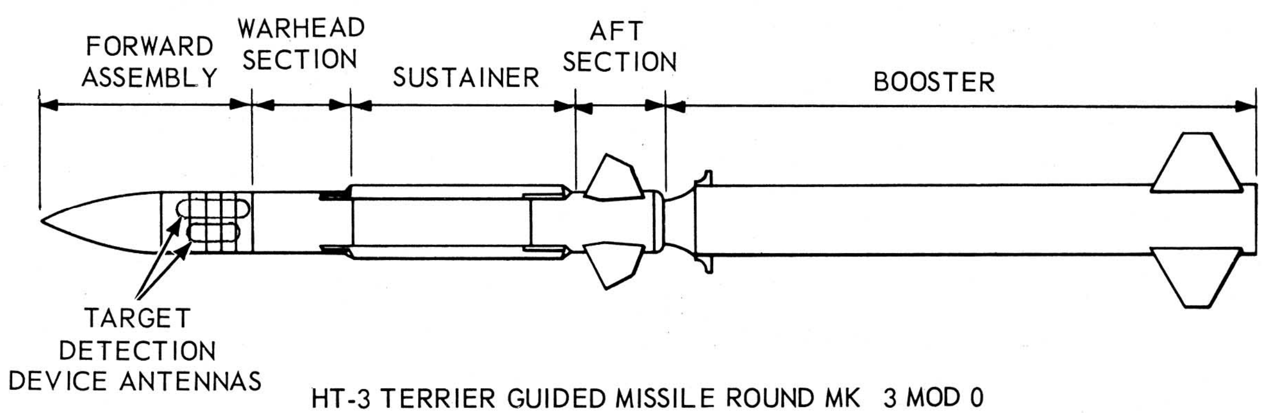
BT-3 TERRIER GUIDED MISSILE ROUND MK 2 MODS 0, 1, AND 2
BT-3A(F) TERRIER GUIDED MISSILE ROUND MK 2 MOD 3

C



BT-3A (N) TERRIER GUIDED MISSILE ROUND MK 2 MOD 4

D



HT-3 TERRIER GUIDED MISSILE ROUND MK 3 MOD 0
HT-3A TERRIER GUIDED MISSILE ROUND MK 3 MODS 1, 2

83.29
Figure 4-27.—Terrier missile family.

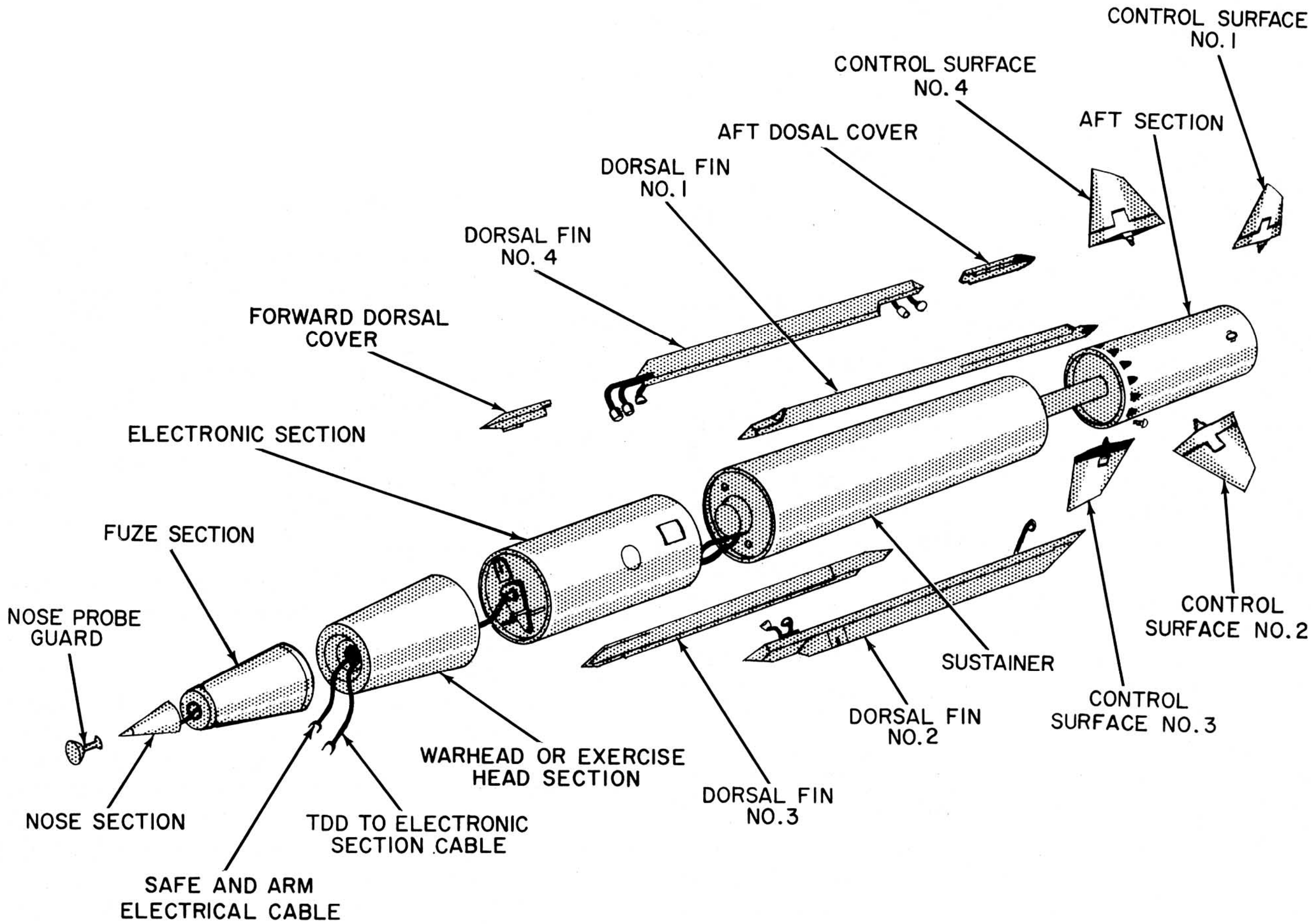


Figure 4-28.—Beam-rider tail-controlled (BT) Terrier missile; components.

occurs when the filament reaches a certain temperature. This process takes time- about 20 seconds. So before a missile is launched, electrical power from a source outside the missile is applied to it.

The electronic section contains other units that require "warming up" before the missile is launched. These are the gyros. It takes time for a gyro to reach its proper operating point. Temperature is not a critical factor in gyro operation, however, but the speed of its rotor is. Therefore, the missile's gyro must be warmed up before flight. The same external source that warmed up the filaments is used to apply current to the gyro wheels and bring them up to operating speed.

There are four gyros in the electronic section- three rate gyros and one position (directional) gyro. Earlier we said that the missile had to know which way is up before it could respond to guidance commands. The position gyro, called the roll free gyro, provides this reference direction. Incidentally, the term roll free gyro does not mean the gyro is free to roll. It means that a free gyro is used to provide a vertical reference line about which missile roll motion may be measured. A characteristic of a free gyro is that its spin axis will remain in the direction in which it is originally pointed. In this case, the rotor (spin) axis of the roll free gyro is placed in the vertical before missile launch. Theoretically, the missile could spin about its center of gravity and when these gyrations were finished the spin axis would still be pointing straight up and down. The other gyros, the rate gyros, are not free.

Two of the three rate gyros, called steering rate gyros, sense and measure the angular velocity of the missile as it turns about its center of gravity in answer to steering commands. The output of the steering rate gyros is a voltage that is proportional to the angular velocity (rate) of the missile body about the yaw and pitch axes. The purpose of these rate signals is to prevent the missile from overshooting and oscillating across the beam axis as it responds to steering commands. This damping technique is similar to the damping method used in some launcher power drive servos. There, tachometer generators sense and measure launcher velocity and send a voltage proportional to velocity to the servoamplifier to reduce over-shooting and oscillation about the desired position. Tach generators can't be used in missiles because there is nothing to gear them to except air. But rate gyros can sense the motion of a body in this kind of environment.

The third rate gyro, called the roll rate gyro, senses the missile's speed and direction as it rolls. The roll rate gyro provides a damping signal to the roll amplifier in the steering system to reduce overshoots and oscillation of the missile about its correct roll attitude.

5. The sustainer is the missile's longest section. It houses a solid propellant which, as it burns, exhausts hot gases through the after section to the atmosphere. The reaction to the hot gas flow is the force that propels the missile. The sustainer of the BT-3B missile is a longer burning type, with a corresponding increase in operation time, which accounts for its greatly increased range.

6. The aft section could have been called the muscle section because it provides the sources of electrical and hydraulic power. This section is the last section of the missile proper. The aft section contains two power supplies- a hydraulic auxiliary power supply and an electrical auxiliary power supply. (The term auxiliary is used to differentiate between these two units and the sustainer, which is considered to be the primary source of missile power.) The hydraulic auxiliary power supply furnishes hydraulic fluid under pressure to the four hydraulic systems that control the movement of the tail surfaces. The electrical auxiliary power supply furnishes all the electricity to operate relays, gyros, electronic circuits, and other electrical units within the missile.

HT TERRIER MISSILES

The HT-Type Terrier missile, figure 4-29, looks like the BT-3, but the HT-3 is longer. Also, the length of the BT-3 varies with the type of its warhead. Besides the HT-3, the basic version of the homing type Terrier, there is the HT-3S.

Much of the actual hardware of the HT-3 missile is common to the BT-3 missile. Both types use the same Mk and Mod booster and the same sustainer. Also, the after sections of the HT-3 and the BT-3 are identical.

The HT-3 has a semi active homing guidance system. The missile receives signals transmitted from an illuminating radar aboard ship and illumination signals reflected from the target. The missile uses this information to follow a collision course to the target.

The HT missile has four major units: (1) forward assembly, (2) warhead section, (3) sustainer and (4) aft section.

The forward assembly has two main parts - the guidance section and the target detecting device insert and antennas. The radome covers the antennas and is transparent to radar waves. The ram pressure probe in the tip and the blow- away shield are similar to those in the BT-3 missile. The guidance section is composed of five round and flat sections called wheels.

The HT-3 Terrier missile is electronically similar to the Improved Tartar missile. Because these missiles are so similar we will skip a discussion of the HT-3 and turn our attention to the improved version of the Tartar missile. Thus, we call kill two birds with one stone.

TARTAR MISSILES

Tartar (fig. 4-30), is a single-stage, rocket-propelled, supersonic, tail-controlled missile. There are two versions of Tartar - Basic Tartar and Improved Tartar. Basic Tartar is being phased out of operation. At present it is not in production, and is being used only as a training missile. Therefore we will cover it in this text. The improved version however, is one of our major defenses against close-in air targets, and it is the one we will talk about here.

The Improved Tartar, called IT hereafter, contains a semi active homing and a passive guidance system. Normally, the missile uses

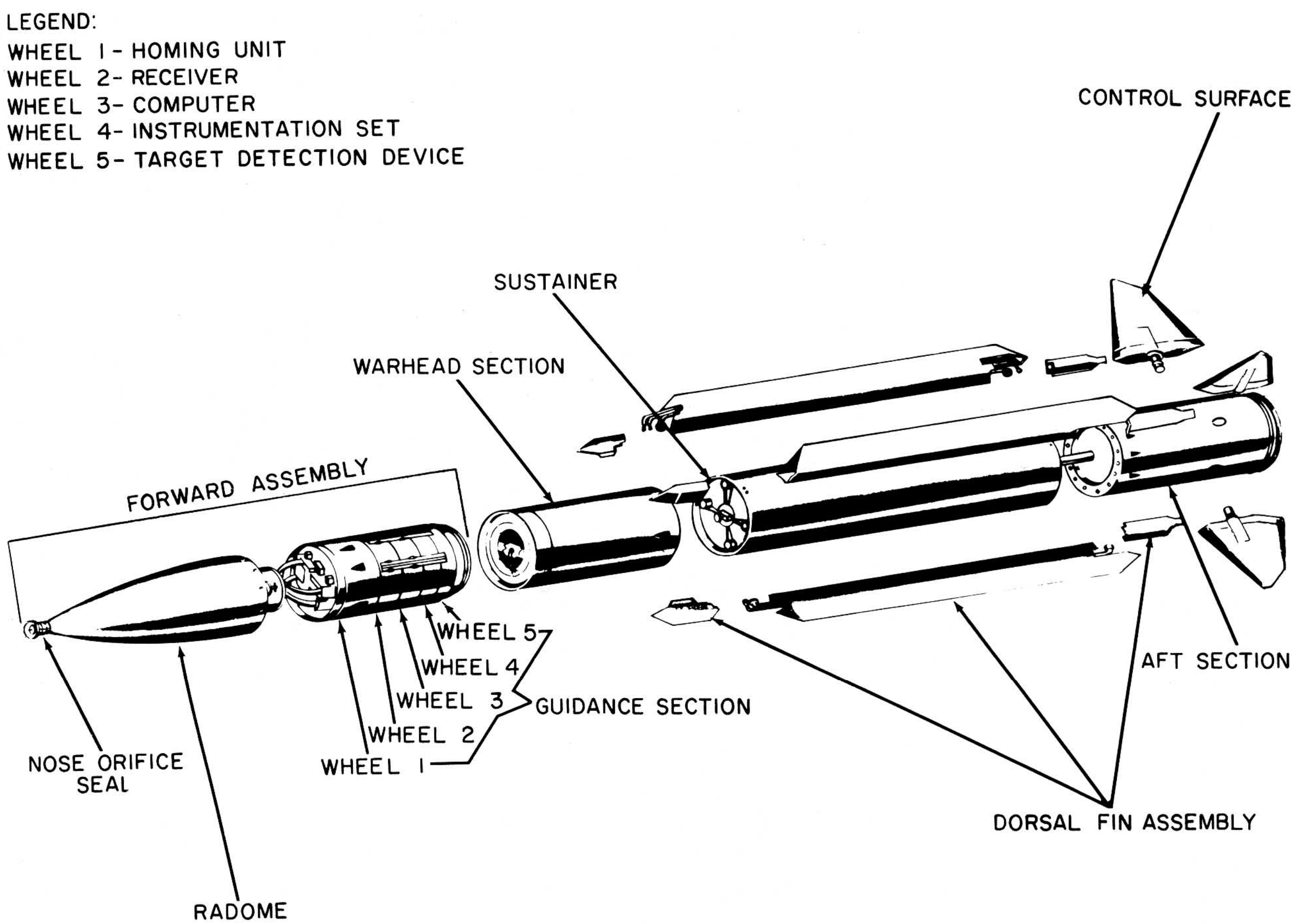


Figure 4-29.—Homing tail-controlled (HT) Terrier missile; components.

semi active guidance to intercept the target. But if the IT is flying toward a target that is jamming, the missile switches from semi active homing to passive homing. Then it homes in on the target.

The IT missile consists of four principal assemblies. An exploded view of the missile is shown in figure 4-30, which indicates the four major assemblies: (1) forward assembly, (2) warhead section, (3) dual-thrust rocket motor, and (4) steering-power section. Note that this is a complete round; the Tartar does not have a separate booster rocket.

Forward Assembly

This assembly consists of the guidance section and the Target Detection Device (TDD) with its antenna system. The purpose of the homing section is to track the target and develop guidance signals. The TDD senses the presence of the target when it is within destructive range of the warhead.

The guidance section is made up of five ring-shape units called wheels, or wheel packages. They are numbered 1 through 5 from front to rear. These five wheels are:

1. Homing Unit (Wheel 1). The first wheel contains the seeker head antenna, reference antennas, and passive homing circuitry.

2. Homing Receiver (Wheel 2). This package contains most of the seeker head guidance circuits and the self-destruct circuits.

3. Guidance Computer (Wheel 3). The computer uses output signals from the homing system to produce missile steering orders that keep

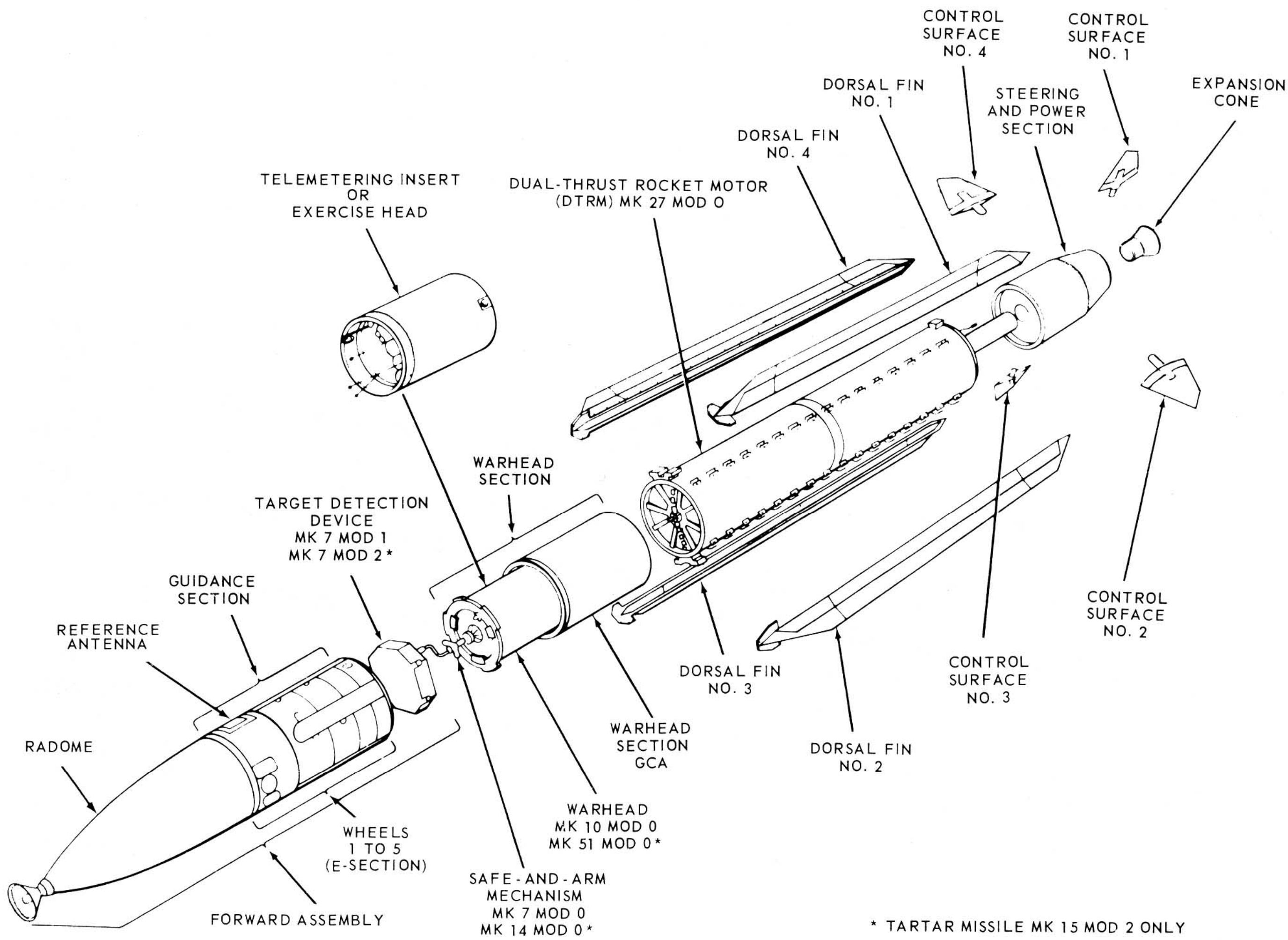


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Figure 4-30.—Improved Tartar round; exploded view.

the missile on a collision course with the target. Outputs of the roll free and roll rate gyros are also used by the guidance computer to generate roll stabilization commands to the control surfaces.

4. Instrument Set (Wheel 4). The instrument set contains the circuitry that connects the roll stabilization gyros mentioned above to the guidance computer. This section also contains the circuitry that times various functions in the missile.

5. Target Detection Device (Wheel 5). The target detection device is located here. It detects the presence of the target when it is within lethal range of the warhead. At intercept the target detection device sends a pulse of energy to the warhead. This pulse sets off the warhead charge.

Warhead Section

The warhead section contains a high-explosive charge and a continuous rod warhead. A Safe and Arm (S&A) mechanism, along with a fuze booster, is installed in the center of the warhead. The S&A device will detonate the warhead charge if:

1. The target detecting device senses the target.
2. The missile fails to receive the illuminating radar signal at the reference antenna.
3. The missile electrical power fails.

The S&A device permits safe handling of the missile aboard ship and makes sure that the warhead will not detonate until the missile is a safe distance from the ship after launch. The explosive units in the missile are discussed in more detail in chapter 10.

As seen in the figure, the warhead section GCA is simply a metal sleeve that forms the missile skin along the warhead section. The letters GCA stand for Guidance, Control, and Airframes, and indicate components, in addition to the explosive, that are part of the warhead section.

Figure 4-30 also shows an exercise head or telemetering insert. This is inserted in place of the warhead when the missile is used for practice. You are not going to use live missiles, each costing many thousands of dollars, when you have practice sessions with missile firing.

Dual-Thrust Rocket Motor (DTRM)

This section was covered in chapter 3. At the present time, the Tartar and Standard (MR) are the only Navy missiles that use this type propulsion system, which combines the sustainer and the booster.

Steering and Power Section

In Terrier missiles BT-3 and HT-3, the components of this section are contained in the part called aft section (figs. 4-28, 4-29).

Two auxiliary power supply (APS) gas generators are in the steering and power section. One generator supplies hydraulic power, whereas the other unit supplies electrical power to operate the electronic section. The tail control system which moves the missile tails is also a part of the steering-power section.

Fuel carried in the steering-power section is ignited in a combustion chamber. This produces hot gases which drive the electrical and hydraulic generators. After the gases are used, residue from the gases is vented out the sides of the steering-power section. Incidentally, this bit of information is helpful in distinguishing between a misfire and a dud. But we'll talk about this in chapter 9 where we will cover missile firing.

The APS gas generators, described very briefly above, form a complex system. New missiles will use a much simpler all-electric power source.

STANDARD MISSILES

The Standard missiles RIM-66A and RIM- 67A are surface launched, rocket propelled, homing type, supersonic guided missiles that may be used against surface or air-borne targets. RIM-66A is a medium range missile (MR) that resembles the Tartar missile. RIM-67 A is an extended range missile (ER) that resembles the Terrier missile.

The following paragraphs give a brief description of the sections and components of the missiles. Unless otherwise indicated, the discussion applies to both the ER and MR configurations. This is in part due to the interchangeability of many sections and components of the two configurations.

Figure 4-31 shows the major sections and components of the MR missile and figure 4-32 shows the major sections and components of an ER missile.

The ER and MR missiles consist of the following major sections: (1) Guidance section, (2) Ordnance section, (3) Control section, (4) Propulsion section.

Guidance Section

The guidance section of the ER and MR missiles operate as either a semi active or passive homing system. Roll stabilization and steering are accomplished by the movement of four aerodynamic control surfaces (tails).

Guidance by semiactive homing requires a surface based continuous-wave (CW) radar signal to illuminate the target, and a missile receiver to continuously receive and track the energy reflected from the target. Angular changes in the missile or target heading are sensed by the missile guidance system and transferred into appropriate control surface movements to steer the missile along a target intercept course.

The guidance section is identical for ER and MR missiles and consists of a radome assembly, two reference antennas, and a guidance assembly. The radome structure assembly consists of an aluminum guidance section shell and an rf transparent radome. The radome serves as a protective covering for the guidance unit while allowing reception of the target signal, and is made of a pyroceramic material terminated at the forward end with a small metal tip. The reference antennas are flush-mounted in cutouts on the top and bottom of the radome structure and receive the rf energy directly from the surface based radar.

Ordnance Section

The ordnance section for the ER and MR missiles in interchangeable and consists of a fuze shroud assembly, warhead, safety and arming

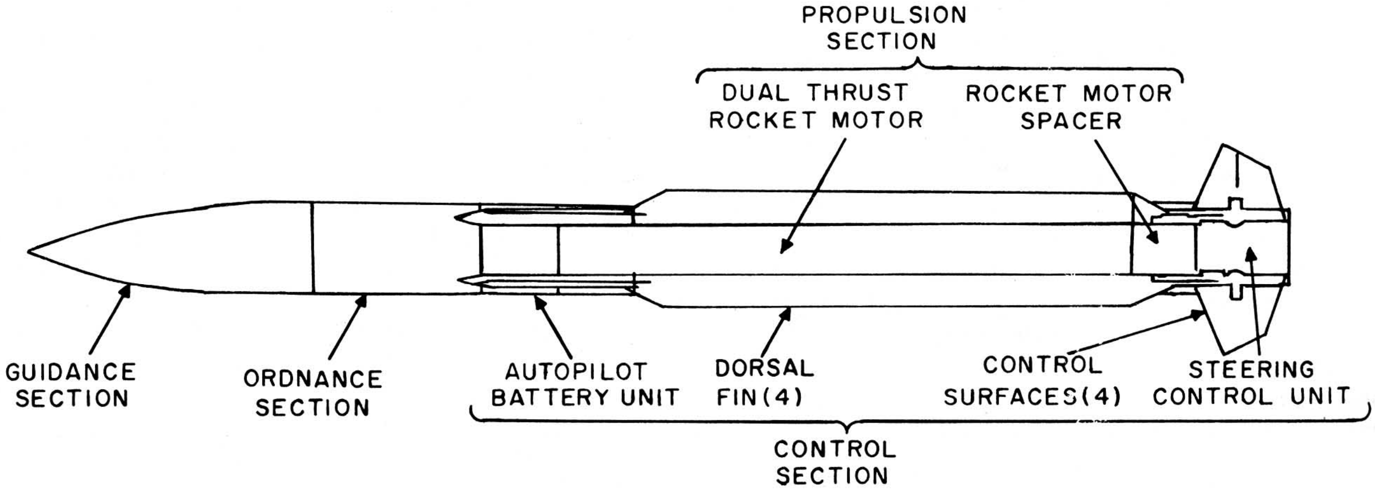

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Figure 4-31.—Standard missile RIM-66A, major sections and components.

(S&A) device, and a fuze booster. The fuze shroud assembly houses the components of the ordnance section. The fuze shroud includes a proximity fuze, contact fuze, and an antenna assembly, which are all installed in the aft end of the antenna shroud.

The proximity fuze with its associated four antennas, detects the target through its own radar transmitting and receiving system. The fuze trigger circuit is enabled for an airborne target and disabled for a surface target by a target select signal prior to launch. The contact fuze is a shock sensing device consisting of a piezoelectric crystal accelerometer and a switching circuit. When the crystal accelerometer output exceeds a predetermined level (caused by impact with the target), it drives a switching circuit which supplies a signal to the proximity fuze firing circuit.

The fuze booster is an explosive device that continues the fuze train initiated by the S&A device to detonate the warhead.

Control Section

The control section consists of the autopilot-battery unit, steering control unit, dorsal fins, dorsal telemeter assembly, and control surfaces.

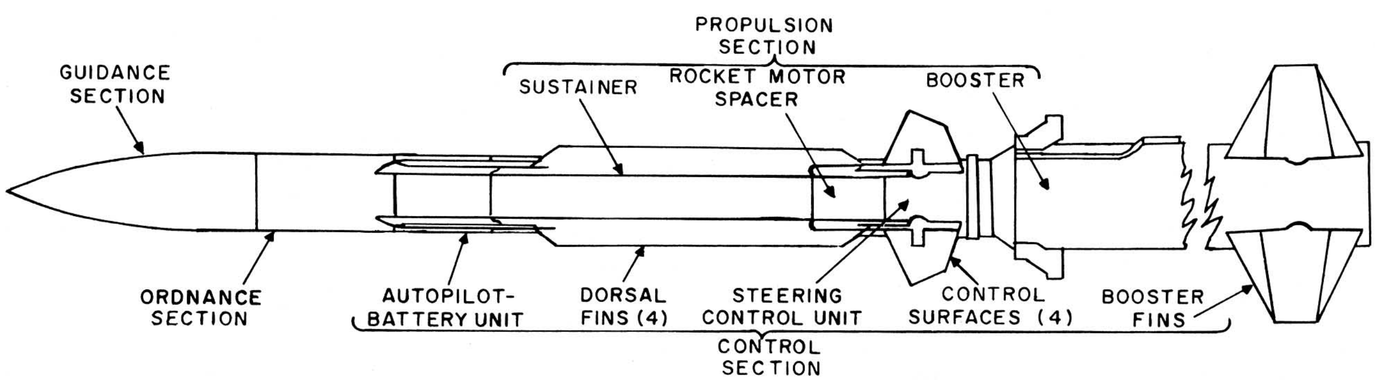

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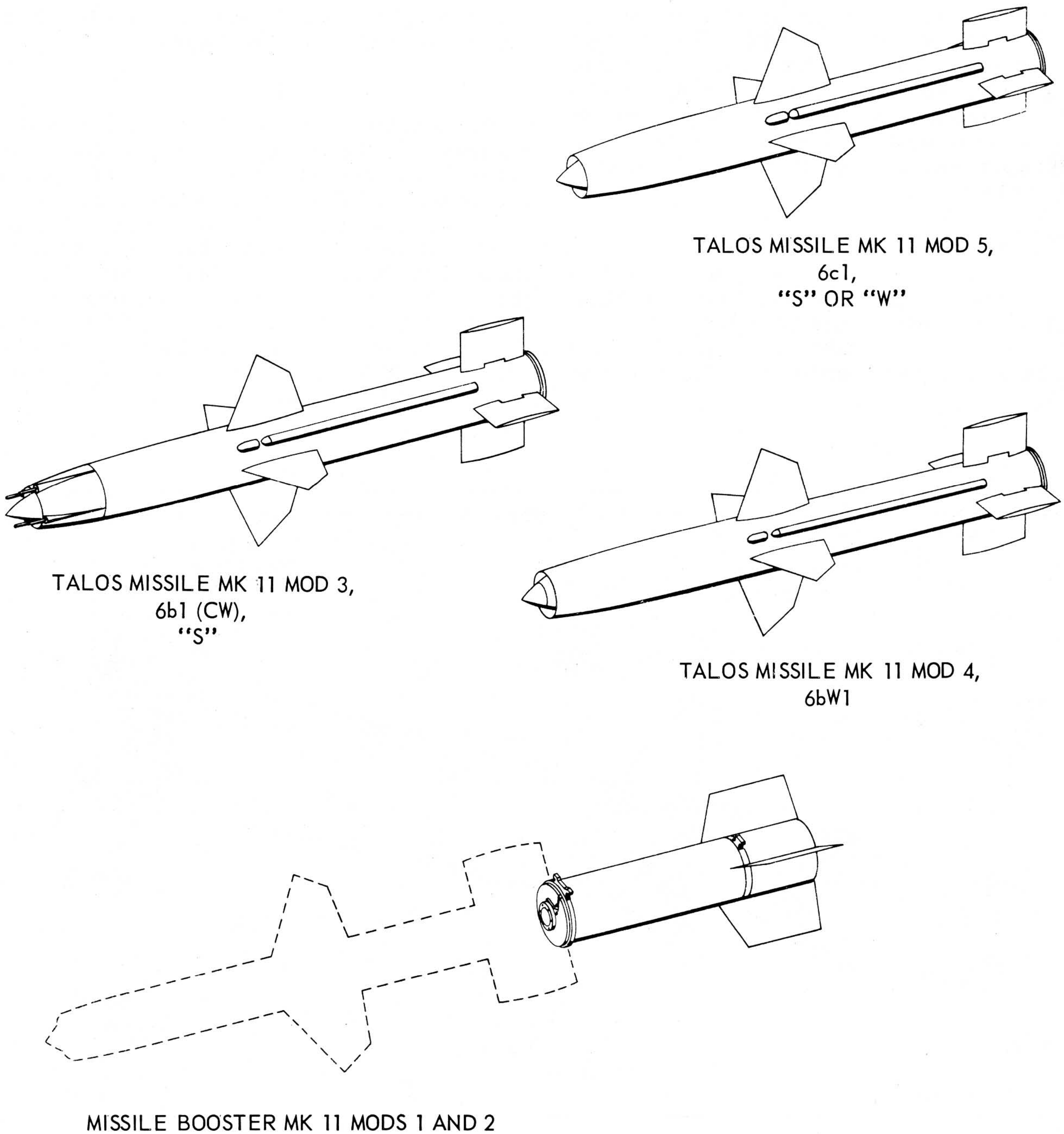
Figure 4-32.—Standard missile RIM-67A, major sections and components.



83.33
Figure 4-33. — Talos missile types, and booster.

With the exception of the control surfaces, none of these assemblies are interchangeable between the ER and MR missiles.

Power Supply

The missile power supply is composed of a primary battery and a power distribution assembly. The remotely activated, dry charged primary battery supplies all missile power during flight. The power distribution assembly distributes the primary battery power to the various missile components and contains circuits for limiting the delaying power to certain missile components.

Propulsion System

Propulsion for the MR missile is supplied by a solid fuel, dual-thrust rocket motor (DTRM) which provides short duration high thrust for the initial or boost flight period, and long duration low thrust for the remainder of the propelled flight.

. The ER missile is propelled by a solid fuel booster which provides short duration high thrust for the initial or boost flight period. When booster thrust decays, aerodynamic drag forces separate the booster from the missile. Separation of the booster results in ignition of the sustainer rocket. When ignited, the solid-fuel sustainer rocket supplies long duration low thrust for the remainder of the propelled flight.

TALOS

Talos is larger than either Terrier, Tartar or Standard. It differs from Terrier, Tartar and Standard missiles not only in size but in its type of propulsion. Talos is a ramjet, whereas Tartar, Terrier and Standard are rocket propelled. Talos is supersonic and so are the other members of the Bumblebee family. Like Terrier and Standard (ER), Talos is a two-stage missile, consisting of a solid propellant rocket booster and the missile proper. Talos missiles are either beam-riders with terminal homing guidance, or beam-riders during their entire flight.

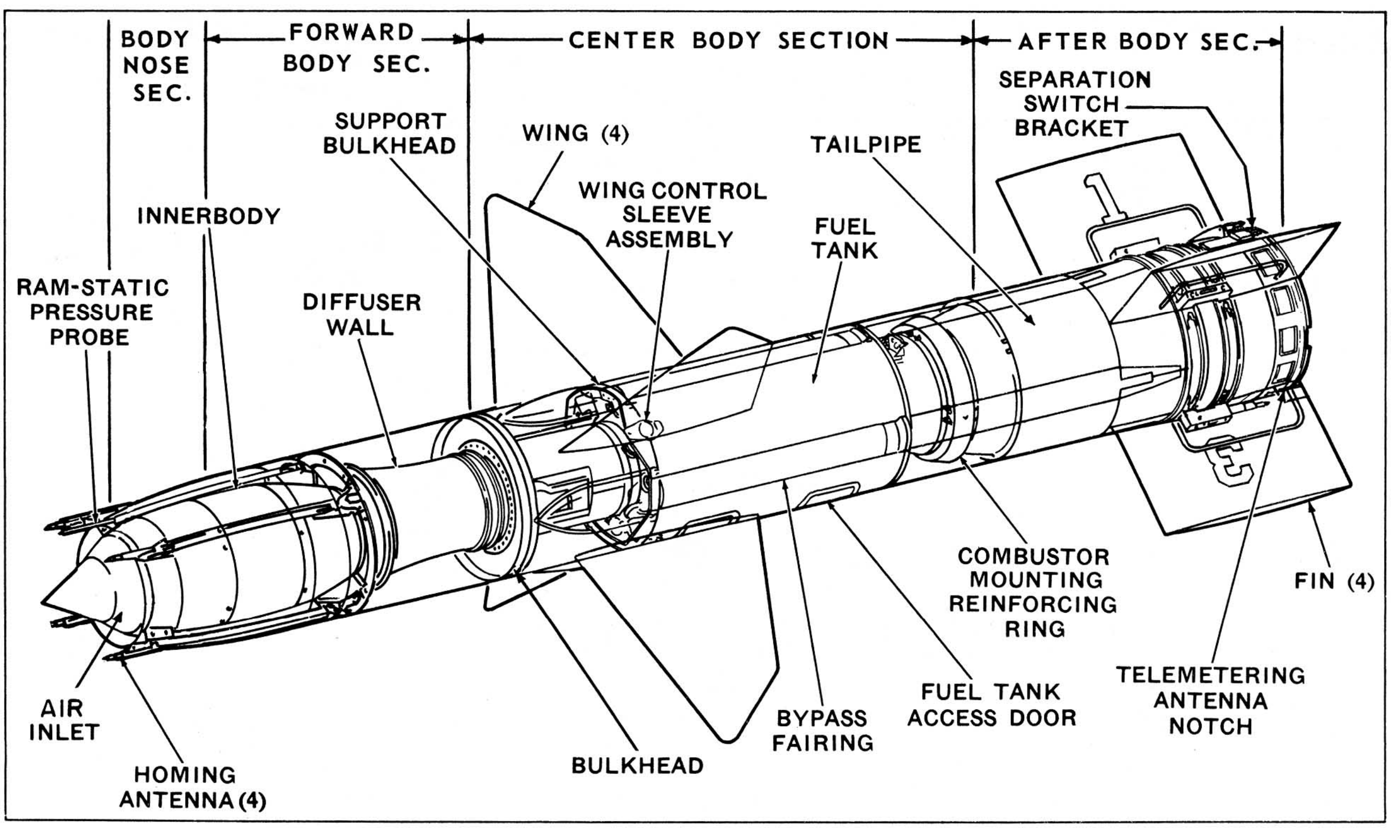


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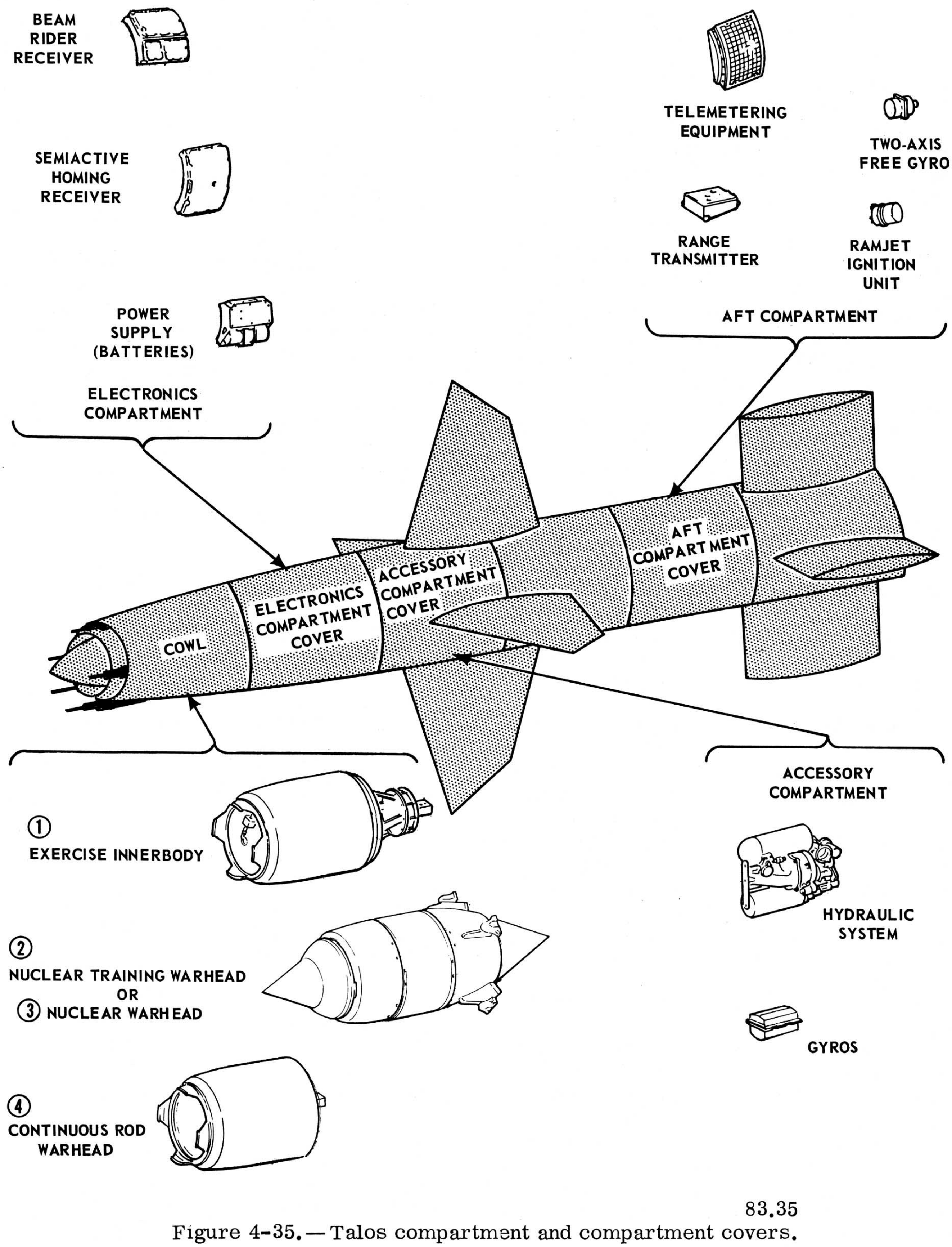
Figure 4-34.—Major sections and some components of Talos missile.



83.35
Figure 4-35.—Talos compartment and compartment covers.

The Talos missile itself is officially designed as guided missile Mk 11. There are three modifications: 3, 4, and 5, as shown in figure 4-33. The mod designation is further elaborated with descriptive symbols such as:

1. 6b1 (CW) for the mod 3 (RIM 8F).
2. 6bW1 for the mod 4 (RIM 8D).
3. 6c1 for the mod 5 (RIM 8E).

For practical purposes, the Talos missile is categorized according to the type of warhead it is intended to carry. The capital letter S indicates a high explosive warhead, and capital letter W indicates a missile intended to carry a nuclear warhead. Therefore, Talos Guided Missile Mk 11 Mod 3, 6b1 (CW) is an S type missile because it is designed to carry only a standard high explosive warhead. But Talos Missile Mk 11 Mod 5 can be called either an S type or W type because it can carry either a standard or nuclear warhead. The Mk 11 Mod 4 (6bW1 or RIM 8D) is only a "W" missile.

At first reading the methods of classifying Talos missiles may seem confusing but in a few years it will be easy. There will be only the 6c1 to worry about. It is planned to phase out the other two missiles. And this is one of the reasons we will cover only the 6c1 in this course. Another reason we will limit the coverage to this particular missile is that it contains all the features of the 6b1 and 6bW1. In other words, the 6c1 is a unified version of the 6b1 and 6bW1.

The Talos 6c1 is a two-stage, surface-to-air, solid-rocket launched, ramjet propelled, guided missile. After it is boosted to supersonic speed, it is guided during its midcourse flight phase by a beam-rider guidance system. Near the end of the missile's flight it switches from beam-rider to semi active homing guidance. During this terminal phase, the target is illuminated by a shipboard tracking and illuminating radar. The missile then homes in on the reflected radar energy from the target. When the missile is in the vicinity of the target, the kill is made with either a nuclear warhead or a standard continuous-rod high explosive warhead. (The continuous-rod warhead is described and illustrated in chapter 11.) The 6c1 is capable of carrying one or the other. For peacetime exercises the missile can be fitted with the continuous-rod warhead, exercise warhead, or a nuclear training warhead. Aboard ship you will handle the warheads we mentioned above.

The body structure of the 6c1 (fig. 4-34), is divided into three major sections:

1. Forward body section
2. Center body section.
3. Aft body section

They are not taken apart on board ship. But you will have to remove and replace modules or packages in these sections. As in the case of Terrier, the trend is toward packaging components so if a part malfunctions, the complete component can be pulled out as a unit and a new one put in without disassembling the module. To make it easy to get at the modules, compartment covers are provided. Figure 4-35 shows the location of the covers. Now let's start forward on the missile and work aft.

First, the cowl is a one-piece removable cover. Incidentally, the cowl is very easily damaged and must be very carefully handled. A scratch or dent will destroy the missile in flight. The inner body is under the cowl. There are three interchangeable innerbody assemblies. One innerbody assembly can be used for either the tactical nuclear warhead or for the nuclear warhead training warhead. Another innerbody is used for the exercise head. Still another innerbody is for the continuous rod warhead. The outer contours of all three innerbodies are the same. Together with the cowl, the inner body, besides acting as a container for warheads, forms the compressor section for the ramjet propulsion system.

Now we come to the electronic compartment cover. It is a one-piece removable wraparound cover which forms the outer skin of the forward section. Hinged doors on the cover provide access to test receptacles and switches.

Most of the missile's electronic guidance and control equipment is located under the electronic compartment cover. The beam rider and semi active homing receivers are there The power supply for the electronic equipment is also located there.

Next is the accessory compartment cover. It is a two-piece cover which provides access to the hydraulic system, wing control components, missile batteries, and the ramjet fuel system. The gyro packages and accelerometers are also there.

Finally, we come to the two-piece aft compartment cover. The principal units under it are the telemetering equipment, the range transmitter (Beacon), and the ramjet ignition unit.